XXXVIII IAH Congress

Groundwater Quality Sustainability

Krakow, 12–17 September 2010

Extended Abstracts

Editors:
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University of Silesia Press 2010

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abstract id: **112**

topic: **0**
Keynote lectures

title: **The SuRF-UK framework for sustainable soil and groundwater remediation**

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keywords: sustainable remediation, sustainable development, assessment framework

It has long been assumed that contaminated land and groundwater risk management was intrinsically sustainable because, for example, it controlled risks from pollutants and facilitated the re-use of brownfield land so reducing greenfield development pressures. However over the past decade it has increasingly been recognised that this simple assumption may not always be true (SURF, 2009). The "sustainable remediation" debate centres on how to identify the optimum management strategy that maximizes the benefits while limiting the impacts of undertaking remediation.

The United Kingdom's Sustainable Remediation Forum, SuRF-UK, is a multi-stakeholder initiative to develop a framework for sustainable soil and groundwater remediation, which involves incorporating sustainable development principles in remediation decision-making. Created in 2007 it has involvement and support from industry, service providers, government agencies and academia, and is indepedently led by CL:AIRE (www.claire.co.uk/surfuk). SuRF UK has developed a framework to allow balanced decision making in the selection of a sustainable remediation strategy to address land and groundwater contamination (CL:AIRE, 2009). This paper describes the SuRF-UK framework.

Sustainable remediation is part of a broader sustainable development agenda. Sustainable development is defined by "the Brundtland report" (UN World Commission on Environment and Development, 1987) as *development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs*. This is commonly applied as those actions that, taking account of environmental, social and economic considerations, optimise the overall benefit.

SuRF-UK has defined "sustainable remediation" as *the practice of demonstrating, in terms of environmental, economic and social indicators, that an acceptable balance exists between the effects of undertaking remediation activities and the benefits the same activities will deliver*.

A wide range of management goals often affect the scope of remediation work and its sustainability assessment, and these can impact the scope of possible remediation approaches in two ways. Firstly in terms of regulatory and planning controls on environmental risks, say to human health, water and the wider environment – these considerations relate to the desired end use of the site; secondly, practical boundaries such as the time and space available to carry out remediation, could also limit the range of possible interventions.

The decision points recognised by SuRF-UK as impacting on contaminated site management for a particular site are:

- High level decision making for policy and regional spatial planning by national government/regional agencies;
- Local level land-use planning and policy — by local authorities;
- Project based decision making that sets remedial objectives (e.g. related to risk management/development needs) for land owners and developers; and,
- Remedy selection and implementation including monitoring and verification implications.

The SuRF-UK assessment framework takes account of the social, environmental and economic benefits and impacts of remediation, and relies on a series of indicators to inform stakeholder discussions to identify the optimum solution. A tier of assessment methods are available to inform the decision-making process, from simple qualitative methods, through semi-quantitiative (e.g. multi-criteria analysis) to fully monetised cost-benefit analysis.

This paper will describe the SuRF-UK framework and show how it is applicable to both existing regulatory processes in the UK, and to emerging pan-European legislation set out in, for example, the draft EU Soil Framework Directive, which its February 2009 draft, required remedial costs to be proportionate to environmental and social benefits.

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abstract id: **463**

topic: **0**
Keynote lectures

title: **Occurrence and use of thermal and medicinal waters in Poland**

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keywords: thermal waters, medicinal waters, Carpathian province, Sudetic province, Polish Lowlands

According to the Polish legislation thermal groundwater is a mineral product and comes under the Geological and Mining Law, voted 1994. Its temperature is by definition 20°C at the outflow from a well or spring. Another type of groundwaters included among mineral products are medicinal (curative) waters. To obtain this qualification a water has to contain at least 1000 mg/dm³ TDS (mineral water) and/or one or more components of specific biologic impact on the human body (Fe^{2+}, J^-, F^-, CO_2, H_2S, Rn, H_2SiO_3) in defined minimum amounts.

It must also be approved by the Council of Ministers. Also a simple thermal water without any specific component may be recognized as medicinal, A business exploiting thermal or medicinal groundwater is reckoned as a mine and, consequently, the extraction and protection of such water must be done under the supervision of mining offices.

Geologically Poland may be divided into 3 provinces: Carpathian (including the Carpathian Mts, and the fore–Carpathian basin, (D on Fig. 1), Sudetic (including the Sudetes Mts and the fore-Sudetic block (C) and .the Polish Lowlands.province (B, A).

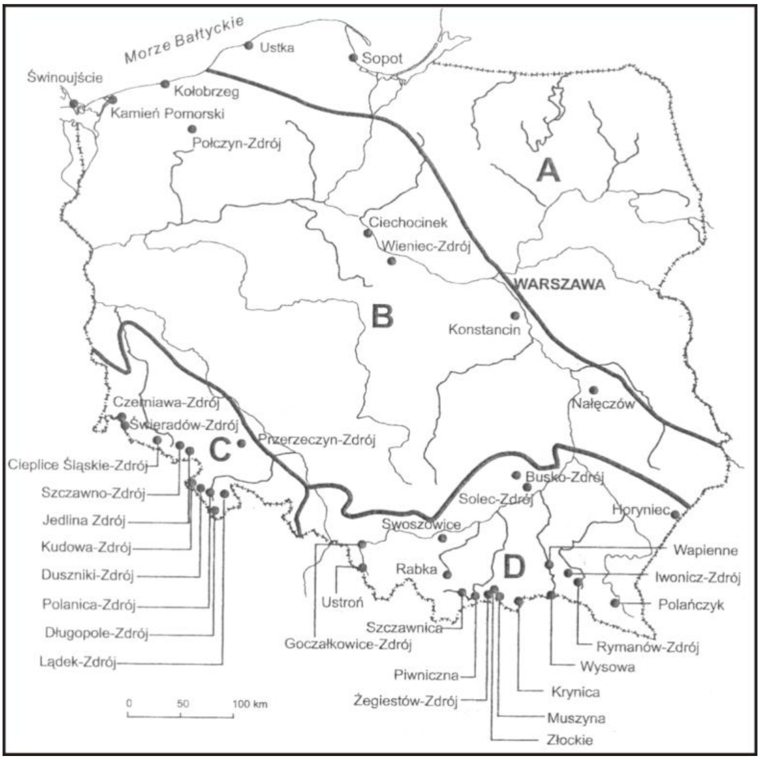

Figure 1. Polish health resorts in which mineral and thermal wayers are recognized as medicinal and applied for therapeutic treatments. A — Polish Lowlands, Precambrian platform; B — Polish Lowlands, Palaeozoic platform; C — Sudetes Mts and the fore-Sudetic block; D — Carpathians Mts and the Carpathian foredeep.

1. The Carpathian Mts (D) consist of Inner (Tatra Mts. and Podhale basin) and Outer Carpathians. The Podhale synclinorium is a typical artesian structure supplying considerable amounts of thermal, slightly mineralized water for space heating and recreation, from Eocene and Trias-

sic deposits. Typical of the Outer Carpathians are waters: a) carbonated, b) Cl-Na, c) mixtures of a) and b) types. The origin of c) type waters is an object of discussion as some scientists consider them to have been released from clayey sediments during the process of their diagenesis, while other ones tend to attribute their saline component to relic sea waters. The a) type waters are grouped mainly in the Poprad R. catchment, recognized as medicinal and used in numerous health resorts like Krynica or Muszyna. Waters of b) type occur within the flysch formation, sometimes appearing as springs which were the ground for founding health resorts like Rabka or Iwonicz, but generally at depths of several hundred m. They are often connected with oil and gas deposits. Springs of c. type water also appeared formerly as springs and allowed to start the therapeutic activity (e.g. Wysowa, Szczawnica, Rymanów). At several places drilling aimed at increasing the medicinal water amount was successful. However the flysch is generally typical of low permeability and yields are scarce from boreholes except those situated in fault zones. This is the reason why the use of thermal waters for heating purposes (to be certainly found in deep boreholes) did not develop here so far. The Carpathian fore-deep provides saline waters from thick Miocene sediments. These waters occur often in connection with gas deposits. Waters connected with evaporite (gypsum) deposits of Badenian age contain often considerable amounts of H_2S, a product of sulfate bacterial reduction, and are used for therapeutics in health resorts like Busko, Solec or Horyniec.

2. The Sudetes Mts. (C) are an area , where in a number of renowned health resorts mineral and thermal waters are recognized as medicinal and used for heaaling treatments. The most common type of these waters are carbonated ones, appearing in springs and shallow wells situated in areas where faults cut cerystalline Precambrian and Palaeozoic formations (Świeradów, Duszniki) Sometimes they occur also in sedimentary formations of Carboniferous (Szczawno) or Cretaceous (Polanica, Kudowa) age. Slightly mineralized thermal waters appear in springs at Lądek (gneiss) and at Cieplice (Carboniferous granite). Spring water temperature at Lądek does not exceed 29°C while 700 m. deep drilling provided water of a temperature over 45°C. Natural springs at Cieplice supplied water of maximum temperature 43°C. A 2000m deep borehole resulted in an spontaneous water outflow (40 m^3/h) with temperature exceeding 86°C. The Sudetic thermal waters are of meteoric origin and owe their temperatures to deep circulation enabled by considerable altitude differences and a dense network of dislocations rather than to the tetrrestrial heat flow, which in most parts of the massif does not exceed 60 mW/m^2.

3. The Polish Lowlands province is typical of a thick Cenozoic series covering in its NW part (B) the formations belonging to the Caledonian platform and in the SE part – to the Pracambrian platform. Thick Palaeozoic and Mesozoic series occur in the western part of the province while to the East they are thinning or even do not exist. (A). Zechstein evaporites form in the western part numerous salt structures penetrating into the Mesozoic and being there the source of groundwater salinization. Another source of salts dissolved in these waters are possibly connate marine waters present in Triassic and Jurassic sediments. In several sites saline waters appear at the ground's surface as for instance at Kołobrzeg, where they have been used for salt production already in the Middle Ages and at present are applied as medicinal mineral waters in the local health resort. Other sites where saline groundwaters are used for curative purposes are: Świnoujście, Międzyzdroje, Ciechocinek etc. At Ciechocinek thermal saline water was reached in Lower Jurassic sediments by drilling to around 1300 m. Recently another drilling was carried out in Toruń and over 60°C thermal water was reached in the Lower Jurassic at

depth exceeding 2000 m. Thermal waters from Jurassic and Cretaceous sediments are used for space heating and recreation in other sites of the western part of Polish Lowlands at Pyrzyce, Mszczonów, Uniejów etc. This is possible due to high heat flow density which at places exceeds 90 mW/m^2 as well as to good reservoir parameters of a considerable part of the Mesozoic series The possibilities of medicinal and thermal waters use in the eastern part of the Polish Lowlands is considerably limited because of low heat flow density and thinning or even absence of Permian and Mesozoic formations.

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abstract id: **488**

topic: **0**
Keynote lectures

title: **Underestimated role of tree transpiration and groundwater evaporation in groundwater balancing and modelling**

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keywords: groundwater, transpiration, evaporation, modelling

Field isotope experiments confirm that many tree species (phreatophytes) capture groundwater by roots to survive (Lubczynski, 2009). This process is called transpiration from groundwater or shorter groundwater transpiration (T_g). A combination of field experiments and modeling show also that groundwater can be discharged by evaporation directly from water table or capillary fringe (Gowing et al., 2006; Lubczynski, Gurwin, 2005). This process is called groundwater evaporation (E_g). The sum of T_g and E_g called groundwater evapotranspiration is typically underestimated in hydrology and hydrogeology despite in many environments significantly affects groundwater balances.

The T_g and E_g, next to recharge (R), are spatio-temporally variable fluxes. In contrast to R, relevant mainly in rainy season, the T_g and E_g are significant in dry seasons when surface water is unavailable and shallow soil moisture negligible. The T_g and E_g are driven by water stress and vapor pressure deficit, therefore affect mainly dry, water limited environments (WLE). In general, the more arid environments and drier conditions, the more important role of T_g and E_g in groundwater balances is. Besides, the T_g and E_g depend also on the hydrogeological conditions, mainly lithological composition and texture of unsaturated zone and groundwater table depth.

The hydrogeological importance of T_g will be presented by explaining: (i) interactions between trees and groundwater, emphasizing tree groundwater dependence due to hydraulic redistribution process; (ii) environmentally dependent tree adaptation processes, comparing root water uptakes in shallow (few meters) water table condition of Spain with root water uptakes in deep (few tenths of meters) water table condition of Kalahari Desert; (iii) state of art in experimental assessment of total tree transpiration by sap flow measurements; (iv) state of art in partitioning of tree transpiration into groundwater and unsaturated zone components by using combination of sap flow and isotope measurements; (v) potential of mapping T_g by remote sensing upscaling of field transpiration measurements.

The hydrogeological importance of E_g will be presented by explaining: (i) complexity of liquid and vapor water transport in the unsaturated zone, including experimental assessment and modeling; (ii) dependency of E_g on environmental factors such as climatic aridity, groundwater table depth, unsaturated zone texture etc.; (iii) perspectives and difficulties in extracting E_g from total evaporation; (iv) potential of mapping E_g by remote sensing upscaling.

The presentation will be concluded by presenting concept of integration of T_g and E_g in numerical groundwater models using MODFLOW code. The benefits of such integration will be discussed with reference to different environmental constrains. The importance of T_g and E_g integration will be emphasized by comparing water balances and model uncertainties of the proposed integrated solution with the standard MODLFLOW solution.

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abstract id: **539**

topic: **0**
Keynote lectures

title: **Ecohydrology — challenges and opportunities from the perspective groundwater surface water interactions**

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keywords: ecohydrology, ecological engineering

In the face of global challenges such as changes in geopolitical and economic centers, as well as demographic processes, combined with progressing degradation of the environment its resources and climate changes, there is an urgent need to formulate a new proactive strategy that harmonize the humanity needs with water resources and ecosystem potential . The one of the critical issues of the integrated water resources management is sustainable use of groundwater resources by society.

Ecohydrology (EH) is defined as sub-discipline of hydrology that focuses on ecological processes occurring within the hydrological cycle and strives to utilize such processes for enhancing environmental sustainability (Zalewski, 2000, 2006; Zalewski et al., 1997). It has been developing in the framework of the International Hydrological Programme of UNESCO is focused on regulation of water biota interplay from the top of the river basin up to the bottom of the reservoir and costal zones, toward slowing down transfer of water from sky to the sea, enhance groundwater resources and maintaining critical habitats for water, energy and nutrients circulation, which in turn maintain biodiversity. Also for reduction of the input and regulate allocation excess nutrients and pollutants toward reversing ecosystems degradation and improvement of human well being.

This follows the three criteria by ICSU, which define that the science of the XXI century has to be (1) integrative, (2) problem solving and (3) policy oriented. Integrative because integrates ecology and hydrology as a sub-discipline of environmental sciences. Problem solving because considering society priorities such as water quality, food production, flood protection, drought compensation, cultural aesthetic values and truism. Policy oriented because sustainable development and reversing biosphere degradation is the MDG GOAL.

What kind of "know how" Ecohydrology propose to achieve those three goals?

The general assumption is that water is major determinant of carbon retention in terrestrial ecosystems, biomass and plant production and ecological succession in different climatic (zones) (Zalewski, 2002).On the other hand the diversified plant biomass efficiently reduce leakage of nutrients from terrestrial to aquatic ecosystems and to costal zones. Ecohydrology due to methodological specifics has been based on interconnected two phases- terrestrial and aquatic. The terrestrial has been focused on water plant soil/ground waters interactions and plant cover is first important filtering system and system enhancing the infiltration and stabilizing water circulation within the catchment. In the aquatic phase, the content of the nutrients in surface and ground water to great extent determine freshwater and costal zones ecosystem biological productivity and in consequence biodiversity.

As far as Ecohydrology is not only curiosity driven but also problem solving science three principles are provides framework for research and problem solving

The hydrological principle — The quantification and integration of hydrological and biological processes at the basin scale is based on the assumption that abiotic factors are of primary importance and become stable and predictable when biotic interactions start to manifest themselves (Zalewski, Naiman, 1985) The quantification covers the patterns of hydrological pulses along the river continuum and monitoring of point and nonpoint source pollution. (Fig. 1).

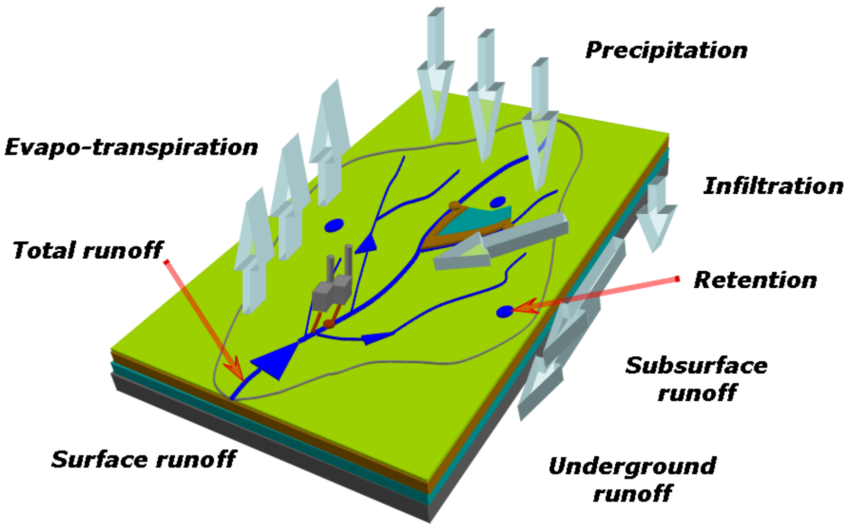

Figure 1. First Principle – Hydrological - quantification of hydrological cycle analysis from the point of view of socio-economy and spatial-temporal dynamic vs. various forms of human impact.

The ecological principle — The ecological principle is based on the assumption that under intensive global changes it is not enough to protect ecosystems against increasing energy consumption and pollutants emission. It is necessary to regulate ecosystem structure and processes toward enhancement of the "carrying capacity" (water quality, restoration of biodiversity, ecosystem services for society, resilience of river ecosystem). Understanding the role of vegetation in water cycling as far as hydrology-biota interplay from molecular to landscape scale processes is of crucial importance (Vorosmarty, Sahagian, 2000) (Fig. 2).

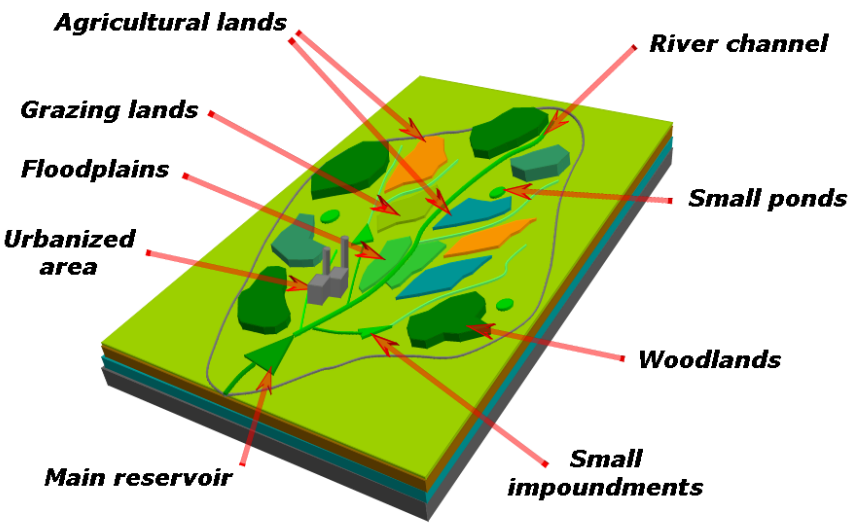

Figure 2. Second Principle – Ecological – the analysis of distribution of various types of biocenosis and its potential to enhance resilience and absorbing capacity for human impact (GIS).

The ecological engineering principle — The use of ecosystem properties as management tool is based on the first and second principles of EH. (Fig. 3).

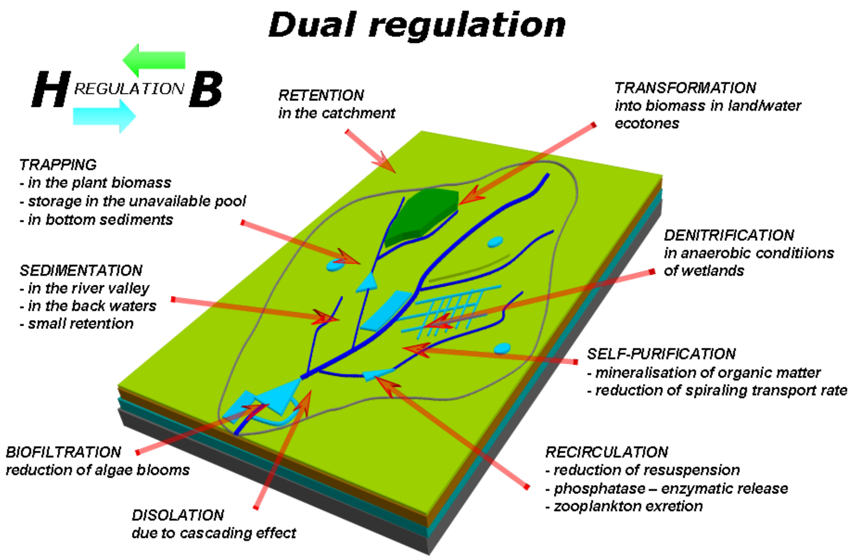

Figure 3. Third Ecological Engineering Principle — using of biota to control hydrological processes and vice versa, using hydrology to regulate biota.

This principle features three steps of implementation:

1. 'Dual regulation'–biota by hydrology and, vice versa, hydrology by shaping biota or regulating interactions.
2. Integration at the basin scale of various types of biological and hydrological regulations toward achieving synergy to improve water quality, biodiversity and freshwater resources.
3. Harmonization of ecohydrological measures with necessary hydrotechnical solutions (dams, irrigation systems, sewage treatment plants, etc).

As far as the freshwater ecosystems are situated in depressions in the landscape where all forms of human activities in catchment are cumulated dual regulation can be done toward changing the allocation of excess nutrients and pollutants in to no available pool (soil, sediments, wood, biomass/bioenrgy, fodder) or at least from more dynamic -opportunistic (e.g. toxic cyanobacteria) to less dynamic pool within organisms (zooplankton, fish, macrophytes).

To define the role of EH for sustainable water and ecosystems services , the analysis the pattern of the scientific methodologies in environmental sciences the three stages can be distinguished:

INFORMATION, structure, states, relationships (First hydrological principle EH). Hydrological–based on GIS analysis of the abiotic structure of the river basin, quantification of the hydrological processes and different forms of the anthropogenic impacts distribution ;

KNOWLEDGE, the synergies between information from the different scientific disciplines is helpful in highlighting the patterns and processes toward basin resilience enhancement (Second ecological principle EH).

WISDOM, ability to use the information and knowledge to develop innovative solutions ecological biotechnologies"dual regulation" of the environmental problems with the consideration of the society priorities. (Third ecological engineering principle EH) (Fig. 4).

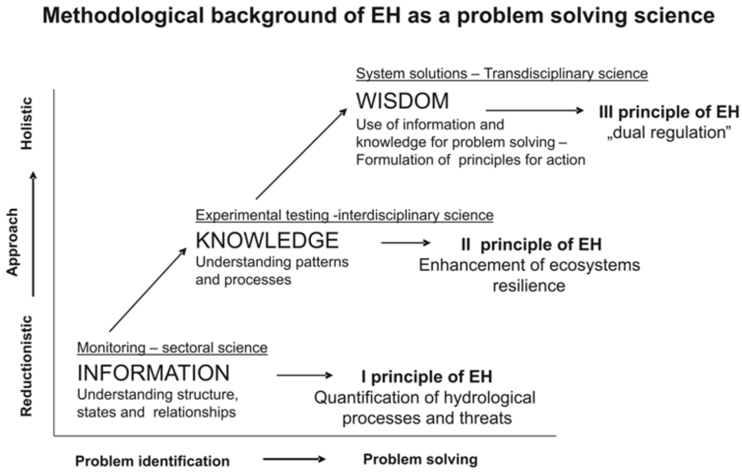

Figure 4. Methodological background of Ecohydrology.

Thus Ecohydrology improves the potential to regulate the complexity of interactions between, water cycle, ecosystems and societies by :

1. Reduction of threats of **floods and droughts** by control of stochastic character of hydrological processes in catchments by: Incorporation of an understanding the past (e.g. paleohydrology, ecological succession patterns, human settlements spatio-temporal dynamics). Integration of specific environmental science knowledge, e.g hydrogeology ,soil, groundwater, plant cover and the floodplain characteristics used for understanding the specific patterns of hydro peaking process and its reduction . Use of social learning and communication methodology for harmonisation of society's priorities with enhanced ecosystem carrying capacity.
2. Increasing the food /bioenergy productivity, reducing diffuse pollutant emission and enhancement of biodiversity in the agricultural landscape ecohydrological biotechnologies (based on"dual regulation).
3. Improve quality of life and reduce cost of functioning in urban areas by consideration in the city spatial planning the enhancement of the retention purified storm water in "green areas". Such change of management and perception storm waters in urban water management, due to applying ecohydrological methodology for purification reduces energy consumption, pollutants transfer and accumulation and improves human health, aesthetic and cultural values.
4. Reduction of fluxes of nutrients and pollutants into costal zones by ecohydrological measures application in the basin scale.

To achieve Millennium Development Goals and adopt to global changes the proactive strategy should be based on holistic, trans-disciplinary environmental science system approach, foresight methodologies, and social dialogue. It has to be done by broader involvement of trans disciplinary team of scientists in large scale projects on environmental processes regulation from molecular to landscape scale with special emphasis in understanding the socioeconomic processes and dynamics of ground water resources, which are critical for compensation and adaptation to increasing stochastic character of the climatic processes and sustainable future.

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IAH 2010 Krakow

abstract id: **540**

topic: **0**
Keynote lectures

title: **Groundwater dependent ecosystems: hydrology, conceptual models and vulnerability**

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keywords: groundwater dependent ecosystems, conceptual models, GENESIS project

INTRODUCTION TO GROUNDWATER DEPENDENT ECOSYSTEMS

Groundwater dependent ecosystem (GDEs) are a vital yet poorly understood component of the natural environment. Groundwater sustains different surface and terrestrial ecosystems such as wetlands, peatlands, streams and lakes. In many cases groundwater form an important but so far quite unknown contribution to these ecosystems. Some systems such as springs are completely fed by groundwater and would not exist without. This is reflected in fauna and flora too, by species adapted to the special conditions. Others systems depend partially on groundwater. In general, the role of groundwater can be to provide water, nutrients, cooling, and buoyancy but these effects are not always known.

Most fresh water on earth is in groundwater and this is a main storage in the cycling of freshwater within the hydrological cycle. Groundwater (GW) provides base flow and water release from land to surface water also during droughts. More information should be provided on how ecosystems depend on groundwater and in which way. The identification of water sources is a key component in such an evaluation of whether the system is dependent on groundwater. However, the source and contribution of GW can not be the sole classification as some systems might be indirectly dependent on groundwater. This can occur if GW provide buoyancy, but the surface vegetation shows low nutrient status and relies on precipitation. The overall role of groundwater must be better understood for both aquatic and terrestrial systems. This includes the role of groundwater in the hydrological cycle and the role of groundwater in specific ecosystems such as rivers, lakes and wetlands. This knowledge is needed to protect and manage the several functions that groundwater provide to ecosystems and society.

The role of GDE is specified in the Water Framework Directive (WFD, 2000/60/EC) and the Groundwater directive (GWD). This paper puts together past knowledge and new observations on ecosystems and discusses the role of groundwater in them. Especially, the different case studies of ecosystems involved in a European project 7th framework project GENESIS will be reviewed. The objective is to focus on hydrological and ecological properties of ecosystems connected to groundwater and on vulnerability of these systems. The presentatrion outlines the conditions needed for protecting these systems and for management of groundwater in a more integrated way. Also uncertain issues related to protection of GW ecosystems will be highlighted.

HYDROLOGY AND CONCEPTUAL MODELS

The presentation will review different case study sites in the GENESIS project and also previous knowledge held by the GENESIS conortia. The hydrology of different systems will be presented along with conceptual models on the role of groundwater. The sites to be presented inlcude different type of weltands such as mires and lagoons, small lakes, rivers and springs.

ACKNOWLEDGEMENTS

The paper was prepared with contribution from participants from work package WP4 “Groundwater dependent ecosystems” of the GENESIS project www.thegenesisproject.eu funded by EU 7th framework project (contract 226536).

abstract id: **541**

topic: **0**
Keynote lectures

title: **Evaluation of environmental tracer data to estimate the transit time of water under saturated conditions**

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keywords: environmental tracer methods, groundwater residence time

INTRODUCTION

Many problems in hydrogeology require some understanding of the timescales of groundwater flow and contaminant transport. Over the past five decades, a powerful suite of environmental isotope and tracer methods has been developed to address the question of groundwater residence time on a wide range of timescales (Fig. 1).

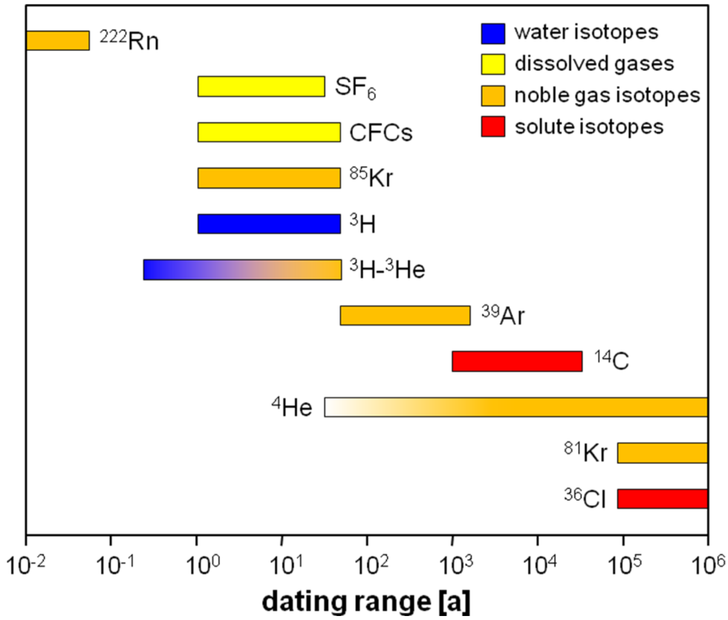

Figure 1. Overview of environmental tracer methods and their dating ranges.

A short review of these methods is provided here, covering their strengths and weaknesses, examples of their applications, and ways to evaluate and interpret the resulting data sets – often comprising multiple tracers. More detailed reviews and various case studies can be found in two special issues on environmental tracer and dating methods in hydrogeology, which are due to appear soon in Hydrogeology Journal and Isotopes in Environmental and Health Studies. Another great resource was provided a decade ago by Cook and Herczeg (2000).

One goal of these publications is to raise awareness of the potential and requirements of environmental tracer methods, as despite their successful use in many research studies, they remain underutilized in practical applications in groundwater management. As groundwater models are often calibrated only by hydraulic data, despite the well-known shortcomings of this approach, it is important to note that tracer dating provides valuable independent constraints, even though the dating methods also have limitations.

The available dating methods together cover a time range from days (^{222}Rn) to millions of years (^{81}Kr, ^{36}Cl, Fig. 1). However, the coverage of this age range is uneven. Several methods (so-called transient tracers — ^{3}H, CFCs, SF_6, ^{85}Kr) are based on the anthropogenic release of compounds and radioisotopes to the environment over the past five decades, leading to a time-dependent input into groundwater. Therefore, this young age range is well covered. On the longer time scales, methods based simply on the radioactive decay of solute isotopes (^{14}C, ^{36}Cl, ^{39}Ar, ^{81}Kr)

are available. However, while the complex geochemistry of the elements C and Cl can substantially complicate the respective methods, the use of the more ideally behaving noble gas radioisotopes is hampered by the difficulty of their analysis. The accumulation of the stable isotope ^{4}He is an alternative tool in the range of high ages and potentially also for the younger range, but the He accumulation is rarely known sufficiently well to provide quantitative age information. Finally, the ^{3}H-^{3}He method, combining the decay of the water-bound ^{3}H with the accumulation of the stable noble gas isotope ^{3}He, is a powerful tool but also limited essentially to the period since the tritium bomb-peak in the 1960s.

As the young age range (up to 50 years) is of particular importance in many applications related to groundwater quality and abstraction, the present contribution will focus on this range in the following. The wide choice of methods in this range enables multi-tracer studies and a comparison of the different methods.

DISCUSSION OF SELECTED METHODS AND THEIR APPLICATIONS

Tritium is the classical dating tool in hydrology, but it has lost much of the power it had in the decades after the bomb peak, as concentrations in precipitation have returned almost to natural levels. Quantitative dating based only on tritium is hardly possible, but a distinction of pre-bomb and post-bomb water is still very effectively possible. More promising than ^{3}H alone is its combination with ^{3}He. The ^{3}H-^{3}He method has proven to be particularly reliable and has in many case studies been used to compare with other methods and to detect effects influencing CFCs or SF_6 (e.g., Horneman et al. 2008; von Rohden et al., 2010a). The biggest disadvantage of the ^{3}H-^{3}He method is probably that it requires a rather large experimental effort.

The transient trace gases CFCs and SF_6 are cheaper and easier to apply than the ^{3}H-^{3}He method. Another advantage of the CFCs is that several compounds are available, which can compensate for the fact that some of them may be affected by contamination or degradation. As the atmospheric concentrations of the CFCs have leveled off since the 1990s (due to the ban of these ozone-destroying compounds), SF_6 has gained increased attention. However, it is becoming increasingly clear that SF_6 excesses of natural, terrigenic origin, are quite wide-spread, occurring not only in crystalline or volcanic rocks and hydrothermal environments (Busenberg and Plummer, 2000; Koh et al., 2007), but also in sedimentary aquifers (Deeds et al., 2008; von Rohden et al., 2010a). Therefore, recent proposals for new tracers such as SF_5CF_3 and CFC-13 (Busenberg and Plummer, 2008) are very welcome.

Despite some problems mentioned above, successful applications of the established dating tracers abound. ^{3}H-^{3}He ages have been used to determine groundwater flow velocities both horizontally and vertically. Vertical ^{3}H-^{3}He age profiles enable the determination of recharge rates (e.g. Solomon et al. 1993; von Rohden et al., 2010b). Horizontal transects of ^{3}H-^{3}He ages have been used to study river infiltration (Stute et al. 1997) or to provide a time-scale for the propagation of contaminant plumes (Shapiro et al. 1999). Another important application of the method is to provide chronologies of past environmental change, in particular histories of groundwater contamination including the retrospective proof that trend reversals have taken place (e.g., Aeschbach-Hertig et al. 1998; Tesoriero et al., 2007; Visser et al., 2007a). Another straightforward use of age information obtained by ^{3}H-^{3}He dating is the determination of the rates of chemical processes such as oxygen depletion (Beyerle et al., 1999) or denitrification (Singleton et al., 2007).

Applications of CFCs include among many other topics the study of water exchange between groundwater and lakes or rivers (e.g., Katz et al. 1995; Modica et al., 1998). Detailed vertical CFC profiles were used to assess vertical recharge velocities in a shallow sandy aquifer (Cook et al., 1995) as well as to study groundwater flow in fractured rock (Cook et al., 2005). As other dating tools, the CFCs were also used to reconstruct histories of contamination, e.g. by nitrate in agricultural watersheds (Böhlke and Denver, 1995).

DATA EVALUATION: EFFECTS TO CONSIDER

Many dating methods for groundwater are based on gas tracers, which inescapably are affected by gas/water partitioning in the subsurface. Interaction with a gas phase leads to excesses or deficits of dissolved gas concentrations relative to atmospheric solubility equilibrium, referred to as excess air or degassing. Excess air has long been recognized and various models accounting for the effect of air entrapment on dissolved gas concentrations have been proposed and applied (Aeschbach-Hertig et al., 2000). Atmospheric noble gases can be used to constrain excess air and its composition by fitting the different models to the data (Aeschbach-Hertig et al., 1999).

In contrast to excess air, the phenomenon of degassing has only recently received more attention. In particular, it has been encountered in studies of contaminated or naturally anoxic aquifers, where it occurs as a result of biogeochemical gas production in the subsurface (e.g., Visser et al., 2007b). The equations of the closed-system equilibration (CE) model, which has been quite successful in describing excess air, can also describe the case of equilibrium degassing (Aeschbach-Hertig et al., 2008). The feasibility of modeling the effects of degassing on conservative gases suggests that reasonable dating is possible even in cases of considerable degassing.

Many transient tracer methods used for dating young groundwater are affected by "contamination", i.e., the presence of tracer components in addition to the expected atmospheric sources. Such excesses can have a variety of causes, even natural ones as mentioned above for SF_6. Thus, the term contamination may not always seem appropriate, but dating is hampered irrespective of the origin of the excess. Contamination in the strict sense is commonly associated with waste disposal or industrial effluents. Such contamination is most prominent for the CFCs. Apart from leakage from landfills, sewer lines, underground storage tanks, and disposal of industrial wastes, another source of contaminated recharge can be rivers (IAEA, 2006). A further complication for CFC dating is degradation in anaerobic environments, which has frequently been observed (IAEA, 2006). Finally, sorption may affect CFC transport, but this process has received comparatively little attention.

With regard to the complicating effects of excess air, degassing, contamination, degradation, and sorption, the noble gas radioisotopes ^{39}Ar, ^{85}Kr, and ^{81}Kr are exceptionally robust among the gas tracers. Groundwater dating with these isotopes is not affected by gas/water partitioning, as only the ratio of the radioisotope to a stable isotope of the respective noble gas is required for dating. Degradation, sorption, and contamination appear highly unlikely for these inert gases. Particularly useful among these radioisotopes is ^{39}Ar, because it is uniquely able to close the gap in the dating ranges between about 50 and 1000 years (see Fig. 1). The applicability of the noble gas radioisotopes is currently limited by the requirement of very large samples and sophisticated analytical methods due to their extremely low abundance. A new analytical technique (ATTA: Atom trap trace analysis) has recently been demonstrated for the case of ^{81}Kr (Sturchio et al., 2004). Progress is currently being made towards implementing ATTA also for ^{39}Ar (Welte et al., 2009).

The best practical way to deal with the various effects that may disturb the different groundwater dating tools is to combine several methods in multi-tracer studies. Such combinations enable the identification of problems affecting the single methods. Moreover, attempts can be made to consistently interpret the multi-tracer data sets in terms of mixing and transport models. The most direct approach is to estimate parameters of lumped-parameter models by optimizing the fit of modeled and measured tracer concentrations (Corcho Alvarado et al., 2005; 2007). A more sophisticated approach includes distributed-parameter models, whose spatially variable parameters are constrained by the requirement of consistency with the tracer data. The combination of environmental tracers with numerical groundwater flow and transport models clearly is the way to go to extract the maximum benefit from tracer studies. This approach has been demonstrated successfully for almost two decades (e.g., Reilly et al., 1994; Sheets et al., 1998; Mattle et al., 2001), but it still is not used as often as it would seem appropriate.

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abstract id: **542**

topic: **0**
Keynote lectures

title: **Integration of environmental tracer information into groundwater modelling**

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keywords: environmental tracers, groundwater modelling

Numerical groundwater models, which are calibrated with the help of head data are often non-unique to some degree. A fit to head data alone is necessary but not sufficient. The basic dilemma in flow modelling consists of the fact that hydraulic conductivity is in general poorly known. Since boundary fluxes, recharge rates, and fluxes to or from rivers cannot be measured directly, they have usually to be estimated independently. Both types of information are uncertain, and therefore, the resulting flow model is error-prone. Consequently, the resulting flow field is often too inaccurate for solute transport modelling. An example is the inaccurate simulation of a pollutant plume in groundwater due to uncertain boundary fluxes. Environmental tracers can offer a possibility in this case by estimating or at least by improving the boundary fluxes. Can environmental tracers help in improving flow and solute transport models in general? They can be useful at least to some degree. Environmental tracers can for example indicate that there is recent recharge, or they allow estimating the age of groundwater or its residence times, or they can yield streamline information, or ratios of fluxes including recharge rates, or effective porosity values. Indeed, many examples from the literature show that various environmental tracers were successfully used in the past to check or to improve flow models, to select among several scenarios or conceptual models, and to determine solute transport parameters. Parameter estimation using environmental tracers has usually been performed manually.

However, there exist a series of limitations for the use of environmental tracers in groundwater modelling. For example the input function is not always well known, or the age window of a particular tracer is limited. Environmental tracer data do not provide direct information on Darcy fluxes. Dissolved gas tracers yield information which is different from that of solute markers of the water molecule. Estimated porosity values can still exhibit quite some uncertainty. Moreover, the effective porosity may not be constant due to dual porosity effects. Furthermore we have to keep in mind that hydraulic heads show a momentary situation while tracer data integrate over longer time periods. The residence time of tracers in the unsaturated zone can sometimes be larger or much larger than in the saturated zone of the aquifer. This can increase the uncertainty since information on unsaturated flow conditions is usually very sparse. Nevertheless, the range of possible results from a calibrated flow model can sometimes be restricted considerably by using environmental tracer information in the modelling. This depends on the sensitivity of a particular parameter like effective porosity to simulated environmental tracer concentrations. There exist examples where transmissivity is not or only little sensitive.

We might pose the question why environmental tracers are not used more intensively in flow and transport modelling. Besides the above mentioned problems, reasons might be the relatively high costs, and the lack of knowledge about the sensitivity of a particular tracer. Moreover, too high expectations in the past may have led to frustration.

As a conclusion, environmental tracer data allow to check and to improve groundwater flow and transport models. Moreover, environmental tracers are the only available means to estimate effective porosity and travel times on the field scale. The combination of several environmental tracers with differing properties (like gaseous tracers with different diffusion coefficient and water bound tracers) is certainly more demanding, but can make the application much more reliable. The flow and transport models should be used to check the consistency of all collected data (even with respect to proxi-data, which do not enter the model directly) and to confirm or to exclude hypotheses. As a general suggestion environmental tracer information should primarily be used for getting ideas about the conceptual model, and not necessarily for getting higher accuracy. Of course if the latter can be achieved, so much the better. The integration of environmental tracers in groundwater models can reduce the range of possible alternative interpretations, which are consistent with all observations.

abstract id: **544**

topic: **0**
Keynote lectures

title: **Groundwater quality problems in European Union Water Framework Directive implementation**

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keywords: groundwater quality, Water Framework Directive, environmental quality standards, threshold values

The Water Framework Directive that is one of the most important legislative acts for the protection of European waters has arrived into a key phase of its implementation. EU Member States prepared their river basin management plans by the end of 2009, those containing the necessary measures for bringing waters of Europe into good status by 2015. The European Commission has already started assessing the plans and will report on the findings of its analysis in the frame of the 2012 'Blueprint to safeguard EU waters'.

The European Commission has recently published a Report in accordance with Article 3.7 of the Groundwater Directive 2006/118/EC (GWD) on the establishment of groundwater threshold values (TVs). The Report is accompanied by a Commission staff working document.

The Report is based on the information provided by Member States on groundwater threshold values established for the assessment of chemical status.

26 Member States have reported on the establishment of threshold values. Some of them indicated that the information submitted was not yet final, as work on the finalisation of the river basin management plans was still ongoing. 24 MS established threshold values for substances in total for 158 different pollutants/indicators.

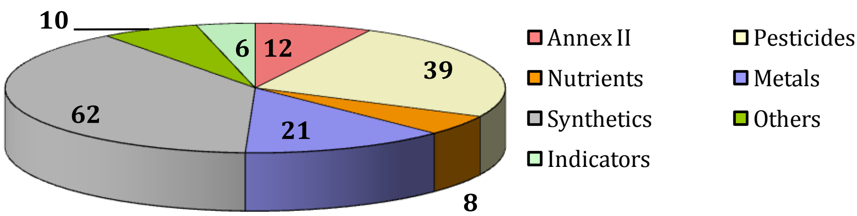

Figure 1.

RESULTS/CONCLUSIONS

Drinking water standards were most frequently reported as basis of threshold values: 23 Member States referred to drinking water standards to be considered for TV establishment.

5 Member States reported TVs for nitrates and 7 Member States for pesticides that are stricter than GWD quality standards.

18 Member States established groundwater TVs for pollutants that do not pose risks to groundwater bodies.

Substances of Annex II GWD cause risk in a considerably high number of Member States

The ranges of threshold values established in Europe which is very broad for many substances

From all the pollutants considered nitrate is posing risk to and cause poor status of the highest number of the groundwater bodies in Europe

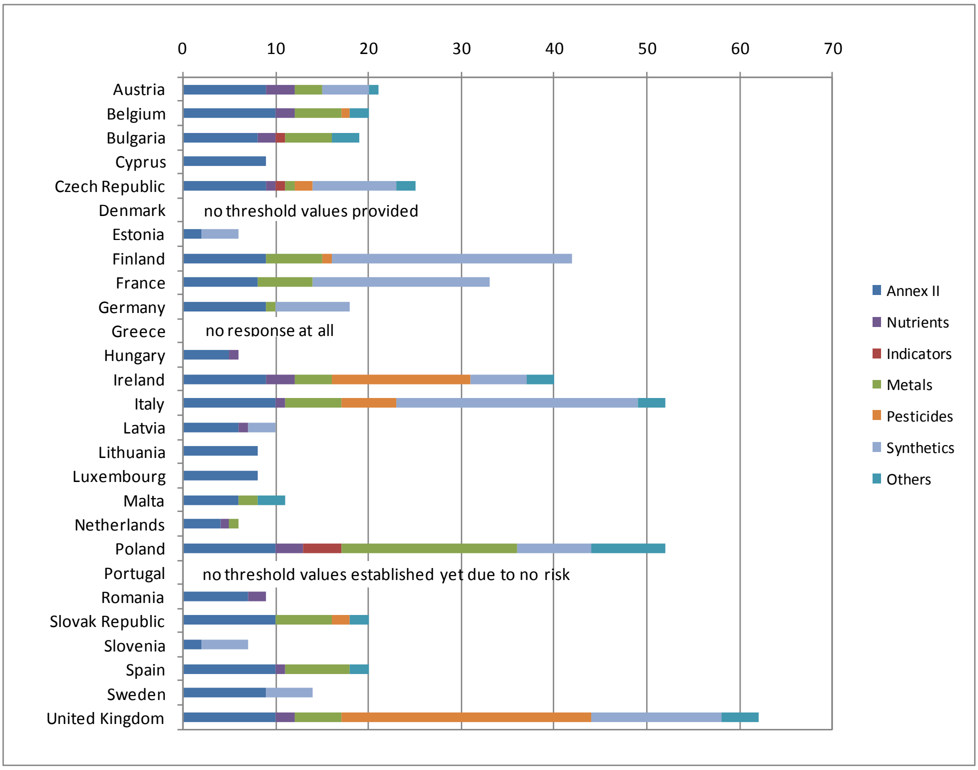

Figure 2. Number of pollutants/indicators for which threshold values have been established by each Member State

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abstract id: **545**

topic: **0**
Keynote lectures

title: **Polish Hydrogeological Survey — challenges and achievements**

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keywords: hydrogeological survey, Water Framework Directive, groundwater management, drainage basin action plans

Poland joined the European Union in May 2004. Intensive preparations had been underway since 2000, i.e. since the EU Framework Water Directive came into force. Taking into account the necessity to introduce considerable changes in water management, water resources protection, water status reporting and actions undertaken in connection with this, an idea was put forward to organise Polish hydrogeology within a national service institution.

The Polish Hydrogeological Survey (PHS) has been operating for 9 years and was established based on the Water Law Act of 2001. As far as I know, it is the first national hydrogeological survey in Europe and possibly in the world. The fact that the duties of the state as regards groundwaters are delegated to a unit established specifically for this purpose shows on one hand that hydrogeology is highly ranked in the field of Earth sciences, and on the other it reveals the significance of groundwater resources for society, the economy and the protection of groundwater-dependent terrestrial ecosystems. After 9 years of the PHS being in operation we are entitled to draw conclusions regarding the scope of responsibilities and the method of their implementation in practice, and to assess the effectiveness of the largest hydrogeological organisation in the country.

At this point it ought to be mentioned that the term ‘hydrogeology’ meaning the branch of science devoted to groundwaters has been in use in Polish for 120 years. For 60 years Polish academic institutions have been promoting graduates in the field of hydrogeology. Approximately 2000 people currently work in design and consulting offices, in administration and in academic centres in the specialised branch that is hydrogeology and engineering geology. This branch has solved a series of problems connected with detailed cartography of the country, mining excavation dewatering, construction excavation dewatering, intake construction and the provision of water to cities and districts.

CHALLENGES FOR POLISH HYDROGEOLOGY

In the last two decades, Poland has undergone system and economic transformations, has become a member of the European Union and is currently implementing the Union’s policy as regards protection of groundwater resources, along with neighbouring countries. Once Poland became a member of the EU in May 2004, the necessity arose to change the legal regulations by harmonising them with EU directives and to adapt activities that could make it possible to determine GWBs, evaluate their status and design and undertake actions to improve it. These activities are being successfully implemented, mainly due to structural and organisational changes, such as the establishment of the Polish Hydrogeological Survey at the Polish Geological Institute – the National Research Institute.

The 21st century brought new challenges to hydrogeology, especially:

- Increased demand for groundwater as drinking water. Currently some 68% of drinking water in Poland comes from groundwaters, with an annual increase trend of 1-2% in favour of groundwaters;
- During droughts excessive exploitation of groundwater resources can be observed, while in periods of prolonged downpours there is an excess of water. In the last 15 years we have experienced 3 enormous floods, including those in May and June this year;
- Construction of reservoirs is hindered by pro-ecological organisations. However, it is possible to retain the excess of water in aquifers during floods and to store the resources re-

tained in case of a drought. The retained groundwater resources can be of particular significance during emergency situations in the country. During the nuclear power plant disaster in Chernobyl, Poland supplied drinking water from groundwater intakes only, where no radionuclide contamination was detected;

- Plans and projects of storing CO_2 in rock masses pertain also to the area of Poland. However, there are possible problems with CO_2 injection to aquifers of the greatest hydraulic conductivity – the reaction of gas with rock matrix and the effectiveness of the levels that isolate and prevent gas from escaping to the atmosphere;
- Increased use of rock mass for underground storage of toxic and radioactive substances can be expected. In this case there are also some not entirely solved problems involving migration of contaminants, effectiveness of isolation and methods of securing aquifers against contamination across centuries;
- In the last decade problems of the temporal and the spatial scale have become increasingly evident. Groundwater flow modelling results at a regional scale give approximate outcomes, most often for steady-state conditions. Data for the models come from on-the-spot studies of hydrogeological conditions carried out in wells or from laboratory tests of small soils samples. This leads to errors arising from extrapolation. Errors can also be caused by assuming the boundary conditions that are known at the moment of measurement and they usually do not exceed the horizon of human life;
- another challenge for groundwater resources protection is the increasingly frequent use of renewable energy sources (RES). The largest geothermal water resources in Poland occur in Mesozoic aquifers. Geothermal waters have been observed in sandy forms of the Lower Cretaceous and Lower Jurassic periods. Geothermal power plants draw thermal waters from a depth of over 1500 m and their testing projects and hydrogeological documentations must be confirmed. These procedures do not apply to heat pumps, of which there are already thousands of installations. The obligation of filing environmental impact assessment reports does not apply to them either.

THE TASKS OF THE POLISH HYDROGEOLOGICAL SURVEY UNDER THE WATER LAW ACT

The basic objective of the Polish Hydrogeological Survey is to perform the tasks of the state for the purposes of studying, balancing and protecting groundwaters so that they can be rationally used by society and the economy. The tasks specified in the Water Law Act, which implements the provisions of the Water Framework Directive, are the fixed responsibilities of the Polish Hydrogeological Survey and are performed based on long-term agreements ordered by the Ministry of Environment and financed by the National Fund for Environmental Protection and Water Management. These tasks can be grouped in several sections:

Groundwater measurements and observations

The Polish Hydrogeological Survey organises and modernises the groundwater monitoring network and makes it possible to maintain it in a condition that permits constant measurements, observations and research. The network has over 800 points (primary and secondary stations) and will ultimately comprise around 1200 monitoring points. Automated measurement and data transmission equipment is installed in some stations. Depending on the needs, the network's monitoring points observe the chemical (diagnostic, operational monitoring) and quantitative condition.

Groundwater condition measurement results are a basis for assessing groundwater status (chemical and quantitative) in the territory of the country. Changes in groundwater conditions can be caused by human activity, such as excessive exploitation of resources in areas of large municipal and industrial groundwater intake, water intake for agricultural purposes, mining drainage and construction dewatering. Changes in groundwater conditions can be also caused by natural factors, which include mostly weather anomalies or, so far poorly proven, climatic changes (greenhouse effect). The Polish Hydrogeological Survey prepares annual reports (assessments) and forecasts of groundwater conditions and hazards. This is possible due to long-term observations collected in GIS databases and processed according to standard procedures (in conformity with the INSPIRE guidelines).

The groundwater monitoring network's measurement and observation data kept in the database is made available by PHS to state administration and municipal governments, state institutions and upon the consent of the data owners (State Treasury) – to commercial companies and private persons.

In addition to managing the basic groundwater monitoring network, the Polish Hydrogeological Survey also manages measurements and observations within dedicated monitoring. For this purpose PHS carries out measurements in the monitoring network along the country borders (border monitoring), around facilities that strongly affect underground waters (local monitoring) and protected areas. PHS is also entitled to enter private premises in order to measure the water condition and to collect samples for analytic tests. Representatives of the Polish Hydrogeological Survey actively participate in the work of the border water committees in collaboration with all the neighbouring countries.

Hydrogeological data collection, verification and processing

The Polish Hydrogeological Survey is responsible for updating and verifying information resources of hydrogeological databases nationwide, as well as making them available. The data collection and processing system managed by PHS is the largest hydrogeological database in the GIS system, constantly updated and processed and made available based on proper legal regulations.

Data on the parameters of aquifer masses, specific resources, potential discharge of intakes, quality and systems of groundwater circulation are obtained in the country during construction work of new intakes, searches for natural resources or specialist field studies. The results of these studies are very costly and cannot be conducted for one-time purposes due to financial reasons, e.g. for the purpose of assessing the condition of groundwater resources in regions or in the area of the country. It is therefore necessary to accumulate and verify the data in the Central Hydrogeological Data Bank (the HYDRO Bank), which has been under constant development for 40 years in the Polish Geological Institute – the National Research Institute. According to data as at 2010, the HYDRO Bank contains information on around 135,000 hydrogeological features.

Information on the groundwater monitoring network and results of measurements and observations carried out since 1974 is stored in the *Groundwater Monitoring* database (over 900 measurement results for the groundwater table level are annually entered in the database).

Another important database is a digital Hydrogeological Map of Poland, at a scale of 1:50,000, made as a digital serial map comprised of 1069 sheets, covering the whole area of Poland. The integrated, spatially continuous GIS database makes it possible to select informational layers according to freely defined boundaries (voivodeship, river basin, catchment area etc.) and to analyse spatial information accumulated in the database. Starting in 2004, the GIS Hydrogeological Map of Poland is being constantly enriched with new thematic layers connected with identification and characteristics of the first aquifer level.

The *Groundwater Resources* and *Intakes* databases contain periodically updated information to be used in regular assessments and forecasts of changes in groundwater resources, prepared for people who make strategic decisions regarding the country's economy and population. The condition of the resources and the possibility of their use are also very important issues in the case of emergencies. Moreover, for the purpose of reports for the EU, changes in the quantity of groundwater reserves in the country and in particular water management regions or river catchments are annually assessed. Reports containing groundwater resource balances are part of water management balances of regions, catchments and the area of the whole country. Collaboration with the Polish National Hydrological and Meteorological Service in terms of uniform water balances for catchments and regions in order to prepare annual reports on water resources in the country is mandatory.

Warnings against hazardous phenomena in groundwater recharge or intake zones

High groundwater levels entail a risk of flooding. They commonly accompany high levels of surface waters in river valleys or in topographic lows beneath escarpments and rock steps. Also endangered by floods are mining areas after the discharge systems of mining plants are disconnected. These processes change slowly; in the case of mine dewatering they last for ten plus years up to several decades. PHS develops forecasts of the scope, scale and duration of these hazards.

High groundwater levels during precipitations and considerable soil humidity cause additional flow-off pressure in escarpments and high embankments, which is usually the cause of landslides and soil creeping (surface mass movements). PHS is responsible for assessing the risk and studying an endangered area. A map of areas endangered by flood in the valleys of Poland's main rivers was successfully and thoroughly verified during this year's flood.

In the case of failure of the water supply network, danger of warfare, terrorist attacks or as a result of chemical contamination of surface waters, groundwater resources are the only reserve of drinking water for people. Strategic groundwater reservoirs and their protection are supervised by PHS.

Publications, training, personnel qualifications and national standards as regards groundwater resources protection and use

Development of reports, announcements, balances and groundwater monitoring systems requires uniform procedures and techniques as regards measurements and field work, sample collection, data collection and processing. PHS takes care of the development of procedures and standard techniques for the country through publications, training and scientific workshops. For educational purposes and reports, assessments and forecasts, graphic representation of groundwater database results is necessary. This is developed in Poland by means of standard GIS systems, computer cartography and result visualisation methods for the decision-makers.

PHS disseminates and popularises knowledge on groundwaters, their protection and use. Within the ecological education of society, the Survey approaches water resources as an element of the environment that is necessary for ecosystems to function.

SUMMARY

Polish hydrogeology has had some considerable achievements in the last decade. 2004 marked the completion of a serial edition of the Hydrogeological Map of Poland, scale 1:50,000, comprised of 1069 sheets. Currently, new informational layers are being added to the database.

In 2007 *Regional Hydrogeology of Poland* was compiled – a two-volume monograph prepared by a team of over 30 authors from all the hydrogeological centres in Poland. It is also available in a digital version on the website of the Ministry of Environment and the official PHS website: www.psh.gov.pl. These pages systematically present results for groundwater measurements and tests for groundwater chemical composition – hydrogeological annual reports and quarterly informational bulletins on groundwaters, available also in print ready versions. Printed and placed on internet sites are also PHS informational brochures on provision of water to the largest agglomerations in Poland, announcements and forecasts of groundwater status.

Along with numerous scientific institutions and geological companies, the Polish Hydrogeological Survey documents the Major Groundwater Reservoirs (MGR). The studies help determine the most perspective resources and protect drinking waters in Poland which are also an alternative for current water supply sources and apply to future generation of citizens.

In response to the current demand of society for drinking water, between 2007 and 2008 PHS determined alternative sources of drinking groundwater for cities of over 50,000 inhabitants which currently use mainly surface water intakes in circumstances of emergency hazards.

The Polish Hydrogeological Survey works also on flood hazards caused by surface mass movements – landslides and flooding during floods. Prepared between 2003 and 2006, *The Map of Areas in Danger of Being Flooded in Poland* is an important tool assisting flood risk management in the country, confirmed during this year's flood in Poland.

In the last decade, a series of engineering geology atlases at a scale of 1:10,000 were prepared for those large cities that show the greatest development dynamic. They can be used for the purposes of planning, preparing an initial evaluation of construction conditions, assessing the intensity of surface processes, such as mass movements and the depth to groundwaters, as well as creating land maps.

EU regulations require that information on the environment, and in the case of non-living nature – geoinformation, be made available to the public. This is in conformity with the INSPIRE directive in force. Therefore, geological, hydrogeological and geoenvironmental study data is presented via web browsers with the number of visits reaching hundreds of thousands a year.

To summarise, it ought to be stated that the experience accumulated over the 9 years of the Polish Hydrogeological Survey in Poland permits forming the conclusion that this is a good solution for every country that aims to limit the degradation of groundwaters intended mainly

for consumption and to attain balanced groundwater resources management. Therefore we highly recommend a national hydrogeological survey as a solution which showed its usefulness in Poland in the difficult period of joining the structures of the European Union.

Polish Geological Institute – National Research Institute

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Polish Hydrogeological Survey

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1 Groundwater quality sustainability

1.1 Evaluation and management of groundwater — sustainable exploitation

IAH 2010 Krakow

abstract id: **113**

topic: **1**
Groundwater quality sustainability

1.1
Evaluation and management of groundwater — sustainable exploitation

title: **Water quality in the Bou Areg plain and the Lagoon of Nador (Morocco): the land use connection and groundwater pollution**

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keywords: Nador, transition areas, salinization, groundwater quality

INTRODUCTION

The coastal Plain of Bou Areg, is located in the Mediterranean shore of Morocco, close to the Spanish enclave of Melilla (Fig. 1). This aquifer covers a surface of about 190 Km^2 (Dakki, 2003) and consists in two sedimentary formations of Plio-Quaternary age. The upper layer is made of fine silts and the lower one is made of coarse silts with sand and gravels (El Yaouti et al., 2009). The thickness of the aquifer ranges from environs 40 m at Kebdana to 1 m next to the shore.

The aquifer communicates with the lagoon of Nador, which represents its main outlet.

Several *oueds* are present in the area, also contributing to freshwater input of the lagoon of Nador; but only few have a permanent regime and most of them also have human contribution such as sewage and wastewaters.

The alimentation of the Bou Areg aquifer is given by groundwater from the Gareb confining aquifer, rainwater, freshwater from the Selouane River (as the main surface drainage), and irrigation waters (El Yaouti et al., 2009).

Aquifer salinization is widely recognized (Dakki, 2003), making the groundwater of the plain not diffusely used for agricultural purposes. If on the one hand the high salinity can be related to the soil nature, on the other the increase in salt content (e.g.14-10gL^{-1} in the area close to the City of Nador) could be associated to a local saline water (and lagoon water) intrusion (Dakki, 2003).

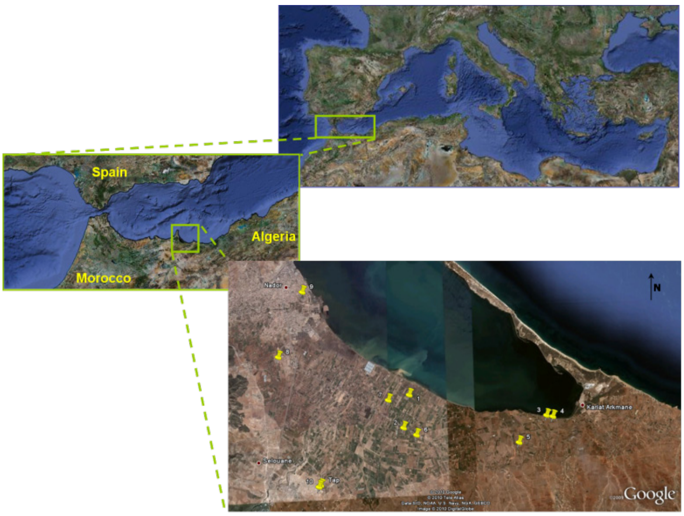


Figure 1. Location of the Bou Areg plain and the Lagoon of Nador. Sampling sites.

As in most of the coastal zones in the Mediterranean area, and worldwide, the increase in urban development in the Grand Nador area is negatively affecting natural resources quality through uncontrolled liquid and solid wastes discharge.

This catchment contains a mix of arable farming, grazing industries and urban settlements, whose combined action is damaging the natural environment especially due to the by-products of those human activities. Moreover the increase in use of phytosanitary products and synthetic fertilizers, contributing to the decrease of groundwater quality, is also affecting lagoon quality, resulting from surface runoff and groundwater discharge.

Understanding and quantifying the origin of groundwater pollution and salinization, as well as assessing the interactions between the aquifer and the lagoon is the firs step for performing adequate management practices. Therefore the main goals of the present work are to contribute to the provision of specific and reliable data on groundwater quality in the Bou Areg coastal plain and to define and quantify the interactions between the Bou Areg Costal Plain and the Lagoon of Nador.

Moreover, as this work is framed within the Strategic Partnership for Mediterranean Sea Large Marine, Ecosystem, UNESCO-IHP Sub-Component: "Management of Coastal Aquifer and Groundwater", this pilot case study will be assumed as an example of the application of hydro-geochemical and hydrogeological tools to support long term science based management practices and Integrated Water Resource Management in transition zone in coastal aquifers.

MATERIALS AND METHODS

In order to restrict the sources and the processes of salinization and to discriminate among different contribution to groundwater pollution in the Bou Areg aquifer, groundwater samples have been collected in 10 dug wells spread across the coastal aquifer (Fig. 1). This first field activity, performed in November 2009, represented the preliminary mission of the project aimed to obtain information on the status of the aquifer quality, and to identify the potential sampling sites for the subsequent missions (June 2010 and November 2010). *In situ* measurements have been performed to determine pH, Electrical Conductivity, Salinity, groundwater and air temperature. Hydrochemistry of major and minor elements (e.g. B, Br, Li, Si, Sr), together with the environmental stable isotopes of water molecule ($\delta^{18}O$ and $\delta^{2}H$) and $\delta^{13}C$ has been used to restrict the sources and the processes of salinization and trace the origin of groundwater recharge.

Moreover, as the area is mainly exploited for agricultural activities, the natural abundance $\delta^{15}N_{\_NO3}$ was investigated to trace the main sources of NO_3^-, as a fundamental step to prevent the plain from further contamination. The $\delta^{18}O$ composition of nitrate adds some more information on the origin of NO_3^-, and it allows distinguishing between synthetic and natural fertilizers (Clark and Fritz, 1997).

RESULTS AND DISCUSSION

In situ measurements pH has a mean value of 7.7, with values ranging between 7.4 and 8.3, showing neutral or slightly basic nature. Electrical conductivity suggests the presence of exceedingly mineralized waters, with an average of 4,780 μScm^{-1}, and a maximum of 8,120 μScm^{-1} in well 4. Water temperature of collected samples varies between 15.4°C and 22.3°C, with an average of 20.6 °C, these values are typical of cold-hypothermal waters.

The abundance of major ions, especially of nitrates, chlorides and sulphates (Figure 3 and 4) suggest an elevated alteration of physical-chemical properties in fresh water resources, and thus an increased risk for public health. Mineralization processes are relevant and concern areas where farming and rural or urban life can affect the groundwater quality.

GROUNDWATER RECHARGE

The δ18O and δ2H values for groundwater sampled in the Bou Areg plain, were plotted and compared with the Global Meteoric Water Line (GMWL: $\delta^2H = 8.13\ \delta^{18}O + 10.8$; Craig, 1961; Figure 2A).

Due to the absence of rain measurements for the studied area, data were compared to the dataset of the closest available station, also considering that the main sources of precipitations are Atlantic driven precipitations. Therefore, obtained values were also compared with the Local Meteoric Water Line (LMWL: $\delta^2H = 8\ \delta^{18}O + 13.7$) provided by Ouda et al. (2005). Deviations from both the global and the local meteoric water line, with an average slope of 6.7, suggest the occurrence of evaporative processes and mixing with saline sources. The evaporative enrichment and the deviation even from the LMMWL reflect the evaporative loss of the aquifer (Clark and Fritz, 1997). This is also confirmed by the comparison between the isotopic signal of oxygen-18 and chloride (Figure 2B).

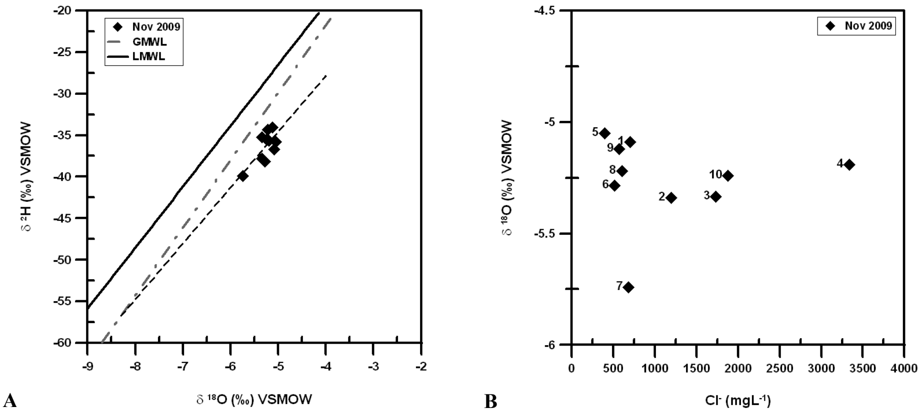


Figure 2. Delta Deuterium and oxygen-18 variations in groundwater from the Bou Areg coastal plain (A), [Dashed green line: Fit linear data NOV 2009; Grey dashed line:Global Meteoric Water (GMWL; Craig, 1961; Clark and Fritz, 1997); Plain line: Local Meteoric Water Line (LMWL; Ouda et al. 2005)]; Delta oxygen- 18 vs chloride.

SALINIZATION

Based on this preliminary analysis, and according to the results of several authors (Chaouni et al., 1999; El Mandour et al., 2008; El Yaouti et al., 2008; El Yaouti et al., 2009) it is clear that groundwater in the Bou Areg aquifer are affected by salinization problems. El Mandour et al.(2008) among the others pointed out the possible interaction of different sources of groundwater salinization: seawater intrusion, the influence of marly gypsum-bearing terrains and the influence of anthropogenic products as the agricultural fertilizers.

In fact if we plot Na concentration versus Cl concentration (Figure 3A) we can observe that almost all the samples have quite high concentrations in both Na and Cl, confirming the possible salinization processes affecting the aquifer. In particular only two samples (4 and 10) have a composition coherent with the progressive dilution with sea water, while all the others plot above the dilution line. This enrichment could indicate water-aquifer interaction, and cation exchange reactions between the silicates fractions of the aquifer and groundwater rich in dissolved calcium; therefore in first approximation we could assume that the circulation is slow, facilitating the exchange with silicates, with liberation of Na^+ (El Yaouti et al., 2009) and a possible associated decrease in Ca^+. However by plotting Ca versus Cl, (Figure 3B) an increase in Ca^+, is observed, possibly indicating the occurrence of carbonates or gypsum dissolution. The highest value of Ca concentration for well 10 (Figure 3 B) could be representative of its origin, therefore associated to its baseline conditions.

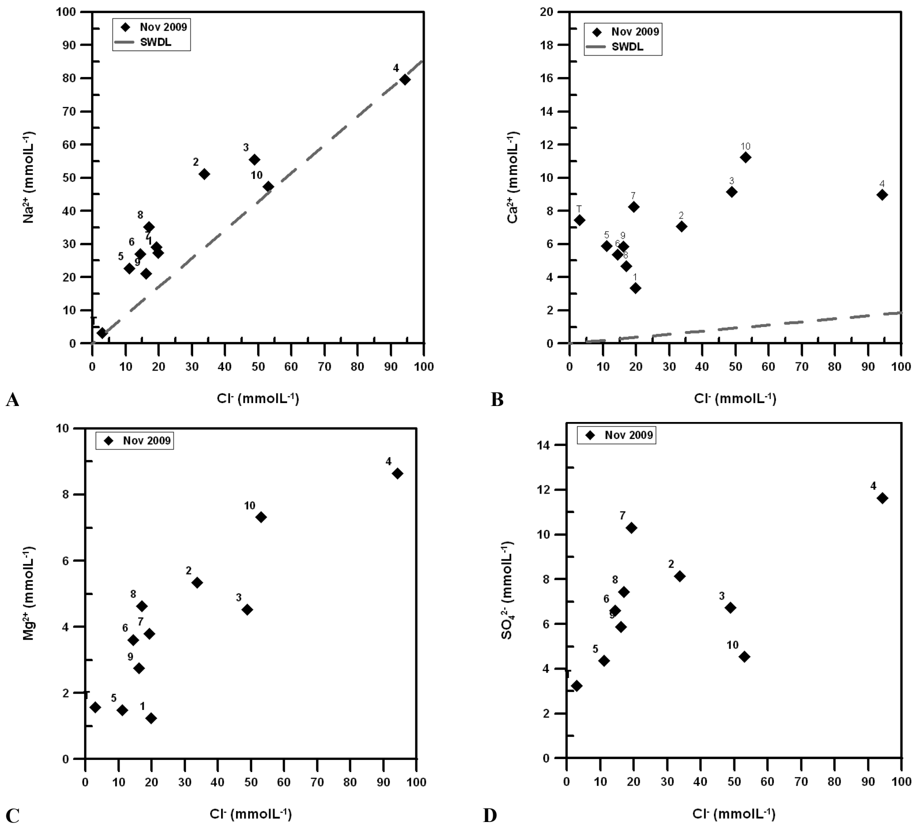


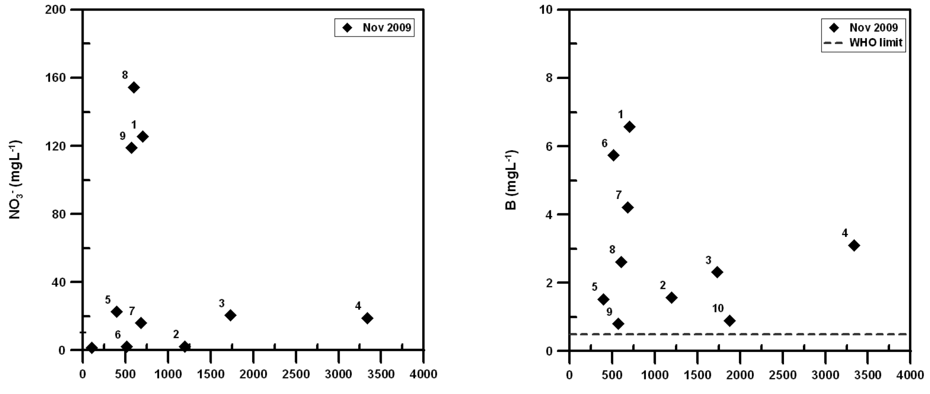
Figure 3. Plots of dissolved species versus chloride concentration (in mmolL-1). (A) Na vs. Cl; (B) Ca vs Cl; Mg vs Cl; (D) SO_4 vs Cl; dashed lines represent Seawater Dilution Line (SWDL).

WATER POLLUTION

In order to identify the different sources of nitrate, the isotopic composition for nitrogen and oxygen have been studied. Intensive human activity in this area has resulted in pollutant loads, in some cases exceeding drinking water standards, in particular, for nitrate and Boron (Fig. 4) For this reason, in order to build up the correct policy for groundwater management, the identification of the different sources of nitrogen pollution is required.

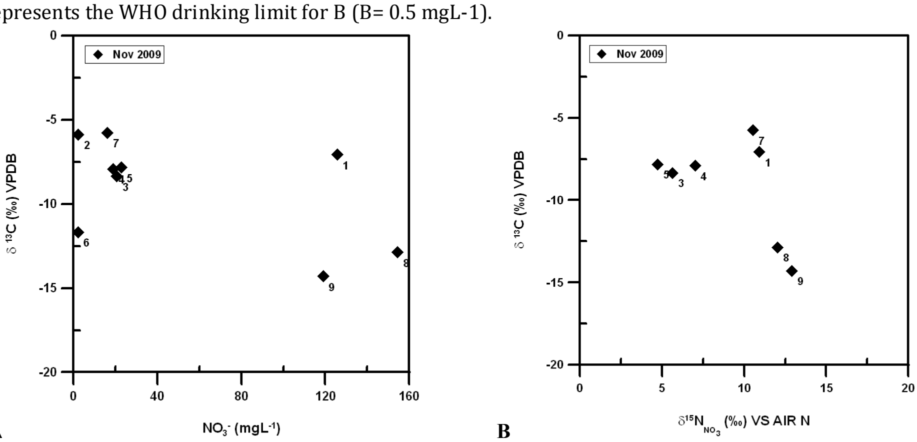
Considering the isotopic composition of the wells, (Figure 5 and 6) the samples lay within the ranges consistent with an origin from soil organic matter and, manure or septic system effluents

(10-15‰), as expected if considering the position and the social situation of the region. In fact in rural areas and in over inhabited region, the main impact on groundwater is represented by the combined action of fertilizers and septic effluents, thus confirmed by δ13C.



A B

Figure 4. Nitrates concentration versus chloride (A); Boron concentration vs chloride (B). Dashed Line represents the WHO drinking limit for B (B= 0.5 mgL-1).



A B

Figure 5. Delta carbon 13 (‰) versus nitrates concentrations (A) and delta 15 nitrogen (‰; B).

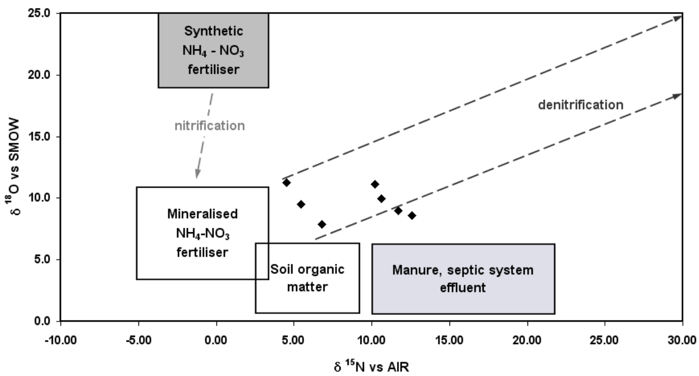


Figure 6. Isotopic composition of Nitrates for the Bou Areg coastal plain.

Moreover, considering the isotopic signal for carbon-13 in Dissolved Inorganic Carbon (DIC), few wells (6, 8, 9) have a signature coherent with the recharge in a open system , while the others have a composition coherent with the mineralogical matrix (Figure 5).

AKNOWLEDGEMENTS

The work has been partially funded by UNESCO-IHP, in the framework of the Strategic Partnership for Mediterranean Sea Large Marine, Ecosystem. Authors would like to thank the Facultè Pluridiciplinaire de Nador, Universitè of Oujda for the logistic support and the help during the field wok and sampling preparation. We also thank ISO4 s.s. for the isotopic analysis and CNR IGAG for the chemical analysis of water samples.

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IAH 2010
Krakow

abstract id: **133**

topic: **1**
Groundwater quality sustainability

1.1
Evaluation and management of groundwater — sustainable exploitation

title: **Evaluation of the agricultural development impact in an arid-semiarid region of the Argentine Republic**

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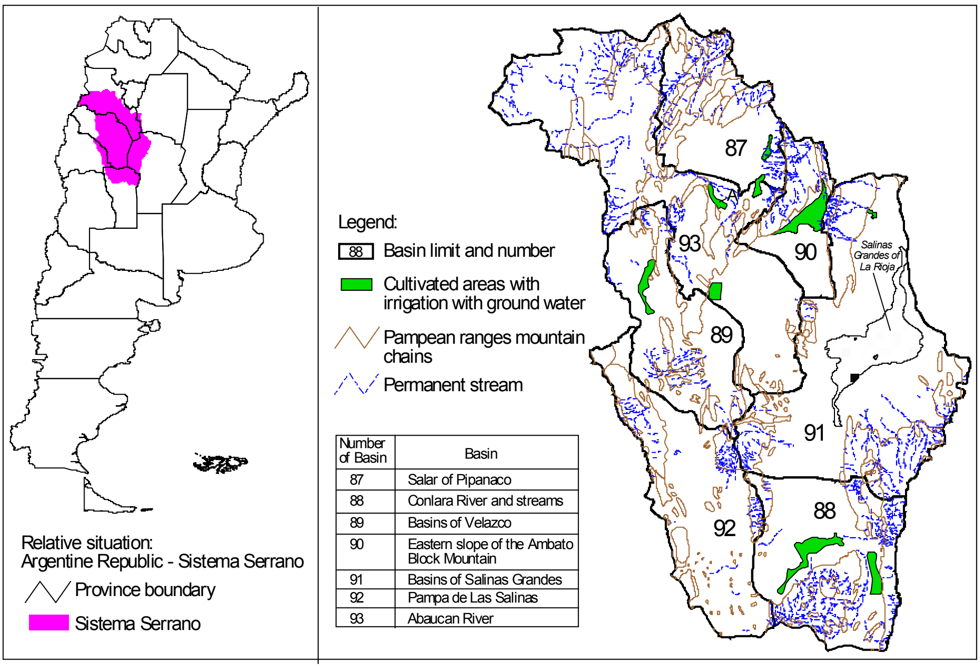
keywords: irrigation, intensive exploitation, mathematical models

INTRODUCTION

The dimension of irrigation in Argentina is turning into something noteworthy. It is considered that 75% of its territory belongs to arid and semi-arid conditions.

Groundwater plays an important role in the total of system of public supplying in a large part of Argentina, particularly throughout the rural population and in a mixed way in major cities.

Groundwater has especially contributed to an agricultural expansion and to industrial park in the inner country. Nevertheless overexploitation and mismanagement have contributed to non desirable troubles like decrease of groundwater levels and to get damaged the quality of groundwater in urban areas. The word overexploitation intends to qualify a concerning evolution from certain points of view, but has no precise hidraulic meaning (Custodio, 2002). One of the most important changes which are now generating in Argentina is to establish the racional use of water both in the agricultural economy and to suply human needs. This last one is extremely related to its development generated in vast urban centres. The current paper analizes some changes which were produced in a north-eastern Argentinian region, named “sistema serrano” (Fig. 1), which takes part of the map of basins and hydrologic regions in Argentina. This region is located in the arid and semi-arid area over a surface of 181,000 km^2, where productive agricultura is only available under irrigation.



Number of Basin	Basin
87	Salar of Pipanaco
88	Conlara River and streams
89	Basins of Velazco
90	Eastern slope of the Ambato Block Mountain
91	Basins of Salinas Grandes
92	Pampa de Las Salinas
93	Abaucan River

Figure 1. Situation of the “Sistema Serrano” and areas cultivated with ground water.

Based on historical non systematic data, and governmental decisions led to determinate the sustainability of the intensive exploitation; this paper aims to announce a prospect about the present development of groundwater use and to advice how to stength further studies with the pourpose of achieving the mayor benefits to its use. To that end it will be necessary to carry out control observations and to intensify the knowledge of system. Everything should be done within a framework of political decisions and set up tasks in order to be taken into account environmental, social and economical issues. It is, then, necessary a joint work of scientists, politicians and public in order to achieve sustentability, development of water policies and water resource management to satisfy the future demand of water, and to avoid unacceptable impacts (Grabert, 2006).

The explotations of ground water as a result of the expansion of the cultivated surface under irrigation are supposed to have a decrease in the storage during the analysed period. This current analysis will enable to take decisions about the degree of overexploitation, whether it is aceptable or advisable. Evolution of pressurized irrigation in different regions in Argentina, points out a total surface of 61,406 hectares. This surface will clearly have suffered a certain growth with the incorporation of equipments of pumping in this area; and therefore in humid areas or sub-humid ones as complementary or supplementary, irrigation, due to long periods of drought in regions of dry land. It is currently estimated that these ones will exceed 77,000 hectares under irrigation and it keeps constantly growing.

At about the late 1980's, in Argentina, modern systems of pressurized irrigation with groudwater begin to be incorporated to. Since that period a very fase growth of the irrigated surfaces began over the whole Argentinian western (Chambouleyron, 1993). The agricultural development through these systems has been motivated by political decisions of tax benefits for the mention systems and the development of modern technologies. It proves that the development of these mentioned methods have played a predominant role which has been accompanied by governmental decisions led to the execution of hydrological studies with the purpose of determining the degrees of sustainability. This last topic was supported in the last constitucional reform held in Argentina in 1994. It determinates that natural resources belong to each jurisdiction. Thanks to these taken actions, in the current paper, different areas under pressurized irrigation in the region are shown and analysed, moreover the effects that they have caused in the aquifer-systems.

The hard anthropic pressure over this zone, because of water consuming for irrigation added to a narrow dependence of the ground water systems during the last 20 years, turns the knowledge of the extractions into a main issue for the suitable treatment of the resource and the entire satisfaction of the demands. It also arises the need to develop knowlegde about the availability of the aquiferous systems, so as to be properly exploited to the implementation of complementary irrigation, will be able to improve the availability of surfaces for farming uses.

STUDY AREA

“Sistema Serrano” corresponds to a basin with endoreique characteristics where all ground water ends its cycle in Salinas Grandes of La Rioja (Fig. 1). There it will be shown the areas developer ander irrigation with intensive exploitation of groundwater.

AQUIFER SYSTEMS

The study area is included in the geological province Pampean Ranges. All of them make up a geological unit which is characterised by mountain ranges where the crystalline metamorphic basement, migmatic and intrusive Precambrian-Paleozoic, separated by wide depressions covered by Quaternary deposits. This mountain chains line up predominantly north to south, although many ones change its direction dramatically. Practically, it is considered that these rocks take part of the hydrological basement of the subterranean water basin. The main recharge of the aquiferous comes through from the infiltration of superficial runoffs which flow into the mountain area, and the area which generates the main contribution to the recharge which is situated out of the limits of the reservoir.

Sedimentary fill of intermontane valleys includes two geological units of subsoil: a lower one named Fine Clastic Formation which develops itself straightaway over the crystalline basement and an upper one named Coarse Clastic Formation.

Fine Clastic Formation which probably belongs to Tertiary Superior-Quaternary Inferior. It is composed by an alternated sequence of clay silt, silty clay, clays, sands, gravel and pebbles. The largest part of the formation consists on fine material. Silty clay becomes the most frequent component whilst the isolated layers of sand and gravel are generally thicker than 1 m. Predominant colours are brownish-yellowish slightly reddish; occasionally red-a shade of violet, dark brownish, yellowish, blue-greenish and white. Clays are generally plastic and coarse can be frequently found. Coarse Clastic Formation is displayed over the Fine Clastic Formation previously described and is equivalent to the set of units of Quaternary age; conforming units of decreasing age since Pleistoceno till Holoceno. It is generally composed by an alternated sequence of silty clay, silt, sandy silt, silty sands, sand and gravel. It is frequent to find coarse. This Formation, which is integrated into materials of medium to high permeability, contains the most important aquiferous system exploited nowadays. It is worth pointing out that the proportion of coarse grained beds in the Fine Clastic Formation is around 10 % whilst in the Coarse Clastic Formation varies from 50 to 70%. This characteristic evidences an important element of decision in well design.

EFFECTS OF GROUNDWATER DEVELOPMENT

The results displayed in (Tab. 1), have been elaborated with discontinuos data which begin in 1965 up to date.

Table 1. Areas under irrigation and volume extracted of groundwater.

Number of Basin	Basin	Total surface (km^2)	Exploited surface (ha)	Pumped volume (Hm^3)
87	Salar of Pipanaco	18029.57	1000000	146.06
88	Conlara River and streams	22977.44	2008500	140.63
89	Basins of Velazco	17877.74	1323100	132
90	Eastern slope of Ambato	9732.71	1720000	122.04
91	Basins of Salinas Grandes	44506.77	0	0
92	Pampa de las Salinas	24800.08	0	0
93	Abaucan River	43091.95	1448900	143.1
Total		181016.25	7500500	683.83

In most of the studied areas, these parctices have not caused decrease of groundwater levels which may indicate that we are in the presence of overexploitation if we compare with historical registers from seventies. In the areas located in the basins Nº 89 and 93, where there is no more data available than the recent one, they show a decrease of the piezometric water levels. This can be explained if the pluviometrical registers are observed at (Fig. 2). There it is possible to observe that from years 1974 and 1975 a remarkable increase of these registers is produced. Even though they show that from year 2000 on, it might be attending to a decrease of rainfall pluviosity.

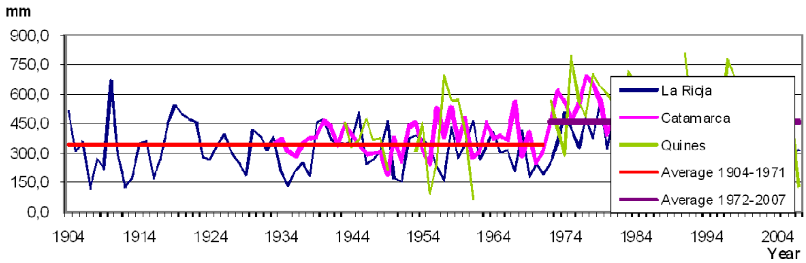


Figure 2. Annual precipitation. La Rioja, Catamarca and Quines (Northern Plain).

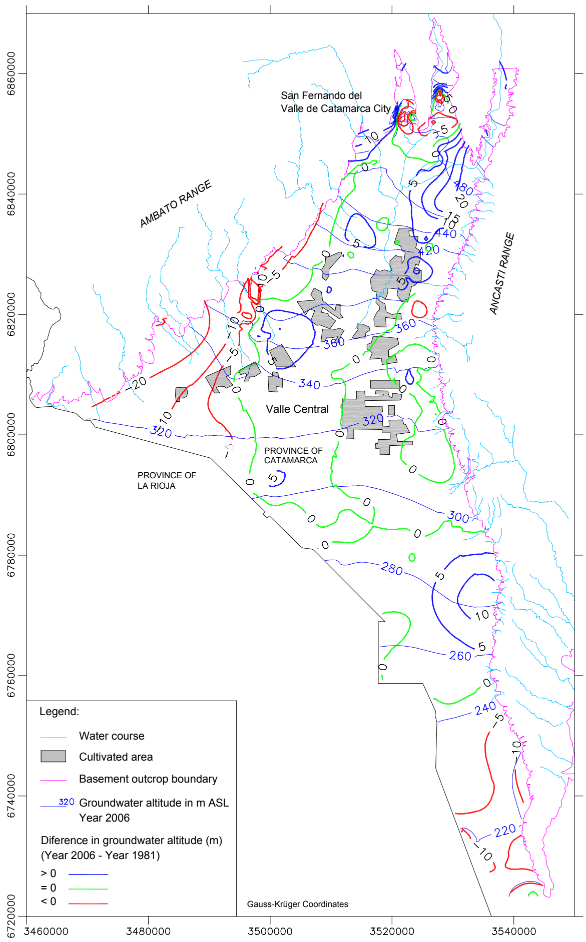


Figure 3. Groundwater level altitude difference. Year 2006 – Year 1981. Catamarca Central Valley.

The mathematical models of aquifer systems carried out in some of these regions (Bucich, 2009) advise the continuous implementation of these techniques so as to follow up on the growth of the agricultural demand and to turn it compatible into systems of potable water supply. In the (Fig. 3, 4 and 5) it can be shown some of the analysed areas as an example of previously indicated. (Fig. 3) represents the current area under irrigation in the Catamarca Central Valley and its variations of levels from 1981 to 2006. It is shown overall that they have suffered an increase at about 3 m, except for the area of San Fernando del Valle de Catamarca city where it is focused the largest drops (nearly 15 m) by intensive exploitation with the purpose of stocking up of potable water.

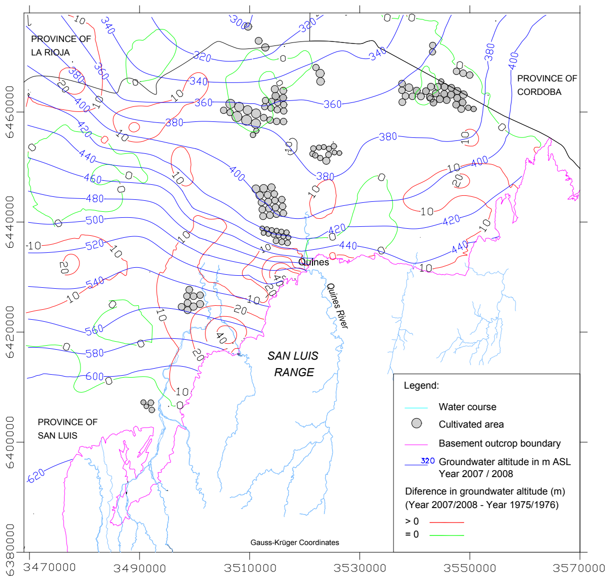


Figure 4. Groundwater level altitude difference. Year 2008. Year 1976. Northern Plain.

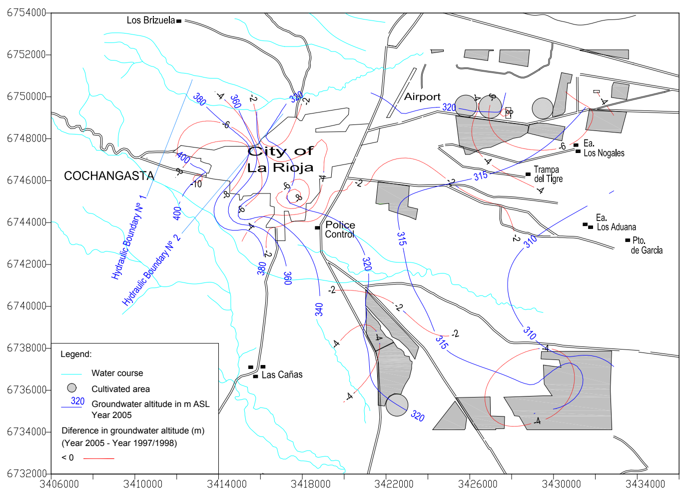


Figure 5. Groundwater level altitude difference.Year 2005 – Year 1998. La Rioja.

In the same way than in the previous area, in the area of Northern Plain, province of San Luis (Fig. 4), with 17,000 hectares under irrigation, groundwater levels compared between the years 1976 and 2007 have suffered an average increase of 7 m.

In the area Cono Aluvial in the province of La Rioja (Fig. 5) it is show, on the contrary a reverse effect where the groundwater leves have suffered a maximum drop of 10 m in the area of capitaline tissue for water extraction for human consumption, roughly 6 m in some areas of agricultural undertakings where water for irrigation is extracted. According to what we have written before, these results should alert the authorities to take measurements of managements in these areas, plus the proteccion of the systems and its consequences.

CONCLUSIONS

The severe antropic pressure over this zone, as far it is concerned to the consumption of water to irrigate, and the almost dependence on the subterranean water during the last 20 years in the study area, means that the knowledge of the extractions, a fundamental issue to the appropriate management of the resource and hoe to satisfy the demands.

The observed decrease in the pluviosity from year 2000 should be monitored onward the continuity of the measurements in order to verify its evolution and to foresee its impact.

Authorities should be alerted about the areas where some decrease of levels have been observed, in order to set up measures of management and the protection of the systems, plus its consequences.

The mathematical modelling of the aquiferous systems, which was made in some of these regions, recommends the continuous application of these techniques with the purpose of controlling the growth of the agricultural demand; and make it compatible with the systems which provide potable water.

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abstract id: **179**

topic: **1**
Groundwater quality sustainability

1.1
Evaluation and management of groundwater — sustainable exploitation

title: **Groundwater quality of the Limpopo Province basement aquifers and its impact on rural groundwater supply**

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keywords: groundwater, basement aquifers, quality, pollution

INTRODUCTION

Crystalline basement rock aquifers are distributed extensively in Africa and underlay large parts of the semi-arid Limpopo Province in South Africa. Some of the greatest groundwater needs occur within the Limpopo Province and constitutes the only dependable source of water for many users. Surface water resources in many areas of the Limpopo Province are now fully utilized and almost the only opportunity left for further development lies in the exploitation of groundwater. Groundwater is available and widely used throughout the Province, but in varying quantities depending upon the hydrogeological characteristics of the underlying aquifer. However, the availability of groundwater and the suitability of its quality for different uses are inextricably intertwined. There is a perception amongst water users that groundwater resources are not as viable as surface water resources. Remote communities with no other source of water view abstractions from a borehole as second hand and regard it as a poor man's resource. The growing importance of groundwater is not yet reflected in the improved management of the resource and together with the vulnerability of basement aquifers has lead to wide spread pollution. Despite indications that groundwater resources are evidently under-utilized and underdeveloped, the prospect of groundwater to successfully eradicate backlogs in provision of community water could be severely jeopardised by inadequate control or management of groundwater qualities in the Limpopo Province.

STUDY AREA

The focus area of this study covers an area of 23 500 km^2 in the Limpopo Province, South Africa. It is almost entirely underlain by Achaean basement lithologies (gneiss, granite and greenstones), which outcrop in an approximately rectangular area bordered to the south by younger overlying sedimentary strata, to the north by the Soutpansberg Group (Volcanic rocks), to the west by the Northern limb of the Bushveld Complex and to the east by the Drakensberg basalts of the Lebombo mountains (Figure 1). The western portion of the area can be referred to as the Limpopo Plateau and the eastern portion as the Letaba Lowveld respectively (Figure 1). The Limpopo Plateau is flat and almost featureless with the Blouberg Mountains towards the west and the Soutpansberg Mountains towards the northeast forming topographic highs. The climate of the Limpopo Plateau is semi-arid with a mean annual rainfall from of 300 mm to 600 mm. The Lowveld region east of the watershed is generally characterised as a moderately undulating plain with highly irregular hilly surfaces associated with the escarpment (Figure 1). The Lowveld is characterised by sub tropic temperatures with a fairly high humidity. Orographic rains occur frequently along the escarpment and the mean annual rainfall varies accordingly from 1 000 mm in the west to only 300 mm in the east. The runoff is highly seasonal and variable, with intermittent flow in many of the tributaries. Only a number of major river courses are perennial and most rivers sustain flow only during the wet season (December to April) or during intense rainfall events.

The basement rocks of the Limpopo Province contain some of the world oldest known rocks and are geologically and structural complex, shaped by multiple tectono-metamorphic events spanning at least 600 million years (Kramers et al, 2006). The study area is located on the north-eastern part of the Kaapvaal craton and the southern marginal shear zone (SMZ) of the Limpopo Mobile Belt (LMB) (Figure 1). Some authors (e.g. Roering et al., 1992; Windley, 1993) have suggested that the LMB in the northern part of South Africa is the world's earliest example of a Himalayan-type continent-continent collisional orogeny between two large cratons (Kaapvaal- and Zimbabwe Cratons respectively). The northward dipping Hout River Shear Zone (HRSZ) on the southern side of the LMB forms the boundary between the low grade basement lithologies of the Kaapvaal Craton to the south and the higher grade rocks (amphibole and granulite) of the SMZ to the north.

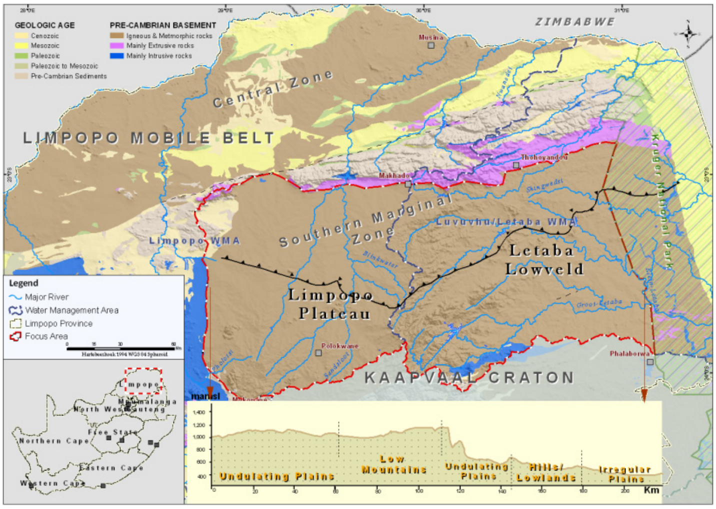

Figure 1. Area of investigation.

The aquifers systems developed in the focus area are: 1) composite aquifers; comprising of a variable thickness of regolith overlying bedrock, the upper part of which is frequently fractured, 2) fractured aquifers; composed mainly of crystalline material (i.e. igneous and metamorphic rocks) characterised by an intact and relatively unweathered matrix with a complex arrangement of interconnected fracture system and 3) alluvial aquifers; alluvial material overlies or replaces the weathered overburden and creates a distinct intergranular aquifer type. These elongated aquifers with limited width and depth follow rivers (so called valley trains), sand rivers or drainage lines.

DATA ANALYSIS

The dataset is based on the national groundwater database obtained from the South African Department of Water Affairs and the Limpopo Province Groundwater Resources Information Project (GRIP) database. Approximately 2 500 boreholes were analysed during the last decade as part of these programmes. The analyses included mainly major ions pH, TDS and electrical conductivity.

GROUNDWATER QUALITY

The dominant water types in Limpopo Plateau vary from a Na-Mg-HCO_3 to a Na-Mg-Cl groundwater facies, with the first being found in recharge areas (e.g. Blouberg and Soutpansberg), and the latter a result of prolonged residence and fluid-rock interaction times in the subsurface in areas of discharge (e.g. alluvium along rivers) or low recharge (e.g. quaternary deposits in the northern part of the sub-region). Groundwater in the Letaba Lowveld is generally a fresher Mg-HCO_3 facies (in comparison to the Limpopo Plateau), with a recognizable pattern of elevated mineralization with reduced precipitation/recharge is.

Borehole yields in basement aquifers are typically relatively low (usually less than 5 l /s and often less than 1 l /s) and groundwater quantities are usually limited. The presence of undesirable natural hydrogeochemicals or by introduced contaminants reduces the exploitation value even further. Neglecting the variation in groundwater chemistry due to either ignorance or lack of information can cause harmful or even detrimental effect to the community who relies on the bad quality water as their domestic source. Table 1 presents the overall drinking guideline classification of the major ion chemistry of the Limpopo Plateau and Letaba Lowveld basement aquifer region under investigation.

Table 1. Potability classification of the area of investigation (EC in mS/m, all other in mg/l).

SANS*	EC	Ca	Mg	Na	K	SO_4	Cl	NO_3 as N	F	TDS	Final Class
Class I Rec. operational Limit	< 150	< 150	< 70	< 200	< 50	< 400	< 200	< 10	< 1	< 1000	
Class II Max. allowable limited	150-370	150-300	70-100	200-400	50-100	400-600	200-600	10-20	1-1.5	1000-2400	
Exceeding Class II (Consumption period)				7 years					1 year	7 years	
Limpopo Plateau											
Class I	70%	94%	75%	85%	99%	99%	73%	54%	87%	96%	34%
Class II	26%	4%	15%	11%	1%	0%	20%	27%	5%	0%	34%
> Class II	4%	2%	9%	4%	0%	1%	6%	19%	8%	4%	31%
Letaba Lowveld											
Class I	78%	96%	78%	90%	100%	100%	81%	60%	94%	98%	47%
Class II	19%	3%	13%	8%	0%	0%	15%	16%	4%	0%	24%
> Class II	6%	2%	17%	6%	0%	1%	9%	38%	8%	5%	54%

* SANS 241:2006 (SANS, 2006).

Thirty one percent of samples within the Limpopo Plateau and fifty four percent of samples within the Letaba Lowveld show major ion concentration far from ideal. The most noticeable elements of concern for water consumption are nitrate (measured as nitrogen (N)) and fluoride. In addition, several samples show major ion concentrations (e.g. Mg, Na, Cl) and subsequently electric conductivities beyond acceptable limits. This can mostly be related to evaporative concentration of elements in discharge areas or due to low recharge values as well as long residence times for selected samples. According to Marais (1999) the single most important reason for groundwater sources in South Africa to be declared unfit for drinking is nitrate levels exceeding 10 mg/l (as N). The main inputs of nitrate to groundwater in rural environments are derived from anthropogenic activities such as inappropriate on-site sanitation and wastewater treatment, improper sewage sludge, drying and disposal, and livestock concentration at watering points near boreholes. The extensive occurrence of nitrate in groundwater in uninhabited regions suggest non-anthropogenic sources possibly related to evaporative enrichment of dry and wet deposition, biogenic point sources through N-fixing organisms, or to a geogenic origin (Figure 2). In contrast to nitrate, the occurrence of fluoride is primarily controlled by geology and climate. Therefore, there are no preventative measures under the given spatial limits of a water supply to avoid contamination. High intake of fluoride from drinking water is the main cause of flourosis and may lead to many other health problems.

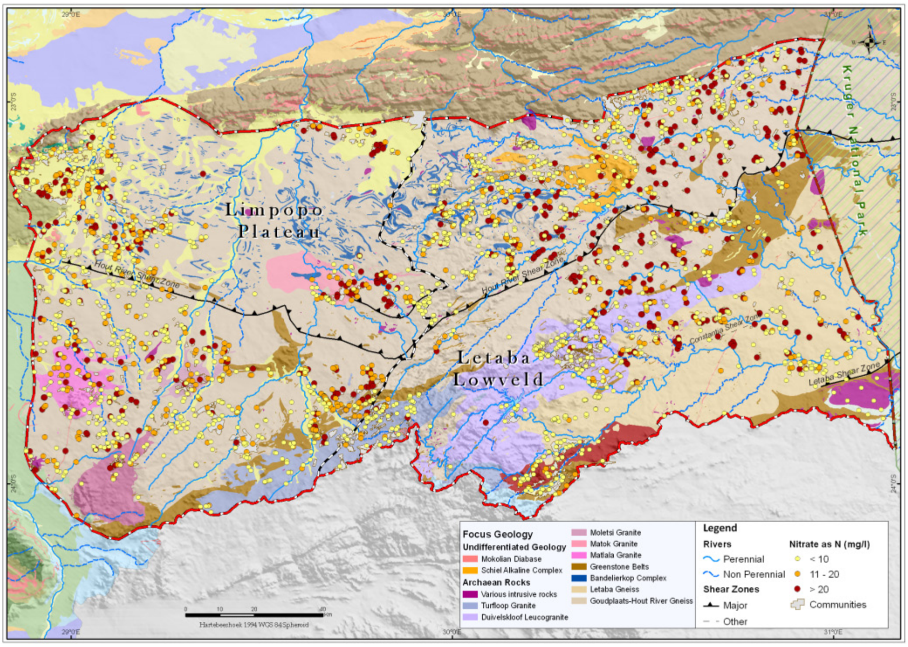

Figure 2. Map showing distribution of nitrate in groundwater in the Limpopo Plateau and Letaba Lowveld.

Heterotrophic bacterial counts are used to indicate the general microbiological quality of water, i.e. the amount of bacteria present in the water. The total coliform bacteria count, which includes bacteria from the faecal group, is an indicator of the general sanitary quality of the groundwater, with many of these bacterial colonies originating potentially from an aquatic environment. The total faecal coliform bacteria count, which is related to human or animal faecal pollution, refers to probable faecal pollution of water. The presence of coliform bacteria implies the potential presence of waterborne pathogens (DWAF, 1996). According to the Department of Water Affairs' water quality guidelines (DWAF, 1996) for domestic use, the total heterotrophic bacterial plate count of all groundwater samples from both areas indicates a slight or increased risk of bacterial infection and infectious disease transmission. Fourteen groundwater samples show a significantly increased risk for infectious disease transmission according to the total coliform bacterial range and two samples indicates a significant risk for faecal coliform and e.coli (Table 2).

Table 2. Microbiological analyses for selected boreholes in Muyexe village (DWAF, 1996).

Allowable compliance contribution*				
95% min.	*100*	*Not detected*	*Not detected*	*Not detected*
4% min.	*1 000*	*10*	*1*	*Not detected*
1% min.	*10 000*	*100*	*10*	*1*
Sample	Heterotrophic *count/ml*	Total Coliform *count/100ml*	Faecal Coliforms *count/100ml*	E.Coli *count/100ml*
Nr of Samples	51	19	10	10
Compliance 4% min.	45	4	5	5
Compliance 1% min.	11	14	2	2

* The allowable compliance contribution shall be at least 95% to the limits indicated with a maximum of 4% and 1% respectively.

IMPLICATION FOR RURAL WATER SUPPLIES

Results show that many rural groundwater supplies are contaminated. Approximately 35% of rural communities in the region are dependent on groundwater alone and 50% have conjunctive use of both surface- and groundwater. A large part of the rural population lives in areas underlain by basement rocks which might release fluoride to groundwater. In addition anthropogenic sources such as inappropriate on-site sanitation at rural villages, pit latrines and animal feedlots frequently lead to pollution and the abandoning of well fields. Protection of groundwater resources that serve as a drinking water supplies should be equally important target as creating new water supply infrastructure in a country. If mitigative measures are not established early, groundwater quality will have a severe impact on the exploitability of groundwater resources in the Limpopo Province. These measures may include the provision of accurately mapped water quality information, proper borehole construction, protection zoning and appropriate water treatment for drinking purposes. The management of groundwater has to date failed to feature prominently in the national and regional development plans. Despite the new national water Act (1998) which includes excellent general protection measures the challenge lies in the implementation of the available approaches and instruments. However, perhaps one of the biggest weights lies on water service providers to convey the value of groundwater to the communities. The consensus is that communities will only concern themselves with the quality of the water when there is enough to meet their basic needs.

ACKNOWLEDGEMENTS

The author acknowledges the Water Research (Pretoria, South Africa) commission for funding.

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abstract id: **184**

topic: **1**
Groundwater quality sustainability

1.1
Evaluation and management of groundwater — sustainable exploitation

title: **Grout curtain construction using bentonite for the control of groundwater seepage and contaminant migration**

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keywords: bentonite grouting, permeability, vertical barriers, contaminant flow

BACKGROUND

The contamination of groundwater resources from point or extended sources has been a source of worry to groundwater users and researchers. Identifying the contaminated source and clearing it from spreading could be the best way of addressing contamination issues. However, this might not be very effective as some traces could still be left behind. The only way to prevent potential sources from spreading as corroborated by many researchers is to construct a vertical barrier to block water or leachate from entering or leaving the contaminant source respectively.

Grout curtains are vertical, low permeable grout walls constructed in the ground to block horizontal fluid flow. They are constructed by injecting grout at certain pressure directly into the soil or rock through drilled holes at closely spaced intervals such that each plume or "pillar" overlaps the next, thus forming a continuous wall or curtain. The injected grout permeates through the soil thereby sealing the pores and cavities resulting into low permeable barrier. In most cases, vertical barriers are constructed by *in situ* mixing of cement and soil in deep trench to form the barriers. However, constructing such barriers at great depths below the ground surface may be limited by the capability of the trenching equipment. This method requires heavy machinery which may be capital intensive and environmental unfriendly. However, in grout curtain, the grout can be injected to considerable depths which can also penetrate tiny pores of the soil or fractured rocks of small aperture sizes.

A laboratory test on the suitability of using bentonite grout for the construction of vertical barriers was investigated. In this research, grout injection into artificial rock fracture and porous medium (river sand from Okayama area of Japan) using Salt/bentonite slurry was conducted. The paper discusses how a grout curtain can be constructed in the saturated-to-unsaturated soil and rock conditions to ensure complete containment of contaminant.

CRITICAL HYDRAULIC GRADIENT

Barrier thickness is a determining factor to the effective performance of the barrier. The design of the thickness wholly depends on the critical hydraulic gradient of the bentonite used. This implies that, prior to the construction of grout curtain, it is important to determine the critical hydraulic gradient. The critical hydraulic gradient is the hydraulic head beyond which a failure of the barrier occurs. This is given by the relation

$$\frac{\Delta h}{L} < I_C$$

where Δh is the effective hydraulic head, L the thickness of the barrier and I_C is the critical hydraulic gradient which can be determined experimentally.

APPLICABILITY AND LIMITATIONS

Grout curtains may be used up-gradient of the contaminated area, to prevent clean water from migrating through waste, or down-gradient, to limit migration of contaminants. They may also be used as cut-off wall for groundwater storage in underground dams. However, effectively creating a wall without defects has been problematic in certain environments and operating conditions. Especially, if very coarse-grained materials are encountered, defects in the curtain may occur. The site must be well characterized to minimize unexpected geologic conditions.

METHODOLOGY

The method involved injecting salt/bentonite slurry at Liquid/Solid (L/S) mixing ratios of 6, 8 and 10 into cylindrical columns of compacted river sand of porosity ($0.33 \le n \le 0.40$). The resulting grouted columns were then set up for permeability test with subsequent determination of critical hydraulic gradient. Determination of the critical hydraulic gradient involved running the permeability test for a long time while maintaining a given hydraulic gradient and the permeability determined with time until a constant permeability was attained. Measurement continued at stepwise increase in hydraulic gradient till failure occurred where the permeability was observed to increase with time.

Similar injection was conducted on artificial fracture of aperture sizes 60, 80 and 100 µm and the critical hydraulic gradient determined.

RESULTS AND CONCLUSION

The results showed that grout of the given mixing ratios was successfully injected into compacted river sand and artificial fracture. The critical hydraulic gradient for the compacted sand was between 180 and 200 while that for the grouted fracture was between 30 and 35. It is thus safe to use the lower values of critical hydraulic gradient of 180 and 30 for sand and fracture respectively in calculating for the barrier thickness. The permeability values for the porous media was in the range of 10^{-9} cm/s while the values for the grouted fracture in the range of 10^{-6} to10^{-7} cm/s which are recommended for seepage barrier.

The critical hydraulic gradient for porous media is thus higher than for fracture medium. The lower value for the fracture could be due to the smooth nature of acrylic used for the fracture model. A rough surface is thus recommended that may mimic fracture conditions on the field.

abstract id: **204**

topic: **1**
Groundwater quality sustainability

1.1
Evaluation and management of groundwater — sustainable exploitation

title: **Geochemical, multi-isotopic and hydrogeological characterization of the mineralized groundwater body of the Entre-deux-Mers area, Gironde (South-West of France)**

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keywords: geochemistry, multi-isotopes, hydrogeology, salinity

INTRODUCTION AND OBJECTIVES

In the south-west of France, the Eocene aquifer is one of the main resources for irrigation, thermo-mineral water, and mainly for drinking water in the Bordeaux region.

This aquifer is characterized by the presence of a large saline area (Fig. 1a), centered on the Entre-deux-Mers area, between the Garonne and the Dordogne rivers, where the ground waters show strong mineralization and anomalous levels of critical elements (Chery, 1993; Chery et al., 1994 and Corbier et al., 2005), such as sulfates and fluoride, leading to difficulties of resource exploitation for drinking water supply.

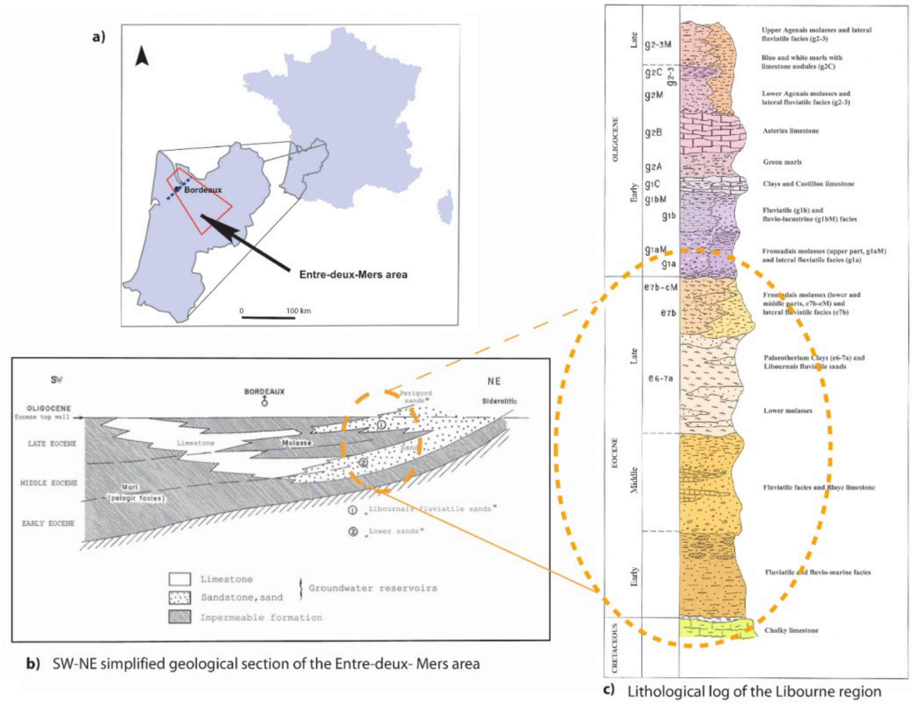

Figure 1. a) Location of the Entre-deux-Mers area, b) SW-NE simplified geological section, c) Lithological log of the Libourne region.

Initiated in 2009, the CARISMEAU 2 project, funded by the Bureau de Recherches Géologiques et Minières (BRGM), the Institut EGID — University Bordeaux 3 and the French Water Agency Adour-Garonne (AEAG), focuses on the geochemical, multi-isotopic and hydrogeological characterization of this mineralized groundwater sector of the Entre-deux-Mers area. Its main objectives are to improve the understanding of the origin of the salinity in this mineralized area and to investigate how these waters circulate in the Eocene aquifer and more largely in the multi-layer aquifer system.

GEOLOGICAL AND HYDROGEOLOGICAL SETTINGS

The deposit sequences characterizing the Eocene aquifer system are progradational westward (Fig. 1b), from detrital deposits (Fig. 1c) to carbonates. The Eocene sands and the Eocene limestones are hydraulically connected, the limit of their extension is located under the city of Bordeaux (Dubreuilh, 1987 and Moussié, 1972). The groundwater recharge may occur through the Eocene outcrops located in the north and north-east of this mineralized area of the Entre-deux-Mers, and also by vertical leakage from the Oligocene aquifer.

Furthermore, the second aspect to consider in this saline area concerns the piezometric evolution of the Eocene aquifer years after years. In fact, a trough in the potentiometric surface is noticeable for the Eocene Aquifer, centred under the city of Bordeaux (Corbier et al., 2005). For years, the decline of the piezometric surface is roughly one meter per year in the center. The cone of pressure relief in this confined aquifer stretches to the east year after year in the same direction, toward the Garonne and the Dordogne rivers. Moreover, two groundwater ridges separate the through in the Early and Middle Eocene potentiometric surface from the Atlantic Ocean in the South-West and from the Gironde estuary in the North-West.

GROUNDWATER SAMPLING AND ANALYTICAL METHODS

In order to improve the understanding of the origin of the salinity and to investigate how these waters circulate, combined geochemical analyses (major and trace elements) and classical isotopic methods using $\delta^{18}O_{H2O}$ and $\delta^{2}H_{H2O}$, $\delta^{34}S_{SO4}$ and $\delta^{18}O_{SO4}$ are carried out. In addition, an innovative isotopic method using strontium isotopes ($^{87}Sr/^{86}Sr$) and more exploratory isotopic methods using boron ($\delta^{11}B$), lithium ($\delta^{7}Li$), uranium ($^{234}U/^{238}U$) and radium ($^{228}Ra/^{226}Ra$) isotopes will be applied on the mineralized area (Négrel et al., 2006, 2007, 2008 and Malcuit et al., 2008).

The first investigation, carried out from September to December 2009, allowed the characterization of about 50 groundwater sampling points in the mineralized area.

The water samples were collected after measurement of their physical-chemical parameters *in situ*. Furthermore, for the wells without any pump completion, a geochemical logging has been done. These geochemical logging have validated the representativeness of abstracted water (Fig. 2).

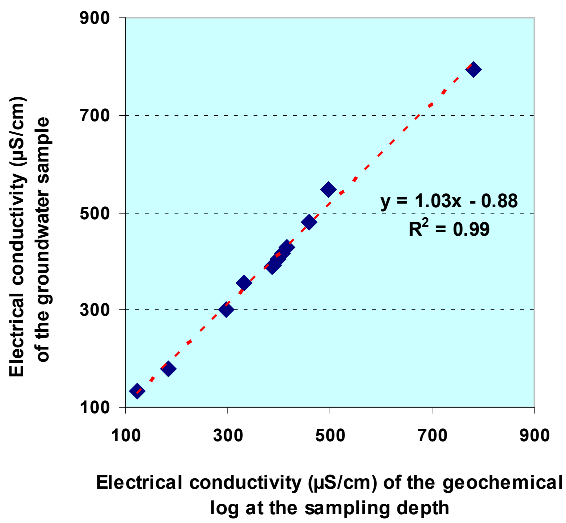

Figure 2. Correlation between the electrical conductivity measured in the wells and conductivity of the sampled groundwaters.

In addition the *in situ* parameters (pH, temperature, electrical conductivity, dissolved oxygen, redox potential, and fluoride concentration) have helped to better characterize the actual hydrogeological and geochemical status of the drillings.

RESULTS

Spatial distribution of the mineralized ground waters

The *in situ* electrical conductivity ranges from 130-1630 µS/cm (Fig. 3). It allows to characterize three highly mineralized areas: the first, centered in Bordeaux and the north-west vicinity of the city; the second in the Entre-deux-Mers area and the last one, in the south-east of the studied area, near the town of Langon.

The geochemical facies

Most of the abstracted groundwaters show a HCO_3-Ca water type (Fig. 4), in agreement with the interaction between the waters and the carbonates rocks of the Aquitaine Basin. However, 12 of the analysed groundwaters have a sulphated-calcic type: these samples are all from the Middle Eocene aquifer. The Piper diagram (Fig. 4.) shows how the Middle Eocene groundwaters are influenced by the sulphates concentration, at the difference of the aquifers over or under the Middle Eocene. We hypothesize these results of the influence of gypsum deposits.

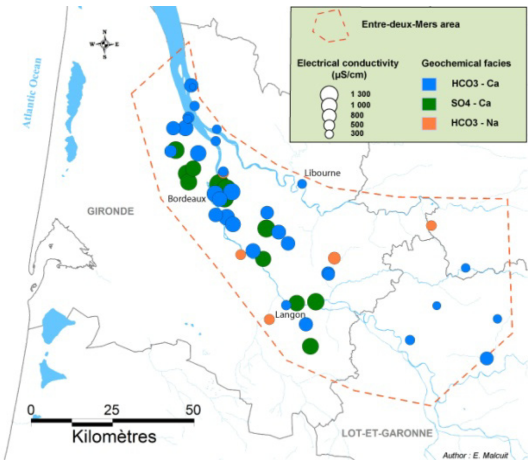

Figure 3. Groundwater sampling sites of the first investigation, their electrical conductivity and their geochemical water type.

The spatial distribution of geochemical water types (Fig. 3) indicates that the sulphated-calcic type coincides with the three most mineralized areas, although the bicarbonated-calcic type is the main one in the studied area.

In addition, groundwaters in the saline area with a sulphate concentration exceeding the potability standard also display a fluoride content above the standard. Among the 50 sampling points, 3 exceed drinking water standard for sulphate concentration (e.g. 250 mg/l) and 12 for fluoride (e.g. 1.5 mg/l). All these points correspond to boreholes used for drinking water.

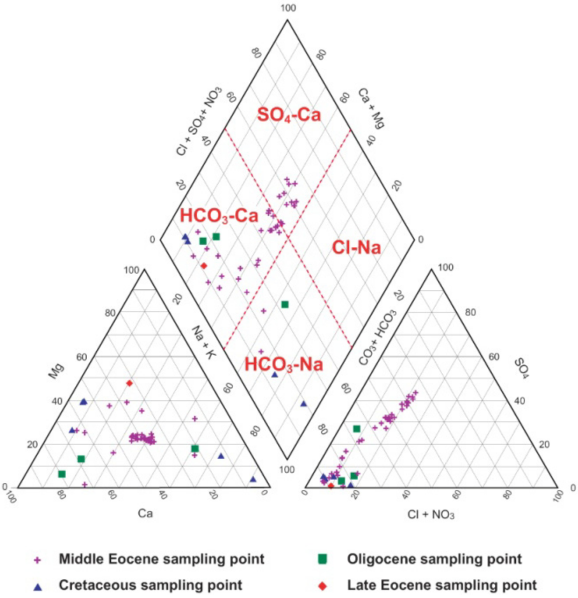

Figure 4. Piper diagram of the sampling points.

Spatial and temporal evolutions/variations of the water quality

Over the past 20 years, the boreholes used for drinking water in the Entre-deux-Mers have presented variations of the water quality and contrasting trends can be highlighted.

A first characterization has been done by comparing the electrical conductivity of the water and chlorides, sulphates and fluorides contents. These four parameters do not always present identical trends. For example some groundwaters show an increase, others a significant decline. But most do not indicate any specific trends.

So far the observed trends do not seem to depend on geographical location or on the excessive mineralization of waters. Further investigations are needed to better understand these results.

CONCLUSION

Ongoing analyses of major elements confirm the salinity variation in the groundwater system in the Entre-deux-Mers (S-W France). The first results of geochemical analysis and multi-isotope combination will be presented at the conference so as to improve our understanding of the origin of these elements, their behaviour and migration in aquifers.

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abstract id: **217**

topic: **1**
Groundwater quality sustainability

1.1
Evaluation and management of groundwater — sustainable exploitation

title: **Development of a mass flow-based spring capture zone delineation tool for drinking water pollution risk management**

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keywords: pesticides, fractured aquifer, water protection zone, linear optimization

INTRODUCTION

In southern Luxembourg as in many regions where intensive farming takes places, groundwater from a large fracture sandstone aquifer has become increasingly at risk from pollution by pesticides. In order to avoid further deterioration of this essential drinking water resource, the immission situation at the surface has to be reduced or modulated by adapting land use and management practices. This requires the correct attribution of contributing surfaces to a specific spring or group of springs. As it is uneconomical to try calibrating fractured rock transport models for each spring, a mixing-cell like tool (Klaus et al., 2008) was developed that links predicted leached concentrations in the soil to the spring chemical fingerprinting via an inverse optimization procedure based on consistent mass flow equations.

EXPERIMENTAL SETUP AND METHOD

The three main axis of the project were:

- To define the input signal using the physically-based model PEARL. What pesticide leaching concentration C_{mean} should be considered typical for the sandy soils overlying the sandstone? What spatial and temporal variability should be considered?
- To characterize the aquifer's transfer function. Which transport dynamics are worth taking into account? As the mixing-cell approach requires pseudo steady-state, what are the probable residence time distributions in the soil and aquifer compartments?
- To use these results for catchment delineation.

Field work took place over two years focused around a sandstone plateau north of Luxembourg City. To characterize the pesticide sources from the agricultural areas, bromide infiltration tests were performed, TDR arrays installed, and a soil sampling campaign performed to collect soil physico-chemical parameters as well as pesticide residues. Thirty springs draining the plateau and the surrounding area were sampled monthly for water chemistry, pollutants, stable isotopes, and four times over two years for tritium, while a subset of seven springs were sampled weekly. Additionally, an observation borehole was drilled on the plateau downgradient of the agricultural area, and sampled weekly as well.

RESULTS AND DISCUSSION

Input signal

The soil's leaching dynamics and leaching potential was studied with the calibrated PEARL model. Although such process-based approach was limited by the amount of data available, it nonetheless yielded essential information concerning the soil's leaching behaviour.

Results showed that the inertia of the soil system meant leaching would go on at a significant rate for about five years after the last application. This is of importance, as the main pesticide of interest, atrazine, has been banned in Luxembourg in 2005. The leaching rate was dependent upon the crop rotation, with a factor ten between annual and triennial applications (Figure 1).

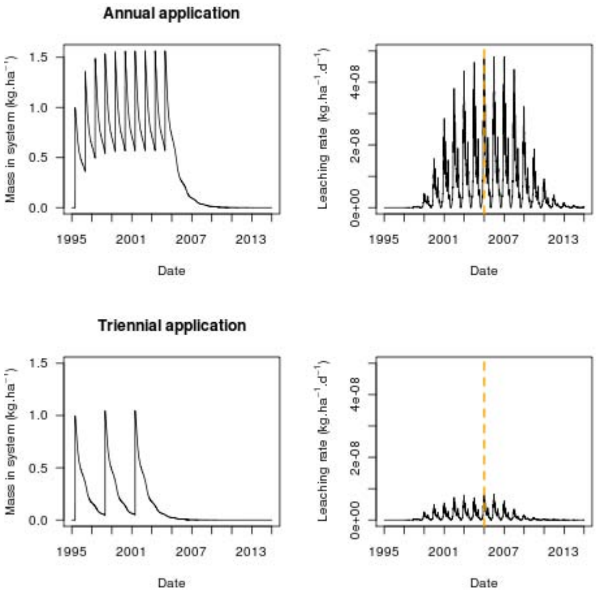

Figure 1. Comparison of the effect of crop rotation on pesticide leaching. The dashed orange lines mark the last field application.

Input parameters describing water transport are relatively straightforward to derive from water balance calculations, using a simple groundwater recharge metamodel for plausibility check. On the contrary, the number of governing processes controlling pesticide leaching (sorption, degradation), the relatively high uncertainty in the values of the process parameters as well as spatial and temporal variability regarding these (to name but a few: organic carbon content for sorption; soil water content, nutrient availability for microbial activity responsible for degradation) makes the prediction range of probable mean pesticide input to the groundwater system immensely larger, all the more so that even the apparently simple question of the initial pesticide application dynamic depends in a non-trivial way on agricultural practices, which cannot necessarily be regarded as unique on the plateau, let alone on individual fields.

Transfer function

Groundwater dating with both tritium and stable isotopes has helped shedding light on the aquifer's hydraulic and contaminant transport behaviour. The springs' stable physico-chemical parameters, as well as a discharge displaying little short term variations are first indicators of a well buffered groundwater system. Stable isotopes measurements have allowed rejecting the hypothesis of a karst-like system for the fractured sandstone in the study area, according to which large fractures rapidly would react to rain event by filling up and drain water quickly to the spring. Hydrograph separation using deuterium clearly showed that even strong precipitation events have little direct influence on spring discharge (quickflow amounting to no more than 10 % of total discharge at all time). Rejecting the karst hypothesis proved an essential step in the study, as this meant that the representative equivalent volume (REV) could be considered small enough to treat the entire formation as a porous-equivalent media, still possibly inhomogeneous and anisotropic, but continuous at the problem scale.

Tritium values in the sampled springs ranged from 6 to 9.5 TU, with most value around 8 TU. A parameter estimation exercise on these data with both a dispersion and an exponential-piston flow transfer function (Maloszewski, Zuber, 1982), describing the transformation of an input signal as it travels through the aquifer, yielded mean groundwater residence times of eleven to seventeen years, with similar values for both transfer functions.

Once a transfer function has been parameterized with environmental isotopes, predictions concerning pollutant transport become possible assuming the pollutant of interest behaves similarly to the isotope used for parameter estimation. As no data concerning degradation and sorption within the aquifer were available, these two processes have been ignored. The aquifer displays a large inertia to pollutant transport, with a flushing period of at least 15 years (without the possible additional retardation effect due to sorption processes). Adding this to the five years' response lag of the soil system means that the atrazine concentration in the springs should not be expected to start decreasing before 2020. On the other hand, this was favourable to the implementation of the optimization algorithm, as steady-state in spring pesticide discharge could be assumed.

Catchment delineation

The core of the catchment delineation tool is a linear optimization algorithm (Loucks et al., 1981), whereby the boundaries of the spring's capture zone are calculated by minimizing an objective function based on a cost-distance matrix and subject to a number of constraints (Fig. 2):

- a water balance constraint.
- a mass balance constraint for pesticides measured at spring level.

Different cost-distance matrices have been tried out, from a simplest non-directional linear increase to more complex anisotropic cases accounting for the main fracture directions. The major hurdle to a satisfactory implementation of the optimization algorithm is the large uncertainty concerning the spatial variability of pesticide leaching, and hence in the mean leaching value used in the optimization algorithm, as the total surface of contributing agricultural land is linearly related to that value. Because the high spring density draining the sandstone plateau allowed subsurface catchments to be relatively well defined by a water balance constraint alone, it was decided to turn the problem around and use these computed catchments to calculate the mean soil leaching on the plateau C_{mean}. This simple approach made use of the natural averaging effect of the aquifer. Spring concentration of a given pollutant is however due to two overlapping control factors:

- Varying proportion of agricultural surfaces in the zone of contribution,
- Varying intensities in pesticide application between fields in the zone of contribution.

While the first factor is precisely the study's focus, mapping the various leaching intensities required additional spatial information. The residues from the soil sampling were combined with crop rotation census data and then split into intensity classes. These classes were then interpolated using kriging, yielding a leaching map. The calibration done, the delineation tool could then be applied in forward mode to the other springs sampled during the project.

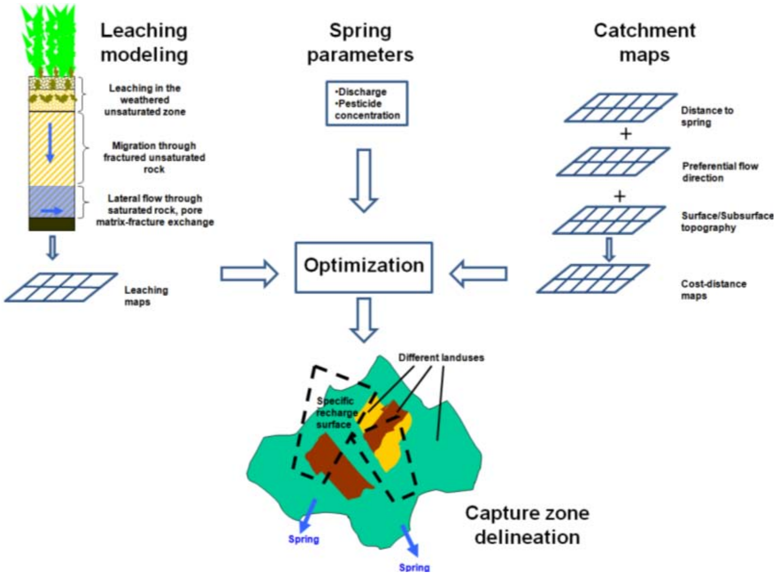

Figure 2. Optimization workflow.

Lastly, in order to study the sharpness of the obtained catchment boundaries, a pseudo spatially distributed approach was also simulated by running multiple optimizations with different leaching maps generated from randomly sampling the soil leaching's frequency distribution, making sure the distribution mean was equal to the mean soil leaching C_{mean} (Petach et al., 1991). The final capture zone resulted from the union of all optimal solutions.

OUTLOOK

As often the case in environmental problems, the stepping stone was to quantify the pollutant sources and their spatial distribution. This could be partially circumvented in the present study thanks to the particular morphology of the catchments, but precludes a wider application of the delineation algorithm for other soils and regions until the uncertainty concerning pesticide leaching prediction has been significantly reduced.

Despite this major drawback, the proposed methodology has a number of interesting features.

- Use of available physico-chemical parameters measured at spring level in a quantitative way.
- Integration on a scientific basis of water balance (catchment's surface area) and mass balance (contributing areas) in a physically consistent distance-based model.
- Substantial leeway to add additional geomorphological and geological information (anisotropy, faulting, folding) of different quality and origin (from surveys, tracer tests, risk mapping) to the cost-distance matrix.
- Computer-based tool to assist the delineation process.

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abstract id: **224**

topic: **1**
Groundwater quality sustainability

1.1
Evaluation and management of groundwater — sustainable exploitation

title: **Groundwater quantity in the Zagreb aquifer**

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keywords: Zagreb aquifer, groundwater quantity, overpumping

INTRODUCTION

The Zagreb aquifer is built of saturated gravel and sand deposits stretching in NW-SE direction along the Sava River at the City of Zagreb territory. The aquifer is about 30 km long, from 10 to 15 km wide, and between 5 and 10 meters thick on average in the western parts to about hundred meters thick in the eastern parts of the aquifer system.

The Zagreb aquifer is located between Mt. Medvednica at the north and Vukomeričke Gorice hills range at the south (Fig. 1). The Sava River divides the aquifer into the left and right valley.

The Zagreb aquifer is of unconfined type. Considering hydraulic aspects, its boundaries are: impermeable boundary at the north, inflow boundary at the west, inflow boundary at the south, and outflow boundary at the east. Generally, the groundwater flows in W-E/SE direction.

The municipal water supply relies on groundwater from the aquifer which is abstracted at six currently operating wellfields shown in Fig. 1. During longer dry periods, smaller well fields which are usually not used by the water supply system are put into operation.

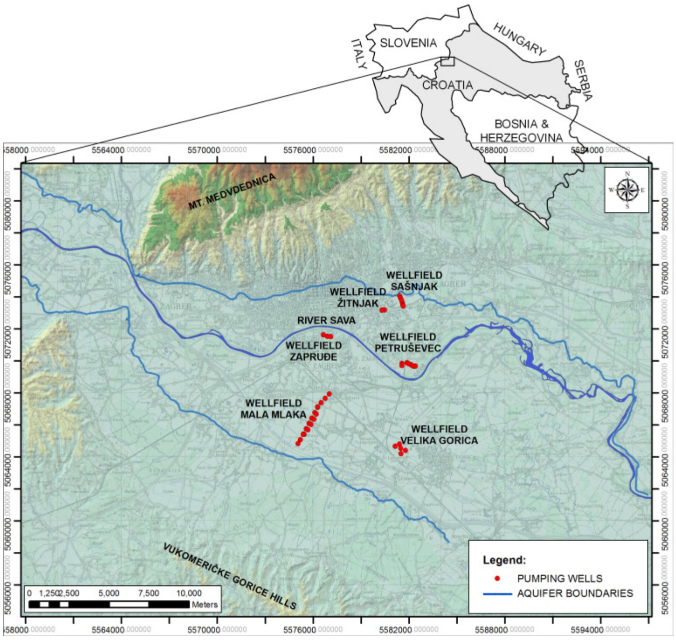

Figure 1. Location of the Zagreb aquifer.

The quantity of groundwater for the City of Zagreb territory is estimated from measurements of groundwater table carried out at 500 piezometers and aquifer geometry. The groundwater table measurements are carried out by the Croatian Meteorological and Hydrological Service and municipal utility Watersupply and Sewage Company.

GROUNDWATER QUANTITY ANALYSIS

The aquifer is generally recharged by (1) infiltration from the Sava River, (2) infiltration of precipitation; (3) infiltration from leaking water supply and sewage networks; (4) inflow along the western boundary from the neighbouring Samobor aquifer; and (5) inflow along the southern boundary from the Vukomeričke Gorice area.

The Sava riverbed cuts into the gravel and sand deposits of the aquifer. An analysis of the equipotential maps determined that during high water levels the Sava recharges the aquifer along its entire course at the Zagreb territory, and during medium and low waters aquifer drainage is noticed in some parts of the river course, which has unfavorable impact on the groundwater table and, consequently, on water quantity available during the dry periods. Comparison of the Sava and groundwater hydrographs with data recorded at the piezometers in the immediate vicinity of the river Sava shows very strong relation between the Sava water levels and groundwater table.

The analysis of the groundwater table fluctuations measured since 1950 indicates an average groundwater drawdown at the entire aquifer area of 1-2 m every 10 years for the last forty years (Fig. 2). The reasons for the groundwater drawdown could mostly be attributed to (1) deepening of the Sava riverbed caused mostly by construction of the hydropower plant reservoirs on the Sava upstream from Zagreb and gravel mining in the riverbed, (2) increase in groundwater abstraction for the City of Zagreb water supply, and (3) construction of dikes along the Sava River to prevent random flooding of the floodplain, and consequently potential inflow of water from the flooded areas into the aquifer. Total quantity of water pumped at the Zagreb well fields increased from 3300 l/s in 1983 to about 4700 l/s nowadays. This means that the water pumping rates have been continually increasing by about 700 l/s every 10 years. The increase in pumping rates quantity is caused not only by increased growth of the city and its population, but also by aging water supply network the losses from which, according to the Watersupply and Sewage Company (2003), amount to 40%.

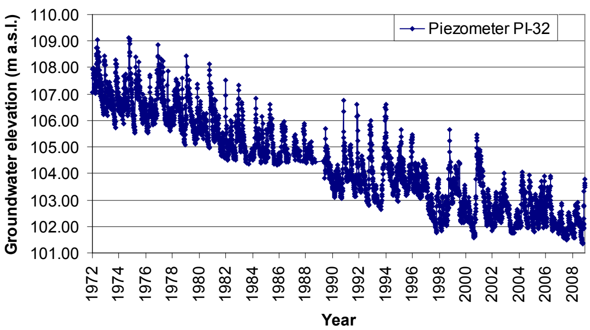

Figure 2. Typical hydrograph.

Continuous groundwater drawdown threatens the yields of well fields. During dry periods, the phreatic line decreases below the upper screen edge level in specific wells, which results in decrease in yield. For identification of relations between groundwater levels and positions of screen in wells, the hydrographs of the piezometers closest to the water wells were analyzed. The data on water tables in the pumping wells were not available.

Mala Mlaka wellfield consists of ten dug and eight drilled wells. During dry periods, groundwater tables in all dug wells and three drilled wells drops below the level of the upper screen edge. To illustrate the relations, one dug and one drilled well have been selected (Fig. 3 and 4).

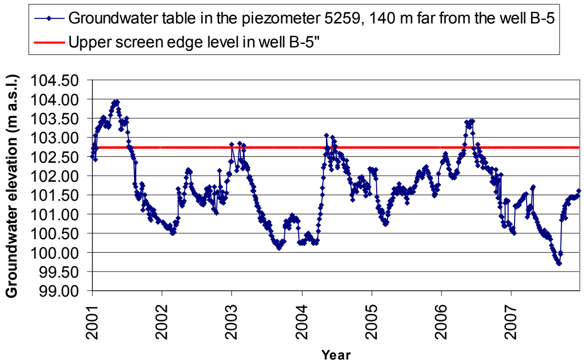

Figure 3. Mala Mlaka wellfield — comparison of the upper screen edge level in dug well B-5 and hydrograph for the piezometer 5259 placed at 140 m distance from the well.

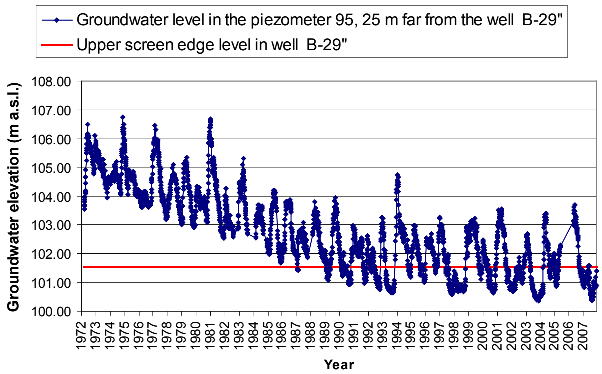

Figure 4. Mala Mlaka wellfield — comparison of the upper screen edge level in drilled well B-29 and hydrograph for the piezometer 95 placed at 25 m distance from the well.

Presently, groundwater table in only one of six wells at the Sašnjak wellfield and in two of three wells at the Zapruđe Well Field falls below the upper screen edge. Minimum groundwater tables at the Petruševec wellfield are between 2.7 and 8 m above the upper screen edge, depending on the screen position in individual wells. Minimum groundwater tables at the Velika Gorica wellfield are between 1.7 and 7.1 m above the upper screen edge, depending on the well, and the minimum tables at the Žitnjak wellfield exceed the upper screen edge level by more than 12 m. It should be stressed that the analysis was carried out using different water tables in piezometers rather than in wells, which means that the actual situation is even more unfavorable.

Based on a recession analysis, it was concluded that Petruševec, Velika Gorica and Žitnjak wellfields will be available for pumping during the future twenty odd years provided the groundwater table drawdown trend does not change (Posavec, 2006; Posavec et al., 2006).

Analysis of the minimum groundwater levels and Zagreb aquifer geometry for the period 1976-2006 determined gradual decrease in water volume (Fig. 5). Summary data for the period 1976-2006 indicate a decrease by approximately 4%.

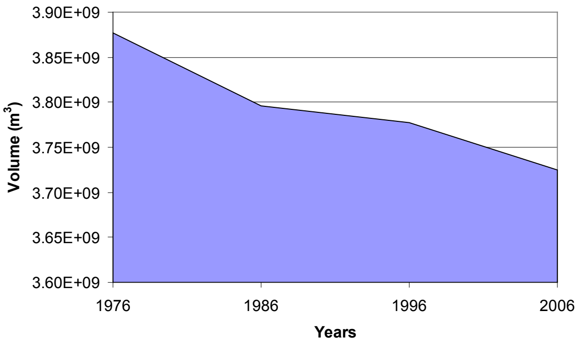

Figure 5. Groundwater volume below minimum annual groundwater tables.

Annual recharge of the aquifer is determined as the water volume between minimum and maximum annual groundwater tables. An analysis of the water surfaces at minimum and maximum groundwater tables for the period 1996–2006 determined that the annual recharge show no strong trend, which is understandable since they depend on annual precipitation.

Comparison of annual recharge of the aquifer with average annual pumping rates at the Zagreb well fields during the period 1996–2006 indicates that the pumping rates exceed the recharge (Fig. 6). This means that the part of abstracted groundwater which exceeds recharge is taken from unreplenishable reserves, which results in decrease of reserves in time and "overpumping" of the Zagreb aquifer.

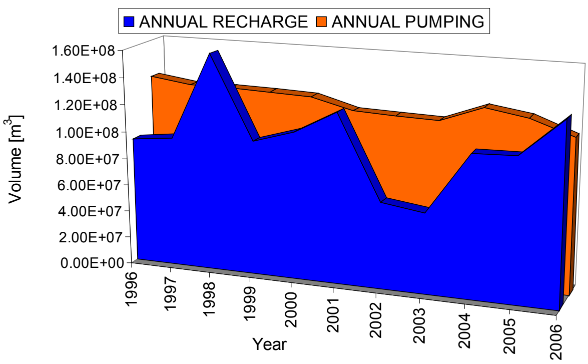

Figure 6. Comparison of the recharge and the pumping.

CONCLUSION

The analysis of groundwater table data collected for the Zagreb aquifer indicates an average groundwater drawdown 1–2 m every 10 years since 1950. Reasons for the groundwater drawdown include: (1) deepening of the Sava riverbed caused mostly by construction of the hydropower plant reservoirs on the Sava upstream from Zagreb and gravel mining in the riverbed, (2) increase in groundwater abstraction for the City of Zagreb water supply, and (3) construction of dikes along the Sava River to prevent random flooding of the floodplain, and consequently potential inflow of water from the flooded areas into the aquifer.

During dry periods, groundwater table falls under the upper screen edge level in the wells at the Mala Mlaka, Zapruđe and Sašnjak Well Fields, which decreases their yields. The upper screen edge levels in the wells at the Petruševec, Žitnjak and Velika Gorica wellfields are several meters below minimum groundwater table, on average, which shall enable unobstructed pumping during the future twenty odd years provided the groundwater drawdown trends do not change.

Total annual pumping rates for all Zagreb well fields exceed the annual groundwater replenishment rates, which mean that the Zagreb aquifer is "overpumped". The part of the pumped quantity that exceeds the replenishable reserves is made up from unreplenishable reserves. The permanent reserve volume was 3.88 km^3 in 1976, and 3.72 km^3 in 2006, therefore it decreased by 4% in thirty years.

To conclude: total groundwater quantity in the Zagreb aquifer is comparatively abundant, however presence of a negative groundwater table trends and excessive pumping from the aquifer ask for caution, which means quality monitoring and systematic analysis and interpretation of the monitoring results. This ensures realistic inputs for an optimum management of water as a strategic Croatian resource.

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IAH 2010
Krakow

abstract id: **237**

topic: **1**
Groundwater quality sustainability

1.1
Evaluation and management of groundwater — sustainable exploitation

title: **Using a stochastic approach to reduce risks in groundwater resources development: a case study in Sur, Oman**

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INTRODUCTION

With increasing pressure on water resources in coastal regions, desalinization is often considered as a viable option. To this end, large amounts of seawater are needed. We present a case study for a desalination plant in Sur, Sultanate of Oman. Here the aquifer is strongly heterogeneous and is made of early Palaeocene-Eocene carbonates in sub-horizontal layers. This sediment deposition makes groundwater development particularly risky. Fresh water was not found in the area and the aquifer suffers from seawater intrusion. According to few existing seawater production boreholes at the site (for an existing desalination plant), there are no doubts that the seawater invades the aquifer system, certainly due to a very small hydraulic pressure gradient of freshwater. Thus, fresh groundwater is almost non-existent in the area and water supply at Sur city relies exclusively on seawater desalination.

The desalinization project involved the design, construction and 22-year operation of a new 80,200 m^3/day capacity Seawater Reverse Osmosis (SWRO) desalination plant at a given site close to the city. The plant requires up to 9,200 m^3/h of seawater, theoretically extracted either from the sea through an open intake or through beach wells along the coastline. If the first option is generally more costly than the second, the second is riskier, given that the availability of such a huge yield in a limited space and heterogeneous aquifer is hard to prove before well drilling and testing. This paper presents an analysis of the uncertainty of groundwater availability that was carried out using a stochastic approach and presented to the project founder to assist them in deciding which option to choose.

AVAILABILITY OF THE WATER RESOURCE

The objective of the first stage of the project was to identify the flow range of seawater that could reasonably be extracted from the site using on-shore boreholes or radial wells hereafter called “beachwells”.

An initial recognition survey was defined to appreciate the type of aquifer and the possible availability of the sea-water resource. This survey was conducted in three steps: an initial overview of the existing literature about geology and hydrogeology in the study area, 14 profiles of electrical resistance tomography for a total of 7000 m, and the drilling of four recognition boreholes to clarify the geological and hydrogeological contexts. The materials making up the first 50 meters of the aquifer were recognised as generally consolidated or cemented, except for a persistent clay layer typically found at depths between 27–35 meters. The dominant materials were generally light colored limestone, from off-white to pink, with coral and other sea fossils, suggesting a reef environment. In some places, the limestone was fragmented and coarse (breccia), and these deposits were usually hard especially in zones where the chert content was high. The geological deposits found at greater depths were quite different from those above. The average depth of the formation change was positioned at approximately 49–61 m b.g.l. These strata were darker, usually grey or grey-green in color, and were identified as calcarenites, quartz sands, and marls, and sometimes as siliceous limestone or calcareous sandstone. These consolidated rocks were interlayered with materials which had a lesser degree of induration, i.e. layers of soft clay or fairly friable sandstones, or a mixture of clay, sand and gravel. The aquifer conditions could be described as a fractured system, with large solution cavities (karst features) predominant at the top portions of the aquifer. The top of the aquifer typically appeared at the contact of the top layer of alluvium/conglomerate and a hard pinkish coloured limestone. The water strike was associated with a recrystallised zone of dolomitic limestone and chert, and often showed evidence of fractures. The karstic limestone was characterized by cavities and conduits, with sediments filling or partially filling these voids. Below the static water level (here the sea level) and up to 40 m deep, electrical resistivity of the terrains was low to very low with resistivity less than 20 Ω.m and mostly less than 1 Ω.m, due to seawater intrusion. If the existence of high sea-water production sites was not certified with this survey, it demonstrated that an important production could be expected from the first karstic levels when filled by sand and the lower levels from the underlying terrains. Production should be done through standard borehole equipped with screened casing and gravel-pack (in opposition to the radial wells initially planned).

A second recognition phase was defined in order to conduct the first quantitative evaluation of the karstic aquifer. The aquifer parameters were estimated by pumping tests over twenty new drilled test boreholes and by the previous geophysical investigations. From December 2006 to January 2007, 20 boreholes were drilled on the site and tested and for 19 of them, the pump test interpretation was possible. It gave an aquifer transmissivity ranging from 2E-1 m^2/s to 5E-3 m^2/s. The aquifer transmissivity was compared with the geological geometry, approached with the electrical resistivity of the terrain obtained from the geophysical campaign. The geophysical data (data on series of vertical profiles) was migrated in a single plane (vertical averaging) then analysed with geostatistical methods. The modelling of the experimental variogram with a theoretical variogram allowed the generation of a great number of equiprobable simulations, using the turning bands method, each of which respected the existing measured points and the spatial structure provided by the variogram (texture, size of heterogeneities), and the histogram of the resistivity values. The electrical resistivity maps were then converted in transmissivity. The main difficulty here consisted in finding a correct correlation between electrical resistivity and transmissivity, as this correlation is not linear. Geological interpretations of the area have shown that different possible transmissivities could correspond to a single resistivity value: a low resistivity could indicate the presence of clay, but it could also be interpreted as karstic conduits filled with sea-water. In this case, the relation had a crescent shape, confirmed by experimental data. The interpolation of transmissivity on the whole domain was carried out using the collocated cosimulation method. This method allowed us to create conditional simulations of transmissivity T (conditioned by the 19 measured values) using a background information (the maps of resistivity ρ), approximating the crescent-shaped relationship with a linear correlation. A hundred out of the infinity of descriptions of the spatial distribution of the aquifer transmissivity were generated in this way, each time using a different ρ -field for the background information. This enabled to propagate the uncertainty from the ρ -field to the T-field. The next stage involved classic groundwater flow computation (mathematical modelling), repeated for the hundred transmissivity maps (T-field). The flow calculation was done for three theoretical sets of wells, selected for the large variety of results obtained: 21 wells well dispersed on the productive zones, 78 wells located along a single line 100 m from the seaside and 140 wells along the seaside 50 m from the sea plus additional wells inshore. The drawdown in the wells was simulated with constant head conditions at the well location and the total discharge was extracted from the flow model balance. A statistical analysis was then conducted from these hundred total discharge estimates. The result of this stochastic modelling was a histogram of simulated maximum yields as shown in Fig. 1. It showed that sufficient sea-water resources were available to supply the desalination plant beneath the site. The boreholes number and position should then be optimised in order to reach an industrial operational well field.

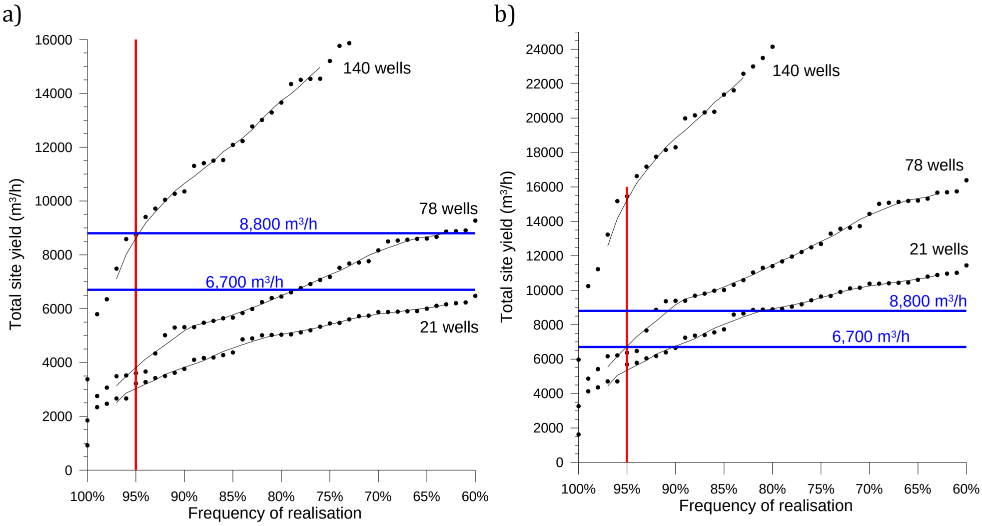

Figure 1. Maximum yield extracted from the site with a drawdown of 7.5 m. The black curve shows the cumulated histogram; the black dots show each of the simulated maximum yields. As the aquifer thickness may locally be about 30 to 35 m in the plant area, a value of 30 m is set for a series of conservative runs (a) and a value of 35 m for the aquifer thickness is set for a series of optimistic runs (b).

OPTIMISATION OF BOREHOLE NUMBER AND POSITION

The groundwater flow characterisation methodology included data filtering, well testing and stochastic inversion (Alcolea et al., 2009). In a first step, 200 simulations of transmissivity and storage coefficient fields were generated, conditioned to transmissivity and storage coefficient from pumping tests, using the regularized pilot points' method. Four head variation data sets (i.e. response to tidal fluctuation and to three long term pumping tests) were considered, and the models were calibrated simultaneously to the four data sets. In a second step, for the sake of comparison, we also obtained a "single best" solution by conditional estimation to the aforementioned data sets. Outcomes of these two sets are compared in terms of physical plausibility and fit to head variation data. We obtained 200 equally likely simulations of the transmissivity and storage coefficient fields that are plausible and fit well to the indirect head variation measurements. 100 out of the aforementioned 200 calibrated transmissivity fields were then used to design an optimum well field layout (Fig. 2).

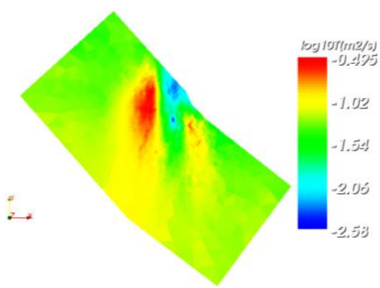

Figure 2. One of the hundred estimated transmissivity field obtained using optimum statistical parameters, conditioned to all available data.

The simulated transmissivity fields were first used to evaluate whether a global abstraction of 9,200 m^3/h was possible with a reasonable number of wells. These first simulations show that, with about 30 wells and a prescribed fixed uniform drawdown of a reasonable value of 8 m in all realizations (which involve having different discharges in each realisation and in each wells), such total discharge could be reached. Based on that result, the question was to define an optimal pumping configuration that was technically and economically feasible. The optimisation was carried using a genetic algorithm (Popov, Filipova, 2004; Popov, 2005) that minimized a cost function accounting for: (1) drilling, operational and maintenance costs, (2) target discharge and minimum drawdown (i.e., minimum aquifer vulnerability) and (3) technical feasibility of the solution. The pump types were limited to two for maintenance considerations. Potential well locations matched mesh nodes and the total number of potential well locations was restricted to 126, due to computing time considerations. These potential locations were placed on the entire model, but preferably in areas that seemed adequate *a priori*: close to the seaside and in zones of high transmissivity. An important constraint was that wells could only be drilled in a relatively limited portion of land owned by the project. The maximum acceptable drawdown in the aquifer was set to 15 m, since a larger drawdown would lead to insufficient saturated thickness and possible failures of the pumps. The optimum well field layout included 33 beachwells (including 8 ancient wells) producing either 100 or 70 l/s each. The position of 3 spare wells was obtained by increasing the water demand by 10%, allowing 3 new wells. The expected drawdown in the optimised wells (before head losses) was expected to range from 6 to 12 m (Fig. 3).

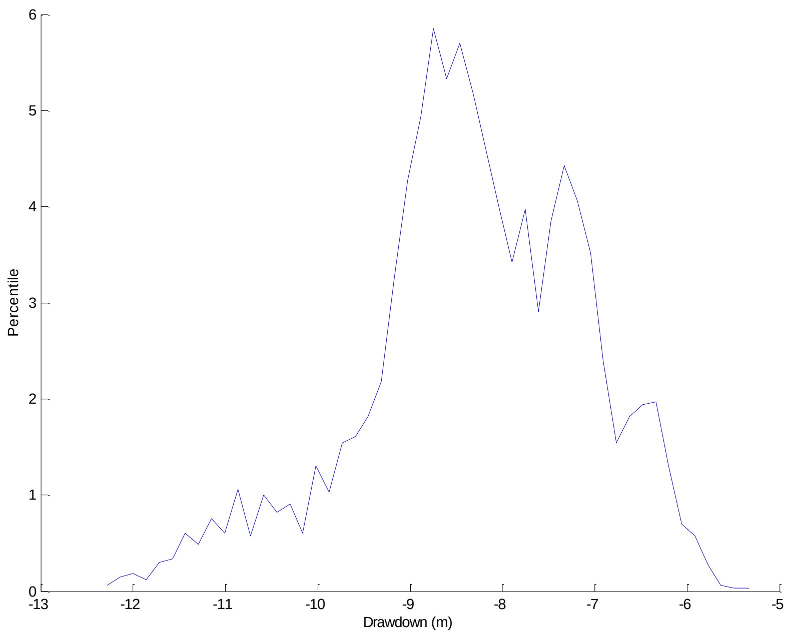

Figure 3. PDF of the drawdown at all optimized wells considering all realisations.

CONSTRUCTION PHASE

The results of the investigations described above were presented to the project founders and led to the project team deciding to implement the 100% beach well option at the construction stage. Based on the optimisation analysis, it was decided to drill 7 wells producing 70 l/s, lined with 14 inch casing, while 18 wells would produce 100 l/ s, lined with 16 inch casing. Additional 3 spare wells producing 100 l/s were also drilled, as well as 4 new wells (100 l/s) to replace inefficient existing wells (initially used for the existing plant). Boreholes were drilled to a depth from 75 to 90 m in order to obtain yields of 70 to 100 l/s and constructed in a manner that minimized the drawdown associated with these discharges. The drilling method employed was an air/foam system. Drilling bits were tri-cone roller-rock bits, 12¾ inch for the pilot hole, and 23½ inch for the reamed hole. After the hole was reamed, an air-lift system was put in place to clean out the fractures and estimate the yield of wells. After having performed open hole development, the holes were equipped with a minimum of 30 m of screen. Slot size was 3 mm to allow the placement of large size gravel (5–10 mm), with open areas of 9% and 7.5% for the 14 inch and 16 inch casings respectively.

All 32 beachwells were not drilled at the modelled location due to various technical constraints. Nevertheless, individual well performances were found to be as expected: a production from 65 to 125 l/s for drawdown limited to 1 to 10 m. The well field was then tested by sector and then globally, up to a production of some 9,200 m^3/h. The water quality was found as expected: EC ranged from 47,000 to 54,000 µS/cm. An estimate of suspended solids was done with Imhoff cones which consistently indicated a concentration of less than 5 mg /l. Silt Density Index (SDI) ranged from 4.9 to 5.8 and turbidity was less than 1.2 NTU. Such water needs little filtration before being used for reverse osmosis system. The new wells have all been equipped with submersible pumps and ancillary equipments. This includes a flowmeter and a pressure level transducer link to telemetry for each individual well in order to monitor their performance.

DISCUSSION AND CONCLUSIONS

Industrial operators are generally reluctant to drill water production wells when other options are feasible. Most often, the main argument is the uncertainty in the yield of the projected wells (David et al., 2009.). For the Sur project, a stochastic characterization of hydraulic parameters from tidal fluctuation and pumping test data was efficiently used to quantify the risks and help decision makers and later to design an optimum pumping network of brackish groundwater. This is therefore a promising methodology for designing well fields in highly heterogeneous aquifers.

The model was built in a conservative way to compensate for the different assumptions made such as discretisation, boundary conditions, pumping considered as continuous, etc. For example, the drawdowns calculated by the models can be underestimated in the pumping wells: they would have been different if another discretisation had been used. The bias caused by discretisation affects all the potential locations in the same way. However, this means that the actual values of the forecasted drawdowns in the pumping wells (before head losses) are slightly higher than these estimates. Nevertheless, the total 9,200 m^3/h required for the new plant facility can now be withdrawn from 32 "beachwells" with an average drawdown of about 12 m including head loses in the wells. Although such "beachwells" have already been in operation for many years in several countries around the world (e.g. Malta, Spain, Canary Islands, Greece, Israel, Saudi Arabia, US, etc.), they have usually been restricted to smaller scale plants (Schwarz et al., 2000; Wang et al., 2007). This project makes Sur the largest SWRO desalination plant in the world fed only by "beachwells".

ACKNOWLEDGEMENTS

The authors wish to thank David Ginsbourger for his advice with regard to optimization techniques and J. Malcolm Ashworth and Nick Lombardi for outstanding a difficult yet proficient field work.

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abstract id: **278**

topic: **1**
Groundwater quality sustainability

1.1
Evaluation and management of groundwater — sustainable exploitation

title: **Water management in abandoned lignite open pits in Poland**

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keywords: water management, open pits

INTRODUCTION

In Poland approximately 2400 open pits of different rock materials are operated, and some 60 million tons of lignite are mined by surface method. The most rational method for reclamation of open pits is filling the voids with ground water, supported by surface water. The objective of this paper is to acquaint the participants of the XXXVIII IAH Congress held in Poland with reclamation by flooding of abandoned lignite open pits in the host country. Besides, it provides also some data on hydrogeological conditions of lignite mines in Poland.

HYDROGEOLOGICAL CONDITIONS OF POLISH LIGNITE MINES

Lignite is one of two main sources for electric energy production in Poland. The operated lignite open pit mines are Tertiary age and occur in the Central (Bełchatow Region), Western (Konin-Adamów Region) and South-Western (Turów Region) part of Poland (Fig. 1). Presently the lignite output is in range of 57–60 millions tons per year. The floor depth of seams below the terrain surface varies from 40 to 260 m. The thickness of lignite occurring in 1 to 3 seams is from 5 to 60 m and overburden thickness is from 30 to 240 m. The overburden constitutes Tertiary and Quaternary formations consisting of silt and clays (30%–75%) and sands (70%–25%). All deposits are below the natural groundwater table that occurs most frequently right under the terrain surface (from 1 down to 5 m) and have different hydrogeological conditions (Libicki, 1987). Annual precipitation in the regions of lignite basins varies from 500–700 mm/year, the climate is moderate with the average annual temperature about 8°C. Groundwater is drained by deep wells with submersible pumps.

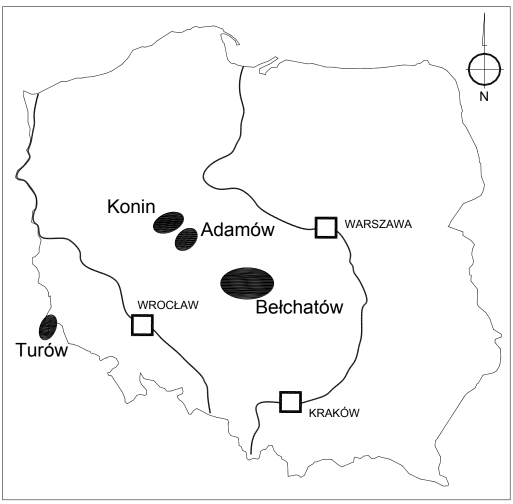

Figure 1. Lignite production in Poland.

In the **Konin-Adamów Basin** the most important are the confined aquifers (Tertiary and Mesozoic) with average permeability 3 m/d, but it may increase until 40 m/d in the cretaceous marls (Fig. 2). Depending on the open pit, the groundwater table is lowered from 40–100 m, and the radius of cone of depression is 4–9 km. The mine water inflow for all open pit mines in the region is in average 310 m^3/min.

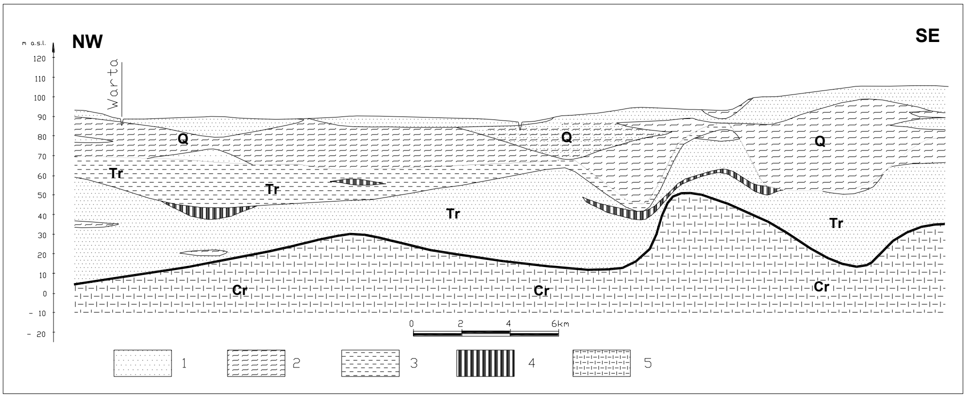

Figure 2. Simplified geological cross-section through the Adamów-Konin Lignite Basin. Explanations: 1 — fine and medium sands, 2 — clays, 3 — silts, 4 — lignite, 5 — marls, Q — Quaternary, Tr — Tertiary, Cr — Cretaceous.

Turów Lignite Basin has a shape of real basin (tectonic depression), having thickness from 50 m on the boundary to 300 m in the middle. The bed constitutes impermeable Palaeozoic rock filled with two lignite seams inside (Fig. 3). The overburden (Quaternary and Tertiary) consists of clays and sands which occur in form of closed lenses from 1 to 30 m thick with average permeability of 13 m/d. They contain static groundwater under pressure of 2–20 Ba depending on the depth. The mine water inflow is 20–30 m^3/min and the cone of depression is about 2 km.

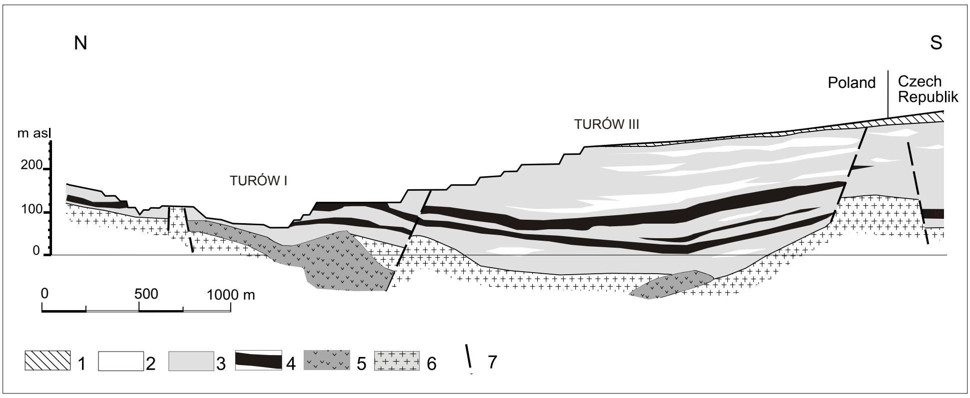

Figure 3. Simplified geological cross-section through the Turów Lignite Basin. Explanations: Quaternary: 1-gravels, sands and silts; Tertiary: 2-gravels and sands, 3-clays and silts; 4-lignite; 5-basalts; Palaeozoic: 6-granitoid and decomposed rocks, 7-main faults.

Bełchatów Lignite Basin is deposited in the tectonic rift valley. The aquifers occurring in the particular stratigraphic series (Mesozoic, Tertiary and Quaternary) have many geological and hydraulic connections, so the whole complex of the permeable rocks creates one huge and heterogeneous aquifer in the whole region (Fig. 4). The hydraulic conductivity for Mesozoic aquifers (fractured limestone, marls and sandstone) is very diversified, the highest is in the karstified limestones. The average hydraulic conductivity for Quaternary sand-gravel series is 20 m/day. The mine water inflow for two working open pits amounts to 500 m^3/min. The groundwater table is lowered about 300 m, and the radius of cone of depression is 3-9 km.

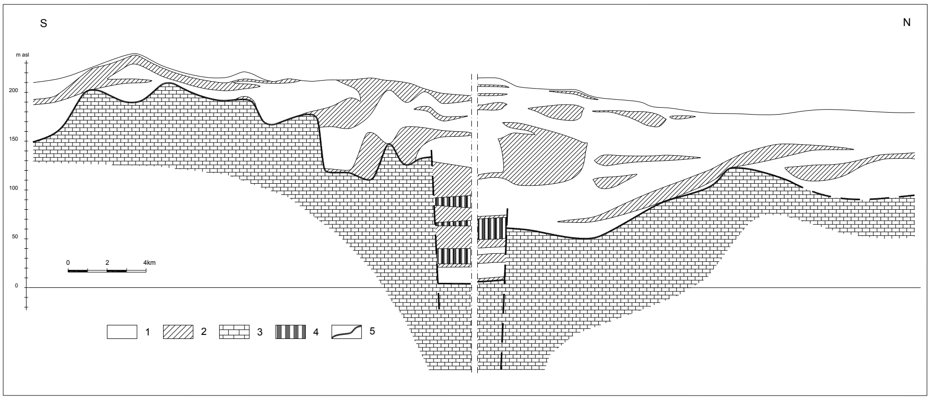

Figure 4. Simplified geological cross-section through the Bełchatów Lignite Basin. Explanation: 1 — porous, permeable formations, 2 — impermeable and slightly permeable formations, 3 — fissured-karstic formations, 4 — lignite, 5 — faults.

RECLAMATION OF ABANDONED LIGNITE OPEN PITS BY FLOODING

The final reclamation of abandoned lignite open pits in Poland faced no major problems as yet, owing to small depth and size of open pits (between 15 m and 40 m) changed into water reservoirs and, due to the possibility of their complete or partial backfilling by the overburden from adjacent open pits, and also due to a relatively simple water regime as well. Pit lakes (Tab. 1) are formed deliberately as a planned part of the after-use of a lignite mine voids and they can be used as wildlife habitats, fisheries, water sports venues or other forms of amenity. In **the Adamów Lignite Mine** the water reservoirs have been a part of the Bogdałów, Koźmin (Janiszew) and Adamów (Przykona) post mining areas (Fig. 5) with a total capacity of 12 mln m^3.

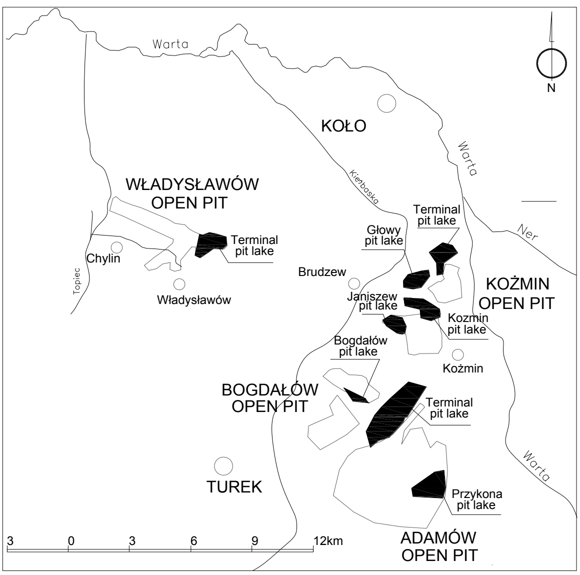

Figure 5. Site map of pit lakes in the Adamów post mining area (courtesy of the Adamow Lignite Mine).

Table 1. Reclamation of abandoned lignite open pits by filling with water in Poland.

Lignite mine	Lignite production	Number open pits	Pit lakes total area (km^2)	Pit lakes total volume millions m^3)
Adamów	1964–2023	4	1.1	252
Konin	1946–2037	12	3.1	968
Bełchatów	1981–2038	2	38.9	3 100
Turów	1904–2040	1	16.9–18.7	1 220–1 600

In the near future, the next pit lakes are planned to be built in the post mining areas of the Koźmin, Władysławów and Adamów mines with a total volume of 239 mln m^3. The flooding of the Koźmin and Władysławów post mining voids is likely to take 2-3 years, but in case of the Adamów voids 15-20 year (information from the Adamow Lignite Mine). In each case the surface mine voids will be flooded by natural groundwater inflow, water pumped out from dewatering of the neighboring open pits and water courses. As regards to **the Konin Lignite Mine** in the final excavations of the five abandoned open pits (Morzysław, Niesłusz, Pątnów Gosławice, Kazimierz S) the pit lakes were established (Fig. 6). Presently the Lubstów post mining void is under flooding. No problems shall also be faced with future filling with water of the other open pits having average depth from 50 to 65 meters.

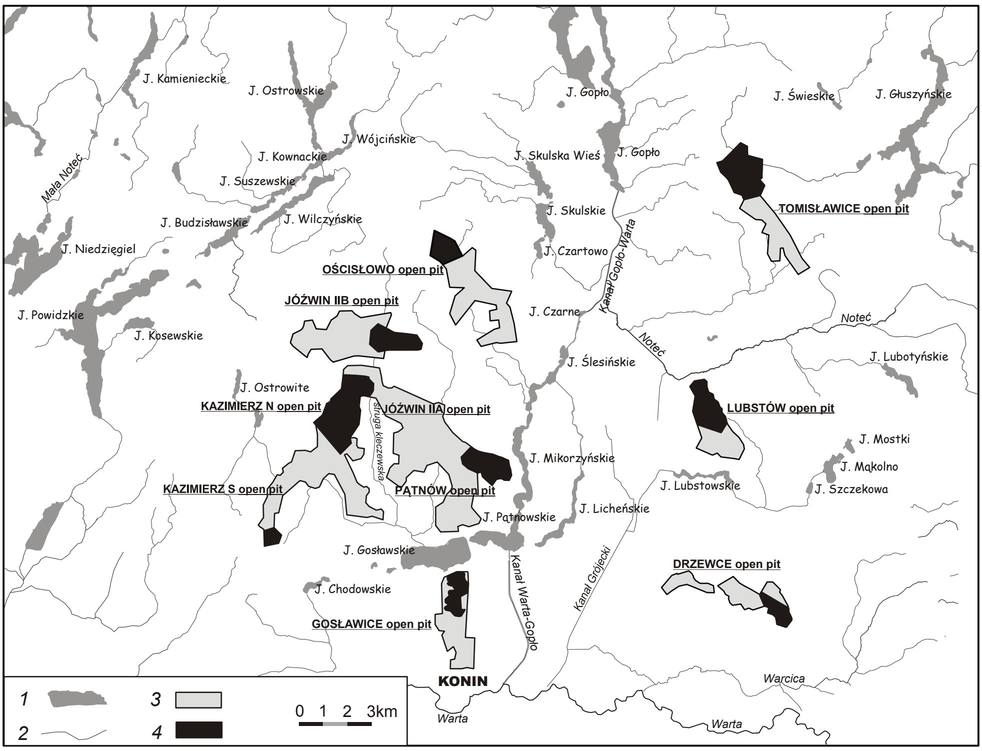

Figure 6. Site map of pit lakes in the Konin post mining area. Explanation: 1-natural lakes, 2-rivers and courses, 3- internal dumping sites, 4-pit lakes.

Modeling studies reveal that the flooding the next post mining excavations in the Konin Lignite Mine using only natural groundwater inflow is likely to take between 10 - 30 years. It will finish in 2069 (Fiszer et al., 2009). To speed up this process it is provided to use water from dewatering of neighboring open pits or from surface waters.

Considerably much more difficult will be the solution of problems associated with the reclamation of final excavations of the Turów Lignite Mine in the south-west part of Poland and **the Bełchatów Lignite Mine** in the central part of Poland. An effect of lignite mining in these areas will be large-space abandoned open pits whose volume will exceed one billion cubic meters. In 2019, it is planned to cease lignite production in the Bełchatów open pit and in 2038 at the adjacent Szczerców open pit. As a result of reclamation works the Bełchatów and Szczerców voids will be formed, which area will reach 16.9 km^2 and 22.0 km^2 and volume of 1.3 billion m^3 and 1.8 billion m^3 respectively (Fig. 8).

The process of filling the post-mining excavations with water in the Bełchatow void will start in 2027 and in the Szczerców void it will start in 2049. Two conceptions of flooding have been taken into consideration (Kasztelewicz et al., 2008). For the first one the assumption was that the water reservoirs will be filled with groundwater in a natural way, by additional recharge with water from the well barriers located around the open pits. Calculations reveal that the process of flooding will be finished after 2100 (Fig. 7).

Figure 7. Site map of pit lakes in the Bełchatow post mining area.

In the second conception the assumption was that the voids will be filled with groundwater in a natural way, but aided by additional recharge from the Warta river and the Widawka river at a rate of 2.25 m^3/s or 4 m^3/s. The results of calculations have shown that the flooding will last until 2072 and 2062 respectively. Water from the pit lakes will discharge into the Widawka river.

Lignite production in the **Turów Lignite Mine** is planned to cease in 2040. The preparation of void for flooding will be completed in 2050. In order to estimate the time of flooding the void the following assumption has been made: (1) the reservoir will be flooded only with surface water from the Nysa Łużycka river and the Miedzianka river at a rate of 3.87 m^3/s, (2) groundwater inflow into the void, average 20 m^3/min, will be prevented by water collected in it, causing excess pressure on the groundwater in the vicinity of the void, (3) precipitation on the pit lake surface supplements the losses associated with evaporation.

The calculations made for average hydrological conditions reveal that the time of filling the void will reach 10 or 13 years depending on the final excavation shallowing (Fiszer et al., 2005). Therefore the flooding will finish between years 2060–2063 (Fig. 8).

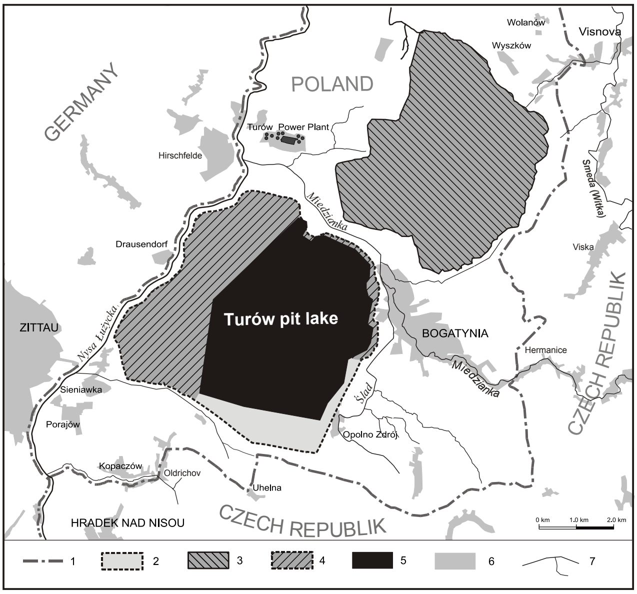

Figure 8. Site map of the Turów pit lake. Explanation: 1-state border, 2-post mining areas, 3-internal dumping site, 4-external dumping site post-mining areas, 5-pit lake, 6-villages, 7-rivers and courses.

After filling the reservoir the water, in order to compensate for evaporation losses, the pit lake will be feed by water from the Nysa Łużycka river in an amount of 0,075 m^3/s. Water from the pit lake will discharge into the Miedzianka river.

It should be noted, that in the existing and abandoned Polish lignite open pits there are favorable conditions in terms of water quality formation (Polak, 2004). An analysis of geologic profiles in the Pątnow open pit indicates on the carbonate rocks and low content of pyrite in the overburden. The results are that acidic water are largely neutralized. However, the studies indicate a potentially threat to the water quality in flooding voids, where they are recharged only by groundwater. In many cases, what is crucial for the chemistry of the pit lakes is flooding the voids using water from outside of the pit. Filling the void with surface water or even water pumped out from dewatering well reduces the probable pit lakes deterioration.

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abstract id: **279**

topic: **1**
Groundwater quality sustainability

1.1
Evaluation and management of groundwater — sustainable exploitation

title: **Groundwater quality status and problems of sustainability in Azerbaijan**

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keywords: aquifer, groundwater contamination, yields of wells, springs

AQUIFER SYSTEMS

From geostructural point of view, the territory of the Azerbaijan Republic is represented by the Greater Caucasus, the Lesser Caucasus Mountain Ranges and the Kur-Araz Lowland lying between these two mountain ranges (Alekperov et al., 2008). The mountain structures of the Greater Caucasus and the Lesser Caucasus are composed of Meso- Kainozoic and Palaeo-Kainozoic rock formations, respectively. Thick weathered, fractured rock formations and intermountain troughs with soil content of alluvial and fluvioglacial sediments are specific features of both mountain ranges. A distinguishing geological feature of the Azerbaijani part of the Greater Caucasus is higher prevalence of sedimentary deposits. The layers composed of fractured and Karstic formations are much richer in water reserves, whereas volcanogenic and intrusive rock formations have less water content. Natural groundwater discharge locations / springs with approximate yields of 5-10 l/s are seen at the foothills. The springs with flow rates up to 60-100 l/s are encountered mostly in the areas with karstic limestone rocks. Significant stock of groundwater is available in 70-90 m thick alluvial deposits forming the substructure of riverbeds. Springs linked to underflow have yields varying from 0.5-1.7 to 25-30 l/s. Permeability of water-retaining rocks is 1.7-14.2 m/day. Confined and unconfined aquifers have been penetrated by exploratory wells with depths varying from 40-50 to 250-300 m. Level of non-pressurised groundwater varies from 0.1-1.0 to 60-85 m and yields of the wells are between 0.1 – 5.5 l/s. Yields of exploratory wells drilled into the confined aquifers vary from 0.8 to 12 l/s and the piezometric levels are both below (5-8 m) and above (0.8-4.0 m) the level of ground surface. Higher yields have been recorded in layers composed of sand and limestone sediments. Permeability of aquiferous layers varies from 0.1-0.2 to 12-15 m/day. Pressurised groundwaters of the Lesser Caucausus are associated mainly with tectonic faults and cracks. Recharge and transit of groundwater within the Greater Caucasus is facilitated by existing tectonic structure, weathering zones, numerous fractures and joint fissures, as well as structural and textural properties of flysch and metamorphic formations. These peculiarities create conditions for formulation of significant volume of mineral content groundwater. Thermal and mineral water sources are located in linear position as their discharge is associated with tectonic fault lines. Thermal waters are linked to main fault lines and cold mineral sources are linked to subfaults. Yields of mineral water sources vary from 0.01-0.02 to 2.8-3.7 l/s. The absolute majority of mineral waters of Azerbaijan are in the Lesser Caucasus. The famous sources include Istisu, Badamly, Sirab etc.

Piedmont and intermountain troughs forming the Kur-Araz lowland are considered to be basins of porous-fractured waters and are rich in fresh and low-mineralized (up to 3 g/L) groundwater. They are formed by confluent fans of Upper Pliocene-Quaternary ages, alluvial quaternary and alluvial-dealluvial strata, which are basically rather thick (up to 300-500 m, seldom 1000-1500 m). Almost all of these basins contain one unconfined and several confined aquifers (Fig. 1).

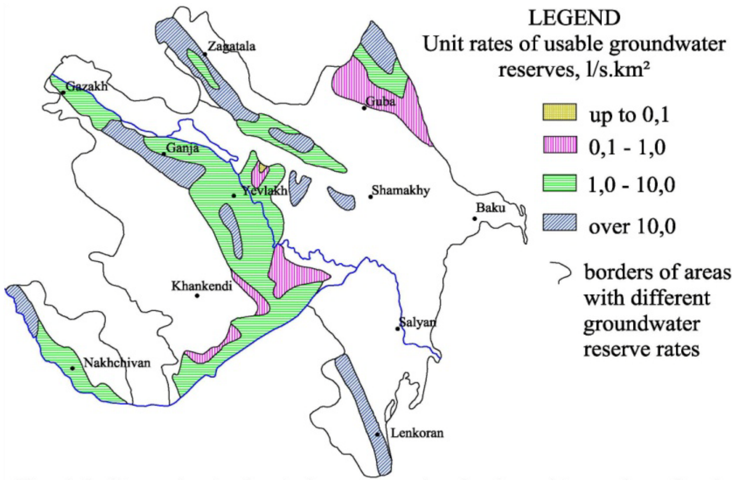

Figure 1. Groundwater in piedmont troughs, fresh and low-mineralized.

Unconfined aquifer exists almost everywhere along piedmont plains. Occurrence depth of non-artesian aquifers varies from 60-80 meters at foothill parts of alluvial fans down to several centimeters at discharge zones. Yields of wells drilled into unconfined aquifers vary from 0.1-0.2 to 25-30 l/s. However, the majority of yields is between 3-5 and 15-20 l/s. Discharge rates of springs fluctuate from 0.1-0.3 l/s to 15-20 l/s and may reach 280-300 l/s, though rarely. Permeability of the aquifer changes between 0.1-0.5 m/day and 25-48 m/day. Confined aquifers lie several kilometres below the contact zone of parent rocks and alluvial sediments. The confined aquifer has been penetrated by wells with depths varying from 10-20 m up to 110-300 m. Piezometric levels of pressurized water are both below (from 0-3 m to 70-80 m) and above (from +1+3 m to +20+50 m) ground surface. The flow rates recorded during pump tests are between 0.1-0.2 and 57-98 l/s. Permeability of the water retaining rocks varies from 0.1-0.4 m/day to 10-46 m/day (Alekperov et al., 2008).

The lowlands of Azerbaijan, mainly composed of continental marine sediments and merely marine sediments are distinguished for their unfavourable hydrogeological conditions.

Geostructural and lithofacial properties of piedmont porous-stratal groundwater basins and the common recharge sources give rise to tight hydrodynamic connection between the unconfined and the confined aquifers. The situation concerning the porous-fractured groundwater basins is rather different. Groundwater of the Lesser Caucasus originating from the fractures is associated with intrusions recharge local porous waters. In the Greater Caucasus, however, basic sediment fractures are fed by precipitation, i.e. porous-fractured waters have common recharge sources. There is no connection between groundwater reserves originating from different fractures.

USABLE GROUNDWATER RESERVES

Potentially usable reserves of fresh and low-mineralized groundwater in the whole territory of Azerbaijan are estimated to be 24 mln m^3/day (Alekperov et al., 2008). These reserves were estimated in 1970-1980, and no longer reflect a complete realistic picture, because of considerable changes that took place recently in water industry, as well as in qualitative and quantitative indices of groundwater sources. In fact, stock of usable groundwater resources is much larger than estimated. Annual groundwater production rate is between 3.0-3.5 bln. m^3.

GROUNDWATER QUALITY

Groundwater in the mountainous zones is of good quality. Total dissolved solid (TDS) content of spring waters is usually between 0.3-0.6 g/L and chemical contents include HCO_3-Ca. Groundwater under river beds is also of drinking quality with TDS content of 0.3-1,0 g/L and chemical content including HCO_3-Ca-Na and SO_4-HCO_3-Na-Ca. Slightly saline waters with TDS content of 1.3-1.4 g/L and chemical content of Cl-SO_4-Na are observed in the places adjoined to the sides of the river beds. TDS content of groundwaters extracted by wells drilled into the aquifers of the Greater Caucasus varies between 0.3-0.5 and 8-10 g/L and in the Lesser Caucasus this content varies between 0.3-0.5 and 20-22 g/L. Chemical status is quite heterogeneous with various combinations of anions and cations. There is a consistency in respect of chemical content and TDS content of groundwater in the Greater Caucasus. TDS content increases while moving from north-west to south-east and chemical contents shift from HCO_3-Ca to SO_4-Na due to several factors such as increased clay content of water retaining rocks, decreased rainfall and poor diversification of terrain.

Waters discharged by majority of these sources have lower TDS content (0.3-1.7g/L) with SO_4 Na-Ca-Mg composition and H_2S smell. Water temperature at some of these sources reaches 39-40^0C. The main distinctive feature of mineral waters of the Azerbaijani section of the Greater Caucasus is that water does not contain carbonic acid and almost all water sources are hydrosulphuric. In other parts the situation is different. Some springs contain iodine, bromine, boron, and silicates. Mineral water sources in the Lesser Caucaus have TDS content ranging from 0.5 up to 7.4 g/L. Water temperature in some sources reaches 51-74°C.

Fresh and low-mineralized waters are widely spread within piedmont plains depending on specific features of their geological structure, recharge and discharge conditions of the aquifers (Table 1.). In depressions (mostly peripheral zones of debris cones of Garabagh, Mill, and Shirvan plains) fresh and low-mineralized waters are shifted by very salty or salty waters due to influence of features mentioned above. Groundwater resources in Alazan-Ayrichay, Gusar-Devechy valleys and almost everywhere in Gyanja-Gazakh, Garabagh and Jabrail plains are of drinking quality. Higher TDS content characteristic of pressurised waters found in Neogenic formations spread along Gyanja-Gazakh, Garabagh, and Mil plains. The Garabagh, Mill, and Shirvan plains are distinguished for their complex hydrochemical state. For instance, in Garabagh and Mill plains, one unconfined and two confined aquifers contain mineralized water and the confined aquifer in between contains fresh water.

Table 1. Quality parameters of groundwater bodies in piedmont hills.

Indicators	Porous-stratal groundwater basins							
	Alazan-Ayrichay	Gusar - Devechi	Gyanja-Gazakh	Garabagh & Mill	Shirvan	Jabrail	Nakhchivan	Lenkoran
TDS, g/L	0.2-0.5	0.2-0.7	0.3-3.0	0.3-2.3	0.5-3.0	0.3-3.0	0.2-2.4	0,4-2,8
pH	6.7-8.2	6.9-8.2	6.5-8.2	7.4-8.4	7.5-7.7	7.0-8.1	6.6-8.3	6.6-8.2
Cl, mg/L	4 -110	4-980	4 -1900	10-1040	7-200	4-480	3-540	18-1420
SO_4, mg/L	14-132	12-206	4-1400	9-810	4-133	10-886	18-1270	7-229
NO_2, mg/L	up to 9	up to 10	up to 9	up to 10	up to 5	up to 9	up to 10	up to10
F, µg /L	up to 680	up to 1500	up to 1520	up to 800	up to 750	up to 1080	up to 1200	up to 600
Mn, µg/L	up to 30	-	signs detected	up to 90	N/A	signs detected	signs detected	-
Fe, µg /L	up to 10	up to 30	up to 125	up to 70	up to 50	up to 100	up to 25	-
Cu, µg/L	up to 60	up to 750	up to 200	up to 200	up to 500	up to 34	up to 100	up to 15
Zn, µg/L	up to 50	up to 4000	up to 400	up to 400	up to12	up to 160	up to 4200	up to 45
Sr, µg /L	300-700	up to 1400	up to2000	up to 1950	50-1300	85-2000	p to 2000	350-2100
Pb, µg /L	N/A	up to 100	up to 90	5-80	up to 80	up to 100	up to 50	-

The plains' groundwater is salty, often very salty with solid residues totaling to 100-200g/L. Saline groundwater is widely used in Azerbaijan along with fresh groundwater.

QUALITY SUSTAINABILITY CONCERNS AND MITIGATION POSSIBILITIES

Sustainability of groundwater quality is an issue, linked directly with the state of main recharge sources i.e. surface waters and aeration zones. Groundwater reserves in the mountainous areas i.e. all porous-stratal and stratal groundwater basins are less endangered considering the conditions of natural protection. In piedmont plains, the first stratum from the surface of the aquifer is unconfined and not protected anywhere. Confined aquifers are naturally protected against contamination (Alekperov et al., 2006).

The chemical state and TDS content of non-pressurised water in mountainous areas and some areas of the Kura-Araz lowlands were influenced by natural seasonal changes. No variations influenced by natural conditions are observed in salinity and chemical content of pressurised waters.

Catchment basins of the two main rivers in Azerbaijan, the Kur and the Araz, occupy considerable parts of the territories of two neighbouring countries, Georgia and Armenia. Annual wastewater material and effluent disposal into the Kur and its tributaries in the territory of Georgia is approximately 330 mln m^3. The water of the Akstafachay River (the Kur's right tributary flowing through Armenia) contains chemical dye, oil products, phenol, ammonia nitrogen and other contaminants that are discharged into the river together with wastewater material in Injevan, Dilizhan and other Armenian towns. The rivers Alazan and Iori (left tributaries of the Kur River) also carry over contaminated waters from Georgia to Azerbaijan. While crossing the borders of Azerbaijan, the Kur River already contains oil products, phenols, and other contaminants in volumes exceeding admissible limits 2-6 times depending on periods: phenols 3-20 times, copper 7-14 times, sulfate 2-3 times. In the territory of Azerbaijan, contamination is enhanced by agricultural pollutants and wastewater from industrial premises and cattle farms.

Left tributaries such as Razdan, Arpachai, Okhchuchai etc of the Araz, Azerbaijan's second biggest river in terms of its length and flow, contain hazardous substances (nitrite nitrogen, ammonia nitrogen, heavy metals and other pollutants exceeding the sanitary norms dozens of times), which come from Armenia with water flow. Volume of annual wastewater disposal into the Araz River in the territory of Armenia exceeds 350 mln m^3. Every year the ore and copper-ore mining and processing enterprises discharge highly contaminated wastewater into the Okhchuchai River, which flows into the Araz River making it red-brown and almost black. The red-brown liquid contains high concentration of aluminium, zinc, manganese, titanium, bismuth and other components. After the confluence of Okhchuchay with Araz River, microflora content of the river is reduced by 65-80%. The main reason for this situation is the lack of effective drainage system, treatment facilities as well as technical insufficiency of existing plants in most towns and settlements of not only Georgia and Armenia, but also Azerbaijan.

In huge parts of the lowland, subsoil and aeration zones are exposed to natural pollution and Salinization rises sharply in poorly drained and drainless areas below the zero contour. Salinization rate in irrigated areas ranges from 0.25% to 1-2%. Local pollution of subsoil and aeration zones with organic and mineral fertilizers can be observed in irrigable lands and in the vicinity of fertilizer storages. Land plots around oil fields and industrial premises are also considered vulnerable in terms of contamination of subsoil and aeration zones by petroleum products and chemical agents. From time to time, concentrations of nitrates and nitrites in aeration zones of certain irrigable areas exceed admissible rates for more than 10 times. Aeration zones around fertilizer storages sometimes contain 1.7 to 97.7 mg/kg of nitrites. There are higher concentrations of nitrates, nitrites, phosphates, sulphates, chlorine, iron and aluminum around the sludge pit at the Ganja aluminum plant.

Groundwater pollution of regional scale has not observed in Azerbaijan. Pollution is of domestic, industrial and agricultural nature. The main factor causing domestic pollution is the lack of effective drainage system and purification facilities in most communities. Domestic wastewater is being disposed into the rivers, the sea, natural or manmade pits. Groundwater pollution is caused by infiltration of contaminated river water or migration of chemical agent via the zones of aeration. For instance, chemical elements such as phenol (0.007-0.13 mg/L), sulphates (960-1280 mg/L), Iron (0.5-5.0 mg/L), and BOD 5 (0.46-23.9 mg/L) were found in groundwater reserves in the vicinity of pits used for disposal of already treated sanitary and domestic wastewater coming from Ganja city. Aluminum (0.08-3.5 mg/L), iron (3.5-50 mg/L), phenol (0.008-0.004 mg/L), high concentrations of nitrites, nitrates, ammonia and sulphates were encountered in groundwater at sludge pit of Ganja aluminum plant.

Groundwater contamination with agricultural contaminants is observed mostly around fertilizer storages. Contaminants include nitrate, nitrite and phosphate, which exceed admissible rates by 2-5 times. Concentrations of nitrites and nitrates in irrigable lands do not exceed the admissible rate, while around cattle farms such concentrations may reach 10-19 mg/L and 12-145 mg/L correspondingly. Evidences of bacteriological pollution of groundwater have been recorded in irrigable areas, cities, cattle farms and near wastewater treatment plants. Contamination of pressurised water has not been observed.

The quality of groundwater in the coastal zones is affected by the rise of the Caspian Sea, which causes contamination in two ways: 1) chemical elements and combinations of sea water change the composition of groundwater via migration in the coverage areas of low-mineralized groundwater; 2) increased sea water occupies coastal lines composed of rocks with good condensing capacity and thus deteriorates conditions for formulation of fresh and low-mineralized groundwater.

To ensure sustainability of the groundwater quality, it is necessary to carry out comprehensive investigation of recharge conditions, hydrochemical and bacteriological composition of groundwater under the influence of rivers; to prepare diagrams for integrated use of water resources; to identify possible ways of avoiding pollution; to conduct independent monitoring of surface and groundwater flow; to restrict disposal of untreated wastewater into rivers at least in large cities and settlements; to construct drainage facilities and treatment plants for entrapment and neutralization of highly contaminated infiltrates in waters intended for irrigation purposes etc.

In recent years Azerbaijan has consistently carried out the restoration and construction of drainage network that drains the salty and polluted groundwater on huge areas along Kur-Araz lowland. Extensive work is being undertaken for the construction of sewerage network and treatment plants for large urban settlements and industrial plants. Such measures will significantly contribute to sustainability of groundwater quality.

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abstract id: **308**

topic: **1**
Groundwater quality sustainability

1.1
Evaluation and management of groundwater — sustainable exploitation

title: **Factors of stability of hydrogeological systems to an exhaustion and pollution**

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keywords: hydrogeological systems, stability, reserve of stability, factor of stability

Problems of system sustainability assessment and prediction of system behavior on the basis of this fundamental feature are studied in many fields of knowledge - mechanics, economics, ecology, etc. However, the mechanical placement of both the concept of sustainability and the methodology and research techniques of this feature on the hydrogeological systems (HGS) faces some difficulties.

Being the most active component of the groundwater natural resources subsurface runoff into rivers first of all determines the hydrodynamic stability of the HGS parameters and serves as a reliable indicator concerning the different types of negative processes. This component of the groundwater natural resources is the subject of the largest industrial transformations. For example, the balance between recharge amount through the infiltration of atmospheric moisture (n·10-2 ÷ n·10l/s · km2) and discharge (0 ÷ n·10) indirectly points at the massive opportunities (almost two orders of magnitude) of the HGS regulating reservoir and therefore their resistance to humidity changes of the saturated zone in the multi-year perspective. In such a way the feeding groundwater discharge (inflow or outflow) on the basis of natural resources assessments could become essential regional empirical basis, which could allow evaluating many types of stability and, therefore, reasonably regulating the development pressure on the underground hydrosphere.

Hydrodynamic stability (resistance to depletion) is determined by criteria: a) the balance between natural resources and volume of extracted water; b) identifying the extent of the depression cones, combination of local conical depressions into a single broad zone of depression which can to be ministerial to the active flux and accumulation of pollutants.

Asynchronous recharge and discharge changing is due to the inertial features of HGS and is determined by the rate of water exchange of the hydrogeological structures. This is the kind of characteristic of the dynamic component of groundwater resources, which also characterizes the stability of HGS and its elements. But on a regional scale this index is more a function of the system heterogeneous structure. It follows an important conclusion that the hydrodynamic stability of system of water-bearing strata is provided exactly by the water exchange.

Taking into account the hydrogeological conditions of formation of natural groundwater resources (Qn.r.), subsurface runoff (Qs.r.) and subsurface runoff into rivers (Qs.r.r.) are classified areas (hydro-geological structures), according to which we classified to stable HGS those systems in which there is approximately the same ratio of the listed above categories of groundwater resources.

- The most stable categories of HGS (Qn.r.≈ Qs.r.≈ Qs.r.r.) are formed within the closed bailing structures - mold, synclines, troughs, arrays, sediments, which are deeply cut by river valleys. Aquifers are not separated from the rivers by the impermeable sediments. Matured confining layer prevents the outflow of groundwater in the underlying horizons. Such conditions create the preconditions for an active (perfect) hydrodynamic connection of groundwater with rivers, conducive environment of lateral percolation to river valleys and, consequently, the active water exchange. Because of the evaporation and transpiration the discharge of the groundwater is absent or it is very small in relation to the large capacity of the aeration zone.
- Relatively stable HGS (Qn.r≈ Qs.r. >Qs.r.r.) are formed within the uplands which are dissected by river valleys; aquifers are separated from rivers by impermeable sediments and can be extended beyond the selected system (drainage area). Confining layer has disconti-

nuous character, which determines the possibility of groundwater infiltration into the lower horizons taking into account the respective free surface elevations and piezometric heads. Evaporation and transpiration are practically absent, side outflow is possible.

- Weakly stable HGS (Qn.r.> Qs.r.> Qs.r.r.) are inclined to dissected broad river valleys, which are swamped in whole or in part, which have weakly expressed hydraulic connection because of the drains imperfections and high resistance of channel alluviations, with the heterogeneous nature of the cut. The role of evaporation and transpiration increases from the slopes of the rivers to floodplains. Lateral outflow may be significant, that affects the parameters of the underground runoff into rivers.
- Unstable HGS (Qn.r.> Qs.r. >> Qs.r.r.) developed within the flat or slightly hilly topography, which is slightly dissected by river valleys partially or completely swamped, with a weak hydraulic connection because of the high channel resistance and the drains imperfection; heterogeneous nature of the cut is partially drained, leading to low rates of water exchange system in the whole. The main types of discharge except Qs.f.r. are evaporation, transpiration and outflow in other systems or underlying horizons.
- Highly unstable HGS (Qn.r.> Qs.r≈ Qs.r.r.) are created within the dissected topography within the dividing areas; there is the development of impermeable sediments which are drained by narrow valleys with close almost perfect hydraulic connection. At divides the main types of discharge are evaporation and transpiration in relation to the small thickness of the aeration zone and the development of permafrost; there are the limited quantities of underground runoff into rivers in the river valleys.
- Critically unstable HGS (Qn.r.>> Qs.r.> Qs.r.r.) predominate in the plain conditions of the topography, it has weakly expressed valleys and vast territories are intensivly swamped, which is connected with the development of impermeable sediments and in the riverine areas, which prevent active groundwater discharge into rivers. Impermeable sediments can be caused by ground-freezing processes.

In light of the above-mentioned regularities we offer the following rating system (Table 1) in order to determine the stability of HGS.

Table 1. Assessment of HGS stability for lowland areas.

Categories of HGS stability	Possible ratio of natural resources composing	Modules, l/s·km²: Natural resources	subsurface runoff	subsurface runoff into rivers	Coefficient of ground water inflow (underground recharge) %	Power (thickness) of the aeration zone, m
The most stable	$Q_{n.r.} \approx Q_{s.r.} \approx Q_{s.r.r.}$ 1:1:1	>10 >50	>10 >50	>10 >50	>40	>10
Relatively stable	$Q_{n.r.} \approx Q_{s.r.} > Q_{s.r.r.}$ 1:1:0,75	8-10 40-50	8-10 40-50	6-8 30-40	30-40	8-10
Weakly stable	$Q_{n.r.} > Q_{s.r.} > Q_{s.r.r.}$ 1:0,75:0,50	6-8 30-40	4-6 20-30	2-4 10-20	20-30	6-8
Unstable	$Q_{n.r.} > Q_{s.r.} >> Q_{s.r.r.}$ 1:0,75:0,25	4-6 20-30	2-4 10-20	<2 <10	10-20	4-6
Highly unstable	$Q_{n.r.} > Q_{s.r.} \approx Q_{s.r.r.}$ 1:0,5:0,5	2-4 10-20	<2 <10	<2 <10	5-10	2-4
Critically unstable	$Q_{n.r.} >> Q_{s.r.} > Q_{s.r.r.}$ 1:0,5:0,25	<2 <10	<2 <10	<2 <10	<5	<2

* Note: there are the possible coefficients in the denominator

Let us take the estimates of stability and standardization of geochemical load on the basis of hydrogeochemical parameters.

Hydrogeochemical stability will be determined by the ratio of surplus quantity of component Mdi which is derived from the aquifer system to its additionally received quantity Mri. Hydrogeochemical stability can be expressed in percentages or fractions of units, so coefficient of stability is Csi = Mdi / Mri.

Calculations are based on a basin approach with assessing the balance of pollutants entering the aquifer. This method is widely used for regulations of wastewater discharge into surface streams. The catchment area of river basin is considered to be the elementary object and it is expected to be the equal distribution of concentration for the basin (Fig. 1).

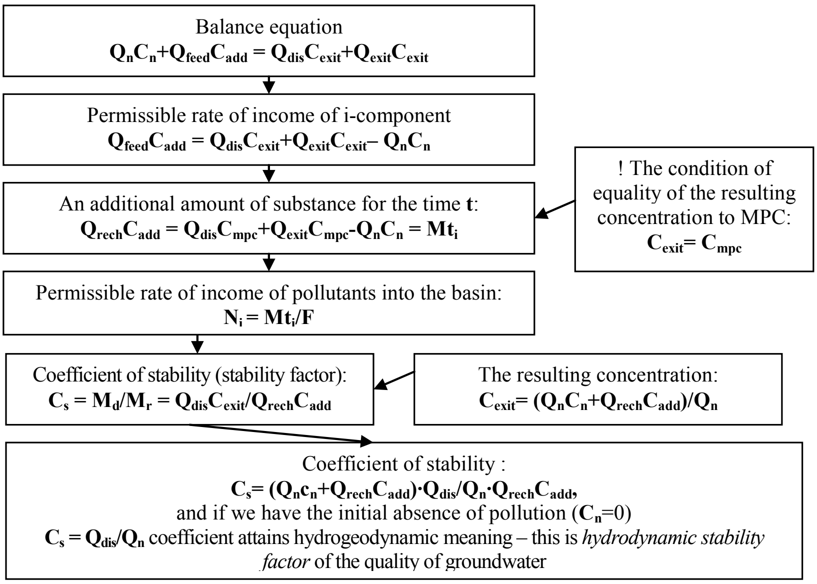

Figure 1. The scheme of the calculation of the hydrodynamic coefficient of stability. Qn - natural resources (incoming part) of groundwater in the given elemental basin; Qrech - additional feeding which is received by aquifer in the area of the basin; Qdis - groundwater discharging on the area of the basin (drainage system, water intake facilities); Qexit - underground runoff from the area of the given elemental pool to adjacent basins Cn, Cadd, Cexit - concentration of component in natural conditions, in additional inflow as a result of pollution and the resulting concentration; Cmpc - maximum permissible concentration; F - catchment area.

The resulting correlation of the coefficient Cs = Qdis/Qn once again confirms the thesis about the crucial role of water exchange in the filtration resistance of HGS. From the viewpoint of maintaining ecological health of surface waters the most dangerous elementary basins are the basins with the maximum coefficient of stability of groundwater quality; it is so because it is assured by the removal of pollution in the river network. Therefore there is an important conclusion: the factors influencing the formation of surface runoff stability are different from the factors that determine the stability of underground runoff into rivers.

From these positions its discharge into the river network is of great interest. It is known that variations in the spatial and temporal context are determined by a number of factors; the stability margin of HGS is formed under the influence of this factors. This is a kind of "corridor" within it a fluctuation state of the object takes place. The upper and lower limits of the stability of HGS can be set by the calculations according to the known relations between the module of underground chemical runoff into rivers Mucr 5% and 95% of security:

$$M_{ucr\ 95\%} = \frac{Q_{max} \cdot C_{min}}{F}, \ M_{ucr5\%} = \frac{Q_{min} \cdot C_{max}}{F},$$

where: Mucr5% is the quantity of the module of UCR 5% (t/km2 per year), which is calculated as the product of minimum flow of the river during summer low water period (Qmin) times appropriate mineralization of water or normalized chemical element (Cmax); Mucr95% is the product of quantity of minimum flow in rivers during the winter time (Qmax) times the quantity of maximum mineralization (Cmin); F is the catchment area, km^2.

Stability margin (Δ) is calculated in relation to the contamination of groundwater by substances which flow to the surface of the river catchment (with precipitation or from other sources); in the first approximation it can be calculated as the difference between different secured volumes of USR:

$$\Delta = M_{ucr5\%} - M_{ucr95\%}$$

At its core Δ is the amount of salts leaching under the different conditions of drainage of certain amounts of dissolved rocks, partly affecting the unsaturated zone of catchment.

High rates of water cycle include an intensive removal of pollutants from aquifers, at the same time they include minimum time of contact with enclosing rocks and determine the low degree of natural purification of groundwater as the result the insignificance of the processes of sorption and diffusion. Here it should be noted that the rapid removal of contaminants from groundwater leads to a predominance of the surface waters pollution prosesses. This conclusion once again confirms that the mechanisms of emerging resistance for surface and groundwater catchments are different despite the close relationship between surface water and groundwater in the basins of the northern rivers.

Quite different regularities inhere in the formation of stability of runoff forming complexes in conditions of long-term permafrost. Thus, it increases from south to north correlating with the reduction of periods of water exchange and it is due to the discreteness of the interaction of surface and groundwater. As a result of repeated glaciations, transgressions and regressions of the Arctic Sea in the Quaternary period, the freezing of the rock and types of structure of the cryolithic zone have pronounced latitudinal direction according to the data.

It is important to emphasize that for any HGS stability can be assessed only in relation to specific types of technogenesis, because every system has the property of the selectivity against the disturbances sources. This suggests that all natural systems, including the HGS, are characterized by multiple forms of stability, which are controlled by the power of resistance.

Apparently estimates of stability of HGS will be long conducted on an empirical basis, because the theoretical universal apparatus of similar estimates for the natural systems has not been created yet, and the assessments themselves have a specific purpose depending on the nature of charge (depletion of aquifers, its pollution, industrial waste injection, flooding areas, etc.). In addition, any HGS has the property of selectivity towards reactions on environmental loads and is characterized by multiple types of resistance. In this context introduction to substantiation of norms of the impact the concept of "limiting factor" becomes relevant.

These limiting factors on the basis of regularities of natural groundwater resources formation for the platform areas are:

- significant differences of the shares of participation of groundwater from different hydrodynamic zones;
- the most intensive feeding of aquifers in the side parts of the artesian basins due to vertical cross-flow which is a key element of water exchange;
- rivers draining effect can be traced not only to a depth of downcutting, but it also covers the deeper parts of the cut, if they are not covered by weakly permeable sediments;
- watershed areas are the areas of nutrition with a predominantly downward movement of water and they are the most vulnerable to aerogenical pollution;
- reducing the rate of lateral filtering occurs for all horizons as they deep from the periphery to the center, which creates prerequisites for the accumulation of pollutants;
- in the riverine (lowland) part of the aquifer there is a growth of the rate of lateral filtering speeds, as well as the vertical from the lower horizons and the active mobilization of dissolved substances occurs, including man-made pollution;
- amplitude of the vertical speeds of water exchange in interfluvial arrays is more constant with the deep of aquifer than the lateral speeds; it is connected with an increase of the relative role of vertical water exchange with the depth;
- the intensity of vertical water exchange is due not only to facial irregularities of overlying sediments, but also to a small-block structure of the sedimentary basin which creates conditions for local groundwater pollution throughout its thickness, and for the removal of pollutants in the overlying horizons and at the surface of the earth;
- the rate of transit water exchange through the slightly permeable thickness in the vertical direction is disproportionately higher than those that are for the full water exchange.

abstract id: **322**

topic: **1**
Groundwater quality sustainability

1.1
Evaluation and management of groundwater — sustainable exploitation

title: **Regional spatial-temporal assessment of groundwater exploitation sustainability in the south of Portugal**

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keywords: groundwater, sustainable yields, climate change, Algarve, finite element models

INTRODUCTION

Groundwater was the main source for public supply in the Algarve, in the south of Portugal, until the end of the 20th century, after which it was replaced by surface water supplied by large reservoirs. The large drought that hit the region in 2004 and 2005 revealed the problems related to a water supply strategy based on a single source. It is well-known that in semi-arid regions such as the Algarve, the seasonal and annual variations in rainfall are extreme. The intensity and frequency of occurrence of extreme droughts will most likely increase significantly in the future (Giorgi, 2006; Santos, Miranda, 2006). Research on climate scenarios and impacts for groundwater resources and dependent ecosystems in the Algarve is currently ongoing, in the scope of the CIRCLE-Med project CLIMWAT (Stigter et al., 2009b), using regional climate model data from the PRUDENCE and ENSEMBLES projects. Integrated water resource management will be essential in the near future, including surface and groundwater resources, as well as alternative resources such as treated wastewater for irrigation. Within this scope, a qualitative and quantitative screening of groundwater sources for integration into the public water supply system of the Algarve region has been performed (Stigter et al., 2009a). Current work aims to address the regional quantification of groundwater availability and exploitation sustainability, as well as their dependence on factors such as the spatial and temporal distribution of recharge, aquifer heterogeneity and the location of the pumping wells.

GROUNDWATER RECHARGE VERSUS CONSUMPTION

The present state of development of the Algarve hydrogeology allows the definition of 17 aquifer systems with regional importance, shown in Fig. 1 (Almeida et al., 2000). The most productive aquifers are built up of karstified limestones and dolomites. The six most important aquifers for public water supply are characterized in Tab. 1. Many of the other aquifer systems are directly and indirectly exploited for irrigation. Due to its large area and significant recharge, as well as the high degree of karstification, aquifer system M5, known as Querença-Silves, constitutes the most important groundwater reservoir.

Table 1. Characterization of aquifer systems with regional expression in the Algarve.

Aquifer system		Main aquifer lithology	Area (km^2)	Recharge (hm^3 yr^{-1})
M2	Almádena – Odeáxere	lmst, dlmt	63.49	16.6
M3	Mexilhoeira Grande – Portimão	lmst, dlmt, sand	51.71	10
M5	Querença – Silves	lmst, dlmt	317.85	93.4
M8	S. Brás de Alportel	lmst, dlmt	34.42	5.5
M9	Almansil – Medronhal	lmst, dlmt	23.35	6.5
M14	Malhão	lmst, dlmt	11.83	3

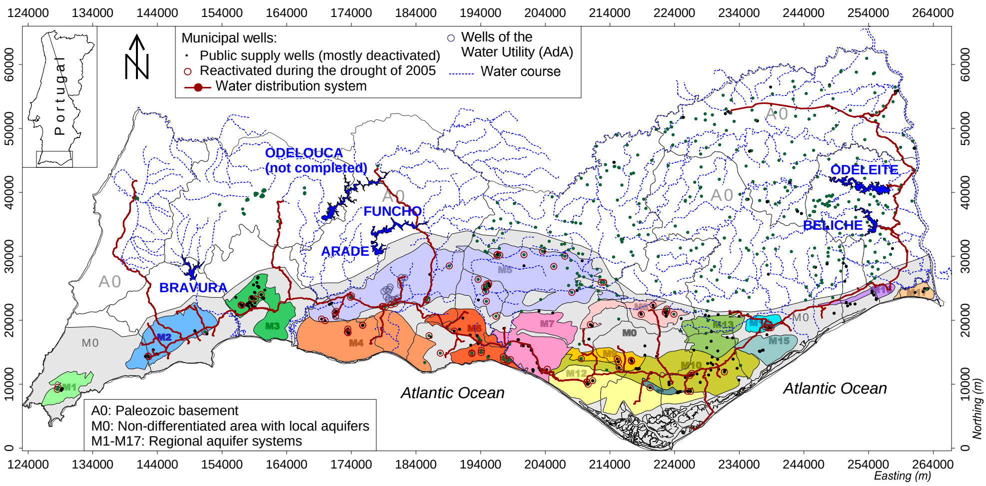

Figure 1. Location and geometry of the aquifer systems in the Algarve also shown is the location of the the municipal wells (mostly abandoned) and surface water reservoirs.

The estimation of aquifer recharge is a crucial and continuously ongoing task. Stigter et al. (2009a) provide an overview of some of the applied methods. Recent research has taken into account parameters such as daily precipitation, soil texture, moisture content and vegetation cover, allowing a deeper insight into the processes controlling recharge and its temporal evolution (Mendes Oliveira, 2009). Fig. 2 presents the estimated mean annual recharge volumes for the entire Mesocenozoic strip (M0-M17 in Fig. 1), the 17 main aquifer systems (M1-M17) and the six most relevant aquifers for public water supply.

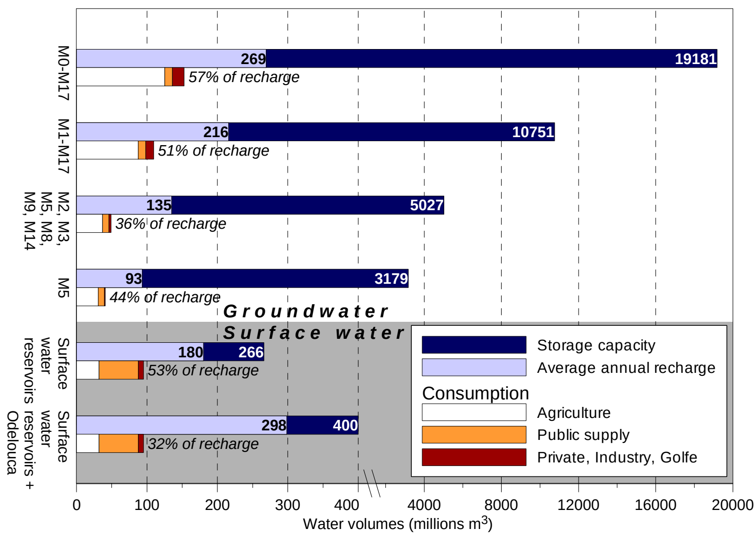

Figure 2. Storage capacity, mean annual recharge and water consumption volumes for groundwater and surface water in the Algarve; for groundwater the three categories refer to: the Mesocenozoic strip (M0-M17), the aquifer systems (M1-M17) and the main aquifers for public supply (M2, M3, M5, M8, M9, M14); for consumption, the labels indicate total volumes as a percentage of mean annual recharge.

For the area of non-differentiated aquifers and aquitards (M0) recharge was considered 10% of mean precipitation calculated in a GIS using the data Nicolau (2002). Roughly estimated total storage capacities are also presented in Fig. 2, considering an aquifer thickness of 100 m and effective porosity of 10%. Though these estimates are extremely simplified, they allow a good perception of their magnitude as compared to surface water storage, also presented in Fig. 2 (based on observed values). For instance, the total estimated storage of the Mesocenozoic strip is about 50 times higher than that of the surface reservoirs including Odelouca, currently in the phase of completion. It is also 70 times the mean annual groundwater recharge volume. The question is what fraction of storage is exploitable, both on a short-term (i.e. yearly) and long-term basis.

Fig. 2 also presents the present-day groundwater consumption volumes, and there distribution among users. The numbers are based on a detailed study of available data, provided by the Regional Water Utility, the Portuguese Ministry of Agriculture and literature (Do Ó e Monteiro, 2006). Agriculture is by far the main consumer of groundwater, with a total of approximately 150 hm^3 withdrawn from the Mesocenozoic strip, 47% of mean annual recharge. Total consumption amounts to 57% of recharge. Though groundwater is the main source for irrigation (165 hm^3), irrigation with surface water is gaining importance, allocating increasing water volumes.

SUSTAINABLE YIELD ANALYSIS

Safe yield was initially defined by Sophocleous (1997) as the attainment and maintenance of a long-term balance between the amount of groundwater withdrawn annually and the annual amount of recharge. Subsequently, the emphasis shifted to sustainable yield (e.g. Sophocleous, 2000; Custodio, 2002), which reserves a fraction of safe yield for ecological demands. This fraction depends on factors such as climate (variability), hydrogeological setting, location of the wells and the presence of groundwater dependent ecosystems. The concept of sustainable yield (or volume) can be studied by analyzing different groundwater recharge/capture/discharge scenarios.. Capture is defined by Lohman et al. (1972) as the sum of the increase in recharge and decrease in discharge, caused by abstractions due to pumping. Capture predominantly results in a decrease of groundwater discharge and a removal of water from storage. In this paper the analysis is performed for the largest aquifer system, Querença-Silves (M5), and compared to the simulation results of a groundwater flow model. A period of six (hydrological) years is considered, starting in October 2001, when the MPWSS was fully operational and groundwater consumption was comparable to the present-day picture.

The analysis starts with the definition of a so-called "safe storage volume" (S_{safe}), below which undesirable effects may occur as a result of overexploitation, such as the drying up of groundwater dependent streams and wetlands or the intrusion of seawater. The mean annual recharge is considered to adequately represent the safe storage volume. Considering a simple black box model, the hypothetical evolution of aquifer storage is then calculated for different discharge scenarios, using the following equations:

$$S_t = (1-f)\times(S_{t-1} + Rn_{\{(t-1),t\}} - W_{\{(t-1),t\}} + Ra_{\{(t-1),t\}}) \qquad (1)$$

$$Q_{\{(t-1),t\}} = f(S_{\{(t-1),t\}} + Rn_{\{(t-1),t\}} - W_{\{(t-1),t\}} + Ra_{\{(t-1),t\}}) \qquad (2)$$

$$Rn_{\{(t-1),t\}} = \frac{P_{\{(t-1),t\}}}{\overline{P}} \times \overline{Rn} \qquad (3)$$

where: S_t and S_{t-1} are the aquifer storage at time t and t-1, respectively, with a discrete time step of one hydrological year, $P_{\{(t-1),t\}}$ is precipitation between hydrological years t-1 and t, $Rn_{\{(t-1),t\}}$ is natural recharge, $W_{\{(t-1),t\}}$ is withdrawal $Ra_{\{(t-1),t\}}$ is artificial recharge (irrigation return flow) and $Q_{\{(t-1),t\}}$ is groundwater discharge for the same period; f is the fraction of surplus contributing to discharge. Surplus is the defined as the storage at the beginning of the preceding year plus the difference between natural and artificial recharge and abstractions throughout the year. Equation 2 indicates that a higher surplus will result in a higher discharge. For the first considered year ($S_{t=1}$), S_0 is considered 75% of the natural recharge of the preceding year. The latter is calculated as a ratio of observed to mean annual precipitation times mean annual recharge (Equation 3).

On average 45 hm^3 of water is pumped yearly from the Querença-Silves aquifer system, with an average annual recharge rate of 93 hm^3. In the dry year of 2005 abstractions are believed to have been exceeded 70 hm^3. The hypothetical scenarios of available water volume are generated by varying parameter f between 0 (no outflow) and 1 (100% outflow). The curves defining each of the six scenarios (0, 20, 40, 60, 80 and 100% groundwater outflow) are drawn in Fig. 3, where S is plotted as a fraction of S_{safe} storage volume.

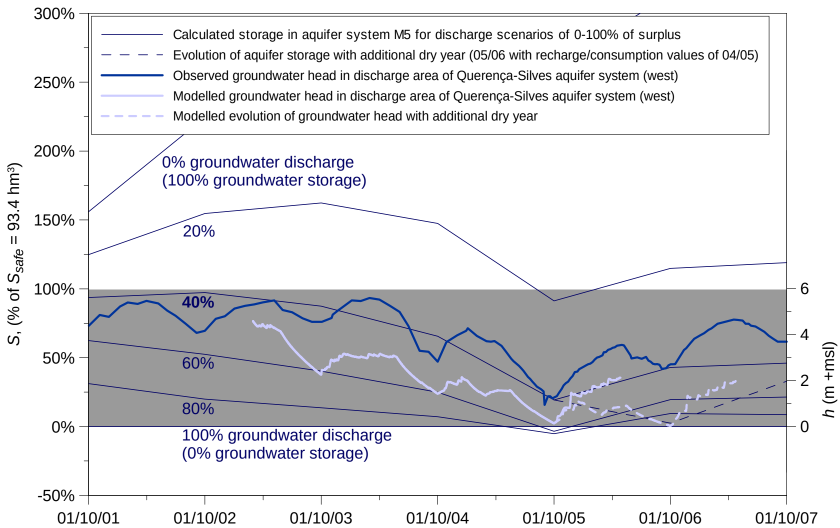

Figure 3. Scenarios of the evolution of available water volumes as a percentage of safe storage volume in the Querença-Silves aquifer system (M5), as well as modeled and observed time series of groundwater levels in the discharge area. Dashed lines indicate potential evolution with a second consecutive dry year.

In the scenario of 0% groundwater discharge, naturally unrealistic, all surplus is stored in the aquifer. In the opposite, equally unrealistic scenario of 100% outflow, no surplus exists and available water volumes are 0% of safe storage. The remaining four discharge scenarios are all hypothetically realistic, but the question is which one, if any, represents a more or less truthful simulation of reality. Naturally, the equations greatly simplify the actual behavior of the systems. For instance, groundwater discharge depends on the spatial and temporal distribution of recharge, whereas the impact of abstractions also depends on the location of the pumping wells. Moreover, in reality discharge is not a fixed percentage of the available water volume in the aquifer, but will be higher in wet years and lower in dry years.

In order to interpret the accuracy of the scenarios, they can be compared to observed groundwater head time series, which are related to aquifer storage volume. Time series are shown in Fig. 3, for a well located in the discharge area of the aquifer system. First of all it can be seen that the yearly trends are correctly portrayed by this simple analysis. Second, it appears that the 40% surplus discharge scenario (*f* = 0.4) most correctly follows the observed water level trend. The choice of the axis limits (minimum and maximum water levels) for the time series plot may be a matter of debate. The maximum observed values are considered to provide a correct indication of the 100% aquifer storage volume, whereas 0 m represents the limit below which overexploitation occurs, resulting in zero discharge at the springs and causing seawater intrusion.

When considering the 40% outflow scenario, total storage can be calculated for the six main public supply aquifers, based on known (estimated) abstractions and recharge rates. Fig. 4 provides the results, as % of maximum storage, 133 hm^3. The figure also gives an idea of potential storage and discharge volumes for higher pumping rates and compares values to reservoir storage evolution. This comparison cannot be straightforward, since 0% available volume in an aquifer implies overexploitation with possible negative consequences, whereas in reservoirs 0% indicates a dry reservoir, with no further possibility of exploration.

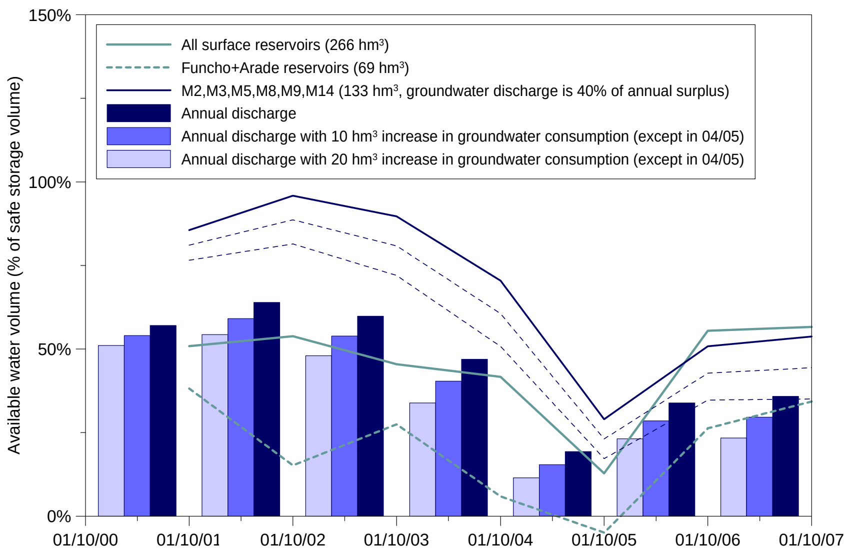

Figure 4. Evolution of annual storage and discharge volumes in the six main public supply aquifers, using f=0.4 (40% of surplus is outflow). Also shown are higher consumption scenarios (dashed lines).

The development of steady-state and transient groundwater flow models for the M5 aquifer system is described and discussed by Monteiro et al. (2006, 2007) and Stigter et al. (2009a). The conceptual flow model was translated to a finite element mesh with 11663 nodes and 22409 triangular finite elements. Transmissivity values were optimized by inverse calibration of the model and allowed a significant improvement of the simulation reliability of the observed regional flow pattern (Stigter et al., 2009a). Current work focuses on further calibration of the transient model, which involves optimization of the storage coefficient, among others. Fig. 3 shows the results of a simulation run for the groundwater head of the same observation well. Despite the lower simulated groundwater levels, the tendency and amplitude of oscillation are correctly simulated. During calibration of the transient model it was clearly noticed that groundwater pumping from private wells in 2005 started earlier than usual, namely in January (rather than in May). To simulate the larger drawdowns in that year, 17 hm^3 had to be added to the annual 31 hm^3 considered in the model for irrigation. This fact clearly indicates the "double-negative" aspect of droughts, i.e. lower recharge and higher (uncontrolled) pumping. When simulating a second consecutive dry year following 2004/2005, with the same recharge and extraction values as 2005, it was observed that the groundwater head in the discharge area dropped to values close to 0 m above mean sea level (msl). Longer droughts could therefore potentially lead to overexploitation, gradient inversion, drying up of springs and local seawater intrusion at the western border.

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abstract id: **379**

topic: **1**
Groundwater quality sustainability

1.1
Evaluation and management of groundwater — sustainable exploitation

title: **Ten years of groundwater exploration and development in the Caribbean Islands**

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keywords: groundwater, Caribbean, exploration, sustainable

INTRODUCTION

In many of the Caribbean islands, groundwater has been developed as a necessity when no surface water supplies were available. Over the years numerous funding agencies have sponsored drilling programs, which have resulted in various degrees of success. The programs that were successful often occurred in those islands where laterally extensive limestone aquifers existed, and developing groundwater therefore was relatively easy. In other islands that had no significant limestone aquifers, shallow alluvial sediments along drainage courses were targeted. Until recently (2000), fractured bedrock aquifer or permeable unconsolidated volcanic deposits had not been targeted with any degree of success, nor were they considered as potential aquifers.

This paper reports on the sustainable development of fresh and brackish groundwater supplies in deep volcanic aquifers on three Caribbean islands utilizing an integrated multi-disciplinary exploration program. In the last 10 years over 20 million imperial gallons per day has been developed by the author and his teams on seven Caribbean islands using this approach. Past attempts at developing groundwater on the islands using minimal field exploration were marginal, leading the island water authorities to assume that only desalination could solve their water supply shortages. Case studies of the exploration results in Tobago, Antigua and Nevis will be presented (Figure 1). These islands are primarily volcanic in origin, highly vegetated, have sparse fresh outcrops and minimal sources of hydrological data. Therefore remote sensing, GIS integration, recharge analysis, geological mapping and extensive geophysical surveying was critical in evaluating each islands water resources.

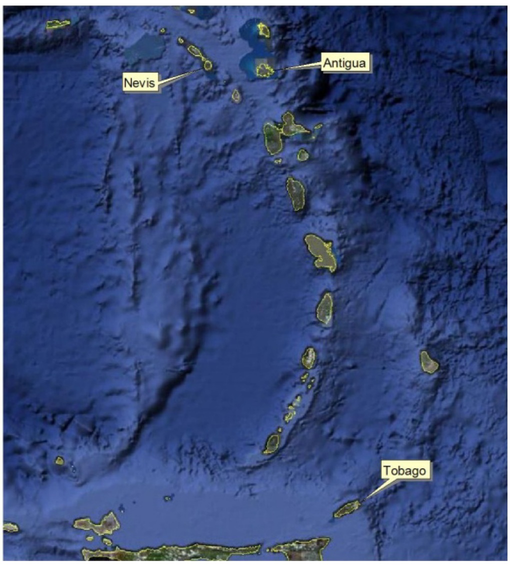

Figure 1. Location map.

OVERVIEW OF THE INTEGRATED GROUNDWATER EXPLORATION PROGRAM

The technologies integrated recently in the successful development of groundwater supplies in the islands of the Caribbean include the use of imagery, ground surface testing and sub-surface investigations as summarised below:

- Geologic and hydrologic data acquisition and evaluation;
- Satellite imagery, aerial photographs and Digital Elevation Model (DEM) interpretation;
- Hydrological modelling to determine groundwater recharge;
- GIS integration of the data sets and various interpreted information;
- Field verification of implied geological features;
- Geophysical surveys such as resistivity, magnetic, electromagnetic and gravimetric;
- Test drilling using a dual rotary drilling rig that allows for accurate sampling of water quantity, water quality and rock type.

Expert integration of this data in addition to an in-depth understanding of the regional and local geology is the key to determining the presence of fractured bedrock and volcanoclastic aquifers, and adequate recharge into the aquifers.

TOBAGO — 2000

Tobago is the smaller of the twin island Republic of Trinidad and Tobago (300 square kilometres in area). The republic is the southern-most of the chain of Caribbean island countries of the Lesser Antilles. Tobago is composed of 100 million old volcanic and meta-sedimentary rocks originating in Central America and transported along the Caribbean plate boundary in the southern Lesser Antilles island arc which is a very different origin than the other islands of this arc. The island's geology consists of predominantly Mesozoic igneous and metamorphic rocks that form a southwest to northeast trending mountain range along the long axis of the island, and younger Cenozoic sedimentary deposits consisting of Pliocene conglomerates, Quaternary deposits of coralline limestone and alluvium in the south-western lowland area. Brittle fault systems caused by the plate boundary movement have transected the island, pervasively fracturing the Mesozoic belts.

Thirty years of prior groundwater development efforts performed by several consultants resulted in the development of three (3) alluvial wells producing 0.05 MGD to 0.10 MGD per well and a conclusion that the total groundwater potential was only 0.4 MGD.

Results

Average rainfall ranges from 2,800 mm on the main ridge to less than 1,400 mm in the south western lowlands. The island was divided into 1 km square sub-basins, called Groundwater Recharge Units (GRUs). Recharge was calculated by developing equations that related evapotranspiration and runoff to precipitation using several gauged watersheds. Using the equation Recharge = Precipitation – runoff – evapotranspiration, a recharge contour map of the entire island was developed. The recharge to each of these GRUs was calculated by overlaying the GRUs with the recharge contour map.

An evaluation of the published geological reports indicated that the most likely targets for large aquifers would be fracture and fault zones in the crystalline volcanic and sedimentary rocks enhanced by the tectonic activity rather than in rocks with primary permeability. Multi-basin Aquifer Systems (MBAS), three dimensional fractured bedrock aquifers crossing surface water divides, were delineated through an analysis of satellite, aerial photography and digital elevation shaded relief maps of the island in conjunction with the distribution of GRUs. Where implied fracture zones cross major watershed boundaries, the recharge to GRUs adjacent to these fractures are summed in order to estimate the recharge to the MBAS. Areas were selected for detailed investigation based on favorable fracture characteristics, accessibility to a drill rig, and recharge amounts. The MBAS were ground-truthed by the geological team. Those that showed evidence of major fracture permeability were selected for geophysical surveying.

The geophysical techniques that were selected to pinpoint drill sites in the selected favorable zones included those that are effective in delineating fracture zones such as electromagnetic, magnetic, micro-gravity and resistivity surveys. A Foremost Dual Rotary drilling rig was used so that the casing could be advanced to case off caving formations while obtaining accurate water and drill cutting samples. As a result of these surveys seven production wells were drilled in large fault and fracture systems and four million gallons per day of excellent quality groundwater (up to 0.8 migd per well) were developed.

ANTIGUA 2002–2003

Antigua is 280 km^2 in area. It has a relatively dry climate, with an average annual rainfall of 840 mm in the lowlands and 1270 mm in the higher elevations. It is the southernmost of the "Limestone Caribbes" and is considerably younger than Tobago (28 to 33 my) and is part of the eastern volcanically inactive island arc. Three major geological units form a relatively gentle monocline dipping to the northeast. The lowermost unit is a volcanic complex consisting of basaltic to andesitic lava flows, pyroclastic rocks and lahars (mudflows). The overlying unit, about 500 m thick, consists of conglomerates, sandstones and shales resulting from the erosion of the volcanic complex. The uppermost unit (Antigua Formation) is a 500-metre-thick limestone. However the volcanic units are highly weathered and have considerable less faulting and fracturing than Tobago because of the island distance from the active tectonics.

The exploration program was carried out in the volcanic portion of the island with a goal of developing 2.5 migd of fresh groundwater. This area had the greatest rainfall, and thus was most likely to have sufficient recharge into the volcanic rock sequence. Over a 50-year period, numerous foreign aid projects resulted in the drilling of more than 150 wells and the development of 1.5 migd of groundwater supplies. All of the projects either focused on the alluvium or the limestone, with limited or no geophysical surveying used to select well targets. No wells had been drilled in the fractured volcanic rocks.

Results

An integrated exploration program was applied in an effort to develop fresh water with a Total Dissolved Solids (TDS) concentration below 800 mg/l. Remote sensing using IKONOS satellite imagery, aerial photography and a digital elevation model were used to map potential fractured bedrock aquifers. Detailed geological mapping was conducted in order to identify areas favourable for geophysical surveying. Electromagnetic, magnetic and gravity surveys were conducted in to pinpoint drill sites in the volcanic terrane.

Over 20 wells were drilled into fractured bedrock aquifers with the most productive well, in an area of high rainfall, yielding about 250 igpm with a surprisingly high total dissolved solid (TDS) content of 1700 mg/l. Most of the other wells drilled also had high TDS concentrations between 1500 and 3000 mg/l. These very high TDS concentrations can be explained by the following factors: relatively low rainfall, high influx of salt from "dry fallout" due to the physiography of the island, soils and bedrock with a low permeability, and high groundwater evapotranspiration rate because of shallow groundwater tables.

While in a sense this project had a disappointing result in that large supplies of fresh groundwater do not apparently exist in the volcanic rock, it does appear that substantial supplies of brackish water can be developed. We estimate that between 2.0 and 4.0 migd of brackish water could be developed, representing an opportunity to substantially reduce desalination costs. Based on the results of this project and the identification of large supplies of brackish water, APUA is considering an aggressive exploration program to develop this brackish water in order to more cost-effectively meet a growing need for more water. Multiple groundwater sources sited at strategic points of demand would also buffer APUA customers against threats of hurricanes, droughts, oil spills and vandalism.

NEVIS 2007–2010

The island of Nevis is located in the northern region of the Lesser Antilles. Nevis is 93 km^2 in size and has a population of about 11,000. It is part of the volcanically active island arc and is the youngest of the three islands with the age of the volcanic rocks ranging from 4 million to only 100,000 years. The young age of the rocks dictates a completely different exploration approach than the other islands. Precipitation is similar to Tobago, ranging from 900 mm in the lowlands to 3000 mm on Nevis Peak. The island is mainly composed of loosely consolidated highly permeable reworked volcanic deposits which do not support a significant amount of fracturing. Consequently the major aquifers are expected to be primary volcanic formations such as buried alluvial channels and lava flows requiring geophysical techniques capable of penetrating to great depths.

Results

Even though the island is composed of several volcanic centres the youngest and highest centre, Nevis Peak, has the greatest impact on both the total quantity of rainfall, as well as the permeability of the aquifer materials. Because Nevis Peak is 900 metres (3000 feet) high, moist tropical air rises from sea level and condenses on the mountaintop. The intrusive rocks of the peak appear to be highly fractured and permeable.

Prior to the most recent volcanic events that occurred about 100,000 years ago erosion deeply dissected the flanks of the volcano creating deep valleys. During the last eruption these valleys were filled with highly permeable volcanic deposits and/or lava flows that have subequently been covered with recent permeable reworked volcanic deposits (mud and debris flows, landslides, etc.) leaving little surface evidence. These buried valley aquifers act like arteries that carry the bulk of the rainfall from the mountain as groundwater that discharges to the ocean. Since these aquifers are not obvious on the surface extensive geophysical surveying was required in order to identify them for drilling exploration targets.

The physical properties of subsurface volcanic deposits can be measured with various geophysical devices, however we found in previous projects that a resistivity method capable of providing a high-resolution resistivity profile from the surface to a depth of more than 400 meters is the Controlled Source Audio-frequency Magnetotelluric method (CSAMT). The resulting profiles were used to effectively delineate the buried volcanic deposits.

The Nevis groundwater exploration project has resulted in the development of approximately 1.5 migd of high quality groundwater from three production wells situated in proximity to the existing infrastructure of the Nevis water system. The program also resulted in the development of a hydrogeological map which will be used to develop additional groundwater resources in the future as the demand increases.

CONCLUSIONS

Failure to identify the geologic processes that result in productive aquifers has limited understanding of the groundwater potential of the Lesser Antilles. The three most important tasks in developing groundwater in the varied and complex environments of the Lesser Antilles are:

- Identification of the geological processes responsible for the development of aquifers so that a properly designed exploration program can be developed.
- Geophysical methods are selected based on their capability of measuring the physical properties defining the dimensions and groundwater potential of the conceptualized hydrogeology.
- Drilling methods that allow for the accurate sampling of water and formation materials must be selected so that the conceptual model is properly verified.

The results of these three projects have demonstrated that aquifers in the younger volcanic islands and the tectonically active older volcanic islands have excellent water quality, a very high recharge rate and substantial yields. Whereas the intermediate aged highly weathered volcanic islands in a tectonically quite area have brackish groundwater due to a combination of less recharge, a higher water table and a substantial influx of salt from dry fall out due to the geometry of the island. However in spite of this lower grade resource a substantial groundwater supply exists that can be more cost effectively desalinated than seawater.

abstract id: **401**

topic: **1**
Groundwater quality sustainability

1.1
Evaluation and management of groundwater — sustainable exploitation

title: **Automatic baseflow separation**

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keywords: automatic baseflow separation, hydrograph recession, recursive digital filtering

INTRODUCTION

Monthly baseflow values in majority of hydrogeological zones are reported yearly by the CHMI in accordance with the Water Framework Directive (WFD). Information on low flow characteristics provides threshold values for different water-based activities and is required for such water resource management issues as water supply, irrigation, and water quality and quantity estimates. An understanding of the outflow process from groundwater is essential in studies of water budgets and catchment response. The knowledge about baseflow fluctuation is also useful for calibration of hydrological models since baseflow is usually one of the runoff components being simulated and its fluctuation considerably determines the correspondence of measured and calculated stream flow. But, the quality of low flow data is often a limiting factor when analysing hydrograph recessions. Accuracy and frequency of the low flow measurements determine and restrict the process that can be studied. Contemporary development in recession analysis tends to work out automatic and objective methods, which eliminate some of the subjective elements of recession analysis. Use of fixed parameters, some of which might be derived from stream flow records, ensures repeatable and consistent results.

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Baseflow as defined by Hall (1968) is the portion of flow that comes from groundwater or other delayed sources. The gradual depletion of discharge during periods with little or no precipitation makes up the drainage or recession rate. The Boussinesq equation (Boussinesq, 1877) assuming the groundwater storage behavior as a liner reservoir has the form

$$S = kQ \tag{1}$$

where Q is the discharge, and k a recession constant. In accordance with the Hall's definition Q can be henceforth viewed as baseflow within the presented equations. The equation for the recession curve first derived independently around the 1904 by Maillet (1905) and Horton (1933) can be expressed by

$$Q_t = Q_0 \exp(-t/k) \tag{2}$$

where Q_t is the discharge at time t, Q_0 the initial discharge. Assuming the constant time step the term $\exp(-t/k)$ can be replaced by a and for consecutive time steps we get the simplified form

$$Q_i = a\,Q_{i-1} \tag{3}$$

Where i is the time step number. Such an equation can easily be processed on a computer. Werner and Sundquist (1951) showed that eq (2) is the linear solution of the one-dimensional general differential equation governing transient flow in confined aquifers. Wittenberg and Sivapalan emphasized that parameter a fitted to different discharge ranges of the recession curves in actual rivers does not remain a constant but increases systematically with the decrease of stream flow (Chapman, 1963; Wittenberg, 1994; Wittenberg, 1994; Wittenberg and Sivapalan, 1999), which is a strong indication of nonlinearity. Therefore, they introduced the nonlinear relationship in the form

$$S = kQ^b \tag{4}$$

The skewed distribution of the exponent *b* is mostly peaking between 0.3 and 0.4 with the mean value of b ≈ 0.5. Furthermore, Wittenberg proposed replacing the eq 3 in case of shallow aquifer and developed the form:

$$Q_i = \frac{Q_{i-1}(1+(1-b)Q_{i-1})}{ab^{\frac{1}{b-1}}} \tag{5}$$

However, the formulas introduced above may describe only the decreasing part of the stream flow records after the crest when flow diminishes and no precipitation or consecutive infiltration occur and thus no ground water supply may be induced. The question arises then how to assess the baseflow during the periods when the storage has been supplied, too.

Lyne and Hollick (1979) appear to have been the first to suggest the use of a digital filter. Recursive digital filters, which are routine tools in signal analysis and processing, are used to remove the high-frequency quickflow signal to derive the low-frequency baseflow signal.

$$y_i = f_i + b_i \tag{6}$$

where *y* denotes total stream flow, *f* direct runoff and *b* baseflow. For the b_i holds

$$b_i = ab_{i-1} + \frac{1-a}{2}(y_i + y_{i-1}) \tag{7}$$

subject to $b_i \le y_i$, where *a* is the filter parameter.

The Lyne-Hollick algorithm has been used by Nathan and McMahon (1990) and Arnold and Allen (1999), for instance. Nathan and McMahon have noticed that using the filtering technique (Equation 7) the base flow recession curve does not follow the exponential decay function associated with storage depletion (Equation 1). Moreover, Chapman (1991) pointed out that this algorithm implies constant baseflow values without recession during periods with no direct runoff and provided the improved algorithm where *a* got the hydrological meaning of the recession constant, i.e. with no direct runoff observed the baseflow gradually decreases being multiplied by constant *a*. Chapman and Maxwell (1996) further simplified the equation:

$$b_i = \frac{a}{2-a}b_{i-1} + \frac{1-a}{2-a}y_i \tag{8}$$

Nevertheless, according to the author's observation, the main weakness of the filtering technique remained: the filter provides baseflow values with BFI value equal to 0.5, which is obviously physically incorrect. BFI is often used to express the rate of baseflow to total stream flow and may vary between 0.2 in poorly fractured crystalline rocks to 0.8 in sedimentary Cretaceous aquifers. So, what the filter actually provides is just variable baseflow dynamics handled by parameter *a*, but using a range of *a* the long term baseflow mean remains constant.

Eventually, Eckhardt (2005) developed the filter algorithm constructed under the assumption that the outflow from an aquifer is linearly proportional to its storage:

$$b_i = \frac{(1-\mathrm{BFI}_{max})ab_{i-1} + (1-a)\mathrm{BFI}_{max}y_i}{1-a\mathrm{BFI}_{max}} \tag{9}$$

where *a* denotes filter parameter and BFI_{max} maximum baseflow index.

METHOD TESTING

Eckhardt's filter among some others has been tested on a set of 170 gauging stations in the period 1971–2003 in daily time step.

The filter parameter a can be expressed using the recession constant k in (2). Therefore, it can be objectively derived by recession analysis during dry-weather periods. For this purpose, the *recess* program inspired by Rutledge (1998) has been developed. The data processing applies the *matching strip method*, which involves ranking multiple recession curves derived from the hydrograph in order of decreasing maximum discharge (Toebes, Strang, 1964). Each recession curve is superimposed and adjusted horizontally to produce an overlapping sequence. The master recession curve is interpreted as the mean to this sequence, and the recession constant k can be derived from its slope (Equation 2).

The program uses the following parameters fixed for all the series: the recession is considered to start 10th day after the peak flow and should last at least 20 days. The length of the recession period is limited to 300 days. The visual inspection of stream flow hydrographs and its respective recession periods derived by *recess* program has revealed that even the periods of evident recession might be split or unidentified by the program. This is caused by occasional day to day swing in hydrographs because the program strictly identifies only the decreasing flow series as a recession. Therefore, it can be recommended smoothing the stream flow records before the recession analysis is to be performed. The 11 days moving minimum followed by 30 days mean has been used in our analysis. Such an approach may induce slightly less steep course of stream flow during recession periods with only negligible effect on the recession constant k and enables the program to identify the periods of flow generally considered as a recession.

The filter parameter BFI_{max} is the maximum rate of baseflow to total stream flow. According to our experience BFI_{max} can be derived by manual calibration with a values already known. The most appropriate BFI_{max} is usually the parameter value that naturally accomplishes the condition $b_k \leq y_k$ and derived baseflow should closely trace the course of stream flow during the low flow periods. The comparison of BFI_{max} values derived by manual calibration mentioned above with hydrogeological maps reveals the very good fit with basin lithology giving the BFI_{max} value higher in sandstone basin aquifers and lower in low permeable aquifers in crystalline rocks.

The baseflow separation using the Eckhardt's formula is partly objective: parameter a can be objectively derived by the recession analysis and BFI_{max} can be optimized to meet the condition that baseflow should not exceed total stream flow. On the other hand, the *kliner-kněžek* method, which has been used to derive baseflow in the CHMI so far, is rather subjective (Kliner, Kněžek, 1974). It depends a lot on a subjective decision on how to relate piezometer heads measured in a borehole with the stream flow records. The method is highly sensitive to the selection of a representative borehole or spring, respectively. The fact that the method incorporates the information on groundwater storage is unquestionably beneficial. However, the appropriate borehole or spring is often difficult to meet. An example of baseflow separation driven by Eckhardt's formula compared with the *kliner-kněžek* separation is given in Fig. 1. The nearest suitable borehole in this particular case is located in the Teplá basin in the alluvium of the Lomnický brook, which is adjacent to the basin of the gauge 1750 Trpisty but northward oriented. The yearly maximum of piezometric head is constant within the whole period. Even in the year of countrywide heavy flooding like in 2002 the piezometric head does not exceed the maximum achieved in other years. It means that no matter how intensive groundwater recharge and consecutive groundwater level rise is the maximum baseflow separated by the *kliner-kněžek* method is also giving constant values over the years. It is evident from the figure that despite the occasional better-than-average groundwater conditions of the basin the borehole represents only the very local processes depending on an actual stream discharge.

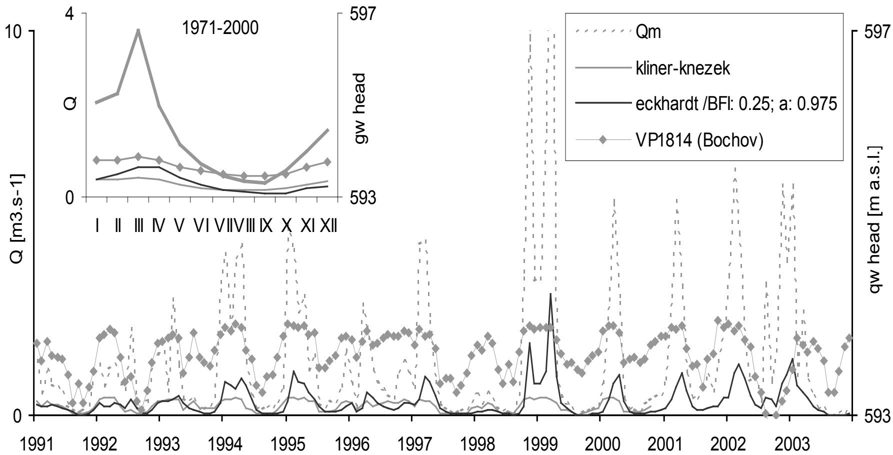

Figure 1. Comparison of mean monthly baseflow values for the gauge 1750 Trpisty (Úterský p.) obtained with the *kliner-kněžek* method and digital filtering using Eckhardt's formula. VP 1814 is the borehole used in *kliner-kněžek* separation. Qm is total monthly stream flow. The small figure shows mean monthly values for the 1971–2000 period that is used as normal for ground water regime assessment in CHMI.

RESULTS

The Eckhardt's method of baseflow separation has been tested on a set of 170 gauging stations in the period 1971–2003. 30 gauges out of the whole set have been compared with the results obtained with the *kliner-kněžek* separation. The baseflow separated using both methods differs at particular stations. The monthly baseflow mostly varies up to 20% (often to 10%) relatively to total discharge. Much higher differences have been registered in the stations where corresponding borehole or spring measurement is inadequate for a range of reasons. It might be supposed that the Eckhardt's filter can be recommended for the routine baseflow assessment in the CHMI.

ACKNOWLEDGEMENT

The analysis was supported by a grant of the Czech Ministry of Environment
(VaV SP/2e1/153/07).

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abstract id: **410**

topic: **1**
Groundwater quality sustainability

1.1
Evaluation and management of groundwater — sustainable exploitation

title: **Limits for use of thermal waters in the Bohemian Cretaceous Basin**

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The groundwater system of the Benesov and Usti nad Labem area in the Bohemian Cretaceous Basin (Czech Republic), taking up around 2000 square kilometers, is more or less a closed hydrogeological unit with a relatively easily definable boundary. The largest thermal water accumulation known so far in the Czech Republic with temperatures often exceeding 30 degrees centigrade and in some spots approaching 40 degrees centigrade can be found in the voluminous and spacious Cretaceous aquifers (Hercik et al., 1999). Exploitation of these thermal waters has thus far been concentrated in the Usti nad Labem and Decin regions (Datel, Krasny, 2005).

Thermal water of Usti nad Labem and Decin areas had not been known in the past. Therefore, before deep boreholes have helped discover the thermal water resources, the whole area of thermal waters known now represented a hydrogeological structure with very slowly flowing, almost stagnating groundwater. Exploiting the resources has made the groundwater flow significantly faster. Even though the area of interest belongs to zones of increased heat flux in the deeper parts of the earth's crust, the question arises whether sufficient heating of these waters will occur with the current accelerated groundwater flow and whether in the future the temperature of the thermal water resources will not fall. It is important to bear in mind that the thermal waters have been exploited for a relatively short period of time - for approximately one century. This period is too short considering the pace of the hydrogeological processes, so no substantial negative consequences of the exploitation can be expected. With continuing or even increasing exploitation of the resources, however, falling temperature and possible quality changes cannot be excluded in the future.

The conceptual model, as the first step necessary for a numerical model (groundwater and heat flow), was based on all the available information that could be collected (Datel et al., 2009; Hercik et al., 1999). Limiting factors for the use of thermal waters consist both in the balance of the amount of water in the structure and also the balance of the amount of heat flowing into the structure.

MAIN CONCLUSIONS

- The framework balance was calculated for the basal and main Cretaceous aquifers (where thermal waters are located) of the defined area and yielded the maximum sustainable yields of natural thermal waters in the drainage areas — 40–45 $l \cdot s^{-1}$ in the Usti area and 250–300 $l \cdot s^{-1}$ in the Decin area (Datel, 2008). Because of the lack of precision in the calculation, these are approximate values that, however, do not differ from estimates to date and practical experience in the utilization of thermal waters and are in accordance with first outputs from numerical models (Baier et al., 2010).
- The main drainage sites for the whole structure were defined — in addition to the Usti and Decin areas, the Kamenice area and the Litomerice area are important drainage areas.
- Data on the occurrence of tectonics and their hydrogeological function were collected and newly evaluated, 8 detailed hydrogeological cross-sections were constructed.
- On the basis of data from new boreholes, data on the thickness of the aquifers, depths of important geological boundaries, basic hydraulic parameters (K,T) and the piezometric contours of aquifers were updated and regionalized.
- Analysis of the piezometric contours of aquifers indicated areas with the greatest potential for vertical groundwater flow.

ACKNOWLEDGEMENTS

This research was supporetd by the Czech Science Foundation, Nr. GACR 205/07/0691.

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IAH 2010
Krakow

abstract id: **425**

topic: **1**
Groundwater quality sustainability

1.1
Evaluation and management of groundwater — sustainable exploitation

title: **Groundwater quality in Hungary — results of EU River Basin Management Plan**

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keywords: groundwater, River Basin Management Plan, chemical status assessment

The assessment of the chemical status of Hungarian groundwater quality is based on the data from the Hungarian WFD monitoring wells as well as the medians of available and reliable national data sources. An evaluation of organic compounds is based on data from the Hungarian WFD monitoring wells, also taking into account data collected between 1996 and 2007 from local monitoring objects (wells, springs). Firstly the natural background levels were defined, and then different threshold values were established. The methodology to evaluate the status of the groundwater bodies is based on the Guidance on Groundwater Status and Trend Assessment of the WGC-2 workgroup (Grath, Ward, 2008), and involved 5 specific tests.

EVALUATION OF THE RISK OF EXCEEDING THE THRESHOLD VALUES

The exceedance was checked at the monitoring sites according to three standard criteria. Based on the evaluation of the results of this test — exceedance which may cause risk to any DWPA — 13 groundwater bodies were determined to have a poor chemical status. In most of the cases the pollutant is nitrate, but in some cases ammonia and chlorinated hydrocarbons can also result in poor status. Other pollutants such as sulphate or triazine, are minor compared to the above mentioned parameters, and would not result in water quality changes requiring technological intervention.

GENERAL ASSESSMENT OF THE CHEMICAL STATUS OF THE GROUNDWATER BODY AS A WHOLE; DIFFUSE POLLUTION

The diffuse pollution status of groundwater bodies was evaluated based mainly on the nitrate content data of 32000 wells and springs. Groundwater bodies where the percentage of objects exceeding the threshold value for nitrate was >20%, were defined as nitrate polluted, a total of 30 bodies of 185. All of them are shallow (less than 20–30 m deep), karst or hilly groundwater bodies. Nitrate pollution occurs in less than 20% of deeper groundwater bodies, since these groundwater resources are very old and well protected. Shallow groundwater on the Western part of Hungary (Transdanubia) is more polluted than in other areas due to more intensive agricultural activity. The agronomic type N balance (OECD) for 2007 of the arable and orchard lands of Transdanubia is +20 kgN/ha in contrast of the 6 kgN/ha for the Great Hungarian Plain. The ammonium content of groundwater is generally high (up to 10–20 mg/l), found predominantly in the old, well protected, deep groundwater. Conceptional models and environmental isotopes prove that the main part of ammonium originates from natural processes occurring in the aquifers.

Significant reduction in the chemical and ecological quality of associated surface waters due to transfer of pollutants from the groundwater body.

This test was carried out at those surface water bodies where the poor status of the surface water could not be explained by other pollution sources. In practice this meant the nitrate concentration had to be examined in detail. Out of a total number of 28 surface bodies, 22 showed the effects of water quality reduction which could possibly be attributed to the transfer of pollutants from the groundwater. Most of these cases are in the Trans-Danubian region. Based on this test, 10 groundwater bodies were assigned a poor chemical status.

The detailed evaluation of *significant damage to groundwater dependent terrestrial ecosystems* (GWDTE) due to transfer of pollutants from the groundwater body is in progress. A lack of sufficient data meant that the chemical status of the groundwater bodies could not be evaluated by this test.

INTRUSION TEST

The intrusion test was carried out at those localities where it is considered that direct or indirect water exploitation may cause chemical or temperature changes in the groundwater regime, due to changes in the flow paths. Over-exploited parts of the deep groundwater in porous groundwater bodies show a slight intrusion of shallow groundwater, but this does not present problems on the level of the groundwater body. The chemical composition of thermal waters did not change to such an extent that they would have required technological intervention or that their usage should have been stopped. None of the groundwater bodies were shown to have poor chemical status on the basis of this test.

RESULTS OF THE CHEMICAL STATUS ASSESSMENT OF GROUNDWATER BODIES

Out of the 185 groundwater bodies evaluated in Hungary, 38 are shown to have poor chemical status, and based on a trend assessment, another 5 groundwater bodies are considered to be at risk. Most of the groundwater bodies with a poor status are shallow ones. Their poor chemical state is mainly the result of a diffuse pollution load from unregulated agricultural activity. Four karst, two porous, and one mountainous groundwater bodies have a poor chemical status. All of the karstic thermal and porous thermal groundwater bodies have a good chemical status.

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abstract id: **440**

topic: **1**
Groundwater quality sustainability

1.1
Evaluation and management of groundwater — sustainable exploitation

title: **The development of a groundwater quality index for the Niger Delta Region, Nigeria**

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keywords: groundwater, quality, Nigeria

INTRODUCTION

The Niger Delta region is the most important place in Nigeria from economic view point due to the enormous oil and gas reserves. The area suffers from water scarcity and pollution problem. Groundwater in the area is used for drinking, domestic, agricultural and industrial purposes. Hence there is the need to develop an index for assessing the quality of groundwater in the area. The index is intended to simplify the reporting of complex and technical water quality data (CCME 2001) rather than assessment conducted on a variable-by-variable or benchmark-by-benchmark basis which is very tasking (Rosemond et al., 2009).

STUDY AREA

The study area is situated between latitude 4°00' and 6°00' North and longitude 5°30' and 8°30' East. The climate of the area is tropical with wet and dry seasons. The maximum temperature range from 34 to 43°C and the relative humidity ranges between 60 to 96%. The delta receives between 2073 and 4366mm of rainfall annually (Akpokodje, 1987). Three lithostratigraphic units underlie the study area. These include the Benin (coarse grained gravelly loose sands with intercalations of clays and shales), Agbada (sands, sandstones and shales) and Akata (shales with minor intercalations of sandstones and siltstones) Formations (Short and Stauble, 1967).

DATA ANALYSIS

The groundwater quality index (GWQI) utilizes six parameters including static water level (SWL), total dissolved solids (TDS), pH, chloride (Cl), sulphate (SO_4) and nitrate (NO_3). These parameters highlighted mainly the natural and anthropogenic sources of pollution.

The median (med) values from 43 sites were computed for each variable and were as follows: SWL=1.25m, TDS=77.44mg/l, pH=6.45, Cl=81.50mg/l, SO_4=8.00mg/l and NO_3=0.50. The raw data (fd) for 43 sites were then compared with the median values and scored as one (fd > med) or zero (fd < med). However, for static water level, the reverse was the case as one was assigned if the SWL at a particular site was less than the median value and vice versa. Since the deeper the SWL, the less vulnerable the groundwater is to pollution. These scores were summed for all six variables and divided by the number of variables as follows:

$$\Sigma = \frac{SWL_{score} + TDS_{score} + pH_{score} + Cl_{score} + SO_{4score} + NO_{3score}}{6}$$

This resulted in an index value ranging from zero to one for each sampling site. An index value of zero indicated that a site has good quality water, while a score of one indicated a site that had poor water quality.

RESULTS

Table 1 presents the quality class interval used in assessing the quality of groundwater in the area while table 2 and figure 1 includes details of water quality for the Niger Delta area.

Table 1. Classes used to assessed the quality of groundwater for the study area

Class	Index value	Remarks
I	0.80-1.00	Very deteriorated
II	0.61-0.80	Deteriorated
III	0.41-0.60	Poor
IV	0.21-0.40	Moderate
V	0.00-0.20	Good

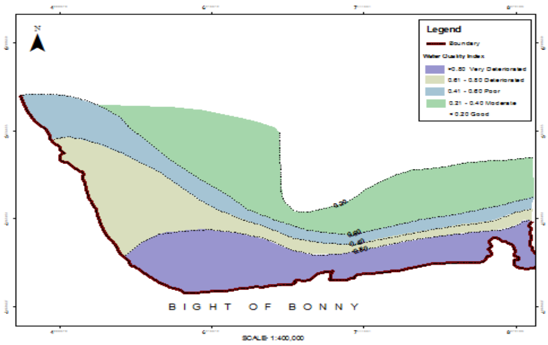

Figure 1. Groundwater quality index map for the Niger Delta.

The correlation between different ion is presented in table 3.

Groundwater quality index values show that in the study area, five sites representing about 12% of all the sites were very deteriorated, eight sites (19%) were deteriorated, fifteen sites (34%) were of poor quality, ten (23%) were of moderate quality and the remaining five sites had good water quality. Correlation analysis shows that the chloride, sulphate and water level are the major variables controlling the index and in turn the deterioration of groundwater (Table 3).

Table 2. Summary of GWQI values and quality of groundwater in the area.

N^{o}	Location	North	East	Index values	Remarks
1	OL	4^{o} 27.055	7^{o} 11.085	0.67	Deteriorated
2	OW	4^{o} 28.035	7^{o} 11.933	0.88	Very deteriorated
3	UP-1	5^{o}40.000	5^{o}34.005	0.39	Moderate
4	AG-1	5^{o} 20.010	7^{o}05.090	0.50	Poor
5	BR-1	4^{o}18.000	6^{o}15.000	0.78	Deteriorated
6	OG-1	4^{o}58.006	5^{o}51.000	0.50	Poor
7	TD-1	4^{o}32.000	5^{o}52.001	0.83	Very deteriorated
8	OO-1	5^{o}26.009	6^{o}37.000	0.56	Poor
9	AK-1	5^{o}36.070	6^{o}40.003	0.25	Moderate
10	KW-1	5^{o}39.070	6^{o}30.003	0.44	Poor
11	EB-1	5^{o}28.011	6^{o}43.003	0.58	Poor
12	OB-1	4^{o}35.000	6^{o}14.004	0.39	Moderate
13	CK	4^{o}50.000	5^{o}40.000	0.67	Deteriorated
14	OS-1	5^{o}06.001	6^{o}30.004	0.67	Deteriorated
15	OS-2	5^{o}05.008	6^{o}30.377	0.42	Poor
16	RU	4^{o} 06.440	6^{o} 46.991	0.17	Good
17	MG	4^{o} 57.526	6^{o} 48.816	0.33	Moderate
18	IG	4^{o} 57.373	7^{o} 00.804	0.33	Moderate
19	EN	4^{o} 53.568	7^{o} 01.921	0.50	Poor
20	KK	4^{o} 51.348	7^{o} 09.637	0.33	Moderate
21	AF-1	4^{o} 51.117	7^{o} 11.593	0.25	Moderate
22	BE-1	5^{o}22.007	5^{o}13.000	0.57	Poor
23	IK-1	4^{o} 34.119	7^{o} 32.794	0.94	Very deteriorated
24	SC-1	4^{o}34.60	8^{o} 10.96	0.72	Deteriorated
25	IWC	4^{o}34.070	7^{o}58.313	0.39	Moderate
26	IWA	4^{o}33.095	7^{o}57.493	0.11	Good
27	OKU	4^{o}33.439	7^{o}56.492	1.00	Very deteriorated
28	OKE	4^{o}32.869	7^{o}59.089	0.33	Moderate
29	IY	4^{o}32.398	7^{o}59.100	0.67	Deteriorated
30	IWO	4^{o}32.087	7^{o}55.029	0.83	Very deteriorated
31	ATQ	4^{o}32.097	7^{o}50.021	0.67	Deteriorated
32	NT	4^{o}32.137	7^{o}51.288	0.50	Poor
33	AK	4^{o}31.657	7^{o}51.760	0.17	Good
34	ATE	4^{o}31.852	7^{o}47.466	0.50	Poor
35	IKO	4^{o}31.381	7^{o}45.251	0.50	Poor
36	OKP	4^{o} 33.405	8^{o} 16.958	0.17	Good
37	ITA	4^{o} 32.545	8^{o} 17.124	0.17	Good
38	LOC	4^{o} 32.746	8^{o} 17.024	0.67	Deteriorated
39	TOM-1	4^{o} 34.806	8^{o} 11.324	0.50	Poor
40	TOM-2	4^{o} 34.842	8^{o} 12.204	0.50	Poor
41	TOM-3	4^{o} 36.442	8^{o} 11.024	0.33	Moderate
42	OSU	5^{o}37.000	5^{o}47.003	0.50	Poor
43	IB-1	4^{0} 53.562	7^{0} 08.269	0.41	Poor

Table 3. Correlation matrix between GWQI value and some parameters.

	GWQI	SWL	TDS	pH	Cl^-	SO_4^{2-}	NO_3^-
GWQI	1.000						
SWL	-0.372	1.000					
TDS	0.085	-0.135	1.000				
pH	-0.001	0.407	0.175	1.000			
Cl^-	0.351	-0.264	0.621	0.013	1.000		
SO_4^{2-}	0.308	-0.272	0.265	0.212	0.271	1.000	
NO_3^-	-0.022	0.439	-0.172	0.325	0.061	-0.215	1.000

SUMMARY

Overall, the Niger Delta region show generally poor or deteoriated water quality in most cases (65%) in coastal regions and moderate or good water quality (35%) in inland areas. Variations in water quality between sites reflects variation in chloride and sulphate concentrations, however many sites throughout the area display effects of static water levels. This has implications for the communities, suggesting that many sites within the Niger Delta do not have access to suitable water for to meet their daily needs.

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abstract id: **470**

topic: **1**
Groundwater quality sustainability

1.1
Evaluation and management of groundwater — sustainable exploitation

title: **Integral approach to manage saltwater intrusion in a Mediterranean aquifer (Tordera's delta)**

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keywords: marine intrusion, groundwater management, flux and transport numerical modelling, transport calibration, future strategic scenarios

INTRODUCTION

The Catalan Agency of Water (the Agency) is the organism in charge of water control, management and planning in Catalonia. One of the main tasks consists of meeting the environmental objectives of the Water Framework Directive and, at the same time, ensuring water supply for different uses. This may be a quite difficult objective in Mediterranean semi-arid areas which support a high density of human activities, where urban and industrial supplies require important amounts of water that is obtained from small, heavily exploited coastal aquifers. This was the case of Tordera's Delta: a tiny alluvial aquifer close to Barcelona city, in NE of Spain (Fig. 1).

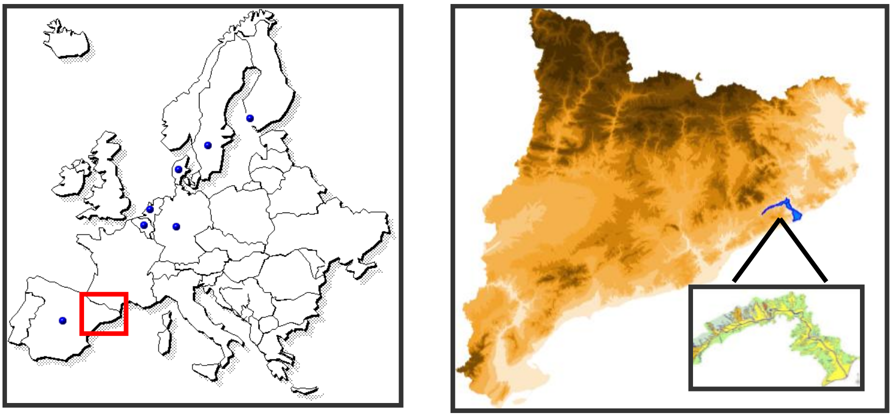

Figure 1. Location of Tordera's Delta aquifer, 70 km NE Barcelona, in NE Spain.

Between 1997 and 2002, the intensification of groundwater extractions, mainly in summer, gave rise to a serious marine intrusion problem (Figure 2) that affected the viability of urban, industrial and irrigation wells.

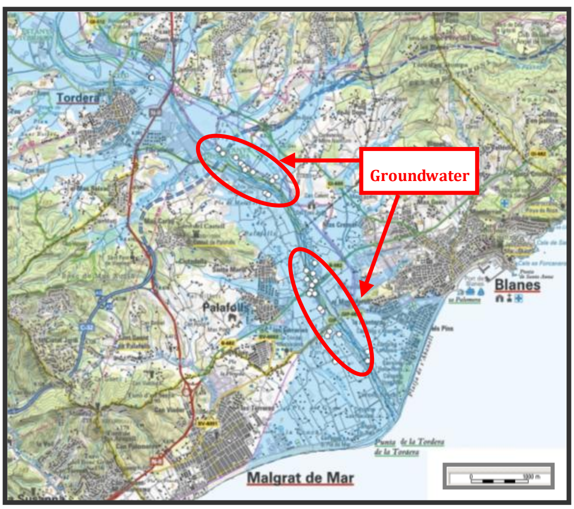

Figure 2. Identification of main group of extraction for supply uses.

In 2002 chloride concentrations reached values as high as 2,500 ppm 2.5 km inland and peak electrical conductivities of 14,000 μS/cm (Figure 3).

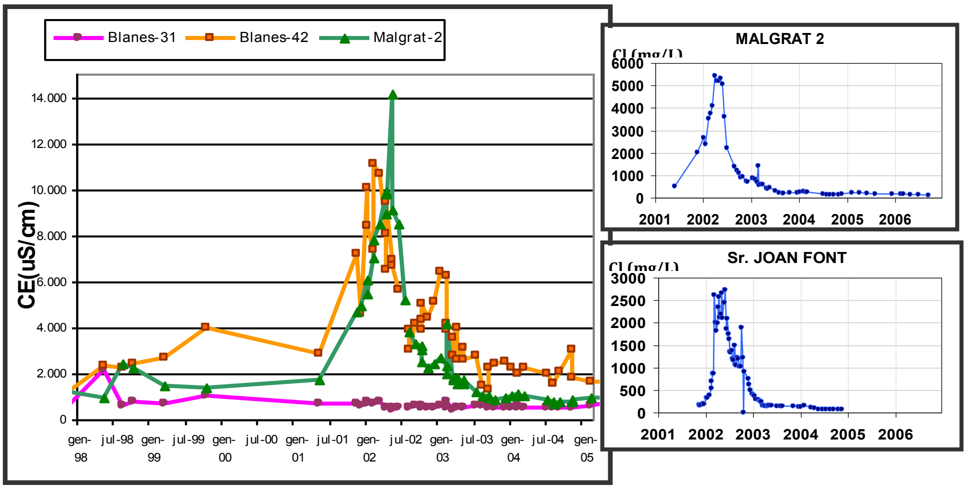

Figure 3. Electrical conductivity evolution at three points in Tordera's Delta (in left) and Chloride concentrations in two points at the same area (in right).

For these reasons, the Agency decided to (1) build a seawater treatment plant capable of producing $10 \cdot 10^6$ m^3/yr of drinkable water in order to reduce groundwater extraction, and (2) develop a groundwater flow and transport numerical model (2002) without calibrating the transport. In 2009, some aspects of the previous model have been notably revised and the resulting numerical model has been calibrated also with regard to chloride transport, both for management purposes.

THE NEW MODEL TORDERA'S AQUIFERS MODEL

The original model (year 2002, Figure 4) has been revised in order to update the conceptual model and to calibrate the transport problem based on chloride measurements from the Agency's network. The new conceptualization aims at improving the initial assumptions, mainly in the Delta. Improvements include:

- New data on geology, review of the geometry of the layers and hydrologic interpretation through the definition of new and justified permeability areas.
- Improving hydrologic factors such as recharge, head levels, extractions and numerical model conditions.

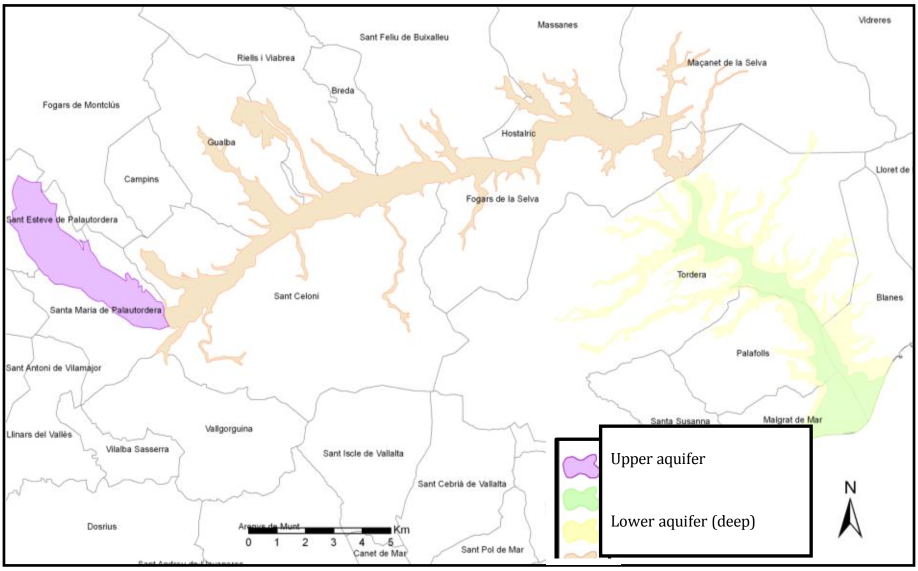

Figure 4. Tordera alluvial aquifer domain where each color represents a part of the aquifer.

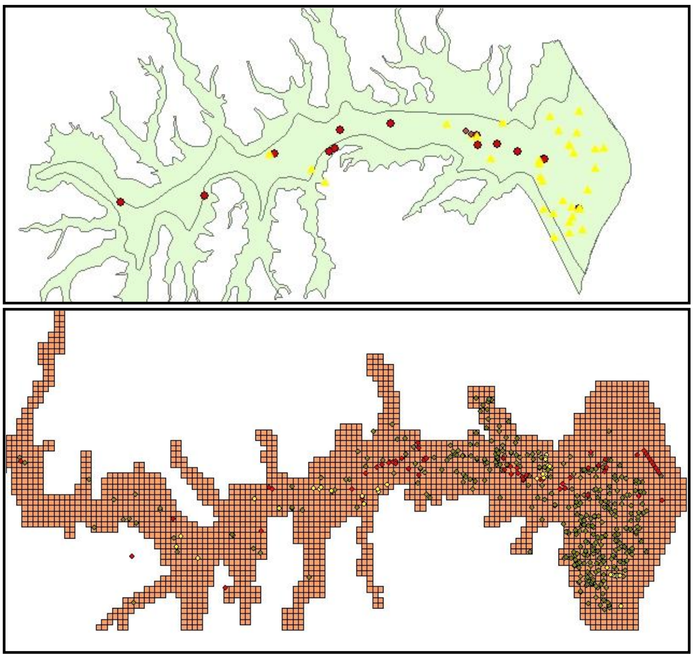

Figure 5. Points of the Agency network used to calibrate chloride concentrations (up): wells in shallow aquifer in yellow and deep aquifer in red. Wells situated at Tordera's delta (down): supply in red, industrial in yellow and irrigation in green.

The final groundwater model was implemented in the well-known Visual Modflow code, which is a pre- and post-process system based on code Modflow.

In general, the heads adjustment can be considered very good. Furthermore, the represented heads of the deep aquifer in Tordera's Delta were even better, area that belongs to the transport model domain.

As for chloride transport, the calibration process (Figure 6) is much more affected by heterogeneities presents in the aquifer. This adds a difficulty in reproducing peak concentrations produced in a very short time, as it occurs with some wells of the shallow aquifer. However, the deep aquifer results are considered to be correct. In short, the model is robust and is well calibrated with current hydrological information.

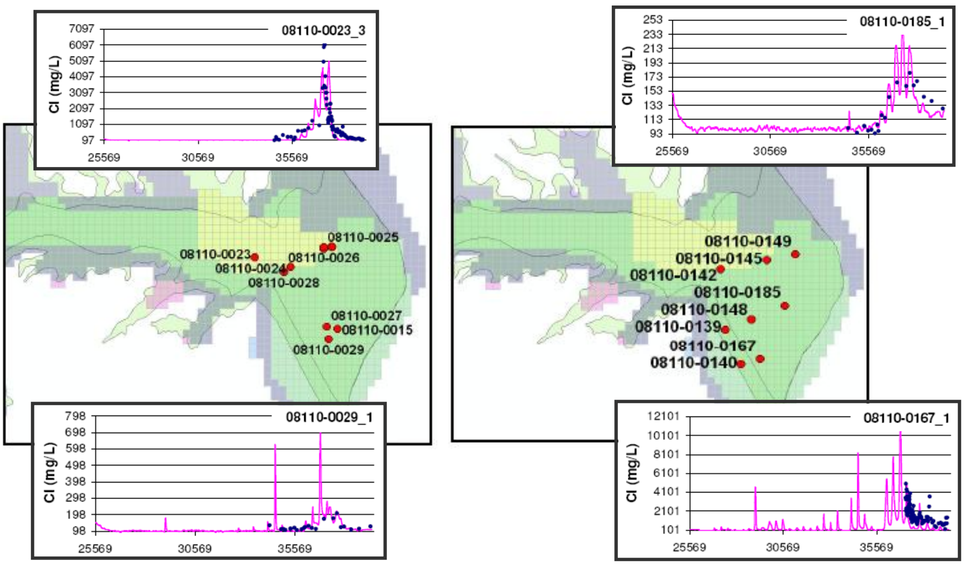

Figure 6. Examples of the transport calibration process. The blue points are measured values of chloride concentrations and red are simulated. Points with _1 suffix belong to shallow aquifer and _3 suffix to deep aquifer.

FUTURE ACTIONS IN THE TORDERA'S AQUIFERS: MODEL SCENARIOS

The new numerical model can be used as a groundwater management and planning tool suitable to simulate future, potential scenarios. The Agency was conducted different actions during the last years in Tordera's basin which now allow envisaging changes in future water resources management. Among these, the following steps must be remarked: joint use surface water-groundwater, reclaiming water to replace wells, passing more-sustainable aquifer's exploitation rules, promoting artificial recharge (e.g. the construction of a tertiary treatment of a wastewater plant for recharge purposes) and improving the quality of flowing waters by means of better treatments and control on discharges.

The analysis of future scenarios has been done with both the original and the updated models in order to assess their robustness for predictive purposes. Increasing the pumping regime yields quite different results between them (Table 1).

Table 1. Comparison between 2002 (1) and 2009 (2) Tordera's aquifers model from the perspective of sustainability (viability to support an increase in pumping from wells of +2, +4 and +6 Mm^3/yr, expressed as Hm^3/a below).

	CALIBRATE FLUX	CALIBRATE TRANSPORT	PUMPING + 2 Hm3/a	PUMPING + 4 Hm3/a	PUMPING + 6 Hm3/a
MODEL 1	Y	N	VIABLE	**VIABLE**	UNVIABLE
MODEL 2 (new)	Y	Y	VIABLE	**UNVIABLE**	UNVIABLE

Model 1 only yields small piezometric head variations (-0.5 m) in wells close to the shoreline when pumping is increased by $4{\cdot}10^6$ m^3/yr, whilst the new model (2) results in chloride concentrations increased by a 2-3 factor. Both models agree on the non-sustainability of increasing withdrawal by $6{\cdot}10^6$ m^3/yr.

Besides, the model can face more complex scenarios. For instance, it would be possible to increase groundwater abstraction by $6{\cdot}10^6$ m^3/yr as compared to current pumping provided that an adequate (reclaimed water) recharge scheme was adopted. Figure 7 shows the three configurations analysed, depending on the location of recharge wells.

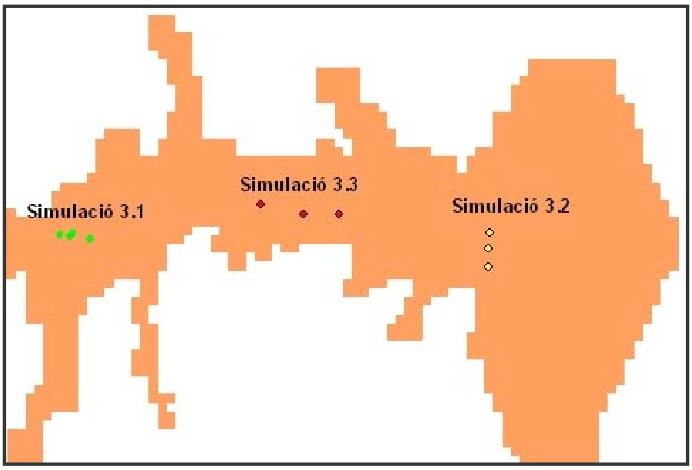

Figure 7. Three possible options considered to drill reclaimed water recharge wells in Tordera's Delta in order to allow increasing pumping for human supply by $6{\cdot}10^6$ m^3/yr.

The simulation 3.1 shows that recharging 2 10^6 m^3/yr would have almost no effect on piezometric heads and chloride concentracions. This is probably due to the fact that recharged water would be discharged to surface streams.

The simulation 3.3 consists of recharging 15,000 m^3/day since year 2012, which would noticeably improve head levels and also would cause a substantial reduction of chloride content within the aquifer; however, marine intrusion would not be completely prevented. However, if the same recharge is done through wells parallel to the shoreline, then results improve remarkably, showing around 2-m rise in heads in nearest wells and a complete removal of chloride concentration to the base or reference level (Figure 8).

Therefore, after evaluating the 3 simulations, it can be stated that pumping may be increased in Tordera's Delta aquifer if an adequate recharge configuration is implemented. The new model helps identifying the best management alternative.

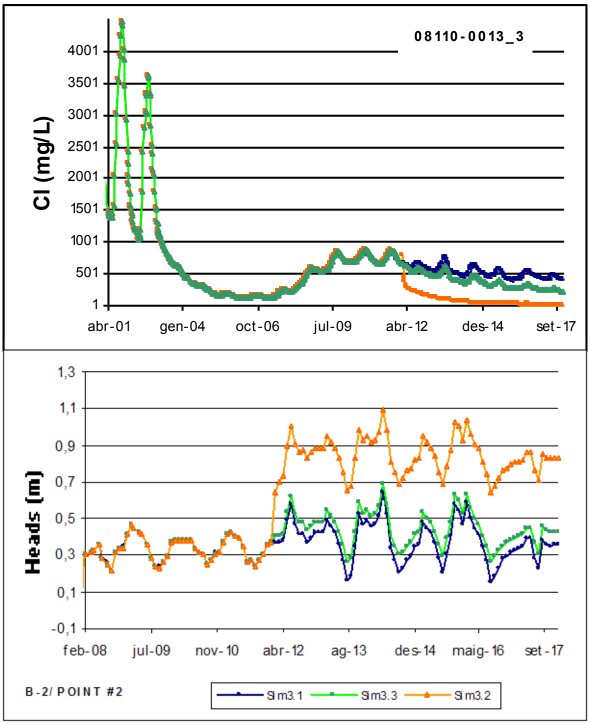

Figure 8. The new model allows to analyze more complicated scenarios, such as the best choice for artificial recharge facilities.

CONCLUSIONS

Numerical modelling is a key to achieve the Water Framework Directive goals and, at the same time, to meet the needs of water users. This is definitely the case of coastal aquifers, provided that the conceptual model is right and that both flow and transport are properly calibrated, which requires improving both our conceptual and numerical approaches. This has been done for the Tordera's aquifers, in NE Catalonia, Spain: the revised model is now far more robust than the original one and can be wisely used for integrated water resources management needs.

The implementation of several actions by the Agency and other stakeholders has reversed the situation in Tordera's Delta aquifers, as both its quantitative and chemical status are nowadays good, contrarily to the dramatic marine intrusion episode that took place just in the beginning of this century. Future plans preview now scenarios in which aquifer pumping will be moderately increased provided that adequate artificial recharge facilities are implemented.

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abstract id: **490**

topic: **1**
Groundwater quality sustainability

1.1
Evaluation and management of groundwater — sustainable exploitation

title: **Groundwater supply deterioration due to an upconing process**

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keywords: groundwater deterioration, upconing, Esperanza city, Argentina

ABSTRACT

Groundwater is of fundamental importance in Esperanza city, Santa Fe province, Argentine Republic, since there is no other water supply to satisfy regional demands. The exploited aquifer is lodged in a sandy sequence of fluvial origin with good quality water.

Loess and clayey silt deposits, having in depth aquitard behaviour, overlie these sands. These deposits lodge water of variable quality with fluoride and arsenic presence. Grey sands and green clays of marine origin underlie the fluvial sands. The aquifer has been intensively exploited since the beginning of the ‘70s. As a result of this abstraction and its exploitation scheme, in several pumping wells groundwater levels decreased and its quality had a progressive deterioration. In these wells, the increment of chloride and sulfate was due to an upconing. The areas affected by this salt water rising were identified taking into account: the conceptual model previously defined and the space-time evolution analysis of the hydrodynamic and hydrochemical conditions. The salt water volume that could have entered the fresh groundwater system was quantified by mathematical modelling. The studies that have been carried out allow obtaining the proper system knowledge in order to adequate the management model guaranteeing the protection of the water supply.

INTRODUCTION

Esperanza city is located 31°25’ S and 60°56’ W, at the west centre of Santa Fe province (Argentine Republic), with a population of 35,000 inhabitants. The study area (Figure 1) covers almost 300 km^2, belonging to the great “Pampeana” plain. The climate of the region is humid and moderated, the average annual temperature and precipitation are 18°C and 930 mm, respectively.

In this zone, the aquifer system constitutes the only available water resource which supports not only the local socio-economical requirements but also those of an extensive zone of influence. The neighbouring city of Rafaela (90,000 inhabitants) 40 km westward from Esperanza, also supplies its demands through this system. The region’s main economic activities are agriculture, livestock, and industries of various kinds: textiles, metallurgical, tannery, food, furniture factories, among others.

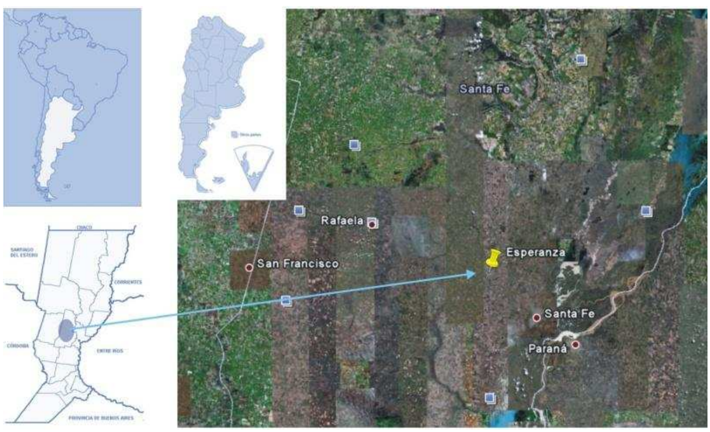


Figure 1. Location of the study area.

In the study area, from 15 m in depth, there is an aquifer layer whose hydraulically behaves as semiconfining to confining unit, without local recharge, lodging good quality fresh water.

This aquifer layer is being exploited since 1930. Underlying this layer, there are saturated marine sediments which lodge high salinity water but of continental origin.

The pumping wells were concentrated in two sectors: one of them located in the urban area (Esperanza town) and the other located 4 km westward, in the rural area. It has been estimated that the total yield extracted for water supply from this aquifer system in the study area is of about 11 millions of m^3/year.

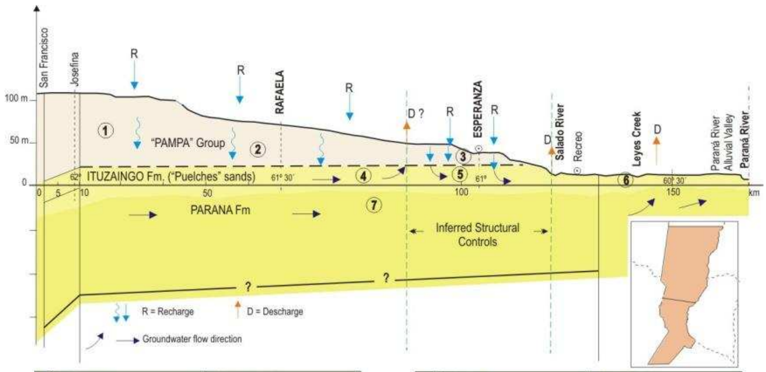
The conceptual model of the aquifer system and the spatial and temporal evolution of the hydrodynamic and hydrochemical conditions allowed identifying the areas affected by this upconing process. Hydrogeological mathematical modelling allowed estimating the volume of salt water that could have entered the system, deteriorating its quality.

GEOLOGY–HYDROGEOLOGY

The hydrogeological local column corresponds to Tujchneider et al. (1998), and define the geohydrologic system composed by:

1. An aquiclude basement composed by green clays (Paraná Formation, of marine origin, Upper Miocene). Above these clays, and always belonging to the same formation, are located heterogeneous grey sands. These marine sands are directly in contact with sands of fluvial origin. The general direction of the groundwater flow is from west to east and the discharge area is the alluvial valley of the Paraná River, located 40 km eastward from the study area.
2. A semiconfining o leaky aquifer, composed by fine to medium-sized grain sands, (Ituzaingó Formation — Upper Pliocene), with an average thickness of 24 meters. In much of the Chaco-Pampeana Plain, are also called "Puelches" sands. Ituzaingó Formation is of fluvial origin and its sediments lodge good quality fresh water. Isotopic investigations have led to corroborate that its recharge is allochthonous (D'Elía et al., 2004). The general groundwater flow direction is from west to east and the hydraulic gradient was estimated at 2×10^{-4}. The hydraulic parameters: transmissivity (T = 750 m^2/day), hydraulic conductivity (K = 30 m/day) and storage coefficient (S = 7E-04), were obtained by pumping tests.
3. Sedimentary deposits, mainly of aeolian origin, composed by silts, clays and loess, belonging to Pampa Formation (Holocene). There is a semiconfining layer or aquitard towards the bottom, discontinuous to the east. The water lodges in these sediments has variable contents of fluorine and arsenic.

This system has a multiunit hydraulic behaviour, with the possibility of downward flow through the aquitard layer and/or upward flow from the underlying sands of marine origin, according to the prevailing hydraulic heads relations (Figure 2).



	Sediments	Water salinity
1	Loess	High to very high
2	Silt - Loess	Medium to high
3	Silts	Low
4	Sands	Medium

	Sediments	Water salinity
5	Sands	Medium to low
6	Silts, clays and sands	Very high
7	Marine sediments (sands and clays)	Very high

Figure 2. Hydrogeologic Model (by: Tujchneider et al., 2004).

HYDROCHEMICAL AND HYDRODYNAMICAL BEHAVIOUR

The waters used for supplying the needs of the population — and lodging in the semiconfining layer — are sodium bicarbonates. However, the cationic branch presents a differential behaviour, spatially coincident with the water samples of such wells located in the urban area of Esperanza town. Besides, it is important to remark that in those wells where the highest pumping discharges were registered there was a change in the water type from sodium bicarbonate to sodium chloride type.

Since mid-90s, these changes were noticed in some pumping wells of the urban area. As an example, Figure 3 and Figure 4 show the temporary increase of sulfate and chloride contents in three pumping wells of this zone. As a particular case, pumping well E17 presents the highest chloride contents — almost five times greater than its initial concentration — whereas total alkalinity contents (TAC) decrease. This content variation comes together with the increment of the pumping discharges, due to the exploitation schedule changes. With regards to the groundwater flow, in 1994 the equipotential lines clearly showed the influence of both pumping fields (two cones of depression, at the rural and urban areas) (Figure 5). Two years later, 1996, these lines shown a considerable variation, proved in an average groundwater lowering of almost 2 meters and a defined divide in the 29 m equipotential line.

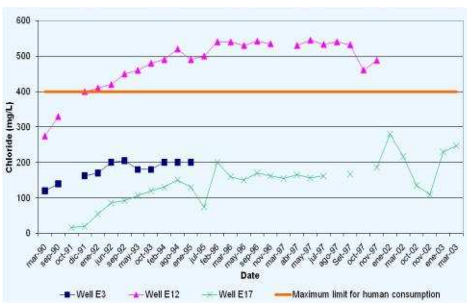


Figure 3. Chloride increment.

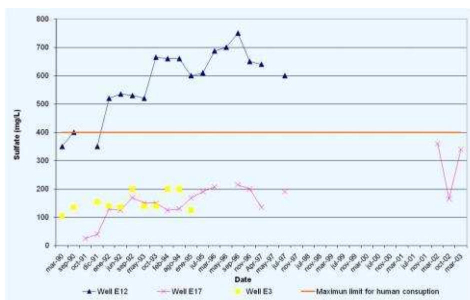


Figure 4. Sulfate increment.

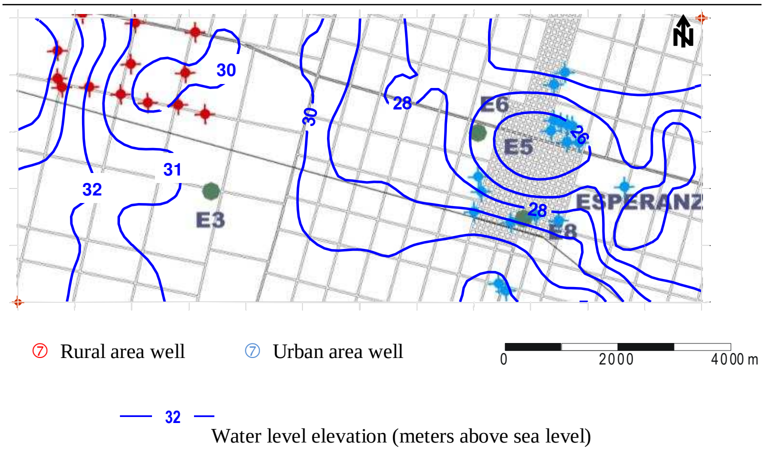


Figure 5. Potentiometric surface in 1994.

METHODS AND RESULTS

In order to identify the areas affected by the upconing process the following physicochemical contents were considered: total dissolved solids (TDS), bicarbonate (HCO_3^-), sulfate ($SO_4^=$), chloride (Cl^-), nitrate ($NO_3^=$), calcium (Ca^{++}), magnesium (Mg^{++}) and sodium (Na^+). These records correspond to different sources of information and water samples collected in the wells located in both urban and rural area from 1990 to 2003. The statistics of the ionic records were calculated. They summarised the characteristics of the water sample ionic contents and their great variability. The R-mode cluster analysis (using the r-Pearson correlation coefficient as a similarity measurement and the non-weighted average pairs as the linking rule) was applied. The main groups identified are shown in Figure 6.

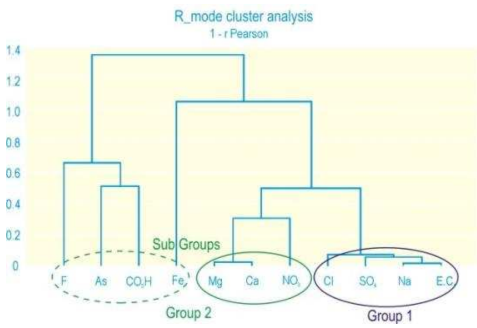


Figure 6. R-mode cluster analysis (1 – r Pearson).

The Q-mode cluster analysis (using the Euclidean distance coefficient as a measure of similarity and the non-weighted average pairs as the linking rule) allowed identifying several groups and subgroups. These clusters are related both to the chemical characteristics of the water samples from the urban and rural wells and to the changes in the exploitation schedule. There were identified two groups:

Group 1: water samples from wells located in the urban area with high salinity and chloride contents. The records belonging to this group correspond to those wells from the urban area that were removed from service between 1995 and 1997, and those who remained operating until 2002.

Group 2 — subgroup 2A: water samples from urban and rural wells with medium to high salinity and sulfate concentrations, belonging to the beginning of the period when saline increases began to be recorded.

Group 2 — subgroup 2B: water samples from wells in the rural area and those located in the urban area before the increasing of their salinity.

Group 3 — Subgroup 2B and Group 2 — Subgroup 2A according to the increase in salinity as well as concentrations of sulphates and chlorides.

The mathematical model implemented allowed estimating the incoming flow from the underlying marine formation to the exploited layer. Visual Mod Flow v2.7.1 code (Guiguer, Franz, 1997) was used to simulate the upconing process.

The simulated area, of 288 km^2, was discretized into rectangular elements of 500 m, and was refined in areas of greater interest such as the zone where the withdrawal was more intense. The vertical discretization consisted of three layers of variable thickness. They were considered isotropic and homogeneous, depending on the conceptual model defined in previous studies and available information. The downward recharge and the regional flow were considered as boundary conditions. The model calibration was done depending on the groundwater levels registered in monitoring wells located in the area for 1999. The model was validated as a prediction tool for the period 1999–2003. The simulation carried out during this period allowed to estimate the rate of salt water flow that might have entered by upward flow. This is of about 22 mm year^{-1} (Figure 7).

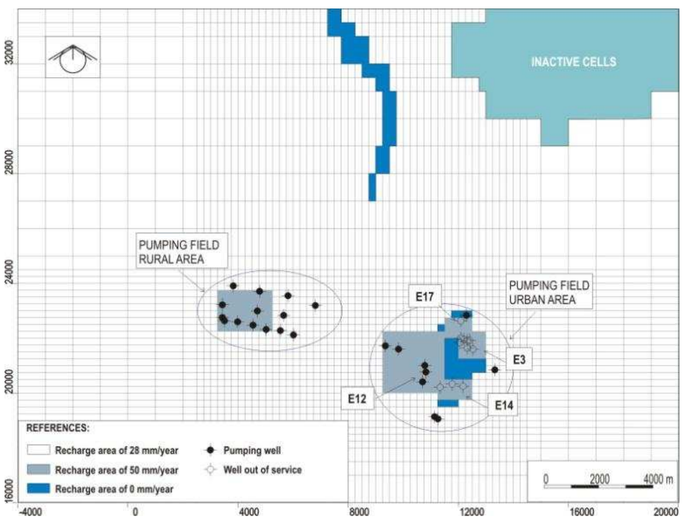


Figure 7. Discretization of the study area.

CONCLUSIONS

Groundwater systems in the Chaco-Pampeana plain behave very subtle. In this case, freshwater aquifer lodges in sands of fluvial origin is located above an aquifer layer comprising by marine sediments with salt groundwater. The hydrodynamic balance between the two types of waters is maintained whether the operation is done properly.

The changes manifested in the hydrodynamic and hydrochemical behavior between 1994 and 1996 indicate the effect of pumping, which is consistent with the increase of chloride and sulfates and lower TAC. This fact, together with the water balance carried out in the simulation made it possible to identify the upward intrusion of the overlain salt water by the breakdown of the hydrodynamic equilibrium. The involvement of the freshwater aquifer by salt water forced the company that provides water service and sanitation to abandon the wells affected by the upconing process. Because up to now there is no other source of water to meet regional demands, it is critical to maintain the balance of hydrodynamic and hydrochemical multilayer aquifer system so as to protect the freshwater source that supplies Esperanza and Rafaela cities and their surrounding areas. It is therefore strongly recommended to monitor the spatial and temporal evolution of the areas affected by this process.

ACKNOWLEDGEMENTS

To the Esperanza City Government, Aguas Santafesinas S.A., Faculty of Engineering and Water Sciences of the National University of El Litoral, National Agency of Scientific and Technological Promotion (ANPCYT) and National Council of Scientific and Technical Research (CONICET), for their support.

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IAH 2010 Krakow

abstract id: **493**

topic: **1**
Groundwater quality sustainability

1.1
Evaluation and management of groundwater — sustainable exploitation

title: **Integrated water resources management: from monitoring to eco-strategic initiatives**

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keywords: protection, prevention, monitoring, eco-strategic initiatives

INTRODUCTION

Act locally, plan and interact globally. Effectively, despite each site and each water source are particular, the overall approach towards groundwater management and survey is generally going through the following processes:

- Hydrogeological study from local recognized Hydrogeologists and Geologists in order to fully understand how the aquifer systems in place are functioning from the recharge area to the catchments. These investigations are ideally leading to a schematic conceptual model of the site, what is helping also non-specialist actors involved in the integrated water management to get a good idea of the natural behaviour.
- Vulnerability study with proper risks assessment of the aquifers and production catchments, as well as proper water balance to help preserving the Water Resources over the long term in an efficient and proactive way.
- Efficient monitoring system (production wells but also representative and relevant piezometers) to ensure full overview of the water-bearing's status and evolution in terms of quantity and quality.
- Definition and triggering of strategic sustainable projects aiming to reduce as much as possible the potential threats that might have been identified against the environment and the groundwater in particular (i.e. agricultural practices, land use, flooding).

STANDARDISED MONITORING SYSTEM

You only can manage what you can measure, this is also true for the groundwater, reason why Nestlé Waters developed an interactive tool to monitor closely each of its water source.

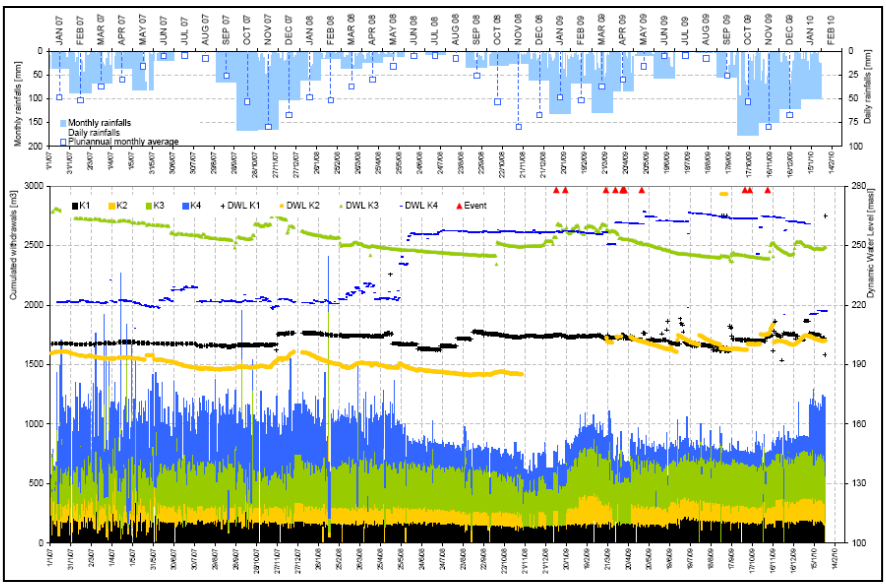

Figure 1. Example of processed synthetic information representing simultaneously the recharge by the rainfalls (upper graphic) with the dynamic water levels (DWL) in response to the withdrawals from four different wells.

For all of them, withdrawals, instantaneous discharge, temperature, conductivity, dynamic water levels and rainfalls are monitored continuously or on a daily basis, while other parameters like static water levels in relevant piezometers and turbidity are also monitored on a regular basis. On top of that, a high performing quality monitoring system (chemistry and microbiology) is carried out from the water sources to the filling machines, including pipes, water storage tanks and water treatment processes. The key data provided by each industrial site for each of the production well is then regularly processed and reviewed by the Zone Water Resources Manager. This Hydrogeologist is consolidating, reviewing, organising and regularly updating these important data with the relevant figures and graphics.

CENTRALISED INTERACTIVE WATER RESOURCES DATABANK

All the key information concerning Water Resources in general is important to be shared internally between the different responsible managers (Water Resources, Environment, and Quality).

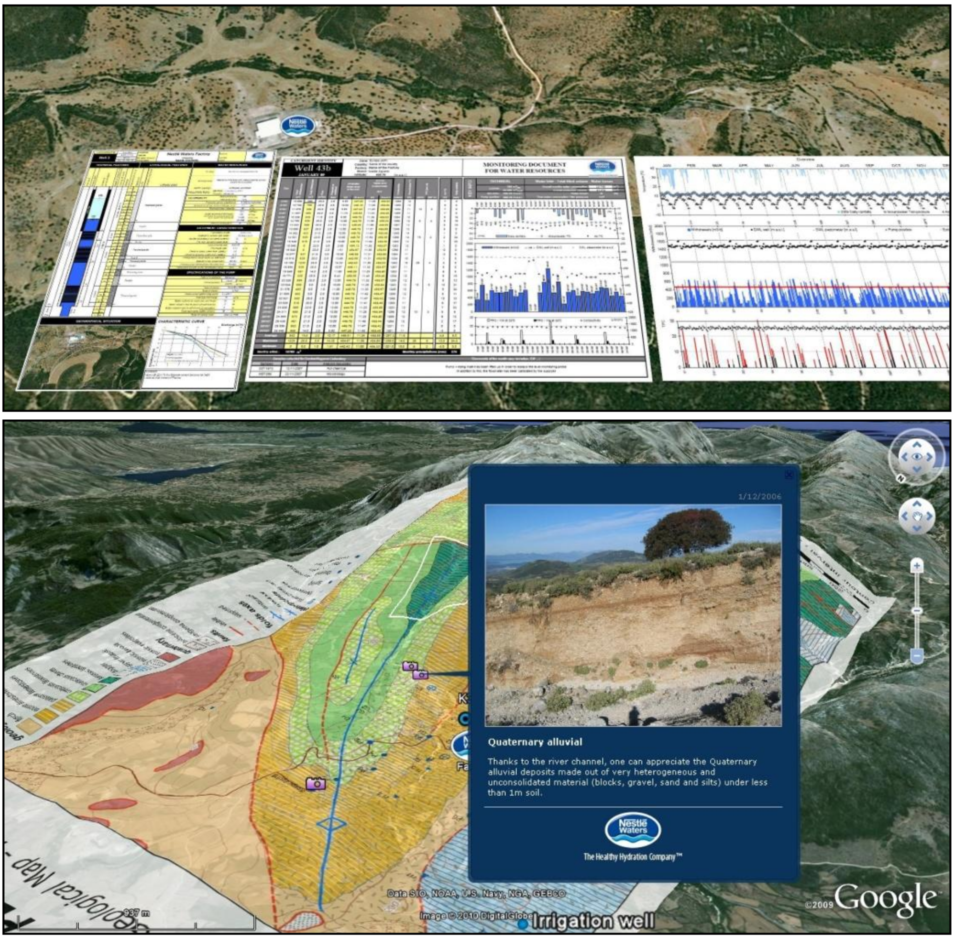

Figure 2. Above: representation of the daily key information collected from each production catchment. From left to right: Well ID, monthly and yearly graphical compilations. Bellow: example of customized window representing relevant observations from the field.

Nevertheless, in a big Group like Nestlé Waters, the specialists are often far from the production sites and the local management. So, in addition to the monitoring data and graphics those need to be updated regularly, a lot of multidisciplinary figures and references must also be available through a centralised and secured corporate server. For this reason, Nestlé Waters developed and implemented through Google Earth a customised Water Resources databank. In a very interactive way, this tool is allowing the organisation and the access to many important documents like maps and pictures of course, but also to full studies or reports concerning Geology, Hydrogeology or Vulnerability that are sometimes getting lost or "sleeping" in folders or cupboards. Just like an intranet site, this is how all the responsible persons within the Markets have a remote access to the most updated water resources databank.

LONG TERM ECO-STRATEGICAL INITIATIVES

The groundwater management cannot be separated from the global water cycle. So once the groundwater functioning and vulnerability are well understood and the monitoring system is in place, a preventive approach intends to stimulate and to coordinate at the level of the whole recharge area, a number of preventive eco-strategic initiatives to protect the aquifers and the environment over the long term. The objective is to harmonize the economic development on the one hand, and the sustainable preservation of the environmental resources on the other hand. The aim is to reduce on the long term the potential threats on the water resources. These eco-strategic projects are going from application of new alternative agricultural practices (without pesticides) to original initiatives like phyto-remediation, biogas installation or short circuits for fruits and vegetables for example.

CONCLUSION

The sustainable and responsible management of the Water Resources is the baseline for Nestlé Waters's business. Hydrogeological knowledge and high performing monitoring system are the pillars for relevant integrated management. Nevertheless, the Group is also convinced that Sustainable Management is simultaneously an excellent opportunity for local economic development, by creation of "Shared Value" with the local Stakeholders that want to collaborate over the long term. As a matter of fact, the stimulation and the implementation of eco-strategic initiatives are now totally part of this "partnership" sustainable management that Nestlé Waters wants to disseminate all over its production sites.

IAH 2010 Krakow

abstract id: **500**

topic: **1**
Groundwater quality sustainability

1.1
Evaluation and management of groundwater — sustainable exploitation

title: **Estimation of suitable groundwater safe yield under the unusually constraints of environmental conditions in Taipei basin, Taiwan**

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keywords: water supply system, management and redeployment case, MODFLOW, MODMAN, LINDO

Because there is no reservoir in Changhua area, all the source of water requirement comes from the groundwater. However, the groundwater here is not enough that needs other water supply from Feng-yuan and Lin-nei. In the recent years, several areas near the coast in Changhua are set to be the groundwater restricted areas that the groundwater yield is limited.

In the present study, the hydrological numerical model was built to simulate the groundwater system by the MODFLOW code. To calibrating the numerical model by groundwater level to fit the field conditions, there were limits including yield in each area; location of pumping wells; limit of groundwater restricted areas; water requirement and deployment of water pipe network. The MODMAN code was introduced to construct the response matrix, and the code, LINDO, was used to estimate the best water supply system in management and redeployment among Changhua area.

The results showed that the management cases are set with 3 limits of water level and 4 systems of supplied surface water. The best one among 12 cases is the combined water supplies from Feng-yuan, Lin-nei, Kuai-guan and Jhu-tang under the limit of groundwater with the safe groundwater level. The reduction of pumping was about 7.06×10^4 tons/day, which resulted in the increment range of groundwater level from 1.98 to 5.84 m.

1.2 Groundwater vulnerability and quality standards

abstract id: **119**

topic: **1**
Groundwater quality sustainability

1.2
Groundwater vulnerability and quality standards

title: **Arsenic in groundwater in Western Anatolia, Turkey: a review**

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keywords: groundwater, arsenic, water quality, western Anatolia

INTRODUCTION

Occurrence of arsenic (As) in groundwater has been a major problem worldwide for the last hundred years. Considering its toxic effects on human health, the presence of elevated levels of arsenic in groundwater resources used in drinking water supply has been an active research field throughout the world (Van Halem et al., 2009). In this regard, case studies from Bangladesh, India, Nepal, El Salvador, Ecuador, Honduras, Mexico, Chile, China, Canada, Argentina, Peru, Taiwan, United States, Bolivia and Turkey have been documented with regards to the detection of natural levels in groundwater, the occurrence and distribution mechanisms, the human health effects and the in-situ and ex-situ treatment techniques (Jean et al., 2010). In many of these locations, arsenic is naturally found in the subsurface strata within volcanic and sedimentary formations as well as in areas of geothermal systems related to tectonic activity. Western Anatolia in Turkey is one such area of complex geology with active tectonics and high geothermal potential. This natural setting serves as a suitable environment for the presence of high levels of arsenic in subsurface waters. Based on these fundamentals, this study presents a general overview of arsenic presence in western Anatolia.

GEOLOGICAL SETTING IN WESTERN ANATOLIA

Turkey is one of the most seismically active regions in the world. Its geological and tectonic evolution has been dominated by the repeated opening and closing of the Paleozoic and Mesozoic oceans (McKenzie, 1972; Dewey and Sengör, 1979; Jackson and McKenzie, 1984). It is located within the Mediterranean Earthquake Belt, whose complex deformation results from the continental collision between the African and Eurasian plates (Bozkurt, 2001). The border of these plates constitutes seismic belts marked by young volcanics and active faults, the latter allowing circulation of water as well as heat. The distribution of hot springs in Turkey roughly parallels the distribution of the fault systems, young volcanism and hydrothermally altered areas (Simsek et al., 2002). There are a total of about 1000 thermal and mineral water spring groups in the country (MTA, 1980; Simsek et al., 2002) (Fig. 1).

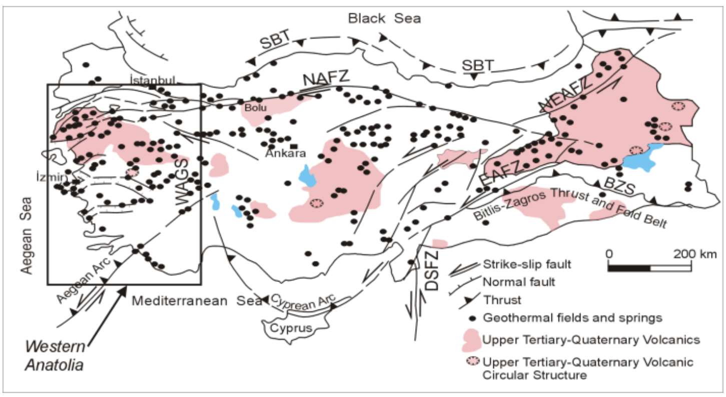

Figure 1. Tectonic map of the eastern Mediterranean region showing structures developed during the Miocene to Holocene time and distribution of geothermal areas around Turkey (compiled from; Simsek et al, 2002 and Yigitbas et al, 2004). (SBT, Southern Black Sea Thrust; NAFZ, North Anatolian Fault Zone; NEAFZ, Northeast Anatolian Fault Zone; EAFZ, Eastern Anatolian Fault Zone; WAGS, Western Anatolian Graben System; DSF, Dead Sea Fault Zone; BZS, Bitlis-Zagros Suture) (Baba and Armannsson, 2006).

The activity of Western Anatolia is believed to be a result of tensional forces that resulted from rigid behavior during the Neogene and Quaternary and the development of extended near-coastal graben areas (Baba and Ármannsson, 2006).

ARSENIC LEVELS IN WESTERN ANATOLIA

The volcanic structure that is dominant in the geological formation of Turkey and particularly western Anatolia is the primary mechanism for the presence of numerous trace elements in earth's crust including but not limited to arsenic, antimony, boron, nickel, lead and zinc. They are also found as impurities in the ores of other minerals including coal (Karayigit et al., 2000; Baba et al., 2009) reaching to levels as high as 6413 ppm as in the case of arsenic. Consequently, these trace elements are dissolved in all geothermal waters and in some cold groundwater resources in many locales in western Anatolia. The concentrations of arsenic in rocks and ores of westerns Anatolia are given in Table 1. Accordingly, arsenic levels as high as 4% are observed in mineral deposits particularly in Kutahya-Emet area, which is known to contain the world's largest boron deposits. In this area, arsenic is typically found in numerous boron minerals as discussed by Helvacı (1986), Helvacı and Orti (1998) and Helvacı and Alonso (2000).

Table 1. Arsenic concentrations in rocks in Western Anatolia.

Site	Province	Type	Maximum level recorded (ppm)	Reference
Halıköy Hg-Sb Mine	İzmir	Ore	8900	Akar (1981)
Kalecik Hg Mine	İzmir	Sediment	9660	Gemici and Oyman (2003)
Bayındır-Sarıyurt	İzmir	Ore	200	Bulut and Filiz (2005)
Balya Pb-Zn Mine	Balıkesir	Ore	1000	Wagner et al (1984)
Kızıldere	Denizli	Rock	268	Ozgur (2002)
Etili	Çanakkale	Rock	700	Unpublished data from Alper Baba
Doğancılar	Çanakkale	Rock	3000	Wagner et al (1984)
Soğukpınar	Çanakkale	Rock	6000	Wagner et al (1984)
Çan	Çanakkale	Coal	6413	Baba et al (2009)
Emet	Kütahya	Rock	500	Aydın et al (2003)
Gökler coal mine	Kütahya	Coal	3854	Karayigit et al (2000)
Emet	Kütahya	Rock	3900	Dogan and Dogan (2007)
Igdekoy-Emet	Kütahya	Ore	40000	Colak et al (2003)
Simav Sb Mine	Kütahya	Ore	660	Gunduz et al (2010)
Dulkadir	Kütahya	Rock	4197	Atabey (2009)
Emet	Kütahya	Rock	19487	Atabey (2009)
Kırka Borate Mine	Kütahya	Ore	>2000	Helvacı and Alonso (2000)
Alaşehir Hg Mine	Manisa	Waste rock	1164	Gemici (2008)

The high levels in Table 1 are mostly related to the alterations in volcanic formations. Typically, arsenic is observed in the alteration zones of volcanic formations as well as in some sedimentary rocks. Based on the tectonic characteristics (see Fig. 1) and the geological structure, many parts of Turkey are likely to have arsenic containing geological formations within which groundwater is also likely to contain high arsenic levels. Most of these rocks are altered and fractured due to the effects of active faults. Basement rocks are composed of Oligocene aged volcanic rocks such as andesite, dacite, rhyodacite, basalt, tuff and agglomerate. Several mineral deposits including numerous industrial metals as well as some precious metals have been found in the alteration zones or fractured parts of these volcanic rocks where arsenic is typically seen as an impurity (Baba, 2010).

Due to the neotectonic structure and volcanism, various altered rock types which may affect the quality of water resources. Thus, arsenic found in groundwaters is typically geogenic in origin and has strong links to the local regional geology. In particular, arsenic is an indicator parameter for hot water reserves of Western Anatolia. It is found in almost all geothermal waters and is used as a tracer (together with lithium and boron) for the detection of contamination in surface and subsurface waters with geothermal fluid (Gunduz et al, 2010). Arsenic levels in geothermal waters of Western Anatolia are presented in Table 2.

Table 2. Arsenic concentrations in geothermal fields in Western Anatolia.

Geothermal Field	Province	Maximum level recorded (ppb)	Reference
Heybeli	Afyon	1249	Gemici and Tarcan (2004)
Çan	Çanakkale	100	Baba and Deniz (2008)
Tuzla	Çanakkale	136	Baba et al (2009)
Karaılıca	Çanakkale	88	Baba and Deniz (2008)
Kestanbol	Çanakkale	100	Baba and Ertekin (2007)
Alibeyköy	Çanakkale	290	Yılmaz et al (2009)
Kızıldere	Denizli	1500	Ozgur (2007)
Balçova-Narlıdere	İzmir	1420	Aksoy et al (2009)
Seferihisar	İzmir	172	Tarcan and Gemici (2003)
Dikili	İzmir	480	Personal comm. with Alper Baba
Simav	Kütahya	594	Gunduz et al (2010)
Gediz	Kütahya	300	Dogan and Dogan (2007)
Yoncalı	Kütahya	950	Dogan and Dogan (2007)
Salihli	Manisa	315	Tarcan et al (2005)
Alaşehir	Manisa	939	Bulbul (2009)
Sart	Manisa	198	Ozen (2009)
Kurşunlu	Manisa	3455	Ozen (2009)
Hamambogazi	Uşak	6936	Davraz (2008)

As seen from the table, arsenic levels are extremely high in many geothermal fields such as Hamamboğazı in Uşak, Kızıldere in Denizli and Balçova-Narlıdere in İzmir. Although ingestion of geothermal waters is not a typical practice in Turkey as it is in some other parts of the world, these high levels serve as potential contamination sources for local cold groundwater and surface waters that are used for drinking water purposes as discussed in details by Aksoy et al. (2009) and Gunduz et al. (2010). These levels are two-to-three orders of magnitude higher than the levels depicted in national (ITASHY, 2005) and international standards (EPA, 2003; WHO, 2004).

Table 3. Arsenic concentrations in groundwater resources in Western Anatolia.

Site	Province	Source	Maximum level recorded (ppb)	Reference
Bigadiç	Balıkesir	Spring	337	Gemici et al (2008)
Ayvacık	Çanakkale	Well	282	Baba (2010)
Çan	Çanakkale	Spring	71	Baba et al (2009)
Etili	Çanakkale	Well	150	Unpublished data Alper Baba
Menderes plain	İzmir	Well	463	Simsek et al (2008)
Nif mountain	İzmir	Spring	294	Simsek et al (2008)
Balçova	İzmir	Well	170	Aksoy et al (2009)
Aliaga	İzmir	Spring	120	Unpublished data Orhan Gunduz
Simav plain	Kütahya	Well	562	Gunduz et al (2010)
Hisarcık	Kütahya	Spring	152	Atabey (2009)
Emet	Kütahya	Spring	634	Oruc (2004)
Igdekoy	Kütahya	Spring	9300	Dogan et al (2005)
Göksu-Sarıkız	Manisa	Well	59	Personal comm. with IZSU* officials
Eşme	Uşak	Well	50	Local newspaper article (2006)

* İzmir Municipality Water and Sewerage Administration.

Similar to geothermal waters, arsenic levels are also high in many locales in western Anatolia as shown in Table 3. Accordingly, high arsenic levels exceeding the standards are observed in provinces such as Balıkesir, Çanakkale, İzmir and Kütahya. Majority of these high levels are from spring and shallow groundwater samples that are in direct contact with alteration zones, which also contain high arsenic levels or that are under the influence of geothermal fluids. It should also be noted that these high levels demonstrate carcinogenic risks on people who ingest these resources for domestic water supply. Furthermore, although there are reports of arsenic occurrence in water resources of many other settlements in western Anatolia other than the ones reported in Table 3, there are unfortunately very few examples of reported and published case studies. Majority of these occurrences are based on sporadic measurements from water supply networks in local laboratories and predominantly find space in newspaper articles. Data published in peer-reviewed journals are rather limited. Thus, there is a need for a state-wide arsenic survey to be conducted on hot and cold water samples taken from surface and subsurface water resources. Such an inventory will provide the necessary spatial and temporal extent required for a detailed review.

CONCLUSIONS

Due to its neotectonic structure and the influence of volcanism, Anatolian Plate contains various altered rock types that contain elevated levels of arsenic and other trace elements. These rocks demonstrate a strong potential to influence the quality of water resources as a result of rock-water interaction in geological formations. Thus, high arsenic levels of geogenic origin are observed in wide spatial extent in Western Anatolia. Values in the order of milligrams per liter are common in some parts of Western Anatolia. These values are several orders of magnitude larger than the national and international standard values and demonstrate a significant health risk for people consuming these waters.

ACKNOWLEDGEMENTS

The authors acknowledge the financial support provided by The Scientific and Technological Research Council of Turkey (TUBITAK) thru project number 109Y029.

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IAH 2010 Krakow

abstract id: **181**

topic: **1**
Groundwater quality sustainability

1.2
Groundwater vulnerability and quality standards

title: **An application of cluster analysis and multivariate classification methods to evaluate spatial characterization of groundwater chemistry in southeastern of Tunisia: a case study of Jeffara of Medenine**

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keywords: aquifer, Jeffara of Medenine, geochemical process, mulivariate analyses, Tunisia

The Southeastern of Tunisia depends entirely on groundwater for domestic and agricultural use (Romangey and Guillaume, 2004). The Jeffara of Medenine aquifer system, which represents the unique resource of water for the region (Medenine, Jerba, Zarzis and Jorf cities), is represented by three main aquifers namely, from the top to the bottom: the Miocene (Jorf-Jerba-Zarzis), the Jurassic (Zeuss-Koutine) and the Triassic (Sahel El Abebssa). Sampling surveys were undertaken in January 2004 from 46 wells. 11 variables (temperature, pH, Total Dissolved Solids (TDS), Na^+, Cl^-, Ca^{2+}, Mg^{2+}, SO_4^{2-}, K^+, HCO_3^-, and F^-) of water samples were measured and analyzed.

In this study, hydrogeologic and hydrochemical information from the Jeffara of Medenine groundwater system were integrated and used to determine the main factors and mechanisms controlling the chemistry of groundwaters in the area (Fig. 1).

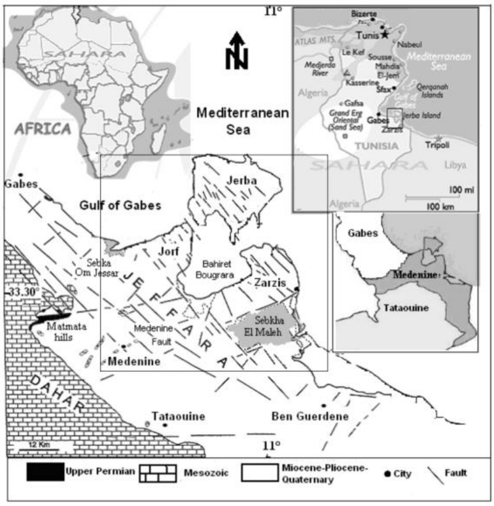

Figure 1. Location and geologic map of the study area.

The large number of data can lead to difficulties in the integration, interpretation and representation of the results. Two multivariate statistical methods, hierarchical cluster analysis (HCA) and principal components analysis (PCA), were applied to analyze the similarities or dissimilarities among the sampling sites (Ragno et al., 2007; Cloutier et al., 2008; Templ et al., 2008) to identify spatial variations in water quality, with the objective of defining the main controls on the groundwater hydrochemistry.

The main processes influencing the groundwater chemistry in the jeffara of Medenine aquifer system are salinisation, mineral precipitation and dissolution, cation exchange and human activity.

Cluster analysis based on major ion contents defined 3 main chemical water types, reflecting different hydrochemical processes (Fig. 2). So, three geochemically distinct clusters, C1–C3, resulted from the HCA. Samples from cluster C1 are mostly located in preferential recharge areas and have low salinity. The majority of these samples have Ca–SO_4. Samples from the other two clusters (C2, C3) are characteristic of an aquifer system under confined conditions. The majority of these samples have Na–Ca–Cl–SO_4 evolved groundwater.

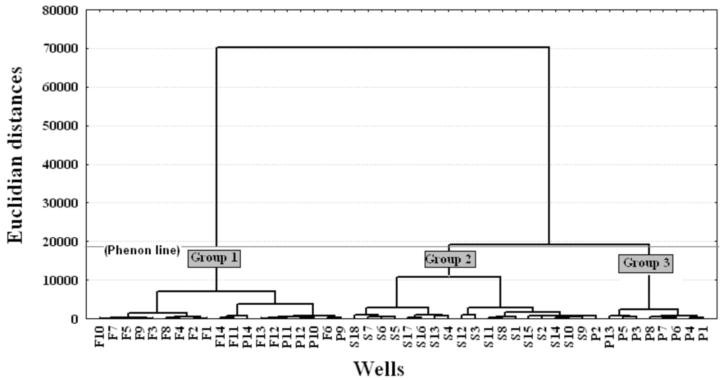

Figure 2. Dendrogram of Q-mode cluster analysis (Ward's linkage method and squared Euclidean distances).

In addition to recognizing the importance of hydrogeological conditions on groundwater geochemistry, the distribution of clusters also showed the importance of the geological formations and hydrodynamic conditions. Results obtained from principal component analyses (PCA) indicate that the variables responsible for water quality composition are mainly related to soluble salts species (Na^{+}, Cl^{-}, Ca^{2+}, Mg^{2+}, SO_4^{2-} and K^{+}).

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IAH 2010
Krakow

abstract id: **206**

topic: **1**
Groundwater quality sustainability

1.2
Groundwater vulnerability and quality standards

title: **Hydrostratigraphical setting and groundwater quality status in alluvial aquifers: the low Garigliano River Basin (Southern Italy), case study**

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keywords: 3D model, nitrate contamination, vulnerability map, risk map

INTRODUCTION

Background

Aquifer characterization is critical to understanding groundwater flow systems, especially when the spatial variability has a significant influence on the hydrogeological structure (Ahmed, 2009). With this in mind, the present study applies a 3D lithologic model to characterize the Garigliano River plain aquifer in central-southern Italy (Fig. 1).

The Garigliano River plain (about 170 km^2) presents a complex geological pattern and geomorphological evolution which have been extensively investigated (Cosentino et al., 2006, among others). The plain holds a major aquifer, the subject of an in-depth study by Nicotera and Civita (1969).

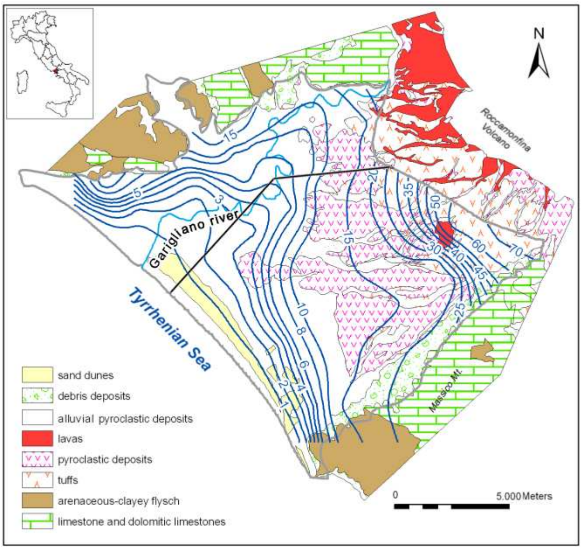

Figure 1. Hydrogeological map of the lower Garigliano river basin showing the study area (red line), the piezometric surface of the aquifer in m a.s.l. (April-May 2009; blue line) and the trace of the hydrogeological cross section of Fig. 3 (black line).

Hydrogeological setting of the study area

The Garigliano River plain is a NE-SW oriented graben filled with upper Miocene-Quaternary infralittoral, deltaic and continental clastic deposits, containing in the uppermost part volcano-clastic sediments from nearby Roccamonfina. The Roccamonfina volcanic district, located NE of the plain, developed between 630 and 53 ka, and has a maximum thickness of the volcanics of about 1000 m (Cosentino et al., 2006). The substratum to the volcanics, also dissected by NW-SE normal faults, is represented by Apenninic platform carbonates, which also crop out along the SE and NW limits of the alluvial plain. Along the SW border two sand dunes run parallel to the coastline. These sand dunes in the past created secluded ponds and coastal lagoons filled by groundwater, runoff and direct rainfall which could not reach the sea.

Stratigraphic reconstruction of the main aquifer was obtained by interpolating stratigraphic data from more than 80 boreholes. The aquifer consists (Figs. 2 and 3) of marine and alluvial deposits, often with peat levels**.** In the NE sector these deposits overlap (or are interbedded with) pyroclastic layers of the Roccamonfina complex. Depending on the stratigraphy and granulometry of the deposits, the aquifer is confined or semi-confined.

MATERIALS AND METHODS

Piezometric setting

The piezometric pattern (defined by the piezometric network consisting of more than 60 sites measured in April-May 2009) shows the groundwater flow directed toward the sea and the Garigliano river (Fig. 1). Along the slopes of the Roccamonfina volcano the piezometric gradients are in the order of 2%, while in the plain they are substantially lower (about 0.1–0.2%). At piezometric levels less than 10 m a.s.l. the hydraulic gradient increases (from 0.2 to 0.4%) due to the presence of less pervious sediments. As this impedes flow towards the sea, the water table rises above ground level creating ponds and marshes behind the coastal dunes (§1.2).

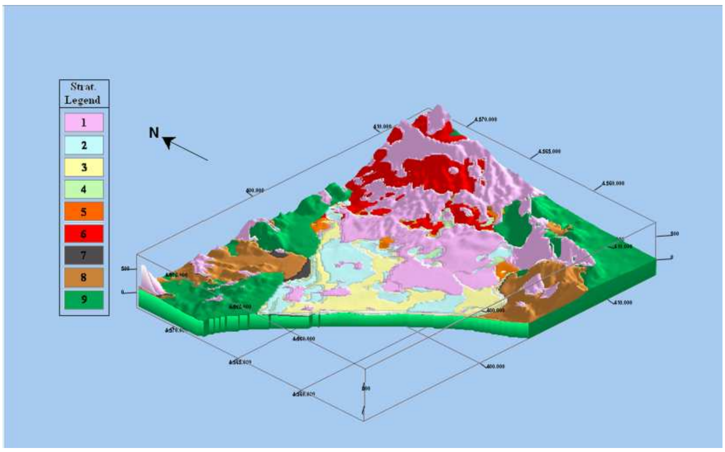

Figure 2. Hydrostratigraphic 3D model of the lower Garigliano river basin: 1) pyroclastic deposits, 2) deposits of fine grain size, 3) deposits of medium grain size 4) deposits of medium-coarse grain size, 5) tuffs, 6) lavas; 7) fluvial-palustrine plio-quaternary unit (SR) 8) arenaceous-marly-clayey torbiditic unit (AM), 9) limestone.

Hydrochemistry

Hydrochemical sampling was conducted in the same wells used for the the piezometric measurements. NO_3 is the most pervasive contaminant, widely exceeding the drinking-water quality guidelines of 50 mg/L (Fig. 4). Close to the Garigliano river, lower nitrate content is related to reducing conditions, testified by low values of SO_4 and high content in Fe and Mn. In the same area there are high fluoride contents (>1.5 mg/L).

3D lithostratigraphic model

3D lithostratigraphic reconstruction of Garigliano river basin model was carried out by using more than 80 borehole stratigraphies. The boreholes, with depth varying between 10 and 318 m, were distributed with greater concentration at the bottom of the Roccamonfina volcano and Mt. Massico; there was a lower borehole density in the surrounding areas. It was necessary to select boreholes on the basis of their reliability and utility. The boreholes were integrated with geophysical information concerning the thickness of the upper aquifer and the depth of the substrate (Nicotera and Civita, 1969).

Stratigraphic succession is very complex and heterogeneous. Therefore, a critical reinterpretation was necessary, with a view to differentiating particle size of deposits rather than their origin and nature. On the basis of these considerations, the conceptual model structure provides:

- the upper aquifer: it has a thickness of 60 m and is the object of the model reconstruction;
- fluvial-palustrine plio-quaternary unit (SR): formed by clay with intercalations of gravel, sand and conglomerate, with a thickness of several hundred meters. The unit, almost impermeable, represents the base of the upper aquifer;
- arenaceous-marly-clayey torbiditic unit (AM): it is not always present. The unit is impervious and in some sectors forms the base of the upper aquifer;
- limestone platform (C): it is always present and represents the bottom of the model.

The software used to create the lithostratigraphic model was Rockworks 2006 (www.rockware.com), which allows a 3D model to be constructed with a detailed geostatistics analysis. The data were organized in a database, imported within Rockworks 2006 and developed by interpolation algorithms, reconstructing a grid model (Fig. 2). The algorithm chosen for modelling is inverse distance because, compared with other methods (e.g. Kriging), it made it possible to obtain hydrogeological cross sections very similar to hand-drawn sections (Fig. 3).

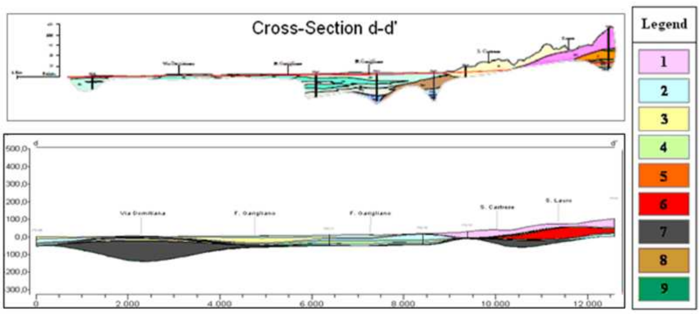

Figure 3. Hydrogeological cross sections constructed a) by hand drafting; b) by the 3D model (inverse distance interpolation): 1) pyroclastic deposits, 2) deposits of fine grain size, 3) deposits of medium grain size 4) deposits of medium-coarse grain size, 5) tuffs, 6) lavas; 7) fluvial-palustrine plio-quaternary unit (SR); 8) arenaceous-marly-clayey unit (AM), 9) limestone. Trace is in Fig. 1.

Potential risk of nitrate contamination

With the purpose of verifying the source of groundwater nitrate contamination the pollution vulnerability map of the aquifer (§ 2.4.1) and the agricultural nitrate hazard map (§ 2.4.2) were drawn up.

Assessment of aquifer contamination vulnerability

The last twenty years have seen the widespread use of point count system methods in evaluating aquifer vulnerability to pollution, such as DRASTIC (Aller et al., 1987) and SINTACS (Civita and De Maio, 2000), based on the most commonly found Italian hydrogeologic settings. Both evaluate vertical vulnerability using the same seven parameters: depth to groundwater (S), recharge action (I), attenuation capacity of the vadose zone (N), attenuation capacity of the soil (T), aquifer media (A), hydraulic conductivity (C) and topographic slope (S). In the Garigliano River Plain, the layers of depth to groundwater, attenuation capacity of the vadose zone and hydrogeological characteristics of the aquifer media were evaluated not for the single boreholes and piezometers, but by the 3D model.

Agricultural nitrate hazard index: IPNOA

Significant experimentation in the risk evaluation of nitrate contamination has been reported worldwide, and some Italian methods have also been applied (Capri et al., 2009; Corniello et al., 2007). In 2002, the agricultural nitrate hazard index (IPNOA — Padovani and Trevisan, 2002) was developed to assess the potential hazard of groundwater contamination by nitrates from agricultural sources at regional and provincial scale, using a parametric approach. IPNOA integrates two categories of parameters: the hazard factors, which represent all farming practices that cause, or might cause, an impact on groundwater in terms of nitrate, and the control factors, which modify the hazard factors according to the site characteristics and agricultural practices. All factors are inter-related after being classified, assigning them an index that characterises the nitrogen load or incidence of the factors involved in nitrate leaching. The potential hazard index (HI) for nitrate contamination from agricultural sources is evaluated by multiplying the different hazard classes (HF) by the control classes (CF). The IPNOA hazard map is then obtained from the HI by classifying the resulting values. Finally, intrinsic vulnerability (evaluated by SINTACS) was linked to IPNOA to assess the potential risk of groundwater contamination.

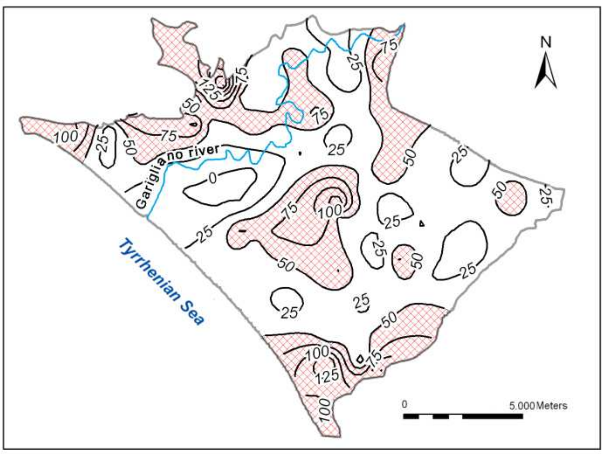

Figure 4. NO_3 distribution in groundwater in mg/L (April-May2009); highlighted areas with nitrate values exceeding 50 mg/L.

In the Garigliano River Plain, in order to assess the nitrate contamination hazard using the IPNOA method, the data collected are the following:

- type of animal husbandry;
- climatic and hydrologic factors;
- agricultural activities (obtained from the "CORINE Land Cover 2000 level III" APAT, 2004).

All the data were stored in a geographic database and managed by GIS. The Potential Risk Map (R) was obtained by multiplying in terms of classes, through the GIS, hazard and vulnerability, and then classifying the obtained values into risk classes (see Corniello et al., 2007 and Capri et al., 2009, for the explanation of the scores and crossings).

RESULTS AND DISCUSSION

The Potential Agricultural Nitrate Contamination Risk Map (Fig. 5) shows a prevalent high-very high risk In the north-western and south-eastern sectors of the plain the map reflects the aquifer Vulnerability map (here the aquifer is unconfined, with low depth and high permeability), more than the IPNOA map (prevalent classes: low and very low). In the central sector of the plain the IPNOA values are higher, which suggests for sure that the source of groundwater nitrate content originates in agriculture.

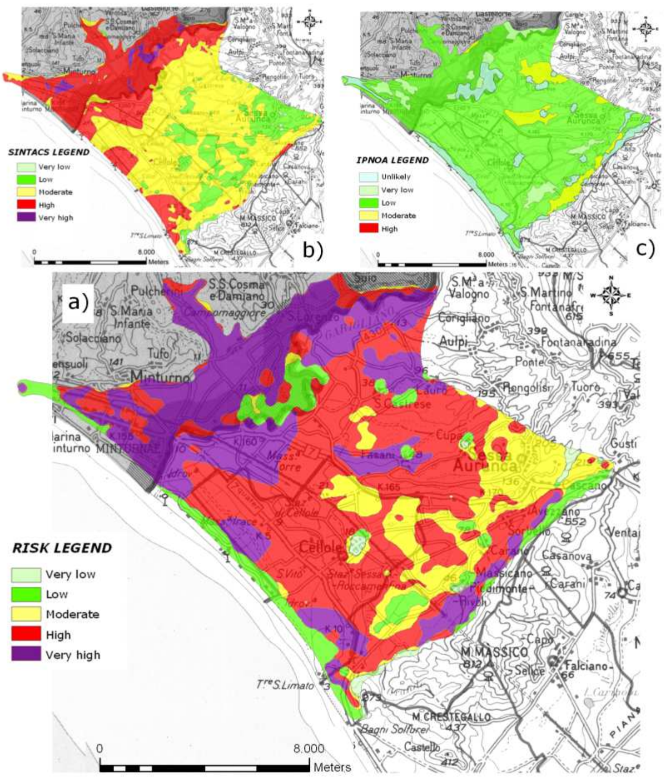

Figure 5. Potential Agricultural Nitrate Contamination Risk (a) derived from the Vulnerability (SINTACS) map (b) and the IPNOA (Agricultural Nitrate Hazard Index) map (c).

CONCLUSION

The risk map presents a good spatial correlation with the nitrate content of the aquifer (Fig. 5), highlighting the sectors most affected by nitrates and supporting the identification of the

source of nitrate contamination. This suggests that the source of the groundwater nitrate is chiefly related to intensive cropping or livestock. However, the authors recommend complementary isotope analysis (δ15N and δ18O), that are now being applied, to verify the hypothesis of the agricultural origin of nitrates and to test the validity of the methods.

This paper highlights the great advantage of using a 3D model of the subsoil of a alluvial plain (Garigliano basin) and the substantial results that can be achieved. Indeed, the author would stress that the originality of this paper lies not in the application of the method to assess nitrate contamination risk, but rather in its application directly from the 3D lithostratigraphic model.

ACKNOWLEDGEMENTS

The study was funded by the research project of national interest (PRIN) “Nitrate Contamination in Groundwater" launched in 2007 (National Project Coordinator, Prof. Alfonso Corniello).

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abstract id: **252**

topic: **1**
Groundwater quality sustainability

1.2
Groundwater vulnerability and quality standards

title: **Groundwater nitrate vulnerability assessment using process-based models and weights-of-evidence technique – Lower Savinja Valley case study (Slovenia)**

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keywords: groundwater nitrate vulnerability, weights-of-evidence, Lower Savinja Valley (Slovenia)

Groundwater is the most important and valuable source of drinking water in Slovenia, and alluvial aquifers contribute a vital part to the dynamic reserves of all Slovene groundwater. More than one third of the alluvial groundwater in Slovenia has poor chemical status, most frequently due to a high concentration of nitrate. The Lower Savinja Valley alluvial aquifer (79 km^2) in central part of Slovenia (Fig. 1) with important regional water resources and high pollution pressures due to agriculture (50.4% of the area) and urbanization (34.0% of the area) was selected as a case study for experimental field-verified groundwater nitrate vulnerability mapping. A spatially explicit identification of the potentially vulnerable priority areas within groundwater bodies is being required for cost-effective measures and monitoring planning.

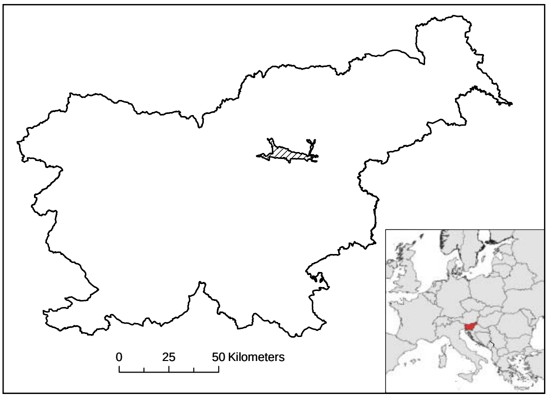

Figure 1. Location of the Savinja Valley groundwater body in Slovenia.

The shallow Lower Savinja Valley unconfined aquifer system consists of high permeable Holocene and middle to low permeable Pleistocene gravel and sand with a maximum thickness of about 30 meters, mainly covered by shallow eutric fluvisoils or variously deep eutric cambisoil. The hydrogeological parameters, e.g., the depth to the groundwater, hydrological role of the topographic slope etc., usually used in different point count schemes are in the case of the lowland aquifer and shallow groundwater spatially very uniform with low variability. Furthermore, the parametric point count methods are generally not able to illustrate and analyze important physical processes and validation of the results is difficult and expensive. Instead of a parametric point count scheme, we experimentally used the Arc-WofE extension for weights-of-evidence modeling (Kemp et al., 1999), considering recent groundwater vulnerability studies from the United States (Baker et al., 2007) and from northern Italy (Masetti et al., 2007).

All measurement locations with a concentration higher than the threshold value of 20 mg NO_3^- per litre of groundwater have been considered as training points (179) and the three process-based model generalized output layers of long-term groundwater recharge (Andjelov, 2009), groundwater flow velocity (Vižintin, Uhan, 1999) and nitrogen load in seepage water served as evidential themes. The technique is based on the Bayesian idea of the phenomena occurrences probability before (prior probability) and after consideration of any evidential themes (posterior probability), which were measured by positive and negative weights as an indication of the association between a phenomena and a prediction pattern. The response theme values describe the relative probability that a 100×100 metre spatial unit will have a groundwater nitrate concentration higher than the training points threshold values with regard to prior probability value 0.0018 (Figure 2).

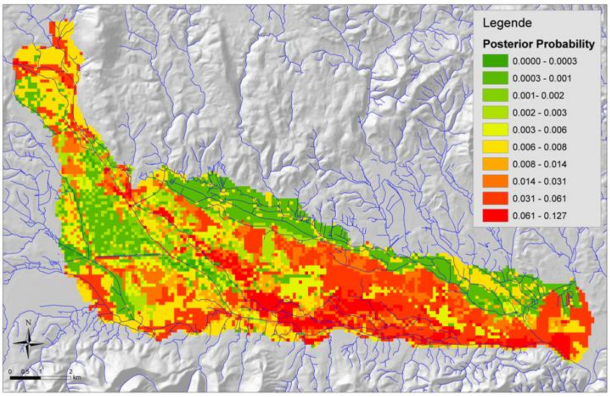

Figure 2. Posterior probability map of groundwater nitrate occurrence in the Lower Savinja Valley aquifer.

The lowest probability of groundwater nitrate occurrence is in the parts of the Lower Savinja Valley aquifer, which are known as anoxic condition areas with very likely denitrification processes. Due to findings of anoxic conditions and the indication of a denitrification process in some parts of the study area, a separate dissolved oxygen response theme was generated (Fig. 3). The upper quartile of the dissolved oxygen data from the same wells as the nitrate concentration data for the nitrogen response theme served as the training points theme. A dissolved oxygen response was compared with the existing nitrogen response theme and used the Kappa (κ) coefficient (Jenness, Wynne, 2007) as a measure of spatial agreement between different themes. The Kappa coefficient calculated for the Lower Savinja Valley groundwater nitrate and for the dissolved oxygen response theme (κ=0.87) indicates sustainable agreement of the themes and verifies that dissolved oxygen is a good predictor of nitrate vulnerability.

The confidence values of the groundwater nitrate model area, as a ratio of posterior probability to its estimated standard deviation, ranged from 1.80 to 3.53 (Tab. 1). These values inicated that the confidence level was above 90% for the majority of the model area (Fig. 4). Area of lower confidence corresponde with area that lack training points.

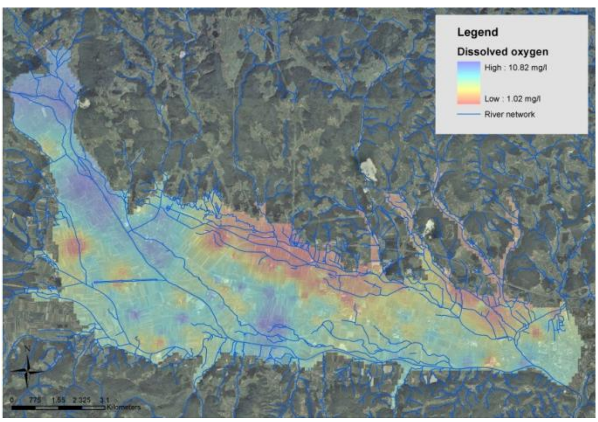

Figure 3. Distribution of dissolved oxygen in groundwater of the Lower Savinja Valley aquifer.

The weights-of-evidence model result map was tested for conditional independence. The actual training sites used in the model vesus the predicted points from the response theme is the confidental independance ratio. Calculated confidental independance ratio for Lower Savinja Valley aquifer model is still within the range 1.00±0.15 (Rainers, 2001) and used evidential themes were considered independent of each other.

Table 1. Calculated weights (W1 in W2) for each evidential theme with associated contrast and confidence values.

Evidental Theme	W1	W2	Contrast	Confidence
Long-term groundwater recharge	0.485	–0.704	1.189	1.800
Nitrogen load in seepage water	0.297	–0.465	0.762	2.400
Groundwater flow velocity	0.900	–0.572	1.472	3.534

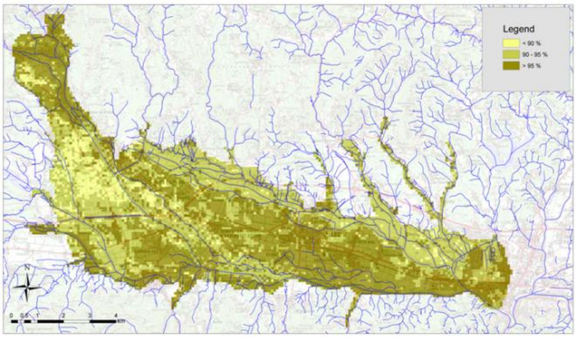

Figure 4. Distribution of confidence values for groundwater nitrate response theme in the Lower Savinja Valley aquifer.

The weights-of-evidence model results very clearly indicate regional groundwater nitrate distribution and enable spatial prediction of the probability for increased groundwater nitrate concentration in Lower Savinja Valley aquifer in order to plan the groundwater nitrate reduction measures and optimize the programme for monitoring the effects of these measures.

ACKNOWLEDGEMENTS

The authors would like to deeply thank Vlado Savić and Janja Turšič from the Environmental Agency of the Republic of Slovenia, who provided us with useful and helpful assistance in field measurements and laboratory work.

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abstract id: **283**

topic: **1**
Groundwater quality sustainability

1.2
Groundwater vulnerability and quality standards

title: # Wellhead protection against diffuse pollution at catchment scale

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keywords: groundwater pollution, catchment area, vulnerability, wellhead protection

INTRODUCTION

Solutions such as agri-environmental measures, land management, afforestation and grasslands are used to protect underground water, especially when used for human water supply, against persistent chemical contaminants, such as nitrates and pesticides. The cost of such measures, which can be very important if considering the whole groundwater catchment area, requires having a specific and optimized approach based on the identification of areas where the actions will be the more efficient. This approach is based on the crossing of catchment area vulnerability with pollution pressures (Fig. 1).

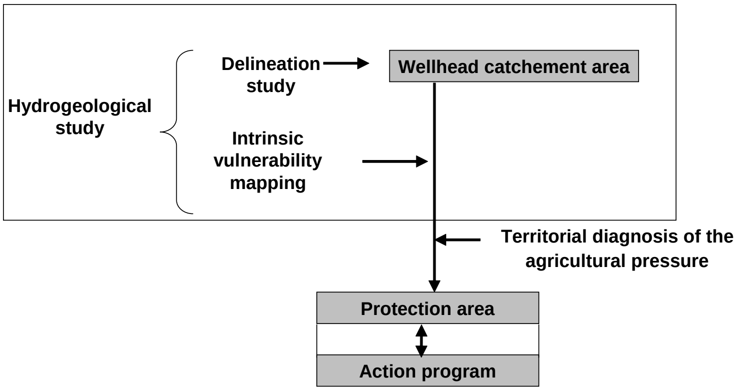

Figure 1. Approach for the protection of water well againt diffuse pollution.

METHODOLOGY

A methodology was developed by BRGM in order to delineate such protection areas and action plans according to the type of aquifers present in France : alluvial, sedimentary (karstic or non karstic), basement (Vernoux et al., 2007 ; Vernoux et al., 2008). Nevertheless, it can be applied to any type of aquifer as long as the considered aquifer was classified among three proposed types : continuous aquifer, discontinuous fractured aquifer, discontinuous karstic aquifer. The methodology consists of three steps : (i) identifying the aquifer area that supplies the groundwater source or well, (ii) defining on the ground surface the catchment zone of the well or source in question (Fig. 2), (iii) mapping the vulnerability of the catchment zone from a multicriteria analysis. The aquifer area that supplies the groundwater source or well depends on structural geology and hydrodynamic criteria. In the same way, different methods were developed for vulnerability mapping, according to the type of aquifer. The proposed methods of vulnerability mapping were adapted from existing methods (DRASTIC, RISKE and DISCO). The needed parameters for multicriteria analysis are : soil characteristics, efficient rainfall, infiltration in the overlying layers, unsaturated zone thickness, aquifer permeability and karst specific parameters (karst network development and epikarst).

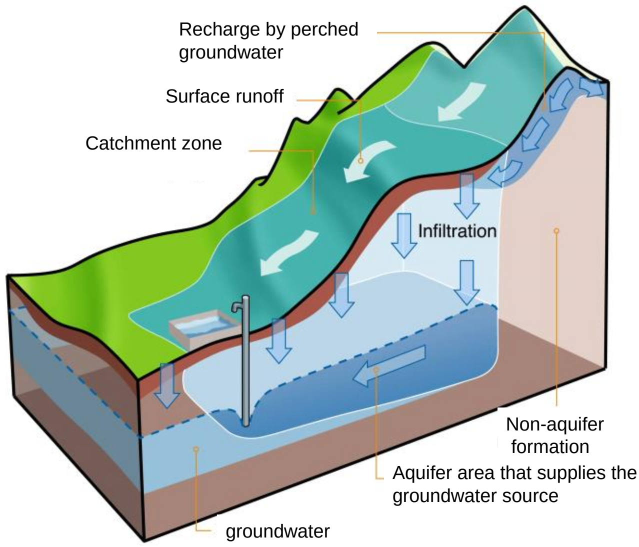

Figure 2. Schematic representation of a catchment area.

APPLICATION TO A SAND AND CHALK AQUIFER

The methodology was applied to the study of 24 wellheads located about 50 km south-west of Paris. The aim of the study was to delineate the catchment zone for each wellhead, to map aquifer vulnerability, to identify pressures and to propose action plans to reduce pollution, especially diffuse pollution (Vicelli et al., 2008). The aquifer is made up of Fontainebleau sand et cretaceous chalk that can be locally separated by clay formations (Fig. 3). On a hydrodynamic point of of view, the two formations can be considered as a single aquifer.

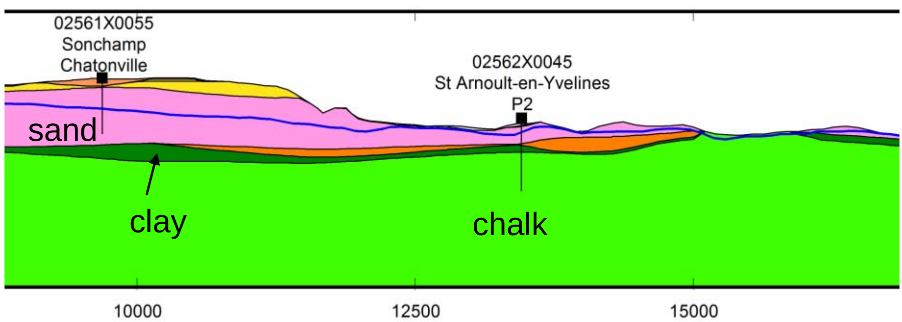

Figure 3. Hydrogeological section of the study area.

Ten catchment areas were defined from piezometric map and hydrodynamic modelling and the vulnerability was assessed from a continuous aquifer approach with (Fig. 4):

Vulnerability = $0.1 \cdot P + 0.25 \cdot S + 0.3 \cdot I + 0.2 \cdot H + 0.15 \cdot K$ (where P is efficient rainfall, S is soil, I is infiltration, H is unsaturated zone thickness and K is aquifer permeability).

One of the main parameters is infiltration (I). Typically, this parameter is estimated from precipitation, evapotranspiration and runoff (I = P - R – ETR). BRGM developed a tool named Network Persistence and Development Index (IDPR) which gives an indirect approach to infiltration (Mardhel et al., 2007). Based on the comparison between two drainage patterns (one calculated from a Digital Elevation Model (DEM) and the natural hydrological pattern), it reflects the influence of the underlying geological formations toward surface-water runoff or infiltration.

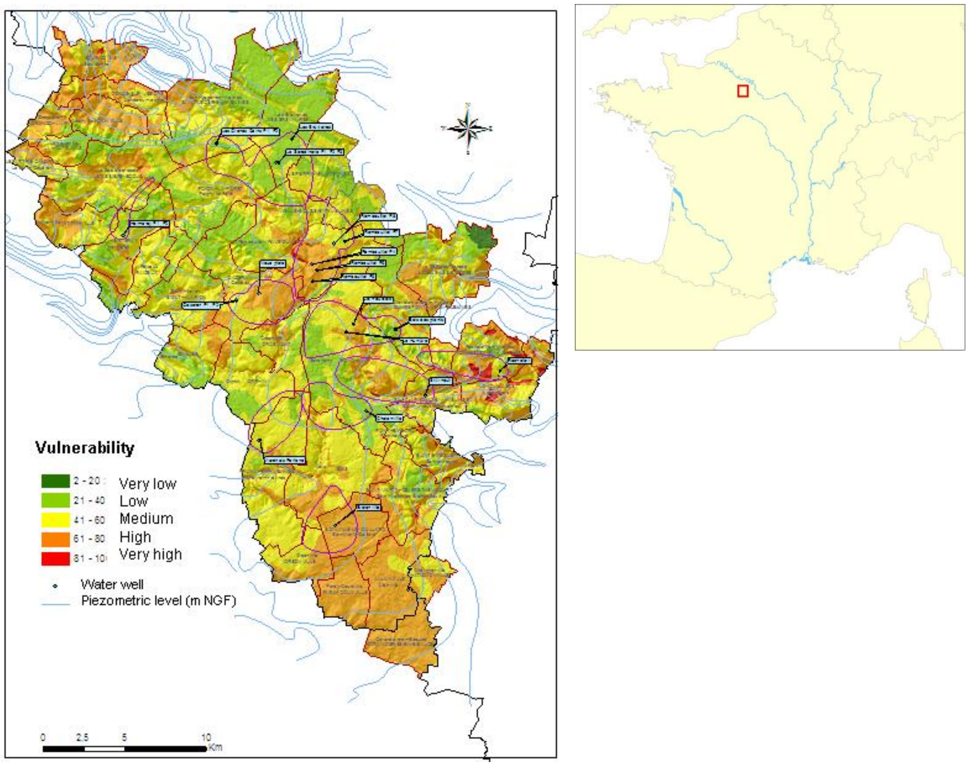

Figure 4. Catchment areas and vulnerabilty mapping.

ACTION PLANS TO REDUCE DIFFUSE POLLUTION

Action plans were developed to help deciders to efficiently adapted preventive action against contamination. The aim of the action plans is to propose realistic measures for the studied area and to suggest proportional responses to the risk. This allows giving advices which are more likely to be accepted. For instance, action plans to prevent fertilizers or plant protection products contamination take into account pedoclimatic context and farm economic viability. Realistic responses are possible by the promotion of mitigation measures already used. The dissemination of knowledge and technologies is a key-principle. The actions plans are hence established for the different types of contaminations identified (e.g. gardens, fields). Proportional responses to the risk are achievable by the description of different classes of risk (high, medium, low) for the each type of contamination. Actions plans are gathered into a set of forms which give a brief description of plans for deciders and give applicable methods and financial aspects. Forms are not standalone products but are a help during the decision-making process.

The catchment area were shared into three zones : zone with a high risk, zone with a low risk and zone with a moderated risk. Different action plans were designed to be adapted to each zone (Fig. 4). The practices modifications should be more important with a high risk. Plans of practices modifications were also designed to be adapted to the different users of pesticides and fertilizers such as the farmers or the gardeners. Plans were also designed to take into account the differences between the diffuse pollutions and the point source pollutions.

Several plans were designed to reduce contamination from field diffuse pollutions. A set of way of improvement were proposed. This set was presented by 17 specification sheets. Each sheet described a way of doing to decrease the pressures of pesticides or nitrates on groundwater. Few sheets were advised to farmers in zones with a low risk whereas the complete set of sheet was advised to farmers in a high risk zone.

Some sheets concern fertilizers and pesticides uses. For instance, new technologies and methods for calculating the nitrogen needs of crops (such as N-testers use) are a possible way for reducing nitrates transfers from the surface to groundwater. Other ones concern agricultural practices as the use of long crops successions. Long crop successions are easy ways for reducing pesticide uses since the planting of the same crop at short interval attracts specific pests. Cultivating new successions could be complicated if no advices is received from the local farm advisors. Practice improvements are not only expected from the farmers but also from the farmer's partners. Action plans point the needs for implications of all the partners (farmers, farmer advisers, municipalities) to decrease the pressures on groundwater.

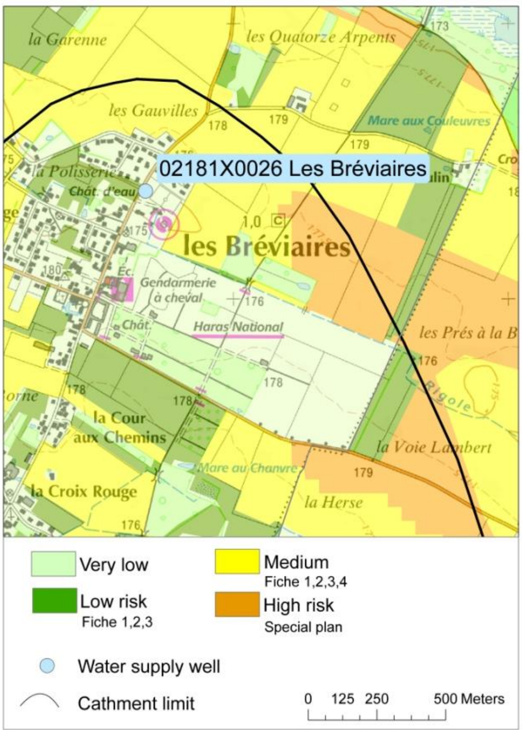

Figure 5. Use of action plan around a water supply well.

Some specification sheets concern the possibility of reducing risks by modifying the practices only on precise areas. These areas could be identified only on high risk zone by farm advisors specialized on the detection of those areas. Once the area detected, the farmers have to make important changes in their practices. To create new grassland or to convert the plots to organic farming are possibilities. The municipalities can buy these plots or exchange the risky plots with low risk ones. The farmers need to deeply modify their practices only on a reduced area. In the rest of the high risk zone, their practices are modified. In the low risk zone, their practices are little modified. Identifying different zones is a way to reduce the pressures of pesticides and nitrates on the groundwater without jeopardizing a farm future. The method could yield to economically viable modification.

Plans have to be designed to be used locally. Advices on new crops successions or on new hoeing method have to be useable on the studied area. To ensure that the advices are realistically useable, meetings with local farming advisers and farmers were realized.

CONCLUSION

The proposed approach is based on the assumption that it is very expensive, and thereby almost impossible to effectively protect against diffuse pollution the entire catchment zone of a groundwater source, especially if it is large. Rather than dispersing financial resources on the whole basin with limited expected results, it appears more appropriate to focus on sensitive areas.

The methodology is based on the intrinsic characteristics of the basin (geology, soil science, hydrodynamics, rainfall). It consists in defining as precisely as possible the catchment zone and afterwards to identify the most sensitive to the transport of pollutants to groundwater source. In a second step, the realization of a territorial diagnosis of the pressures (especially agricultural) related to vulnerability, will enable the effectiveness and efficiency of the action.

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IAH 2010
Krakow

abstract id: **318**

topic: **1**
Groundwater quality sustainability

1.2
Groundwater vulnerability and quality standards

title: **The level of awareness of groundwater quality issues among private well users in Ireland**

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keywords: groundwater contamination, health, awareness, private wells

INTRODUCTION

Private groundwater schemes in Ireland currently supply water to an estimated 720,000 people from two main source types: small private supplies (SPS) - private, unregulated groundwater supplies typically serving individual households - and private group water schemes (PrGWS), which are committee or shareholder run schemes serving fewer than 50 people, or supplying <10m^3/day (Tab. 1). It is estimated that a further 200,000 people regularly use groundwater from non-transient, non-community (NTNC) systems (workplaces, schools, licensed premises, etc), equating to approximately 21.7% of the total population (CSO, 2007). Recent figures indicate that 31.4% of PrGWS showed evidence of *E. coli* contamination at least once during the period 2007-2008, with an average figure of 33% over the period 1998-2008 (EPA, 2009). A higher proportion of microbial contamination is to be expected among SPS, which are currently unmonitored and unregulated.

Table 1. Sources of domestic water supply in Ireland (After CSO, 2007; EPA, 2009).

Source	% (Total Population)	Number Supplied
Surface Water (Public)	73	3,095,089
Groundwater (Public)	9	381,586
SPS	12.9	546,940
PrGWS	4.1	173,833
Other/Unknown	1	42,398

The main groundwater contaminants of concern in terms of human health are microbial enteric pathogens including verocytotoxigenic *Esherichia coli* (VTEC), *Cryptosporidium parvum*, *Giardia lamblia*., and the enteric viruses (*Rotavirus, Adenovirus*, etc). There is a wide range of symptomatic illnesses which may result from direct consumption of one or more of these pathogens via groundwater (Macler, Merkle, 2000; Strauss et al., 2001; Nwachcuku, Gerba, 2004), the most commonly diagnosed being acute gastrointestinal illness (AGI) or gastroenteritis. Although, the majority of AGI cases are minor, of short duration and self resolving, some cases, particularly those encountered in vulnerable sub-populations including infants, elderly and immunocompromised individuals may lead to more serious infection or even death. On a global scale, inadequate treatment of gastroenteritis kills 5-8 million people per year (Kasper et al., 2005).

Sources of groundwater contamination in Ireland include point sources such as septic tank systems, farmyards, silage pits and waste disposal sites, and diffuse sources including landspreading of animal manures and chemical fertilisers, plus grazing animals. All of these contamination sources may be associated with both microbial and chemical contaminants.

A research project is being carried out to assess the health risks associated with small private well schemes in Ireland. This research includes sampling of private groundwater sources and assessment of the susceptibility of these wells to potential contamination sources. Owners and users of private well schemes are also being surveyed about their level of awareness of their wells and about the linkages between water contamination and health. This paper focuses on the results of the awareness survey of well owners and users in Ireland.

RESEARCH OBJECTIVES

The main objectives of the awareness survey were to establish the level of knowledge among private groundwater users in Ireland regarding the status of their well supplies and the potential health hazards associated with the consumption of contaminated groundwater.

The work presented in this paper is part of a larger overall research project which seeks to quantify groundwater awareness as a factor in private groundwater source susceptibility and subsequently to develop a set of guideline documents for owners/users of private groundwater sources in Ireland.

METHODS

This study was conducted in 5 separate study areas in the Republic of Ireland (population 4.24 million in 2006 (CSO, 2007)).

Design of the questionnaire

The survey questionnaire was devised to examine the overall level of awareness amongst private well users with regard to a variety of contamination issues including specific knowledge of their own private source i.e. design and construction details, source age, use and importance of water treatment processes and maintenance of sources. Respondents were also surveyed on their knowledge of potential groundwater contaminants and potential health effects of these contaminants in addition to potential sources of contaminants and the presence of these hazard sources in relation to their own well. Finally, to aid in the completion of a human health risk assessment, which is being developed as part of the overall research project, household composition, groundwater consumption patterns and historical health patterns with regard to gastrointestinal illnesses were examined.

Identification of population and sample

For the purposes of this survey, the sample population was defined as those members of the Irish population who own or are served by a private groundwater source. This population is mainly located in rural areas, outside the perimeter of towns and cities served by public/local authority water schemes. Using standard sample size calculation equations (Moore & McCabe, 2006) and a total population of approximately 720,000, a sample size of approximately 400 surveys was calculated as being necessary to achieve a 95% level of confidence, with 5% error.

Study area selection

Four study areas were chosen from a variety of potential locations using a site selection matrix developed for this project. This selection matrix ensured that suitable sites were chosen based on hydrogeology (groundwater vulnerability, aquifer type) and practical factors (laboratory proximity and availability of existing data). Three study areas were selected where the groundwater vulnerability was classed as "high" or "extreme", with a fourth area of low vulnerability for comparison. Three of the study areas contained regionally or locally important limestone aquifers, with one area having poor or locally important igneous and metamorphic rock aquifers. Additionally, awareness surveys were completed in a fifth area (not selected as a full study area) owing to its large number of private wells.

Statistical analyses

Responses were numerically coded and analysed using the Statistical Package for Social Sciences (SPSS, 16.0) (SPSS, 2007). A chi-square (χ^2) test of independence (two-way analysis) was carried out in order to investigate significant associations. The p-value (significance) less than 0.05 is used by convention (Agresti, 1996).

RESULTS

To date, 590 awareness surveys have been completed: 227 completed on a face-to-face interview basis and 363 completed as self-administered group surveys. The following section presents interim results from the 227 face-to-face interview surveys, completed over 5 study areas as outlined above (95% confidence interval, 6.5% error).

General findings

Slightly over half of respondents were male (56%). 75% of surveys were completed with owners/users of boreholes (Bored SPS), with the remainder (25%) being completed with users of hand dug or spring wells (HD SPS/Spring wells). There are no data available regarding the relative proportion of HD SPS to Bored SPS in Ireland; however, it is unlikely to exceed 10%.

A high level of awareness was found with regard to knowledge of previous water quality analysis, with only 6.3% of respondents unaware of previous testing. However, approximately 37% of respondents' sources had never been tested for microbial or chemical quality, with this figure increasing to 54% for HD SPS sources. Furthermore, although there was no significant difference in the level of importance attributed to regular testing between Bored SPS and HD SPS respondents, a significant proportion of HD SPS users (55.3%) indicated that they would not be prepared to pay for water quality analysis of their source ($p = 0.02$).

Approximately 8.8% of consumers served by groundwater supplies used bottled water as the main source of water for domestic consumption, the most common reason given for this being a lack of confidence in the quality of the groundwater, especially in cases where infants and young children were present in the household. The median consumption of water from their own private source has been found to be in the range 0.5-1 litres per capita per day.

Source investigation

Approximately 59% of respondents identified at least one potential hazard within 100m (a generalised inner protection zone) of their well. However, further questioning revealed that approximately 73%, 88% and 82% were aware of the presence of slurry/fertiliser spreading, grazing animals and septic tanks, respectively, within the generalised inner protection zone. This suggests that 14%, 29% and 23% respectively, did not consider these activities as being "potential contamination sources". There was no significant difference found between Bored SPS and HD SPS respondents in relation to contaminant source awareness.

Pathway investigation

Respondents were asked a series of questions about the design and construction details of their sources including well diameter, well depth, use of a casing/liner and presence of a grout seal.

Previous studies have shown that "localised" pathways (rapid bypass mechanism where contaminants enter the intake of the water supply due to poor design and/or construction) can be more prevalent routes for contaminant ingress than aquifer pathways, particularly in developing countries (Howard et al., 2003; Godfrey et al., 2005). There was found to be an overall higher level of awareness of well design/construction details among HD SPS respondents ($p = 0.002$) (Tab. 2).

Table 2. Level of awareness of design and construction details of private wells.

	Total (% aware)	Bored SPS (%)	HD SPS (%)
Well diameter	48.9	44.5	64.3
Well depth	63.4	61.4	71.4
Average watertable depth	33.9	27.7	53.5
Use of liner/casing	61.2	59.6	67.8
Use of grout seal	22.5	16.9	39.3
Pump type	59	59.6	60.7

Receptor investigation

Respondents were asked if they were aware of particular contaminants in relation to groundwater and the potential human health effects of these contaminants. Results showed a relatively high overall awareness of faecal coliforms/*E coli*, *Cryptosporidium* and nitrate as groundwater contaminants; however, there is a knowledge gap exists concerning other contaminants, particularly *Rotavirus* and *Giardia* (Tab. 3), both highly infectious enteric pathogens. Further questioning found that 30% of respondents were not aware of any illnesses or symptoms associated with drinking from contaminated water supplies.

Table 3. Level of awareness of potential groundwater contaminants.

	Total (% aware)	HD SPS (%)	Bored SPS (%)
Faecal coliforms	94.7	94.6	94.5
Rotavirus	26.4	23.2	27.1
Cryptosporidium	74	69.6	74.7
Giardia	4.4	0	5.4
Manganese	33	25	34.3
Lime (hardness)	96.4	96.4	96.4
Nitrate	78.4	69.6	80.7

Additionally, it was found that there are a higher proportion of elderly groundwater users (>65 years) in households supplied by HD SPS. Approximately 47% of HD SPS supplied households had at least one elderly resident, while this figure was 18% in households using Bored SPS.

CONCLUSIONS

The surveys confirmed that private groundwater sources in Ireland are not regularly tested for water quality, with levels of water quality analysis lower in HD SPS, which are commonly constructed in areas with a shallow water table and are therefore particularly vulnerable to contamination. The awareness surveys have identified a number of knowledge gaps amongst private groundwater users. Around a quarter of groundwater users did not recognise adjacent septic tanks or grazing animals as potential contamination threats (23% and 29%, respectively). Considering that the majority of private groundwater sources are located in rural, un-serviced areas, these particular contamination sources are widespread and typically the most common sources of microbial contamination.

Approximately 30% of respondents were unaware of potential illnesses or symptoms associated with contaminated groundwater consumption, with 73% and 95% having no previous knowledge of *Rotavirus* and *Giardia*, respectively.

It is unclear as yet whether these knowledge gaps may be responsible for increased contamination susceptibility and therefore increased risk to human health. The next phase of the research will investigate if this is the case and if it is found to be, will seek to quantify the overall burden of illness which may be attributed to private groundwater sources as a result of low levels of awareness.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support of the Environmental Protection Agency in Ireland which is funding this research under its STRIVE programme.

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abstract id: **326**

topic: **1**
Groundwater quality sustainability

1.2
Groundwater vulnerability and quality standards

title: **Use of factorial correspondence data analysis to evaluate groundwater chemistry and pollution of a shallow aquifer (Loures Valley, Lisbon, Portugal)**

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keywords: contamination, multivariate data analysis, correspondence analysis, risk

A significant industrial development, associated with a demographic expansion, occurred during the last decades of the XX century, in Loures valley, a region located in the vicinities of Lisbon. This was accompanied with an important modification of land use and occupation patterns, mainly the decrease of the agricultural land.

One of the main consequences was the augmentation of domestic sewage, which, combined with the low levels of wastewater treatment and the reduced dilution power of the watercourses, contributes to the deterioration of the water quality of Trancão River and associated shallow alluvium aquifer. This one is continuous unconfined aquifer and mainly exploited for irrigation by several dug wells.

In order to characterize the magnitude of anthropogenic impact in the groundwater, the results of physic-chemical analyses of waters of 36 shallow wells and soils were sampled during three campaigns (Silva, 2003). The first campaign refers to data collected in a wet year during the summer season; the second campaign refers to data collected in the same year, during the winter season and the third campaign refers to data collected in the next year, a dry year, during the summer season. The list of monitored parameters are EC (electrical conductivity), pH, major anions (HCO_3, SO_4, Cl, F), major cations (Na, K, Ca, Mg) and trace elements (Al, Cr, Mn, Fe, Ni, Cu, As, Se, Br, Sb, Hg, Pb). Spatial and temporal correlation between variables and time horizons were carried out by using a multivariate statistical approach based on the principle of correspondence factor analysis (CFA).

Developed by Benzécri in the early sixties (Benzécri, 1977, 1982), CFA belongs to a group of factor extraction methods whose main objective is to discover the underlying pattern of relationships within a data set. This is basically done by rearranging the data into a small number of uncorrelated "components" or "factors" that are extracted from the data by statistical transformations. Such transformations involve the diagonalisation of the some sort of similarity matrix of the variables, such as a correlation or variance-covariance matrix. Each factor describes a certain amount of the statistical variance of the analysed data and is interpreted according to the intercorrelated variables. The main advantage of CFA is that symmetry is conferred to the data matrix thus permitting the simultaneous study of correlations within and between variables and samples (Stigter et al., 2006).

With this type of statistical treatment, a similarity/dissimilarity hydrochemical interpretation model is inferred between classes of quantitative variables (build with threshold concentration values) and of qualitative variables (e.g. build with type of soils) for various time horizons.

With this interpretation it was possible to attribute a meaning to the factorial indices (e.g. geogenic vs. anthropogenic or diffuse vs. punctual pollution) and to map the magnitude of each sample in the area under study. Analysis of these maps can be very useful for decision risk management.

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abstract id: **361**

topic: **1**
Groundwater quality sustainability

1.2
Groundwater vulnerability and quality standards

title: **Groundwater vulnerability maps of large areas — application of DRASTIC method in the National park "Djerdap"**

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keywords: groundwater vulnerability, small scale map, DRASTIC method

Groundwater vulnerability methods became a standard tool for creating a base for sustainable groundwater management. In the past decade a number of new methods were created for more precise determination of groundwater vulnerability. However, a large number of input parameters are needed for more precise evaluation of groundwater protection and vulnerability and as a consequence the whole procedure became very complex. This is especially evident when groundwater vulnerability maps of large areas are created. That is why new methods are difficult to apply when **small scale** groundwater vulnerability maps are made.

This paper describes the creation of groundwater vulnerability map of the **National park Djerdap**. The National park is situated in the southeast of Europe, in the northeast of Serbia, along the border with Romania. The most famous natural phenomenon is the beautiful Djerdap canyon, through which the Danube River flows. The National park covers the area of **650 km²**, and the protection zone of the park covers the area of nearly **940 km²**.

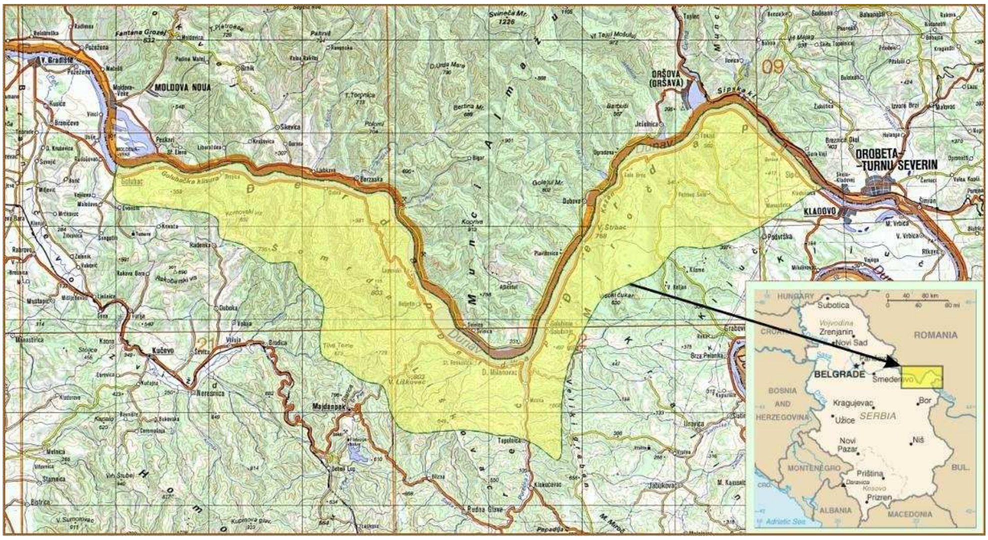

Figure 1. Geographic location of the National Park Djerdap.

This large region is characterized with very complex geological structure. Most extensive are sedimentary rocks, although igneous and metamorphic rocks are easily found. The oldest rocks are of Precambrian age, while the youngest are of Quaternary age. There are more than 80 stratigraphic units found on the territory of the National Park. This resulted in existence of different types of aquifers (Figure 2). Although a large area of the National Park is characterized with insignificant aquifers, there are large areas with karst and fissured aquifers, especially in the eastern part of the Park (Miroc Mountain).

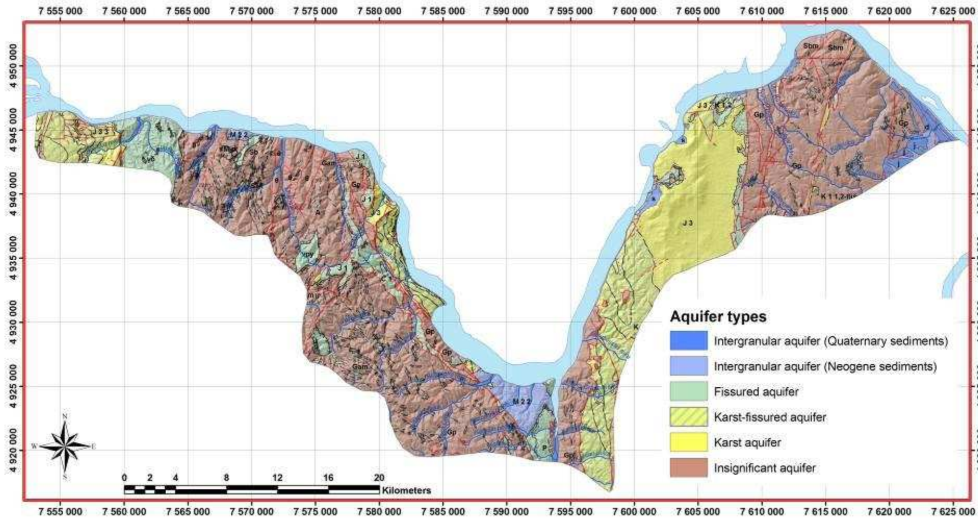

Figure 2. Hydrogeological map of the National Park Djerdap.

DRASTIC method is developed by US EPA and is intended to be a standardized system for evaluating groundwater vulnerability to pollution (Aller, 1985). This method uses seven parameters in order to evaluate the groundwater vulnerability: **D** (Depth to the Water Table), **R** (Net Recharge), A (Aquifer Media), S (Soil Media), T (Topography), I (Impacts of the Vadose Zone) and **C** (Hydraulic Conductivity of the Aquifer).

There are several reasons why DRASTIC method is being chosen:

- Very large area of investigation characterised with different types of aquifers
- Small scale of investigation (1:200 000), which limits the use of some new methods like PI (Goldscheider, 2000), COP (Vias et al., 2006) etc.
- Insufficient geological and hydrogeological data, particularly in the vertical profile.

While using DRASTIC methodology, most difficult was to define the first two parameters, factor D and factor R. Parameters A, I and C were easily defined based on geological and hydrogeological settings in the area. Parameter S was determined using the pedological maps of the National Park, while the map of factor T was easily obtained using the DEM model. In the further text close attention is given to describing how factors D and R are determined.

Factor D. Main parameters which affect the depth of groundwater levels are: hydrogeological characteristic of the terrain on the one hand and distance of the water features on the other. First, the map showing the nearness to the springs, streams and rivers was made (Figure 3).

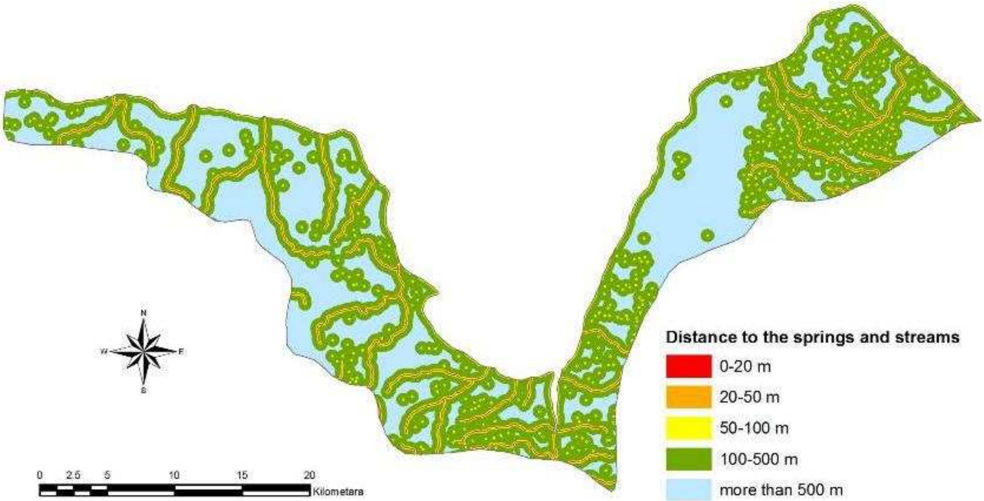

Figure 3. Map showing the nearness to the springs, streams and rivers.

This map is combined with hydrogeologic map of the National Park Djerdap where the depth to the groundwater level is being defined using Table 1.

Table 1. Determination of R factor.

Aquifer type	Distance to the spring or stream (m)	Groundwater depth (m)	R factor
Intergranular aquifer	0–20	0.0–1.5	10
	> 20	1.5–4.5	9
Karst aquifer	0–20	0.0–1.5	10
	20–100	9.0–15.0	5
	100–500	15.0–22.0	3
	> 500	> 30	1
Fissured aquifer and insignificant aquifer	0–20	0.0–1.5	10
	20–50	1.5–4.5	9
	> 50	4.5–9.0	7

Using these values and using the range and rating for factor D according to DRASTIC methodology, map shown in Figure 4 is crated.

Factor R. There are no earlier investigations about infiltration degree at the territory of National park Djerdap. That is why factor R is defined using special methodology where parameters influencing the recharge are being analysed (Piscopo, 2001):

1. Slope analysis and DEM model were used to create the slope map were 4 categories are isolated
2. Precipitation. Data from 21 rainfall stations on the territory of the National park were used. Kriging interpolation was used to create the map of spatial distribution of precipitation and classes were isolated based on the degree of the rainfall.
3. Soil permeability map was created using pedological maps of the research area.

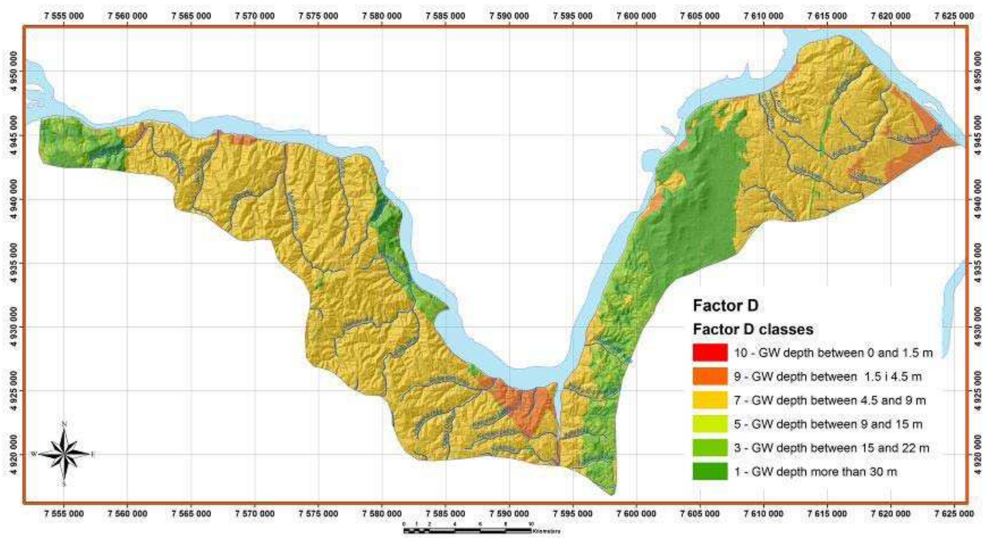

Figure 4. Factor D map.

Scheme presented in figure 5 was used to calculate the R factor and to produce R map shown i figure 6.

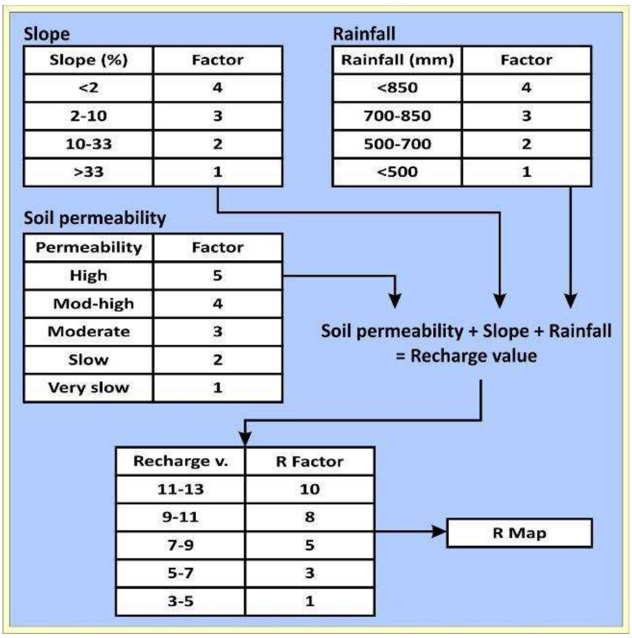

Figure 5. Determination of R factor (Piscopo, G., 2001).

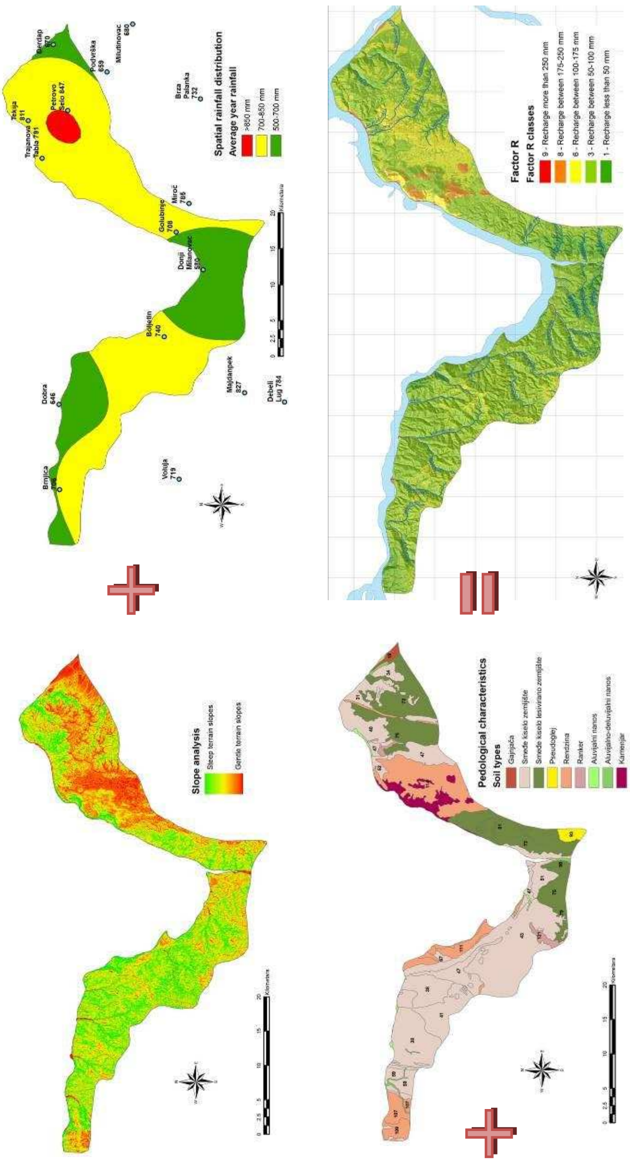

Figure 6. Map of R factor.

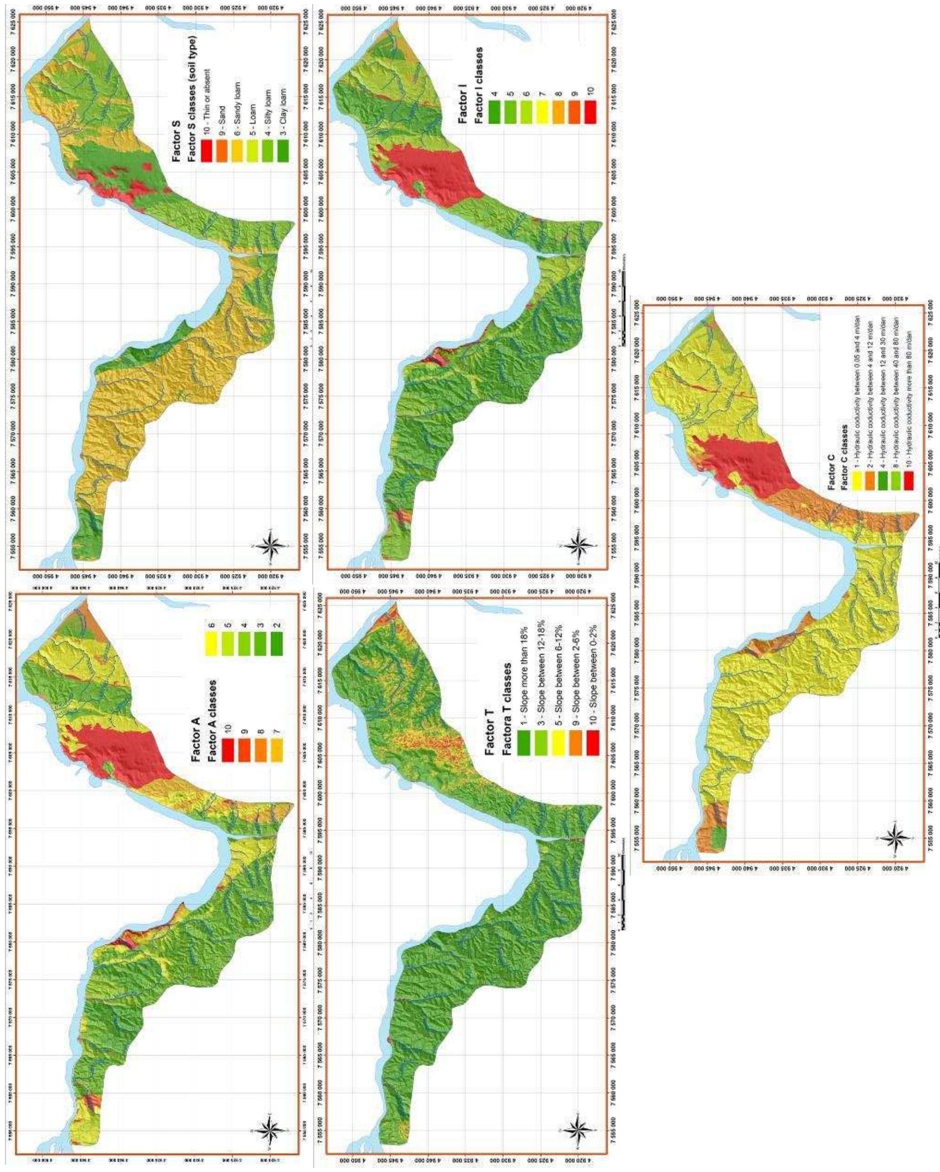

Figure 7. Maps showing spatial distribution of A, S, T, I and C factors.

Determination of the other factors which were necessary to produce the groundwater vulnerability map was much easier. A, I and C factors are determined in descriptive way using the data about geological and hydrogeological settings of research area and rating proposed by the authors of DRASTIC method. Evaluation of pedological properties was done in order to produce the S map, while slope analysis was used to create the T factor map. Final maps of these factors are showed in Figure 7.

Final Groundwater vulnerability map

Aquifer vulnerability or DRASTIC index is calculated by using this formula (Aller, 1985):

Drastic index $= D_r \cdot D_w + R_r \cdot R_w + A_r \cdot A_w + S_r \cdot S_w + T_r \cdot T_w + I_r \cdot T_w + C_r \cdot C_w$

where: r — ratings, w — weight (D_w=5, R_w=4, A_w=3, S_w=2, T_w=1, I_w=5, C_w=3).

Calculated DRASTIC index was used to classify the territory of the National Park Djerdap into areas with different vulnerability degree. Classes are determined by using table 2.

Table 2. DRASTIC index and vulnerability classes (Aller, L., 1985).

DRASTIC index	Vulnerability degree
Less than 75	Very low
between 75 and 100	Low
between 100 and 125	low-moderate
between 125 and 150	moderate-high
between 150 and 175	High
more than 175	very high

Final groundwater vulnerability map using DRASTIC method is shown in figure 8.

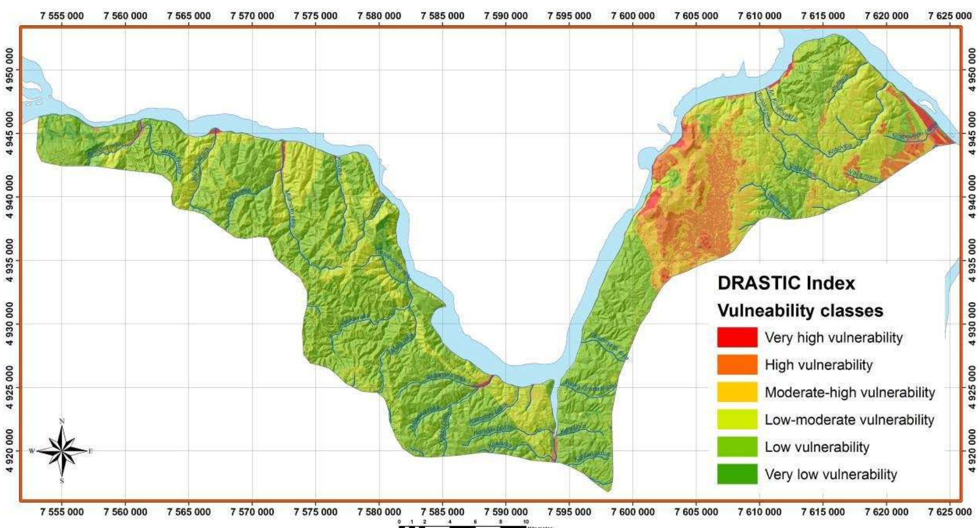

Figure 8. Groundwater vulnerability map of the National Park Djerdap.

Vulnerability map has showed that the biggest part of the National Park area is characterized with low or very low vulnerability. This was expected because the biggest part of the research area is made of rocks where water flows through small fissures and where groundwater level is not near the surface. In these areas soil is well developed as a result of weathering and infiltration is limited due to steep slopes of the terrain. High and very high vulnerability is characteristic for areas in the eastern part of the National Park Djerdap, especially for karst terrains of Miroc Mountain and Quaternary sediments near Kladovo city. These areas are characterized with very good infiltration conditions, high permeability soils, good aquifer conductivity and with very gentle terrain slopes in general.

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abstract id: **385**

topic: **1**
Groundwater quality sustainability

1.2
Groundwater vulnerability and quality standards

title: **Hydrogeophysical study of well fields for drinking water supply for the city of Damascus**

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keywords: groundwater, pollution, vulnerability, geophysics, well-fields

This research aims to evaluate the ability for pollution of the quaternary aquifer, which directly recharge the well–fields for drinking water supply of the city of Damascus under the geological and hydrogeological conditions of the aquifer and the pollution sources spreading nearby.

To achieve this aim, a geological, hydrogeological and hydrogeophisical studies were carried out using the available geological data of boreholes, the geophysical measurement, the results of water level monitoring, the chemical analysis of ground-water and the pumping tests analysis. A surface geo-electrical sounding (VES, R.VES, SP, EP) and geophysical well logging were executed, groundwater samples for chemical analysis were collected and field survey of pollution sources, affecting the aquifer, was carried out.

Data analysis and interpretation as well as data correlation were done, using an advanced package of computer software. As a result the following deductions were reached:

- Neogene–Quaternary sediments in Damascus plane form a complex aquifer system consists of several water bearing horizons of different depths and different thickness.
- Alluvial deposits and partly prolluvial (a – ap Q iii – iv) are dominant in the area of drinking water well field. The thickness of these deposits exceed 300 m, but the effective and productive thickness is in the range of 40–100 m, which is due to the increase of clayey facies with depth.
- The zone of aeration in the studied area is loamy to clayey with sands and gravels; its thickness varies between 1 m up to 29 m.
- The aquifer in the well field is inhomogeneous and the coefficient of permeability is widely variable. It changes from 0.5 m/day up to 146 m/day, which reflects a variable water productivity presented by changing in the value of transmissivity that is ranging from 500 m^2/day up to 6000 m^2/day.
- A preliminary assessment of the productivity of the well fields has been done through calculation of the mathematical formula that simulates the discharge as a function of draw down in each field. A rating of the studied fields could be done according to their productivity, starting with Ibin-Asaker (Al-Talaee & Baitara) as the most productive field followed by Joubar, Kadam (Sikka), Kaboun, Amawieen and ending by Madina Jameieah.
- Indications of high pollution has been noticed in the surface water which recharge the aquifer in the area of well-fields, also high nitrate pollution has been noticed in the ground water, with some heavy metals pollutants still under the permissive limit.
- Sources of pollution surrounding the studied well-fields were located including the following pollutants: Nitrate, lead, Chromium, Cadmium, Arsenic, Zinc, Mercury, Copper, Iron. Those sources of pollution are endangering the ground water to be polluted in the future.
- A calculation of DRASTIC indices has been done for each well field, and as a result it was possible to classify the well-fields area for drinking water supply of Damascus City into three groups, according to its ability to pollution.

As a result, the study has proved, depending on geological and hydrogeological characteristics of the aquifer in the area of drinking water well-fields in Damascus city, that this aquifer is highly vulnerable to pollution, and the existence of pollution sources spreading in the surrounding area increases the danger of pollution of the aquifer. Immediate measures should be taken to establish zones of protection surrounding the well fields to ensure sustainable and healthy source of drinking water.

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abstract id: **408**

topic: **1**
Groundwater quality sustainability

1.2
Groundwater vulnerability and quality standards

title: **The groundwater intakes protection zones as an important element of measures for the protection of drinking water resources**

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keywords: groundwater protection, safeguard zones

THE GROUNDWATER INTAKES PROTECTION ZONES IN POLICY AND LAW REGULATIONS OF UE

Groundwater is a very important and often the only source of drinking water for human supplies. Considering its usable quality and limited resources, it is treated usually as the national strategic good which should be a subject of special regulations relating to its use and protection. This conviction began to spread in the majority of European countries after the II world war and contributed to a quick development of modern hydrogeology, particularly of hydrogeological cartography, evaluation of the groundwater resources by mathematical modeling methods and evaluation of groundwater aquifers vulnerability to contamination. Every country created its own policy in the range of water management and protection, gaining various experience and achieving a lot of success in this field. Extension of the European Union in 2004 r. created a completely new situation in water management, changing in many countries the existing way of seeing the matter. The possibilities of experts' cooperation and the exchange of experience between the countries opened. Implementation of the Water Framework Directive 2000/60/EC (FWD) by the members' countries, standardized the principles of water management and the approach to water protection in the whole territory of the European Union.

One of the principal tasks of the common European policy in the domain of water management is to ensure effective qualitative and quantitative protection of water resources used, or intended to be used in the future, for humane consumption. Those resources should be preserved in a good chemical and quantitative state, similar to their natural state. General conception and the principles of this protection were introduced in the WFD, the basic document which regulates the matters of water management in the members' countries. However, in WFD, as well as in new Groundwater Directive 2006/118/EC (GWD) and WFD CIS —Guidance document No.16, „Groundwater in Drinking Water Protected Areas", there are no detailed directions how to ensure the effective protection of groundwater intakes resources for human supply from their quantitative and qualitative degradation.Generally, we can say that WFD is set on the diagnosis of groundwater resources state, understood as a permanent control of their qualitative and quantitative state (monitoring) in delimited groundwater bodies (GWB). However, the matter of their protection in the form of specific prohibitions, orders and limitations in the use of the terrain is left to the decision of individual states. In accordance with the Directive, the object of protection is not a groundwater intake with its recharge area, but the so-called "*groundwater body*" (GWB) understood as a part of the groundwater used for human consumption or intended to be used in the future. According to art.6 of the WFD, the water resources of these objects must be properly protected. General recommendations concerning such protection are presented in the Guidance document No 16, „Groundwater in Drinking Water Protected Areas". In this document it is stated that the protection of GWB should be realized by delineation and formal setting up the so-called "Drinking Water Protected Areas*" (DWPA*). For this purpose, the so-called "safeguard zones" (SZ) can be set up for the groundwater intakes used for the collective supply of the population. Protection measures proposed for DWPA and SZ should become a part of programs of measures taken for water protection for each river basin district. According to the conception presented in GWD (p. 15) , SZ can be a part of GWB or can cover fragments of several GWBs and even the whole territory of a country. It is incomprehensible and far from protective zones delineation practice applied in most of the countries. It should be underlined that the two terms, DWPA and SZ, are often incorrectly used in above-mentioned documents as synonyms, although they have a different meaning. DWPA is a general notion meaning all the protective areas which are settled up by the members' countries for the protection of their groundwater resources for human consumption, whereas "safeguard zone" is a specific term relating to the protection of water intake recharge area. It would be much better to use the term „groundwater intake safeguard zone" (GISZ) instead of "safeguard zone" (SZ).

GROUNDWATER INTAKE SAFEGUARD ZONES IN THE EUROPEAN COUNTRIES — REQUIREMENTS AND PRACTICE OF THEIR ESTABLISHING

Although setting up of the safeguard zones for drinking water intakes is not required in European regulations, most of the EU countries protect their intakes in this way and the implementation of the WFD did not change anything in this area. In many countries safeguard zones are treated as a principal element of the programs of measures undertaken for protection of groundwater resources designed for human consumption. The principles of safeguard zones delineation and setting up, as well as the effectiveness of the protective measures often differ considerably in various countries. Setting up of those zones for water intakes is important, but often underestimated element of the groundwater resources protection. Therefore, the comparison and confrontation of the experience and regulations in various European countries can be interesting and important for the accomplishment of common European policy in this domain.

The object of the protection — In the European countries it is the rule that safeguard zones are settled up only for the collective supply water intakes. Some countries permit establishing protection zones also for other intakes, at the owner application and cost. Such possibility exists also in Poland for the intakes used by food production and pharmaceutical enterprises, which need water of a high quality.

The duty of setting up the zones — In majority of European countries safeguard zones setting up is obligatory and required for the water intakes for the collective supply with high vulnerability of their water resources to pollution. In Poland this duty was suppressed by the Water Law from 18.07.2001 and the decision in this matter is left to a user.

Criteria and the principles of delineation the safeguard zones — European countries are lacking a uniform approach to this question. Applied criteria are different and the size of established zones are considerably diverse. However, it is the rule that a zone consists of 3 or 4 protective terrains, called variously. In Poland, the Water Law of 2001 r. introduced the protective zone divided into 2 terrains only: the terrain of the direct protection (around the well) and terrain of indirect protection limited by the 25-year izochrone of the water flow to the well. However, there is no any particular reason for this izochrone or for any others.

The methodology of delineation safeguard zones — In Poland, like in all countries, the limits of protected zones are established on the basis of hydrogeological recognition. Differences appear in the range of this recognition and applied computational methods. Simple analytic methods are usually applied only to small, isolated intakes. In case of larger ones or groups of intakes mathematical model investigations are commonly used. In many countries, when a safeguard zone for a groundwater intake is established, they prepare the so-called "vulnerability map" for the whole recharge area. That map becomes the basic element of the risk analysis, necessary for the establishing effective measures aimed at eliminating or reducing the anthropogenic influence on groundwater quality. Modeling methods and the vulnerability maps are still too rarely used in Poland for the delineation of groundwater safeguard zones. The necessity of taking into account the natural resistance of aquifers to the pollution from the surface of the terrain while establishing the groundwater protected areas is unquestionable. The controversial matter is still the way of this analysis and applied methods. In different countries it looks variously what causes that the results of the analysis are incomparable. Some countries apply rang methods (e.g. DRASTIC, EPIK) and other ones apply methods based on calculation of groundwater flow time or pollution migration time.

The principles for establishing protective measures for safeguard zones

Effectiveness of the protection of groundwater resources mainly depends on the range of introduced limitations in the use of the terrain and their execution. The approach to that matter and experience of different EU countries vary a lot. In some countries (e.g. Germany, Holland) the protective zones delineation is strictly regulated by law, which means that it is based on prohibitions, orders and limitations in the use of the terrain. Other countries (e.g. France, Belgium, Denmark, Poland) do not have strict regulations in this domain and proposed protective measures are based on the analysis of the pollution threat to groundwater in the whole intake recharge area. The social and the economical sides are also taken into account. That approach is recommended in the Guidance document No 16, „Groundwater in Drinking Water Protected Areas" , although the European Union does not impose the way in which the problem should be solved.

Institutions setting up the groundwater intake safeguard zone

In most countries the decision about setting up a safeguard zone is taken by local administration. In Poland since 2002 such decisions have been taken by the directors of Regional Water Management Board.

State contribution to the protection of groundwater intakes

In a lot of countries the governments are strongly involved in the protection of groundwater intakes for human consumption. They create national programs and organize financial support for that purpose. France and Hungary are the best example of this approach. Local societies are not able to deal with the problem on their own, so it is the state's role to help them.

Society contribution to the process of setting up safeguard zones

That contribution looks different in particular countries. In those ones where there are strict law regulations in the use of terrains, the citizens' participation in the process of setting up the zones is relatively small (e.g. Germany). In the countries with less strict law in this range (e.g. France, Denmark) this participation is much more significant and really contributes to the success of the whole process. WFD lays stress on inducing societies to be active in the area of water management, so we can expect that in the future societies of EU countries will contribute to it in a higher degree. Polish society has not taken part in the process of setting up safeguard zones since 2002 and there are no any special law regulations concerning the matter in our country.

PRESENT STATE OF THE PROTECTION OF GROUNDWATER INTAKES IN POLAND

Quite a lot of decisions setting up safeguard zones for groundwater intakes have been taken in Poland for last eighteen years. It is estimated that only 14% out of about 11 000 those intakes for humane supplies have a safeguard zone. Even if we accept that not all of them need such preventive protection, because they are not vulnerable to pollution, the number of intakes without protection is still significant. We should also remember that the formal establishment of a zone itself does not assure the proper protection of the water intake resources. The most important is the effective execution of the set up protective measures. The report prepared in 2009 r. on the Minister's of Environment order showed low effectiveness of actions in the area of the protection of groundwater intakes for collective supply and established the „weak points" of the whole process of delineation and setting up zones. On the basis of the report there was then prepared the National Program of the protection of the groundwater intakes resources for the drinking water collective human supply, within which a complex solution of the problem was proposed. It supplements currently realized National Program for setting up protection areas of major groundwater basin (MGB), delineated in Poland in 1990, which are not identical with groundwater bodies (GWB) set up on the basis of FWD criteria. Protection areas MGB and the safeguard zones of groundwater intakes will fulfill FWD requirements in the range of the protection of groundwater resources designed for human consumption.

RECAPITULATION

In the author's opinion, the protection of the groundwater resources from their quantitative and qualitative degradation should begin with the protection of groundwater intakes recharge areas and then spread to the areas which can be used for this purpose in the future (strategic). In all countries, where this matter is treated really seriously, the protection of the groundwater intakes for collective supply makes the most important element of the nationwide programs for drinking water resources protection. Unfortunately, in EU countries the problem is seen in different ways and sometimes belittled. Although the European Union law regulations, expressed in Directives 2000/60/EC (WFD) and 2006/118/EC (GWD), dedicate special attention to the protection of water used for human consumption, they do not require (only recommend) setting up special protective zones for the groundwater intakes.

To sum up, a wider cooperation of EU countries is necessary to deal with the problem. Such cooperation should bring real effects like a uniform methodology of delineation and setting up safeguard zones for groundwater intakes for the collective human supply and also common policy in this range. It should be underlined that in the new GWD text it s stated that the studies for assuring more effective underground water protection have to be continued. In GWD they assume further development and the changes in the Directive so that it could fulfill its task better.

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abstract id: **409**

topic: **1**
Groundwater quality sustainability

1.2
Groundwater vulnerability and quality standards

title: **Improvement of original DRASTIC model for groundwater vulnerability assessment of the Izeh plain**

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ABSTRACT

Groundwater is an invaluable resource that meets a large portion of drinking water for mankind demands. The main objective of this study is to generate groundwater vulnerability map of the Izeh plain. For this purpose, besides the original DRASTIC model, 12-modified DRASTIC models were run. The model that achieved the highest correlation coefficient with water quality data was selected as an optimal model. Seventh modified DRASTIC model has the most correlation coefficient between all groundwater vulnerability models with a correlation coefficient of 0.65. Resulting map revealed that the aquifer is highly vulnerable in the south, southwest and northwest in comparison with other areas of the basin.

INTRODUCTION

Groundwater vulnerability to contamination could be described as the natural tendency for contaminants to reach some particular position in the groundwater system after their presentation at some point of the uppermost aquifer (National Research Council, 1993). It prioritizes the areas where groundwater protection is critical and evaluates land use activities with respect to the development of pollution. In addition, groundwater vulnerability map can expedite the remediation process with efficient allocation and information for clean up and also with designing of the monitoring network.

The main objective of this study is to generate groundwater vulnerability map for the Izeh Plain. The Izeh Plain is located in southwest of Iran (Figure 1). The plain extends about 140 km^2.

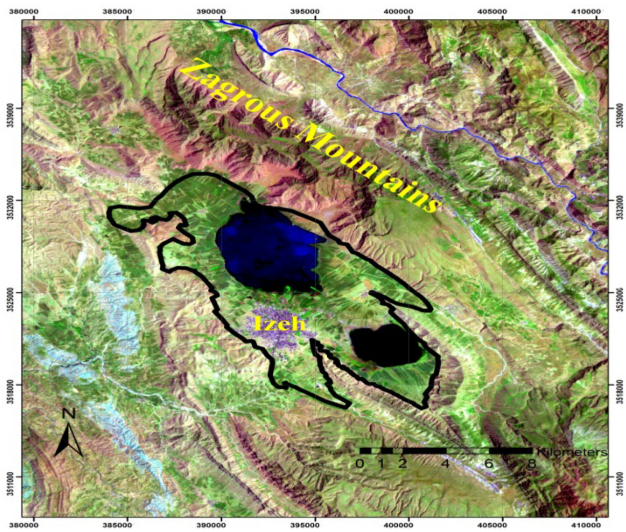

Figure 1. Study area.

METHODOLOGY

In this research, DRASTIC model was applied in GIS environment to create groundwater vulnerability map. DRASTIC model has developed by the United States Environmental Protection Agency (EPA) to assess groundwater contamination potential (Aller et al., 1987).

The parameters required for using DRASTIC model are: D - Depth to water, R - net Recharge, A - Aquifer media, S - Soil media, T - Topography, I - Impact of vadose zone media and C - hydraulic Conductivity. The original DRASTIC model applies a combination of all the parameters with a given weight (w) and rate (r), according to the following equation:

$$\text{DRASTIC Index} = DrDw + RrRw + ArAw + SrSw + TrTw + IrIw + CrCw \quad (1)$$

RESULTS AND DISCUSSION

All seven DRASTIC factors were integrated in GIS platform. At first, the original DRASTIC model was provided using original weights and rates suggested by Aller et al., 1987. Pearson's (r) correlation coefficient of original model with nitrate samples was 0.37. This correlation coefficient was not satisfied. In order to improve and optimize the initial vulnerability map, the rates of each class and the weights of each DRASTIC parameters ware modified subjectivity, according to the conventional DRASTIC model, which allows the user to calibrate the model based on the particular region (Dixon, 2005). To do this, twelve models were run and correlation coefficients of the models were compared with water quality data (Table 1 and Figure 2). D7-DRASTIC model with the highest correlation coefficient, 0.65, with the field data was selected. Figure 3 illustrate the scatter diagrams of D7-DRASTIC model with nitrate samples and groundwater vulnerability map of this model is shown in Figure 4.

Table 1. Pearson correlation coefficient of each DRASTIC model.

DRASTIC Models	D-Original	D1	D2	D3	D4	D5
(r)*	0.37	0.11	0.43	0.53	0.47	0.19

DRASTIC Models	D6	D7	D8	D9	D10	D11	D12
(r)*	0.26	0.65	0.61	0.55	0.59	0.48	0.58

*(r) = Pearson's correlation coefficient

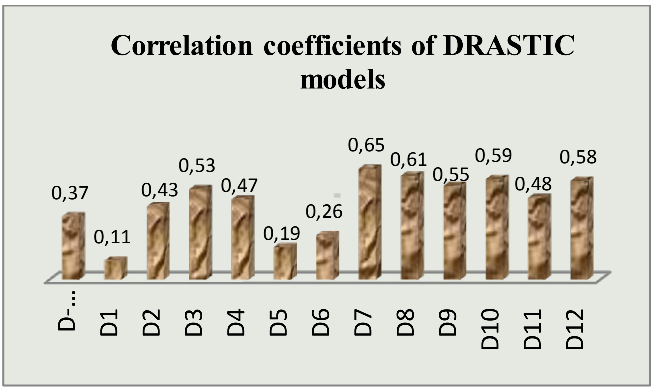

Figure 2. Correlations coefficients between DRASTIC models and nitrate concentrations.

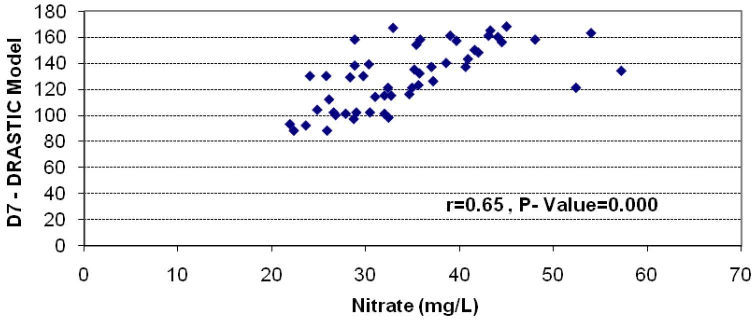

Figure 3. Scatter plot between D7-DRASTIC model and nitrate concentrations.

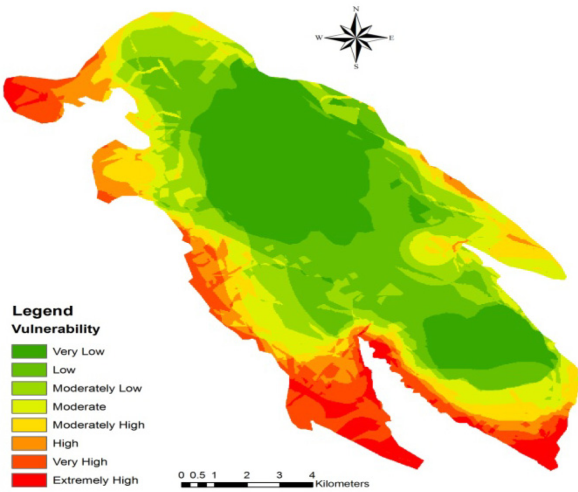

Figure 4. Groundwater vulnerability map.

CONCLUSIONS

Groundwater vulnerability map for Izeh Plain was generated. The final vulnerability map was created from the D7-DRASTIC model. D7-DRASTIC model achieved from improving initial DRASTIC model with correlation coefficient of 0.37 to 0.65. Resulting map revealed that the aquifer is highly vulnerable in the south, southwest and northwest in comparison with other areas of the basin.

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IAH 2010 Krakow

abstract id: **424**

topic: **1**
Groundwater quality sustainability

1.2
Groundwater vulnerability and quality standards

title: **Vanadium as an indicator of groundwater arsenic contamination in urban environments**

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keywords: groundwater arsenic, vanadium, aquifer contamination, particulate

ABSTRACT

Variable concentrations of arsenic, As, and vanadium, V, have been found in the Salamanca aquifer system, in Mexican Highlands. Water supply located inside the urban area show temporal and spatial variations of arsenic content. There are not rock outcrops containing such elements. A groundwater and a soil monitoring were carried out. Groundwater arsenic is related to particulate emitted for local industries using fuel number 6. Particulate deposited over vulnerable areas migrates to the upper part of the aquifer system. High As and V concentrations are been found in soils around the industrial area. As is also coming from As-bearing minerals of deeper units.

INTRODUCTION

Since early 90´s, arsenic, As, concentrations over Mexicans standards for drinking water has been detected in the Salamanca aquifer system (Rodriguez et al, 2005; Mendoza, 1980). Vanadium as also been detected in groundwater. Both elements present spatial and temporal variations. As and V were found in the particulate emitted by local industries, mainly a refinery and a thermoelectric plant (Mejia et al., 2007). The origin of both elements was not associated to any formation outcrop. Salamanca City is located in Guanajuato State, central Mexico (Fig. 1).

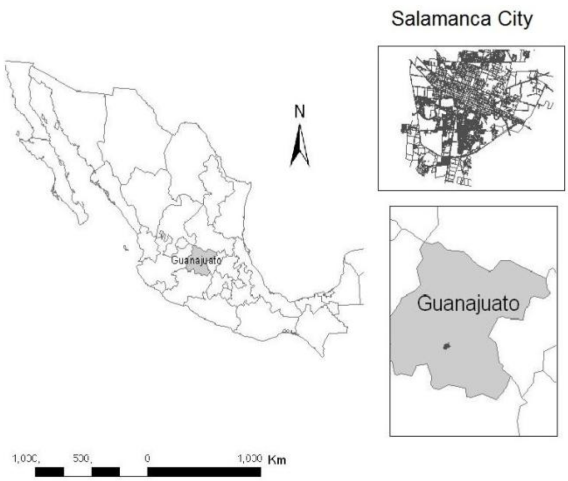

Figure 1. Location Map. Salamanca City.

The area is part of the Mexican Transvolcanic Belt. The oldest rocks are ignimbrites. Tertiary granular sediments overlay the volcanic rocks. Quaternary sediments of variable grain size and thickness form the shallow unit (Rosales, 2001). Groundwater is the only source of water for the more than 140, 000 Salamanca inhabitants. There are not alternate water supply source. The Lerma River crosses the urban area, but it is one of the most polluted rivers in Mexico.

Groundwater vanadium does not represent environmental risks, for that reason it is not included in the Mexican drinking water standards. There are not health affectation reports due to water ingestion even for long periods of time (NIOSH, 1977). By the way arsenic is a dangerous contaminant. It health effects are well known.

METHODOLOGY

A preliminary groundwater monitoring was carried out using the portable test kit Arsenator© for arsenic determinations in situ. Samples form areas with anomalous As values were analyzed in the Analytical Chemistry Lab of the Geophysics Institute using Graphite Furnace.

A soil monitoring was carried out, 10 cm depth. Soil monitoring points were located over vulnerable areas around the industrial area. An aquifer vulnerability assessment based on the SINTACS method (Civita and De Maio, 1997) was carried out. A monitoring network was defined around the industrial area, where a thermoelectric plant, a refinery and chemical industries are located. Samples were collected after Mexican standards. Samples were desiccated over plastic trays into a greenhouse type tunnel. Desiccated samples were crushed in a tungsten vial using a Sepx 8000 Mixer/Mill equipment, after that, samples were quartered and classified to get the finest particles. A second monitoring was carried out in a northern rural area between Salamanca and Irapuato Cities. Analyzes including vanadium, V, some trace metals that conform hydrocarbons; chromium (Cr), lead (Pb), Zinc (Zn) and nickel (Ni).

Descriptive statistic (mean, median, standard deviation, range, minimum, maximum and variation coefficient) was applied using STATISTICA 7.0 Stat Soft Inc and OriginPro 8, OriginLab Co. Correlation and determination coefficient was calculated to determine relationships between variables and its linear tendency.

RESULTS

The presence of fine sediments of high permeability determines the relatively high aquifer vulnerability of areas around the riverbed. The water table is near to surface contributing also to increase vulnerability (Fig. 2).

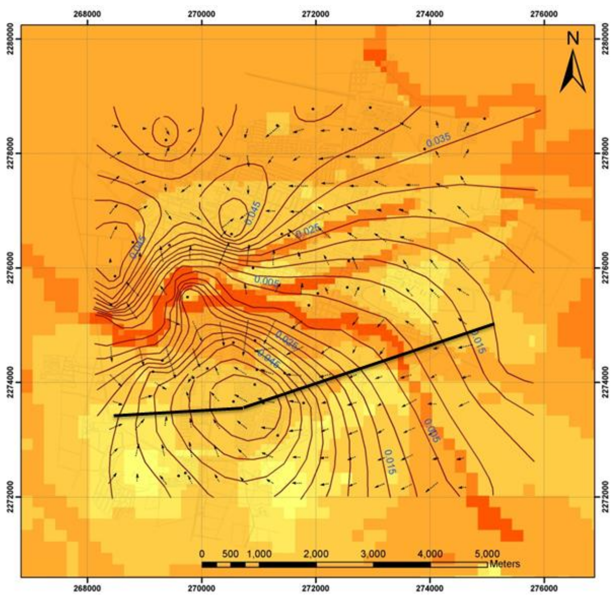

Figure 2. Aquifer vulnerability assessment with V concentrations, November 05 (yellow low values, red high values), including geological profile.

The rural area was considered as a pristine zone. Soil V in such area is related to geology, to volcanic rocks like basalts and rhylites, where as in the Salamanca urban area soil V concentrations has not relation with local geology. Urban soil V concentrations were higher that rural values. Maximum values up 600 ppm were found. Higher concentrations are associated to particulate distribution. Arsenic in the urban area showed greater values that in rural zones. There are not clear As tendencies in rural zones. In Groundwater V and As has similar tendencies.

Vanadium in urban soils is a consequence of the constant deposition of particulate, when V falls over aquifer vulnerable areas, it can migrate to the aquifer when water is available (precipitation, leakages form pipelines and sewage).

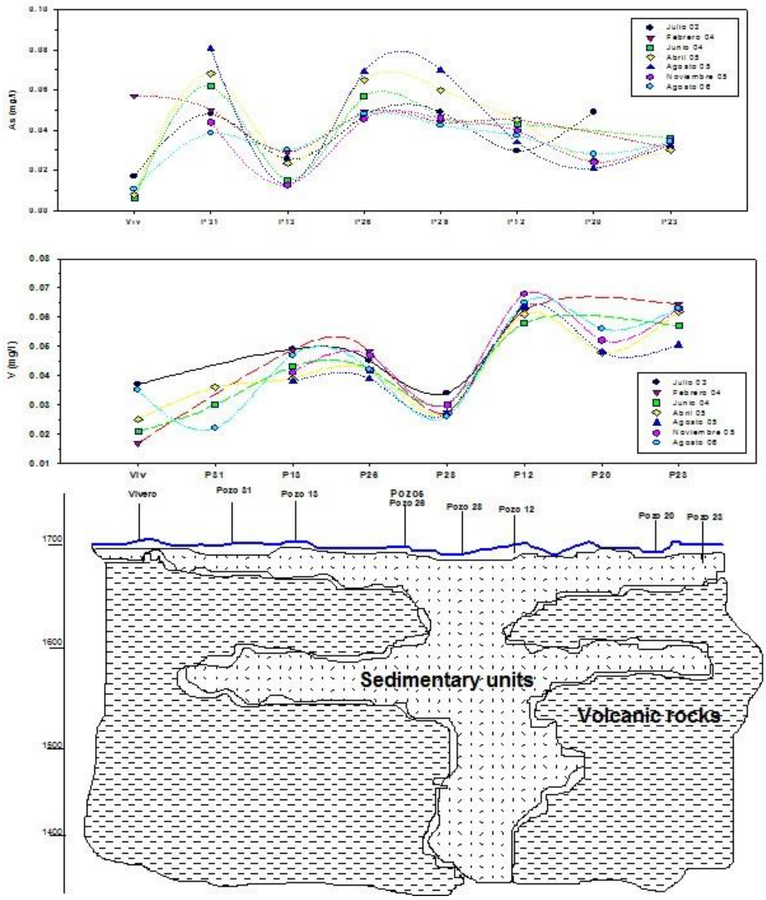

Figure 3. As and V variations and geological profile crssing the southern part of the Lerma River.

Particulate contains As, V, Ni, Zn and other elements and compounds. Its content variations in groundwater depend on solubility, load, composition of soils and vadose zone. Groundwater V and As variations are not similar in time and space (Fig 3). V ans As show a linear relationship in wells located over vulnerable zones (relatively fast infiltration, water availability). Its concentrations are differents but tendency is similar (Fig. 4).

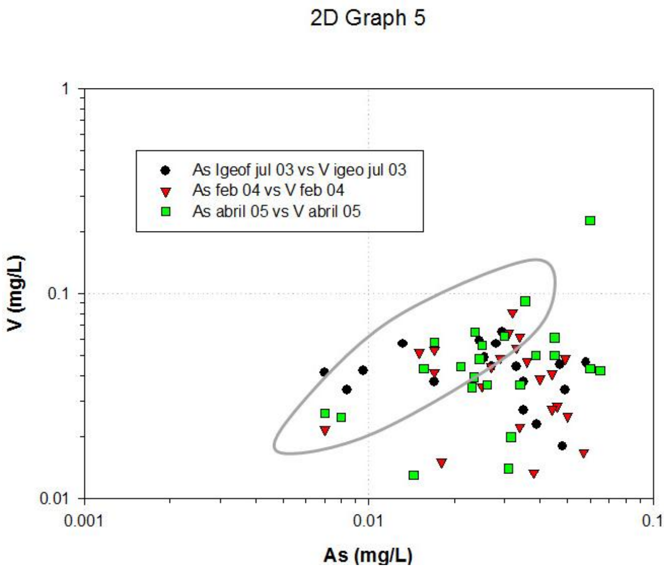

Figure 4. V vs As linear relationship in wells located over vulnerable areas.

DISCUSSION

Vanadium was used as a chemical tracer for arsenic. Vanadium is not an environmental concern whereas arsenic represents a risk for water consumers. In soils V can be used to proof the environmental impact of industrial particulate.

V and As found in urban soils are associated to particulate deposition over vulnerable areas according the results obtained with the SINTACS aquifer vulnerability assessment method. Rain infiltrations and locally water coming from pipeline leakages facilitate its incorporation to the local aquifer system. A subsidence induced fault also propitiates fast water infiltrations. Particulate emitted by industries using fuel num 6 contain great contents of V, As, Ni and Zn. The thermoelectric plant used 5,000 m^3 per day of this fuel. Its V contents vary from 290 to 500 ppm (Salinas et al., 2001). The accumulated contaminant in the last 50 years can explain the presences of both elements in soil and groundwater.

In the urban area must be also geologic contributions. The sedimentary rocks are originated in the surrounding volcanic ranges. The Guanajuato range ore areas are not so far from Salamanca.

ACKNOWLEDGEMENTS

Partial founding was provided by DGAPA, Universidad Nacional Autonoma de Mexico, PAPIIT grant IN116010-2. Groundwater chemical analyses were performed at the IGF Analytical Chem. Lab. by Aguayo A. Ceniceros N. and Cruz O.

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abstract id: **474**

topic: **1**
Groundwater quality sustainability

1.2
Groundwater vulnerability and quality standards

title: **Uranium and radon concentration in groundwater of the Taejeon area, Korea**

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keywords: uranium, radon, MCL

Uranium and radon are naturally occurring elements in groundwater and may lead to harmful effects in human beings. Nationwide survey on radionuclide concentration in groundwater was conducted for four years (1999–2002) after a NGO issued that uranium concentration in some groundwater in Taejeon area, Korea exceeded the US EPA proposed value (20 μg/L). The total number of the groundwater samples during the survey was 636. According to the survey, Taejeon area was regarded as one of the highest potential area in Korea. The geology of the area is rather complex. However, uranium and radon concentration in groundwater is commonly linked to geology, the area was simplified to 3 groups for this study, two-mica granite, biotite granite, and meta-sedimentary rock area. For estimation of the uranium and radon concentration in groundwater of the area, ninety-three groundwater samples were collected in 2000, 2006 and 2008. Most of these groundwaters are used for domestic purposes. Well depth ranges from 15 to 250 m with an average of 115 m (NIER, 2006).

The results of uranium and radon measurements in groundwater are given in Table 1. The uranium concentration in groundwater samples was found to vary from 0.01 to 3,607.0 μg/L with a median of just 4.43 μg/L. About 32% of the samples exceeded 15 μg/L of the WHO guideline based on its chemical toxicity. The radon concentration in these 82 groundwater samples was found to vary 140 to 40,010 pCi/L with a median of only 2,470 pCi/L and about 23% of the samples exceeded 4,000 pCi/L of US EPA's Alternative MCL (AMCL). Since uranium and radon concentration in groundwater is commonly linked to geology, the geology of the area was grouped into 3 for this study, two-mica granite, biotite granite, and meta-sedimentary rock area. The uranium and radon concentration in groundwater returned high in two-mica granite area and low in meta-sedimentary rock area (Tab. 1). Compared with the contents of other countries having similar geology (Morland et al., 1997; Salonen and Hukkanen, 1997) the value of uranium and radon concentration in the groundwater of the area is low. Radon concentration in groundwater has been monitored at a well with a sampling time of 2 or 3 days during early November in 2006 to see the effect of rainfall (Fig. 1). A large variation is observed, with a low value of 3,200 pCi/L after some precipitation, and increase up to 8,600 pCi/L before another precipitation. This large fluctuation associated with rainfall maybe due to direct infiltration of rainfall to the aquifer. Even though the monitored well depth is 134 m and having casing to prevent direct rainfall infiltration. This is one of the reasons why the relationship between uranium and radon concentration in groundwater and other possibly controlling factors, such as well depth, HCO_3 was poor in the area.

Table 1. Uranium and radon concentration 1.

Geology	Samples	Rn-222 (pCi/L)			U (μg/L)		
		Mean	Med.	Max.	Mean	Med.	Max.
Two-mica Gr.	54(45)	5330	3090	23000	117.06	11.14	3607
Biotite Gr.	20(18)	2990	1665	20500	26.39	0.98	402.3
Meta-sedi.	19(19)	*3807*	*1140*	40010	1.79	0.47	11.09
Total	93(82)	4392	2470	40010	67.74	4.43	3607

( ): radon sample

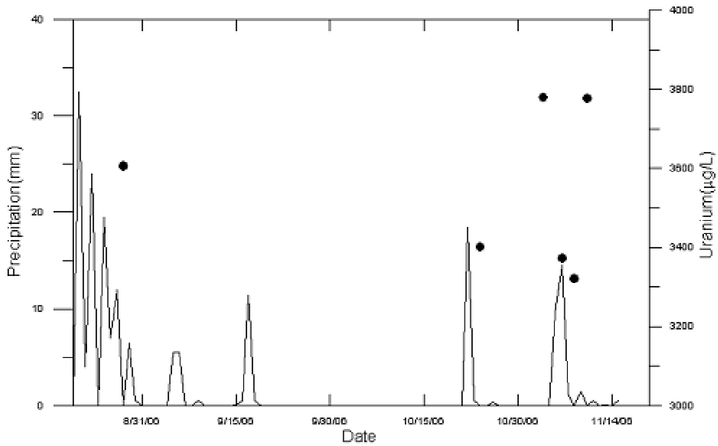

Figure 1. Radon concentration of a well in two-mica area as a function of time.

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abstract id: **501**

topic: **1**
Groundwater quality sustainability

1.2
Groundwater vulnerability and quality standards

title: **Groundwater resources sustainability indicators**

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keywords: groundwater resources, sustainability indicators

INTRODUCTION

Development of water related indicators has been taken up under the Sixth Phase of the International Hydrological Programme. The UNESCO/IAEA/ IAH Working Group has been charged with the development of groundwater resources sustainability indicators that can be applied at the global, national and aquifer level. The following experts, mostly IAH members, joint working group: Jan Girman, Naim Haie, Ricardo Hirata, Annuka Lipponen, Elena Lopez-Gun, Bill Wallin, and Jaroslav Vrba The work has been coordinated by Jaroslav Vrba. The indicators proposed, methodology of their development, the social and economic aspects of groundwater indicators, relevant case studies and indicators sheets were published in UNESCO IHP Series (Vrba and Lipponen ed., 2007).

The main function of indicators is simplification, quantification, communication, ordering and allowing for comparison of different countries and regions . Indicators provide condensate information on the system or process under consideration in an understandable format. They therefore act as important communication tool for policy makers, managers and the public.

The most common use of groundwater indicators is describing the current status of the resource. Regular measurements of indicators provide time series that may inform on the functions of the system or its response to stress. An indicator value can also be compared to a reference conditions and so it can be used as a tool for assessment. Finally groundwater indicators can be used for predicting the future. When models are linked to specific indicators, a time series can be extended into estimated scenarios.

Development of groundwater indicators is a scientific approximation process of presentation of groundwater and aquifer characteristics to various target groups in simplified and understandable form, However, groundwater data scarcity and incompatibility is a serious limitation in formulation of scientific sound and policy relevant indicators. Developing 'good' indicator requires statistically meaningful time series of reliable data to meet defined criteria. If data can be gathered according to commonly agreed standardization measures, than lessons can be drown that may be transposable from one case to the other. However, scaling has to be considered as an important attribute in indicator implementation.

Groundwater indicators serve a variety of management and policy goals. They help in the improvement of groundwater resources planning and management through better assessment of the groundwater resource situation in a given hydrogeological unit, through identification of critical problems and their causes and by providing a basis for comparison with similar spatial unit elsewhere.

THE DPSIR FRAMEWORK

The DPSIR framework has been employed in finalizing the set of groundwater indicators. The DPSIR methodology (D-Driving forces, P-Pressures, S-States, I-Impacts, R-Responses) ensures establishment of the relationship between policy and economic issues and the most burning issues in groundwater resources development and management (Fig. 1).

The DPSIR structure is nor a goal in itself but provides a means to coordinate over the challenges area and supports further cooperation between agencies in sharing knowledge and information. Furthermore, the methodology provides an basis for harmonization in terminology and indicators. The same approach has also been adopted as the framework for the development of groundwater indicators.

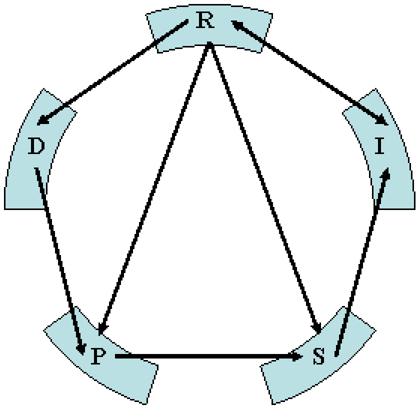

Figure 1. General structure of the DPSIR framework (EEA, 2003).

PROPOSED GROUNDWATER INDICATORS

In the proposed list of groundwater indicators, each of them describes a specific aspect of the groundwater system and/or process and is based on the aggregation of selected variables both quantitative and qualitative. Indicators can be combined into an index, which provides compact and targeted information for groundwater planning, policy and management. The index is dimensionless and weighting and rating systems are applied in its construction.

Proposed groundwater indicators are both scientifically-based and policy relevant, based on measurable and observable data and provide information about groundwater quantity, quality and vulnerability. They are focused on social, economic and environmental aspects of groundwater resources policy and management.

The following groundwater indicators have been developed and tested at the aquifer, national and global scale level:

Renewable groundwater resources (m^3 /year) per capita at aquifer or country level. This indicator defined (estimated) as the total annual renewable groundwater resources is based on groundwater recharge generated from precipitation, the total volume of actual groundwater flow within aquifers coming from and living to the neighbouring countries, seepage from surface water to groundwater and discharge of groundwater to surface water bodies. This is a driving force indicator of social and economic relevance and of great importance for planners and policy makers.

Total groundwater abstraction/Groundwater recharge (m^3) indicator. Total groundwater abstraction means total withdrawal of water from a given aquifer for the water supplies, agriculture and other purposes. Various methods of groundwater recharge have been analysed with respect to climatic, topographic and hydrogeological conditions and effects of land use, vegetation cover and soil type.

Total groundwater abstraction (m^3)/Exploitable groundwater resources (m^3) indicator. The term 'exploitable groundwater resources' means the amount of groundwater that can be abstracted from a given aquifer under existing hydrogeological and ecological conditions, current social and economic constraints and political priorities.

Groundwater as a percentage of total use of drinking water on country level indicator is of social importance since indicates population dependency on groundwater.

Total exploitable groundwater non-renewable groundwater resources (m^3)/annual abstraction of non-renewable groundwater resources (m^3/year) indicator. The annual abstraction should be calculated as a mean value over a significant range of years. An estimate of total lifetime of non-renewable aquifer can be made from current abstraction figures , but must taken in consideration future sustainable development plans for groundwater resource conservation for future generations.

Groundwater depletion indicator expresses excessive groundwater withdrawal from the aquifer which may be reflected in continuous, long term and areal extent of groundwater level decline, drastic reduction or even loss of base flow, changes in groundwater quality and age, land subsidence and in coastal aquifers in increasing groundwater salinity. Increase of pumping costs and decrease of well production jeopardize the economic and social activities sustained by aquifer.

Groundwater quality indicator informs about the present status and trends in groundwater quality and helps to analyse groundwater quality problems in space and time. Indicator is based on groundwater chemical analysis and its comparison with drinking, irrigation or other standards. Availability of data on drinking water standards level is often restricted, indicator can by therefore formulated on widely measured variables electric conductivity, chloride and nitrate, which indicate present status as well as changes in groundwater quality.

Groundwater vulnerability indicator. Natural vulnerability of groundwater is considered for indicator formulation , based solely on hydrogeological factors and defined as an intrinsic property of a groundwater system that depends on the sensitivity of that system to human and/or natural impacts. Parameters of DRASTIC index are applied for groundwater vulnerability assessment.

Groundwater treatment requirements indicator. The classification divides the indicator in three categories according to how extensive a treatment of groundwater is needed: 1) suitable for specific use without treatment (appropriate quality), 2) simple treatment needed (e.g. dilution, filtration, desinfection), 3) technological demanding treatment methods needed(e.g. membrane methods, reverse osmosis, flocculation).

SOURCES OF GROUNDWATER DATA FOR INDICATORS FORMULATION

Formulation o groundwater indicators is affected by uncertainty , which is inherent in several methods of indicators formulation. Uncertainties arise particularly from data scarcity and limitations in knowledge of many aquifers and groundwater basins. In many countries and for many aquifers the necessary groundwater datasets are not yet available.

Establishment and/or improvement and operation of monitoring networks and programmes and real-time data gathering are the main sources of groundwater data for formulation of indicators. Long time series of groundwater data will be a vehicle for better understanding of groundwater system, more accurate and science based groundwater resources evaluation and groundwater indicators formulation. However, in many countries owing to financial and logistic problems systematic groundwater monitoring activities and spatial and temporal coverage of groundwater monitoring variables are decreasing

Various satellite based programmes provide consistent, spatially and temporally coherent data at the global and regional scale and political boundary free view of major elements defining the water cycle. With respect to groundwater the most promising is GRACE (Gravity Recovery and Climate Experiment) mission implemented in several studies focused on identification and assessment of variations in groundwater level and groundwater storage. Space based measurements do not provide accurate data (inclusive of promising gravimetric and radar altimetry remote sensing) and have to be therefore integrated with terrestrial measurements and calibrated according to data acquired from in-situ observations in monitoring wells.

Air born measurements in combination with geophysical photographic and geobotanical methods produced data which may be useful for formulation of groundwater depletion and pollution indicators.

In-situ measured groundwater data is useful for calibration of conceptual and mathematical models of groundwater system. Mathematical models provide reliable predictions of the groundwater system's behaviour and support indicators implementation on spatial (aquifer) scale. The implementation of statistical methods, particularly factor and cluster analysis , can provide reliable data needed for groundwater modelling as well as groundwater indicators formulation.

INDICATORS SHEET

Groundwater indicators profiles are presented on the indicators sheets developed in the framework of the Word Water Assessment Programme for all types of indicators. Standardized indicators sheets facilitate mutual comparability of indicators characteristics, particularly their position in the DPSIR framework, methods of indicator computation, units of measurements, scale of application, interpretation, linkages with other indicators and references.

CONCLUSIONS

The proposed set of groundwater indicators is based on observable data and provide information about 1) groundwater quantity, quality, and vulnerability, 2) human and ecological dependency on groundwater, and 3) human and natural stresses on groundwater and aquifers. The development of more sophisticated indicators depends on international and countries capabilities to cope with challenges related to data monitoring, collecting, assessment , management and reporting both on national and international level.

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abstract id: **512**

topic: **1**
Groundwater quality sustainability

1.2
Groundwater vulnerability and quality standards

title: **Groundwater quality changes due to iron sulphide oxidation in Odra ice marginal valley – long term of the process observations**

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keywords: groundwater quality, ice marginal valley, iron sulphide oxidation

INTRODUCTION

At the well field supplying city of Zielona Góra located in the ice marginal valley of the Oder River near the village of Zawada, significant and catastrophic changes in water quality were observed after three years of pumping.

The changes were related to the oxidation of iron sulphides, which resulted in particularly drastic increase of the content of iron, sulphates, manganese and water hardness as well as in pH reduction. The causes and conditions of the development of the sulphide oxidation process in the first years of the water pumping were discussed in the papers by Kubisz, Ratajczak (1972), Błaszyk, Górski (1981) and Górski (1981). This article presents a comprehensive characteristics of changes in water quality based on the observations conducted for over 30 years of water pumping. Despite the drastic changes in water quality, the well field was still operated, and its water, marked by a high content of iron, was used for purification (coagulation) of the polluted surface water of the Obrzyca River supplying the city of Zielona Góra.

Thus, water has been continuously pumped since the year 1966, and it seems noteworthy that for the whole period of pumping, original structure of the well field has been preserved without any major changes and the influence of antropogenic pollution is minor. This provides a great opportunity to investigate the changes in hydrogeochemical conditions during the long pumping period.

CHARACTERISTICS OF HYDROGEOLOGICAL AND HYDROGEOCHEMICAL CONDITIONS BEFORE THE GROUNDWATER PUMPING

The Zawada well field was situated on the flood terrace of the Oder River in the distance of 1300 m from the edge of a moraine upland (Figure 1).

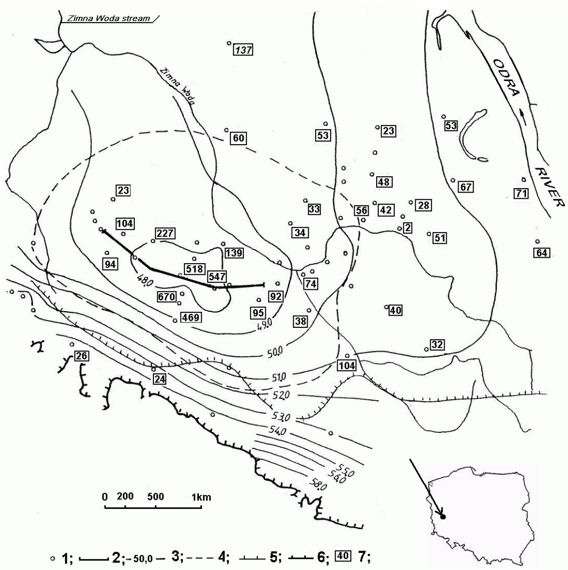

Figure 1. Hydrogeological map of the part of proglacial stream valley near the Zawada well field. Explanations: 1 — observation wells, 2 — well barrier of the Zawada well field, 3 — water level lines (data from the year 1971), 4 — approximate range of depression cone, 5 — range of mud layer occurrence at the land surface, 6 — edge of the moraine upland, 7 — concentration of sulphates in ground water according to data from 1971.

The well field tapping water from the ice marginal valley aquifer with the thickness from several to 30 meters (Figure 2). The aquifer consists of Pleistocene fluvioglacial sands with gravels and pebbles in the bottom part and of a several-meters-thick layer of fine and medium Holocene sands of fluvial origin in the upper part.

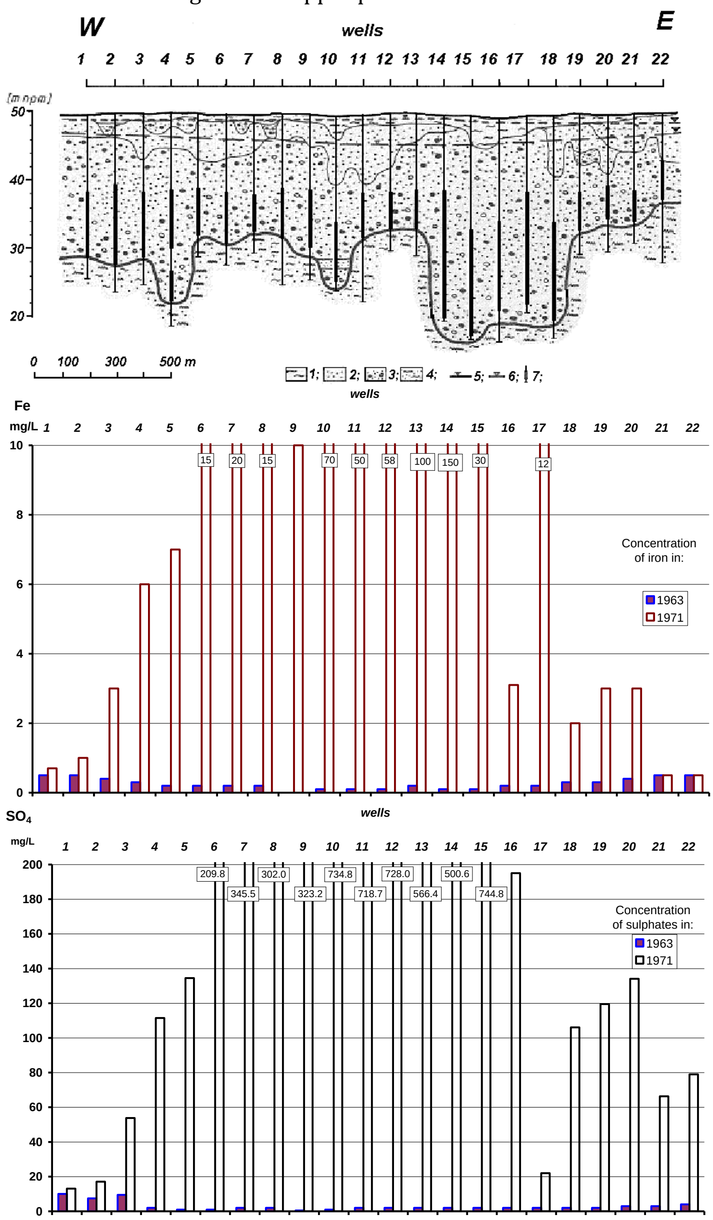

Figure 2. Hydrogeochemical cross section along the Zawada well barrier. Explanations: 1 — muds, 2 — fine and medium sands, 3 — sands and gravels with pebbles, 4 — silts and clays with sand, 5 — water level before pumping, 6 — water level during pumping, 7 — well screen.

At the surface a layer of muds of variable thickness from 1m to 4 m exists. The water-bearing layer is underlaid by muds from the stagnant flood formation series. Before the well field was opened for pumping, the water table was situated very shallowly under the ground surface at the depth of 0.3–0.7 m, and in most wells it was confined by a layer of muds (Figure 2). The recognition of formation lithology at the stage of documentation works was very simplified. Only when the substitute wells were constructed in the years 1971–1972, the lithology was examined in more detail. It was stated that the layer of fluvial formations under a series of muds was enriched with carbonized organic matter and included sulphides. The occurence of sulphides was also stated later in deeper parts of profiles within the fluvioglacial formation series. The water quality along the whole line of the well barrier was exceptionally good, which was the only reason justifying the location of well field in this part of the ice marginal valley.

The concentrations of iron did not exceed 0.5 mg/L, those of manganese — 0.19 mg/L and those of sulphates — 10 mg/L. The good quality was related to the reductive nature of the environment in which iron and manganese precipitated from water in the form of non-soluble sulphides.

CHANGES IN WATER QUALITY IN THE CONDITIONS OF EXPLOITATION

After the well field was opened in July 1966, the first minor changes in water quality were observed in December of the same year. These involved a slight increase of the iron content.

A significant increase of the iron content to 3–4 mg/L was observed as soon as in January 1967. In the following period, the increase was systematic, and so at the end of 1969 the iron concentration amounted to approximately 8 mg/L. From the beginning of 1970 the rate of changes accelerated rapidly and in mid-1970 the concentration of iron in water from all over the well field exceeded 25 mg/L (Figure 3). The increase of iron concentration was accompanied by the increased sulphates, manganese and water hardness. The pH reaction decreased significantly. Very high concentrations of iron persisted until the beginning of the year 1972, and then a systematic decrease was recorded. The stabilisation of iron concentrations at a much higher level than before the pumping was observed from the year 1985, 15 years after the maximum concentrations occured.

Approximately at the same time, the concentrations of sulphates and manganese, as well as water hardness also stabilised (Figure 3). The water quality after the stabilisation of hydrogeochemical conditions is typical for most well fields situated on the flood terraces of ice marginal valleys.

The analysis of changes in water quality from particular wells indicates that the largest, catastrophic changes were observed only in 5 wells of the central part of the well field (wells 10 to 14 — Figure 2). In the outermost wells, the changes were hardly noticeable. The reason for the most significant changes in the 5 above mentioned wells was mainly the fact that in this part of the well field the depth of muds was relatively large, so that the water surface never lowered in natural conditions below the bottom of these formations, which only happened after the well field was opened. In the outermost parts of the well field, the depth of muds was smaller and, consequently, the aeration processes of the upper parts of the water-bearing layer could partly occur also in natural conditions, and the products of hydrogeochemical changes were taken to surface watercourses by means of shallow circulation systems.

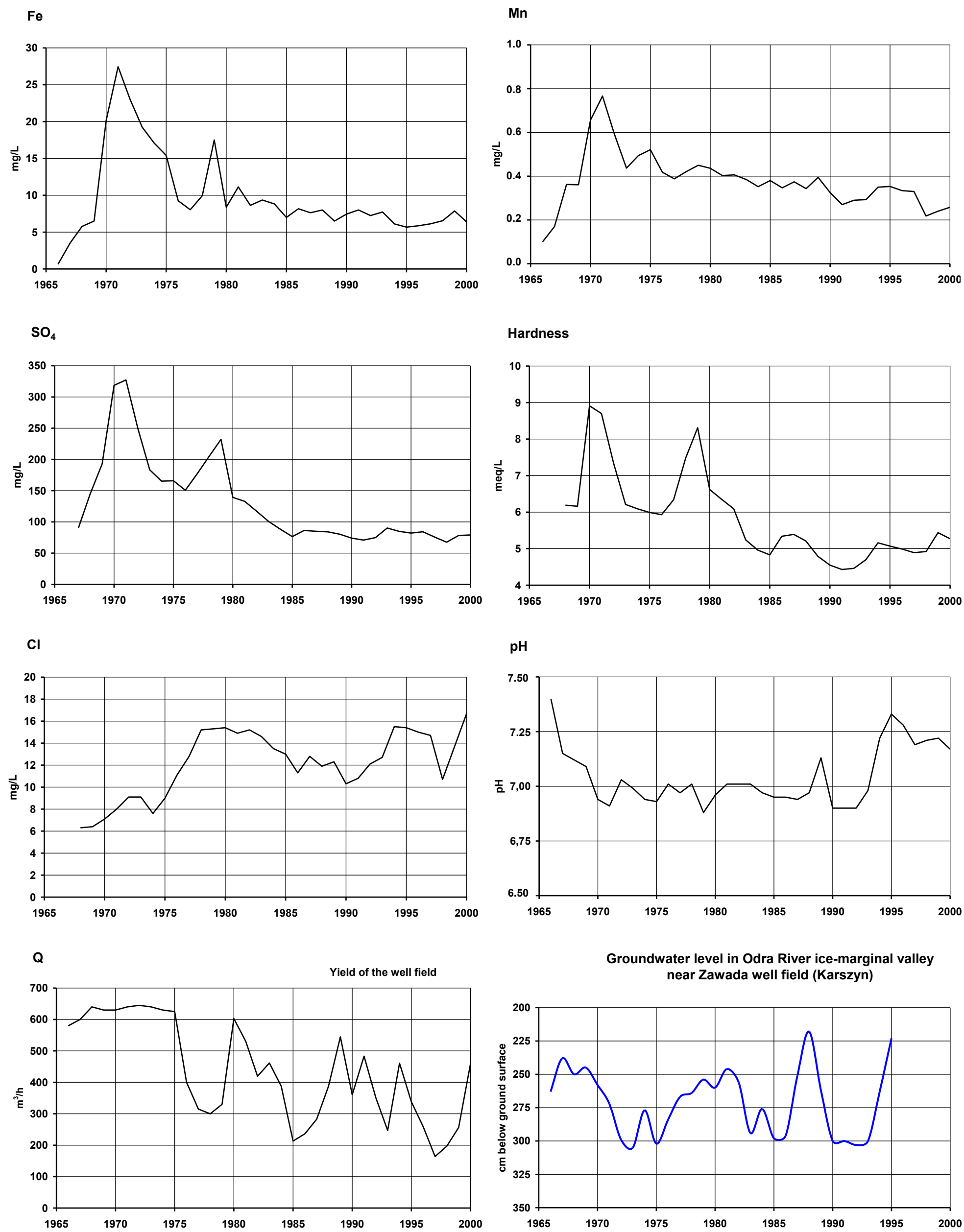

Figure 3. Changes of selected hydrochemical indicators during the Zawada well field pumping on the background of pumping yield and unconfined, shallow groundwater level fluctuations (hydrochemical data from the collective well).

As it may be concluded from Figure 1, the spatial range of intensive hydrogeochemical changes around the well field was smaller than the range of the depression cone and was easily noticeable in the distance of 500 m from the central part of the well field.

IDENTIFICATION OF HYDROGEOCHEMICAL PROCESSES CONDITIONING THE QUALITY OF WATER AT DIFFERENT STAGES OF WELL FIELD EXPLOITATION

As a result of the analysis of the changes in water quality at the Zawada well field based on the iron concentrations graph, the following stages of the process may be distinguished (Figure 4): stage I — lack of noticeable changes in water quality, stage II — systematic deterioration of quality with relatively small gradient of changes, stage III — rapid deterioration of quality, stage IV — persisting high concentrations, stage V — systematic decrease of concentrations with a large gradient of changes, stage VI — systematic decrease of changes with a small gradient of changes, stage VII — relative stabilisation of concentrations. Stage I lasted for about 200 days. In this period, the depression cone was being formed and the inflow from the lower parts of aquifer influenced the water quality.

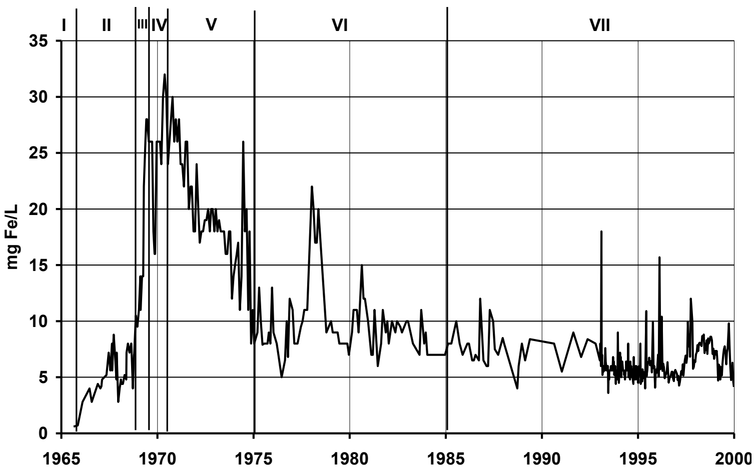

Figure 4. Phases of iron concentration changes in ground water from Zawada well field. I–VII — phases of iron concentration changes (see explanation in the text).

At stage II, which lasted for about 800 days, a systematic increase of iron concentration to the level of 7–8 mg/L occurred. The increase was connected with the oxidation of sulphides. There is no record concerning sulphates in the first period of pumping. However, as soon as at the beginning of 1968, the concentration of sulphates amounted to 70–90 mg/L at the iron content of about 5 mg/L. The deterioration of water quality at the second stage may also have been influenced by the water inflow from the area of the well field supply as well as from the upper parts of the aquifer, where the processes of sulphide oxidation might have developed in natural conditions.

A relatively slow course of changes at the second stage should be connected with the gradual development of *Thiobacillus thiooxidans* and *Thiobacillus thiopharus* bacteria, which are necessary for catalyzing the sulphide oxidation process, and whose presence was stated during the research (Błaszyk, Górski, 1981).

After the period of slow bacteria growth at stage II, their rapid development followed, which caused a rapid acceleration of the sulphide oxidation process (stage III duration — about 150 days).

During the next period (stage IV), a relative stabilisation of concentrations at the level of 25–32 mg/l occurred and lasted for about 300 days. Stage V, lasting for 1460 days, was the period of rapidly decreasing iron concentrations, to the level of about 10–12 mg/L. It should be assumed that this reflects the exhaustion of sulphides subjected to the process of oxidation in the permeable formations. At the next stage (VI), lasting for 9 years, the decrease of iron concentrations to the level of 7.5 mg/L was very slow. It should be assumed that this was linked to the oxidation of sulphides occurring in weakly permeable formations (silts, peats, clays).

It should be underlined that at stage VI a significant periodical increase of iron and sulphate concentrations was noticeable. The increase may be correlated with the increased consumption of water from the well field, as well as with the groundwater table increased after a long period of its lowering (see Figure 3). According to Frost (1979) (after Witczak, 1984), the decrease of concentration caused by the exhaustion of leached sulphides, may be described by an exponential correlation $C = C_m \cdot \exp(-kt)$ where: C_m — concentration of the discussed component at the beginning of the concentration decrease stage (t=0), C — concentration after time t, k — constant characterising the leaching conditions.

In the investigated case, assuming for stage V that C_m = 28 mg/L, C = 12 mg/L, C_o = 0.3 mg/L and t = 1460 days, it may be calculated that the period of semi-decomposition (C = 0.5 C_m) for iron amounts to 1174 days (3.2 years), which is in accordance with the calculations by Witczak (1984) and with the data provided by Frost for the English coal mines, at dehydration, whose time of semi-leaching of sulphides amounted to about 1 year to 5 years.

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abstract id: **528**

topic: **1**
Groundwater quality sustainability

1.2
Groundwater vulnerability and quality standards

title: **Irelands national groundwater protection scheme**

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keywords: vulnerability, permeability

INTRODUCTION

The Groundwater Protection Schemes (GWPS) employed in Ireland (DELG/GSI/EPA, 1999) are based on the concept of groundwater contamination risk assessment and risk management and have been undertaken by the Geological Survey of Ireland (GSI) in partnership with Local Authorities as an effective means of protecting groundwater by informing planning and licensing processes.

The spatially related scheme allows a consistent protection policy approach across the Irish landmass, which is thorough, accurate and systematic, and employs the hazard-pathway-target model. The main components of the land surface zoning element of GWPS are Groundwater Vulnerability and Aquifer maps. This abstract focuses on the groundwater vulnerability.

The GSI has received National Development Plan funding which will allow the completion of a national subsoil permeability map and a depth to rock database. These data will allow groundwater vulnerability and groundwater protection zones coverage to be created, thus assisting in the completion of a National Groundwater Protection Scheme programme.

GROUNDWATER VULNERABILITY

Groundwater Vulnerability is defined as the intrinsic geological and hydrogeological characteristics that determine the ease with which groundwater may be contaminated by human activities (Daly, Warren, 1998). In general, little attenuation of contaminants occurs in the bedrock in Ireland because flow is almost wholly via fissures, therefore, the subsoils (sands, gravels, glacial tills (or boulder clays), peat, lake and alluvial silts and clays) are the single most important natural feature influencing groundwater vulnerability and groundwater contamination prevention. Groundwater is most at risk where the subsoils are absent or thin (areas where the subsoils are absent or thin equates to areas of bedrock outcrop (at surface) or subcrop (within c.1m of the surface)) and, in areas of karstified limestone where direct ('point') recharge occurs, e.g. where surface streams sink underground at swallow holes.

ATTRIBUTES THAT DETERMINE GROUNDWATER VULNERABILITY

The vulnerability of groundwater depends on 1) the time of travel of infiltrating water (and contaminants); 2) the relative quantity of contaminants that can reach the groundwater and; 3) the contaminant attenuation capacity of the geological materials through which the water and contaminants infiltrate. These factors are a function of:

- the permeability/porosity of the subsoils overlying the groundwater,
- the thickness of the unsaturated zone through which the contaminant moves, and,
- the type of recharge (either point or diffuse).

In the majority of situations across the Irish landscape, recharge to the groundwater system takes place diffusely. The rates of infiltration and percolation will depend on how permeable the material is combined with how thick it is e.g. rates will be slow if there is thick clay, as opposed to thin gravels. The result is that the groundwater deep below the surface is protected intrinsically by the recharge mechanism itself as the soil and subsoil filter the recharging water, albeit at different rates and therefore to different degrees of purification.

Also considered is the 'type of recharge' i.e. diffuse verses point recharge. At locations of point recharge, there is rapid flow to the water table via a preferential flow pathway that bypasses the soil and subsoil filter. Mapped locations of point recharge comprise certain karst features such as swallow holes, cave entrances and collapse features.

THE GROUNDWATER VULNERABILITY MAP

The subsoil permeability and depth, and localities of point recharge are mapped and combined to provide a groundwater vulnerability assessment. Four groundwater vulnerability categories are defined: extreme (E), high (H), moderate (M) and low (L). A subset of the 'extreme' category is termed the 'X – extreme' category, and relates to areas of bedrock outcrop or subcrop, or within 30m of a location of point recharge. Vulnerability mapping guidelines are shown in Table 1 and an example of a vulnerability map is given in Figure 1.

Table 1. Vulnerability Mapping Criteria.

Depth to rock	Hydrogeological Requirements for Vulnerability Categories				
	Diffuse recharge			Point Recharge	Unsaturated Zone
	high permeability (*sand/gravel*)	Moderate permeability (*sandy subsoil*)	low permeability (*clayey subsoil, clay, peat*)	(*swallow holes, losing streams*)	(*sand & gravel aquifers only*)
0–3 m	**Extreme**	**Extreme**	**Extreme**	**Extreme (30 m radius)**	**Extreme**
3–5 m	**High**	**High**	**High**	**N/A**	**High**
5–10 m	**High**	**High**	**Moderate**	**N/A**	**High**
>10 m	**High**	**Moderate**	**Low**	**N/A**	**High**

i *N/A = not applicable.*
ii *Release point of contaminants is assumed to be 1–2 m below ground surface.*
iii *Permeability classifications relate to the engineering behaviour as described by BS5930.*
iv *Outcrop and shallow subsoil (i.e. generally <1.0 m) areas are shown as a sub-category of extreme vulnerability.*
(amended from Deakin and Daly (1999) and DELG/EPA/GSI (1999))

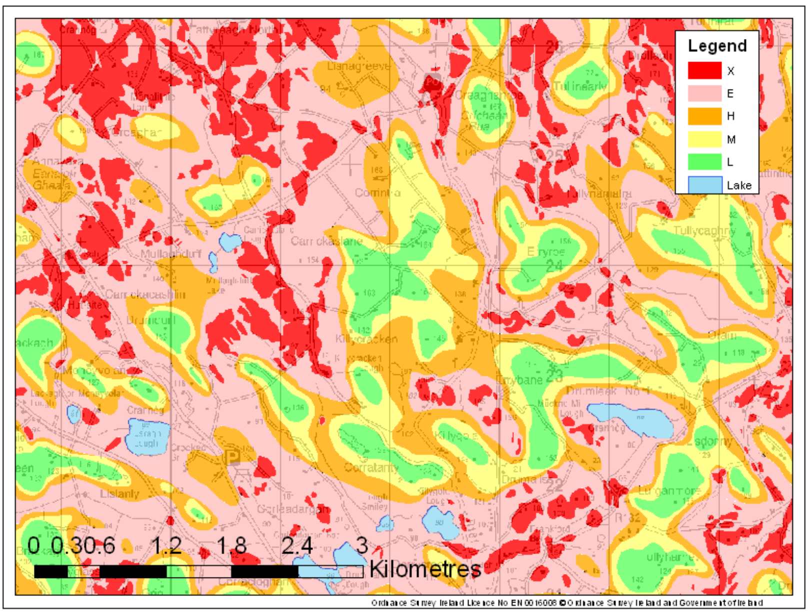

Figure 1. Sample Extract from Groundwater Vulnerability map.

THE SUBSOIL PERMEABILITY MAP

The subsoil permeability map is a critical component of the vulnerability map. Compiling information on permeability of subsoils involves assessing the infiltration capacity of these by direct and indirect means, which is based on the broad question 'can water and contaminants reach groundwater easily?', and results in classifications of 'high', 'moderate' or 'low' subsoil permeability.

High permeability subsoil materials are generally sands and gravels. Moderate permeability subsoils are silty to sandy glacial tills that are generally quite free draining. Low permeability subsoil materials are clayey tills, peats and lake clays.

The GSI and Trinity College Dublin have completed a body of research in recent years on permeability assessment, developing proxies for assessing permeabilities at specific locations and to identify secondary indicators that provide an indication of recharge acceptance and vulnerability as a whole, across a particular area (Swartz et al, 2003; Swartz, 1999; Lee, 1999).

The GSI Vulnerability Mapping Guidelines (Fitzsimons et al., 2003) outlines the approach taken in subsoil permeability mapping. This is a holistic method involving:

- field description/classification/analysis of texture using British Standards 5930;
- sampling and detailed grain size analysis at 'type' localities;
- examination of soil type, particularly presence or absence of mottling;
- presence of 'wet'/'dry' vegetation indicators in the areas examined;
- data on artificial and natural drainage density;
- parent bedrock characteristics and;
- topographic data.

Subsoil permeability mapping is not undertaken within areas where the depth to bedrock is interpreted as less than three metres. In these areas, subsoil matrix and permeability are considered to be unpredictable due to the influence of bedrock, the influence of in-situ weathered bedrock and preferential flow paths.

THE DEPTH TO BEDROCK MAP

For vulnerability mapping, total subsoil thickness is assessed using contours at 3 m, 5 m and 10 m. The contours provide general approximation of broad trends across an area at a regional scale. The contouring process is not an automated process; the contours are drawn based on a combination of data, expertise and experience, and the data include:

- Outcrop and shallow rock locations from the GSI databases and the Teagasc Subsoil Mapping Project.
- Depth to bedrock from borehole databases (includes well data from GSI Groundwater Section; borehole data from GSI Minerals and Geotechnical Sections; borehole records from road schemes, site investigations, academic studies, well surveys and other site data from consultants; Bord na Móna peat depth maps; Local Authority well grant records; and mineral exploration drilling).
- Karst data from GSI databases.

- Geophysical surveys.
- Elevation and slope of ground surface.
- Landscape morphology.

CURRENT STATUS OF GROUNDWATER VULNERABILITY MAPPING

The National Groundwater Protection Scheme, and thus National Groundwater Vulnerability map, will be completed by 2012 as part of the National Development Plan II. Figure 2 shows the coverage to date.

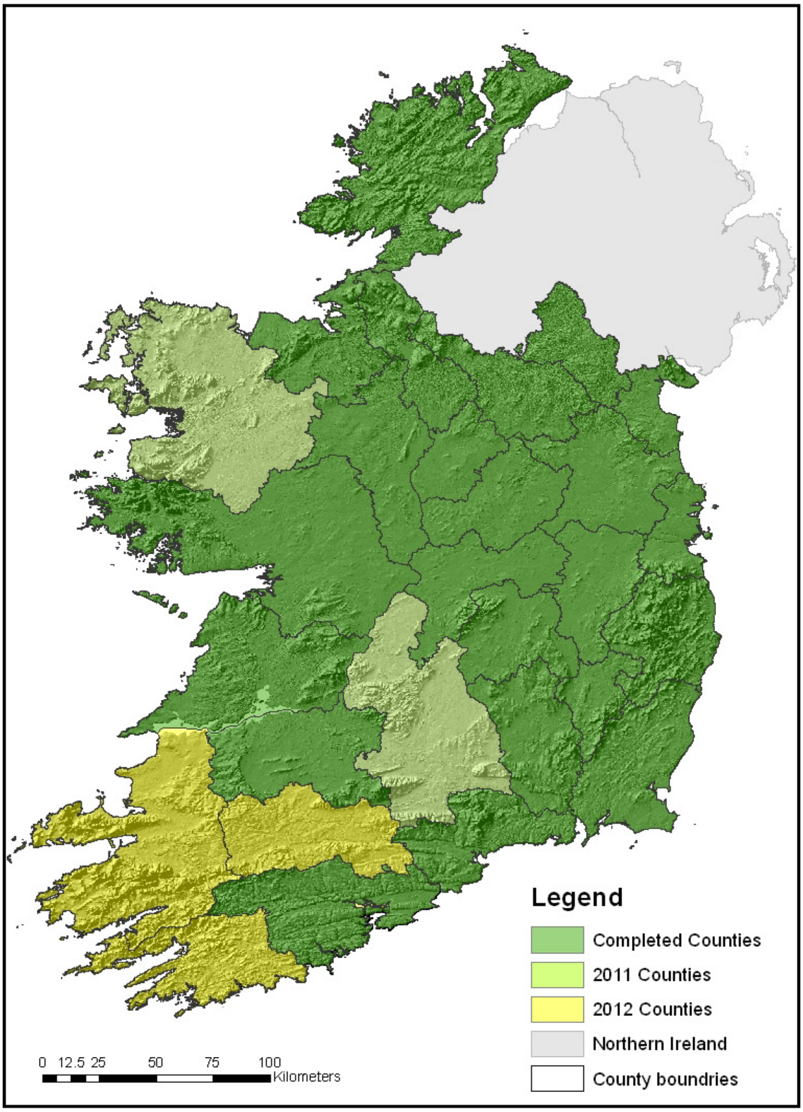

Figure 2. National Groundwater Protection Schemes Status 2010.

CONCLUSIONS

The ongoing vulnerability mapping will continue to improve the national groundwater vulnerability and groundwater protection scheme datasets. Apart from groundwater protection, the underpinning layers, in particular the subsoil permeability map, have been proven to be necessary components for other derived maps, such as the recharge maps. All of these maps are essential to make appropriate decisions in a spatial planning context, which is becoming increasing important with the continuation of the Water Framework Directive process, and to model the impacts of changing environmental parameters on future resources.

ACKNOWLEDGEMENTS

This paper is submitted with the permission of Dr. Peadar McArdle, Director, Geological Survey of Ireland.

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1.3 | Urban hydrogeology

abstract id: **250**

topic: **1**
Groundwater quality sustainability

1.3
Urban hydrogeology

title: **The effects of urbanization on the sustainability of urban groundwater systems**

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keywords: urbanization, recharge, spring flow, water quality, sustainability

The urban and industrial development of Austin, Texas, USA, has affected its streams and groundwater systems. The latter include the karstic Edwards Aquifer and its significant groundwater dependent ecosystem, Barton Springs. Groundwater recharge is impacted by increased "impervious" cover, leakage from utility systems (water mains, sewage lines, storm sewers, and storm water retention/detention ponds), and irrigation systems. These impacts threaten water quality and important groundwater dependent ecosystems, including Barton Springs. The urban hydrological cycle is also altered significantly.

Water budget analyses show a significant increase in recharge in the last 50 years. In addition, double ring infiltrometer studies on pavements show that their secondary permeability is increased with an areal average of 6×10^{-5} cm/sec (Wiles, Sharp, 2008). Preliminary data on storm sewers show leakage rates above commonly-accepted design criteria. Consequently, it is hypothesized that urbanization: 1) increases groundwater recharge by increased localized and artificial recharge; 2) decreases evapotranspiration by native vegetation that is cleared during development; and 3), therefore, increasing recharge with urbanization is probable. This is confirmed by analyses of systems worldwide.

In karstic systems, increasing flow to losing streams adds to the increase of recharge. Recharge rate trends were tested by comparing springflow versus precipitation. Site-specific hydrogeologic data since 1917 in the Barton Springs segment of the Edwards Aquifer were collected and analyzed to develop a relationship between precipitation and discharge. Increased urban recharge has lead to an increase in discharge at Barton Springs relative to precipitation. Trend analyses of monthly-mean springflow and precipitation data demonstrate that Barton Springs discharge is increasing relative to precipitation since 1923 (Sharp et al., 2009); this most noticeable since the 1960s concomitant when the major growth in population and urban area commenced (Garcia-Fresca, Sharp, 2005). This implies that additional sources of recharge are contributing to the overall water budget and that these correlate with the temporal trend of urban sprawl.

Water quality in the streams and groundwater has remained relatively stable, but several trends raise questions about sustainability. In the most urbanized areas of Austin, small streams at low flows have been demonstrated by Sr-isotopic analysis to consist mostly of water that was processed in the City's water treatment plants (Sharp et al., 2006). Leaky utility systems and excess irrigation of lawns maintain the stream low flows (Garcia-Fresca, Sharp, 2005). Barton Springs, which are the main discharge of the Edwards Aquifer, harbor two endangered salamander species. Time trends show increasing levels of anthropogenic contaminants. These include more fertilizers, pesticides, and other organic chemicals. After heavy rains, fecal coliform bacteria concentrations increase significantly. Concerns have been raised that accidental spills or gradual increases in contaminants that come with urbanization might cause extinction of the endangered species.

Detailed spatial management of urban groundwater systems might be the key to their future maintenance and utilization on a sustainable basis. The effects on groundwater, surface waters, and groundwater dependent ecosystems can be managed by a combination of hydrogeologic analyses, urban planning, and engineering design.

ACKNOWLEDGEMENTS

The counsel and assistance of colleagues and former and present students (William Asquith, Jay Banner, Katie Buckner, Trevor Budge, Lance Christian, Bea Garcia-Fresca, Norm Hansen, Jason Krothe, Leslie Llado, Barb Mahler, Mike Passarello, Suzanne Pierce, and Tom Wiles) is gratefully acknowledged. This research was partially supported by the National Science Foundation and the Geology Foundation of the John A. and Katherine G. Jackson School of Geosciences at The University of Texas.

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abstract id: **298**

topic: **1**
Groundwater quality sustainability

1.3
Urban hydrogeology

title: **The impact of recent urbanization on a hard rock aquifer in Malaysia**

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keywords: urbanization, hard rock aquifer, Malaysia

INTRODUCTION

In the last few years the world's proportion of urban dwellers has exceeded 50% (2850 million)(UN, 2009), with most of the most rapid expansions in urban populations taking place in developing nations. Most urban areas in developing countries are located on the coast or on major rivers, as they are in Malaysia (Noorazuan et al., 2003).

When an urban population is increasing, there will be more water consumption and waste production, causing greater pressures on urban water management (e.g. Chilton et al., 1997; Howard and Israfilov, 2002; Tellam et al., 2006). Besides this, urbanization encourages flooding to occur by reducing direct infiltration. It affects the groundwater system by changing, for example, groundwater recharge, modifying existing mechanisms and introducing new ones such that total recharge is often increased (Chilton et al., 1999). If urban water is to be efficiently managed, it is necessary to understand the impacts of urbanization on groundwater systems. In Malaysia, relatively little work has been done on urban groundwater, with most focus being on finding the groundwater sources. In addition, internationally most of urban groundwater research has been conducted in unconfined clastic sedimentary aquifers rather than in hard rock aquifers such as are found in certain of the urban areas of Malaysia. Thus a project has been initiated to provide the knowledge necessary to understand water impacts in urban, hardrock, Malaysia.

Shah Alam has been chosen as the study area since it is the first planned town in Malaysia (Fig. 1), experiencing since 1963 a rapid change from agricultural to industrial development and thus offering an excellent opportunity to study urban impacts as they develop.

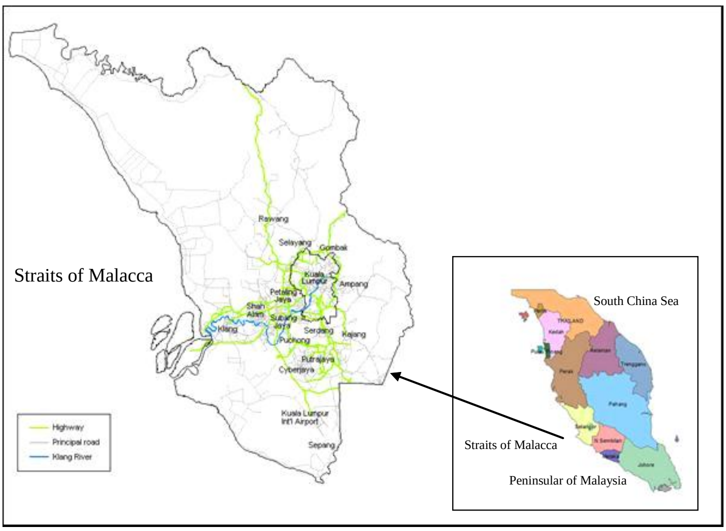

Figure 1. Study area.

This city also has experienced flash floods and shortages of water supply. At present, most of the water comes from surface reservoirs and groundwater has been only used for industry. Shah Alam is underlain by a hard rock aquifer, a type of aquifer also found elsewhere in Malaysia (including the states of Kedah, Selangor, Johor, Sabah and Sarawak), and infrequently studied in the context of urban hydrogeology. Any understandings and methods developed from the present study may therefore be expected to be of use in urban groundwater management elsewhere in Malaysia and internationally.

The aim of this paper is to present a conceptual model of the flow system of this relatively unusual urban aquifer.

HYDROGEOLOGY – DEVELOPING A CONCEPTUAL MODEL

Introduction

Currently, a conceptual model of study area has been developed using information mainly from borehole logs, meteorological data, pumping test data and water quality analyses. Later, this model will be used to develop a full numerical flow model of the flow system.

Borehole Log Evidence

The 31 borehole logs available for the study area have been examined. Table 1 shows the stratigraphy of Shah Alam area. Kuala Lumpur Limestone is overlain by the main aquifer unit, the Carboniferous-Permian Kenny Hill Formation, which consists of coarse- to fine- grained metasediments; overlying the sequence is alluvial deposits of Quaternary age.

Table 1. The stratigraphy of Shah Alam.

AGE	LITHOLOGY
Quaternary	Alluvium
Mesozoic or younger	Granitic rock
Permian - Carboniferous	Kenny Hill Formation (Gobbett & Hutchinson 1973). interbedded sandstone, shale and mudstone. Gentle dips (less than 30°) Geological structure: two sets of vertical joints arranged in north-northeast t south-southwest and east-west and faults
Silurian - Devonian	Kuala Lumpur Limestone

The depth of the boreholes varies, but most are more than 100 m deep. The thickness of alluvium varies, but at most is around 10 m, while the weathered bedrock is up to 30 m thick. The bedrock is fractured and veined with quartz. The lithology across the aquifer varies; with shale in the northern part, interbedded shale and sandstone in the middle part and carbonaceous shale in the eastern part. This variation may or may not indicate changes in aquifer properties. The main flow probably will be by fractures in the sequence underlying the alluvium.

The low permeability of alluvium layer will encourage much of the rainfall in the study area to flow as surface runoff rather than infiltrate to the Kenny Hill Formation below. There is a large river (Klang River), flowing east to west across Shah Alam, and two of the river's tributaries (Damansara and Renggam), flow north-northeast to south-southeast. All three rivers appear to be in direct contact with the Kenny Hill Formation systems, and therefore possibly recharge the aquifer.

Meteorological Evidence

Shah Alam receives on average over 2200 mm rainfall per year. It peaks in March and April and also in October and November. Potential evapotranspiration is around 1500 mm/y. Due to the low permeability of the alluvium, recharge is probably limited, and indeed much runoff is seen in the area. If water levels are lowered by abstraction, greater head gradients across the alluvium may well increase the recharge rates considerably; however, few data are available on the permeability of the alluvium.

Pumping Test Data Evidence

At this moment, abstraction from the aquifer in Shah Alam is only by industry. There are 35 pumping test data sets available from these industrial sites. Typical wells are > 100 m deep, drilled into the Kenny Hill Formation and extract at a rate, on average, of 250-350 m^3/day. There are a few tubewells with pumping rates as low as 170 m^3/day and a few with rates as high as 600 m^3/day.

From standard curve fitting interpretations of the pumping test data undertaken using Aquifer Win 32; transmissivity values are in the range 2 – 4 m^2/day, implying permeability values of 10^{-3} to 10^{-2} m/day. Thus the Kenny Hill Formation aquifer has only modest aquifer characteristics. Storage coefficient values interpreted from the same pumping test data set range from 10^{-3} to 10^{-2}.

Pumping test data from one borehole at a location where the Kuala Lumpur Limestone directly underlies the alluvium are available, and suggest that the limestone may well be more permeable: transmissivity is 160 m^2/day implying a permeability value of 4.2m/day, and the storage coefficient is 10^{-4}. If the permeability of the limestone is as high further south where it underlies the Kenny Hill, this could have a considerable affect on the flow system within the latter.

In addition, the patterns of the pumping test drawdown plots show some interesting features. More than 50% of the tubewells for which pumping test data exist, show recovery to levels below the initial piezometric surface (Figure 2).

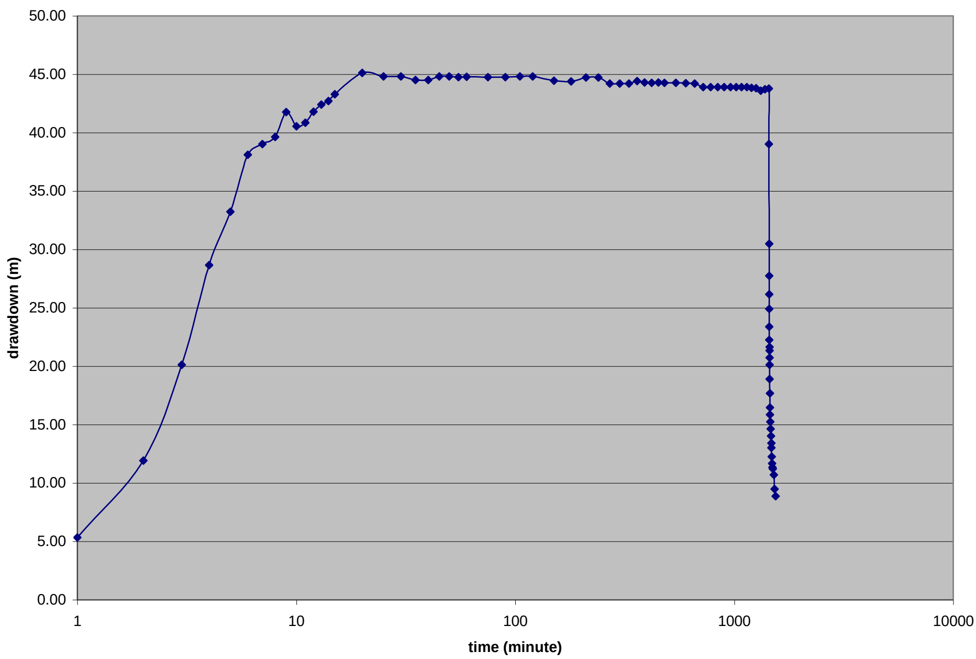

Figure 2. The interesting pattern of drawdown in study area.

This suggests that the pumping tests result in significant depletion of aquifer storage, a result consistent with a flow system compartmentalized perhaps by low permeability discontinuities. However, long term yields are not affected, and in many cases the same wells showing incomplete recover also display a flattening of the drawdown curves suggesting a nearby major source of water (Figure 2), possibilities including the rivers and the underlying Kuala Lumpur Limestone. These and other possible mechanisms are being investigated using numerical modelling of the pumping tests.

Water Quality Evidence

There are 38 tubewells located at industrial/commercial sites in Shah Alam. Water samples have been taken from each of these and analyzed in the laboratory.

The groundwater quality of the study area is characterized by total dissolved solids (TDS) values that are unusually low for an urban aquifer. Most waters have TDS < 100mg/l, as shown in Fig. 3.

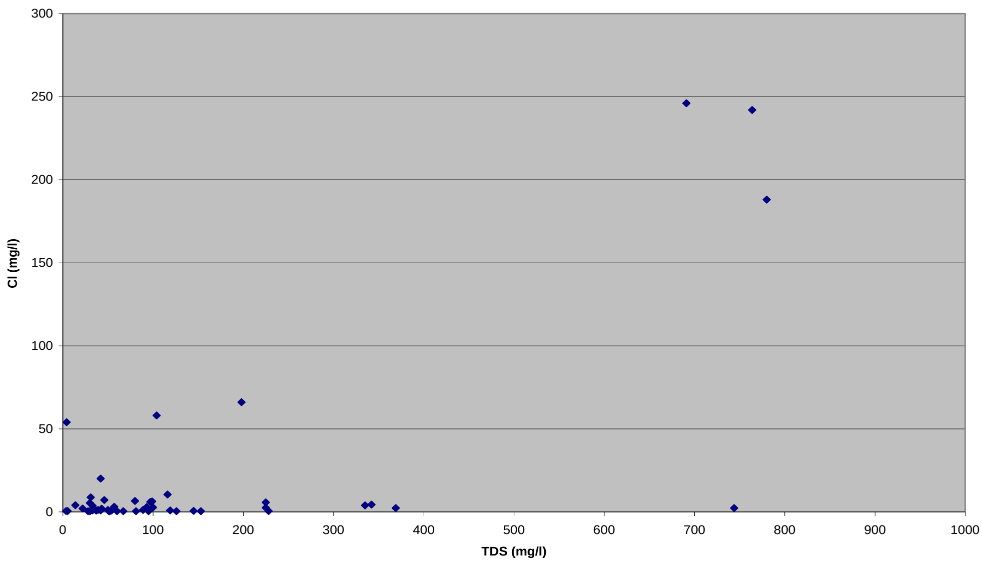

Figure 3. Low concentration of chloride and low total dissolved solid of groundwater sample in study area.

These waters are virtually unpolluted, despite their urban location, and in part this may reflect the young age of the city. Relatively low pP_{CO2} values (0.91- 2.5) suggest that the waters have, nevertheless, passed through a soil zone rather than directly from surface waters. Rainwater chemistry is even lower in concentration, averaging 120 μmol/l TDS, again suggesting that the groundwater has undergone some modification. The increase in TDS from rainwater to groundwater could be accounted for, using two extreme models, by either dissolution with no evaporative losses, or by no dissolution and with evaporation.

Although most water is unpolluted and has a very low TDS, some samples have much higher concentrations, especially in terms of NO_3, heavy metals and bacteria. These are clearly cases of local pollution, showing that the aquifer is far from fully protected by the presence of the alluvium, or by the limited time since urbanization. Viable bacteria suggest that times from surface to well are short, in keeping with fracture flow, though also implying fast pathways from ground surface through the alluvium.

CONCLUSION

This is an unusual urban aquifer that may well pose difficult questions for management. The system appears compartmentalized on a scale that is small compared with the amount of water abstracted by the industrial wells. This suggests that well catchment zones may be controlled by geology rather than by regional flow. Nevertheless, a significant number of wells have a major source of water available to them which limits the drawdown, and this may suggest that vertical flow may well be extremely important in this aquifer. Though water quality is at the moment generally excellent, pollution occurs locally and probably penetrates the aquifer system rapidly. If compartmentalization is occurring, the development of large scale pollution plumes is unlikely, and possibly pollution may be containable. Work continues.

ACKNOWLEDGEMENTS

I would like to thank the Mineral and Geoscience Department, Selangor, Malaysian Meteorological Department and Department of Irrigation and Drainage, Malaysia for supplying the data for this research; also to Ministry of Higher Education of Malaysia and Universiti Kebangsaan Malaysia for sponsoring my study.

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IAH 2010
Krakow

abstract id: **331**

topic: **1**
Groundwater quality sustainability

1.3
Urban hydrogeology

title: **Evaluation of groundwater quality in the wide urban area of Cagliari (southern Sardinia, Italy)**

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keywords: coastal aquifer, monitoring, contamination

INTRODUCTION

Urbanization has a great impact on underlying aquifers as groundwater quality and quantity may be endangered by human activities (Barret et al., 1997; Appleyard, 1995; Baiocchi et al., 2005; Barrocu et al., 1978).

The coastal aquifer beneath the Wide Urban Area of Cagliari, southern Sardinia, Italy (Figure 1) represents a typical case for studying the aquifer dynamics beneath an urbanized area.

The study area has a surface of 100 square kilometers with a population of about of 300,000 inhabitants, representing the 40% of the Sardinian population.

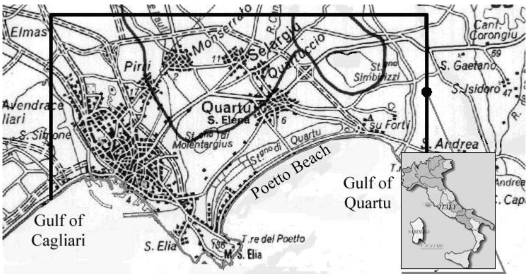

Figure 1. The study area.

The urban area of Cagliari is located in a promontory projected out to the south into the Mediterranean Sea. The promontory, bordered by the coastal ponds of Santa Gilla, to the west, and Molentargius, to the east, consists of ten hills emerging from the plain of Campidano, in the central part of the Gulf of Cagliari. In 1977, the coastal ponds were considered by the RAMSAR convention among the most important wetlands of the Mediterranean area. (Figure 2).

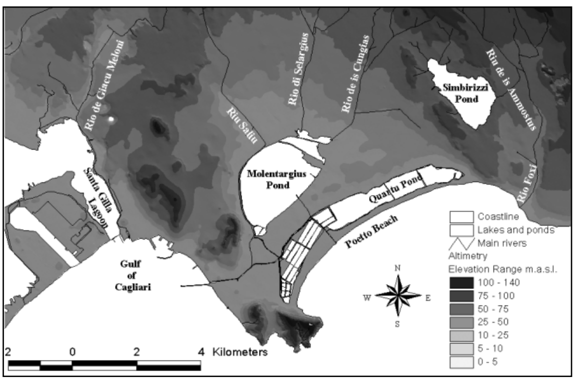

Figure 2. Morphology of the area.

The urban area sprawls from the central hills with their historical settlements to the surrounding plain as far as the slopes of the peripheral hills, pools and coastal borders.

GEOLOGY

The reliefs and the bedrock of the plain are made of a transgressive Miocene series named "Cagliari limestone" (upper Miocene: Tortonian), deposited on the southernmost part of the Sardinian rift in concomitance with the Alpine orogenesis (Santoro, 1970).

The stratigraphy of the urban area of Cagliari is represented in Table 1 (Santoro, 1970). The series consists from top to bottom of biothermal limestones ("Pietra Forte" Auct.), bioclastic sandstones ("Tramezzario" Auct.), and clayeous limestones ("Pietra Cantone" Auct.). The series overlays the "Pirri sandstones" (upper Miocene: Serravallian).

The Quaternary deposits are grouped into two depositional units, the "UBSU (Unconformity-Bounded Stratigraphic Unit) of Portovesme" (upper Pleistocene), and the UBSU of the Holocene deposits, including sediments of different depositional environments (beach, eolian, lacustrine deposits), and anthropic deposits (Barrocu et al., 1981). Hill slope lower parts are locally covered with quarry debris.

The Miocene series was affected and split by several fault systems in different tectonic blocks variously uplifted and depressed with maximum vertical displacements in the order of 200 m, so that the limestone banks of the "Pietra Forte" formation, representing the upper levels of the Miocene series, outcrop on the top of the tectonic blocks and are found a few meters below the present sea level. The ten hills of Cagliari, 76÷145 m high, represent the remnants of the blocks modelled by natural erosion processes and quarrying activities.

Table 1. The main geologic formations of the urban area of Cagliari.

CHRONOLOGY			MARINE, FLUVIO-LACUSTRINE AND LAGOON DEPOSIT	CONTINENTAL DEPOSIT
QUATERNARY	**HOLOCENE**	Actual	*"Formation of Santa Gilla and Molentargius Ponds and Port Formation"*	Quarry debris, artificial ground, sand e coastal dunes
	PLEISTOCENE			
		Würm		*"Red earths"*
		Tyrrhenian /Interglacial Riss - Würm	*"Panchina Tirrenica"*	*Loose "Terraced alluvium"*
		Milazzian II / Glacial Riss		*"Old Terraced alluvium", well cemented*
		Sicilian /Glacial Mindel	*Clays*	
		Emilian/Interglacial Günz - Mindel		
		Calabrian / Glacial Günz		
CENOZOIC		Villafranchian		*"Samassi Formation"*
	PLIOCENE			
	MIOCENE	Messinian	*"Pietra Forte"*	
		Tortonian	*"Tramezzarlo"*	
			"Pietra Cantone"	
		Serravallian	*"Pirri Sandstone"*	
		Langhian	*"Fangario Clay"*	
		Aquitanian	*Marl*	

The hilly land and coastal plain of Cagliari and its surroundings are the final part of a complex hydrographic network system which drains the "Campidano plain" to the north, the mountains of Sulcis to the west and the Sarrabus to the east of the urban area. Many of its original geomorphological features are preserved and have strongly affected regional planning and town development.

The hill of Castello–Buon Cammino is limited to the east by a vertical and locally overhanging cliff 12÷20 m high, representing the visible part of a fault plane, belonging to the fault system which displaced the Miocene series of the area of Villanova in a set of secondary blocks degrading towards the plain bordering y the west the coastal pool of Molentargius. The "Pietra Forte" is locally very fractured and karstified.

Empty spaces due to natural porosity and underground excavations in the carbonatic series, such as ancient cisterns, wells, rock chambers and WWII bomb shelters caused local settlements which seriously damaged building foundations and structures. Relief cliffs experienced serious rockfalls over the centuries, and were considered officially unstable till the 1980's (Barrocu et al., 1981), when a long series of remedial works to prevent rockfalls and erosion were started and eventually carried out, so that slopes are now stabilized.

Underground excavations started in prehistorical times and became systematic in the Punic period. The "hypogean rooms" the large necropolis of Tuvixeddu, one of the most important of the Mediterranean region. were used both as dwellings and tombs. Most of them were destroyed by quarrying dimension stones and limestones for mortar and industrial cement production. Some hypogean tombs of the necropolis were destroyed in the II century b. C. by the Romans, who tunneled through the area with their underground aqueduct system, one of the most important construction of their time in Sardinia. From the necropolis the aqueduct branched out in several canals and pipelines in tunnels to supply water to the ancient quarters of Karalis (Cagliari) (Santoro, 1970).

CLIMATE

The Campidano plain is characterized by a Mediterranean-maritime climate with the maximum rainfall in the winter, generally between November and January, and minimum rainfall, generally in July and August, with great differences between monthly high and low peaks, as shown in Figure 3.

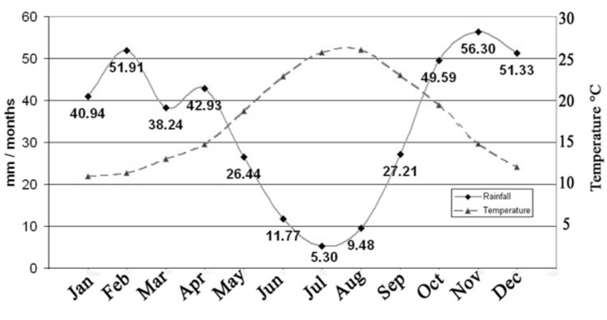

Figure 3. Average rainfalls and temperatures (1974–2003).

In order to determine the average rainfall in the study area, we considered the pluviometric stations of "Cagliari S.I." (7 m a.s.l.), "Settimo" (65 m a.s.l.), "Sestu C.ra" (48 m a.s.l.) and "Coròngiu Aqueduct" (126 m a.s.l.), with a significant period of observations (at least 30 years) from

January 1974 to December 2003. Rainfall and temperature data were provided by the "Nuovo SISS" (New Study of the Surface Hydrology of Sardinia, 1921-1992), and the "Office of Civil Engineers of the Cagliari District" (1993–2004).

The average monthly rainfall was calculated as a weighted average taking into account the influence area for each station. The average yearly rainfall in the area is 410,70 mm, quite lower than the regional average of nearly 780 mm/y) and the national average of nearly 950 mm/y (average rainfall recorded in the period 1950-2000, APAT source). This situation is essentially due the low altitude of the area (only some meters above sea level), and its exposition to the dominant north-west dry wind.

As for the temperature, only the two stations of "Cagliari S.I." and "Corongiu Aqueduct" have been considered: the average annual temperature 17,7°C was calculated for January 1974–December 2003 (Figure 3).

In order to determine the net rainfall, the evapotranspiration, which at the latitude of the study area is an important element of the hydrologic balance, has been considered.

The real evapotranspiration Er was assessed with L.Turc's formula, modified by Santoro [8] for the hemi-arid region of the Mediterranean area

$$Er = \frac{P_a}{0.9 + \frac{P_a^2}{L^2}}$$

where:

P_a — is the average annual rainfall (1974–2003);

$$L = 586 - 10 \cdot T_C + 0{,}05 \cdot T_C^3$$

and T_c is the annual average daytime temperature in Celsius degree corrected to take rainfall into account. This value is obtained with the equation

$$T_c = \frac{\left(\sum_1^{12} P_i \cdot T_i\right)}{P_a}$$

where P_i and T_i are respectively the monthly average rainfall and temperature from 1974 to 2003.

The average *Er* values for each Thiessen polygon is shown in Table 2. The average annual evapotranspiration *Er* = 227.06 mm/y for the area was given by the weighted mean considering the weight of each polygon area.

Table 2. Evapotranspiration (1974–2003).

Pluviometric Station	Area [km²]	T_C	L	Er [mm/y]
Cagliari S.I.	51.20	15.61	430.661	226.849
Settimo S.Pietro	41.19	15.53	431.439	227.236
Sestu (C.ra)	5.22	15.68	430.018	226.626
Corongiu (Acq.)	3.99	15.00	436.773	228.546

This quantity is around the fifty percent of the total annual rainfall so that a potential net rainfall of only 183.64 mm/y is available for recharging groundwater. Of course, the real infiltration rate is much lower given the large extension of the impervious surfaces of the plain, heavily urbanized, and the steep slopes of the hills free from constructions. In agreement with literature data for urban areas of semiarid regions a groundwater recharge value reduced to the 40% of that amount was considered for the water budget, i.e. 43.5 mm/y (Lerner, 2002).

HYDROGEOLOGY

On account of their high porosity, the limestones of the “Pietra forte” formation constitute a very permeable karstic aquifer, whereas the permeability of the underlying “Tramezzario” formation is very low and the clayeous limestones of the “Pietra Cantone” at the bottom of the calcareous series are practically tight.

The main aquifer (Mulas et al., 2005) is represented by the soft sandstones of the “Arenarie di Pirri” formation, underlying the limestones of the hills and an overburden of varying thickness in the surrounding plain.

A great deal of groundwater recharge is likely due to seepage from sewerage and pipeline networks.

Groundwater once used for drinking purposes is presently endangered by nitrate pollution mainly in the eastern part and saltwater intrusion by the coast, so that at present it is only exploited for irrigating city gardens and flowerbeds, and locally for heat pumps.

The eastern plain, once occupied by orchards and gardens, was intensively urbanized, so that locally the aquifer, once phreatic, became confined or semiconfined. Groundwater invaded several basements and the signs of water rise are visible in the foundation walls of many buildings.

METHODOLOGY

The reliability of the data available for the wells known in the urban area was verified, and the following information was updated and collected for each well: position (latitude, longitude, altitude), technical data (type of well, drilled or excavated, depth, geometric dimensions and casing), use (discharge rate and use period), physical and chemical data (hydraulic head, temperature, electrical conductivity, pH and TDS), pictures of the external structure and, where possible, other general information (type of aquifer, stratigraphy, owner, previous chemical analysis and historical information). All data were inserted in the GIS database, in order to locate wells, control altitude, type of aquifer, geology, land use (Corine land cover, 1993), and all kinds of information already updated in the database. A well monitoring network was then established with a grid of 1 well/km^2. Where water could be sampled. Wells had to be working, well hydrogeologically-defined, and, above of all, easily accessible. Thus, 39 wells could be selected.

In order to evaluate water quality, in agreement with the technicians and chemists of Progemisa (the regional agency in charge of the chemical analysis), the sampling campaign was organized to determine the following parameters indicated by the national law DLgs n.152 11.05.99 (updated with DLgs n.258 18.08.2000 and the D.Lgs n.152 03.04.2006): temperature (°C), total hardness (mg/L $CaCO_3$), electric conductivity (μs/cm (20°C)), bicarbonate (HCO_3-mg/L), calcium (Ca^{2+} mg/L), chloride (Cl^- mg/L), magnesium (Mg^{2+} mg/L), potassium (K^+ mg/L), sodium

(Na^+ mg/L), sulphate (SO_4^{2-} mg/L), ammonium ion (NH_4^+ mg/L), iron (Fe mg/L), manganese (Mn mg/L) and nitrate (NO_3^- mg/L).

All sampling was completed in less than two weeks, from May 10, 2006 to May 22,.2006, and in order to ensure the quality of the samples, they were kept in a portable fridge and delivered to the chemical laboratory within a few hours so as to ensure a good hydrogeological correlation (Mulas et al., 2005).

The following determinations were made by Progemisa (the Regional Government Agency — Chemical Laboratory and Material Experimentation — Regione S. Giovanni Miniera 1, Iglesias, CA):

- volumetric analysis (Cl^-, HCO_3^- and total hardness);
- spectrophotometry in the visible (NH_4^+ and NO_3^-);
- ICO-OES (ICO-Optical Emission Spectometer) (K^+, Na^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, and Mn);
- gravimetry (TDS);
- pHmetry (pH) ;
- conductimetry (CES and EH).

Chemical data were elaborated with AquaChem.

The input of this software is given by the chemical and physical data, geology, lithology and general information ; the output is a general report (anions-cations balance, dissolve minerals, etc.) and a “drinking water Regulations” report (SAR, ESR, Magnesium Hazard etc.) for each sample, as well as chemical charts (e.g. Durov, Piper, Schoeller, Stiff).

The classification prescribed by the law 152/99 for the “monitoring and classification of groundwater” was adopted. The groundwater was classified considering seven parameters, called “macro-describers”, which may give an idea of groundwater quality. These parameters are *electrical conductivity*, *chloride*, *manganese*, *iron*, *nitrate*, *sulphate* and *ammonium ion.* The general class of the sample is determined by the worst parameters found in the chemicals analysis.

This way, all data were arranged in four classes, ranking from 1 (the best condition) to 4 (the worst condition) plus a 0 class. The characteristics defined by each each class are as follows:

- *Class 1*: null or negligible human impact with precious hydrochemical characteristic;
- *Class 2*: reduced human impact, sustainable over long periods with good hydrochemical characteristics;
- *Class 3*: important human impact with general good hydrochemical conditions, and a few signs of degradation;
- *Class 4*: relevant human impact with poor hydrochemical characteristics;
- *Class 0*: null or negligible human impact with particularly natural hydrochemical facies and concentrations above Class 3 values.

RESULTS AND DISCUSSION

The first survey was carried out at the end of the summer 2005 in a network of 96 wells and 10 piezometers, where hydraulic heads, electrical conductivity, pH temperature, and organoleptic characteristics (colour, turbidity, smell) were determined.

As shown in the map of Figure 4, in large areas of the plains bordering the ponds of Cagliari and Molentargius the piezometric surface is 1÷2 m deep. The piezometric contour lines drawn on the basis of the water levels put clearly in evidence a watershed crossing the city of Cagliari in direction NNW-SSE, from the "colle San Michele", to the "Monte Urpinu". According to the morphology (Figure 2), groundwater flows from the hills to the pond of Santa Gilla, in the western part of Cagliari, directly to the sea in the central part, and to the pond of Molentargius in the eastern part.

The results of the chemical analyses carried out on groundwater samples show critical situations throughout the area. In particular, 29 samples were included in class 4, 6 in class 3, only 4 in class 2 and none in class 1.

Groundwater resulted affected by widespread contamination due to sulphates and local contamination due to ammonium, manganese and iron. The presence of nitrate (Figure 4) is almost surely caused by wastewater leakage. Nitrate concentration was high in two wide areas, in the oldest and most populated part of Cagliari, to the west of the watershed crossing Cagliari by the San Michele hill to the promontory of Cala Mosca, in the northeastern side of the Molentargius pond, by the historical centres of the towns of Selargius, Quartucciu, and Quartu Sant'Elena.

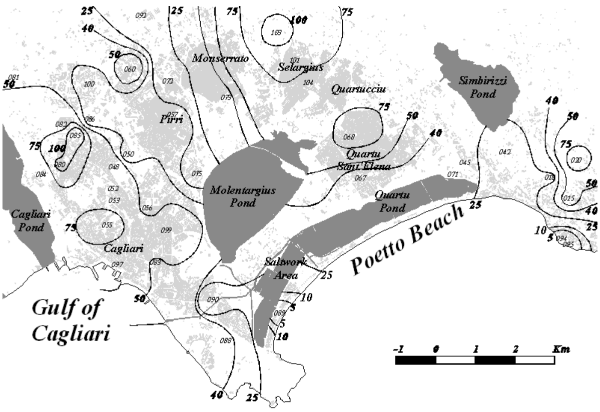

Figure 4. Piezometric map (m a.s.l.) (September–October 2005)

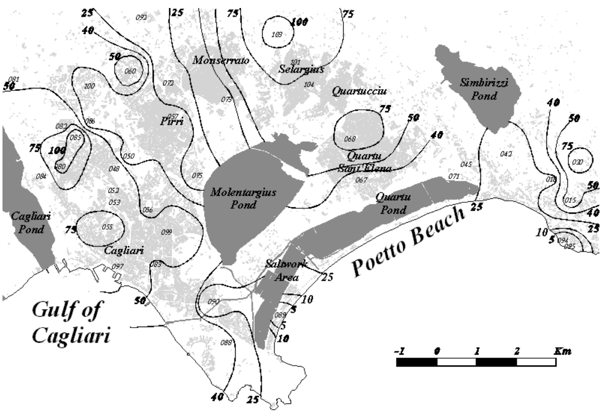

Figure 5. Isonitrate contour lines (values in mg/L).

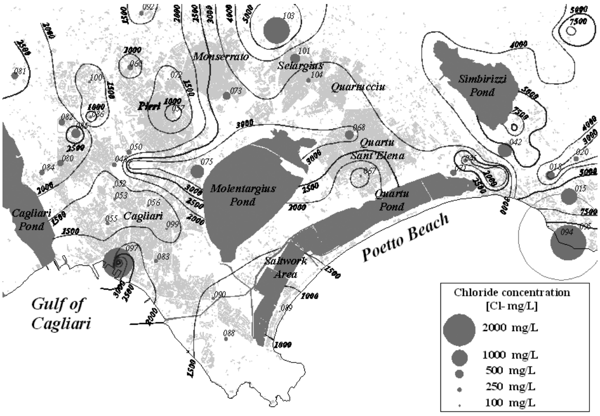

Figure 6. Isoconductivity [µS/cm] and chloride concentration.

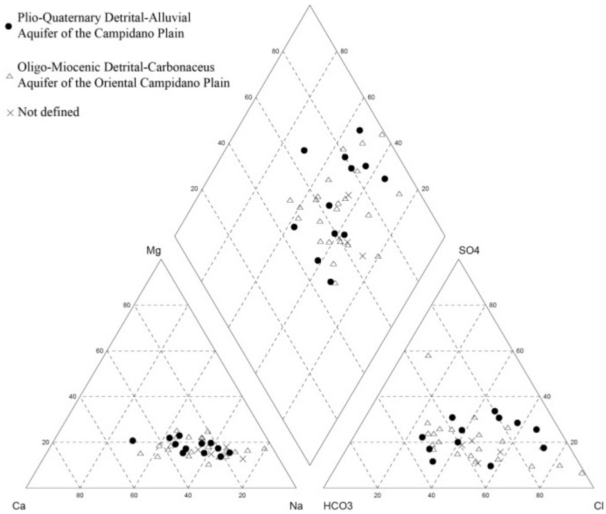

Figure 7. Piper hydrogeochemical diagram. Water samples are distinguished per type of aquifer.

Furthermore, the whole coastal area is affected by high chloride concentration locally due in various measure to lateral salt water intrusion from the sea, and upconing of old connate groundwater and recent groundwater leaching salty sediments.

The Piper hydrogeochemical diagram shows that groundwater samples mainly belong to sodium-bicarbonate, calcium-bicarbonate, sodium-chloride, and calcium-chloride facies (Figure 7). A few samples indicate sodium or calcium dominance with respect to anions. The hydrochemical facies of CaCl, NaCl, and sodium and calcium facies without anion dominance types, which have chloride contents higher than 150 mg/l, indicate the presence of salinization phenomena due to seawater intrusion (Appello, Postma, 1994).

The hydrochemical facies of NaCl and $NaHCO_3$ type with chloride contents lower than 150 mg/l, indicate that some parts the aquifer are subject to flushing of salinized sediments by fresh waters. Some samples pertain to bicarbonate-calcium facies, typical of fresh waters.

If we consider only the wells in the most intensively urbanized area, samples show a geochemistry with no dominance, as shown in Figure 8.

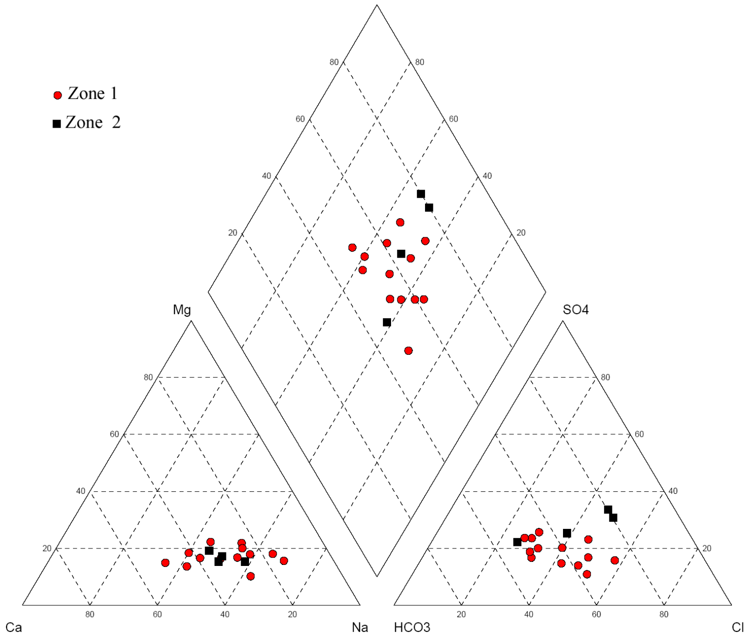

Figure 8. Piper hydrogeochemical diagram, for the sample in the higher urbanized area.

On the whole, the aquifer seems subject both to seawater intrusion and refreshing processes, while part of the aquifer is not affected by salinization.

CONCLUSIONS

The quality of groundwater in the area of Cagliari is generally influenced by urbanization: the more intense and old the urbanization, the worse groundwater quality.

The presence of nitrate is almost surely caused by wastewater leakage, the origin of the high chloride concentration in the whole area has not been clearly defined yet.

To the northeast of the study area, where marl formations are present, the high saline concentration may be due to their salt contents rather than to seawater intrusion.

Finally, the behavior of conductibility and chloride concentration matched with the high nitrate concentration in the more urbanized area could be justified by the recharge of groundwater by seepage of sewerage networks and pipelines. this fact could explain the lack of geochemical dominance for the majority of the samples.

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abstract id: **332**

topic: **1**
Groundwater quality sustainability

1.3
Urban hydrogeology

title: **Determination of water sources for underground structures flooding in Mar Del Plata, Argentina, applying mixing indexes**

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keywords: water mixing, urban structures flooding, Mar del Plata

INTRODUCTION

Mar del Plata city, the main tourist resort in Argentina (Figure 1), registered a massive migration process during the second part of the last century, at a rate of 100,000 inhabitants each decade. During the rapid development of the city as a summer centre, most of the family houses placed near to the coast were replaced by buildings that include subsurface services, like parking lots, cellars or locker areas. Intensive groundwater exploitation led to an important piezometric level drawdown and seawater intrusion.

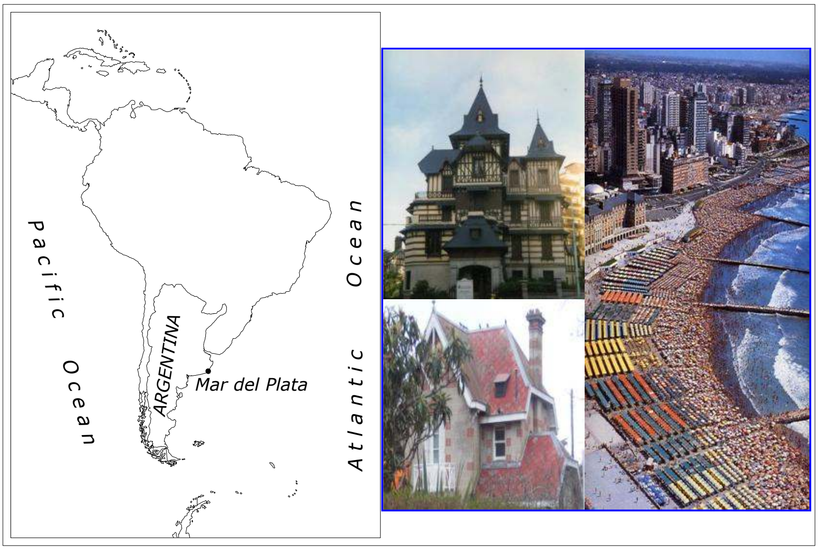

Figure 1. Location map.

As a consequence of salinization many urban pumping wells were abandoned during the late 70's. This process, together with increased recharge due to urbanization (Vázquez Suñé et al, 2005) (leakage from sewage and runoff networks), caused heads recovery up to 22 m over a 25 km^2 area. Many subsurface structures built during low head periods were flooded, which damaged reinforced concrete structures (Figure 2).

Figure 2. Basement flooding and damage of the reinforced concrete structures.

The purpose of this study is to assess water sources in flooding urban underground structures in Mar del Plata**.**

METHODOLOGY

The full approach consisted of the following steps: a) to identify the sources of recharge or end members, b) select the chemical species to be included in the geochemical balances, c) compute mixing ratios, and d) synthesis of results.

In order to quantify the sources of increased recharge, a geochemical and isotopic survey was carried out on both potential end members and samples from underground structures leakage. As end members, five sources were identified: urban groundwater, water supply, sewage water, rain water and sea water intrusion.

The resulting data were interpreted with the aid of code MIX (Carrera et al., 2004), which computes mixing ratios, while acknowledging uncertainties in end members. This methodology was applied to the Barcelona aquifers, where 12 chemical species from 25 wells were analysed, computing mixing ratios of waters from the Besós river, rainfall infiltration, Ter river water supply, Llobregat river water supply, Ter river sewage water, Llobregat river sewage water, city runoff and sea water intrusion (Vázquez Suñé, 2003).

CHEMICAL AND ISOTOPIC CHARACTERIZACTION OF WATERS

Chemical composition of end members are represented through Stiff diagrams (Figure 3).

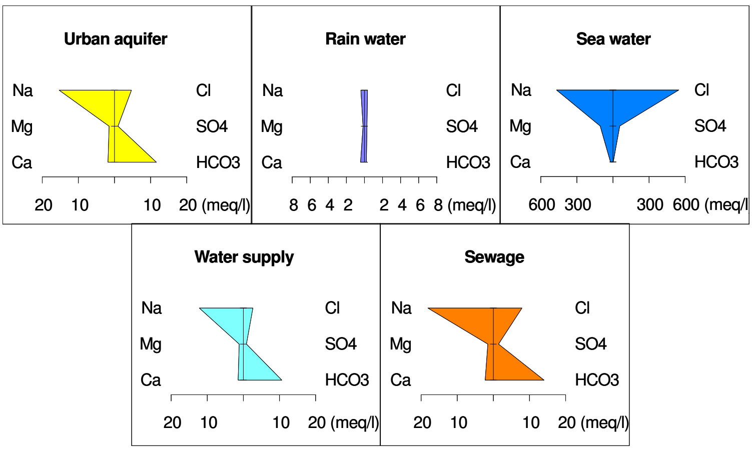

Figure 3. Stiff diagrams of end members.

Water from urban aquifer is sodium bicarbonate, mean electrical conductivity 1645 µS/cm and mean nitrate concentration 106 mg/l. Water supply from the aquifer located on the northern rural area is sodium bicarbonate, electrical conductivity 1200 µS/cm and nitrate concentrations less than 6 mg/l. Sewage water is also sodium bicarbonate, electrical conductivity 2150 µS/cm and concentration of total nitrogen 60 mg/l, 35 mg/l from human excretes and 25 mg/l from the leakage of the fishery industry. Rain water has a very low salinity and the type is sodium calcium without dominant anion; this water would enter to the underground structure by city runoff. Sea water is sodium chloride and its conductivity 56000 µS/cm.

Stiff diagrams and location of twelve samples from cellars of public, commercial and housing buildings in the urban area of Mar del Plata are shown in Figure 4. Water in the underground structures is affected not only by mixing process, but also by interaction with concrete, which affects HCO_3, SO_4, Ca and Mg (Bocanegra et al., 2009).

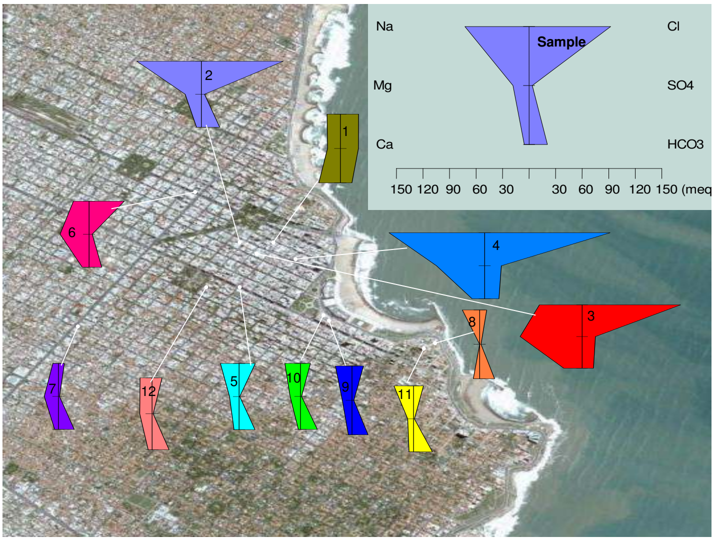

Figure 4. Stiff diagrams of underground structures leakage.

Isotopic composition is represented in a $\delta^{18}O$ vs δ^2H diagram (Figure 5). From this point of view it is noticeable that the water sampled in flooded underground structures in plotted on the meteoric water line, around the groundwater samples. Sewage water has also the same isotopic composition of groundwater, as it can be expected in a city where groundwater is the only source for water supply.

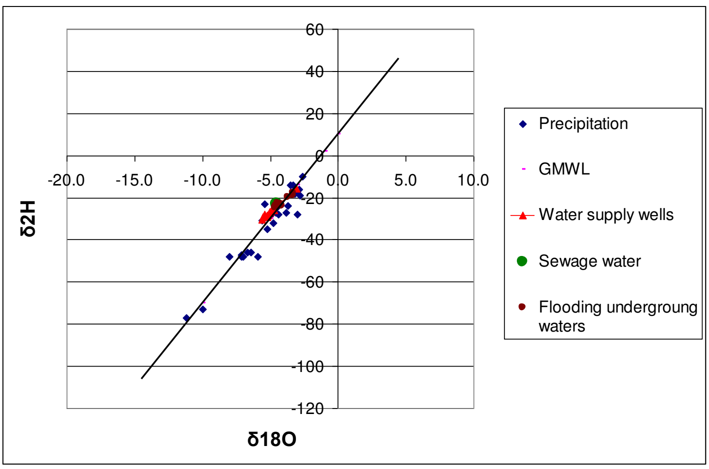

Figure 5. Diagram showing the isotopic composition of end members and water in flooded underground structures.

Mixing ratios were obtained using Cl, total N, δ 2H, and δ 18O as conservative tracers. N vs. Cl (Figure 6) and δ2H vs. δ18O (Figure 7) diagrams show that all samples are in the frame of the end members composition.

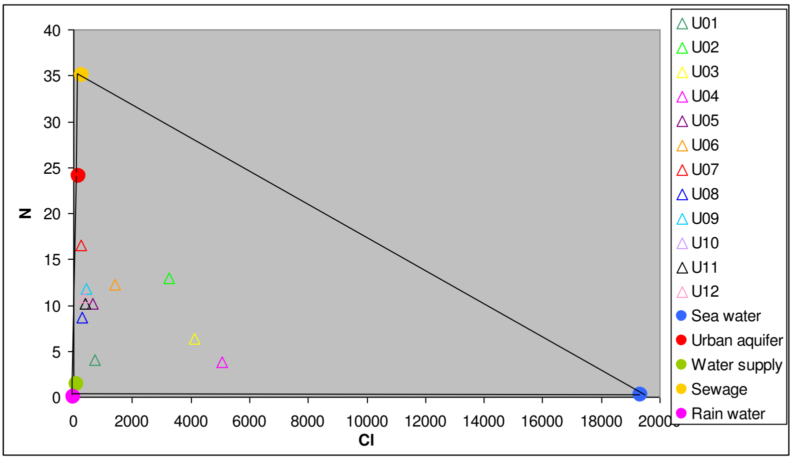

Figure 6. N vs. Cl^- diagram of end members and underground structures leakage.

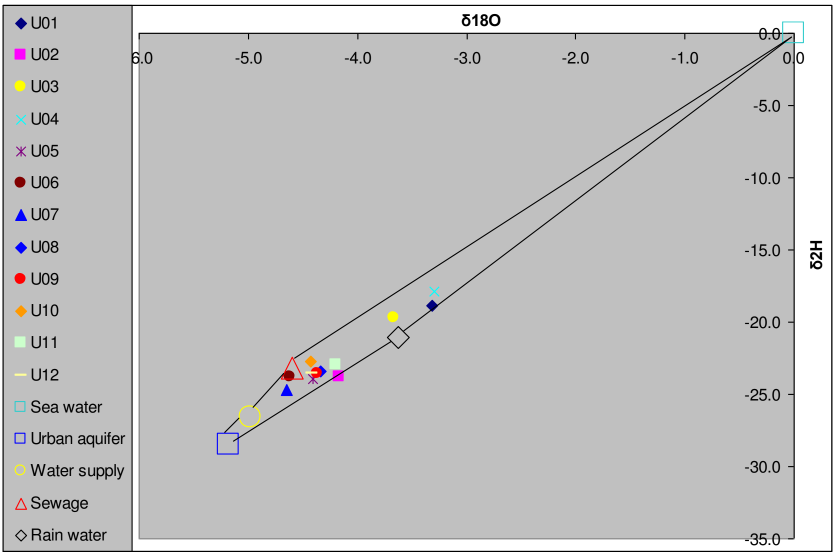

Figure. 7. δ^2H vs. $\delta^{18}O$ diagram of end members and underground structures leakage.

COMPUTING MIXING RATIOS OF END MEMBERS

The results of the computed mixing ratios indicate that concentrations are rather close to the measurements (Figure 8).

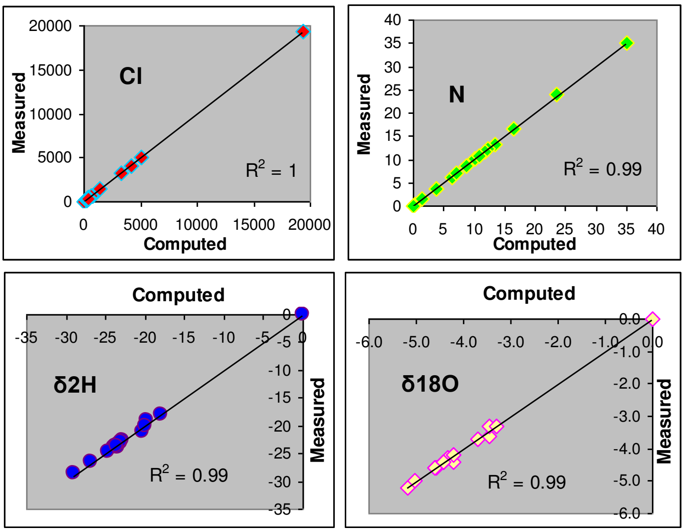

Figure 8. Computed vs. measured composition diagrams of Cl^-, total N, δ^2H and $\delta^{18}O$

Spatial distribution of mixing ratio in each sample is shown in Figure 9. Seawater intrusion is recognized for buildings with two or three under ground floors (samples 1, 2, 3, 4, y 6). Shallow samples just present traces of sea water. Running water and sewage losses and also rain water are the most important sources of flooding.

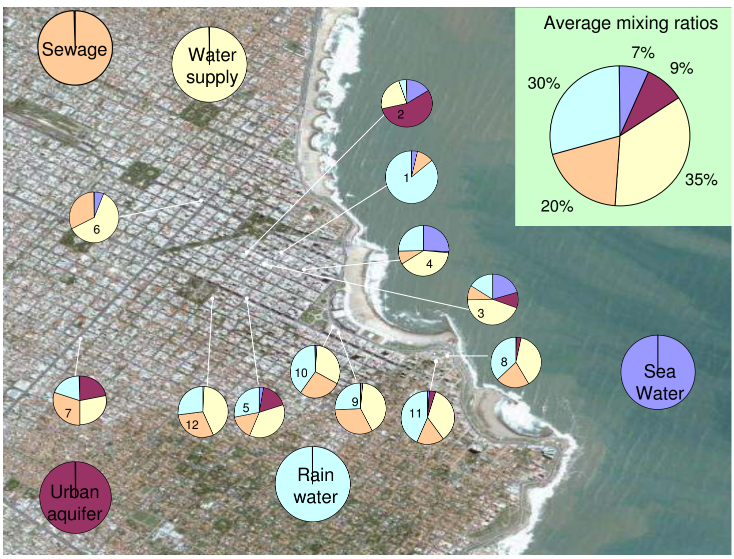

Figure 9. Spatial distribution of mixing ratio with end members.

The Control Agency of Drinking Water and Sewage for the Americas report for Mar del Plata a density of 0.4 running water breaks/km and 0.2 sewage breaks/km (GRTB, 2008). Since running water is 1550 km length and sewage 2900 km length, 1200 breaks are reported each year due to both losses of water and sewage systems.

CONCLUSIONS

Results allowed computing the proportion of each water source in flooding urban underground structures in Mar del Plata. The average mixing ratios for leakage into underground structures are: runoff water 35%; sewage leakage 19%; rain water 30%; seawater 7%; and aquifer water level rising 9%.

This calculation is possible thanks to the use all together of many selected parameters for the considered end members. The applied method is simple tool for preliminary identification of runoff water and sewage pipe lines leaking.

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abstract id: **349**

topic: **1**
Groundwater quality sustainability

1.3
Urban hydrogeology

title: **Groundwater table fluctuations types in urban area, Wroclaw, SW Poland**

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keywords: grundwater table fluctuations, Wroclaw, urban hydrogeology

INTRODUCTION

The following report shows only small part of final results of tests performed in the first aquifer (quaternary formation) in Wroclaw between 2002–2006, which was partially financed by Ministry of Science and Higher Education – No 4 T12B 031 27. Complete study was done by Worsa-Kozak in doctoral thesis (2006).

The first systematic hydrogeological observations in Wroclaw are dated on April 9, 1987 (Jacobi, 1877) and lasted until 1922. All the results were published in municipal yearbooks (Breslauer Statistic, 1877–1922). Observations of groundwater table in Wroclaw with various interruptions and in variable research network are carried out today (Kowalski, 1977; Worsa-Kozak, 2006; Kotowski , Worsa-Kozak, 2009). The purpose of previous researches was to analyze and evaluate the characteristics of the ground and waters conditions in the city and point dependence between groundwater table and the urban factors. This article is the first in its kind and treats about classification of the groundwater table fluctuation in the City of Wroclaw.

STUDY AREA

General information

Wroclaw, the main city of the region and administrative province of Lower Silesia, is situated in south-western Poland (Fig. 1). Sudety Foreland on the southwest, Silesian Highland on the east, and Trzebnickie Hills on the North of the Silesian Lowland, outline the borders of Silesian Lowland where city of Wroclaw is located (Kondracki, 2002). The axis of the Lowland goes through Odra ice-marginal valley and it cuts the city in the northwest – southeast direction.

Wroclaw occupies 293km^2, 40% of which is dense of urban development. Surface waters are also a big part of the area (total 9.55 km^2), 8.26 km^2 includes flowing waters. In terms of hydrography Wroclaw is situated in the Middle Odra Basin. The length of Odra River within the city border is 26 km, and the width of its valley can measure even a few kilometers. Widawa River (length 20 km within the city border) is the major right tributary of the Odra River and the left tributaries include Olawa (8 km), Sleza (16 km), Bystrzyca (15 km) and Lugowina. The total length of the watercourses within the city limit is 280 km.

Geology

Wroclaw is situated on the southwest perimeter of the Fore-Sudetic Monocline, close to its border with the Fore-Sudetic Block. Pre Cenozoic foundation (metamorphic schists and granitogneisses of Middle Odra Metamorphic Complex, in some places rocks of Carboniferous, deposits of Triassic and Permian) is covered with Cenozoic deposits (Neogene). Miocene deposits are created as „Poznan series", which are clays, silts, and sands with some lignite in them. Younger deposits include boulder clays, glacial sands and gravel, sands and muds accumulated by still waters, aeolic sands and Holocene deposits in the beds of valleys - clays, sands, gravel, mud which contain organic residue, and peat (Figure 1) (Buksinski, 1974; Winnicka, 1988). The major part of Wroclaw is located on the valley of Odra, which is filled with alluvial deposits. The south of the city is created mostly out of fluvioglacial and glacial deposits and in the west part of it neogenic deposits are noticed on surface. These parts of the city are situated on uphill, outside of the valley. The youngest sediments can be found in Downtown and these are anthropogenic embankments with thickness even over 10 meters.

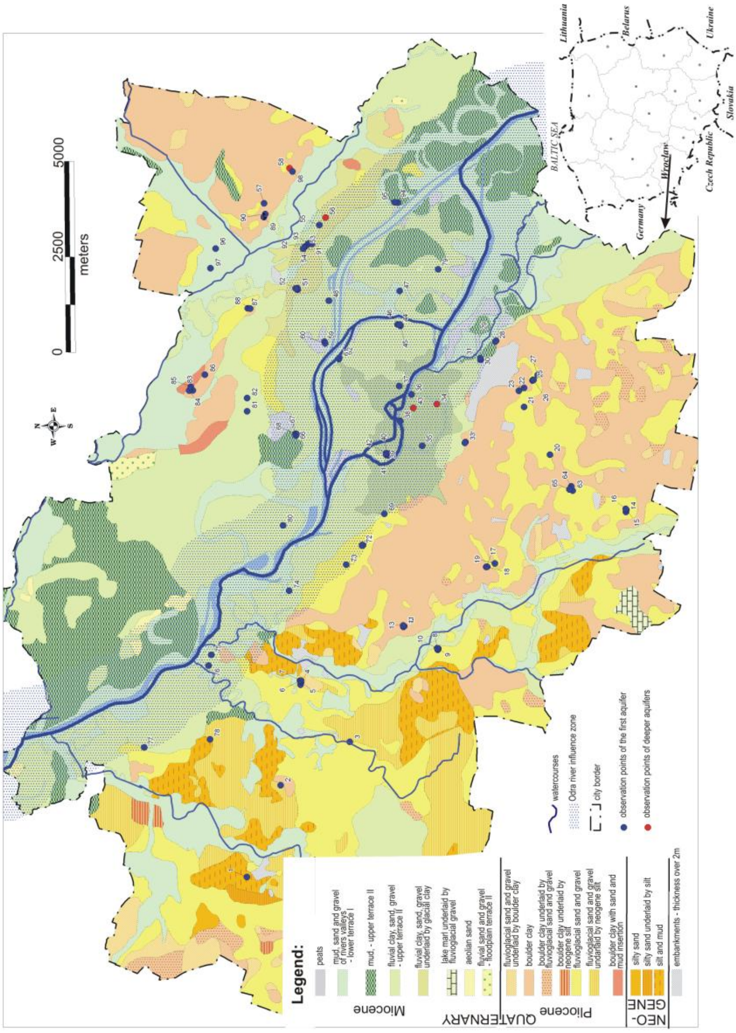

Figure 1. Geological map of Wroclaw and location of observation points.

Hydrogeology

There are three main multiaquifer formations in the city of Wroclaw. (Nowicki, 2007; Paczynski, Sadurski, 2007) (Figure 2): quaternary aquifer is mostly found in fluvioglacial and fluvial sandy-gravel deposits. These can be found in the majority of the area of the city, except for the south-west part. Thickness of this formation varies from 5 to 30 m. Groundwater table is unconfined and lies on average depth of 5 m b.g.l; neogene aquifer, which is bound up with sandy-gravel interbeddings and pockets within clayey deposits. Upper and lower levels are distinguished in this aquifer; triassic aquifer which include fissure waters in "shell limestone" (middle Triassic) and in "variegated sandstone" (early Triassic). "Shell limestone" can be found only in the east part of Wroclaw.

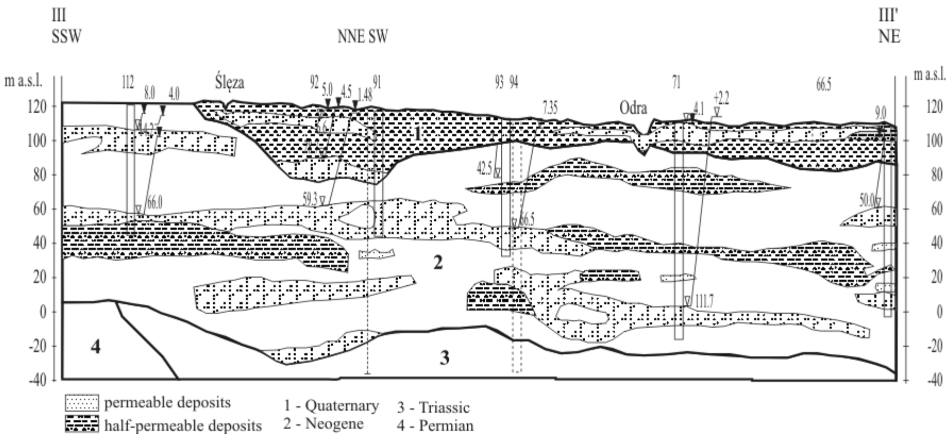

Figure 2. Hydrogeological cross-section trough the City of Wroclaw (after Mroczkowska & Michniewicz, 1976, changed).

The study was performed in the first out of total three aquifers. It occurs in three units within Wroclaw, which were recognized by Kowalski (1977): the area of river deposits in the Odra ice-marginal valley and valleys of Olawa, Sleza, Lugowina, Bystrzyca and Widawa; the area of pleistocene deposits and fluuvio-glacial coverage, which divide into two regions-North and South Upland; the areas of shallow deposition of Miocene and Pliocene sediments.

METHODS

During the two hydrological years (2004–2005) observations of the first water table were performed. The research was done weekly (every Monday). Such a frequency of measurements guaranteed capture short-term changes in the position of the groundwater table (Taylor, Alley, 2001). In the beginning of described observations there were 100 observation points and at the end the number lowered to 85.

According to Tomaszewski (1990) the observation can be classified as medium-term and pointing types of fluctuations could be possible. The point of reference in the study was generalized pattern of shallow groundwater table fluctuation common for weather conditions in Middle Europe and Poland, presented by Konoplancew and Siemionow (1979). This pattern is characterized by two minimal and two maximal states of groundwater table in a year.

In order to classify groundwater table fluctuation the results of only the points researched for over one hydrological year were taken into consideration, so data from 85 boreholes were thoroughly analyzed. The shape of hydrograms, periodicity of fluctuation and occurrence time of extreme states were analyzed and based on final results, the main groups of wells were distinguished. Also factors of correlations between ground water levels and level of Odra river (measured in weirs and water gates) and amount of precipitations were analyzed. The classification was made based on the first groundwater table rises and falls and also on the value of correlation factors.

RESULTS

Based on hydrograms analysis four main types of groundwater table fluctuations of the first aquifer were found in the city of Wroclaw:

- type I: 4-extremal (Figure 3), comparable to the natural cycle described by Konoplancew and Siemionow (1979). Two minimal levels and two maximal ones during a period of one year distinguish this type. The first minimal levels (H1) appeared in spring time (April and May) and then in the months of June and July the table was rising to reach its first peak in the middle of the month July (H2). Right around October and November appeared the second minimal level (H3) and in December and January we could observe the second maximum (H4), which was slightly lower than the spring one. This kind of periodicity of groundwater table fluctuation was being noticed in 10 observational points in the south highlands, particularly in the Gaj District.

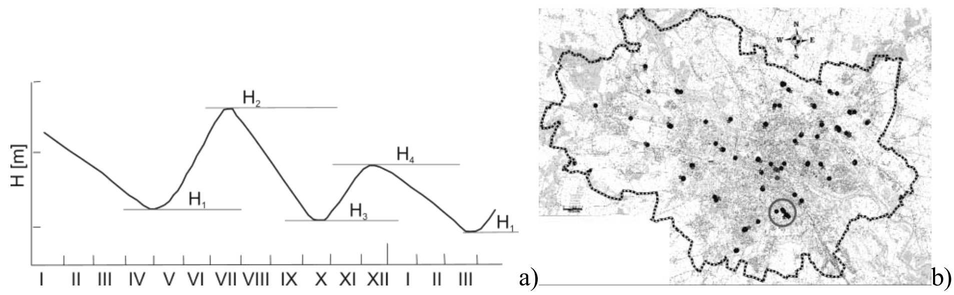

Figure 3. Type I of groundwater table fluctuations: a) general hydrogram, b) location of characteristic observation points.

- type II: 2-extremal (Figure 4), was characterized by one distinct minimum and one maximum. The rise of the table was noticed until April (H1), and than it was gradually lowering until it reached a minimum in October and November (H2). This type qualifies as the most common type of groundwater table fluctuation in the city of Wroclaw (39 hydrological boreholes). The boreholes, which represented Type 2, were localized within south and north highlands and also on the border of river valleys. This cycle of groundwater table fluctuation is typical around river areas and is characterized with mild changing process. It points to major influence of Odra (far over the valley limits) in water dynamics in the first aquifer in the city of Wroclaw.

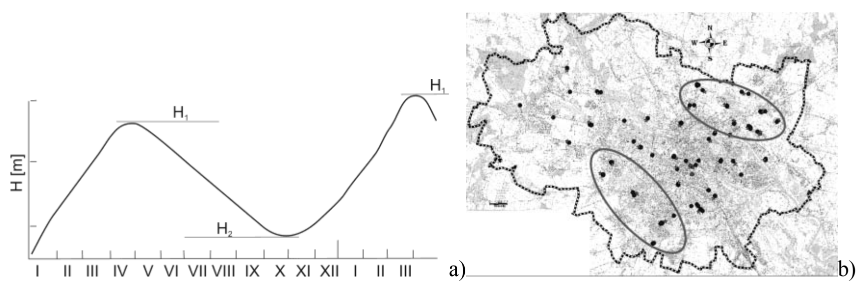

Figure 4. Type II of groundwater table fluctuations: a) general hydrogram, b) location of characteristic observation points.

- type III: 2-extremal (Figure 5), influenced by the rhythm of the Odra fluctuations. This kind of groundwater table fluctuation was described by a high frequency depended on the level of Odra. Boreholes were situated hundreds of meters from riverbed and its hydrograms strictly imitate these of Odra. Also seasonal and annual amplitudes of fluctuations are very similar to the values observed in the river. Changes of the water table in Odra almost immediately influence changes in groundwater level – it was clearly visible in the few observed daily points. Despite the high frequency of water table fluctuations the two extremes (spring – H1 and fall – H2) were still noticeable on the hydrograms. This type was marked out in 25 hydrogeological boreholes in the basin of the Odra and the area directly influenced by it. Within the city limits Odra is divided into many branches, its bed is regulated and waters are damming up by weirs, which belong to Wroclaw Water Node (Wroclawski Wezel Wodny). Damming up of Odra waters and balancing of its table at designed levels causes the rhythm of fluctuation being unnatural.

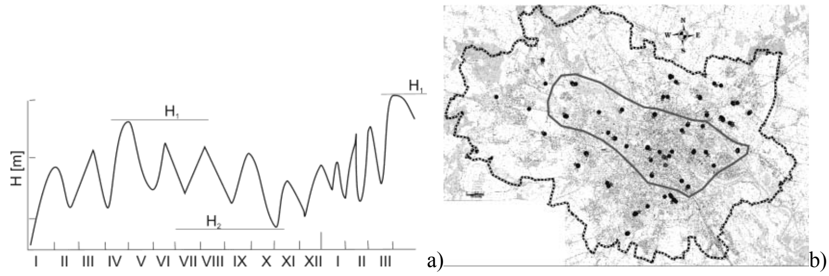

Figure 5. Type III of groundwater table fluctuations: a) general hydrogram, b) location of characteristic observation points; c) example of hydrogram.

- type IV: irregular and being a result of incidental anthropogenic events (Figure 6). Hydrographs that present the Type IV of groundwater table fluctuation show numerous disturbances of the fluctuation rhythm–sudden, high drops (H_x) and rises of the groundwater level. Further analysis of the local conditions pointed to human influence. Short lived and intense drainage of the surrounding areas, pumping of the water for domestic and farming purposes and also frequent failures of water supply system were the most common causes of sudden groundwater table variations. These features were distinctly observed in 11 observational points placed in different parts of the city.

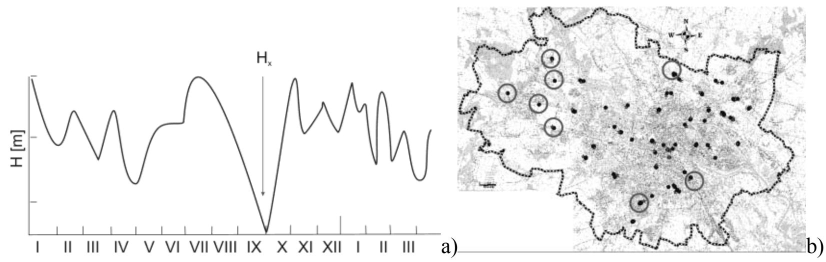

Figure 6. Type IV of groundwater table fluctuations: a) general hydrogram, b) location of characteristic observation points.

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abstract id: **363**

topic: **1**
Groundwater quality sustainability

1.3
Urban hydrogeology

title: **Comprehensive urban hydrogeological survey program to optimise dewatering design and reduce risks related to large infrastructure projects — case study: the Metro Cityringen in Copenhagen, Denmark**

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keywords: dewatering, metro, site investigations, construction projects, geophysics

Large-scale infrastructure projects in urbanised centres must balance the impact to environment and existing structures – e.g. preserving historical structures - with financial and technical constraints. Lowering the groundwater table in urban areas without sufficient hydrogeological data and appropriate planning can result in general ground settlement, damage to adjacent buildings, contaminant mobilisation, and adverse effects to water supply. Therefore a focused strategy for identifying and handling the concrete risks, through comprehensive urban hydrogeological surveys when conditions require, is necessary.

SURVEY SETTING

A new metro line, "Cityringen", is being planned in Copenhagen, Denmark. The line, shown in Figure 1, comprises 15.5 km of twin-tube tunnels, 17 stations and four shafts, as well as five caverns for cross-overs and bifurcations. Deep construction works will begin in 2011, with tunnelling due to commence in 2013. Inauguration is planned for 2018.

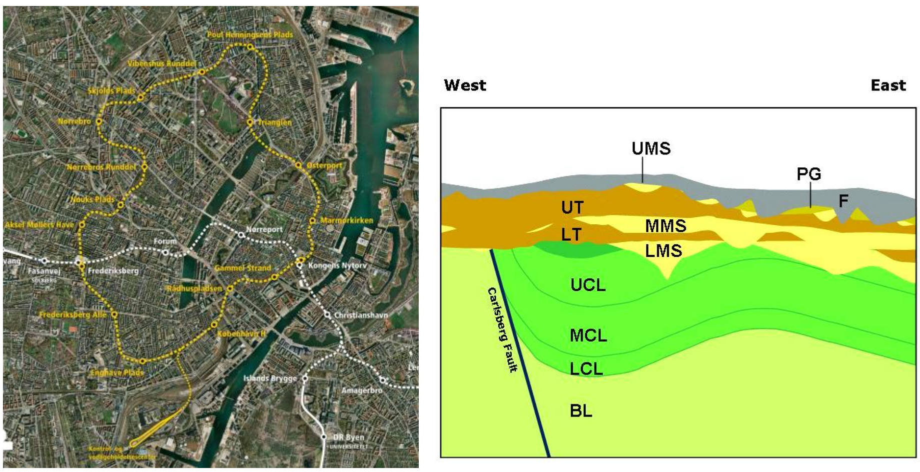

Figure 1. Overview map of Cityringen (left), conceptual geology (right). Geology is comprised fill (F) and post-glacial deposits (PG), glacia till (UT — Upper till, LT —Lower till), meltwater sand/gravel (UMS — Upper, MMS — Middle, LMS — Lower) and limestone (UCL — Upper, MCL — Middle, LCL — Lower, BL — Bryozoan)

The eastern part of the Cityringen alignment passes the inner city of Copenhagen where many buildings are old and sensitive to variations in groundwater levels. For this reason the municipality of Copenhagen has in this area prohibited any groundwater lowering outside the construction zones unless appropriate measures are taken to keep the groundwater level within natural limits. The western part of the alignment passes through a catchment for domestic water supply at Frederiksberg where a key issue is protection of the groundwater resource in terms of quantity and quality, with chemical parameters of interest being salinity/chloride, nickel and sulphate. Numerous contaminated sites — typically originating from former dry-cleaning shops, petrol-filling stations and mechanical workshops — are located close to the planned construction sites. In these instances the dewatering activities will not be allowed to alter the existing groundwater contamination regime, for instance by spreading of the existing contamination plume.

HYDROGEOLOGY OF COPENHAGEN

The conceptual geology of Copenhagen is shown in Figure1. The soils in the project area are composed of fill, underlain by Quaternary layers of alternating sand and till in varying thicknesses. The Quaternary layers are underlain by Copenhagen Limestone, CL (from the Danian period), the surface of which is generally found at 10 to 30 m below ground level. At several locations the tunnels will have to pass through the interface between limestone and glacial soils and will thus encounter mixed face conditions. The upper limestone can be locally glacially disturbed and heavily fractured down to 4 m below the top of the limestone surface.

The primary aquifer is comprised of the limestone together with meltwater sand and gravel layers when in hydraulic contact. At Frederiksberg, the primary aquifer is exploited for domestic water supply and the abstraction is the main controlling factor for groundwater levels in the western part of the alignment. The main flow within the limestone occurs in fissures and the permeability of the limestone can vary widely within short vertical and/or horizontal distances. Within the working area, one or several secondary aquifers occur above the primary aquifer. Although the secondary aquifers are partly separated from the primary aquifer by aquitards, drawdown of the groundwater level in the primary aquifer will often cause considerable drawdown in the secondary aquifers also.

RISK REDUCTION

Groundwater-related potential risks in relation to the deep construction works as such include breakdown of the dewatering system, causing e.g. risk of uplift of the bottom and/or flooding of the excavation; and large inflows from peak flow zones to open excavation in the limestone, such as caverns or adits. In terms of risks for the surrounding environment dewatering can, if appropriate measures are not taken, result in undesired lowering of the groundwater level. This may potentially lead to a range of adverse effects, including: Jeopardising existing building foundations if wooden piles get exposed to oxygen for longer periods; intrusion of saltwater from the sea or up coning of residual saltwater; increase in contents of nickel or sulphate in case deposits containing pyrite become unsaturated; and to spreading of existing groundwater contamination if the existing groundwater flow regime is altered. Other environmental risks include improperly treated water, with high contents of dissolved limestone or iron, being discharged to recipients (harbour, lakes, streams), potentially causing discoloured water in the recipient.

PRACTICAL GROUNDWATER CONTROL FOR CONSTRUCTION OF CITYRINGEN

The permanent constructions of Cityringen are designed as watertight constructions and the dewatering is thus limited to the construction phase. The practical measures to reduce the groundwater inflow to excavations during the two years of construction, and thus limit the lowering of groundwater level in the surroundings, include water-tight retaining walls to the appropriate depth in order to cut off significant flow zones and at times grouting to reduce the permeability of particularly water-bearing flow zones. In particular cases it might be necessary to resort to more costly methods, such as freezing or working under compressed air. In Copenhagen the preferred method in the latest years has been to recharge the abstracted groundwater (or occasionally harbour water) back into the groundwater aquifer. This principle is outlined in

Figure **2**. It is expected that in total 20-60 million m^3 of groundwater will have to be handled for construction of Cityringen if the appropriate measures to reduce yields, as outlined above, are taken.

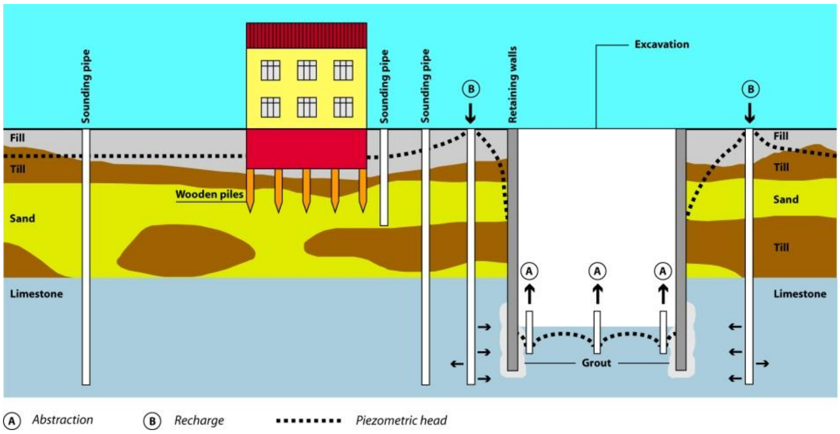

Figure 2. Principle of groundwater control in Copenhagen.

COMPREHENSIVE SURVEY AND PLANNING STRATEGIES

In light of the environmental regulations, complex site conditions and timeline the following overall strategies have been implemented:

- Extensive site investigations in order to ensure improved knowledge of the site conditions
- Integrated interpretation of the results, continuously as the data materialise, in order to improve the tender design — also by use of extensive groundwater modelling — and to improve otherwise the basis for bidding, as "Project Information".
- Dialogue with authorities in order to ensure a common understanding and to assess the likely authority requirements that the contractor will have to respect.
- Early groundwater monitoring in order to ensure proper determination of baseline groundwater levels.

SITE INVESTIGATIONS

In order to assess the site conditions in detail targeted site investigations are necessary. Extensive site investigations have been carried out for Cityringen. It has been the intention that such a high level of knowledge, ahead of tendering for detailed design and construction, will ensure that 1) less feasible design solutions will be eliminated and the tender design thus be optimised, and 2) the risk of unforeseen situations will be reduced and a solid and clear basis for the pricing of the design and build contracts will be established. It has, in other words, been the aim that surprises should be avoided. The site investigations before tender comprise the following key data:

- 374 geotechnical and/or hydrogeological boreholes with accurate geological description,
- 246 geophysical logs, including flow logs,

- 600 short duration pumping test, of 1 hour of pumping and 1 hour recovery carried out in all screens after cleaning, as well as 33 long duration pumping test, mostly of 5 days of pumping and 5 days recovery, with use of 15-30 observation wells for each test,
- Groundwater samples for chemical analysis: 101 for inorganic parameters as well as 251 for selected contaminants,
- Seismic surveys at selected sections.

The above site investigations and concurrent evaluations have been carried out in parallel with the design. It has, therefore, been possible to adjust the investigations continuously as a function of both the first part of the investigations and of the developing needs and considerations in the design.

Apart from the above site investigations a comprehensive groundwater monitoring programme has been initiated in mid-2008. The programme covers approximately 250 observation wells (screens), of which 100 are sounded continuously by use of wireless data loggers and 150 are sounded manually. Based on two years of data the contractor will have to derive target groundwater levels which he will have to operate his groundwater control scheme against, thereby ensuring that the groundwater levels during construction are maintained within acceptable ranges.

The data from the monitoring programme have also been a support in defining the design groundwater levels for the permanent constructions. However, the main factors in determining these levels have been the estimated increase in groundwater level due to the following:

- Cessation of the abstraction for domestic water supply at Frederiksberg. Comprehensive groundwater modelling has shown that such a cessation will result in increasing groundwater levels in almost the entire project area (up to more than 10 m at the stations located the closest to the well field),
- Climate change. An increase in the harbour water level of e.g. 0.5 m within the planned 100 years lifetime of Cityringen will result in significant increases in groundwater level in the entire eastern and southern part of the alignment.

INFLUENCE OF SITE INVESTIGATIONS ON DESIGN

The results of the site investigations and the concurrent evaluations served as input to Environmental Impact Assessment (EIA) as well as the conceptual design and the subsequent tender design of Cityringen. Groundwater modelling has been used extensively in the design phase in order to guide the groundwater control, such as the necessary depth of cut-off walls.

At a number of sites the design has been adjusted or completely changed as a function of the evaluated site investigations. For instance, the original design for a 180 m long cross-over cavern was lowered by several metres in order to avoid excavating into highly permeable flow zones in the upper part of the limestone aquifer. As a consequence the neighbouring future station had to be lowered as well. Another cross-over cavern, with very limited limestone cover, was changed to a cut and cover structure with deep cut-off walls as a result of the high transmissivity values determined (approximately $8 \times \cdot 10^{-3}$ m^2/s).

Along an approximately 600 m long southern section Sprayed Concrete Lining (SCL) tunnelling is alternating with cross-over and bifurcation caverns by use of the New Austrian Tunnelling

Method (NATM). Groundwater modelling, however, showed that such open excavation in the limestone along this long section — without any cut-off walls to limit the inflow — may yield relatively high dewatering yields. Therefore it was decided that the tender design should include extensive grouting carried out from a pilot tunnel, as well as sequential excavation so that only limited sections will be open and draining at any given time.

At a couple of locations in particular the site investigations showed that the surface of the limestone was found at large depths. Therefore the tender design ended up including very deep cut-off walls.

KEY FINDINGS AND IMPLICATIONS FROM SITE INVESTIGATIONS

When pumping from the limestone aquifer the drawdown in the upper sand or gravel layers was usually measured to be in the range 10–80%, i.e. highly variable but usually considerable. This underlines the need for watertight retaining walls around the excavation combined with efficient recharge in order to avoid lowering in upper layers.

The flow zones in the limestone are often not consistent within a given site. Figure 3 shows two examples where the flow zones can be either at constant levels throughout the area or heterogeneously distributed.

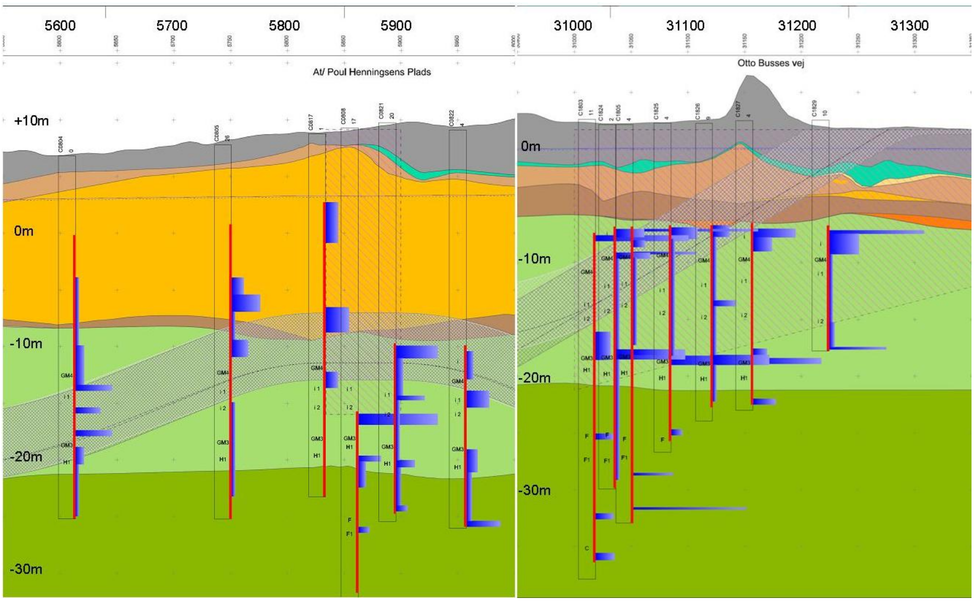

Figure 3. Examples of flow distribution: Left) Otto Busses Vej, with very even distribution, Right) Poul Henningsens Plads, with very heterogeneous distribution.

The finding that the vertical distribution of flow zones is very variable means that site-specific knowledge — i.e. from numerous good-quality flow logs — is crucial in order to be able to arrive at a proper design of the groundwater control scheme for a given site, in particular the depth of cut-off walls.

CONCLUSIONS

The comprehensive hydrogeological survey campaign carried out throughout Central Copenhagen and the subsequent continuous evaluations have resulted in a very good basis for planning and design of Cityringen. By presenting these data and evaluations — as Project Information — to the bidders for the design and build contracts it has been the intention to provide a clear basis for the contractors' tendering and subsequent work. An early dialogue with the authorities has also been undertaken with the aim of assessing, at an early stage, the expected environmental requirements to be adhered to in the design and build phase. This case study demonstrates that large scale infrastructure projects within urban centres require increasingly more comprehensive and innovative surveys to address the complex challenges to reduce environmental impact and overall risks.

abstract id: **372**

topic: **1**
Groundwater quality sustainability

1.3
Urban hydrogeology

title: **Using GIS mapping to assess groundwater studies in urban areas (Porto, NW Portugal): combined potential contamination sources and radon susceptibility**

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keywords: urban groundwater, GIS mapping, radionuclides, NW Portugal

Urban aquifers are particularly important but extremely fragile, easily damaged, and slow to restore. Groundwater conditions are also of primary significance in the construction and maintenance of the subsurface engineering structures (e.g., tunnels, sewers, underground storage facilities and building foundation) and more generally in urban drainage. The aquifer vulnerability assessment is an important basis in order to fulfil demands of the EU Water Framework Directive 2000/60/EC and EU Groundwater Directive 2006/118/EC. These legislations demand that all groundwater must be protected and state that pollutant concentration in groundwater should be used in the risk assessment for groundwater bodies (Robins et al., 2007). Radionuclides are one of the sources of contamination in groundwater, occurring often in concentrations above the limits defined in the legislation; thus, the consumption of waters naturally enriched in radionuclides can be considered an environmental health hazard. The U isotopes (^{235}U and ^{234}U), ^{226}Ra and ^{222}Rn are the main radionuclides generally observed in natural waters, occurring in highly variable concentrations constrained mainly by geological factors (Desideri et al., 2007). In general, aquifers composed by rocks enriched in uranium also have higher concentrations of its daughter isotopes dissolved in the circulating water.

This integrated study presents the preliminary results of the hydrogeological and natural radioactivity studies of granitic rock masses. Hydrogeological methods were used to assess the nature and suitability for use of groundwater from spring galleries located in Porto urban area (NW Portugal, Iberian Peninsula), the so-called *Arca D'Água* underground catchworks (*c.* 3,3 km extension and ≈ –20 m of depth). These springs represented one of the main ancient water supplies of Porto city, for more than six centuries. The water supply of Porto City was secured through fountains fed by numerous springs. Several underground galleries were excavated on granite throughout the centuries to conduct the water of these springs. An inventory of surface potential contamination sources around *Arca D'Água* spring galleries was also performed. These sources are, dominantly, point sources in character, according to the proposal of Zaporozec (2004) with a moderate to high potential contamination load. Almost two-thirds of these sources correspond to garages and spring galleries' entrances and ventilation shafts (Afonso et al., 2007, 2010). Groundwater samples were collected from several sampling sites for hydrogeochemical studies. Most of the groundwater are enriched in sulphate and nitrate and are classified in two groups: SO_4–Ca and HCO_3–Ca types. However, these groundwater may be suitable for irrigation purposes (Afonso et al., 2007, 2009).

In addition, several radiological parameters were investigated, namely radionuclides ^{238}U, ^{234}U, ^{226}Ra and radon gas on the basis of liquid scintillation counting techniques. The uranium isotopes have activities, predominantly, below 0.2 BqL^{-1}, and even below the detection limit. The ^{226}Ra activities vary between 0.13 and 0.45 BqL^{-1}. On the other hand, ^{222}Rn shows a large variation, ranging between 2 and 799 BqL^{-1}.

All parameters show a wide range of variation which is correlated with the geology of the area. The results of this study will contribute to a better water management of an urban geo-space. It also demonstrates that the applied multidisciplinary approach is realistically adequated to understand urban hydrogeological processes and their dynamics.

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abstract id: **485**

topic: **1**
Groundwater quality sustainability

1.3
Urban hydrogeology

title: **Impact of urbanization and industry on groundwater resources. Case study of the Silesian-Cracow Triassic aquifer systems (Southern Poland)**

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keywords: urbanization, groundwater, mining, Triassic, pollution

The Upper Silesia urban industrial region (southern Poland) constitutes one of the most industrialised areas in Europe. It results from a huge concentration of mineral deposits, including hard coal, zinc and lead ore and other raw materials. The population is about 3.9 million inhabitants within the area of ca 6600 km^2.

Triassic carbonate formation covering the area of about 4000 km^2 is divided into five major aquifer systems (Fig. 1). It is the most important and valuable source of potable water for the Upper-Silesian region.

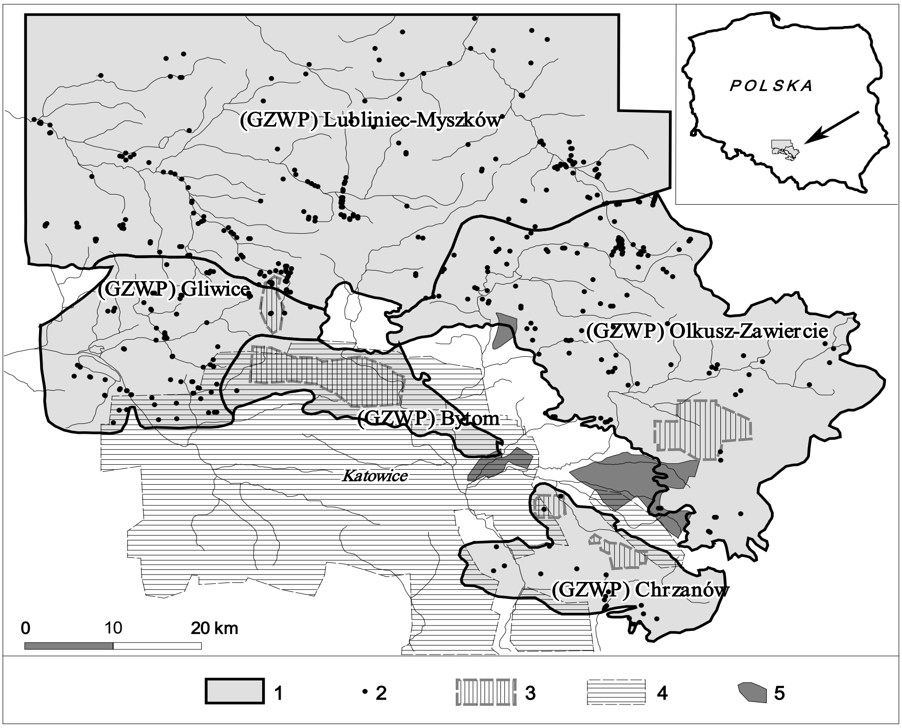

Figure 1. Location of wells and mining areas within the Triassic major aquifers in the Upper Silesia region (Southern Poland). 1 — extend and boundary of the Triassic major aquifer (MA) systems; 2 — wells; 3 — Zn-Pb ore mining areas; 4 — hard coal mining areas; 5 — sand open pits.

Within the Triassic formation there are four regions with Zn-Pb ore mining activity in the Middle Triassic beds, and within two of them there is the system of two-level exploitation of Zn-Pb ores and hard coal deposits in Carboniferous.

There are four major elements of human impact in the area of the Silesian-Cracow Triassic aquifers: long-lasting metal ore mining (underground and surface), intensive groundwater abstraction by mining and well fields, numerous urban-industrial centres, agriculture.

Mining and intensive groundwater abstraction.by well fields have predominated impact on transformation of hydrogeological conditions of the considered area. Urban and industrial areas with compact settlement influenced groundwater are dispersed throughout the whole area.

Through the long industrial history of the region the aquifer systems have been subjected to a significant abstraction by numerous wells and zinc-lead ore mines, still active or abandoned. At the end of the 1990s total abstraction of groundwater ranged from about 9 to 10.6 m^3/s (773 000–893 000 m^3 per day). Consequently, major changes to the groundwater flow systems have occurred. The water table has declined by 40–70 m in well fields and by 100–260 m in mining areas (Kowalczyk, 2003) (Fig. 1).

According to the assessment by means of the mathematical modelling performed for the regional groundwater flow systems the recharge for the whole systems of the main aquifers amounts to 13% and 21% of precipitation. These are areal average recharge rates of the studied areas. For zones of very intensive water drainage by wells and mining where recharge intensification or activation of new sources of recharge takes place the rates of recharge obtained by analytical estimations vary from 20% to 55% of the average annual precipitation (Kowalczyk, Witkowski, 2008). The paper summarizes the changes of groundwater resources due to urban and industrial impact on Triassic carbonate formation taking into account quantity and quality of the groundwater.

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IAH 2010 Krakow

abstract id: **497**

topic: **1**
Groundwater quality sustainability

1.3
Urban hydrogeology

title: **Bacterial contamination in groundwater due to latrine pits in urban areas — case study in Sri Lanka**

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keywords: Coli Form, permeability, E coli, aquifer

Urban areas of the Sri Lanka mostly groundwater pollution patterns arising from core existing pit latrines and wells. In rural areas the population continues to grow and the land available for homestead use decreases in proportion. In populated areas latrines are sited within the homestead due to small land plots. Land reform programs tend to increase homestead densities in zoned residential areas and reduce distances between pit latrine and family wells thereby increasing the possibility of groundwater effluent pollution. It is therefore possible that effluent from latrines may pollute adjacent groundwater wells within the homestead. Present research study was conducted in out skirt of tsunami affected area in southern Sri Lanka to determine groundwater pollution due to poor sanitary facilities. Continues monitoring was conducted with respect to bacterial contamination parameters (Coli form and E Coli), groundwater level, pH and Electrical conductivity (EC). The results significantly revealed that the E coli and Coli form (bacterial) contaminations depend on the well constructions, well water collection method, latrine pit depth (latrine pits are constructed above and below the groundwater level) and distance of dug well and latrine pit. In dug wells constructed below the groundwater table, bacterial contamination is higher than the wells constructed within the unsaturated zone. Bacterial contamination is higher in well water collection using the bucket than electrical water pump installed wells. Soil sampling were conducted to identify saturated (aquifer) and unsaturated zone characteristics within the study area. Soil samples were taken from surface layer and followed by each 50 cm depth until reach water table and also water samples were taken from auger holes. Soil samples were studied with respect to physical and chemical parameters. The Soil analysis results show that pit latrines aquifer permeability contribute significant affect to contamination of bacterial pollution.

The necessity for groundwater protection is considered in the European Union in the context of its influence on the state of surface water and connected directly with terrestrial and water ecosystems as well in the context of its significance for the drinking water supply of the population. An estimation of ground and surface water quality includes among others the recognition of its biological elements of quality: plankton, macrophytes, phytobenthos and benthic invertebrates (Directive No 2000/60/EC, 2000).

The authors have carried out an investigative project on this topic. Investigations have carried out on the carbonate massif of the Cracow-Czestochowa Upland (the CCU). This is an area of upland karst not fully developed and differentiated in its inner structure. The Upper Jurrasic aquifer, which is the Major Ground Water Basin (MGWB No 326), is located in this area. In the southern part of the CCU it is a typical unconfined aquifer, which is closely connected with surface water. The Upper Jurassic aquifer is also closely connected with the surface water including living biocoenoses and other biocoenoses which depend on the state of water. With the aim of protecting the natural environment and groundwater resources, most of the area in the CCU is protected by law (Ojców National Park, Landscape Parks, Nature 2000 area). Therefore, this region with its unique karstic features, that is environment extensively managed and protected by law, is an excellent area for hydrogeological studies (Różkowski, 2006).

The presented project refers to hydrogeoecological studies. They include interdisciplinary studies of ecosystems of damp areas under the influence of ground and surface water as well marshes. Investigations have dealt with the water environment regime and also with the presence of subterranean microorganisms and invertebrates in it (Humphreys, 2009).

These habitats connected directly with groundwater outflow are treated in the so-called Habitat Directive of the European Union as very valuable and they have the rank of European cultural heritage. In the area of the CCU there are several hundred springs. They are not only the local groundwater drainage points but they also set composite hydrologic biotic ecosysytems (Springer, Stevens, 2009). The durability and stability of habitat conditions in springs results in the occurrence of a specific fauna (crenobionts) and some relic species, e.g. in the area of the CCU — Crenobia alpina and Bythinella austriaca. The composition of fauna living in springs is influenced by hydrogeological conditions, their surroundings, zonal differences eucrenal–hypocrenal and also by disturbances, especially in the form of anthropopression (Dumnicka et al, 2007). Existing faunistic and ecological studies on the springs located in the CCU indicate that they are highly diverse although the number of taxa found in individual springs was not substantial. However, there are no complex studies on fauna which take into account the presence and conditions of populations of crenobiontic and oligo-stenotermic species in individual springs.

Within the framework of this project in chosen study polygons the unconfined aquifer is investigated. The study is performed in spring drainage areas in zones of unconfined flow systems as well as in caves and outflows from caves, and in water-logged quarries. Such an approach to the natural environment will allow water and terrestrial esosystems connected with the water of the unconfined aquifer to be recognized. An assembly of benthic invertebrates, higher plants, bryophytes will be determined as the biomarkers of the environmental state and then they could be compared (on basis of literature) with porous environmental analogs. The study, done together with the recognition of regional management and pollution sources, will allow the influence of natural and antropogenic factors on water environment and its biotic elements within the karstic area of the CCU to be estimated. They will also show the current trends of this environment is development. In addition to the study aspect the project also has practical and methodological aims. For the purpose of providing the effective protection of karst water and its ecological environment in the area of the CCU, the further development of research procedures typical for the karstic areas is necessary.

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abstract id: **503**

topic: **1**
Groundwater quality sustainability

1.3
Urban hydrogeology

title: **Urban water cycle**

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keywords: groundwater, water supply, urbanisation, water cycle

Ljubljana field aquifer is one of the most important gravel aquifers in Slovenia and it is a source for drinking water for almost 300.000 people. More than three quarters of aquifer is lying beneath the urbanised and agricultural areas. The quality and quantity of this valuable resource continues to be threatened by a range of human activities, from over pumping and reduction in sustainable yield, to contamination and water quality degradation from many sources discharging or releasing contaminants to the subsurface.

We'll present the results of analysing the present status of the aquifer and try to find out how the natural hydrological cycle has been modified to the urban water cycle in the last century. In the context of past and current deleterious impacts to groundwater quality, management of urban groundwater basin have to determine and implement appropriate management strategies to ensure provision of groundwater for a variety of beneficial uses in a sustainable way while meeting all quality and human health standards.

1.4 | Groundwater quality and agriculture

abstract id: **103**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **Groundwater contamination by nitrates, salinity and pesticides: case of the unconfined aquifer of Triffa plain (eastern Morocco)**

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Located at the North-eastern part of Morocco the plain of Triffa is under a semi-arid climate. The water resources in this zone are rather fragile and influenced by a highly irregular rainfall distribution, both in time (annual and inter-annual distribution) and in space with an yearly average which does not exceed 240 mm.

In the Triffa plain the impact of anthropogenic activity on the groundwater resources is reflected both by: a) the decrease in the piezometric level due to the over exploitation and droughts; and b) the deterioration of the chemical quality of water. Currently, this situation is felt mainly by the farmers.

The unconfined aquifer is under stress due to increase of the pollution rate, especially nitrates, that is above the WHO standards, and salinity. Pesticides such as aldrin, lindane, heptachlor, etc. (samplings 2007), have also been detected and are indicators showing the need to reduce the pressure on groundwater quality by informing and training farmers on the use of fertilizer and pesticides.

abstract id: **105**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **Impact of agriculture land use change on the recharge and quality of groundwater in the northeastern region of India**

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keywords: agriculture, grounwater quality, groundwater recharge, northeastern India

INTRODUCTION

The northeastern region of India, comprising seven states, lies between 21°57' and 29°28' N latitudes and 89°40' and 97°25' E longitudes. The region, with an area of 255,090 sq km, is predominantly hilly. Though endowed with such natural resource of water, its indiscriminate use and mismanagement has caused resource degradation to the extent that quality and quantity of groundwater has been affected. Fast growing population has pressurized the food production base and to satisfy their needs, the people have misused water resources. The region, though having sufficient water in aggregate, cannot boast of adequate quantity of water for its people at all the places and during all the seasons. Major factors affecting groundwater recharge in the region include; type, amount and distribution of precipitation, land use, initial soil moisture, soil infiltration and slope of the catchment. Hydrologists have considerable interest in land use change and its hydrological consequences, both from the perspective of field monitoring (Bosch, Hewlett, 1982) and from a modelling perspective (Niehoff, 2002). To understand effective eco-system management, there is need to use interactive models to simulate the hydrological processes, together with the meteorological and climatic variables and also with ecological behaviour of the eco-system. Changes in water regime are linked with climate fluctuations as well as environmental changes over time. So, precipitation, vegetation and groundwater quantity and quality are interlinked. The extent of inter-linkage has temporal and spatial variations. The important issue is to promote conservation and sustainable use of resources which allow long term economic growth and enhancement of production capacity, along with being equitable and environmentally acceptable. A study was, therefore, undertaken to see the effect of agriculture land use on the groundwater recharge and its quality.

MATERIALS AND METHODS

To manage water resources effectively, a long-term multidisciplinary study was undertaken on watersheds having slopes varying from 32% to 42% to see the effect of different land uses, and fertilizer use on the recharge and quality of groundwater (Tab. 1). The soil conservation measures followed were bench terracing, half-moon terraces, trenching and grassed water-ways. The land use systems have grasses, forestry, agro-forestry, agricultural crops, horticulture, agri-horticultural crops and shifting cultivation as control. The soil and nutrient losses were monitored through monitoring gauges fixed at the exit point of each watershed. The crops grown in different land use systems, soil conservation measures followed and animals kept as per farmer's requirement are given in Tab. 1. The soil of the experimental area was loam in texture, The pH varied from 5.0 to 5.3 and E.C. from 0.30 to 0.35 dSm^{-1}.

The runoff (surface and base flows) and soil loss was monitored through gauges installed at the base of each micro-watershed. The runoff water as well as groundwater samples were taken from different crop land use systems and analysed for various constituents to ascertain quality. Potential groundwater recharge was estimated using the simple approach, which takes into account crop water requirement, soil type and evaporation from the bare soil viz.; Groundwater recharge (mm) = P – Yw – E – T; where P is the precipitation, Yw is the water yield through surface and base flow, E the evaporation from bare soil and T is the transpiration or crop water requirement to produce a particular crop yield. Soil and water samples analysis was done as per procedures mentioned by Jackson (1973).

Table 1. Vegetation cover in different land use systems.

Land use	Slope (%)	Crops/Trees	Livestock	Soil conservation measure
Fodders	32.0	*Zea mays, Stylosanthes guyanensis, Avena sativa, pisum sativum, Setaria sphaselata, Panicum maximum, Thysanolaena sphacelata*	Cows, pigs, rabbits	Contour bunds, trenches, grass water-ways
Forestry	38.0	*Alder nepalensis, Albziia lebbeck, Acacia auriculiformis*	None	None
Agro-forestry	32.2	*Ficus hookerii, Eucalyptus amygdalina, Pinus longaeva, Ananas comosus, Phaseolus spp., Psidium guajava*	Goats, rabbits	Contour bunds
Agriculture	32.4	*Phaseolus spp., Raphanus sativus, zea mays, Oryza sativa, Zingiber officinale, Curcuma longa, Arachis hypogaea, Avena sativa, Panicum spp.* on risers	Cows	Contour bunds, bench terraces grass water-ways
Agri-horti silvi-pastoral	41.8	*Phaseolus spp., Carica papaya, Citrus spp., Zingiber officinale, Solanum spp., Alder nepalensis, Ficus hookerii,Psidium guajava*	Pigs, goats	Contour bunds half-moon terraces, grass water-ways
Horticulture	53.2	*Prunus persica, Pyrus communis, Citrus spp., Citrus lemon, Psidium guajava* vegetables	None	Same as above
Shifting cultivation	45.0	*Mixed cropping*	None	None

RESULTS AND DISCUSSION

Effect of land uses on the water yield and soil loss

In the present study, the mean values of base flow and surface flow were 114.3 mm and 69.4 mm in the new land use systems as against 275.3 mm and 560.1 mm in shifting cultivation (Tab. 2).

Table 2. Water yield and soil loss from different land uses.

Parameters	Livestock based	Forestry	Agroforestry	Agriculture	Agri-hortisilvipastoral	Horticulture	Shifting cultivation
Base flow(mm)	2.9	365.3	202.2	0.5	8.5	106.8	275.3
Surface flow (mm)	11.1	68.0	35.4	20.4	69.1	212.7	560.1
Total water yield (mm)	14.0	433.3	237.6	20.9	77.6	319.5	835.3
Per cent of rainfall	0.6	17.7	9.6	0.9	3.1	13.0	34.1
In-situ rainwater Retention (%)	99.4	82.3	90.4	99.1	96.9	87.0	65.9
Soil loss (t ha^{-1})	0.2	2.0	1.9	0.1	1.8	8.3	42.4
Benefit/cost ratio	2.1	1.2	1.5	1.8	1.9	1.7	0.6

By and large, more than 90% of rainwater was retained *in-situ* in the new land use systems compared to 65.9% in the shifting cultivation. More *in-situ* retention of rainwater helped in the availability of adequate moisture from the soil to the succeeding crops when the rainy season receded. It was interesting to note that while in shifting cultivation 34.1% of rain water escaped as runoff, it varied from 0.6% to 17.7% in the new land use systems. Maximum of 99.4% of rain water was retained in livestock based land use system, followed by agriculture (99.1%). It was reported earlier also that more than 95% of rain-water can be retained *in-situ* by following these land use systems (Singh, 1989). Annual soil loss due to erosion with runoff varied from 0.2 to 8.3 t ha^{-1} in new land use systems compared to 42.4 t ha^{-1} in the shifting cultivation. The soil loss was very low in newly tried land use systems due to reduced runoff because of proper vegetation cover and water and soil conservation measures undertaken.

Groundwater recharge

Meteorological factors as amount and duration of rainfall, temperature, in-situ retention of rain water, rate of infiltration and amount of run-off as well as aquifer recharge capacity are important indicators of ground water sustainability. Most of the rainfall is confined to the period from May to October in the region. Water levels of aquifers in the region reach their peak from mid-August to mid-October. Heavy rainfall causes huge soil erosion through runoff from the hills and silting of river bed and flood in the plains (Sharma, 1990). Management solutions should aim at restoration of the more natural, dynamic behaviour of the water system, because this will minimize the volume of water discharged from the area and maximize water conservation. Dynamic surface water control implies that greater water level fluctuations are allowed within the constraints of agricultural activity and safety. Prevalence of shifting cultivation, fast increase in the population at, urban development free range grazing, land tenure system and deforestation have significant effect on the hydrological cycle in terms of both water quantity and quality in the region.

Effects of land use

Recharge is the entry into the saturated zone of water made available at the water table surface, together with the associated flow away from the water table within the saturated zone. The precipitation reaches the groundwater and depending on groundwater intensity and state of the soil, some rainfall runs away as runoff and some infiltrates into the soil zone (Hulme et al; 2001). The groundwater recharge was maximum in livestock based land use system, followed closely by agriculture, horticulture and forestry land use systems (average 32.5% of precipitation) as against only 8.3% in shifting cultivation (Table 3).

Table 3. Effect of land use, rainfall and their interactions on groundwater recharge (mm).

Land use	Rainfall (mm)						Mean
	2195	**2705**	**2770**	**2599**	**2288**	**1992**	
Livestock based	738	1212	1294	1101	835	555	956 (39.0)
Forestry	426	729	746	663	477	338	563 (22.9)
Agro-forestry	560	954	984	870	633	459	742 (30.2)
Agriculture	731	1219	1289	1102	831	570	957 (39.0)
Agri-horti-silvi-pastoral	679	1134	1198	1021	769	526	888 (36.2)
Horticulture	516	897	914	815	590	420	692 (28.2)
Shifting cultivation	152	260	274	231	168	125	202 (8.2)
Mean	543 (24.7)	915 (33.8)	957 (34.5)	829 (31.8)	615 (26.8)	426 (21.4)	

The low groundwater recharge in the shifting cultivation was due to minimum land cover and higher slope, resulting in high runoff mainly as surface flow. The affect of precipitation on the groundwater recharge was significant (r = 0.831) as also on base and surface flows. During the six years of study, the rainfall varied from 1992 mm to 2770 mm per annum and groundwater recharge varied from 426 to 957 mm, respectively. The groundwater recharge was 21.4% of the precipitation during the year when the annual fall was 1992 mm and 34.5% when the rainfall was 2770 mm. Though, the runoff was higher at higher rainfall, the groundwater recharge was also higher. The results were validated at other two sites receiving rainfall of 1350 mm and 1060 mm. Application of the simple model; Groundwater recharge (mm) = P – Yw – E – T, showed that the groundwater recharge was only 16.6% and 1.5% of rainfall, respectively, at above sites. On ground situation at second site above has revealed that in most of the dug-wells the water table has considerably gone down due to over-exploitation of these wells and their recharge was almost negligible. It showed that groundwater recharge is negligible at lower rainfall when the evaporation is high. When the annual rainfall is below 1000 mm, no groundwater recharge can be expected. The model gave significant predictability and reliability as verified from the ground situation and predicted and observed values agreed relatively well. Maximum rain water could be retained *in-situ* and the soil can retain sufficient moisture for growing winter crops (Sharma, 2001, Sharma and Sharma, 2003, 2005). This would also helps in reducing runoff and soil loss and, improved environmental conditions could be assured.

Groundwater quality

Uncontrolled disposal of urban wastes into water bodies, open dumps and poorly designed landfills cause ground water contamination and has become one of the most important toxicological and environmental issue in India. The use of fertilizers, pesticides and other agricultural chemicals in an effort to increase crop productivity, results in pollution of groundwater. The ground water is vital form of earth's capital and is easy to deplete and pollute because it is renewed very slowly. The pH of groundwater varied from 5.1 to 5.6 and conductivity from 0.08 to 0.19 dSm^{-1} in various land use systems (Table 4). The variation in Uncontrolled disposal of urban wastes into water bodies, open dumps and poorly designed landfills cause ground water contamination and has become one of the most important toxicological and environmental issue in India. The use of fertilizers, pesticides and other agricultural chemicals in an effort to increase crop productivity, results in pollution of groundwater. The ground water is vital form of earth's capital and is easy to deplete and pollute because it is renewed very slowly. pH and conductivity was non-significant among various land uses. The NO_3-N is the most widespread contaminant affecting the groundwater quality in the aquifers in the region. The NO_3-N in the groundwater crossed the critical limit of 45 mgl^{-1} for drinking water in fodder/grasses, agriculture, agri-horti-silvi-pastoral and horticulture land uses. This may be attributed to the application of inorganic fertilizers in these land uses (Sharma, 1990, 1999). The nitrate may be derived from natural and anthropogenic sources such as application of inorganic fertilizers, septic systems, animal manure, atmospheric deposition and transformation of soil organic matter to nitrate. Nitrate is highly soluble and can be readily transported to groundwater. Sulphates, chlorides, calcium, zinc, Mn, Fe and magnesium concentrations in the groundwater varied from 12.9 to 45.6, 11.6 to 26.2, 30 to 70, 4.2 to 11.8, 0.4 to 1.7, 0.8 to 6.4 and 10 to 33 mg/L, respectively. The sulphates, chlorides, calcium zinc and magnesium were within the critical limits for drinking as well as irrigation purposes. However, manganese and iron concentration was higher than critical limit for drinking water in some samples. This may be attributed to the soil acidity and higher concentrations of manganese and iron in the soil.

Table 4. Effect of land use (vegetation) on the range of pH, conductivity (dSm-1) and elements in groundwater (mg/L).

Land use	pH	Conductivity	NO_3-N	SO_4	Cl	Ca	Zn	Fe	Mn	Mg
Fodders	5.1–5.4	0.13–0.19	25–47	15.1–26.2	11.2–16.0	46–63	4.3–9.5	1.4–3.3	0.5–1.4	16–28
Forestry	5.0–5.2	0.11–0.15	18–26	12.6–21.3	11.0–15.6	36–50	4.7–8.2	0.8–2.4	0.4–1.2	13–23
Agro-forestry	5.1–5.3	0.14–0.18	20–35	14.3–26.8	14.5–19.5	36–58	4.9–10.1	1.0–2.8	0.7–1.3	13–25
Agriculture	5.3–5.6	0.12–0.19	36–55	19.2–45.6	16.8–26.2	48–70	5.6–11.8	1.9–6.4	0.6–1.4	12–33
Agri-horti-silvi-pastoral	5.2–5.4	0.10–0.18	28–48	17.3–32.9	16.8–23.0	46–72	5.2–11.1	1.8–5.5	0.5–1.3	12–30
Horticulture	5.1–5.3	0.14–0.19	27–50	18.1–33.2	17.5–23.6	40–68	4.9–12.2	1.6–5.6	0.9–1.7	20–28
Shifting cultivation	5.2–5.4	0.08–0.09	18–27	12.9–20.0	11.6–15.0	30–49	4.2–7.4	1.2–2.5	0.4–1.2	10–17

CONCLUSIONS

The results of the study undertaken showed that the introduction of new land use systems, with suitable water and soil conservation measures, significantly reduced runoff from the watersheds on hill slopes and helped in more *in-situ* retention of rainwater, thereby increasing the groundwater recharge. The land use and precipitation significantly affect the groundwater recharge and the sediment yields. While the rainfall is a natural phenomenon and its amount and intensity cannot be controlled, judicious management and use of rainwater and proper land use can be controlled. Proper land use and soil and water conservation measures need to be undertaken for higher *in-situ* rainwater retention and reduction in runoff to increase groundwater recharge. The interface between runoff and ground water is signified by gradient, geology of the area and physical and chemical properties of the soil. Heavy rainfall and the anthropogenic interventions are important factors affecting GWR in the northeastern region. An understanding of the mechanisms that control groundwater interactions with surface water is crucial for the effective management of water resources and the conservation of its associated ecosystem.

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abstract id: **140**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **Coupling an unsaturated model with a hydro-economic framework for deriving optimal fertilizer application to control nitrate pollution in groundwater**

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keywords: unsaturated zone, groundwater nitrate pollution, hydro-economic modeling

ABSTRACT

In deriving management policies to control groundwater nitrate pollution, it is important to conduct an integrated modeling which takes into consideration the soil, the unsaturated and the saturated zone. In management regional studies the influence of the unsaturated zone is often neglected. The unsaturated zone can have an important influence in the time delay of nitrate transport and therefore in accomplishing the good groundwater chemical status required by the EU water framework directive. In this paper the unsaturated zone is coupled with a hydro-economic model that obtains the spatial and temporal fertilizer application rate that maximizes the net benefits in agriculture constrained by the quality requirements in groundwater at various control sites. The integrated model was applied to El Salobral-Los Llanos aquifer in central Spain, where the fertilizer allocation that accomplishes with the nitrate concentration in groundwater was obtained.

INTRODUCTION

The EU Water Framework Directive (Directive 2000/60/EC; WFD), proclaims an integrated management framework for sustainable water use, and requires that all water bodies reach a good status by 2015. According to article 4 of the WFD, this deadline can be extended if the "Member States determine that all necessary improvements in the status of the bodies of water cannot reasonably be achieved within the timescale". Therefore, the correct estimation of the timescale to achieve the good quality of the groundwater bodies is very important.

To control groundwater diffuse pollution is necessary to analyze and implement management decisions. The efficiency of these decisions depends on the inertia of the soil-unsaturated-groundwater system. In order to predict future groundwater-quality values, especially after implementation of environmental measures such as reduction in fertilizer use the response time has to be determined. The response time between the fertilizer application and the contamination at a particular site may depend on the distance between the source area and the control site where water quality is measured (Gutierrez, Baran, 2009). In Peña-Haro et al. (2009) an hydroeconomic model was developed to obtain the optimal allocation of fertilizer application in order to maximize the benefits in agriculture while maintaining the nitrate concentrations in groundwater below a predefined standard. In this methodology the unsaturated zone was not explicitly taken into account. In this paper the delay time that nitrate suffers while going through the unsaturated zone is coupled into the hydro-economic model. This is applied to El Salobral-Los Llanos aquifer (Mancha Oriental) in Spain, and some preliminary results are shown.

HYDROECONOMIC MODEL

The hydro-economic model (Peña-Haro et al., 2009) couples an agronomic model, flow and transport models in an optimization framework, where the benefits in agriculture are maximized. From agronomic simulations quadratic functions are derived that relate the nitrate leached and the crop yield with the water and fertilizer use. The groundwater flow and nitrate transport model are used to obtain concentration response matrices, which shows the influence of a pollutant source upon nitrate concentrations at different control sites over time. In this paper a simple unsaturated model, which only considers the gravity flow, was coupled into the hydro-economic model. With this model the time delay from the nitrate leaves the root zone until it arrives into the saturated zone is estimated. The time delay due to the nitrate transport trough the unsaturated zone was included into the concentration response matrix as a shift in the time (Fig. 1).

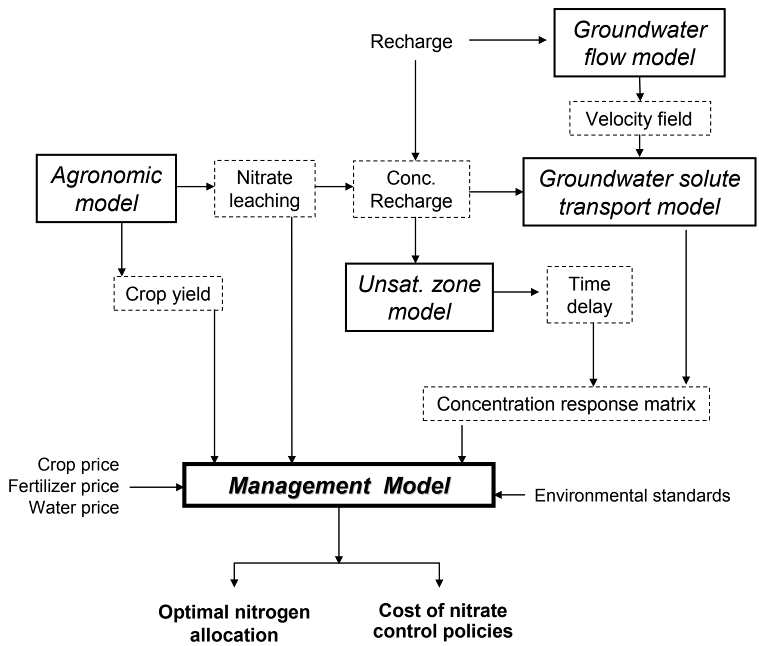

Figure 1. Modeling framework.

UNSATURATED ZONE MODEL

For the simulation of the water flow through the unsaturated zone, a simple model considering a simplification of Richards' equation with kinematic wave was used. Vertical flow through a homogeneous unsaturated zone can be represented by Richards equation:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left[D(\theta)\frac{\partial \theta}{\partial z} - K(\theta) \right] \tag{1}$$

where: θ is the volumetric water content [L^3/L^3], z is the elevation in the vertical direction [L], $D(\theta)$ is the hydraulic diffusivity [L^2/T], $K(\theta)$ is the unsaturated hydraulic conductivity as a function of water content [L/T] and t is time [T].

Equation (1) can be written as follows (Singh, 1997):

$$\frac{\partial \theta}{\partial t} + \frac{dK(\theta)}{d\theta}\frac{\partial \theta}{\partial z} = \frac{\partial}{\partial z}\left[D(\theta)\frac{\partial \theta}{\partial z} \right] \tag{2}$$

If we assume that the vertical flux is only driven by gravitational forces the diffusive term can be neglected (right side of equation 2), and considering that $q=-K(\theta)$, equation 2 is reduced to the kinematic wave equation:

$$\frac{\partial \theta}{\partial t} + \frac{dq}{d\theta}\frac{\partial \theta}{\partial z} = 0 \tag{3}$$

Equation (3) can be solved by the method of characteristics. The characteristics showing the velocity of the wave is (Niswonger et al., 2006):

$$\frac{dz}{dt} = \frac{\partial K(\theta)}{\partial \theta} = v(\theta) \qquad (4)$$

where v(θ) is the characteristic velocity [L/T]

The Brooks-Corey function is used to define the relation between unsaturated hydraulic conductivity and water content (Singh, 1997).

$$K(\theta) = K_s \left[\frac{\theta - \theta_r}{\theta_s - \theta_r} \right]^{\varepsilon} \qquad (5)$$

where θ_r is the residual water content, θ_s is the saturated water content, K_s is the saturated hydraulic conductivity [L/T] and ε is the Brooks-Corey coefficient.

EL SALOBRAL LOS LLANOS AQUIFER

The methodology was applied to "El Salobral-Los Llanos Domain" (SLD) which is located in the southeast of the Mancha Oriental System and extends over about 420 km^2. 80% of the land is agriculture from which 100 km^2 are irrigated crops (CHJ, 2004). The climate can be defined as Mediterranean. The mean summer temperature is about 22°C and the mean winter temperature about 6°C. The mean annual precipitation is about 360 mm. The average groundwater recharge is estimated in 165 mm/year (CHJ, 2008). The irrigated area has increased considerably, in 1961 was about 29 km^2 (Spanish Geological Survey, IGME, 1976) and in 2004 was of 100 km^2. This has provoked a decline of the groundwater levels of between 60 and 80 meters as well as high nitrate concentrations. The highest nitrate concentration is about 54 mg/l and was recorded in the well "El Salobral" (Moratalla et al., 2009), exceeding the allowed concentration for human consumption of 50 mg/l (Drinking water directive, 80/778/EEC). All these facts ended up with the declaration of the aquifer as a nitrate vulnerable area by the Castilla-La Mancha regional government (DOCM, 1998).

El Salobral-Los llanos aquifer is formed mainly by 2 units. The deepest one is constituted by mid Jurassic dolostones and limestones that can reach 250 m in thickness with a mean transmissivity of 10,000 m^2/day (Sanz, 2005). A detrital aquitard overlies it and reaches a maximum thickness of about 75 m. El Salobral-Los Llanos domain is limited by low permeability boundaries which do not allow the lateral inflow of groundwater from/to the neighbouring domains.

RESULTS

In this paper the time delay we estimated by using the unsaturated zone model, which only considers the gravity flow. The unsaturated zone thickness was calculated by considering the difference between the average ground level and the average groundwater level for 2005 for each one of the management areas (Figure 2). These management areas were defined by taking into account the type of crop and the administrative aggregation of farmers.

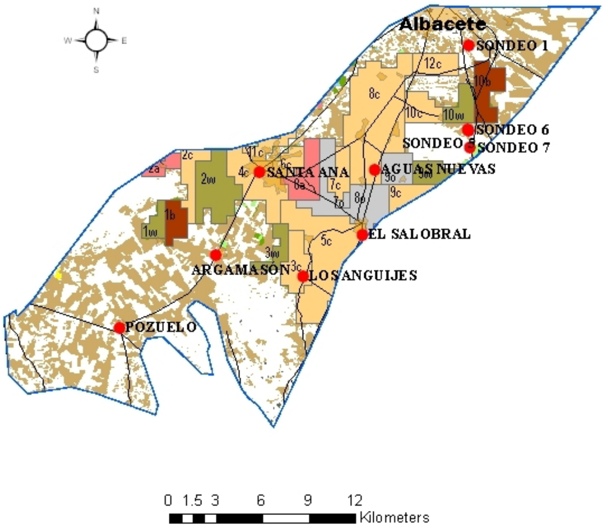

Figure 2. Control sites (red dots), agricultural management areas and dry-land areas.

The estimation of the time delay was done considering a K_s=0.015m/day, ε=3.5 and n=0.025. For estimating the recharge it was considered the values of a dry year. The average recharge was 40 mm/year. The delay time was between 6 and 16 years, with a mean value of 7 years.

The results of the optimal fertilizer allocation were obtained as a reduction from the actual fertilizer use. When taking into consideration the unsaturated zone, the results from the optimization shows that the target value of 50 mg/l can not be reached before 2023. In order to accomplish with the maximum nitrate concentrations, the fertilizer application has to be reduced on all areas, but especially on area 5c which has to be reduced by an 87% and in area 9c by a 64%. With this fertilizer application the benefits are 95.5 M€/year. The difference in time to achieve the target limits is not only influenced by the time that the reduced leaching takes to arrive to the control sites, but also because there is high nitrate concentrations already travelling trough the unsaturated zone (Figure 3).

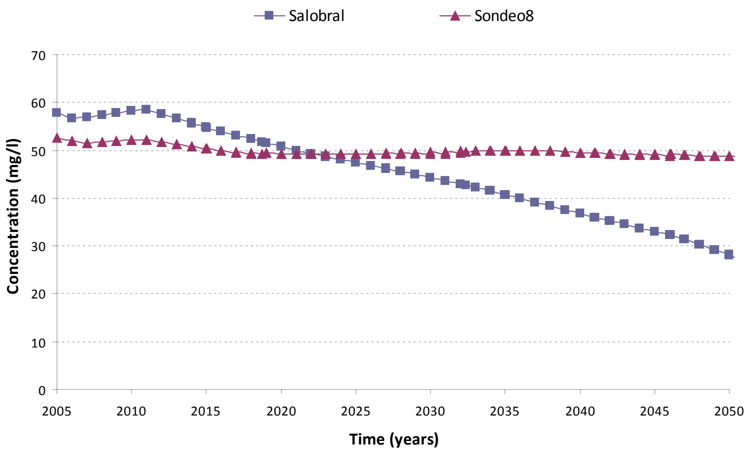

Figure 3. Nitrate concentrations for the optimal fertilizer allocation.

CONCLUSIONS

The WFD established the year 2015 as a deadline for the achievement of the good status and also the possibility to extend it. In this paper it was evaluated the influence of the unsaturated zone in the time of achieving the good status. A dry year (worst case) was selected. The average travel time of the nitrate trough the unsaturated zone was of 7 years, and the nitrate concentrations levels can not be achieved before 2023. The fertilizer had to be reduced to accomplish with the target concentration levels; therefore the benefits were also reduced.

ACKNOWLEDMENTS

The study was supported by the European Community 7th Framework Project GENESIS (226536) on groundwater systems.

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abstract id: **160**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **Alluvial groundwater response to variable rainfall recharge and prolonged pumping: lower Lockyer catchment, Queensland, Australia**

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The Lockyer Valley in southeast Queensland, Australia, is around 80 km west of the capital Brisbane and drains to the Brisbane River, which flows to the coastline. The valley supports intensive irrigation of market garden crops and fodder based on groundwater drawn from Quaternary alluvial deposits within channels incised into Mesozoic age sandstone bedrock. The alluvium is mostly less than 2 km in width and 35 m in depth, and much less in smaller tributaries. Alluvial material typically has upper layers of loamy soils and silts, a thicker intermediate zone of mixed layers of silts and fine sands with clays, and a basal layer of coarse sand and gravel which is highly transmissive, but not regionally continuous.

The climate is subtropical and long term average annual rainfall within the valley is around 900 mm and on the surrounding ranges is 1100–1200 mm. Recharge to the alluvial aquifer system is primarily from ephemeral stream flow fed by rainfall on the surrounding ranges, which are capped by Tertiary age basalt flows (Dvoracek and Cox, 2008). Most significant recharge is a result of summer storms. For most of the catchment regular monitoring (e.g. monthly) occurs in observations bores and several automated recorders, only within the central 30% of the catchment are irrigation bores metered. Largely due to this lack of regulation, groundwater levels have been drawn well down over time.

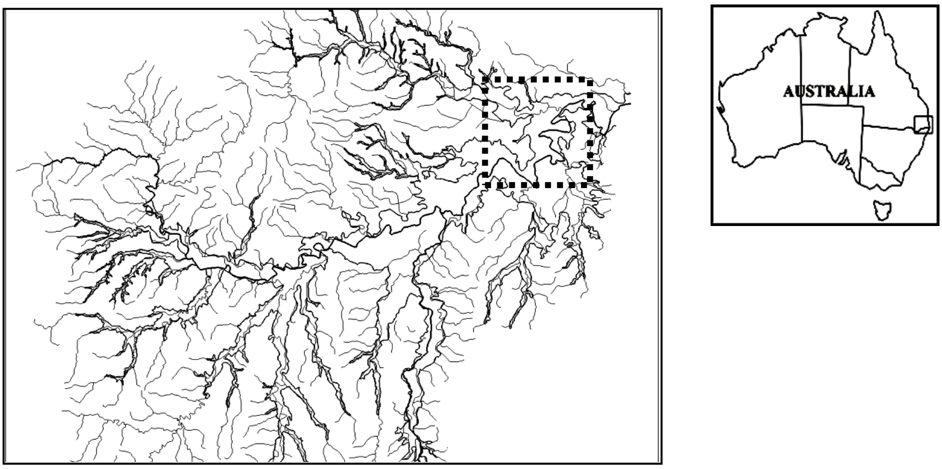

Figure 1. Drainage system of Lockyer Valley showing outline of alluvium. Box shows study area in lower valley (~10 × 10 km); inset shows location in southeast Queensland.

Following almost 15 years of near drought conditions, by 2008 water levels in the whole Lockyer Valley were the lowest for over 20 years. Here we consider the lower section of the catchment where the watertable has been substantially drawn down by pumping locally as well as further upstream. Although water levels clearly respond to high rainfall events, for example in 1996, with limited recharge and continued pumping the long term trend is a decrease. In the study area there are over 200 bores used for irrigation, and around 60 observation bores but regular monitoring only on about 20. Hydrographs (m below surface) for two bores within the central section of the alluvium, 643 and 613, show significant drawdown for the period 1990 to 2009 (Fig. 2). Less so for bore 647 within shallower alluvium of smaller Buaraba Creek which has occasional flow; and bore 625 is towards the edge of the alluvium. Both have much lower pumping rates than 613 and 643.

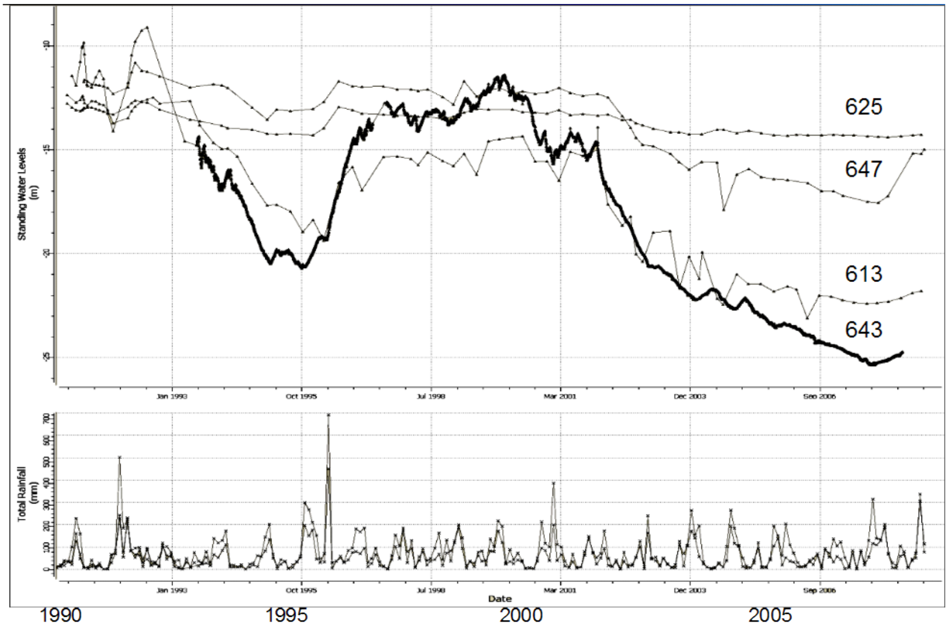

Figure 2. *Top:* hydrographs of 4 bores (locations shown in Fig. 3) for the period 1990 to 2009. *Bottom*: rainfall from two stations in central and lower Lockyer Valley.

In Figure 3 *(right)* the watertable surface for bores in the alluvium (as m above sea level) has been contoured. The contour pattern clearly shows that pumping is actively pulling groundwater from further upstream. Measurements of the alluvial watertable over a 25 km distance in this lower section show a lowering of head of 30 m, which reflects a gradient here of around 1.2 m/km. The zone of greatest drawdown central to the alluvial profile is shown by a continuous line, and of note, is not directly below the meandering stream channel.

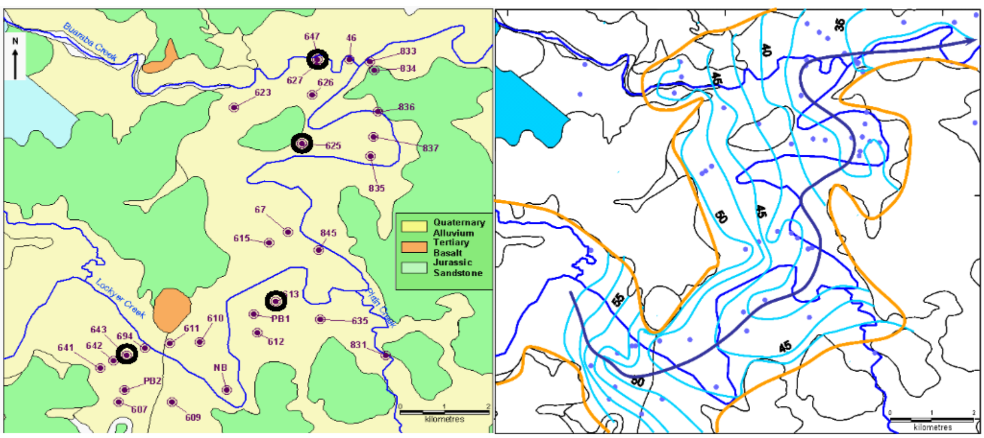

Figure 3. Maps of study area: *(left)* geology and bores measured and sampled, and *(right)* contours of the watertable surface with the deepest zone displayed by solid line.

Within the 25–35 m thickness of the alluvium in the main valley here continued extraction has produced drawdown of well over 15 m and resulted in a saturated thickness of around 5 m, and much of this is central to the main flow path. Typically, bores are drilled < 1 m into the bedrock and are screened in the lower 6 m accessing the basal sands and gravels (see Fig. 4). The relative position of bore 643 is shown with standing water levels of 1995, 2004 and 2009. Of note is that the water level (surface of the saturated zone) is around 15–20 m below the creek bed. With the lack of significant recharge some shallower bores towards the alluvium edges have dried up, for example, 641 in this cross-section (Picarel, 2004).

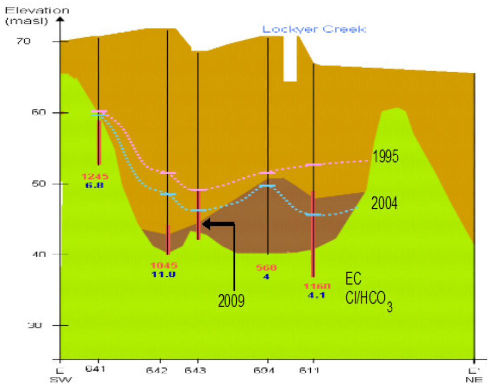

Figure 4. Cross-section of Lockyer Creek (in SW of Fig. 3) showing bedrock morphology and alluvium with coarse sands at base. Bore screens shown in red.

Most groundwater extraction is from the lower layers of coarse sands and gravels within the alluvium, and the lower valley is becoming degraded due to continued local and upstream extraction, and the effects of the decade-long drought. The alluvial groundwater typically has an EC of 800 to 2,000 μScm^{-1} and sandstone groundwaters an EC of 1,500 to 8,000 μScm^{-1} (Fig. 5). One bore in alluvium, 637, has an anomalous EC of 27,000 μScm^{-1}. Bores screened in both alluvium and gravels reflect mixing in their EC and chemical composition, as shown in Figure 4 (EC range 568 to 1245 μScm^{-1}).

Hydrochemical and isotopic analyses have enabled determination of recharge processes and the mixing of groundwaters within this area. Most groundwater sampled is of Na, Mg–Cl,HCO_3 type, with $Na^+ > Mg^{2+} > Ca^{2+}$ (Picarel, 2004). The chemical analyses indicate 4 major groups of water: A, recharging surface water and bores close to the stream; B, groundwater in the alluvial gravels, some near the bedrock interface; C, groundwater in middle and upper alluvium, mostly distant from the stream; and D, bores also extracting from the sandstone bedrock (Gatton Sandstone). These groupings are also displayed in a plot of HCO_3 vs Cl (Fig. 5); the ratio Cl/HCO_3 is found to be a useful discriminator (also see Fig. 4). Group C (main alluvial aquifer) receives recharge from rainfall-sourced stream flow; Group B includes weathered sandstone and reflects the interaction with stream recharge and alluvium. Group D waters are from sandstone aquifers here. Groundwater contribution from the sandstone bedrock is shown to be enhanced by pumping when groundwater levels are low. The high salinity bore 635 is shown, however, the bore does not extract from sandstone.

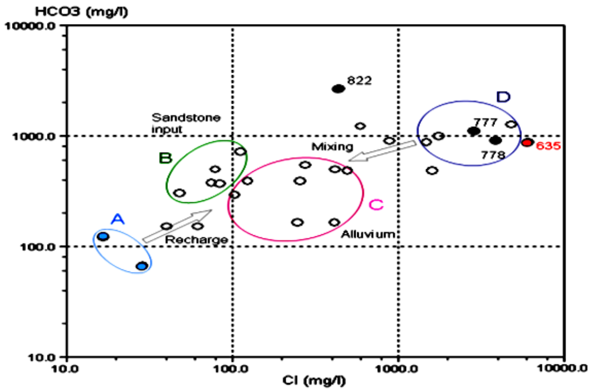

Figure 5. Log plot of HCO3 vs Cl for groundwaters in lower Lockyer Creek, showing grouping. Note high salinity alluvial bore #635. Blue: surface waters; black: bedrock.

Isotopic studies support hydrochemical groupings and identified two main sources of recharge to the alluvial aquifer system of the lower catchment. Groundwaters fall along the (Craig) Global Meteoric Water Line, and display those with direct recharge from stream flow ($\delta^2H \sim -22‰$ and $\delta^{18}O \sim -4.4‰$) plus those slightly more depleted values with recharge and mixing from sandstone bedrock. These sandstone groundwaters are indicated to be substantially older, and themselves are recharged at some distance. In areas close to the stream, δ^2H and $\delta^{18}O$ values indicate that the groundwater receives modern meteoric recharge. Alluvial bores more distant from the stream are relatively enriched along the global MWL; other bores further from the river fall along a slope showing strong evaporative enrichment. Many of these bores are distant from the river where the alluvium is thinner, and this is considered to be partly due to some recycling of irrigation waters (Cox, Wilson, 2006).

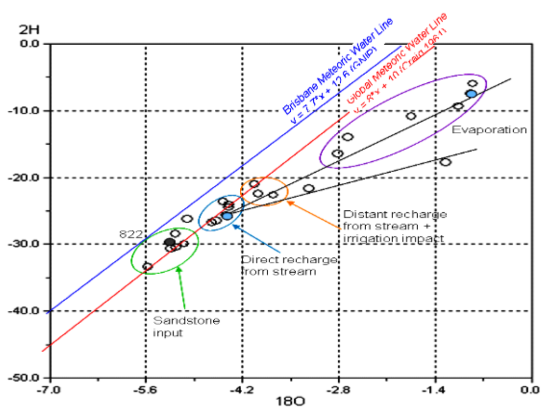

Figure 6. Plot of stable isotopes δ^2H and $\delta^{18}O$ reflecting processes related to mixing, recharge and evaporation. Blue: surface waters; black: bedrock.

Very high salinities in several bores appear due to ponding of groundwater in basement depressions. For the most saline bore 635 (EC = 27,000 $\mu S \cdot cm^{-1}$) this is a long term condition, and combined chemical and isotopic data and drillhole geology logs suggest that the salinity is not due to evaporative processes or to substantial recharge from the sandstone (δ^2H value = –23.6‰). It may be related to the morphology of the bedrock where a depression may lead to groundwater stagnation and concentration of dissolved salts.

SUMMARY

The primary recharge to the alluvial aquifers of the lower Lockyer Valley is from flow in the drainage system as a result of heavy storms in the surrounding ranges. There is a lesser amount from lower quality groundwaters from bedrock sandstones, and this can be enhanced by low water levels and continued extraction. Due to a combination of prolonged dry conditions, continued pumping for irrigation and the location at the lower end of the catchment, this area has substantially degraded groundwater resources. Degradation is both due to increases in salinity ($\gg$2000 $\mu S \cdot cm^{-1}$) and substantial drawdown of water levels into the basal layers of the alluvium.

Current water levels are 15–20 m below the stream bed and there is around 5 m of saturated alluvium. To give this some context: to fill the alluvium to the stream bed, a very rough calculation for 30 km of stream, of average alluvial section 1050 × 14 m, with porosity 25% (poorly sorted sands) gives a volume of 110 GL. The current situation is not sustainable for resource integrity. Several factors therefore need to be considered, (a) future impacts of climate change, (b) potential of artificial recharge and introduction of treated waste waters, and (c) strict management and monitoring.

ACKNOWLEDGEMENTS

We thank the Queensland Department of Environment and Resources Management (DERM) for access to the groundwater database. We appreciate the assistance given by Vivienne McNeil, Andrew Wilson, Pavel Dvoracek, Amy Hawke and Ashley Bleakley.

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abstract id: **164**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **Hydrogeochemistry modelling in La Aldea Aquifer (Gran Canaria, Canary Islands, Spain)**

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keywords: hydrogeochemistry modelling, volcanic-sedimentary aquifer, Gran Canaria Island

INTRODUCTION

La Aldea Valley is located on the western side of Gran Canaria (Canary Islands, Spain) and covers an area of 44 km². In the lower part of the La Aldea-Tejeda basin, shown in Figure 1, the valley presents a flat bottom surrounded to the north and south by high mountains (with heights varying from sea level to 1415 m). It is bounded to the east by the Atlantic Ocean and to the west by the impermeable materials of the inner part of the island. The climate is dry subtropical. Rainfall and temperature mean values are 160 mm/year and 21°C respectively. The main economic activity in the area is intensive greenhouse horticulture. Irrigation water comes mainly from three dams located upstream of the study area, but more than 370 large-diameter wells are exploited in times of drought. The intensive agriculture has an important impact on the aquifer, degrading groundwater quality and, during droughts, causing the drawdown of groundwater levels.

This article deals with the hydrogeochemical model that has been developed in La Aldea aquifer (Gran Canaria, Canary Islands). This model allows the interpretation of major ions taking into account the entire process that takes place in the aquifer.

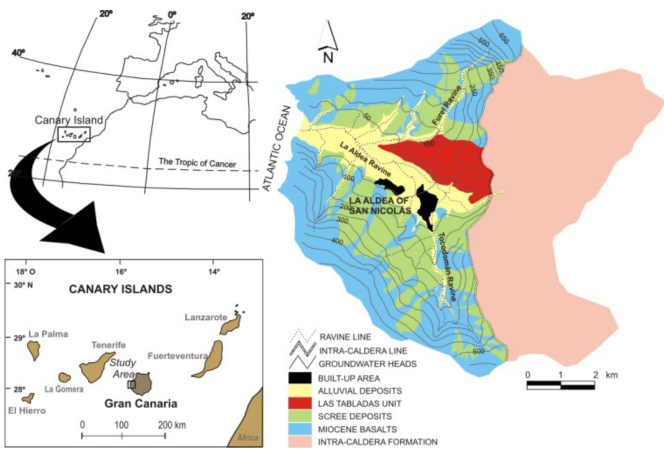

Figure 1. Location of La Aldea aquifer, showing the defined geological units.

HYDROGEOLOGICAL CHARACTERIZATION

A flow conceptual model of the aquifer has been established within the framework of the insular aquifer. It has been conceptualized as a single, stratified, heterogeneous groundwater body where recharge takes place mainly at the top of the island, with groundwater flowing towards the coast (SPA 15, 1974; Custodio, 2007). Within this framework, La Aldea Valley represents a discharge area from the aquifer to the sea.

Based on the geology, four hydrogeologic domains have been defined in the study area: Alluvial formation, scree deposits, Las Tabladas unit and Miocene basalts (Fig. 1), of which the alluvial formation and Miocene basalts are the most significant. The aquifer is unconfined and the alluvial deposits and the basalt rocks can be considered to be a single aquifer with two sub-layers: the upper alluvial deposits layer and the lower basalt layer. The flow has a main east to west direction in the La Aldea ravine, a south-north direction in the Tocodomán ravine and north-south direction in the Furel ravine (Fig. 1). Recharge is a result of rainfall, irrigation returns, supply network leaks and inflow from the intra-caldera zone. Rainfall and irrigation returns are the main sources of groundwater recharge. Discharge takes place by pumping wells and seaward outflow. The maximum permeability values are located in the La Aldea alluvial area, 17–106 m/d. In the Tocodomán and Furel alluvial areas it is 5.5–22 m/d. The permeability for Miocene basalts is 0.0009–0.005 m/d and for scree deposits and secondary tributary alluvial areas permeabilities are 0.25–1.2 m/d and 6 m/d, respectively (Muñoz, 2005; Cruz, 2008; Cruz et al., 2008).

HYDROCHEMICAL CHARACTERIZATION

Groundwater flows mainly through the alluvial materials to the sea and these materials are fed by the basalts in the upper parts and through the bottom of the alluvial unit. Thus, the exploited groundwater is a mix of groundwater from these two units and shows hydrochemical characteristics of both units in different proportions, with all the inputs from different origins (Muñoz et al., 1996).

The electrical conductivity of groundwater ranges from 837 µS/cm in HCO_3^-–Na^+ type water to 11370 µS/cm in Cl^--Na^+ type water. The resulting spatial distribution of groundwater types is shown in Figure 2. The hydrogeochemical inputs that have been considered in the model are: rain water (considering the influence of marine aerosol at the coast and the Saharan dust deposition), dams and runoff water, irrigation returns (increase in concentrations of nitrate and sulphate) and the geologic prints. The geologic inputs identified are two: groundwater from basalts (increase in the concentrations of magnesium and calcium) and trachyte-rhyolitic ignimbrites that form the scree deposits (increase in the concentration of sodium) and saline waters located in the Las Tabladas area that have been attributed to hydrothermally altered materials (locally called "Azulejos").

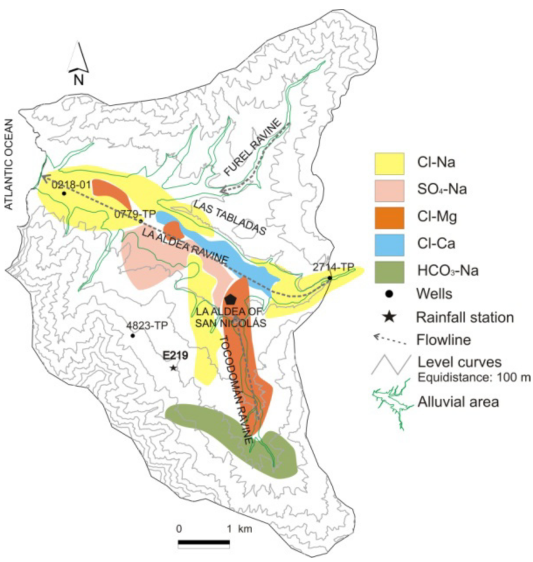

Figure 2. Location of observation wells and rainwater collector. Spatial distribution of groundwater types at La Aldea aquifer.

In general, chloride increases towards the sea, although there are some deviations in samples from wells near to the Las Tabladas area. In this area, a significant increase is observed in the concentrations of chloride, sodium and sulphate (reaching 8100, 3900 and 1800 mg·L^{-1} respectively), localized around the Las Tabladas area.

HYDROCHEMICAL MODELLING

Two chemical models have been made using PHREEQC: one simulates the chemical reactions taking place under the natural flow regime in the unsaturated zone (Fig. 3), and the other considers the anthropic inputs along a flow line in the aquifer (Cruz, 2008).

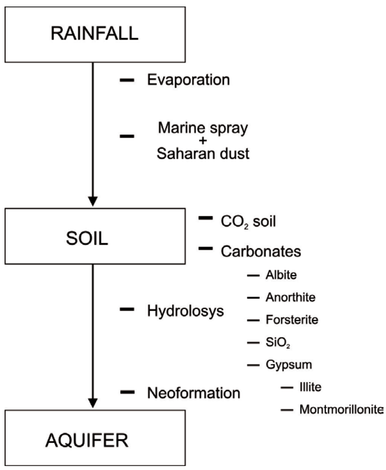

Figure 3. Conceptual model of the groundwater mineralization under a natural flow regime in unsaturated zone.

The quantification of these chemical reactions is in agreement with the groundwater chemical composition, that is controlled by the influence of dry deposition of marine spray and Saharan dust; soil CO_2 input, a significant evapotranspiration rate, silicate hydrolysis, irrigation returns inputs (of anthropic origin) and the saline waters from Las Tabladas input.

RESULTS AND DISCUSSION

Table 1 shows the results of hydrogeochemical modelling for obtaining groundwater from rainwater (Station E219 to well 4823-TP, Fig. 2) and mixtures in low line (well 2714-TP to well 0779-TP and well 2714-TP to well 0218-O1, Fig. 2) by simulating chemical reactions with PHREEQC. The result of modelling in flow line 2714-TP to 0218-O1 allows evaluation of the mixtures produced during the groundwater flow through the main alluvial deposit, from headwaters to the mouth, while the study of flow between well samples 2714-TP and 0779-TP allows its spatial distribution to be obtained, describing the chemistry evolution in the middle of the alluvial aquifer.

Table 1 Summary of results of hydrochemical modelling in natural conditions (from rainwater to groundwater) and anthropogenic conditions (flow line within the alluvial aquifer). Units:mmol/l.

Process	Rain → Groundwater E219 → 4823-TP	2714-TP → 0779-TP	2714-TP → 0218-O1
Evaporation	72.40%		
Mixture with marine aerosol		2%	4%
Mixture with irrigation water return		51%	89%
SiO_2	–0.9	33.1	172.33
Gypsum	–0.126	6.3	7
Calcite	–5.9	1.98	4
Forsterite		6.9	10.3
Albite	3.9		4.5
Anorthite	1.28		
Illite	–3.14	–4	–6.98
Montmorillonite	–0.32	–25.5	–43

The hydrogeochemical simulation for groundwater not influenced by anthropogenic inputs was carried out in the south of the aquifer: rain station 219 and well sample 4823-TP (Fig. 2), both located in the same area and not influenced by the irrigation return flows (nitrates= 0 $mg \cdot L^{-1}$). Equilibrium between rainwater and CO_2 soil was simulated. The evaporation process was introduced by removing 72.4% water (40.22 mol H_2O) to obtain a chloride content similar to that of well sample 4823-TP. The mineralogy of basalts and trachyte-rhyolitic ignimbrites has conditioned the considered minerals: SiO_2 (amorphous), Gypsum, Calcite, Forsterite, Albite, Anorthite, Illite and Montmorillonite. The simulation obtained a good fit between the calculated and observed chemical concentrations for well sample 4823-TP from rain station 219.

Another simulation was carried out according to the east-west flow line and taking into account lithology and system hydrological functioning. Thus, the chemical composition of wells 0779-TP and 0218 -O1 from well 2714-TP located in the header of the ravine is reproduced (Fig. 2). The simulated water from well 0779-TP has been obtained from the composition of well 2714-TP mixed with 51% of irrigation water returns and the resulting water is mixed with 2% sea water to reach the concentrations of sodium and chloride existing in groundwater that represent the airborne salinity. The simulated water from well 0218-O1 is obtained by mixing groundwater from well 2714-TP with 89% of irrigation water return and 4% of airborne salinity. The final groundwater composition implies the hydrolysis and dissolution (positive values) or neoformation (negative values) of the considered minerals (Table 1).

CONCLUSIONS

Hydrochemical modelling has been used to establish mixing processes and chemical reactions evolution that take place in the aquifer, shown to be a useful tool to identify and quantify the processes that are occurring. Consistency is increased if the flow model previously developed allows the characterization of hydrodynamic behaviour of the aquifer and its corresponding flow pattern, identifying main flow lines that are represented in the hydrogeochemical model. Hydrochemical modelling will help in developing a transport model that reproduces the spatial distribution of chloride concentrations in the study area.

If no anthropogenic effects are present, the chloride content (conservative ion) found in groundwater points to an evaporation process which removes 72.4% of rainwater volume, according to the evapotranspiration rates (69%) calculated in water balance from a previous flow model developed in the aquifer (Cruz, 2008; Cruz et al., 2008). Another important source of salinity exists in the area, spatially defined at the base of Las Tabladas area, which has not been taken into account in this study. It is produced by the leaching of hydrothermal *Azulejos* deposits, that affects the wells located near the plume but not the selected wells used in the simulation.

The existence of irrigation return flows in the flow direction has been confirmed and reaches 51% and 89% of the water exploited in the middle part of the aquifer (well 0779-TP) and the coastal area (well 0218-O1). The geological print of basalts has been identified in Tocodomán ravine. These data are also consistent with the previous water budget of the aquifer.

Modelling has confirmed that groundwater chemistry in the study area is the product of mixing water with different chemical characteristics in different proportions depending on the area of the aquifer. Groundwater is mainly of the sodium-chloride type, pointing to the importance of marine aerosol in this area. Where the influence of marine aerosol is low (highest parts of the study area and furthest from the sea), groundwater is of the sodium-bicarbonate-chloride type.

ACKNOWLEDGEMENTS

This work was carried out within a cooperation agreement between the Island Water Council of Gran Canaria and the University of Las Palmas de Gran Canaria, CICYT 1FD97-0525, CONSOLIDER-TRAGUA (CSD2006-00044) and REDESAC (CGL2009-12910-C03-02) projects and is a part of the doctoral thesis of Cruz T., under the direction of the other authors, funded by a Research Scholarship awarded by the Cabildo Insular de Gran Canaria.

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abstract id: **168**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **Hydrochemical and isotopic characteristics of water resources in the Banana Plain (Mungo Division) Cameroon**

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keywords: hydrochemistry, Banana Plain, Cameroon, isotopes, water resources

INTRODUCTION

The availability of reliable and substantial water resources and the fertility of volcanic soils have brought about since ancient times the intense settlement and agricultural exploitation of the lower flanks of volcanoes. The enhanced anthropogenic pressure has substantially increased the demand for water. The consequence has been a greater exploitation of surface and ground water resources in these areas for drinking, domestic and agricultural purposes. Industrial cultivation of banana in Cameroon, is concentrated on the foot slopes of Mount Cameroon on volcanic ash, phonolites and basalts at Buea, Molyko and the Tiko sedimentary (South West Region) and also the volcanic plains on the Kupe-Maneguba foot-slopes at Mbanga, Njombe, and Penja and Loum (Tombel graben-Mungo Division) in the Littoral Region called the Banana Plain (Sama-Lang, 2004).

The development of plantation agriculture and the fertility of the soils in the Banana plain (for traditional and modern agriculture) have created a pole of attraction for laborers from Cameroon and beyond. The towns of Mbanga, Njombe, Penja and Loum are all flourishing because of plantation agriculture. Mbanga town has a population of about 140,000 and covers a surface area of about 544km^2 (population density of 257 inhabitants/km^2) while Njombe and Penja are populated by about 50,800 inhabitants with a surface area of about 260km^2 (195 inhabitants/km^2) (Mbanga Municipal Council, 2008). The populations of these towns have witnessed rapid increases between 1987 and 2006 (the population of Njombe and Penja increased from 33,000 to 50,000 while that of Loum went from 67,000 to 110, 000 inhabitants) (GTZ, 2008).

The rapid increase in population in the Banana Plain was not accompanied by the development of basic infrastructure (water supply and sanitation). Less than 10% of the population is connected to the potable water network of CAMWATER (national potable water utility) and less than 5 % have adequate sanitation facilities. The local populations therefore fetch their drinking water from wells, springs, streams and boreholes and evacuate their wastes (excreta) in poorly constructed pit toilets or in local streams. Consequently, this region has recorded a series of cholera epidemics in the last years (222 cases in 2004, 1112 cases in 2005, 255 cases in 2006) (GTZ 2008).

Groundwater is an important source of drinking water supply in this region because Tangui Mineral Water Company that is one of the most prominent suppliers of bottled mineral water (from borehole) in the country and the Central African Sub region is located in Mbanga. There are also many springs (which serve as water source for irrigation in the agro-industrial farms), boreholes and wells from which the local people fetch their drinking water and for other domestic purposes. Engome (2006) studied the effects of saline water intrusion on the physic-chemical quality of groundwater quality in the Mungo Basin and noted that the physicochemical parameters tend to increase during the dry season. She also noted high feacal coliform counts in surface water resources during the rainy season indicative of probable high levels of pollution of groundwater sources during the dry season. Hence, evaluation of groundwater quality in the Banana Plain which is in the head water region of the Mungo Basin is not only necessary but imperative. Endeley et al. (2001) carried out a preliminary hydrogeochemical baseline study of water resources around Mt. Cameroon. No systematic hydrogeochemical studies have been carried out on the water resources in the Banana Plain of the Mungo Division.

The present study was carried out to evaluate chemical and isotopic characteristics of surface and groundwater of the Banana Plain in order to: evaluate the major ion chemistry, geochemical processes controlling water composition; trace the origin of groundwater and to explore the suitability of the waters for potable, domestic, and irrigation uses.

STUDY AREA, SAMPLING AND ANALYTICAL METHODS

The Banana Plain of the Mungo Division extends from 4°30'-4°53'N and 9°37'-9°50'E between 45 and 520m altitude , 70km north east of Douala, economic capital of Cameroon (Figure 1). The climate is of the Banana Plain is equatorial type influenced by monsoon during summer (July to September) during the rainy season with maximum rainfall in September with about 175-200 rainfall days per year . There are two distinct seasons, a dry season from November to June and rainy season from July to October. Annual average rainfall is 3000mm, annual relative humidity, 78% and annual average temperature is 28°C (CARBAP, 2009).

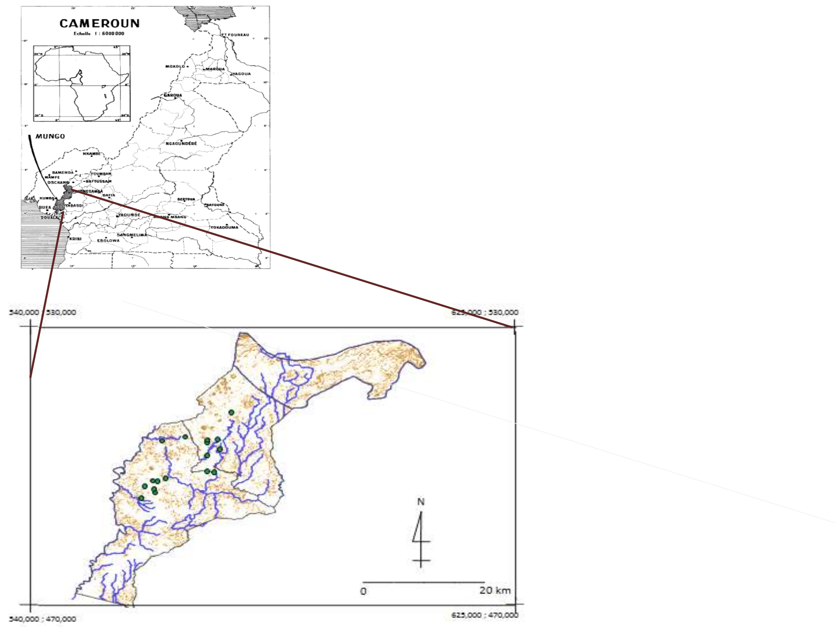

Figure 1. Location of study area and sampling points within its topography and drainage.

Geologically, the Banana Plain is part of a graben (Tombel Graben) located between the strato-volcanoes of Mt Cameroon and Mt Manengouba (Nkouathio et al., 2002), part of the N30°E Cameroon Volcanic Line (Dueruelle et al., 2007). Groundwater occurrence in the Banana Plain is controlled mainly by the development of secondary porosity, e.g., fractures, faults and joints. Principally, recharge to the aquifers is by direct percolation of rainfall along the foothills of the volcanic cones. Minor or indirect recharge also occurs mainly in the rainy season when fractures or mega joints intercept ephemeral stream courses. These channels act as conduits that allow water to recharge the aquifer (GEOBASE, 2008). Sampling campaign was undertaken in April 2009 during which 23 water samples were collected (Figure 1). Samples included 8 wells, 6 springs, 4 streams, 1 lake, 2 boreholes, and two rainfall events. Physical parameters like pH, electrical conductivity (EC), water temperature, Oxygen Reduction Potential (ORP) and Dissolved Oxygen (DO) of sampled water sources were measured in the field. Laboratory analyses for major ions (using ion chromatography) and stable environmental isotopes (by mass spectrometer, ThermoQuest Finnigen H/Device for Hydrogen and Finnigen mat Delta S for Oxygen) were carried out at the Isotope Hydrology Laboratory of Kumamoto University while dissolved silica (by ICP Spectrometer) was analyzed at the Kyushu Agriculture Institute, Kumamoto.

RESULTS AND DISCUSSIONS

Univariate overview of physical, hydrochemical and isotopic parameters measured in the water resources of the Banana Plain indicates that water resources in the Banana plain are generally fresh (TDS, 21.28–493.48mg/l). Fresh waters have Total Dissolved Solids (TDS) < 600 mg/l sufficiently dilute to be potable (Davis and DeWiest 1966; Freeze and Cherry 1979). Water temperatures vary from 27.0°C to 34.3°C with a mean of 28.8°C. Low temperatures suggest quick infiltration and rather shallow flow-paths. Furthermore, it negates any possibility of magmatic heating, as suggested at other volcanic areas (Rose et al.1996). The pH values are in the range 5.0–7.86 with a mean value of 6.52, indicating that the waters are generally acidic to slightly alkaline. pH of most samples is (74%) lower than or equal 6. This acidity is probably related to the hydrolysis of silicates and the reaction in the ground with humic acids resulting from the decomposition of organic matter in the infiltration zones. Alkalinity, the essential anion component of water, shows a large range of values (9.8–377.7 mg/l). This attests that mineralization is acquired in the unsaturated zone.

On the Piper's diagram (Figure 2) (Piper 1944) with defined chemical zones, it is evident that about 80% of the waters had a Ca-Mg-Na/HCO3 composition and 20% Ca-Mg/ HCO3-Cl type.

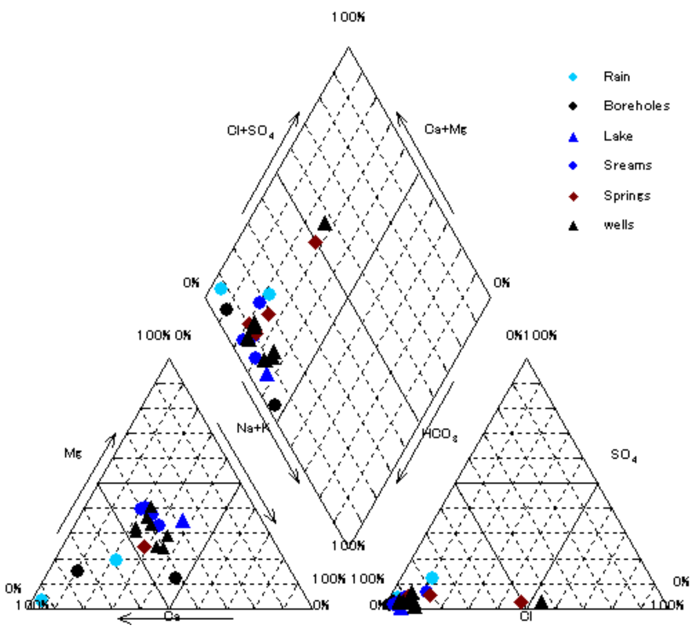

Figure 2. Piper diagram showing water types in study area.

Since most of the chemical parameters were not normally distributed, correlations between major ions were carried out using Spearman's correlation analysis. The results are shown in Table 1. High positive correlations were found amongst the cations (r=0.84 was found between Ca^{2+} and Mg^{2+}, Na^{+} and K^{+}, r = 0.87 between $Mg^{2+}$and Na^{+}, r= 0.8 between Ca^{2+} and K^{+}, r = 0.81 between Mg^{2+} and K^{+}).

Table 1. Spearman rank correlation coefficients of major ions concentration in the water resources of the Banana Plain.

	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	pH	TDS
Mg	0.84									
Na	0.78	0.87								
K	0.8	0.81	0.84							
HCO_3	0.76	0.64	0.57	0.66						
SO_4	0.81	0.71	0.6	0.61	0.78					
Cl	0.64	0.76	0.56	0.6	0.32*	0.46*				
NO_3	0.24	0.56	0.42*	0.39*	-0.61	0.18	0.82			
pH	0.38*	0.4	0.28	0.32	0.58	0.43*	0.1	-0.11		
TDS	0.93	0.87	0.77	0.76	0.88	0.84	0.66	0.28	0.48*	
SiO_2	0.56	0.73	0.58	0.49	0.59	0.64	0.38*	0.22	0.54	0.66

*Number of sample (N) = 21 and r = 0.3 significant at 1 % and 5%.

Amongst the anions, high positive correlations exist between SO_4^{2-} and HCO_3^- (r = 0.78), r = 0.82 between NO_3^- and Cl^-. Since the correlation coefficient between the cation and anion pairs is positively high, it can also be deduced that most of the water samples (minus the rain samples) originate from a common source. Very high positive correlations exist between Total Dissolved Solids (TDS) and Ca^{2+} , Mg^{2+} and HCO_3^- , respectively r=0.93, 0.87 and 0.88. The correlation between TDS and SO_4^{2-} (r=0.84) is also high and significant (r=0.3) at 1% level. On the other hand, correlations between other ions and TDS and among themselves though positive are significantly low suggesting that TDS is derived mainly from Ca^{2+}, Mg^{2+} and HCO_3^-. Chemical composition of water indicates that there is a very weak mineralization in the whole Banana Plain. The most common water type is the calcic and sodic bicarbonate type. The most abundant cation changes according to the sectors of aquifer, which reflects the variety of the mineralogical groups subjected to alteration (Ketchemen et al., 2007). The relative weakness of the ions of meteoric origin such as chloride suggests that the evaporating process does not affect mineralization. These results show that infiltration is relatively fast in the whole area.

Nitrate concentrations of water samples are in the range 0.19-39.26mg/l with 10 of the 23 samples (43.5%) having Nitrate concentrations greater than 10mg/l , exceeding the WHO (2004) drinking water limit. Demlie et al. (2007) illustrate that a positive correlation of NO_3^- and Cl^-, is a diagnostic indicator of anthropogenic activity. In this study, correlation matrix (Table 1) show a strong positive correlation between NO_3^- and Cl^- (R = 0.82) and is a diagnostic indicator of anthropogenic activity on water quality.

Relationships between aqueous inorganic solutes can reveal the source of solutes and the mechanisms that generated the observed composition of both surface and groundwater (Fantong et al. 2008). Sodium/ chloride ratio in the waters is relatively high (0.9-23.4) compared to the seawater ratio of 0.86 (Moller and Detler, 1990). The high Na/Cl ratios are probably controlled by water-rock interaction, most likely by feldspar weathering. Weathering of silicate rocks in the region is one of the important processes responsible for the higher concentration of Na in waters of this area. If silicate weathering is a probable source of sodium, the water samples would have HCO_3^- as the most abundant anion (Rogers, 1989). This is because of the reaction of the feldspar minerals with the carbonic acid in the presence of water, which releases HCO_3^- (Elango et al. 2003). HCO_3^- is the dominant anion in waters of this area. Hence, silicate weathering partially explains the presence of sodium ions in the surface and ground waters of the region.

The δD and $\delta^{18}O$ values of the investigated waters vary from -4.2 to 2.4‰ for $\delta^{18}O$ and from -23.1 to 20.8‰ for δ^2H. The interpretation of these data in terms of both origin and recharge mechanisms of groundwaters is generally based upon the comparison of $\delta^{18}O$ and δ^2H in groundwater and rainwater which is the dominant source of recharge for most continental hydrogeological systems. Figure 3 shows a plot of δ^2H versus $\delta^{18}O$ for all the investigated waters. The global meteoric water line (GMWL) is also given as reference. The conventional δD versus $\delta^{18}O$ diagram shows that the springs, shallow and deep groundwaters plot close to the Global Meteoric Water Line of Craig (1961) indicating their meteoric origin. These groundwaters may thus be derived from direct infiltration of local precipitation, in good agreement with the d-excess values close to 10 (Table 1). The lake water sample is located below the GMWL with a content of stable isotopes testifying enrichment by evaporation. The deep groundwater sample is also close to the GMWL but more depleted with $\delta^{18}O$ content at –4.2‰. This sample seems to correspond to a recharge carried out under climatic conditions different from the shallow wells and springs (humid climatic conditions than at present). The flat topography of the study area does not make it possible to consider it as the result of the altitude effect. The major part of water samples seem to derive from the infiltration of local precipitation, with significant contribution of another type of water in the deeper part of the aquifer.

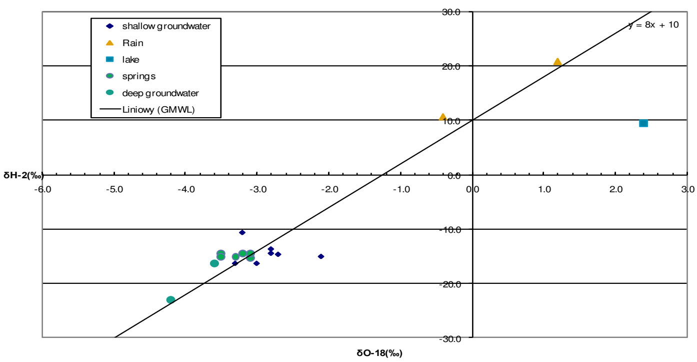

Figure 3. Plot of δ^2H versus $\delta^{18}O$ for waters in the Banana Plain.

To assess the suitability for drinking and public health, the hydrochemical parameters of the waters of the study area were compared with the prescribed specification of the World Health Organization (WHO) (2004). Generally the waters are within the WHO guideline limits of the various major ions for drinking water quality. The pH of the waters in this area is slightly acidic to basic (5–7.86) but generally within the WHO (2004) guideline limits (6.5–8.5) for drinking water. The EC and concentration of TDS are within the desirable limits of 750 µS /cm and 500 mg/l, respectively. Nitrates have undesirable effects when present in drinking water. High concentrations of nitrates can cause methanemoglobinaemia, gastric cancer, goiter, birth malformations and hypertension (Majumdar and Gupta 2000). 43.5% of water samples have Nitrate concentrations greater than 10mg/l, the WHO (2004) limit.

EC and sodium concentration are very important in classifying irrigation water. Sodium percentage (%Na) in the study area ranges between 7.4 and 52.7% (rain samples, 7.4-34.0%; surface waters, 35.5-49.6% and ground waters, 14.2-50.9%). A high sodium percent causes deflocculation and impairment of the tilth and permeability of soils (Karanth 1987) . As per the guideline value, maximum sodium of 60% is recommended for irrigation water. Thus these waters are all suitable for irrigation. The sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of sodium adsorption ratio (SAR). If water used for irrigation is high in sodium and low in calcium, the cation-exchange complex may become saturated with sodium. This can destroy the soil structure due to dispersion of clay particles. The calculated values of SAR in the study area are 0.003–0.048 in rain samples, 0.23-0.52 in surface water and 0.22–1.77 in groundwater with an average value of 0.403. Guideline values for SAR vary between 0 and 2.0 hence the waters in the study area are suitable for irrigation.

CONCLUSIONS

Water resources in the Banana Plain of the Mungo Division are under severe pressure from increasing population growth and agro-industrial activities. The chemical composition of surface and groundwater is strongly influenced by rock water interaction, dissolution and deposition of silicate minerals, ion exchange and anthropogenic contribution from domestic sources and agro- industries. Weathering of silicate minerals control the major ions such calcium, magnesium, potassium and as sodium in surface and groundwater in this area. ^{18}O and ^{2}H data for water from the Banana Plain indicate that groundwaters have been recharged by meteoric water without significantly affected by evaporative processes either during or after the recharge. It seems therefore likely that the infiltration is fast and direct. The quality assessment shows that in general, the waters are suitable for potable and domestic purposes. However, high values of NO_3 at some sites make them unsafe for drinking. The assessment of the waters for irrigation use shows that the waters are of good quality.

ACKNOWLEDGEMENTS

This write up constitutes part of data generated during the Ph.D study of the corresponding author, who is supported by Monbukagakusho scholarship from MEXT (The Japanese Ministry of Education, Science, Sports and Culture). Material support was also provided by Grant-in-aid for scientific research No.21-606 from SASAGAWA Foundation, Japan.

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IAH 2010
Krakow

abstract id: **172**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **The role of the unsaturated zone in determining nitrate leaching to groundwater**

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keywords: nitrate, leaching, modelling, tracers, manure

INTRODUCTION

Nitrate leaching from agricultural sources is a worldwide concern and in Europe a large part of farmed areas are affected by nitrate pollution since decades. In Italy, the Po River valley is the largest and more intensively farmed alluvial plain, heavily impacted by agricultural pollution and especially by NO_3^- groundwater contamination (Onorati et al., 2006; Cinnirella et al., 2005; Giuliano, 1995) and surface water eutrophication (Provini et al., 1992; Palmieri et al., 2005). With the enactment of the European Directive for water protection (2000/60 CE), a large portion of the Po river valley has been declared vulnerable to nitrate from agricultural sources and limitations to the use of N fertilizers have been applied. However, in agricultural practices, the types of soils and soil tillage, different crops and irrigation techniques and different nitrogen fertilizers, which may be synthetic, as ammonium nitrate and urea, or natural, as manures and sludge from different animal farming, form a variety of terms emphasizing site specificity of WFD application and results. Moreover, the general knowledge of key factors governing patterns and processes of N transport and transformations through the vadose zone to the water table are not fully clarified. Within this multidisciplinary framework, for any applied research finalised to reduce nitrogen losses , it is essential to fix a benchmark to star from, which in our view is aquifer recharge assessment, i.e. to quantify water resources and flux toward aquifers (Scanlon et al., 2002). Presently, the most effective tool to quantify recharge flux is to model the unsaturated soil water dynamics, although this process faces many challenges in field conditions (Youngs, 1995).

In order to identify the dominant processes affecting nitrate leaching in the Po River Delta area, a series of tracer tests were performed to determine conservative mass transfer and the fate and transport of nitrogen species.

MATERIALS AND METHODS

Each field site was equipped with: tensiometers and soil moisture probes for continuous monitoring of soil water potential; meteorological stations recording rainfall, wind speed, solar radiation, temperature and humidity; drains and suction cups to collect water samples for anions and cations analysis; core logs down to 2 m b.g.l. were collected to define soil water content, soil texture, organic matter content and bulk density; piezometers (2.5 cm inner diameter) screened from 1.5 to 4.5 m b.g.l., were monitored (via multi level samplers) to quantify the presence of nitrogen dissolved species in the shallow unconfined aquifer. Monitoring started in February 2008 and is still on, not at a constant frequency but following rainfall (on a monthly frequency, increased to daily in occasion of important event). Bromide was applied at the surface as a NaBr salt and nitrogen was applied as urea at a rate of 300 kg/ha, in a sandy and a loamy sites cultivated with maize (Andreotti et al., 2009). According to local practices, the sandy soil had been amended with chicken manure (70 q/ha) from organic breeding in the previous year, while the loamy soil had not. The major cations, anions (Na+, K+, Ca2+, Mg2+, F-, Cl-, NO3-, SO42-) and oxianions (acetate and formate) were determined by an isocratic dual pump ion chromatography ICS-1000 Dionex, equipped with AS9-HC 4 × 250 mm high capacity column and ASRS-ULTRA 4mm self-suppressor for anions and CS12A 4 × 250 mm high capacity column and CSRS-ULTRA 4mm self-suppressor for anions. An AS-40 Dionex auto-sampler was employed to run analysis, Quality Control (QC) samples were run every 10 samples. The flow and transport processes were quantified by inverse modeling with the finite element numerical code HY-

DRUS-1D (Šimunek et al., 2008). The numerical grid was discretized in 200 nodes of 0.01 m each to form a regular grid 2 m long and a surface area of 1 m^2. The grid was subdivided into 2 regions representing the upper and the lower soil horizons, initial water content conditions of collected soil cores (every 0.25 m) at each site, were measured via gravimetric methods and linearly interpolated along the vertical axis. At the soil surface, an atmospheric boundary condition with a maximum surface layer of 0.01 m was selected. As lower boundary condition variable pressure heads were specified in every model using groundwater levels. The transport boundary condition at the surface was a prescribed concentration and at the lower boundary was a zero concentration gradient (free drainage) condition. Input concentrations of Br^- and NO_3^- were gained from soil extracts collected at the soil surface (0-5 cm) throughout the monitoring period. Ammonia volatilisation was estimated in lab by using flow trough system microcosms and evolved ammonia was captured in acid traps (Bolado Rodríguez et al., 2005).

RESULTS AND DISCUSSION

Unsaturated zone modelling

A good model fit of water content and head pressure at various depth was achieved in each site. A robust estimation of cumulative infiltration and evapotranspiration has been derived and the obtained water balance is considered reliable (R^2: 92% for the loamy soil and 84% for the sandy soil). In the loamy soil, NO_3^- and Br^- percolated downwards very slowly, with sharp peaks located approximately 0.3 m below ground level after the harvest (Fig.1).

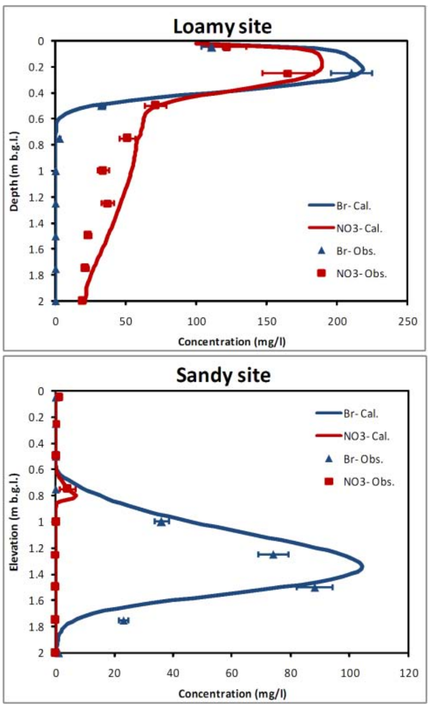

Figure 1. Observed and calculated Br^- and NO_3^-concentrations along the soil profile in the loamy and sandy site after 120 day from the fertilization.

In the sandy soil NO_3^- disappeared within the first meter of soil, while the Br^- peak was recovered approximately 1.5 m below ground level (Fig.1). The fast migration of Br^- in the sandy site was due to the elevated hydraulic conductivity of the soil (Tab. 1), while the disappearance of NO_3^- was essentially due to root uptake and denitrification (Fig.2).

A good match between calculated and observed bromide concentrations was obtained in both sites via the inverse modeling procedure encoded in HYDRUS-1D. A robust reconstruction of the field velocity and of the dispersion coefficient was achieved matching observed and calculated Br^-concentrations.

Table 1. hydraulic and transport parameters used in the numerical models for the two soil horizons of each site.

Parameter	Loam (0-0.75 m)	Loam (0.75-2 m)	Sand (0-0.55 m)	Sand (0.55-2 m)
K_s (m/d)	0.02	0.053	8.1	15.4
θ_s (m^3/m^3)	0.41	0.38	0.36	0.31
θ_r (m^3/m^3)	0.05	0.06	0.039	0.025
α (1/m)	0.12	0.51	8.50	11.21
n (-)	1.45	1.53	2.21	2.42
Disper. (m)	0.01	0.001	0.002	0.001
Diff. (m^2/d)	$1e^{-4}$	$1e^{-4}$	$1e^{-4}$	$1e^{-4}$
μNO_3^- (1/d)	0.003	0.004	0.01	0.1

Very small vertical dispersivity values were obtained (Tab. 1) in both sites, to account for the sharp concentration gradients observed in both fields. Mass recovery of bromide was near 90% for sandy and loamy soils, suggesting that homogeneous transport processes were present at the field scale.

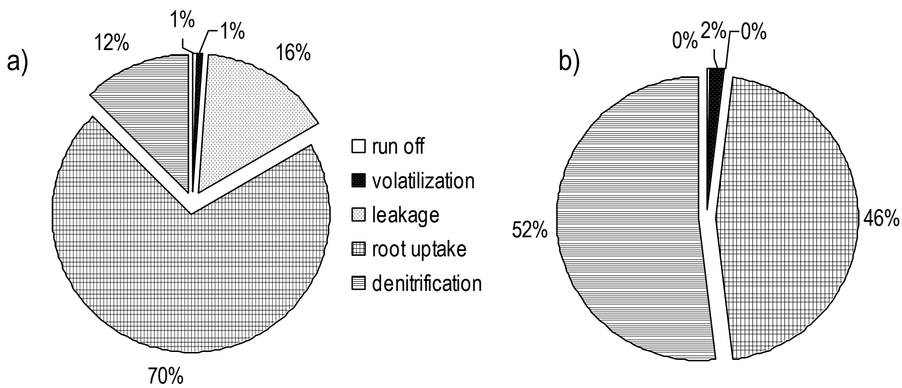

Figure 2. NO_3^- balance cake plot for: a) loamy soil; b) sandy soil.

Results for the nitrogen mass balance are in good accordance with concentrations measured in the field for the same nitrogen species at the same sampling time. NO_3^- leaching was observed in the loamy soil where the redox conditions remained oxidizing throughout the year, while in the sandy soil residual content of organic matter from fertilization with manure in the previous year (fraction of organic carbon: 0.042 and acetate: 34 mg/l) very likely decreased the redox potential to reducing conditions and favored excess nitrate removal via denitrification preventing its migration towards the saturated zone (Fig. 2).

Nitrate leaching to groundwater

Figure 3 shows a largely variable groundwater table in the loamy site, where the groundwater flow is linked with canals level, while, in the sandy site groundwater fluctuations were less pronounced, since it is located near the coast and fluctuations are smoothed. In the loamy soil nitrate mass transfer to the unconfined aquifer was slow as shown in Fig. 1 and concentrated at the end of the winter season, when the water table rise and bring in solution the available NO_3^- (Fig. 3).

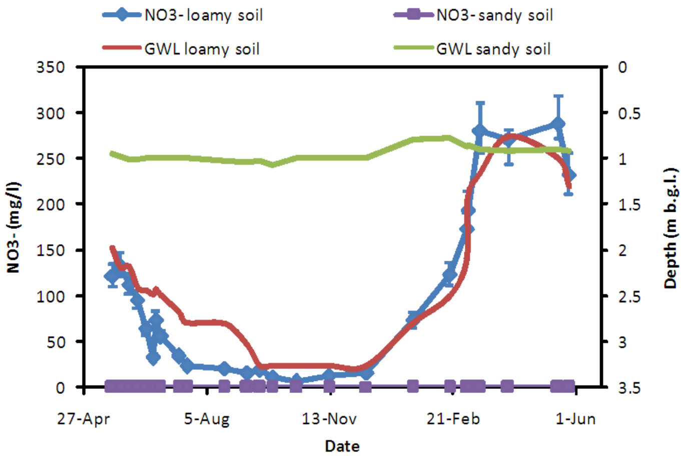

Figure 3. groundwater level fluctuations and NO_3^- trends in groundwater in loamy soil and sandy soil throughout the year.

In the sandy site, despite the fast transfer of mass, NO_3^- was never detected, confirming the results from the unsaturated zone (Paragraph "Unsaturated zone modeling").

CONCLUSIONS

Results highlight the reliability of the use of conservative tracers and numerical modeling jointly, to understand nitrate mass transfer rate and mass balance.

For the practical interest of WFD application, this approach has evidenced that in the sandy soil, more permeable and intrinsically more vulnerable, the relatively low amount of organic matter lasting from manure use in the previous year, was sufficient to prevent nitrate leaking, by removing the excess via denitrification. This result highlights the need to pay attention to the kind of manure used and to the relative degradation kinetics which may also be heavily affected by farming type, organic or industrial. This last term, in fact, other than impacting water quality for the presence of hormones and other undesired chemicals, may influence organic matter and nitrogen mineralization rates, interfering with bacterial activities due to the presence of antibiotics.

ACKNOWLEDGMENTS

Dr. Umberto Tessari is acknowledged for the technical and scientific support. The Emilia–Romagna ARPA SIMC is acknowledge for the meteorological data. The work presented in this paper was made possible and financially supported by PARC-AGRI under "Contratto di Programma (Delib.CIPE n.202)" fund.

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abstract id: **183**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **Use of 15N and 222Rn to identify sources of groundwater nitrates in the Ryukyu Limestone aquifer of Okinawa Island, Japan**

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keywords: nitrates, nitrogen stable isotopes, radon, caves, karst hydrology

INTRODUCTION

Recently, increasing nitrate concentrations in groundwater have been of worldwide concern. Nitrates are implicated in methemoglobinemia and may be a causative factor in other health disorders such as cancer, though at present the evidence is inconclusive. In general, nitrate pollution is considered to be caused by nitrogen loading as a result of human activities such as increased use of chemical fertilizers, inappropriate management of livestock manure, and emission of effluents from septic tanks. Groundwater in karst aquifers is particularly vulnerable to chemical pollution because water moves rapidly through fractures and fissures of an aquifer. Nitrogen loading processes in karst aquifers are considerably influenced by the characteristics of groundwater flow that are closely related to hydrogeological features such as caves and caverns. To control nitrates in groundwater, we must understand the dominant sources and transport processes of nitrates, regarding the impacts of karstic features on nitrogen loading processes.

The Ryukyu Islands, are a chain of southwestern Japanese islands. The largest is Okinawa Island. The Ryukyu Limestone, of the Quaternary age, is extensively distributed on these islands. Recently rising concentrations of nitrates in groundwater have become a problem. The southern part of Okinawa Island is a suburban region with many farms where mainly vegetables and sugarcane are cultivated and numerous livestock farms exist. Nitrate concentrations in groundwater had increased until the mid-1990s, which was believed to be caused by chemical fertilizer applied to upland fields.

In this study, we examined the fate and transport of groundwater nitrates in the Ryukyu Limestone aquifer. The sources of nitrogen affecting the groundwater quality were estimated by analyses of a ratio of two stable isotopes of nitrogen in nitrates, ^{14}N and ^{15}N. In addition, radon (^{222}Rn) were used to clarifying rapid groundwater flow in caves and caverns and its influence to transportations of nitrates in groundwater. ^{222}Rn is useful as an indicator to distinguish the impacts of the caves and caverns, because ^{222}Rn concentrations in groundwater of caves and caverns are relatively low.

STUDY AREA

The study area was located at the southern tip of Okinawa Island. A hydrogeological map of the study area is shown in Fig. 1. The basement rocks in the study area belong to the Shimajiri Group, of the Neogene age, which consists mainly of alternating layers of sandstone and mudstone. The Shimajiri Group is relatively impermeable with a hydraulic conductivity of less than 2.0×10^{-7} m s^{-1}. The Ryukyu Limestone that overlies the Shimajiri Group over most of the study area is thick (generally 30–40 m thick) and porous and contains well-developed cracks and caves that give it high permeability with a hydraulic conductivity of about 1.0×10^{-4} m s^{-1} and effective porosity of 9%. Groundwater in this region flows mainly in the pores of the Ryukyu Limestone above the impermeable Shimajiri Group. Groundwater basins are formed by one or two tectonic blocks where groundwater flows through buried valleys in the upper surface of the Shimajiri Group. Karst terrains are characterized by landforms such as sinkholes and caves, and continuously evolve by dissolution of calcite and dolomite into the groundwater. The study area is a typical karst terrain containing many caves and caverns (Fig. 1; Imaizumi et al., 2003). Two large caverns in the Komesu Basin connect some of the caves to the seashore (Fig. 1), and in these caverns, the groundwater flows preferentially. In addition, springs are also common in the study area.

The study area is a suburban agricultural area. It consists mainly of upland fields of sugarcane and vegetables, but several residential areas are situated among the upland fields. In 2005, acreage of upland field in Itoman City was 15.90 km^2, and sugarcane acreage 5.30 km^2. Population in Itoman City in 2005 was 55,816. Moreover, livestock operations such as hog farms have been established in the residential areas. Most of the livestock farms are located in the residential areas. In 2005, the numbers of beef cattle, cows, hogs and chickens in Itoman City were 1,620, 310, 20300 and 104,000, respectively.

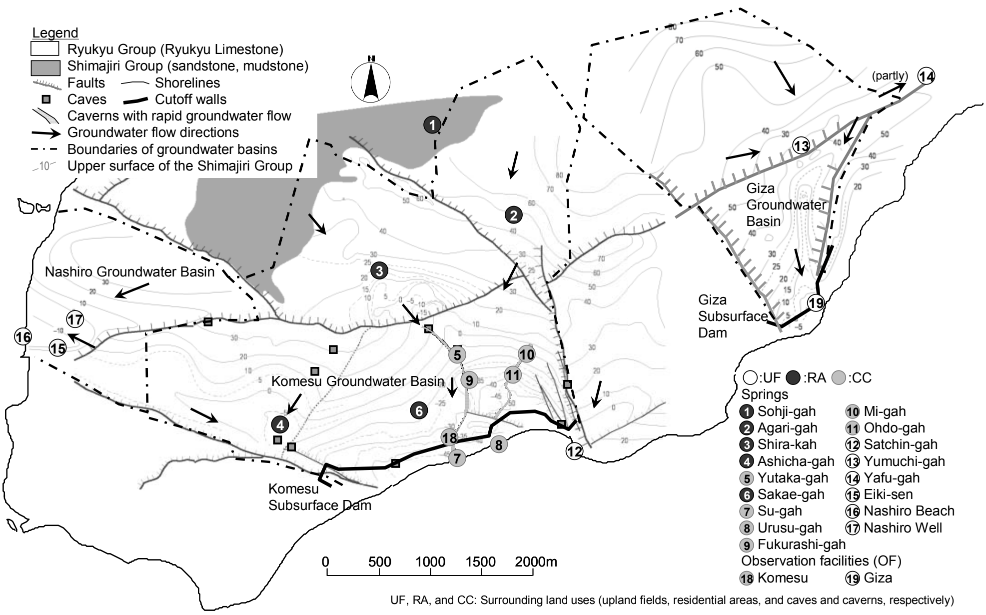

Figure 1. Geological settings and sampling sites of the study area.

METHODS

Sallow groundwater samples were collected in February 2007, March 2008 and January 2009 from 17 springs and from observation facilities of the two subsurface dams in the study area (Fig. 1). The sampling sites were categorized into three types: upland field (UF), residential area (RA), and cave and cavern (CC).

Concentrations of nitrate nitrogen (NO_3-N) in the collected samples were analyzed by ion chromatography (ICA-2000, TOA-DKK, Japan).

For isotopic analyses, nitrate samples were enriched by the freeze-drying method (Böhlke and Denver, 1995) and then converted to N_2 gas by quartz tube combustion for mass spectrometry (FlashEA 1112, Thermo Fisher Scientific, USA). The N_2 gas was analyzed for $\delta^{15}N$ by an isotope ratio mass spectrometer (Delta V Advantage, Thermo Fisher Scientific, USA) with a reproducibility of 0.15‰. Here, the value of $\delta^{15}N$ is defined by the following equation:

$$\delta^{15}N = (^{15}N_{sample}/^{14}N_{sample} - ^{15}N_{air}/^{14}N_{air}) / ^{15}N_{air}/^{14}N_{air} \times 1000\ [‰], \quad (1)$$

where $^{15}N_{sample}/^{14}N_{sample}$ is the ratio in samples, and $^{15}N_{air}/^{14}N_{air}$ is the ratio in air.

Radon (^{222}Rn) concentrations in water samples collected in 2007 and 2009 were measured with a liquid scintillation counter (Tri-Carb 2250 CA, Packard BioScience, United States) after in situ extraction with toluene by the methods of Hamada and Komae (1998). The total error was less than 0.05 Bq L^{-1}. The NO_3-N concentration and the $\delta^{15}N$ value in the sample collected at Nashiro Beach in 2009 could not be analyzed because of high salinity.

We considered chemical fertilizer application, livestock and human wastes, and soil (natural) nitrogen as nitrogen sources having a major effect on groundwater quality. Contribution ratios from these nitrogen sources, denoted as R_{CF}, R_{LH} and R_{SN}, were estimated from the observed NO_3-N concentrations C_{obs} and the $\delta^{15}N$ values X_{obs} by the following simultaneous equations (Nakanishi et al., 1995);

$$1 = R_{CF} + R_{LH} + R_{SN}, \quad (2)$$

$$X_{obs} \approx X_{CF}R_{CF} + X_{LH}R_{LH} + X_{SN}R_{SN}, \quad (3)$$

$$R_{SN} = C_{SN} / C_{obs}, \quad (4)$$

where X_{CF}, X_{LH} and X_{SN} are representative $\delta^{15}N$ values in groundwater nitrates derived solely from fertilizer application, livestock and human wastes, and soil nitrogen, and C_{SN} a concentration of groundwater nitrates from soil nitrogen were assumed to be always constant. The values of X_{CF}, X_{LH} and X_{SN} were set to 3‰, 15‰ and 4‰ from literature values (Fig. 2). In addition, because of absence of spring or well free from impacts of human activities, 1.4 mg L^{-1} (Nakanishi et al., 1995) was employed as the value of C_{SN}.

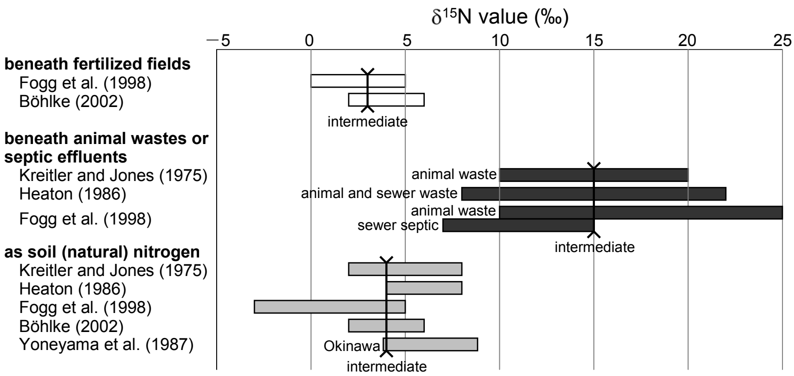

Figure 2. Ranges of δ15N values in the literatures and the applied values in this study.

RESULTS

Nitrate was found in all groundwater samples from the study area. The average NO_3-N concentration was 10.4 mg L^{-1}, and the range was 5.5–18.9 mg L^{-1} (Fig. 3).

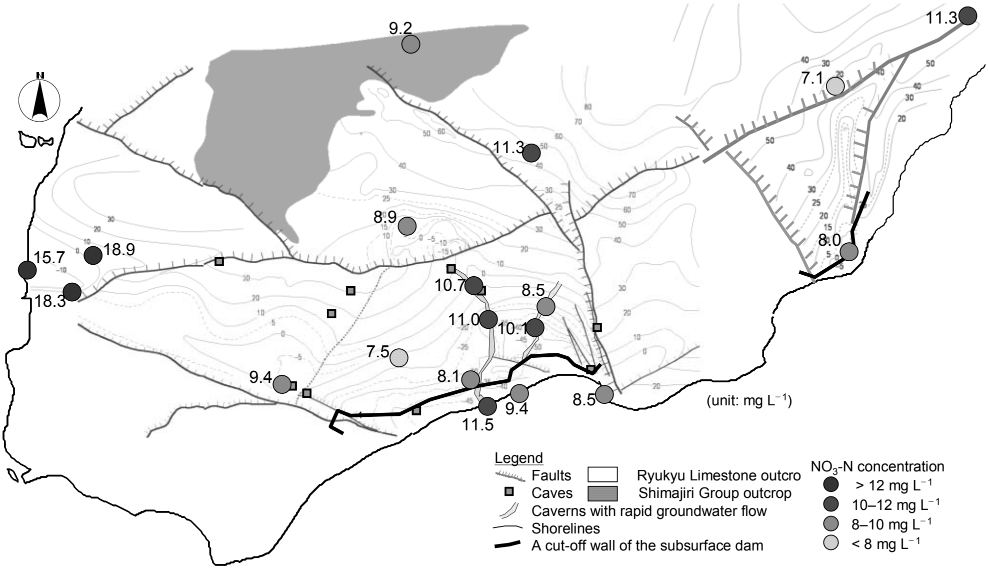

Figure 3. NO3-N concentrations in groundwater in February 2007.

The $\delta^{15}N$ values at all sites averaged 9.6‰, and ranged from 6.1‰ to 13.1‰ (Fig. 4). The average value was 8.5‰ at UF sites, 10.0‰ at RA sites, and 10.5‰ at CC sites.

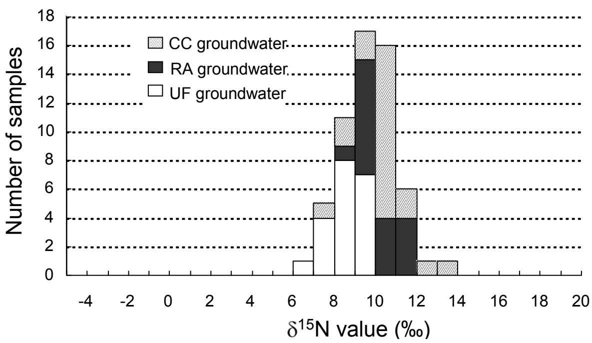

Figure 4. Frequency distribution of δ15N values of groundwater nitrates.

The average ^{222}Rn concentration was 4.4 Bq L^{-1}, and the range was 0.6–13.5 Bq L^{-1}. The ^{222}Rn concentrations at many of the CC sites were relatively low (less than 2 Bq L^{-1}) (Fig. 5).

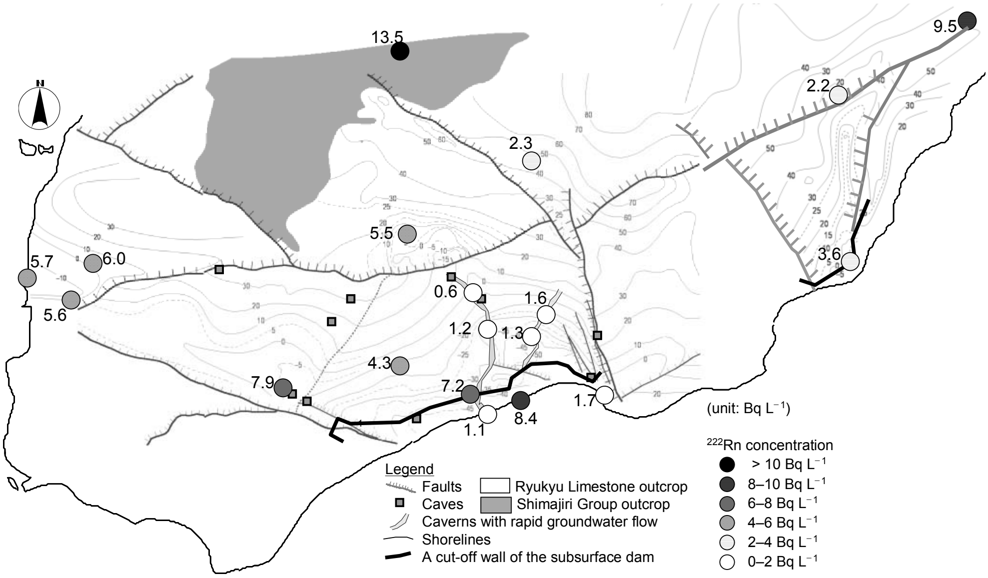

Figure 5. 222Rn concentrations in groundwater in February 2007.

The averages of R_{UF} at UF, RA and CC sites were 41%, 27% and 25%, and those of R_{LH} were 45%, 57% and 61%, respectively (Fig. 6).

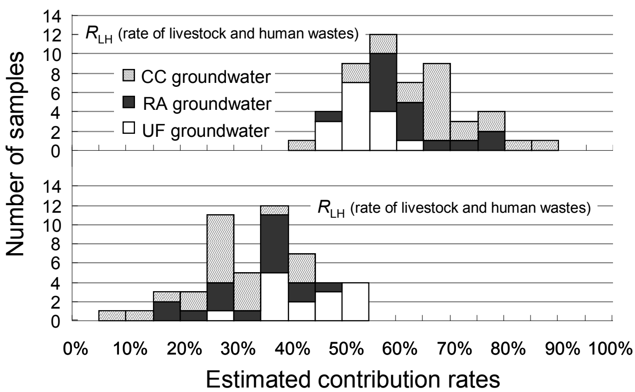

Figure 6. Frequency distribution of estimated RCF and RLH.

DISCUSSIONS

Generally, although in younger carbonate aquifers diffuse flow in matrices is dominant, caves and sinkholes are generated with evolution of karst terrains, and then in mature kasrt regions conduit flow systems with rapid groundwater flow are developed (e.g. Quinlan, Ewers, 1985). The Ryukyu Limestone aquifer can be regarded as "mixed aquifer", where slow diffuse flow in matrices and rapid conduit flow in caves and caverns exist together.

We examined the existence of preferential groundwater flow in caves and caverns from the ^{222}Rn data. In matrices of the aquifer ^{222}Rn is likely continuously supplied by the alpha decay of

^{226}Ra in the aquifer and reaches radioactively equilibrium in three weeks, whereas in caves and caverns the ^{222}Rn in the groundwater is lost through dispersion to the atmosphere and radioactive decay. Therefore, the lower ^{222}Rn concentrations at the CC sites were thought to reflect the influence of caves and caverns.

In the Ryukyu Islands, chemical fertilizer has often been considered the major cause of groundwater nitrates. Yoshimoto et al. (2008) reported that correspondence of the trend of change in NO_3-N to the variation of nitrogen emission from chemical fertilizer suggested that chemical fertilizer more strongly contributed the groundwater nitrates than other sources.

However, $\delta^{15}N$ values at all sites (Fig. 4) were higher than the literature values for $\delta^{15}N$ values in groundwater nitrates beneath fertilized upland fields (0–6‰; Fig. 2). The groundwater nitrates at the UF sites had the average $\delta^{15}N$ value of 8.5‰. It was inappropriate to regard that all groundwater nitrates beneath upland fields came from chemical fertilizer. On the other hand, the average $\delta^{15}N$ value at the RA sites was 10.0‰, which is the lowest in the range of literature values beneath animal and human waste applications (10–20‰; Fig. 2). The average at the CC sites was 10.5‰ which is quite similar to that at the RA sites. At the UF and RA sites, it was reasonable to consider that the origin of groundwater nitrates was composed of chemical fertilizer, livestock manure, domestic wastewater, and soil nitrogen in varying rates of contribution. In addition, at the CC sites, it was also a reason that nitrates were not related to surrounding land uses and carried by preferential groundwater flow in caves and caverns from upstream residential areas.

The averages of R_{CF} at UF, RA and CC sites calculated by Eqs. (2–4) were 41%, 27% and 25%. Even though these results indicated that groundwater at the UF sites were influenced by chemical fertilizer more significantly than at the RA and CC sites, the contribution of livestock manure and domestic wastewater was estimated to be much larger than chemical fertilizer (Fig. 6). This might be because the value of C_{SN} and X_{SN} were assumed to be fixed to 1.4 mg L^{-1} and 4‰ for the calculation of Eq. (2–4).

CONCLUSION

The fate and transport of groundwater nitrates in the Ryukyu Limestone aquifer were investigated. Nitrates were found in the all groundwater samples. Values of $\delta^{15}N$ in the nitrates suggested that the origin of the nitrates would be the mixture of chemical fertilizer, livestock manure, domestic wastewater and soil nitrogen. In addition, nitrates at the CC sites would be carried by preferential groundwater flow in caves and caverns from upstream residential areas.

ACKNOWLEDGEMENTS

This research was partially supported by a grant from the Ministry of Agriculture, Forestry and Fisheries of Japan (Evaluation, Adaptation and Mitigation of Global Warming in Agriculture, Forestry and Fisheries: Research and Development, 34020). We also thank Tadashi Yamashita and Tokue Taira, the former head and the director, respectively, of the Land Improvement General Office, Okinawa General Bureau, and Haruo Bajo and Masahiko Miyazato of the Okinawa Hontoh Nanbu Land Improvement District.

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abstract id: **185**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **Groundwater as a driver of salinity in the Wybong Creek catchment**

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INTRODUCTION

The Wybong Creek catchment is located in central New South Wales, Australia, and has been identified as a priority catchment of the Hunter River for detailed study (Fig. 1). This is due to Wybong Creek delivering significant salt loads to the Goulburn River, which then flows into the Hunter River. Salts from Wybong Creek were also dominated by Na-Cl, which is anomalous with other Na-Mg-HCO_3 dominated rivers in the Hunter Catchment (Creelman, 1994). The 800 km^2 Wybong catchment is bordered in the north by the Liverpool Ranges, which are comprised of Triassic Narrabeen sandstones and conglomerates capped with Eocene Liverpool Range Volcanics. In the east, south and west of the catchment, the Narrabeen Sandstone group occur as gent out crops to extremely steep sandstone escarpments.

North of the Liverpool Ranges, salinisation in the Namoi River catchment and Liverpool Plains has been attributed to dryland salinity (Ringose-Voase et al., 2003). South of the Liverpool Ranges and in the Hunter catchment, conflicting opinions exist on the causes of soil and groundwater salinity, and include dryland salinity (Beale et al., 2000), irrigation salinity (Healthy Rivers Commission, 2002), and seepage from coal and associated formations (Creelman, 1994). Previous work shows that saline regolith (sodosols) occur within alluvial landforms in the mid-lower Wybong Creek catchment (Kovac, Lawrie, 1991). A field site containing showing clear evidence of salinity at the locality of Manobalai was selected for regolith sampling and piezometer installation, in order to assess sources of salinity to Wybong. Field investigations included soil (regolith) sampling at eight sites, and installation and sampling of groundwater from 12 bores and piezometers, and a single spring.

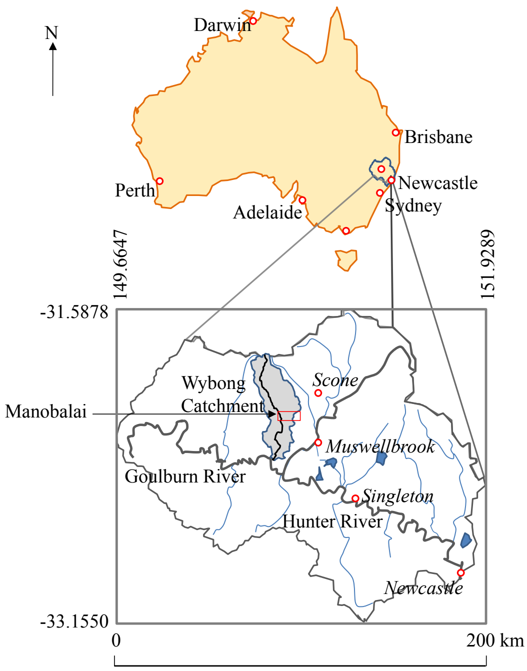

Figure 1. The location of the Hunter River catchment within Australia. The Hunter River, and the Goulburn River which flows into it, is shown in bold.. The Wybong Creek catchment is illustrated in grey.

METHODS

Regolith sampling

Regolith cores were collected on the 8th and 9th of January 2008 and the 25th and 26th of March 2009, from eight sites within the mid-catchment area of Manobalai (Fig. 2). Sites were selected according to landform, including at the breaks of slope (Sites One, Three and Five), in a drainage depression (Site Four) and within a salt scald (Site Two). The evolution of groundwater chemistry between the salt scald and Wybong Creek was study through the sampling of cores and installation of piezometers at sites Six – Eight. A total of 125 samples were collected every 0.25 – 1.00 m along the entire length of the cores, with sampling based on textural and colour changes.

Soil salinity in each of the samples was initially investigated by analysing 1:5 soil:water extracts for electrical conductivity (EC). A range of samples including the most saline, the least saline and a number with average salinity were selected for ion analyses according to the findings of $EC_{1:5}$ results. Samples were analysed for major cations using ICP-AES and ICP-MS, and IC was used for anions. Select samples from Site Two were analysed for minerals using XRD analyses.

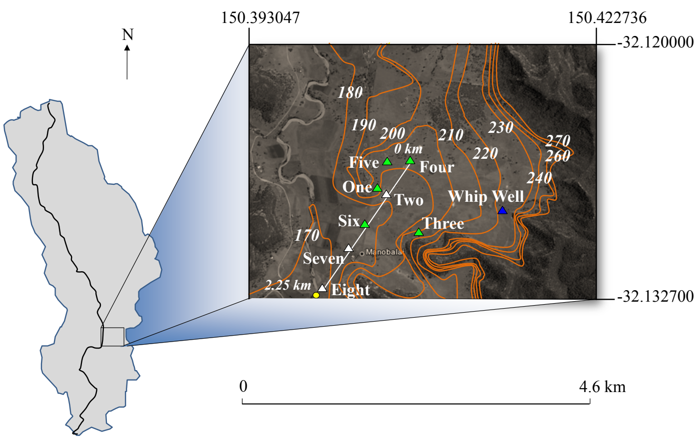

Figure 2. Location of regolith and groundwater sample sites within the Manobalai area of the Wybong Creek catchment. Single piezometers are indicated by (▲), while bore and/or piezometer nests are indicated by (△). The spring at the site is indicate by (▲). Numbers in italics indicate elevation as determined by Google Earth, with topographic contours also shown.

Water sampling

Groundwater was sampled from bores and piezometers at Manobalai, and from a well dug into a spring (Fig. 2). All water samples were filtered in the field. Samples for cation analyses were acidified using 2 mL 50% HNO_3, while anion samples were only filtered. Samples were analysed for major cations using ICP-AES and ICP-MS, and IC was used for anions. Electrical conductivity was measured on unfiltered water samples at the time of sampling using a calibrated Orion DuraProbe™ 4-electrode conductivity cell and conductivity meter. Alkalinity was measured in the field by titration, using filtered water, a Hach digital titrator, HCl and methyl orange.

RESULTS AND DISCUSSION

Regolith in the northern reaches of the study area, is largely composed of interbedded alluvium in the valley floor, though no water course is obvious in the area. The footslopes of the Narrabeen Group escarpments and outcrops overlying the local regolith are instead composed of colluvium, with cores collected from these footslopes showing pedological development. Three hundred metres south of the Manobalai salt scald, regolith cores changed in composition from the alluvium seen at Sites Two and Four, to black – chocolate brown smectitic clay. Little horizonal development was seen in cores collected from this area, which included Sites Six, Seven, and Eight Shallow.

Salinity within the regolith cores collected from the valley floor in the study area varied according to texture. None of the soil samples in the area were saline on an $EC_{1:5}$ basis, however, with saline soils defined as having $EC_{1:5}$ >1500 µS cm^{-1} (Northcote, Skene, 1972). The regolith beneath the salt scald at Site Two, for example, was comprised of sandy clays and clayey sands, with maximum salinities of up to 1200 µS cm^{-1}. Increases and decreases in salinity in the Site Two cores occurred according to texture. Sodium and Cl were the dominant salts in all samples. Salinity in the Site Four core further up-gradient of the salt scald varied similarly to the salinity seen in the Site Two Deep and Shallow cores, and solutes were also dominated by Na and Cl. The salinity in the Site Six core was higher than any of the other samples collected from Manobalai. Though regolith was not saline on an $EC_{1:5}$ basis with a maximum salinity of 1225 µS cm^{-1}, Na and Cl concentrations in two samples were over 0.2 % on a per weight basis, indicating that Na and Cl concentrations in these samples could be problematic to soil health (Northcote, Skene, 1972). Pedologically developed cores from the footslopes of the escarpments and outcrops instead increased from 15 µS cm^{-1} in the upper-most samples, to 313 µS cm^{-1} at the interception of hard-rock.

The solutes in the soil and regolith of many catchments within Australia are thought to arrive with rain and/or dust, with solute concentrations building up over geological time due to inadequate flushing through of salts by precipitation. Rainwater is dominated by SO_4 and HCO_3 when it arrives in catchments and evolves to Na and Cl dominated water as a result of carbonate and sulfate precipitation (Eugster & Hardie, 1975; Jankowski & Jacobson, 1989). Water is increasingly saturated with carbonate and sulfate minerals as it is evaporated (Eugster & Hardie, 1975). Precipitation and/or evaporation would be expected to result in sulfate and carbonate minerals within the shallower layers of the regolith profile, with increasing proportions and dominance of Na and Cl with increasing depth. This is not thought to give rise to salinity at Manobalai, however, with carbonate minerals not identified in any of the four samples from Site Two using XRD analysis and sulfate minerals only tentatively identified in the sample from 0.5 – 1.0 m below the ground surface. The $pH_{1:5}$ of soil:water extracts were below 8.3 within all samples from Sites One – Five, indicating that the conditions for carbonate precipitation do not occur (Charman & Murphy, 2000). Potential for the formation of pedogenic carbonate does exist further downslope at Sites Six – Eight, where $pH_{1:5}$s were as high as 9.6. No clear correlation between Na and Cl and depth occurred at any site, however, with increases expected to occur if Na and Cl dominance was caused by the precipitation of carbonate and sulfate minerals in the uppermost layers of the soil profile and/or evapoconcentration of fresher water. Because meteoric accession of salts would result in sulfate and carbonate dominated soil samples in the uppermost layers, and these did not occur at Manobalai, the Na and Cl dominated soil solutions at

Manobalai indicate salinity occurs as a result of processes not related to direct meteoric accession or evapoconcentration.

The highest soil moistures occurred at depths where groundwater was intercepted, though soil salinity and soil moisture were sometimes inversely at different sites. Total soil moisture was highest at the depth of groundwater interception, at Site Two and Four, with groundwater occurring beneath confining clay layers and within clayey sand layers. Groundwater instead occurred within the saprolitic material at the bottom of cores at the breaks of slope and within the smectitic regolith. The highest regolith salinities in the alluvium at Site Two (1200 µS cm^{-1}), and at the breaks of slope occurred just above the layers where groundwater was intercepted and where soil moisture was highest. Lower salinity regolith layers were instead correlated with the interception of groundwater at Sites Four and Six. The variation in soil salinity was not related to the type of regolith, with similar regolith at Sites Two, Four and Whip Well, but instead the occurrence of groundwater.

Groundwater salinity at the Manobalai site was highly variable, and varied independent of regolith type. Groundwater was fresh at Site Four and Whip Well, for example, where freshwater is defined as having salinities less than 400 mg L^{-1} (Rhoades et al. 1992). Although the bore and piezometer at Site Two had lower hydraulic heads, and were located within alluvium 600 m topographically down-gradient of Site Four, groundwater at Site Two was moderately – highly saline with salinities in excess of 5000 mg L^{-1}. Groundwater salinity again dropped 300 m topographically down-gradient at Site Six, where salinities of 1721 mg L^{-1} occurred. Groundwater at the break of slope was as variable as on the valley floor, with up to 1418 mg L^{-1} occurring at Site One, 4570 mg L^{-1} at Site Three, and no groundwater at all occurring at Site Five.

The occurrence of the highest Na and Cl concentrations in sandy layers at the same depth where saline groundwater occurs indicates that saline groundwater transports solutes to the regolith at Site Two. Groundwater was as little as two metres below the surface at this site, with the depth to water decreasing as drought conditions eased throughout the length of the study. The opposite instead occurs at Site Four and Site Six, where groundwater contains much lower solute concentrations, with groundwater removing solutes from the coarsest layers of regolith through which it flows, in turn giving rise to regolith with much lower salinities. The variability of groundwater salinity at the study site indicates the occurrence of a number of water bodies, with discharge of saline regional systems at Site Two, and the occurrence of fresher, more localised systems at Sites Four and Site Six. The regional and saline groundwater system discharging into the site is likely from the Permian Coal Measures, which cause abrupt increases in salinity elsewhere in the Hunter Catchment (Creelman, 1994). The results presented here are therefore evidence that groundwater is an important means of transporting solutes at Manobalai, bringing solutes to the sandy layers at salt scald (Site Two) and removing solutes from the regolith at Sites Four and Six.

CONCLUSIONS

Saline groundwater did not occur at all sites within the Manobalai area. The occurrence of similar saline water in specific bores and piezometers at the break of slope, and in the valley bottom suggests point source groundwater discharge via fractures and/or faults connected to a saline and regional aquifer, with saline and regional groundwater from the Permian Coal Measures identified as a potential source in research from elsewhere within the Hunter catchment. Saline and discharging water appears to be diluted by fresher local systems in places, such as at Site Four and Whip Well.

These findings have important ramifications in the context of salinity research within Australia, whereby a model of dryland salinity is often assumed and related to salt stores within the regolith, accession of meteoric water, and/or evapoconcentration. The discharge of regional groundwater implies that salinity is sourced from the deeper Permian Coal Measures, and as such, is a naturally occurring processes. This means that the sustainability of agriculture in the catchment necessarily requires the limitation of irrigation using surface and groundwater, including fresher water which can be used to dilute the more saline groundwater which occurs. Further research is required in order to ascertain that human changes to the hydrological cycle have not caused the discharge of regional groundwater into the catchment.

ACKNOWLEDGEMENTS

Many people contributed in some way to the PhD which this work is drawn from including the superb Sophie Lewis, Merinda Nash, Ben Harris, Lloyd Isaacson, Keith Crooke, Anne Felton, David Hoye, and Peter Somerville, and the wonderful farmers of Wybong Creek, most especially Dudley Googe, Percy and Robyn Rayne, and Tracey and Scott Anshaw, and many, many more. Thank you all.

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IAH 2010
Krakow

abstract id: **190**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **Redox controls on the mobility of agricultural nitrogen in groundwater systems in tropical Northern Australia**

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keywords: groundwater redox, nitrogen mobility, organic carbon, floodplain aquifers, karstic aquifers

INTRODUCTION

Aquifer systems have long been recognised as important transport pathways for the delivery of agricultural nitrogen to surface waters (Freeze and Cherry, 1979; Johannes, 1980; Peterjohn and Correll, 1984). The distribution of nitrogen and its mobility within aquifers is highly dependent on groundwater redox conditions. Nitrogen occurs in oxidation states ranging from +5 to -3, and in aquifer systems underlying agricultural regions, nitrogen commonly exists in its most oxidized state (+5) as nitrate (NO_3^-) (Appelo and Postma, 1999). In oxidized systems nitrate is highly mobile and can be used as a conservative tracer (Herczeg and Edmonds, 2000), however, under reducing conditions, nitrate can be highly unstable and may leave the system as N_2 gas or be converted to ammonium (NH_4^+) which readily adsorbs onto mineral surfaces. These NO_3^- reducing reactions require the presence of suitable reductants (electron donors) and the absence of oxidants (electron acceptors) stronger than NO_3^- such as O_2 or some industrial pollutants (i.e. chlorinated ethenes).

The distribution of electron donors and receivers in two groundwater systems in tropical northern Australia are presented; first, the lower Burdekin, which is a coastal floodplain in northern Queensland currently under intensive irrigated agriculture; and second, the Douglas-Daly River catchment in the Northern Territory that is a region being considered for future irrigated agriculture. The geology of the two aquifer systems differ considerably with the lower Burdekin consisting of complex alluvial, deltaic and marine successions deposited during the Holocene and the Douglas-Daly a karstic aquifer system consisting of a Cambrian-Ordovician aged dolostone overlain by highly weathered Cretaceous sedimentary rocks.

DISCUSSION

Lower Burdekin, Queensland. The lower Burdekin floodplain aquifer is adjacent to environmentally sensitive wetlands and the World Heritage listed Great Barrier Reef (GBR) Lagoon (Furnas 2003). It currently supports 80,000 ha of largely irrigated sugarcane that uses 160–220 kg of nitrogen per hectare per year. The complex geology of the lower Burdekin aquifer has resulted in highly variable distributions of electron donors/receivers across the system that directly impacts the mobility of agricultural nitrogen. Organic rich deltaic and marine deposits host groundwater with little to no dissolved oxygen (DO), dissolved organic carbon (DOC) concentrations as high as 80 mg/l and Fe^{2+} and Mn^{2+} > 1 mg/l. Low DO and an abundance of electron donors (DOC, Mn^{2+} and Fe^{2+}), in particular DOC, are geochemical conditions that favour nitrate attenuation (i.e. denitrification or dissimilatory nitrate reduction to ammonium) and consequently little to no nitrate has been detected in these units over a 40+ yr monitoring period. Coarse grained palaeochannel deposits that dissect the floodplain also host groundwater with high DOC concentrations; however, elevated DO (>2 mg/l) within these units decreases NO_3^- attenuation as O_2 is the more thermodynamically favoured electron acceptor for DOC oxidation. In these units, NO_3^- concentrations >20 mg/l have been consistently recorded over the past 40 years. The connectivity of these palaeochannel units to the marine environment suggests the potential for substantial discharge of nutrients into the Great Barrier Reef Lagoon and that nitrogen loads are currently underestimated.

Douglas-Daly, Northern Territory. The Douglas-Daly karstic aquifer system maintains dry season flows in one of Australia's most pristine river catchments, which host unique oligotrophic ecosystems. The potential for nutrient transport through the aquifer to the Daly River is currently being assessed. Preliminary groundwater results from the current dry season (May-December 2009) indicate a largely oxidised aquifer system that contains DOC > 10 mg/l and little to no Fe^{2+} and Mn^{2+}. Increases in HCO_3^- concentrations and decreases in DO along piezometer transects toward the Daly River indicate that O_2 is being consumed through DOC oxidation, a process that trends toward anoxic conditions immediately adjacent to the river (<200 m). DOC levels remain high (10 mg/l), indicating a constant source of DOC, and favourable conditions for nitrate attenuation; however, further data collection and modelling is required to fully assess the potential for nitrogen transport from the aquifer to the river.

CONCLUSIONS

Groundwater redox conditions play a critical role in the mobility of agricultural nitrogen. Understanding current, or predicting future nitrogen distribution and mobility in aquifers in agricultural areas requires a knowledge of the spatial distribution of electron donors (i.e. OC, Mn^{2+} and Fe^{2+}) and electron receivers, in particular dissolved oxygen (DO). In tropical northern Australia, aquifer systems exhibit relatively high groundwater DOC concentrations (DOC>10 mg/l). The presence of organic carbon or other electron donors facilitates nitrate reduction if DO levels are low (<2 mg/l); however, above this level O_2 behaves as the thermodynamically favoured electron acceptor over nitrate. Determining potential impacts of groundwater extraction and enhanced recharge of irrigation waters on groundwater redox conditions is of fundamental importance for predicting future water quality issues within and downstream of agricultural areas.

ACKNOWLEDGEMENTS

This work was supported in part by CSIRO Water for a Healthy Country National Research Flagship and the Cooperative Research Centre for Irrigation Futures.

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abstract id: **193**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **Some evidences of retreating saline groundwater body in the western coastal area at Seocheon in South Korea**

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keywords: Seocheon coastal area, intertidal zone, groundwater quality, fossil saline water, flushing out

Many part of the western coastal area in Korea has broad and flat lowland which is mostly consisting of alluvial deposits and reclaimed land. At those coastal area, high electrical conductivity and high concentrations of Na and Cl components in groundwater has been thought to be simply due to seawater intrusion into the nearby fresh groundwater aquifer. But, a lot of the reclaimed coastal area had been under the environment of intertidal zone for a long time, and therefore now can has somewhat brackish or saline shallow groundwater originated from fossil saline water captured within the intertidal sediments. This study area has been also geologically influenced by quaternary intertidal environment until the estuary dike of Geum river and reclaimed land was constructed for agricultural activity. Now, in this area, groundwater has broad TDS(contents of total dissolved solutions) from fresh through brackish and finally to saline water. Water quality is also complicated and can be classified as follows; Ca(Mg)–Cl(or NO_3), Ca(or Na)–HCO_3, Ca(or Na)–HCO_3(Cl), Na–Cl(HCO_3), Na–Cl type. Groundwater with Ca(Mg)–Cl (or NO_3) type water quality has mostly high NO_3 contents which means strong influences of agricultural activity. Surface water sampled at Bongseonji reservoir, Gilsan stream, drainage for agricultural use and Geum river has water quality of Na(Ca)–HCO_3(Cl) or Na(Ca)–Cl(HCO_3) type with relatively low NO_3 contents. These surface water has been used for agricultural purpose in the study area from April to September and continuously affected the quality of groundwater after land reclamation of intertidal zone. Generally, dominant cation and anion type of groundwater gradually changes from Ca^{+2} and HCO_3^- at upper or middle reach to Na^+ and Cl^- at lower reach of the Gilsan stream catchment. This indicates that groundwater quality is changing through seawater intrusion or flushing out process. The plots of Cl concentrations vs. Mg and Cl contents, Na/Cl molar ratio, SAR(sodium adsorption ratio) and NCHAR(non-carbonate hardness) indicates that fossil saline groundwater has been flushed out by fresh ground or surface water in the study area and the varied water quality has mostly resulted from this flushing out process. The plots of the TDS vs. Na, Cl and Mg concentrations show relatively good correlations, but Ca, K, HCO_3 and SO_4 concentrations show considerably scattered phenomena. This difference indicates that some complicated reasons such as agricultural effect and/or various end member of fresh water in respect of flushing out may be due to scattered features of groundwater quality.

abstract id: **196**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **Geochemical evolution of groundwater quality in shallow and deep wells of volcanic aquifer in Axum, Ethiopia**

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keywords: groundwater evolution, hydrogeochemistry, stable isotope, volcanic aquifer

ABSTRACT

Water samples were analyzed to characterize the chemical and isotope signatures of the local groundwater and to identify the hydrogeochemical processes leading to groundwater quality deterioration in Axum. Hydrochemical data indicates that the anion composition is dominated by HCO_3^- and further modified by human activities as NO_3^- and Cl^- contents rise. The chemistry of the groundwater progressively evolved from Ca^{2+}-HCO_3^- to Na^+-HCO_3^- and Mg^{2+}-HCO_3^- water types. The deep groundwaters evolve toward very high solute concentrations of variable cation contents owing to the influence of aquifer heterogeneity and degree of water-rock interaction.

The chemical composition of groundwater appear to be controlled by complex reactions involving uptake of gaseous CO_2, dissolution and precipitation of silicates and carbonates as well as cation exchange between groundwater and clay minerals. The chemistry of the shallow groundwater is governed by the uptake of soil CO_2. Calcium and bicarbonate is predominantly derived from the dissolution of carbonate minerals in the alluvial sediments. In contrast, in the deeper wells silicate weathering at high pCO_2, which is mainly derived from magmatic origin, is the dominating process. High content of NO_3^- and Cl^- in water samples highlights the impact of human activities on groundwater quality. Contamination of drinking water supply by sewage and farm waste is a major pollution concern from anthropogenic source. The δ^2H and $\delta^{18}O$ data indicate that the solutions are of meteoric origin with apparent effect of evaporation and water-rock interaction.

INTRODUCTION

Groundwater from both shallow and deep aquifers is a significant drinking water supply for the town of Axum. The major concern in drinking water supply in Axum is the deterioration of groundwater quality due to geogenic origin and anthropogenic activities both in shallow and deep boreholes. The groundwater in the study area is hosted mainly by fractured basalt. The fractured and weathered rocks develop good permeability due to secondary porosity. However, the overlying alluvial sediment provides mostly poor condition of surface water infiltration. Hydrogeochemical characteristics of groundwater are of great interest in terms of water quality evolution, as the complex spatial distributions of volcanic rocks have led to extensive changes in groundwater composition. The chemistry of the groundwater primarily reflects the composition of host rocks and the intensity of water-rock interactions that greatly influence the ionic concentration starting from the recharge to discharge zone (Ayenew et al., 2008).

Hydrochemical and stable isotope composition of groundwaters provides information on evolution and source of groundwater and its components as well as on potential impact of human activities on groundwater quality. Knowledge on parameters that control groundwater chemistry is essentially required to develop tailored strategies for water resource management and sustainable drinking water supply for the population in Axum.

METHODS

Water samples were collected from springs, wells and boreholes at various depths. All samples were filtered through 0.45 µm of Syringe Filters in the field and the samples were separated in different aliquots where the samples for cation analysis were preserved using diluted HNO_3, while those used for anion analysis were not acidified. Electrical conductivity, pH, temperature and total alkalinity were measured in-situ. Laboratory analyses comprise dissolved major and trace elements using a coupled plasma-optical emission spectrometry (ICP-OES, Perkin Elmer 4300) and ion chromatography (IC, Dionex 600). Stable isotopic composition (δ^2H and $\delta^{18}O$) of the water was analysed by Finnigan DELTA^{plus} Mass Spectrometer.

RESULTS

Hydrochemistry and water rock interaction

Distribution of major cations and anions in the sampled solutions is shown in Fig. 1 within a piper diagram. Data indicates that cations are mostly dominated by Ca^{2+} and to a lesser extent by Na^+, and Mg^{2+}. However, relative amount of Ca^{2+} ranges from about 20 to 70%, whereas $(Na^++K^+)/Mg^{2+}$ ratio is rather constant at about 0.5 (see lines in Fig.1; $Na^+ >> K^+$). Anions are obviously dominated by HCO_3^-, mostly about 50% and $(NO_3^-+Cl^-)/SO_4^{2-}$ ratio is close to 0.9. Accordingly, local groundwater is mainly of bicarbonate type that progressively evolved from Ca^{2+}-HCO_3^- to Na^+-HCO_3^- and Mg^{2+}-HCO_3^- water types. Most shallow wells hosted within quaternary alluvial deposits and weathered basalt yield Ca^{2+} and HCO_3^- in the range from 0.9 to 2.5 mmol L^{-1} and from 2 to 8 mmol L^{-1}, respectively. Total dissolved solid (TDS) concentration indicates elevated water rock interaction in Mg^{2+}/Na^+-HCO_3^- (mostly deep wells) versus Ca^{2+}-HCO_3^- type solutions (mostly shallow wells). In deep groundwater a maximum TDS value of 2160 mg/L reflects strong uptake of cations from water-rock interaction especially for Mg^{2+} and Na^+ (Fig. 2a).

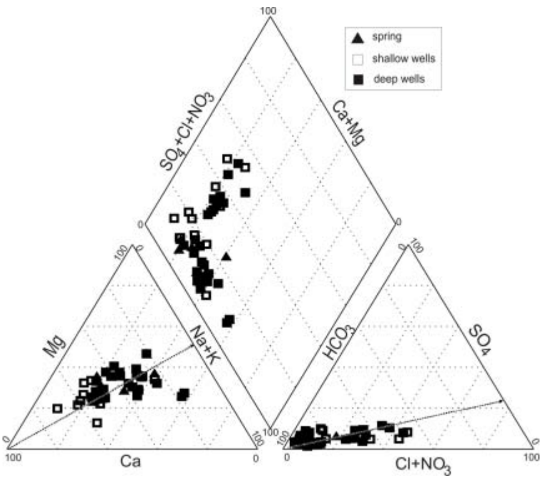

Figure 1. Piper diagram of hydrochemical data from Axum waters.

The calculated internal partial pressure of CO_2 (pCO_2) for all solutions is significantly higher than that of the Earth's atmosphere ($10^{-3.5}$ atm) (Fig. 2b). Groundwaters with pCO_2 values up to about $10^{-0.8}$ atm may be related to a CO_2 source different from soil carbon as soil CO_2 may usually contain $pCO_2 < 10^{-1.5}$ atm. Evidently; CO_2-rich groundwaters (mostly deep wells) contain highest solute concentrations owing to degree of water-rock interaction. The apparent incongruent weathering of silicate minerals results in e.g. kaolinite formation and causes an increase of Na^+, Mg^{2+}, Ca^{2+}, and HCO_3^-. The raise of Mg^{2+} and decrease of Ca^{2+} concentration could be explained primarily by incongruent weathering and leaching of Mg^{2+} from ferromagnesian silicates (Fig. 2c). $[Mg^{2+}]/[Ca^{2+}]$ vs. $[Mg^{2+}]+[Ca^{2+}]$ ratio displays that the shallow wells have lower

$[Mg^{2+}]/[Ca^{2+}]$ ratio at less absolute cation content. Thus, elevated $[Mg^{2+}]/[Ca^{2+}]$ ratios of deep groundwaters may represent strong weathering of mafic minerals, most likely attributed to progressive reaction of Mg-silicate dissolution caused by uptake of elevated content of gaseous CO_2. $[Ca^{2+}]+[Mg^{2+}]$ and $[HCO_3^-]$ concentrations rise at a slope of 1:2 indication both silicate weathering and $CaCO_3$ dissolution in areas where carbonate minerals are present e.g. in the alluvial aquifer and calcite filling veins (Fig. 2d).

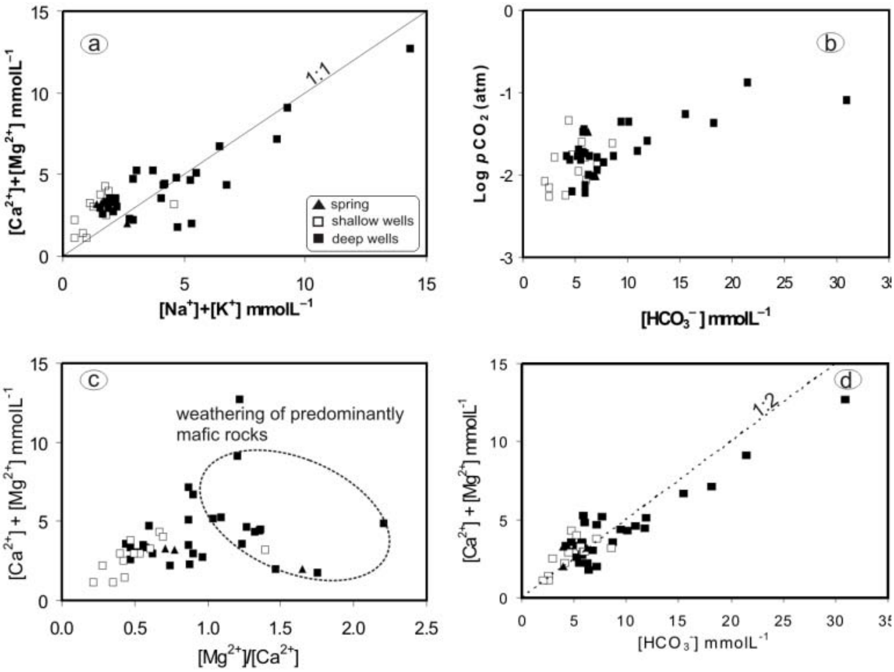

Figure 2. Plots of (a) $[Ca^{2+}]+[Mg^{2+}]$ vs. $[Na^+]+[K^+]$ (b) pCO_2 vs. $[HCO_3^-]$ (c) $[Ca^{2+}]+[Mg^{2+}]$ vs. $[Mg^{2+}]/[Ca^+]$ (d) $[Ca^{2+}]+[Mg^{2+}]$ vs.$[HCO_3^-]$ for Axum groundwaters.

Stable isotope composition of groundwater

δ^2H and $\delta^{18}O$ values of shallow and deep groundwaters as well as surface water from Axum area are given in Fig. 3. Most of the values scatter close to the global meteoric water line (GMWL) of Craig (1961) and the regional line of Addis Ababa (RMWL). In two samples a positive $\delta^{18}O$ shift is likely caused by isotopic exchange with the rock mass through water-rock exchange. The presence of isolated aquifer and high mineralization supports the possibility that such fluids may interact with surrounding rocks more strongly. Most of groundwater from deep aquifers is from semi-confined aquifers, suggesting vertical infiltration of evaporated waters. The δ^2H and $\delta^{18}O$ values for several surface water and spring water are isotopically different from the other solutions which may be caused by evaporation during precipitation and infiltration (see Fig. 3; evaporation line). The $\delta^{13}C$ of dissolved inorganic carbon (DIC) has been analysed for carbon evolution and the values range between +1 and –12‰ indicating magmatic CO_2 and soil CO_2 as predominant sources. The uptake of magmatic CO_2 at higher pCO_2 results in elevated major cations, dissolved SiO_2 and HCO_3^-contents due to strong silicate weathering.

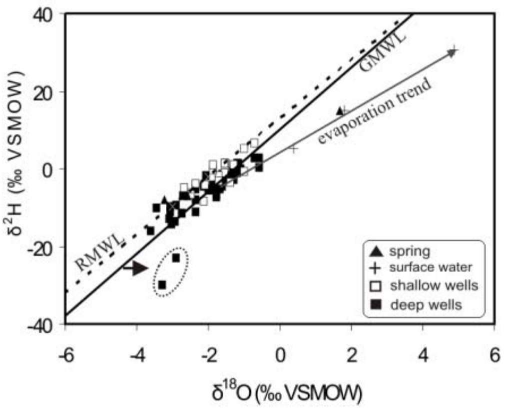

Figure 3. δ^2H versus $\delta^{18}O$ values of H_2O for all sampled solutions. GMWL (solid line) refers to global meteoric water line of Craig (1961) whereas RMWL denotes the regional meteoric water line for Addis Ababa ($\delta^2H = 7.5\ \delta^{18}O + 12.9$) using data from IAEA (2008).

Impact of human activities

Elevated NO_3^- and Cl^- content are indicative for anthropogenic impact. Naturally, NO_3^- concentration in crystalline rocks is very low and, therefore, high concentrations of NO_3^- in some groundwater within the study area indicates that human activity is increasingly impacting the water quality. The influence of human activities is evident in some municipal deep wells as well as shallow wells. The maximum nitrate concentration in the study area is 1.5 mmol L^{-1}, (mean concentration 0.4 mmol L^{-1}). In several solutions the nitrate concentration has exceeded WHO recommended value of 50 mg/L for drinking water. High levels of nitrate accompanied with high content of chloride are suspected to come from human and animal waste effluent. However, there exist no significant overall correlation between NO_3^- and Cl^- (Fig. 4), which is probably due to the non-conservative behavior of NO_3^-. In shallow wells, the origin of high NO_3^- is likely a consequence of farming practices such as manure application that can be introduced into the groundwater systems via infiltration through the soil horizon. The deep wells close to the town are vulnerable to pollutants from sewage, including septic tanks and leaking sewer lines.

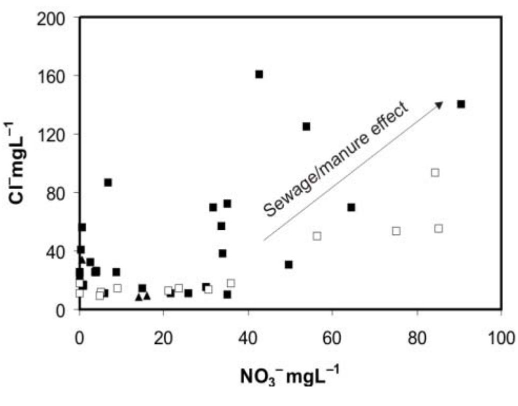

Figure 4. NO_3^- vs. Cl– concentrations in deep and shallow wells. Symbols are given in Figure 1.

CONCLUSION

Hydrochemical data indicates that the anion composition is dominated by HCO_3^- and further modified by human activities. The influence of human activities in the groundwater quality is evident in wells located close to the town. The sign of quality deterioration highlights the need for water quality monitoring and management. The chemistry of the shallow groundwaters is controlled by the uptake of soil CO_2 while weathering of silicate at higher pCO_2 dominates in the deeper aquifers. The incongruent weathering of silicate mineral at high pCO_2 generally enriches the groundwater in HCO_3^- and Ca^{2+}, Na^+, Mg^{2+} and dissolved SiO_2.

Stable water isotopes ($\delta^{18}O$, δ^2H) show that the waters are derived from meteoric origin with apparent effect of evaporation and strong water–rock interaction in few sampled solutions. The groundwater recharge into deeper aquifer is either from base flow of infiltrating rainfall in recharge zone or from directly vertical infiltration of evaporated waters.

ACKNOWLEDGEMENTS

We are grateful to the Austrian Agency for International Cooperation in Education and Research (OeAD) for PhD grant for the first author. Moreover, the authors greatly appreciate support from Mekelle University during sampling and Graz University of Technology (Institute of Applied Geosciences) for providing the necessary facilities to conduct solution analyses in the laboratory.

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abstract id: **208**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **Water quality assessment in North-East India**

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keywords: physico-chemical characteristics, microbial assay, pesticide residue analysis

INTRODUCTION

India's annual precipitation (snowfall and rain) is 4000 billion cubic metre (bcm). This translates into 1,869 bcm of water in rivers, of which, barely 690 bcm is used. Nearly 1,179 bcm of water flows into the sea. Considering 432 bcm of groundwater, the total water availability is around 1,122 bcm amounting only 1,122 cubic metres of water available per person per annum in the billion plus country (Singh, 2002). Moreover, the assessment of water quality (Das, Goswami, 2003) is of paramount importance to find out the suitability of water for various purposes viz., drinking, irrigation and other industrial/.household works particularly in the north east India where the pertinent research on water quality has not been carried out in a systematic manner.

MATERIALS AND METHODS

As such, water from sources like tubewells (shallow/deep aquifers) and surface streams (lakes/canals/ponds) in 3 places (Manipur/Meghalaya/Tripura) in north east India was collected and thereafter analysed to focus on the chemical, microbiological and pesticide residue analysis. The no. of samples collected/analysed were 19 (Manipur), 39 (Meghalaya) and 61 (Tripura) and moreover, seasonal variation of water characteristics was also brought under study.

PHYSICO-CHEMICAL CHARACTERISTICS

In Manipur, water samples were from Imphal (West District) and water pH was found to vary from 6.45 to 9.35 thus indicating the presence of acidic to alkaline nature. The comparatively high pH noted in ponds/dams could be due to erosion load of cationic constituents in the lower reaches of the hills (Manipur valley).

The seasonal variation of chemical analysis (WHO, 1993) in Umiam reservoir (Meghalaya) indicated that water pH varied from 7.12 to 9.11 being maximum during monsoon. Transparency was of the lowest value (upto 2.09 m) during monsoon thus indicating the rain induced erosion of mud or clay materials from the catchment areas. Calcium + magnesium content ranged from 0.06 to 0.15 (meq/100 ml) for pre-rain and 0.07 to 0.28 (meq/100 ml) for post rain samples in Meghalaya. The Fe content in pre- and post-rainy samples from West Khasi Hills ranged from 0.07–0.23 mg/l and 0.14–0.22 mg/l, respectively. The nitrate content among monsoonal samples ranged from 11.2 to 30.8 mg/l, mostly categorized under low and medium group. The chloride content of the monsoonal as well as post monsoonal samples were mostly categorized under increasing toxicity level which is quite safer for irrigation purposes. However, bicarbonate content was detected in almost all the samples and the values ranged from 2.3 to 6 meq/1000 ml for pre-rain and 3 to 5 meq/100 ml for post-rain samples. The carbonate content of the monsoonal and post monsoonal samples may be classified under none which is having no toxic effect for irrigation use.

The chemical characteristics of water as estimated for drinking/irrigation/pond water were evaluated in Tripura. In West Tripura, pH of water showed a variation from 6.11 to 7.68. But, pH of water samples collected from different places in South Tripura showed a variation from 5.37 to 7.48 Concentration of nitrate, phosphate, potassium and calcium in water samples of West Tripura varied from 1.0 to 7.2 mg/l, 0.04 to 1.43, 0.09 to 2.24 and 0.64 to 11.48 mg/l, respectively. On the other hand, concentration of nitrate, phosphate, potassium and calcium in South

Tripura varied from Trace to 4.2 mg/l, Trace to 0.25 mg/l, 0.05 to 2.34mg/l and Trace to 11.27 mg/l, respectively. It is indicated from the mean values that drinking water had more acidity compared to irrigation and pond water. Among the macroelements, drinking water contained high nitrate (2.35 mg/l) though it is much below the permissible limit (45 mg/l). Pond water was found to contain high amount of potassium (1.04 mg/l) and calcium (5.71 mg/l) compared to two other water sources. In West Tripura, contents of Zn, Cu, Mn and Fe varied from trace to 129, trace to 11, trace to 990 and trace to 4205 μg/l. In South Tripura, contents of Zn, Cu, Mn and Fe varied from Trace to 122 μg/l, Trace to 34 μg/l, Trace to 398 μg/l and Trace to 580 μg/l, respectively. So, pond water was also found to have more contamination in copper and manganese, but drinking water which contained iron lower than the permissible limit (300 μg/l), had comparatively high zinc contamination. Both irrigation and pond water contained iron contamination higher than the permissible limit.

MICROBIAL ASSAY

The assay of microbial load (Kistemann, 2001) is necessary to pinpoint water suitable both for drinking as well as irrigation. Some of the water sources from Meghalaya were analyzed for the *Colliform* and *Salmonella* and most probable number (MPN) to find out micro-organisms load in the water samples. The samples with higher MPN are unsafe to use. The water from Umshyrpi river had higher MPN value(>1000/100 ml). This water was also contaminated with *E coli* and Salmonella, hence not safe for drinking as well as irrigation. On the other hand, water present in Jalkund were containing less infection of colliform and salmonella as compared to river water.

PESTICIDE RESIDUE ANALYSIS

Presence of pesticides (Jaysree and Basudevan,2007) is a matter of great concern in water as well as various food materials due to their indiscriminate use for increasing the crop productivity in India. As such contamination or the presence of some pesticides, viz., monocrotophos, cyfluthrin, dimethoate, carbofuran, endosulfan (alfa and beta), chloropyriphos and cpermethrin were estimated in water samples collected from Manipur, Meghalaya and Tripura. Water in most of the rivers in Manipur and Meghalaya had alarmingly high contents of pesticide residue (> 1.0 μg/l) and such water is unsuitable for agricultural purposes. Water from Loktak lift irrigation in Manipur also contained 1.61 μg of beta endosulfan/l. But water from some of the village pond were found to contain pesticide less than 1.0 μg/l but higher than the admissible limit (0.1 μg/l) for drinking water. Water from tubewell in Manipur were found to be suitable for drinking purpose.

CONCLUSION

So, an accurate and reliable information on the water resource system can, therefore, be a vital aid to strategic management of this resources. for arriving at rational decisions that will result in the maximum amount of benefit to the people.

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abstract id: **216**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **Study and modelling non-point agricultural pollution by nitrates in Mateur plain north east of Tunisia**

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keywords: nitrates, unsaturated zone, Mateur, recharge, mechanist model

INTRODUCTION

The groundwater resources constitute significant water resources reserves. In several areas of the world, they are widely exploited to cover the drinking water. Safeguarding groundwater quality constitutes a major preoccupation especially for reasons of public health. The pollution of the aquifers by the nitrogen resulting from fertilization, effluents of farm and waste water discharges constitutes an environmental problem for areas of intense agricultural activity. Prediction of the contamination risks requires a comprehension of the whole processes implied in becoming and circulation of pollutants in the unsaturated zone which constitutes an interface of water exchange, pollutants and micro-organisms between aquifer and the biosphere.

We initially carry out a vulnerability Study of the Mateur plain which is based on DRASTIC (Chebil, 2009) method that constitute an index methods. It is used in order to evaluate the absolute vulnerability on a large scale according to hydrogeologic, climatic and physics parameters of the system. Multiple models were developed in order to simulate the evolution of water flows and transport of nitrogen in the unsaturated zone. The use of a particular model to a hydrogeological basin requires a methodology of division based on the combination of determining characteristics for the processes of transformation and transfer of the nitrogen in the column of soil to aquifer: soil occupation, soil slope, depth of the water level and surface permeability. Simulations will be related then to these homogeneous zones. Methods of interpolation permit to deduce the space distributions of water flows and nitrate which reach the groundwater.

The objective of this study is to quantify non-point agricultural pollution leaving the unsaturated zone and reaching groundwater according to the various activities practised in the area and to the contributions of water. Annual average flows of percolation and its average nitrate concentration are after evaluated.

MATERIALS AND METHODS

Study area

The Mateur zone is situated in North of Tunisia, 50 km of Tunis. It belongs to the large catchment area of Ichkeul which presents a surface of 2600 km² (Fig. 1). It is crossed by a dense hydrographic network where the Lake Ichkeul is the outlet system. The textural analysis of the deposits showed a variation between sand and clay. The interannual average precipitation over the period 1996–2008 is 570 mm. The annual average temperature is about 18°C. According to calculations carried out by ET0 Calculator according to method FAO 56 of Penman-Monteith, the potential Evapotranspiration annual medium (ET0) is 1083 mm over the period 1996–2008. The regular chemical analyses carried out by the National Company of Water Exploitation as well as the campaigns realized by Jendoubi (2000) and Talhaoui (2004), indicate that nitrate concentration exceeded standard concentration of 50 mg/l.

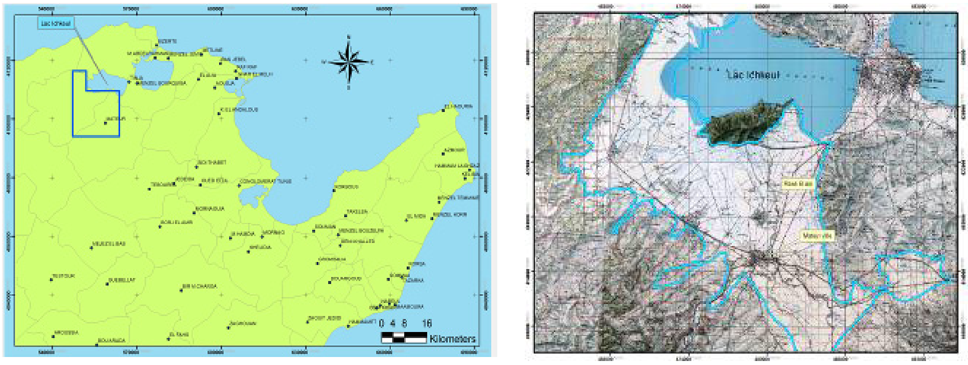

Figure 1. The Mateur zone.

Land use

The study zone is known by an intense agricultural activity because of the fertility of its grounds as well as the abundance of the farm equipment. The mainly cultures practised are: cereals, garden cultures and olives. The total cultivated surface knows a great growth with 51.900 ha in 2000 and 767568 ha in 2007. The intensive cattle's farming is also largely practised which concentrate significant numbers of animals and grazing zones identified by the regional authorities. Discharges of farms are estimated at 120 Kg/ha/an (Jendoubi, 2000).

MODEL DESCRIPTION

LEACHM (Leaching Estimation Chemistry Model) is a deterministic model (Hutson, 2003). It describes physical and chemical processes of water transfer and nitrogen and pesticides transformation in soil in agricultural area. LEACHM Model consists of five sub-models; one of them is LEACHN model which specially simulated for nitrogen transformation. This model has already been extensively applied to different environments (Lotse et al., 1992; Johnson et al., 1999; Sogbedji et al., 2001; Ibnoussina, 2007). This model can be used in either laboratory or under field conditions. It uses a finite-difference form of Richards' equation to predict water contents dynamics and simulate the nitrogen cycle which concern different processes such us: mineralization, Denitrification and uptake root. The boundary conditions represented by precipitations, irrigation and evapotranspiration for the water flux and nitrogen input in the form of fertilizations or rejections for the transport equations. This model was used in order to follow the effects of the intensive use of fertilizer on the groundwater contamination (Singh et al., 2001).

SPATIAL ANALYSIS

Modelling must be carried out on a homogeneous entity on the horizontal level. The application of LEACHM model on a heterogeneous watershed requires its division into homogeneous sectors.

The plain of Mateur is characterized by a wide range of profiles developed at different levels (soil texture, various cultivation practices that are increasing in this area one year to another). This condition makes difficult any attempt to estimate the various terms of nitrogen balance across the entire study zone. For that purpose, the adopted approach in this study is similar to that established by Gnouma (2006) which involves the integration of maps: land use, depth of groundwater, permeability of surface and the slope of the soil. Each one of these parameters is subdivided into three classes of values. Each unit is characterized by a single type of agricultural practice, permeability, depth of the water and slope. Dividing the study area leads to homogeneous units or areas, then the model LEACHM can be used in each area so defined. The selection of profiles is made on the basis the DRASTIC index (Fig. 3) and the combination map of parameters (Fig. 4). For each profile we obtained the flow of water percolation and their nitrate concentration over time.

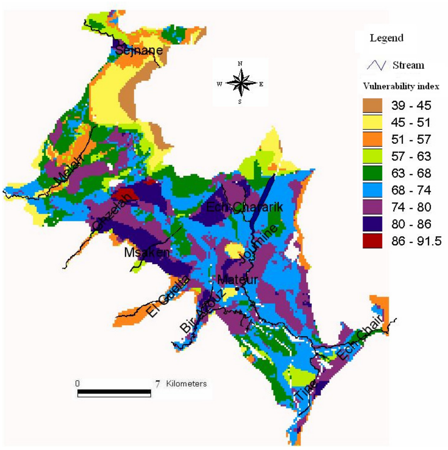

Figure 2. Map of class of vulnerability.

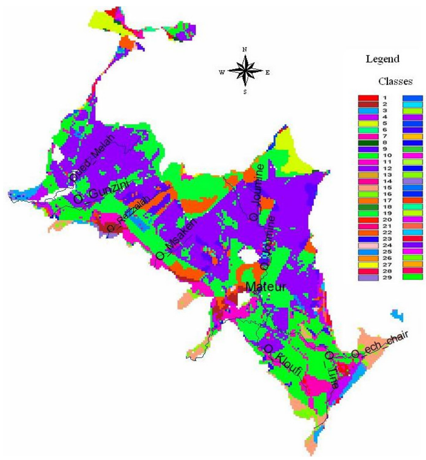

Figure 3. Map of class of homogeneous areas.

WATER FLUX PERCOLATION AND NITRATE LEACHING INTO THE AQUIFER OF THE PLAIN MATEUR

The distribution of recharge flux map (Fig. 4) shows that the most permeable zones allow transfer of pollutants through the unsaturated zone. The study results show that annual recharge rate increases due mainly soil physical properties (texture, permeability ...) since we work with average climate conditions. More soil is permeable more concentration of nitrate is very important. The high recharge areas may also indicate that the groundwater is subjected to a very significant contamination by nitrates. The highest water flux percolation reach 72 mm/year for an average annual rainfall of 570 mm/year for fine textured soils and high permeability. The map shows clearly that the maximum quantities of percolated water are from areas associated with fine textured soils and high hydraulic conductivities and low flux values correspond to clay areas.

Similarly, the map of nitrate distribution shows the average annual nitrate leaving the unsaturated zone and reaching groundwater (Fig. 5). Nitrate concentrations exceed the potability thresholds, which is 50 mg/l. The highest values were observed in areas of continuous release of farms with fertilizer application and sandy soil. Areas in north of Mateur region are characterized by nitrate concentrations around 247 mg/l. The intensive use of nitrogen fertilizers, the very high permeability sandstone areas and the proximity depth of water level allow these high levels of nitrate. In the southern region of Mateur, nitrate concentrations are low because the vadose zone is very clay and the level of water is very deep.

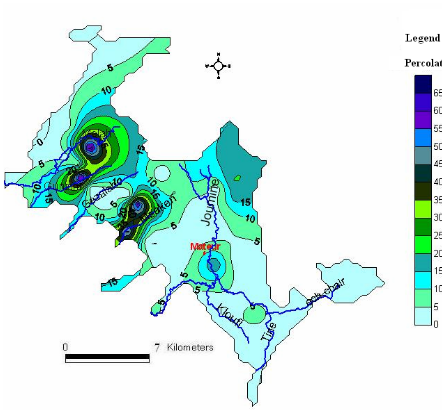

Figure 3. Map of groundwater recharge.

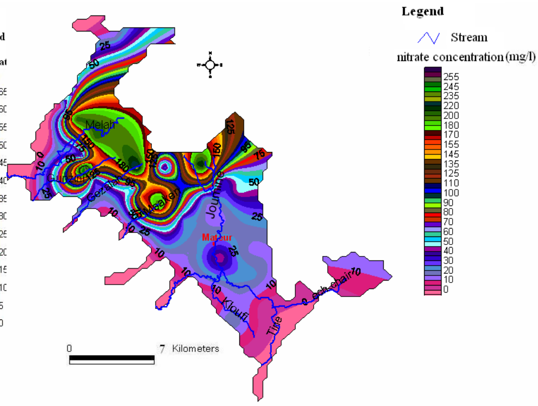

Figure 4. Map of nitrate concentration.

CONCLUSION

Understanding the impact of contamination by nitrate is essential to ensure better management of water quality intended for human consumption. Several models have been proposed to quantify the transport pollutants derived from agriculture in unsaturated soils. The development of vulnerabilities maps by the DRASTIC method constitutes an important support planning and decision making for the determination of the most vulnerable and sensitive to pollution and the information necessary to build a network of surveillance for the protection of the aquifer. The methodology followed in this work is to simulate in soil profiles the water flux to the groundwater and their nitrate levels using the model LEACHM. Given that the distribution of water flux percolation and their nitrate levels over time is highly variable, we adopted the data of precipitation and evapotranspiration averaged over time with an average hydrological year.

Applying such a model in a watershed requires as a preliminary, it's zoning in homogeneous simulations area by carrying out collection of thematic maps. These generate the mapping of cartographic units in which features profiles of soil types have been identified. On each one of these profiles, we simulate unsaturated flux and reactive transfer of nitrogen in a daily time step for an average hydrological year. Spatial integration of these results enabled us to establish a recharge map. The water flux percolation to the groundwater reach 72.2 mm/year, or an average recharge rate of about 7.9% for an average interannual rainfall of 570 mm/year. The average concentrations of nitrates in recharge flows exceed 200 mg/l. The most vulnerable areas are characterized by a fine texture and continuous discharges from farms with fertilizer application. These distributions of flow and their nitrate levels will make it possible to calibrate a hydrodynamic model and transport of nitrate in groundwater of Mateur in steady state.

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abstract id: **239**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **Effect of land use change on groundwater quality in pumping wells**

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keywords: nitrate, trend reversal, tracer methods

Diffuse contaminant sources such as agriculture are among the main causes of a progressive deterioration of groundwater quality in many countries (Bohlke, 2002). The European Water Framework Directive and national directives (e.g. nitrate projects in Switzerland) prescribe measures to reverse persistent upwards trends in contaminant concentrations. In case of nitrate, probably the most pervasive agricultural contaminant, a common measure consists in converting intensive to extensive agriculture (McMahon et al., 2008).

Assessment of the effectiveness of such projects requires a good understanding of dynamics of contaminant transfer from the land surface where measures are taken to the pumping well. The reaction of pumping wells is influenced by numerous factors such as the temporal evolution of the quality of recharge water, reactive processes within the aquifer and the transit time of contaminants through the vadose and saturated zone (Molenat, Gascuel-Odoux, 2002). This study aims to understand and quantify the effect of these factors on the observed evolution of the groundwater quality in the pumping well supplying the town of Wohlenschwil, Switzerland.

The study area, located near Zurich, Switzerland, consists of an unconfined Quaternary sand and gravel aquifer with a recharge area of around 1 km^2. In the central part of the aquifer, the water table is located around 12 m below the surface. The conversion to extensive agriculture has lead to a rapid decrease of the nitrate concentration in the pumping well from about 50 mg/l in 1997 to around 25 mg/l since 2003 (Fig. 1, 2).

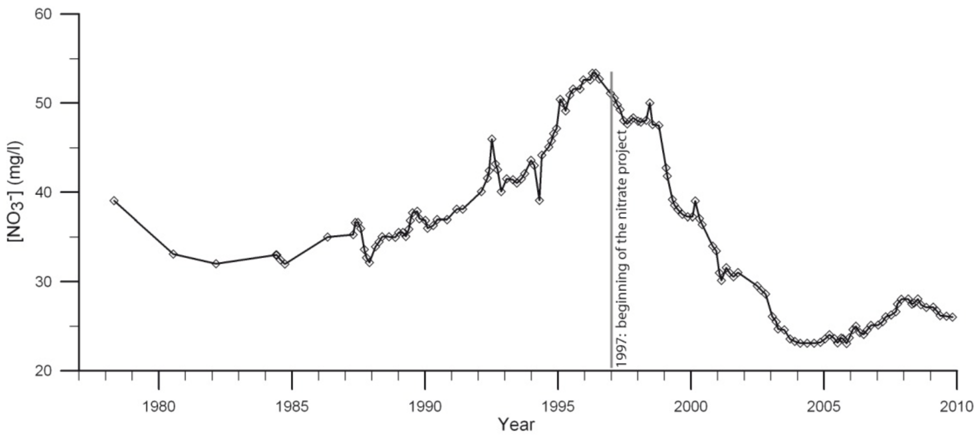

Figure 1. Evolution of concentration of nitrate in the pumping station.

In order to assess the dynamics of contaminant transfer across the vadose and unsaturated zone, a number of different methods were used. The seasonal variability of groundwater recharge was quantified using a soil water balance model based on measured meteorological and water content data. Tracer tests (bromide and chloride) were carried out across the vadose zone at six experimental plots with different land use. Finally, the transit time in the saturated zone was assessed using tracer methods as well (fluorescent dyes). Based on the obtained information and the history of land use which is well known, the response of the system to land use changes was reconstructed and the key factor that control the dynamics of the response identified.

Figure 2. Land use before 1997 (left figure) and after 1997 (right figure). Intensive agriculture area was strongly decreased after 1997 (gray zones).

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IAH 2010 Krakow

abstract id: **287**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **Agricultural waste management and groundwater protection**

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keywords: intensive agriculture, agricultural wastes, groundwater pollution

INTRODUCTION

The largest surface area of greenhouses in Spain covers 30.000 ha and generates some 1,500 million euros each year (Fundación Cajamar, 2006). This intensive agriculture produces around 770,000 t y^{-1} of plant waste. For a long time, this plant waste was burnt or else tipped in the countryside without any special precaution. Over the last two decades, a significant proportion is recycled, separating the plastic waste and making compost with the plant waste. The problem of elimination or recovery and recycling is common to all agricultural areas in the world.

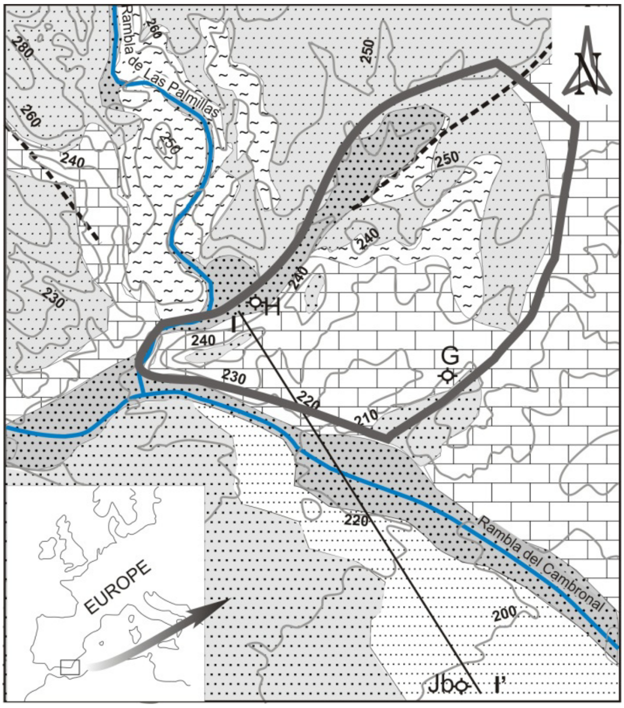

Figure 1. Location of agricultural waste treatment plant and sampling points (I-I': cross-section in fig. 2).

The solid agricultural waste treatment plant that forms the subject of this study is located east of Almería (Figure 1). It covers nearly 4,000 ha and takes some 120,000 t annually of mixed agricultural waste consisting of plant waste with rope, bags, fruit waste, wires from the greenhouse structures, soil attached to plant roots and plastic from the irrigation tubes (Callejón-Ferre et al., 2009). It produces 70 % biomass, which contains 14 % humus, 12 % compost and vermicompost and 12 % inert material. Leachate is stored in impermeable (lined) ponds, although other parts of the site are not lined, including the entire area where the plant waste is stacked, as well as small watercourses and puddles and ponds.

Though the climate in this area is semiarid, rainfall can be intense. Such intense rainfall generates leachate that infiltrates directly into the ground or creates surface runoff that drains into the nearest nearby rambla (dry watercourse), from where it too infiltrates. These leachates have elevated concentrations of organic material, metal and metalloids, depending on the treatments that have been applied. They are highly polluting if there are no mechanisms to contain them within the plant (Sara, 2003).

GEOLOGICAL AND HYDROGEOLOGICAL SETTING

The study area lies within the Betic Cordillera. Outcrops include pre-orogenic and post-orogenic terrains. The pre-orogenic rocks belong to the Alpujarride Complex and comprise micaschists, phyllites, quartzites and recrystallized dolomites at the top. This series is about 400 m thick. The oldest post-orogenic outcrops date from the Tortonian. The most abundant facies are the calcarenites of a reef talus. The Pliocene is represented by sands, as well as yellow calcarenites, marls and sandy marls. Overlying these are Plioquaternary marine conglomerates and sandstones. Then come some Pleistocene alluvial deposits and lastly, gravels, sands and silts of the present-day ramblas.

Triassic limestones and dolomites, Miocene calcarenites and sands, Plioquaternary conglomerates and sands, as well as the alluvia and riverbed deposits all behave as aquifers, which conform to a relatively simple geometry. A simplified scheme of their characteristics is given in the section in Figure 2. The transmissivity of the Alpujarride deposits is 9000 m^2/day (IGME, 1982).

The dominant flow direction is N-S. In the area of the treatment plant, the aquifer is unconfined and varies in thickness from 0 to 160 m, with a saturated zone of 30-35 m, on average. Transmissivity varies from 10 to 900 m^2/day and the effective porosity could be 15-20 % (IGME, 1982). The study borehole furthest from the treatment plant along the direction of the groundwater flow is denominated Jb (see Figure 2). Test pumping in this borehole at a rate of 12.7 L/s, resulted in a drop in water level of 1.74 m after 300 minutes. The value of transmissivity obtained was 1000 m^2/day, while the storage coefficient was 0.08.

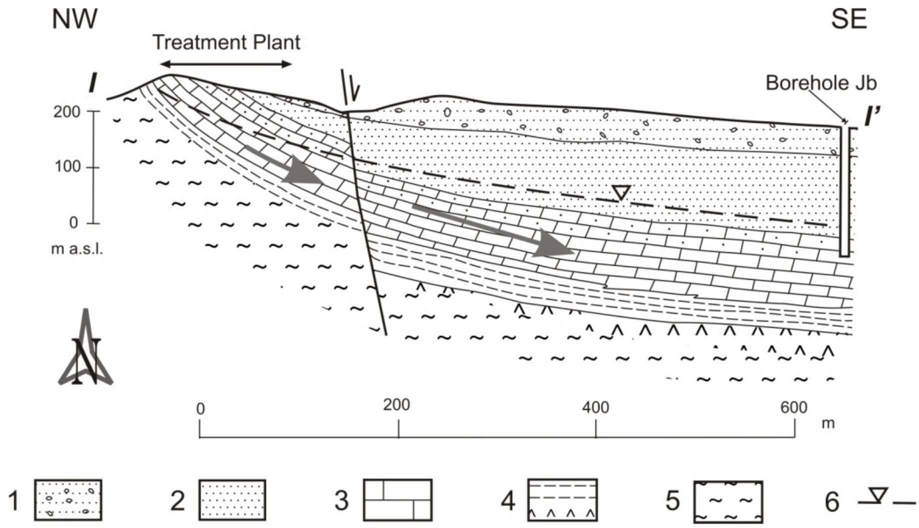

Figure 2. Hydrogeological cross-section. 1: Conglomerates, sands and clays (continental Pleistocene), 2: Sands, sandstones and calcarenites (Pliocene): 3: Calcarenites from a reef talus (Miocene), 4: Sandstones, sandy marls, limestones and reef calcarenites. (Messinian-Andalusian), 5: Alpujarride Substrate (Triass). 6: Piezometric level.

a)

b)

Photos 1 and 2. Aspect of the accumulated plant wastes, showing the leachate emerging in the foreground (a) and a lined leachate pond (b).

The main inflow to the aquifers comes from direct infiltration of rainfall and surface runoff. Rainfall is scarce – generally less than 250 mm/year, which means that recharge rarely exceeds 20% of the rainfall. The main outflows are the pumped abstractions from boreholes. The pumped abstractions have exceeded the inflows to the aquifer for many years, and this has led to a continuous drop in water levels, as well as salinization of many sectors, with the consequent abandonment of wells and farmland.

MATERIALS AND METHODS

The first step was to overlay a 1:10,000 map on an aerial photo of the entire study area. Subsequently, test pumping was carried out (November 2008) and water samples were taken both from the pumped well and from the two boreholes located inside the treatment plant. Electrical conductivity, pH and temperature were measured *in situ,* while the major and minor ions, TOC, COD and BOD_5 were analysed later in the laboratory. Three samples of leachate were also taken and stored at 4 ºC for subsequent analysis in the Bioclinical Analytical Laboratory of Almería.

RESULTS AND DISCUSSION

Physico-chemical characteristics of groundwater

Mean water temperature was 25.8 ºC, electrical conductivity oscillated between 2300 and 3000 microS/cm and pH was slightly acidic (7.2). The Piper diagram (fig. 3) shows the water facies is basically sodium bicarbonate-chloride, which indicates the presence of chloride salts in the aquifer matrix. These salts may be derive from evaporites intercalated in the deposits, or from the lixiviates from salts remaining in Miocene marine deposits higher up in the stratigraphic column.

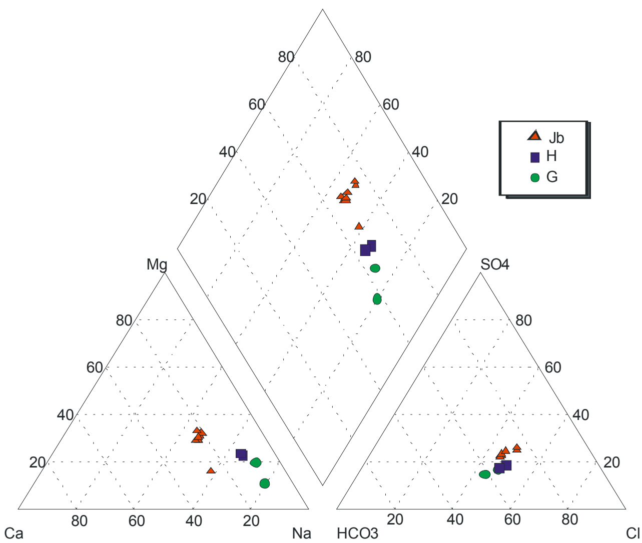

Figure 3. Piper diagram of the groundwater samples.

Heavy metal concentrations in the groundwater allow characterization of the possible pollution of the aquifer. These heavy metals come from plant remains, compost and fertilizers (Amlinger et.al. 2004). The concentration of iron increases considerably between borehole H (11 μg/L) and borehole Jb (more than 600 μg/.L). Manganese concentrations also increase from a mean of 13.4 μg/L in boreholes H and G to 327 μg/L in Jb. The contents of Ba, Ti and Ni also increase, though less sharply (table 1). The marked reducing medium in the vicinity means that the solubility of the metals is substantially raised above their limited solubility in an oxidising medium. The pollutant plume, indicated by the content of organic material and certain minor ions, increases along the direction of groundwater flow, *i.e.* towards borehole Jb.

Table 1. Analysis of groundwater chemistry during the pumping test Leachates.

	H1	H2	G1	G2	Jb1	Jb2	Jb3	Jb4	Jb5	Jb6	Jb7	Jb8
NH_4 mg/L	0,4	0,4	1,0	0,9	8,8	8,6	7,0	8,5	8,0	7,5	7,5	7,5
Ti μg/L	0,2	0,3	0,3	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4
V μg/L	0,6	0,7	0,9	0,9	80,8	0,9	1,0	1,1	1,1	1,1	1,0	1,1
Al μg/L	>10	10,4	>10	>10	>10	0,9	>10	>10	>10	>10	>10	>10
Mn μg/L	10	9	17	17	306	310	311	308	313	317	322	410
Ni μg/L	<5	<5	<5	<5	5,2	5,6	6,5	7,2	7,8	7,1	8,1	9,6
Zn mg/L	<0,01	<0,01	<0,01	<0,01	<0,01	0,03	0,02	0,03	<0,01	0,03	0,03	0,03
Ag μg/L	<1	<1	<1	<1	<1	<1	<1	<1	<1	3,57	1,34	1,20
Sn μg/L	0,04	0,01	0,02	0,02	0,006	0,004	0,006	0,004	0,004	0,005	0,004	0,003
Ba μg/L	15	19	22	22	52	58	57	59	58	58	58	57
U μg/L	2,0	2,1	0,5	0,4	2,4	2,5	2,6	2,7	2,8	2,8	2,9	2,9
Fe μg/L	11	19	66	72	648	667	313	577	253	388	379	393
TOC mg/L	27	29	30	29	29	31	31	37	32	30	27	22
DQO mg/L	27	35	29	26	27	23	22	27	24	50	49	18
DBO_5 O_2/L	9,5	10,5	9,5	9,0	9,5	9,5	10,0	10,5	9,0	8,5	9,0	8,5

Some of the leachates generated in the treatment plant are stored in ponds with an impermeable liner, while other outflows are from unlined surfaces, such as the small watercourses, channels and puddles, as well as the compost and vermicompost storage area. The leachate arises due to the intrinsic humidity of the organic matter, the composting process and, in very wet years, from rainfall. It is an aqueous solution charged with substances in solution and in suspension, and is highly polluting. It penetrates to the saturated zone of the aquifer and from there is carried with the groundwater flow of the aquifer. The majority of the leachate is generated over the aquifer formations of Mio-Pliocene calcarenites, with a smaller volume of leachate generated over the impermeable phyllites. Some leachate also flows into nearby ramblas (dry streambeds) and eventually infiltrates through the rambla bed and into the groundwater flow.

According to the analysis of leachates taken from the containment ponds and from a small channel, average concentrations in major ions are highly elevated, particularly chloride (8100 mg/L), sulphate (1650 mg/L), HCO_3^{-1} (13800 mg/L) and sodium (2080 mg/L). Mean TOC is also high (2300 mg/L), BOD_5 (24 g O_2/L) and DQO (63 g O_2/L), as is NH_4 (370 mg/L) and SiO_2 (300 mg/L). Concentrations of the minor ions Fe, Cu, Zn, As, Ni, Mo Cr, Cd, B, Ba are also elevated. The behaviour of the heavy metals present in residues is important from the point of view of environmental legislation, in terms of the criteria for determining increases in soil residues and the prevention of soil pollution (Robin et al., 2008).

Mean concentration of TOC in the borehole water was close to 30 mg/L. Mean DQO and BOD are 29.5 and 9.5 mg/L, respectively. During the pumping tests, there was a noticeable small in the water taken from the Jb borehole – possibly due to the decomposition of organic material. Nitrate concentrations from the three boreholes were low (0.3 to 2.15 mg/L), probably as a result of the reducing medium.

The degree of groundwater pollution varies from one well to another, as is clearly shown by the NH_4^+ content. Boreholes H and G yielded a mean of 4.42 mg/L, while in Jb the value was 7.9 mg/L. All of these values are extremely high for groundwater.

FINAL CONSIDERATIONS

The study area presents clear evidence of organic pollution, whose nearest point of origin is the Greenhouse Waste Treatment Plant. In particular, the finger points to the migration of leachates from unlined sites within the treatment plants, which are therefore not isolated from the area's main aquifer.

A primary corrective measure would be to line the entire plant waste storage and processing area, and install a leachate treatment station. In addition, an adequate aquifer decontamination system should be in place, even though this latter option would be very costly.

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abstract id: **289**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **Monitoring influences of the groundwater level and quantity on soils fertility of the irrigating lands of the Tajikistan**

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keywords: mineralization, fertility, agriculture, semi-arid

Mineralization and chemical compound of underground and pressure waters of irrigating lands of Tajikistan are subject to regime changes which are not always caught with sufficient clearness. On seasons of year more appreciable changes are in this respect observed on the strongly salted grounds and salt marshes. For them in the hot period of year underground waters cover small-ground with sharply raised mineralization are spent on total evaporation from a soil cover increasing temporarily stocks of salts in soil-ground of a zone of aeration and on a surface of ground. On change of it from bedding thickness of pebbles there come waters in less mineralization. To next vegetation period at the expense of atmospheric precipitation there is happened washing back underground waters and increase of mineralization of the upper layer the lasts. Thus the essential change in chemical compound of underground waters does not occur, in both cases water is usual chloride sodium. At the less mineralization of water in an initial condition there are observed the changes in chemical compound, mainly on ions, sulfate, chlorine, magnesium and sodium. Because of infiltration losses and accumulation of drainage water in the agro-landscape, the total water supply, both from irrigated lands and from zones of accumulation of overflow waters, is increased. On these low territories, a large quantity of water with low and medium mineralization and also fertilizers, leached by drainage waters, are accumulated. All of this degrades the ecological situation. It causes natural and anthropogenic desertification and active degradation of soils. Water logging is another degradation process, widely occurring on irrigated soils. Irrigation causes a rise of groundwater and increases hydromorphism of soils. It occurs in its strongest form in above flood terraces of the rivers, low places, along channels, in zones of water logging and steadily high groundwater level (0.5–1.5 m), zones of oozing out groundwater on slopes. Usually, the process of water logging in arid conditions is combined with a process of salinization. It increases its negative effect on properties of irrigated soils. It degrades their water -, air - and salinity regimes. In particular, active water logging is shown in accumulation zones of drainage waters, including those outside massive irrigation. Water logging is actively is shown on mountain plains, where the irrigation of higher fields results in water logging of lower territories. In the mountain valley conditions of Tajikistan, water logging of soils is occurring, but without any salinization. The process of desertification is related to the drainage of a territory and the disturbance of a water regime of soils, because of moisture deficit. Frequently, this is a result of regulation of water flow. Desertification occurs when the groundwater level lowers and when underground and surface water is reduced. The regulation of a fluvial flow changes a water regime of the flood land soils and deltas, which results in desertification of the earlier hydromorphic soils. There is also loss of forests and other unfavorable consequences occur. It would be interesting to study the effect of application of some water stocking soil conditioners on the water use efficiency for non-irrigated reforestation, irrigated agriculture and horticulture on these degraded and decertified lands. The processes of water erosion, occurring on irrigated soils, are particularly dangerous on high mountain valleys. A plough up of these territories, to use them in irrigated agriculture, results in active water erosion and disturbance of soil properties. Leaching of salty rocks and irrigation of high plains will activate not only erosion but also salinization of lower soils, because of dissolution of salts in groundwater and water logging of lower territories. The development of grey-brown-stony soils in the lower mountain part of the Gafurov-Kanibadam massif of the Sogd area (50–60 th.ha) has caused the rise of groundwater and salinization of soils on lower fields and, as a result of this, new and additional improvement measures are needed. Nowadays, this process occurs in the Chkalov site of the Gafurov region (10 th. ha).Such a technology of cultivation results in degradation of stony and sandy soils, because of leaching of oozy fragments and nutrients. The main factors, restricting fertility of irrigated lands in the Republic of Tajikistan, are the presence of 22% sandy and stony soils, 16% saline soils, of which 8–10% is subject to wind and water erosion and 10–12% are located on squandered land and subjected to other geodynamic processes. Thus, 50–60% of irrigated lands have unfavorable features, restricting their effective fertility. The second-term salinization is a more perceptible process on irrigated land, which inevitably occurs under hydromorphic and semi-hydromorphic conditions, when the groundwater level rises above a critical level (2.5–3.0 m at mineralization of water 3–5 g/l). Modern salt–accumulation is observed practically always on natural hydromorphic landscapes. Nevertheless, when planning irrigation systems on the common part of irrigated lands, including on initially automorphic soils an irrigational, hydromorphic (semi–hydromorphic) regime was planned and originated. A rise of the groundwater level up to 2.5–3.0 m was expected and, as a result of irrigation, hydromorphic conditions, salt accumulation has taken place.

IAH 2010
Krakow

abstract id: **309**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **Application of disjunctive kriging to nitrate risk assessment in the northern aquifer alluvial system of the river Tagus (Portugal)**

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keywords: nitrates, contamination, probability maps, geostatistics, disjunctive kriging

The Water Framework Directive and its daughter directives recognize the urgent need to adopt specific measures against the contamination of water by individual pollutants or a group of pollutants that present a significant risk to the quality of water. Probability maps that the nitrate concentrations exceed a legal threshold value in any location of the aquifer are used to assess risk of groundwater quality degradation from intensive agricultural activity in aquifers.

In this paper we use Disjunctive Kriging (DK) to map the probability that the Nitrates Directive limit (91/676/EEC) is exceeded for the Nitrate Vulnerable Zone of the River Tagus ALLUVIUM AQUIFER.

Now more than ever there is a need to apply robust statistical methodologies to ensure the proper evaluation of the risk of groundwater contamination through agricultural activities. Of these geostatistical methods, the DK technique is less popular because its application is not straightforward. However this method has considerable advantages over Indicator Kriging (IK) because it uses all the information about the Probability Distribution Function of the variable, whereas IK applies a binarized variable.

An initial exploratory data analysis shows that generally the statistical distributions of NO_3 concentrations are tend to be positively skewed and in some cases highly asymmetric, for the period of the three campaigns on both banks of the Tagus alluvium aquifer.

The variographic analysis of the normalized standard transformed variable reveals an increase in the magnitude of the variogram ranges on the right bank through the three summers which is clearly associated to the increased extent of groundwater contamination areas. These areas with a higher probability of groundwater contamination by nitrates can be explained by inter-annual climate variation and by the used fertilization regime. On the left bank the relation between the increasing of variograms range cannot be assess, since the agricultural areas of the left bank are more heterogeneous than the right bank.

Furthermore, the study reveals that the right bank has more areas with higher probability of nitrates concentrations exceeding the 50 mg/L than the left bank.

The probability maps are very useful tools for the decision-makers, because they can reinforce the implementation of agri-environmental measures in vulnerable areas, so as to ensure good compliance with the Nitrate and Groundwater Directives in the EU zone. They can also be used in the areas of land use planning and for the protection of groundwater for public supply.

abstract id: **316**

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title: **Stochastic modeling of space-time variability of nitrate pollution in the Campina de Faro upper aquifer using indicator geostatistics and transition probability**

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keywords: nitrates, contamination, indicator kriging, transition probability

The Campina de Faro aquifer system, bordering the Ria Formosa lagoon in the south of Portugal, has been largely affected by agricultural practices that have caused nitrate contamination and groundwater salinisation (Stigter et al., 1998, 2006, 2008). Groundwater in the upper aquifer, which consists of Miocene sand and Plio-Quaternary sand and gravel, reveals the highest nitrate concentrations, exceeding 300 mg/l in a diffuse, well-defined contaminant plume. In 1997 the area was designated a nitrate vulnerable zone in compliance with the Nitrates Directive (91/676/EEC), but the monitoring program shows that so far the measures that were implemented to reduce the nitrogen load have not led to an overall lowering of the nitrate levels.

The study of the space-time variability of nitrate diffuse pollution was carried out using advanced geostatistical techniques. The study encompassed the following steps:

1. Several thresholds and indicators of the nitrate were built, and a structural analysis was performed.
2. The indicator structural analysis has shown a phenomenon with gradual variations, i.e. a transition through neighboring values. The fact suggests the use of a diffusion-type model for kriging purposes.
3. Iso-probability contour maps of the nitrate content exceeding a specific threshold value were determined.
4. Transition probabilities in function of the distance, i.e. the probabilities to exceed a specific threshold when entering the domain of a lower threshold, were calculated on the basis of the ratios between the cross-variograms of two indicators and their simple variograms. These transition curves represent the probabilities with which, getting into the domain of the values $\geq Z$, one meets a value $\geq Z'$ (upwards) and the probabilities with which, getting into the domain of the values $< Z'$, one meets a value $< Z$ (downwards).

This methodological approach provides a good image of the spatial correlation patterns where the diffuse phenomenon is well characterized by continuity/non continuity models. The probability maps and transition curves can be particularly useful for water managers and policymakers, allowing the incorporation of uncertainty into the monitoring data.

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abstract id: **327**

topic: **1**
Groundwater quality sustainability

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title: **The evaluation of long-term trends in groundwater pollution with nitrates based on the study of surface water**

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keywords: nitrates, surface water, groundwater, influence of groundwater on surface water quality

INTRODUCTION

Groundwater is a significant component in the balance of rivers and lakes recharge. The results of the research show that the groundwater discharge to the rivers in Poland constitutes about 60% in relation to the surface runoff, with up to 80% in some catchment areas (Jokiel, 1994). These proportions indicate that the quality of surface water is to a large extent affected by groundwater, and the analysis of long-term study of surface water quality may be used in the evaluation of groundwater quality changes. Such an analysis may be conducted taking into account the long-term changes of nitrate content in river water. The source of the above changes may be in particular the groundwater from shallow circulation systems.

The paper presents the evaluation of groundwater pollution with nitrates based on the analysis of their content in the Warta River water in the years 1958–2008.

CHARACTERISTICS OF THE WARTA CATCHMENT TO THE POZNAŃ GAUGING SECTION

The Warta catchment to the Poznań gauging section comprises the area of 25083 km^2 (Fig. 1), that is the upper and middle section of the whole Warta catchment basin. In the upper part of the catchment, the substratum consists of the carbonate Jurassic and partly Cretaceous formations, while the middle part consists of post-glacial formations — sands, gravels and glacial tills.

The area is mainly utilised as arable land occupying over 60% of the whole area. The mean precipitation for the whole Warta catchment basin based on the data from the years 1951–1980 amounted to 561 mm, and in the driest year 1959, it only amounted to 358.5 mm (Pasławski, 1992). The mean discharge (SQ) in the Poznań gauging section amounts to 102 m^3/s and the mean low discharge (SNQ) — to 37 m^3/s.

Figure 1. Catchment of the Warta River to the gauging section in Poznań on the background of the map of Poland.

The total runoff from the catchment to the Poznań gauging section amounts to 3.57 $L/s/km^2$, and the groundwater runoff — to 2.34 $L/s/km^2$ (Pasławski, Koczorowska, 1974). High variability of the groundwater runoff may be observed. The highest values of 3.0–4.5 $L/s/km^2$ may be stated only in the upper part of the catchment, formed on the substratum of karstic carbonate rocks. In the remaining part of the catchment, the groundwater runoffs are low — of 1.5–2.0 $L/s/km^2$. The amount of groundwater runoff in this part of the catchment constitutes 85 to 93% of the mean discharge.

The groundwater from the southern part of the catchment occurs in the fractured and karstic carbonate rocks. In the other part of the catchment, the main role in supplying the surface water is played by shallow groundwater circulation systems connected with the sands of river valleys and sandurs as well as shallow aquifers between the layers of glacjal tills.

THE TREND OF NITRATE INCREASE AND THE EVALUATION OF ITS CAUSES

The graph of nitrate concentrations in the Warta river water at the Poznań gauging section presented in Fig. 2 shows a clear increasing trend.

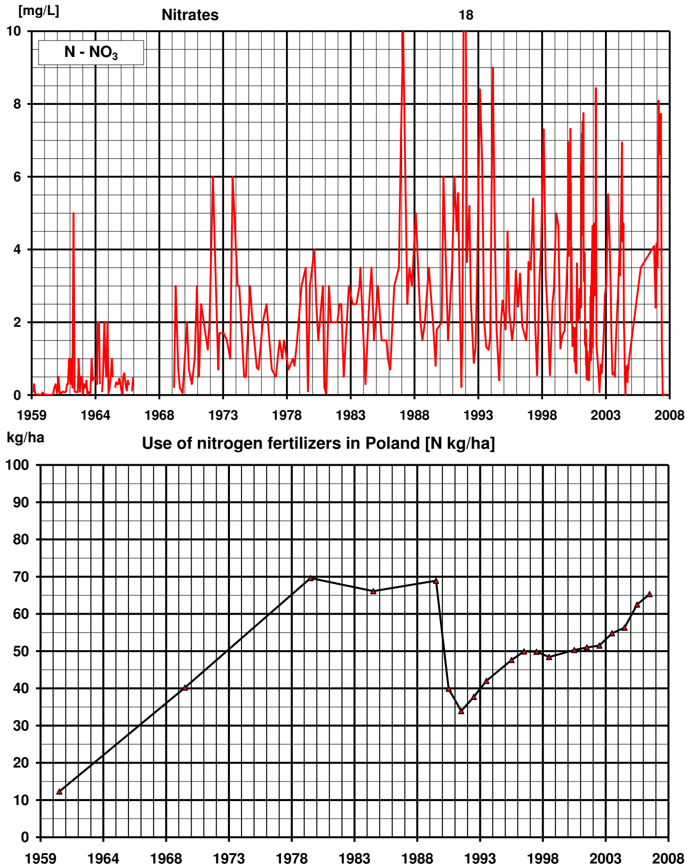

Figure 2. Changes of nitrates in the River Warta water and the use of nitrogen fertilizers in Poland in the years 1959–2008.

The trend is clearly visible regardless of large seasonal and periodical variations. Seasonal variations are connected with the phases of flora and fauna growth in the river. High concentrations only occur in the extra vegetative period, that is in the late autumn, winter and early spring. In the vegetative period, biological absorption of nitrates occurs and their concentration quickly decreases (Fig. 3). Long-term variations, that is the occurrence of particularly high concentrations in some years can be linked to the hydrological and meteorological situation, and especially to the occurrence of longer dry periods.

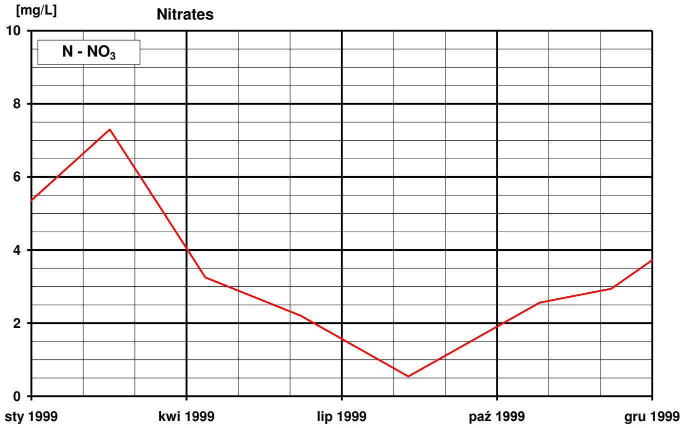

Figure 3. Seasonal changes of nitrate concentrations in the Warta River water.

The reason for the general trend of nitrate increase in river water can be undoubtedly linked to the inflow of more and more polluted groundwater from shallow circulation systems, especially from the agricultural areas. The trend may be noticed in the conditions of progressive lowering of the level of charging the river with sewage and the more frequent application of biogenic removal technology.

This phenomenon is observed in the river water, among other things in the form of systematic decrease in ammonia nitrogene and colour concentrations, which has been presented in Fig. 4. The trend of nitrate increase is clearly correlated with the level of artificial nitrogene fertilizers consumption in Poland (Fig. 2).

The use of fertilizers was low until the early 60s and did not exceed several kgN/ha. Starting from the mid-60s, there was a fast increase in the use of fertilizers which on average amounted to about 70 kgN/ha, reaching up to 100 kgN/ha in the large areas of the investigated catchment.

At the beginning of the 90s, due to the social and economic transformations, there was a decrease in the use of fertilizers to the level of about 35 kgN/ha, which is illustrated by the decrease in the concentrations of nitrates in the years 1995–1998 (Fig. 2). However, the decrease was short-lasting and at present the use of nitrate fertilizers is reaching the level of 70 kgN/ha.

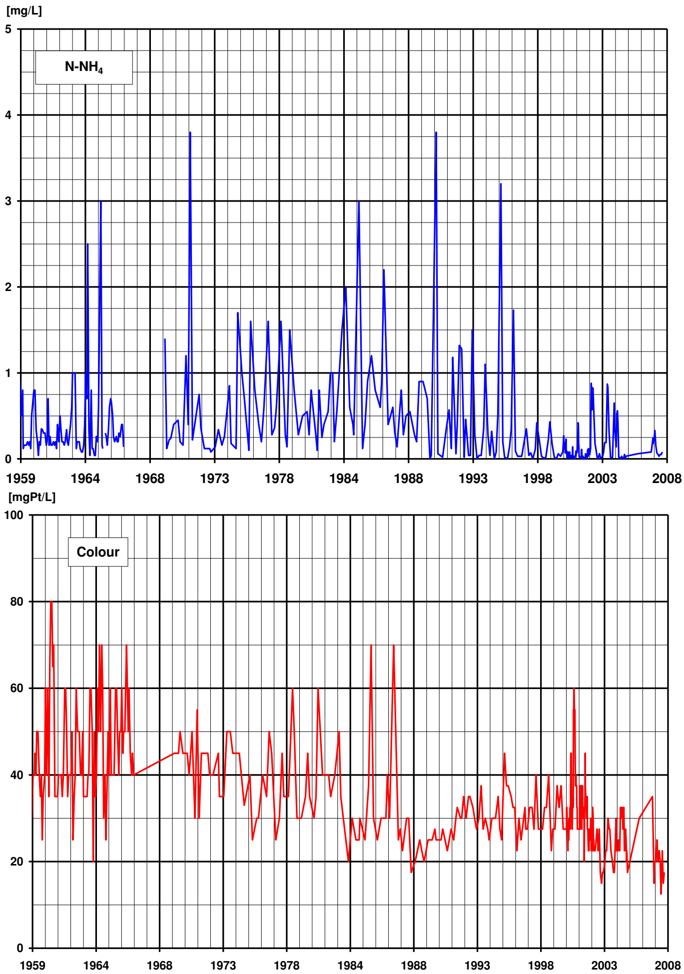

Figure 4. Changes of concentrations of ammonium and colour in the Warta River water in the years 1959–2008.

THE EFFECT OF THE 1989–1992 DROUGHT ON NITRATE CONCENTRATIONS IN RIVER WATER

The analysis of the graph in Fig. 2 indicates the occurrence of particularly high concentrations of nitrates in the years 1992–1994. This phenomenon may be linked to the deep hydrological drought which occurred in Poland, and especially in the Wielkopolska Region and in the Warta River carchment, in the years 1989–1992, which is presented by the comparison of annual precipitation and the Warta River water level (Fig. 5).

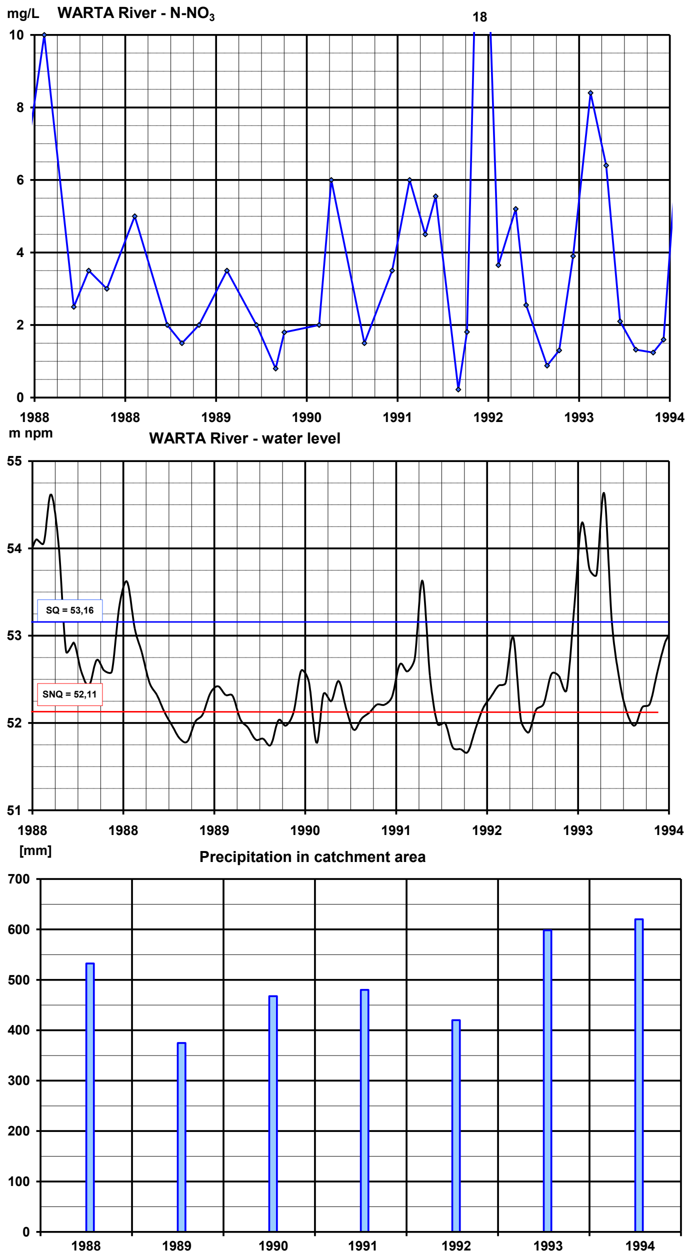

Figure 5. Changes of nitrate concentrations in the Warta River water on the background of river water level fluctuations and precipitation in the catchment area in the years 1988–1994.

During the drought, in the conditions of highly limited infiltration recharge of groundwater, the accumulation of nitrates in soil and aeration zone occurred. After the drought finished, the nitrates were moved to shallow groundwater and next to surface water. This phenomenon was also confirmed by the study of nitrates in groundwater conducted within the network of 8 wells and observation wells in the area of the unconfined aquifer in the Poznań-Warsaw ice marginal valley (Tab. 1). The study revealed a significant increase of nitrates concentrations at the end of 1992, 3 months after the drought finished. The results confirm the phenomenon of nitrate accumulation in the agricultural areas during the drought and explain their high concentrations in the river water after the drought finished.

Table 1. Nitrate concentration in water of chosen wells and observation wells in groundwater recharge area of Mosina well field in different dates.

No of well	Depth of well screen	Nitrates as a N-NO_3 mg/L		
		08.1989	**12.1992**	**09.1993**
2[1]	33.3–46.8	0.02	1.2	0.025
36[1]	24.3–37.8	0.1	1.6	0.03
X[2]	7.5–12.5	0.02	1.2	0.00
8b[2]	17.0–19.0	0.3	2.0	0.00
18b/2[2]	12.0–14.0	0.2	1.4	0.02
47b/1[2]	17.0–19.0	0.04	6.0	1.0
71b[2]	26.2–30.9	0.4	1.4	0.1
6k[2]	7.2–9.2	0.1	1.6	0.015

1 – well, 2 – observation well

SUMMARY

The presented materials prove a great usefulness of the analyses of nitrate content in surface water for the evaluation of the contamination and state trends of changes in groundwater pollution with nitrates. Such evaluation should be an important supplementation of traditional monitoring of groundwater quality. It is also of great educational value in terms of showing interrelations between ground and surface water, as well as the necessity to take crucial action to protect groundwater, which is also essential for the protection of surface water.

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abstract id: **333**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **Assessment of hydrogeochemical processes in a semi-arid region using factor analysis and speciation calculations (Bajo Almanzora, SE Spain)**

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keywords: water quality, semi-arid, alkalinity, factor analysis, nitrate

ABSTRACT

The quality of the water supply of the Bajo Almanzora region for agricultural and domestic uses is mediocre. This region possesses very limited water resources that are variable in time and space, so the water requirement of the population and the agriculture activities has to aid on the use of underground resources.

The main materials that have aquifer behaviour are the quaternary and plio-quaternary conglomerates that fill in the depressions. During December 2004, waters from springs, galleries, wells and boreholes in the study area were sampled. The physical-chemical variability was interpreted in the conceptual framework of the hydrogeology and hydrogeochemistry of the area. Factor analysis and speciation calculations provided evidence of the different hydrogeochemical processes on this area: salinization, precipitation of carbonates, silica dissolution, eutrofization and exchange on clays.

INTRODUCTION

The river basin of the Almanzora River is located in the northern part of the Almeria province. The area of study of this investigation is framed within the Bajo Almanzora region, located to the East of the Almanzora river basin, and covers a surface of 700 km^2 (Fig. 1).

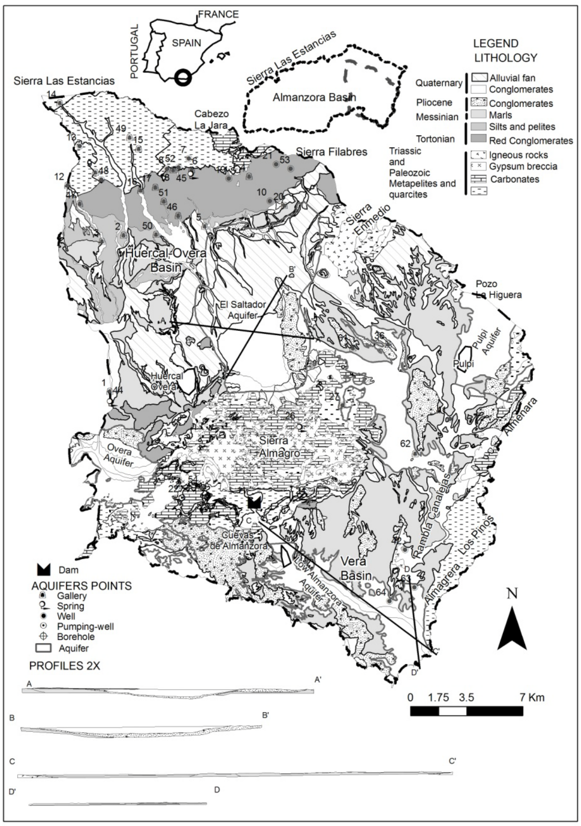

Figure 1. Hydrogeological map of the Bajo Almanzora region.

In a similar way to what occurs in other Mediterranean semi-arid zones, it possess very limited water resources that are variable in time and space and affected by droughts and floods (Martín-Rosales et al., 2007a). The degradation of the quality of the water is a common problem in the Mediterranean region, especially during the summer period (Iglesias et al., 2007). Hidalgo and Cruz-San Julián (2001) determined the main hydrogeochemical reactions that control the composition of the water reserves in a mediterranean detrital aquifer (Guadix-Baza) in an intra-betical basin. The principal aim of the present paper is to identify sources of physical-chemical variability, and to relate them to hydrogeochemical processes defined on the conceptual frame of the hydrogeology and hydrogeochemistry of the area.

The patterns of flow and the aquifer system were studied by sampling the hydrological components for chemical analysis in December of 2004. In order to recognize the patterns in the water quality, hydrogeochemical facies and their spatial distribution were studied aided with a Piper diagram. The study of hydrogeochemical processes that originate the water salinity was aided both in results of factor analysis and of chemical modelling.

STUDY AREA

Hydric resources and demand

Within the study area, the demand of water for domestic supply is 2.7 Mm^3/a. There is an extensive area of irrigated lands, where citruses, vegetables, olive trees, almond trees, and others, are cultivated. The demand for irrigation is estimated to range in between 61 and 88.5 Mm^3/a for the study area. Another point is water demand for animal farming, notably the water consumption of numerous pig farms.

The precipitation presents high inter-annual variability. For the set of the rain gauges of the zone, the value for a typical dry year is 131 mm/a and the value for a typical humid year is 396 mm/a. From thermometry and pluviosity data, it can be deduced that there is a useful volume of water of 20 Mm^3/a, on the average, for the aquifers and aquitards of the Bajo Almanzora region, with a 0.75 variation coefficient. The Almanzora River presents during a typical average year 5.4 Mm^3/a, although, during a typical dry year the run-off can be completely worthless. Two diversions from the Tajo River (14.4 Mm^3/a) and from the Negratín dam (32 Mm^3/a) provide water for agriculture.

Geology and hydrogeology

The study area is located geologically in the eastern part of the Betic Cordillera. It has been differentiated a betic substratum, which emerges at the mountain zones, and a sedimentary filling at the hollow areas (Fig. 1). Superposed tectonic units represent the materials of betic substratum, with micaschists, metapelites and dolomites-limestones members, from bottom to top. At the Sierra of Almagro, the contact between the metapelites and meta-sandstones formations and the carbonated formation folds, and it presents tectonic detachments (Sanz-de-Galdeano and García-Tortosa 2002). In the sedimentary filling, lithology and paleogeography are properly studied (Briend 1990, Mora 1993, Barragán 1997). The Huércal-Overa sedimentary basin is located to the North and to the West of Sierra Almagro, the Vera Basin is located to the Southeast of this mountainous elevation. Towards the end of the Pliocene, deltaic and continental conglomerates were deposited mainly at the Vera basin and the Pulpí Corridor. The

Huércal-Overa sedimentary basin was tilted recently, so that the northern margin was raised, generating several levels of alluvial fans (García-Meléndez et al., 2003). At the southern margin of the Sierra of Estancias carbonated crusts and travertines lay, which have formed during the current period.

The main materials that have aquifer behavior are the quaternary and plio-quaternary conglomerates that fill in the hollow areas. The plio-quaternary conglomerates are conferred heterogeneous transmissivities, normally between 40–75 m^2/day in border areas, and 500–800 m^2/day on the centre of the basins, and storage coefficients of 8-10% or 2-3% in siltier sections (Barragán-Alarcón, 2009). The alluvial materials of the Almanzora river measured between 8000-12000 m^2/day transmissivity; some karstificated carbonates outcrops that are located southeast of the Sierra of Almagro also show very high transmissivities.

At El Saltador, aquifer functions under a semi-confined aquifer regime, affected by the existence of intercalated clay and marl sections. At Overa, a non-confined layer (plio-quaternary conglomerate), well correlated with the Almanzora river flow, overlays a confined layer (tortonian conglomerates), separated by marls on its western half. At Pulpí the aquifer is very depleted of groundwater, the same occurs at the delta of the Almanzora river.

The aquifers at the mountains receive an important part of the recharge due to rainwater, especially at the Cabezo La Jara, which presents the highest elevation on the area. The discharges of these aquifers pour into the detritic aquifers in the depressed areas. All these aquifers are interconnected, working as an aquifer system. The main aquifers are connected by little superficial aquifers (alluvials, fans, plio-quaternary rocks). The interrelations between aquifers have been increasing with the use of irrigation waters of external basins and with the implementation of global management of the underground waters in the area, with the union of the irrigators associations.

METHODOLOGY

For the study of the hydrogeochemical processes, the recharge areas were underlined, because the assessment of them was easier on these ones, and they weren't so affected by overexploitation as the detritic neogene aquifers. The sampling carried out in December 2004 mainly focused on wells and galleries near of the betic substratum, supplied with underground waters of karstic and fractured aquifers (Table 1). A rainwater sample was taken on November 2006, which may be representative of rainwater on winter.

Electrical conductivity (EC), pH, temperature, and redox potential (Eh) were measured *in situ* with a WTW measurement instrument with interchangeable probes, previously calibrated. The alkalinity was measured *in situ* by titration using 1/50 N hydrochloric acid. The samples were filtered at 45 μm and, afterwards, maintained at four degrees until its subsequent analysis. The samples were analyzed searching for major ions, nitrate, and strontium by using HPLC with an ionic chromatograph DIONEX DX-120 at the University of Almería. Silica was measured by photometry at 690 nm with methylene blue after reduction of silicomolybdic acid. The obtained values are presented in Table 2. Isotopic deviations of ^{18}O and ^{2}H were measured with mass spectrometry on some samples in the Zaidín Stable Isotopic Lab of Spanish CSIC. These data were included in Table 2, too.

Table 1. Aquifer points sampled on December of 2004. Some calculated chemical parameters are included, like Balance error (%), dpH, CO_2 (mg/L on equilibrium). Isotopic deviations of ^{18}O and ^{2}H (‰) are included.

ID	Height	Name	Type	Use	Balance	dpH	CO_2	$(N^++K^+)/Cl^-$	$\delta^{18}O$	$\delta^{2}H$
1	305	Almajalejo	Gallery	Irrigation and regulation	-0.8	0.70	0.0520	1.523		
2	596	Las Minas	Gallery	Irrigation and regulation	1.6	0.62	0.0875	1.524		
3	580	La Hoya	Gallery	Irrigation and regulation	-0.6	0.69	0.0937	1.602		
4	709	El Cabezo	Gallery	Irrigation	-0.1	0.83	0.1267	1.377		
5	569	Fuente Nueva	Gallery	Riego	0.0	0.69	0.1578	1.428		
6	785	Zimbra de Erre	Zimbra	Mill	0.5	0.49	0.1647	1.879		
7	835	Erre	Well		-0.6	0.22	0.4880	2.068		
8	815	Fuensanta	Well		-34.8			0.551		
9	847	Los Toscanos	Zimbra		-1.7	0.84	0.0521	2.397	-5.71	-44.67
10	581	Goñar 1	Well		-1.5	1.00	0.0836	1.056	-2.64	-41.92
11	149	Presa	Superficial	Irrigation and regulation	-1.3	0.93	0.0426	1.213	-4.55	-43.04
12	776	La Casica	Zimbra		-2.0	0.70	0.0729	1.746	-6.13	-44.10
13	973	Las Vicarias	Well		0.2	0.25	0.3489	2.100	-6.21	-42.29
14	915	Los Cabrera	Gallery	Irrigation	-0.4	0.74	0.1200	2.047	-6.99	-44.96
15	824	La Pilica	Zimbra		-11.0			2.133	-6.02	-43.50
16	720	Fuente Amarga	Gallery		1.9	0.48	0.1664	1.676	-6.69	-54.06
17	751	Los Rizos	Zimbra		0.1	0.33	0.7921	1.340	-7.37	-45.56
18	782	Fuensanta	Zimbra		0.2	0.61	0.2371	3.235	-6.18	-43.73
19	714	El Almecico	Well		0.6	0.15	0.1635	0.738	-5.48	-39.34
20	518	Goñar	Gallery		0.3	0.68	0.1118	1.133	-6.57	-46.81
21	686	Derramadores Alto	Well		1.3	0.47	0.0929	1.025		
22	260	El Chaupí	Borehole	Supply	-1.5	0.14	0.0328	0.727		
23	308	Variegato	Zimbra		-25.6			1.114	-5.32	-27.89
24	207	Fuente Álamo	Zimbra		1.2	-0.05	0.2257	0.718		
25	519	La Rellana	Spring		1.0	0.20	0.9974	0.767	-5.88	-43.03
26	503	Poza del Pino	Spring		1.7	0.35	0.2954	0.972	-7.44	-45.94
27	378	Rambla de Mahoma	Well		5.1			0.856	-5.29	-23.34
36	250	Los Vizcaínos	Zimbra		-0.6	0.86	0.0580	0.784		
41	134	Canalejas	Well		-0.2	0.26	0.5961	1.051	-5.02	-38.52
42	45	La Mulería	Well	Wheel	-0.7	1.06	0.5533	1.433	-4.43	-32.60
44	290	Almajalejo Spring	Spring	Mill	1.6	0.22	0.6068	1.197		
45	760	Erre	Spring		-0.3	0.81	0.1174	2.011		
46	604	Los Arteros	Zimbra		-2.6	0.78	0.0610	1.348		
47	728	El Purión	Gallery		0.1	0.67	0.0887	1.574		
48	811	Los Toscanos	Well		-0.3	0.60	0.2026	1.785		
49	836	La Seca	Zimbra		-0.1	0.12	0.9312	1.526		
50	563	Algor	Gallery	Irrigation and regulation	0.9	0.60	0.1634	1.862		
51	691	Las Marianas	Zimbra		0.7	0.63	0.1538	1.607		
52	817	Fuensanta-Erre	Well		-1.0	0.37	0.2817	8.340		
53	641	Derramadores Bajo	Well		0.7	0.82	0.0780	1.161		
54	254	El Marqués	Spring		-0.2	0.38	0.3058	0.836		
61	271	Las Avestruces	Zimbra		0.4	0.86	0.0738	0.668		
62	155	La Perlita	Zimbra		2.4	0.23	0.6066	1.394		
63	27	Los Guiraos (Herrerías)	Well		-0.6	0.24	0.1758	1.323		
64	27	Herrerías-	Well		-0.1	0.45	0.2130	0.981		

Table 2. Concentration of major ions and hydrochemical parameters. (Conductivity:mS/cm, temperature: °C, concentrations: mg/L).

ID	EC	pH	TEMP	Eh	Cl	SO4	HCO_3	Na	K	Ca	Mg	Sr	NO_3	SiO_2
1c	1751	8.18	22	413	230.4	351.3	256.2	224.5	5.3	81.2	55.7	1.7	14.9	8.3
2c	1004	8.03	19.5	382	87.2	188.2	280.6	85.1	1.8	81.8	38.6	0.8	24.9	8.7
3c	1293	8.04	20.2	349	124.1	257.3	317.2	127	3.3	93.3	50.9	1	13.4	8.6
4c	1970	7.84	20.8	440	25.4	1004	292.8	21.1	2.7	310.7	120.9	12.3	0.4	14.2
5c	1067	7.93	19.4	341	96.1	131.6	402.6	87.8	2	98.2	40.7	2.2	5.3	13.6
6c	807	7.92	14.6	-31	60.1	60.3	366	72.6	1	66.3	28.8	1	0.3	22.4
7c	794	7.5	13.9	361	48.4	41.7	402.6	64.3	0.9	76.9	27.7	0.9	0.1	10
9c	1431	8.34	15	410	113.9	327.3	312.3	175.1	3.3	80.9	53.7	1.5	28.9	17.7
10c	4280	8.41	13.1	359	1095.5	326.2	617.3	739.6	17.5	99.1	142.6	4.6	4.1	42.2
11c	2520	8.31	9.5	240	280	880	231.8	211.7	14.4	221.3	124.5	6.4	4	0.6
12c	1278	8.13	17.9	380	99.4	254.7	292.8	109.5	5.2	85.6	53.1	0.7	6.6	11.1
13c	1050	7.6	13.7	416	87.9	127.5	366	117.5	3.6	77.7	30.3	1	30.9	25.4
14c	931	8.06	16	458	48.3	154.8	390.4	63.2	1.6	91.6	45.8	1.1	3.2	15.5
16c	1061	7.8	17.7	400	73.5	256.7	305	78.1	3.1	100.1	49.3	2.2	36.7	14.4
17c	1495	7.38	14.2	390	118.7	260.2	524.6	102.9	0.4	146.9	66.8	1.6	0.1	14.9
18c	861	7.89	15.2	378	38.3	22.1	500.2	80.3	0.2	81.6	25.9	1	0	21.9
19c	1448	7.63	14.6	395	153.6	417.2	195.2	67.8	9.8	112.8	89.5	11.1	9.8	11.4
20c	2680	7.9	17.2	397	371.5	671.7	280.6	264.3	14.8	200.3	113.9	9.7	145.4	25
21c	891	8.01	14.5	411	95.5	112	256.2	61.1	4.1	66.5	37.9	3.9	13.2	4.5
22c	514	8.12	18.7	378	85.4	20.6	122	39.1	2	31.7	22.9	1	14.5	9.4
24c	777	7.5	20.1	293	98.3	90.8	207.4	44.2	2.7	51.4	40.4	5	0.4	10.1
25c	3630	7.06	10.8	-10	198.0	1980.9	329.4	96.9	2.8	605.9	203.0		14.1	15.1
26c	2700	7.43	7.8	360	62.9	1677	207.4	34.7	8.5	595.4	89	9.7	0.7	11.6
36c	5250	8.08	18.9	412	1211.5	961.5	250.1	607.9	14.2	264.5	243.5	21.4	67.5	6.8
41c	11510	7.22	12.6	421	2262	3890	341.6	1515	46.4	649	647.1	39.1	100.4	13.6
42c	7630	7.84	20.4	-130	1281.2	1901.2	1451.8	1174.8	26.4	348.7	385.0		20.6	11.5
44c	3160	7.27	18.6	443	540.6	920.0	359.9	414.8	8.3	221.4	120.8	15.0	5.8	
45c	919	8.10	15.1	431	56.6	102.5	398.9	72.6	2.1	96.3	28.2		2.5	4.4
46c	1047	8.34	12.4	358	145.9	49.8	339.2	126.7	1.5	60.5	33.6	1.3	2.9	12.4
47c	1244	8.05	18.8	434	108.6	250.5	298.9	108.5	4	92.1	48.6	1	17.4	5.1
48c	1785	7.9	8.9	386	150.1	404.9	402.6	171.7	3.5	136.7	65.6	1.4	24.8	8.4
49c	1247	7.19	17.4	459	91.5	235.7	414.8	89.3	2.1	120.8	53.8	1.3	4.7	10.4
50c	1137	7.84	19.5	400	71.2	268.3	341.6	83.8	3.6	112.5	50.8	2.3	36	13.2
51c	1044	7.96	15.5	311	82.8	140.7	390.4	85.9	0.8	88.9	40.4	3	0.3	10.6
52c	820	7.74	14.8	315	13.3	102.3	414.8	70.9	1.5	68.2	36.2	1.2	1.5	21.9
53c	1495	8.16	12.3	388	126.7	428.7	311.1	93	4.1	138.4	79.5	8.8	15.9	5.6
54c	929	7.75	8.3	444	88.7	26.4	402.6	46.8	2.3	84.3	41.2	5	0	10.4
61c	5990	8.08	12	442	1628	1036	286.7	698.9	10.3	313.9	326.6	28.1	98.5	17.8
62c	8160	7.16	21.1	452	1698	2086	317.2	1499	61.1	348.3	143.5	6.8	262.4	10.8
63c	5540	7.58	16.5	381	944.7	1762	219.6	795.3	25.5	233.5	262.8	6.1	51.5	6.4
64c	3630	7.58	16.4	419	602.5	1111	256.2	368.5	25.3	302.8	161	7.7	38.9	6.9
Pe	328	7.91	19.4		38.2	56.5	48.4	33.3	1.6	19.1	9.4	7.2		1.1

The hydrogeochemical facies were assigned based on Piper diagram. Factor analysis was used to synthesize the largest possible portion of physical-chemical variability on uncorrelated factors. Factor analysis is commonly used in hydrogeochemical studies. Glynn and Plummer (2005) criticized the use of factor analysis to assess the degree of conservative mixing between end-member solutions compositions, while ignoring the reactions that could cause the precipitation/dissolution of the elements.

The data matrix doesn't adjust to the multivariate normal distribution; thus, the optimal conditions for the application of the factor analysis are not fulfilled. Dreher (2003) advise not to use log-transformations because they modify ionic ratios. To add more complexity to this, some variables are near logarithmic (like chlorine), others are near normal (like bicarbonate), and others don't fit any distribution properly (like Eh). The chosen method of factor analysis is PCA. It is a widely extended erroneous practice to apply Varimax rotation when the aim is to study observation values for the different samples. It was preferred not to apply any rotation to preserve the orthogonality of the vectors of loadings, and at the same time, to preserve the uncorrelation of the scores (Jolliffe 1995). Maps of the scores of the factors were obtained.

To reinforce the hydrogeochemical knowledge, saturation indexes of some mineral phases and dominant phase diagrams were calculated with PHREEQC v2.0 and WATEQF.

RESULTS AND DISCUSSION

Hydrogeological model

Water descends from the Sierra of Estancias and pours into the Saltador aquifer. One net of parallel streams, following a direction SE from the sierra between 1000 and 600 m a.s.l, with slopes of 10–15%. It's expected that these streams download an average of 3–3.5 Mm^3/a. At Sierra Almagro, waters keep stored in carbonated and evaporitic aquifers, and just in a small portion (1-1.5 Mm^3/a as an average) pour into the Saltador aquifer by the N (<400 m a.s.l.) and towards Pulpí corridor to the E (<300 m a.s.l.). To the South the ramblas that descend to the alluvial of Almanzora river (<200 m a.s.l.) pour very little water.

Waters transferred from Negratín and from Tajo-Segura are distributed at Saltador, at Overa, at Pulpí and at Cuevas. The waters of Palomares desalination plant are used to irrigate (3–4 Mm^3/a) on the Almanzora river alluvial and on quaternary deposits on Pulpí corridor. The global management of the aquifer system trends to buffer excessive exploitation of the aquifers effects, distributing the weights of extractions to less over-exploited aquifers. Recently, the drawdowns were near constants at El Saltador, between 3–3.5 m/a, although at borehole 33 were higher, near to 8 m/a. On September 2006 the piezometric level was at 203–209 m a.s.l. on the centre of the depression. On Pulpí aquifer a minimum piezometric level was reached on January of 2005 at 204–209 m a.s.l. on the centre of the depression.

Water classification

High electrical conductivity gradients (EC) are observed in ramblas to the North (>1mS/cm/km) and to the South of the Sierra Almagro (1.8 mS/cm/km in April 2007), that denote the importance of the processes of saline dissolution at these ramblas. This dissolution relates to two causes: the first one is the entry of waters that flow in contact with marine pliocene marls; the second one, waters returning after its use in irrigation, that come highly contaminated with agricultural wastes. The points with the highest EC are located at the Bajo Almanzora aquifer and at the Canalejas rambla.

In Fig. 2A, the collected samples are represented on Piper diagrams. An important group of bicarbonated waters is observed: 6, 7, 8, 13, 14, 15, 17, 18, 21, 23, 45, 51, 52, the majority of them with calcium-magnesium composition. Generally they distribute spatially linked to phyllites, micaschists and limestones, the same as to clayey sections where the surface of contact water-rock is large. On the southern flank of Sierra de Las Estancias it can be observed that lots of points corresponds to this class. Other classes of sulphatated waters at points 11, 19, 25, 26, 27, 41, 63 y 64, of calcic-magnesic composition, are affected by gypsum dissolution and evaporitic salts on the betic substrate and on tertiary deposits. Just on two cases chlorinated waters were found (10, 36), that were linked to evaporation affection. Anyway, water progressively assimilates chlorine and reach very high absolute concentrations.

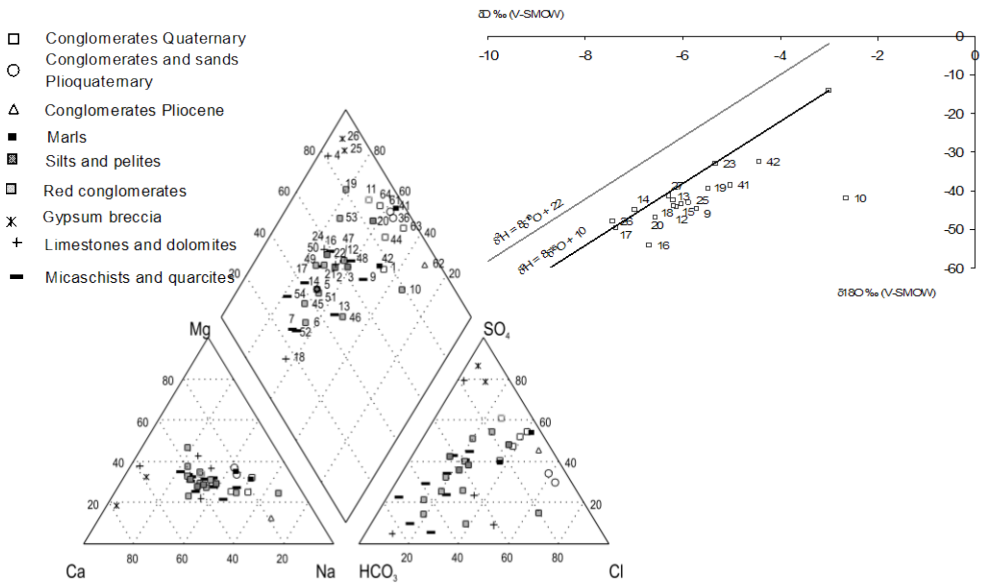

Figure 2. Piper Diagrams for the sampling period (A) and isotopic deviations on the sampled waters (B).

The majority of waters are calcic-magnesic but calcic waters are frequent, too: 25, 26, 4, 8 on gypsum and carbonates, or sodic waters on tertiary deposits and recent conglomerates: 1, 10, 42, 46, 62, 63. Rainwater may present sodic composition, too.

Isotopic deviations permit to figure out the degree of fractionation due to evaporation. Unfortunately there are no rainwater data in this area. All the ground waters are isotopically enriched in relation to a line representing the original rainwater (Fig. 2B). Well 10 presents the higher $\delta^{18}O$, which is registered as the higher degree of evaporation.

Factor analysis

The vectors of loadings are tabulated in Table 3. Factor 1 is related to EC, sulphate and chloride, it characterizes the influence of sulphatated and chlorinated salts in the waters, and of its draining by ramblas in sub-superficial fluxes. This factor explains 53.2% of the variability. Factor 2 is related on the shallow sections to bicarbonate and silica and inversely to temperature and Eh. It characterizes higher dissolution of limestones in underground waters of higher CO_2 content, deep thermal samples were not considered in the sampling or data matrix. It is related, too, with higher silica dissolution, at high pH waters. This factor explains 12.6 % of the variability.

Factor 3 includes nitrate, temperature and Eh versus calcium; it differentiates an organic contribution in superficial environments.

Table 3. Vectors of loadings for the factor analysis.

		Temp	CE	Eh	pH	Cl	SO_4	HCO_3	Na	K	Ca	Mg	Sr	NO_3	SiO_2	% Var
Dec 2004	F1	-0.05	0.99	0.28	-0.42	0.94	0.95	-0.15	0.93	0.9	0.84	0.91	0.83	0.73	-0.02	53.2
	F2	0.42	-0.09	0.23	-0.1	-0.16	0.09	-0.85	-0.15	0.03	0.07	-0.08	-0.01	0.09	-0.85	12.6
	F3	-0.74	-0.02	-0.29	0.08	-0.09	0.17	-0.19	-0.23	-0.24	0.34	0.23	0.33	-0.48	-0.25	9.95
	F4	0.19	0.08	-0.39	0.78	0.19	-0.07	-0.28	0.11	0	-0.18	0.12	0.14	0.05	0.08	7.2

Maps of the scores are presented in Fig. 3. For factor 1, the points that higher scores reached are points 41, 62 and 61, generally the factor increases in the flow path and on the top of marly deposits. Factor 2 finds a minimum at point 10, followed by 6, 52, 18 y 17; all of them are located to the South and Southwest of the Cabezo La Jara, respectively, near sub-actual deposits of travertines and calcretes which cover the apex of the fans. For factor 3, there is a minimum at point 62, followed by 20, 10, 1 and 50; all of them locate at ramblas that present high vulnerability to nitrate pollution. Intensive agriculture, pasturing and growth of almond trees in plowed fields favor this vulnerability.

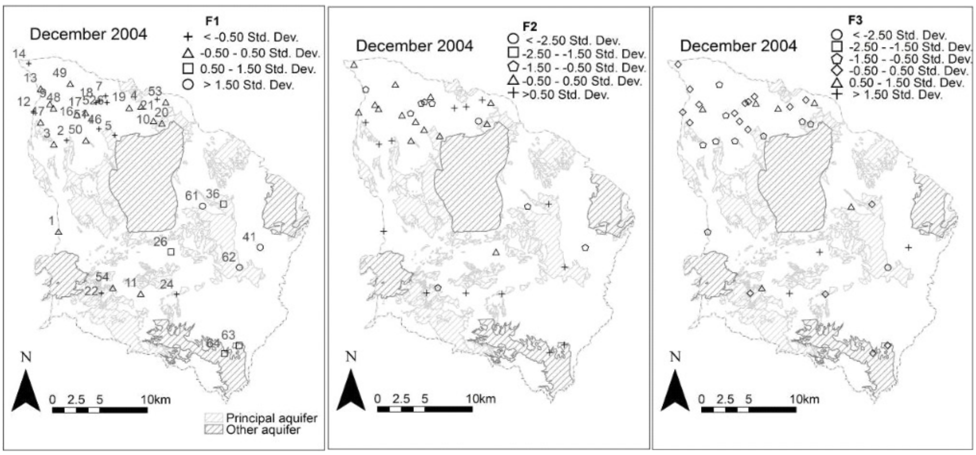

Figure 3. Maps of the scores of the factor analysis on the three factors.

Speciation and hydrogeochemical processes

In Fig. 4 the saturation indexes of calcite, dolomite, strontianite, CO_2, gypsum and quartz are plotted. Halite is always sub-saturated in waters at Bajo Almanzora region. Gypsum usually presents light sub-saturation. Dolomite is always saturated, except in the rainwater sample which has a SI = -1.88. The importance of this rainwater chemistry implies that dedolomitization is a constant in the surface. Gypsum is always under-saturated, except at 41 (SI= 0.06, in a rambla environment at Pulpí corridor) or at 25 and 26 (on evaporitic gypsum). Quartz SI is a bit higher (+0.45) than chalcedony SI; waters over-saturated in quartz are still under-saturated in chalcedony. The high pH values at dolomite-limestone aquifers could have been a factor enhancing silica solubility according to the observations of Knauss and Wolery (1988). The saturation indexes of calcite depict the ability of the waters to precipitate carbonates presenting samples 42, 10, 45 and 11 $SI_{calcite}$>1.

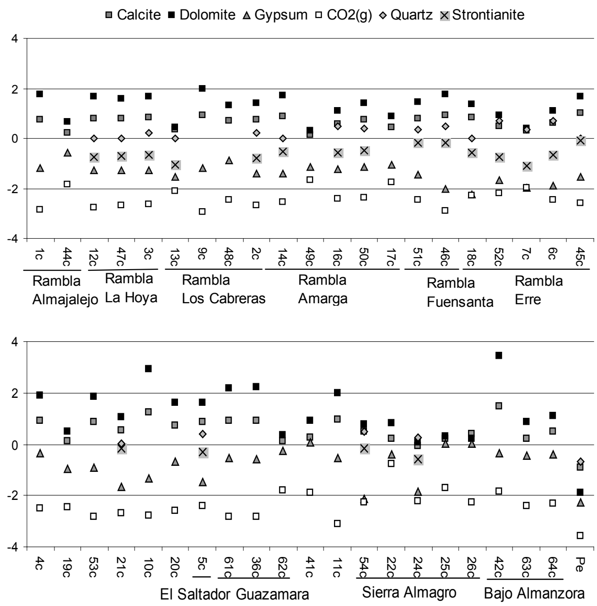

Figure 4. Saturation indexes in some species for the waters of the Low Almanzora region.

Another hydrogeochemical process of considerable importance in the area is cationic exchange. This process is more difficult of quantify considering exchange constant, but can be identified by the low $(Na^{+}+K^{+})/Cl^{-}$ ratios, in meq/L, that are lower than 1 in one of every three points sampled.

CONCLUSIONS

Factor analysis can be used to identify sources of physical-chemical variability, and to relate them to hydrogeochemical processes. Salinization, carbonate dissolution and eutrofization are the most underlined processes in the Bajo Almanzora ground waters. Sodification of soils and clayey sections is a normal process. Good Agricultural Practices have not been sufficiently implemented, and there is a generalized contamination due to nitrates and fertilizers. The kind of contamination is incremented in highly saline regions, such as the Bajo Almanzora aquifer or the Pulpí corridor, since high salinity hinders denitrification. The possible incorporation of the Bajo Almanzora water mass within the registry of Specially Protected Areas under the Nitrate Directive of the European Community can be proposed as a restoration measure.

ACKNOWLEDGEMENTS

The activities and tasks that are related in this paper was performed using funds from a FPU *(Education for University Professors)* scholarship of the Ministry of Education and Science, its reference code is AP2003-0214. This communication was prepared within the framework of the activities developed by the RNM-189 research group “Hydrical Resources and Environmental Geology” of the University of Almería. Zaidín Stable Isotopic Lab performed the isotopes analysis in the frame of its collaboration with the research group.

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abstract id: **336**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **Evaluation and interpretation of groundwater phosphorus and nitrate monitoring data and the implications for groundwater management in Ireland**

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keywords: groundwater quality, phosphorus, karst, Water Framework Directive, nitrate

As in many European countries, eutrophication is the principal threat to surface water quality in Ireland. In some situations, groundwater represents a significant pathway for nutrient transport to surface water. Phosphorus is usually the limiting nutrient responsible for eutrophication in freshwater bodies, with nitrate generally being more important in estuarine and coastal waters. Although much research has been carried out internationally on nitrate contamination of groundwater, there is less recognition of phosphorus as a groundwater contaminant. This paper illustrates how phosphorus, as well as nitrate, can be responsible for groundwater bodies being classified as having poor status under the European Union Water Framework Directive (WFD).

In the interim water quality status assessments, carried out for the WFD in 2008, 43 per cent of river water bodies in Ireland were classified as having less than good status. A significant proportion of river water body monitoring points, 28 per cent, were classified as being less than good status due to phosphorus enrichment. In many instances phosphorus transfer to surface water is mainly via surface or near-surface pathways, but in some instances groundwater can be a significant contributor. The transfer of ecologically significant quantities of phosphorus has been established in the western Irish limestone lowlands, where generally only thin soils and subsoils overlie conduit-dominated karst aquifers, providing little opportunity for phosphorus attenuation. In addition, in this karst region, groundwater often provides the majority of surface water flow, and therefore the contribution of phosphorus to surface water can be important. In Ireland, 15% of groundwater bodies were classified as having poor chemical status, and in 93% of these (mainly in the limestone karst dominated geology of the west of Ireland) this classification was due to the potential deterioration of surface water quality by phosphorus from groundwater.

Very few Irish groundwater bodies (less than 1%) were classified as poor status due to exceedance of the drinking water threshold for nitrate, but 16% of groundwater bodies are at risk due to the potential deterioration of associated surface water quality by nitrate from groundwaters. 41% of Irish estuarine and coastal water bodies (12.8 per cent by area) were classified as having less than good status, as assessed using multiple biological elements for the WFD. Elevated nitrate concentrations in the southeast and southwest of Ireland provide significant nutrient loading from groundwater to some of these transitional and coastal waters.

abstract id: **339**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **PESTO, a risk assessment of pesticide use on groundwater quality in the Chalk aquifer in the province of Limburg, the Netherlands**

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keywords: pesticides, fate and transport, groundwater, chalk aquifer

INTRODUCTION

The use of pesticides has affected the groundwater quality within the catchment area of the River Meuse. The presence of pesticides in this catchment forms a potential risk for achieving the objectives of the European Water Framework Directive, in particular concerning the targets that have been set for groundwater destined for human consumption. The authorities of the Province of Limburg, the Netherlands, and the drinking water company of Limburg (WML) therefore instructed Witteveen+Bos, in cooperation with CLM Research and Advice and KWR Watercycle Research Institute, to investigate the fate and transport of pesticides in the Chalk aquifer of Limburg, the Netherlands, for seven drinking water production sites. Aim of the study was to assist in the identification and implementation of measures to reduce the risk of pesticide use on public water supply.

PESTICIDES IN THE MEUSE CATCHMENT

Pesticides have been detected at significant concentrations in the groundwater of the Dutch part of the catchment area of the River Meuse during several sampling surveys. A survey by Haskoning (2008) revealed concentrations of atrazin ranging between 0 µg/l en 0.29 µg/l; bentazon concentrations of 0.1 and 2.6 µg/l; and dichloorbenzamide (BAM) of up to 0,6 µg/l. Other detected pesticides were diuron (up to 0.05 µg/l); glyfosaat (up to 0.2 µg/l) and simazin (up to 0.16 µg/l). These pesticides were detected in groundwater samples taken from springs and groundwater abstraction boreholes. A similar survey undertaken by KIWA in 2001 showed pesticide concentrations of bentazon of 0.04 µg/l; Mecoprop, or methylchlorophenoxypropionic acid MCPP of 0.03 µg/l and 0.04 µg/l; BAM varying between 0.01 µg/l and 0.17 µg/l; desethylatrazin 0.01µg/l; desethylsimazine 0.02 µg/l and isoproturon of 0.01 µg/l (Witteveen+Bos, 2003).

RISK ASSESSMENT METHOD

Given the observed pesticides in spring water and boreholes, it was thought that the use of pesticides would form a risk to the groundwater quality in the Chalk aquifer. In addition, it was also expected that concentrations of pesticides would rise in the future and the main research question therefore was not “if” but “when” the groundwater quality would deteriorate.

To quantify the effect of pesticide use on groundwater quality, a risk assessment was undertaken using fate and transport characteristics of pesticides and information on the hydrogeological system. For this risk assessment the source-path-receptor concept was used. In this model, the risk of a (contaminant) source is assessed by identifying linkages (pathways) to a receptor. If one of these three (source, path, receptor) is not present there is no risk. The conceptual model we used is presented by a schematic cross section (Figure 2). In our application of this conceptual model, the contaminant source is the pesticides use, the path is the unsaturated and saturated flow of the water through the subsoil, and the receptor is the drinking water abstraction borehole (Figure 1).

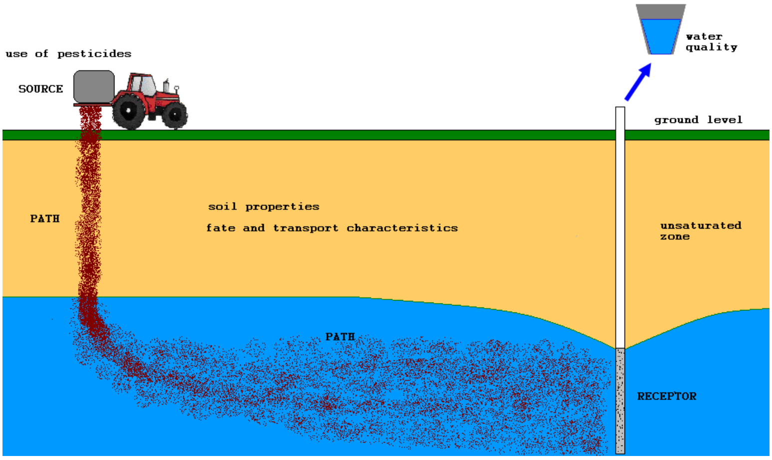

Figure 1. Schematic presentation of the conceptual model.

We calculated transport in the saturated zone using Van Genuchten and Alves, (1982) which is presented in detail by http://www.lmnoeng.com. This calculation simulates one-dimensional (flow line) transport of a chemical in a confined groundwater aquifer and is also valid for transport in an unconfined aquifer if the head gradient is nearly constant, which we assumed is the case in Limburg. The calculation includes advection, dispersion, and retardation. Decay of the pesticides was included by reducing the calculated concentration with a simple half-life equation. An example of the resulting concentration-distance graph for bentazon is presented in Figure 2.

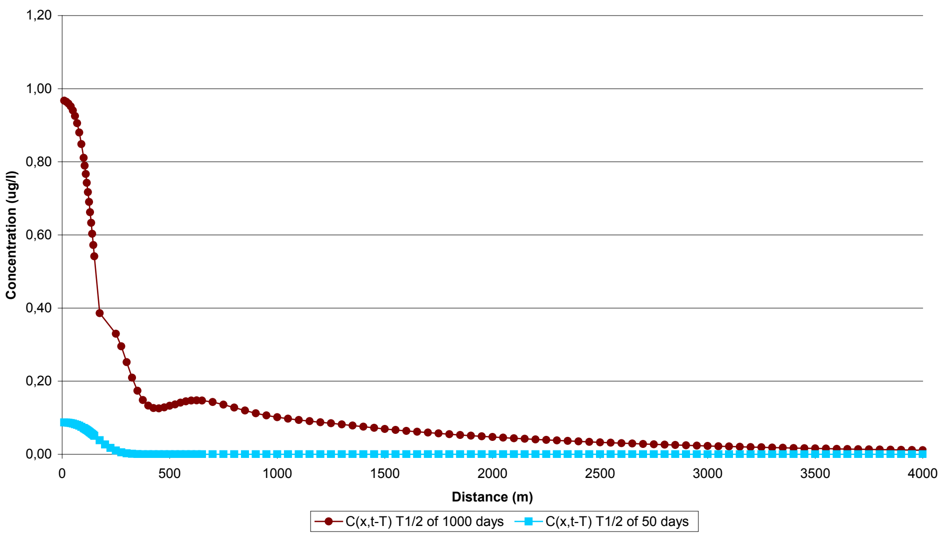

Figure 2. Calculated concentration of bentazon along a flow path.

By combining the results for both saturated and unsaturated flow we calculated "risk circles" which were defined as the circle in which the use of pesticides could affect the quality of the abstracted water. The radius of this circle represents the distance required to reduce the concentration of the pesticide to 0,1 µg/l (Figure 2).

RESULTS AND DISCUSSION

As information on site specific transport characteristics of the subsurface was limited, we used a range of input parameters to calculate maximum and minimum radius risk circles (Figure 2). For all pesticides, the calculated minimum was very small, indicating that the use of pesticides does not pose a risk to the groundwater quality. For some pesticides, however, the maximum radius was large enough to pose a (theoretical) risk to the groundwater quality. However, we judged that the chemical and physical characteristics used to calculate these maximum radius risk circles were most likely too conservative, thus exaggerating the actual risk.

The risk assessment thus indicated that the risk for contamination of water abstraction wells in the Chalk area of the Netherlands is small, due to attenuation and decay of pesticides. In comparison with other regions of the Netherlands, the processes in the unsaturated zone are especially important in the Chalk region, as the unsaturated zone reaches much deeper. The risk is further reduced by an extensive protective cover of loess and flint deposits, overlaying the Chalk aquifer. In these loess deposits the water recharge system mechanisms are dominated by gravitational flows. Brouyere et al. (2004) conclude that in a similar case in Belgium, where chalk is also covered by a layer of loess and conglomerate, the water infiltration rate at the top of the unsaturated chalk is strongly attenuated compared to the actual recharge at the ground surface.

The findings of our study were confirmed by research undertaken in the Chalk areas of the United Kingdom. For instance, Chilton et al. (2005) concluded that the 'time bomb' scenario does not apply for pesticides as it does for nitrate. In their study, only low pesticide concentrations have been consistently observed at the water table, and there is no evidence of a cumulative rise in concentrations of specific compounds. Further dilution is likely within the saturated zone pathway to water supply sources and other receptors. Chilton et al. (2005) therefore concluded that it is unlikely that regular agricultural usage of pesticides in the UK would produce gradually rising concentrations of specific compounds in drinking water supplies.

A detailed reanalyses of all available data in the Chalk area of the Netherlands, showed that the pesticides presented in paragraph 2 were only detected in samples taken from shallow boreholes or springs. No pesticides were detected in any of the deep groundwater samples taken from the Chalk Aquifer, which confirms our findings that risk for contamination of water abstraction wells in this area is limited. In the past, pesticides were detected in the deep groundwater, but since more strict legislation has stopped the use of a number of these persistent pesticides.

CONCLUSIONS

A qualitative risk assessment, in combination with reanalyses of measured data and a literature review, was undertaken to estimate the risk for pesticide contamination of drinking water abstraction wells. It is concluded that the use of pesticides is not likely to pose a risk to the deep groundwater in the Chalk aquifer of the Netherlands, as long as the pesticides are used according to current rules and regulations. During the next stage of the project, a field measurement campaign will be undertaken to confirm these conclusions.

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abstract id: **350**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **Groundwater salinisation of the agricultural plains located in the Northeastern Mediterranean region of Morocco**

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keywords: agricultural plains, Mediterranean sea, aquifers, salinisation, nitrates

INTRODUCTION

The north oriental Mediterranean coast of Morocco (Figure 1) is characterized by the juxtaposition of small plains, Triffa, Saïdia, Gareb, Bou-Arreg and Kerte, localized between the mounts of Beni Snassen and Gourougou at the south and the Mediterranean sea at the north. The rainfall is weak, with an average of 245 mm/year in the plains. It can reach 300 mm/year nearby the Mediterranean sea and 500 mm/year on the mountains. The variation and the scarcity of the rainfall and the geological nature of the lands cause a big variability of groundwater and surface water resources between the Mediterranean and Atlantic sides of Morocco. The Mediterranean coast (500 km long) is indeed characterised by smaller aquifers and shorter rivers than the ones of the Atlantic coast (3000 km long).

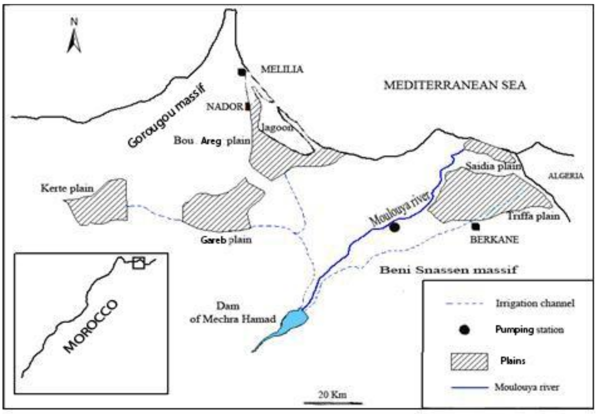

Figure 1. Location of the study area.

The groundwater is widely used for irrigation and drinking water supply. Two dams, located in the massif of Beni Snassen, are used for the irrigation of 60000 ha in the plains of Triffa, Bou-Areg and Kerte.

The exploited Plioquaternary aquifers, formed of detritical deposits of Quaternary age resting on a marly substratum of Mio-Pliocene age (Carlier,1971), show medium to good hydraulic potentialities. However, they are affected by problems of salinity and nitrates contamination.

CLIMATIC DATA AND SURFACE RUNOFF

Tens of pluviometric stations are installed in the plains and the reliefs of Beni Snassen and Gourougous. The rainfall average values are 250 mm/year in the plains and 500 mm/year in the mounts. The evolution of rainfall over a period of 70 years in the Triffa plain shows a big variability. The highest and lowest recorded values are respectively 800 mm in 1962 and 120 mm in 1965.

From west to the east, the study region is crossed by the following rivers: Kiss, Moulouya, Selouane, Kerte and Nakor. The Moulouya is the biggest river; it is 600 km long and brings about 900 millions of m^3/year as average flow. Its watershed is located in the High and Middle Atlas, contrary to the other rivers of the study region, coming from the Rif reliefs. Two dams are installed on the Moulouya river, with a capacity of 410 million of m^3. These dams play an important role in drinking water supply for the cities of Berkane, Zaïo and Nador as well as in the irrigation of the perimeter of the Bas-Moulouya (Triffa, Bou-Areg, and Gareb) with an area of 60,000 ha.

GEOLOGY AND HYDROGEOLOGY

The majority of the plains are generally filled of quaternary deposits constituted by alluvions and silts (Figure 2), resting on a marly substratum of Mio-Pliocene age.

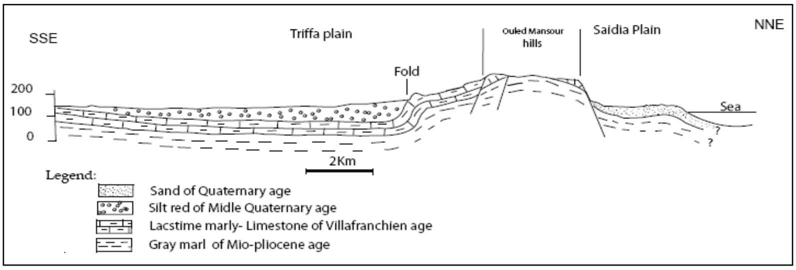

Figure 2. Geological cross section of Triffa and Saidia plains.

The groundwater constitutes an important component of the water resources system. It presents, in comparison with the surface water, the advantage of its regularity and its low costs of mobilization. Two main aquifers are targeted: the superficial aquifer and the deep aquifer which is exploited only at the margins of the plains, near the mountains.

The aquifers of the plains of Kerte, Gareb, Bou-Areg and Triffa generally have good hydraulic potentialities, thanks to the predominance of silts with conglomerate deposits. The pumping tests show transmissivities ranging from $3 \cdot 10^{-2}$ m^2/s to $4 \cdot 10^{-5}$ m^2/s. The low values are related to the marly limestone of the north part of the Triffa plain and the silts of Gareb (El Mandour, 1998).

HYDROCHEMISTRY, SALINISATION AND POLLUTION

The analyses of the hydrochemical data concern 250 samples taken from wells, boreholes and springs of the concerned aquifers. The electrical conductivity varies from 1.3 ms/cm to 55 ms/cm and the values of nitrates from 1 mg/l to 160 mg/l. In spite of the variation in the salinity, the groundwaters present similar chemical facies and are characterized, up to 90% of the samples, by a sodium-chloride water type. A good correlation exits between the electric conductivity and the contents in chloride and sodium.

The degree of salinity measured in the plains is very different (Tab. 1). The coastal plains of Saidia and Bou-Areg are affected by a salinisation related to the seawater intrusion (El Mandour and al., 2008; El Yaouti and al., 2009) and also by ion exchange between the groundwater and the salty marl and gypsiferous deposits of the Mio-Pliocene and Messinean, forming the aquifer's substratum. The continental plains of Triffa, Gareb and Kerte are also affected by a salinisation but less important than the coastal plains. The origin of this salinity is on the one hand the infiltration of the evaporated irrigation water and on the other hand the ion exchange with the Mio-Pliocene and Messinean deposits of the substratum.

Table 1. Chemical variation of groundwater.

	Saïdia			Triffa			Bou Arreg			Kerte			Gareb		
	Min	**Max**	**Moy.**	**Min**	**Max**	**Moy.**	**Min**	**Max**	**Moy.**	**Min**	**Max**	**Moy.**	**Min**	**Max**	**Moy.**
C.E. (mS/cm)	1.60	55.20	13.80	1	13.39	4.1	2.55	21	6.79	1.08	12.3	5.15	1.5	20.1	6.5
pH	7.3	9.6	8.24	7.05	8.5	7.3	7.3	8.5	7.8	6.23	7.7	7.15	6.5	7.6	7.12
Cl^- (mg/l)	319	21396	4727	97	4180	984	448	7797	1828	109	3389	1037	1477	7990	4733
SO_4^{2-}(mg/l)	19	1117	433	57.3	756	336	76	1473	795	69	2029	894	68.5	1288	678
HCO_3^-(mg/l)	244	1830	539	129	488	290	25	854	544	183	1329	400	229	456	342
Ca^{2+}(mg/l)	25	892	255	90	676	205	32	649	180	80	581	319	101	537	320
Mg^{2+}(mg/l)	62	1798	388	16.7	477	154	20	797	142	22	464	136	59	580	319
Na^+(mg/l)	166	12420	2564	144	1334	420	400	3000	1237	40	2500	651	116	3583	850
K^+(mg/l)	10	469	117	8	25	12	7	250	29	1	18	5	7	39	23
NO^{3-}(mg/l)				4	151	65	0.4	95	34	1	145	17	0.5	88	45

The groundwater of Triffa and Saidia plains shows in addition a stratification of the mineralization (Figure 3 and 4) (El Mandour 1998 and El Mandour and al., 2008). The measurements of electric resistivities in the saturated zone of the wells and boreholes of the plain of Triffa (Figure 3) and the application of the Stuyfzand classification (1986) on the waters of the plain of Saidia, (Figure 4) show an increase of the salinisation from the top to the bottom of the aquifers. Concerning the aquifer of Saidia, the existence of a paleo-salinity has been advanced to explain the brines encountered in the Southern limit of the aquifer.

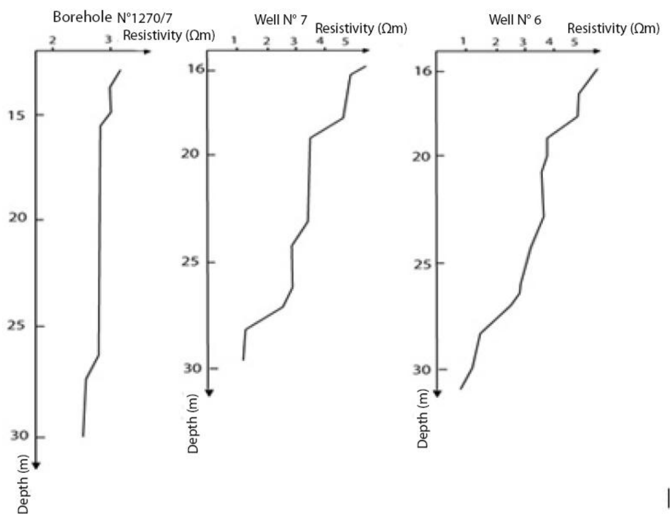

Figure 3. Electric resistivities in the saturated zone of the wells and boreholes.

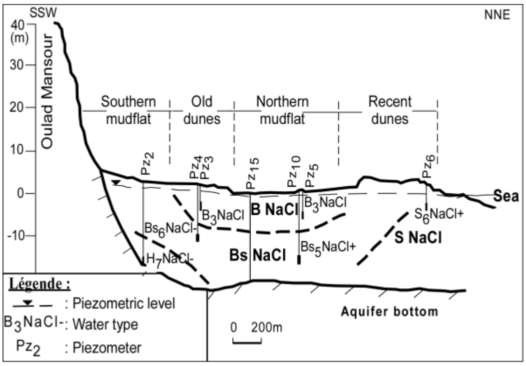

Figure 4. Vertical distribution of hydrochemical water types.

On another hand, the high levels of nitrates (up to 150 mg/l) in the groundwater of the plains of Triffa (Figure 5), Bou Areg and Kerte, indicate the existence of a heavy agricultural pollution.

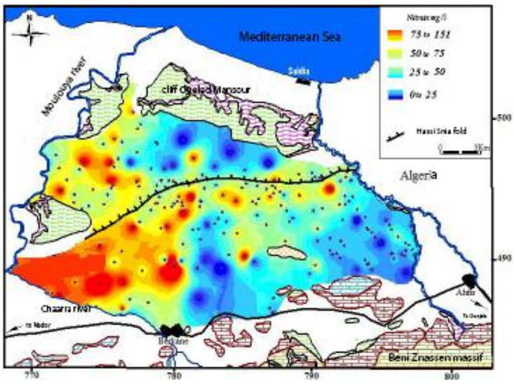

Figure 5. Map of distribution of nitrates in Triffa plain.

CONCLUSION

The sustainable management of Machrar Hamadi dam supplying presently the plains of irrigation water, would contribute to reduce the salinisation of the aquifers.

The construction of new dams on the tributaries of Moulouya river (Cherra and Agbal on the right bank and Kerte on the left bank) will reduce the use of the groundwater and will enhance the aquifers recharge and improve their quality. This should be accompanied by the use of water saving techniques of irrigation, such as drip irrigation which is still not widespread in the study area.

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abstract id: **362**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **Integration of aquifer and wellhead protection in agricultural areas: a case study in the Piemonte region (NW Italy)**

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keywords: groundwater protection zones, WHPA, FEFLOW, vulnerability, Italy

INTRODUCTION

Valuable land management policies reducing the groundwater pollution hazard typically adopt two approaches, aquifer protection and wellhead protection that have to be combined in a suitable way (U.S. EPA, 1991; Foster et al., 2002).

A key factor influencing the hazard posed by a certain land-use activity to a groundwater supply (well or spring) is its proximity. In order to eliminate completely the risk of unacceptable pollution of a supply source all potential polluting activities would have to be prohibited of fully controlled within its entire recharge capture area. This will often be unsustainable or uneconomic especially in developed areas with pre-existing land use constraints. Thus, some division of the recharge zone is required, so that the most stringent land use restrictions will only be applied in areas closer to the source (Barry et al., 2009).

Such an area is referred to as the wellhead protection area (WHPA). The zone of travel can be described as an isochrone indicating the transfer time — time of travel (TOT) — necessary for water or a conservative contaminant to reach the well from that location. The TOT will depend on the pumping rates and the aquifer characteristics such as transmissivity, hydraulic gradient, porosity and aquifer thickness. It has to be noted that the level of aquifer vulnerability should address the selection of TOT identifying the WHPAs. In fact, water wells exploiting low vulnerable aquifers can be protected by limited WHPAs (low TOT values) without any significant prejudice for the protection of drinking water and human health. On the opposite wells exploiting vulnerable aquifers requires extended WHPAs (high TOT) to ensure adequate safeguard for withdrawn groundwater. The proper evaluation of the aquifer vulnerability and the selection of suitable TOT for WHPAs is thus important to avoid overestimates (or underestimates) of land protection measures especially in agricultural areas where fertilizers, agrochemicals and pesticides are intensively utilized.

The problem of the proper association between the aquifer vulnerability and the WHPAs identification has been stressed by the Piemonte region environmental authority (NW Italy) by means of specific regulations (Regione Piemonte, 2006). This study shows through a case study the main characteristics of these procedures.

METHODS

Identifying WHPA in Piemonte region (NW Italy): techniques and regulations

As implemented in the Piemonte region, a wellhead protection area consists of 3 different decreasing protection levels as we move away from to the well (Table 1).

The WHPA is usually differentiated into two sub-areas namely the inner and the outer protection zone (IPZ and OPZ respectively). The IPZ is always individuated by the 60-days isochrone whilst the TOT identifying the OPZ depends by the exploited aquifer vulnerability. Four aquifer vulnerability categories are individuated by regulations, namely, Very High, High, Medium and Low. For low aquifer vulnerability the OPZ must be calculated by means of the 180-days isochrone whilst in the other vulnerability situations the 365-days isochrone is utilized. It should be noted that regulations don't provide any specifications about the methodology assessing the aquifer vulnerability. The suitable method must be decided case by case.

Table 1. WHPAs differentiation and allowed land uses according to the Italian water regulations (modified after Repubblica Italiana, 2006).

WHPA Zone	Individuating criteria	Land uses
Total Protection Zone (TPZ)	Fixed radius (10 m minimum)	None. This zone should be fully preserved, impermeabilized, enclosed, and with limited access for authorized personnel only.
Inner Protection Zone (IPZ)	Time of Travel (isochrone 60-days)	Strongly limited. No excavation and subsurface work is allowed. Hazardous activities should be re-located if they are present. New buildings construction is prohibited.
Outer Protection Zone (OPZ)	Time of Travel (isochrone 180-days for Low vulnerable aquifers or 365-days for Medium, High and Very High vulnerable aquifers)	Limited. Only minor anthropogenic activities are allowed, and safeguard measures against groundwater pollution are necessary for existing and new buildings.

For WHPAs overlaying agricultural areas a specific fertilizers and phytosanitary management plan must be developed integrating the general land use management plan. It should ensure the safe application of fertilizers, agrochemicals and pesticides taking into account the attenuation capacity of the soil cover respect the groundwater pollution. These soil data are generally available on the overall plain territory and the soil protection capacity has been evaluated by IPLA (2006) and it is currently available on the web. Four soil protection capacity categories are individuated, namely Very High, High, Medium and Low.

Combining the exploited aquifer vulnerability and the soil protection capacity within the WHPA in a suitable way (Table 2) four levels of land use restrictions are individuated and the corresponding limitation to agriculture practices have been defined specifically (Table 3).

Table 2. Identification of the protection levels required within the WHPA in the agricultural areas by the association of aquifer vulnerability and soil protection capacity. See Table 3 for details concerning authorized land uses and agricultural practices (modified after Regione Piemonte, 2006).

		Soil protection capacity as regards the groundwater pollution	
		Very High and High	**Medium and Low**
Aquifer vulnerability	Low	Level 4 (minimum protection)	Level 3
	Medium	Level 3	Level 2
	High and Very High	Level 2	Level 1 (maximum protection)

Table 3. Authorized land uses and agricultural practices within the WHPAs according with the protection levels derived by the association of aquifer vulnerability and soil protection capacity (see Table 2) (simplified and modified after Regione Piemonte, 2006).

Water supply Protection Level	In the inner protection zone (isochrone 60-days)	In the outer protection zone (isochrone 180 or 365-days)
Level 1 (maximum protection)	Pasture, fertilizers and phytosanitary products are fully prohibited	Fertilizers balance plan is mandatory. Nitrogen effluent discharges are limited below yearly 170 kg/ha maximum value. Phytosanitary products are authorized under European regulations for organic farming (EU, 1991)
Level 2	Fertilizers balance plan is mandatory. Nitrogen effluent discharges are limited below yearly 170 kg/ha maximum value. Phytosanitary products are authorized under European regulations for organic farming (EU, 1991)	Like the IPZ. A wider range of phytosanitary products and weed practices can be allowed case by case under specific conditions and regulations defined by the public surveillance authority.
Level 3	Fertilizers balance plan is mandatory. Nitrogen effluent discharges are limited below yearly 170 kg/ha maximum value. Phytosanitary products are authorized under European regulations for organic farming (EU, 1991). A wider range of phytosanitary products and weed practices can be allowed case by case under specific conditions and regulations defined by the public surveillance authority.	Like the IPZ
Level 4 (minimum protection)	Fertilizers balance plan is mandatory. Nitrogen effluent discharges are limited below yearly 170 kg/ha maximum value. Phytosanitary products and weed practices are allowed case by case under specific conditions and regulations defined by the public surveillance authority.	Like the IPZ

Test site: the Castagnole well

The procedure individuating the WHPAs described in the section 2.1 has been tested on a water well supplying the Castagnole countryside municipality, 20 km S the urban area of Turin (see Figure 1), the capital of the Piemonte region (well geographical coordinates 45°54’01.93”N, 7°33’23.55’’E).

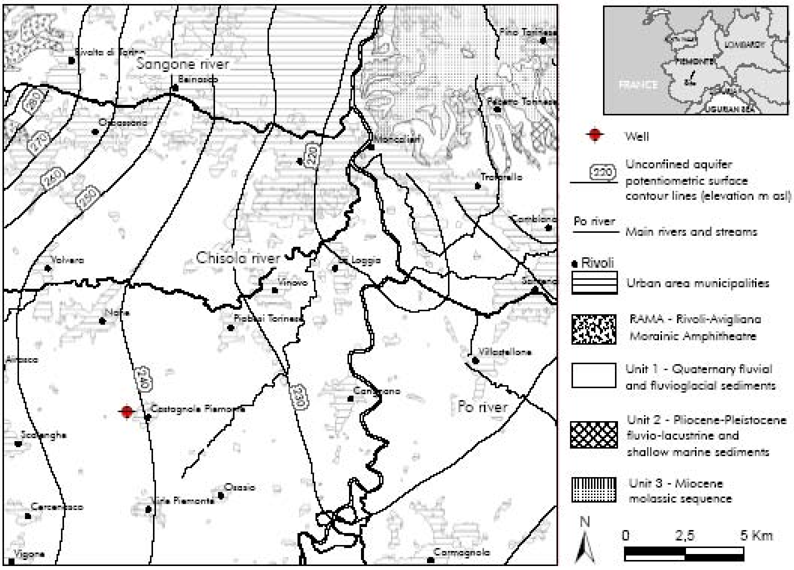

Figure 1. Hydrogeological map of the southern Turin area and location of site (modified after Civita et al., 2004).

The site ground surface is at 244 m a.s.l. The tested well is 88 m deep. The diameter of the casing is 650 mm. The well is cemented from the land surface to 28 m depth. Three screened sections are present in correspondence of productive sandy-gravelly layers between 46–50 m, 67–69 m and 78–81 m deep respectively. The undisturbed water level of the exploited confined aquifer (without any pumping) stabilizes at 243 m a.s.l. (Figure 2).

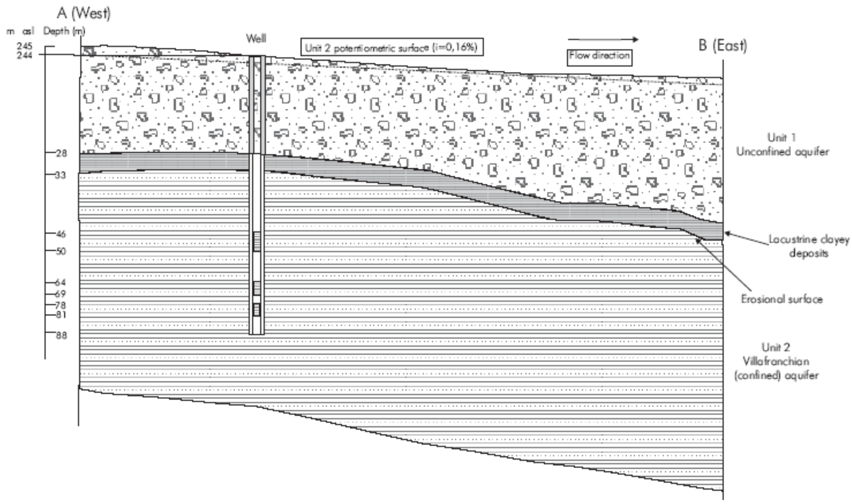

Figure 2. Schematic hydrogeological cross section of the site under study. i: gradient of confined aquifer potentiometric surface.

The Castagnole area is mainly developed on the outwash plain constituted by several glaciofluvial coalescing fans connected to the Pleistocene-Holocene expansion phases towards E of the Alpine glaciers. On the well vertical it is possible to identify (Figure 2):

Unit 1 — (Middle Pleistocene – Holocene; from the surface to 28 m depth). Continental alluvial cover composed mainly of coarse gravel and sandy sediments (locally cemented) derived from alluvial fans aggraded by the Alpine rivers downstreaming towards the east. At the base of the unit there are clayey lacustrine deposits (ca. 4–5m thick) that extend over the entire area and act as a confining layer between Units 1 and 2. The base of Unit 1 (erosional surface) dips gently (0.5%) towards the east, overlaying Unit 2.

Unit 2 — (Early Pliocene – Middle Pleistocene; from 33 m depth). Fluvio-lacustrine facies usually referred to as the "Villafranchian", consisting of fine-grained sediments (sand, silt and clay with interbedded gravel) divided into several sedimentary bodies. The top of the Unit 2 has been eroded away and covered by the lacustrine facies and alluvial deposits of Unit 1.

MODELLING

The modelling study was performed using the finite-element FEFLOW® package developed by Diersch (2005). A conceptual model with three layers was simulated using physical properties appropriate to the hydrogeology of the formation. Layer 1 represented the unconfined aquifer in Unit 1, Layer 2 corresponded to the 5-m thick clayey impermeable level at the base of this aquifer, and Layer 3 to the confined aquifer system of Unit 2. The model was assumed to be closed to fluid flow at its top and bottom. Rainfall infiltration was not included in the calculations due to the lack of measured infiltration data. Instead, the recharge to the system was simulated by fixing groundwater levels at all the outer boundaries of the model (Dirichlet conditions). The simulations were run assuming steady-state conditions for groundwater flow. The withdrawal rate on the tested well (12 L/s) corresponds to the abstraction peak conditions. In reality, such conditions never actually occur because of variable (transient) water demand and the presence of a groundwater storage tank. Therefore, the actual impacts on the aquifer in terms of potentiometric surface changes due to the well pumping will be smaller than those computed by the model. As a result the WHPAs individuated by means of the calculated isochrones will be slightly overestimated and thus cautious.

Aquifers vulnerability and soil protection capacity as regards the groundwater pollution

To identify the suitable isochrones values delineating the WHPAs the exploited aquifer vulnerability must be computed numerically. In this study the modified GOD method (Foster et al., 2002) has been utilized. The calculated Unit 2 GOD value results 0.112 corresponding to a low vulnerability degree. Thus, the OPZ must be identified by the 180-days isochrone. The modelling domain overlays different soil units characterized by a proper level of protection capacity as regards the groundwater pollution. Table 4 and Figure 3 highlight the result of a GIS analysis operated on the modelling domain.

Table 4. Soil Units in the modelling domain and corresponding degree of soil protection capacity as regards the groundwater pollution. (simplified and modified after IPLA, 2006).

Soil Unit	Soil classification	Area (m^2 and %) in the modelling domain	Soil protection capacity as regards the groundwater pollution
U0096	Dystric Fluventic Eutrudept, coarse-loamy, mixed, nonacid, mesic	295 668 (1%)	Medium
U0677	Typic Endoaquept, coarse-loamy, mixed, nonacid, mesic	2 048 817 (9%)	Low
U0095	Dystric Fluventic Eutrudept, coarse-loamy, mixed, nonacid, mesic	4 881 752 (23%)	Very High
U0118	Psammentic Haplustalf, coarse-loamy, mixed, nonacid, mesic	966 420 (5%)	Very High
U0583	Typic Endoaquept, coarse-loamy, mixed, nonacid, mesic (70%UTS - Unit Territorial Surface) Aquic Dystric Eutrudept, coarse-loamy, mixed, nonacid, mesic (30%UTS)	6 633 431 (31%)	Medium
U0586	Dystric Eutrudept, coarse-loamy, mixed, nonacid, mesic (60%UTS) Aquic Dystric Eutrudept, coarse-loamy, mixed, nonacid, mesic (40%UTS)	2 678 799 (12%)	Very High
U0662	Typic Endoaquept, coarse-loamy, mixed, nonacid, mesic (70%UTS) Aeric Endoaquept, coarse-loamy, mixed, nonacid, mesic (30%UTS)	2 484 626 (11%)	Medium
U0678	Fluventic Dystrudept, coarse-loamy, mixed, acid, mesic	1 764 497 (8%)	Medium

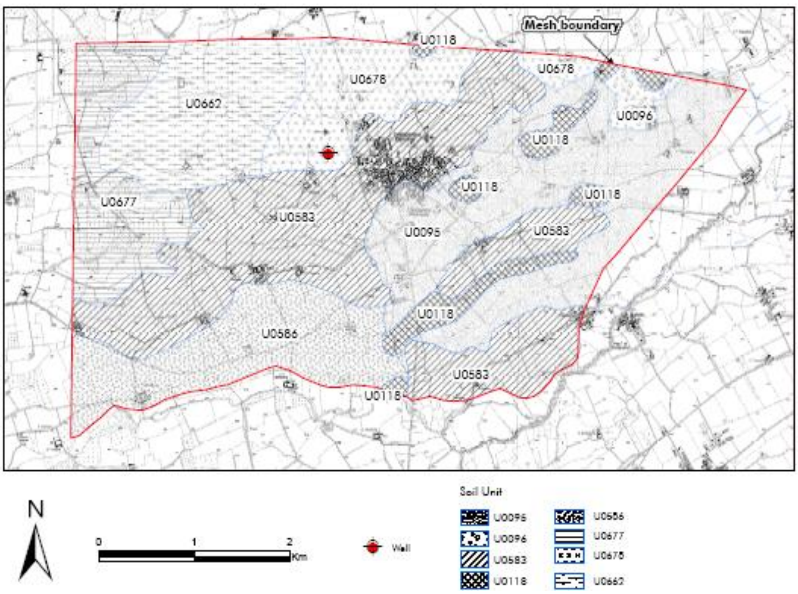

Figure 3. Soil units in the modelling domain (modified after IPLA, 2006). See Table 4 for description.

RESULTS AND DISCUSSION

The calculated test site WHPA is delineated in Figure 4.

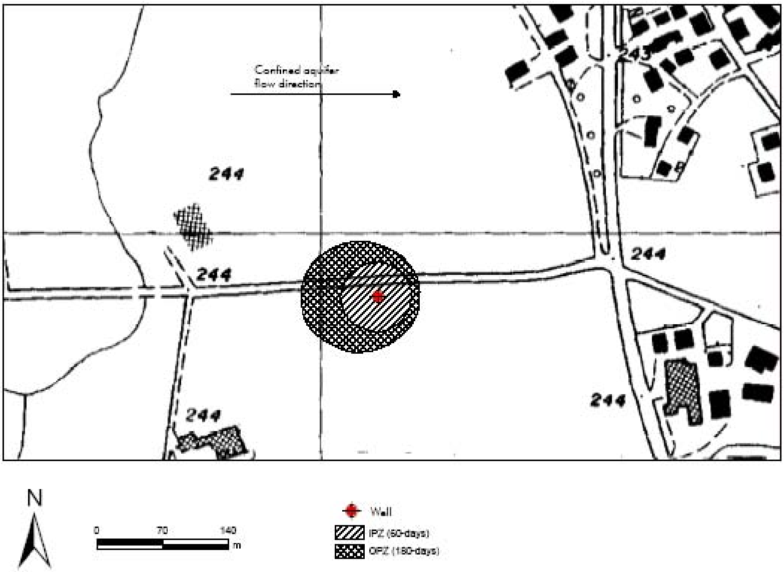

Figure 4. Wellhead protection areas identified by means of isochrones.

The 60-days isochrone (IPZ) covers about 4334 m^2 whilst the 180-days isochrone (OPZ) covers 11734 m^2. Combining the aquifer vulnerability (low) and the medium soil protection capacity of the soil unit overlaid by the WHPA (U0678) the corresponding level of protection (Level 3) is individuated by means of Table 2. The corresponding land use restrictions for agricultural practices are described in Table 3.

CONCLUSIONS

This study has highlighted a technical approach developed in Piemonte region aimed to protect drinking water wells from pollution combining the aquifer vulnerability assessment and the WHPAs delineation. In particular the selection of TOT delineating the WHPA have to be defined depending on the exploited aquifer vulnerability. The methodology has been successfully tested on a drinking water well supplying a public community.

The procedure appeared affordable and effective but highlighted a main methodological criticism that should be overcame in the next future by light adjustments and modifications.

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abstract id: **376**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **Groundwater hydrochemistry of the quaternary alluvial aquifer in Varaždin region — Croatia**

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keywords: alluvial aquifer, hydrochemistry, ammonia, nitrite, nitrate

INTRODUCTION

High nitrate concentrations in surface waters and groundwater have emerged as s globally growing problem for drinking and agricultural purpose (Halberg, Keendy, 1993; Spalding, Exner, 1993; Nolan, 2001). The adverse health effects of high nitrate levels in drinking water have been well documented, that include gastric cancer, non-Hodgkin's lymphoma and methemoglobinaemia (Walton, 1951; Winnerberger, 1982; WHO, 1985; Ward et.al., 1994; Fan, Steinberg, 1996).

The study area is situated in the north-western part of Croatia (Fig. 1) in the Drava river valley.

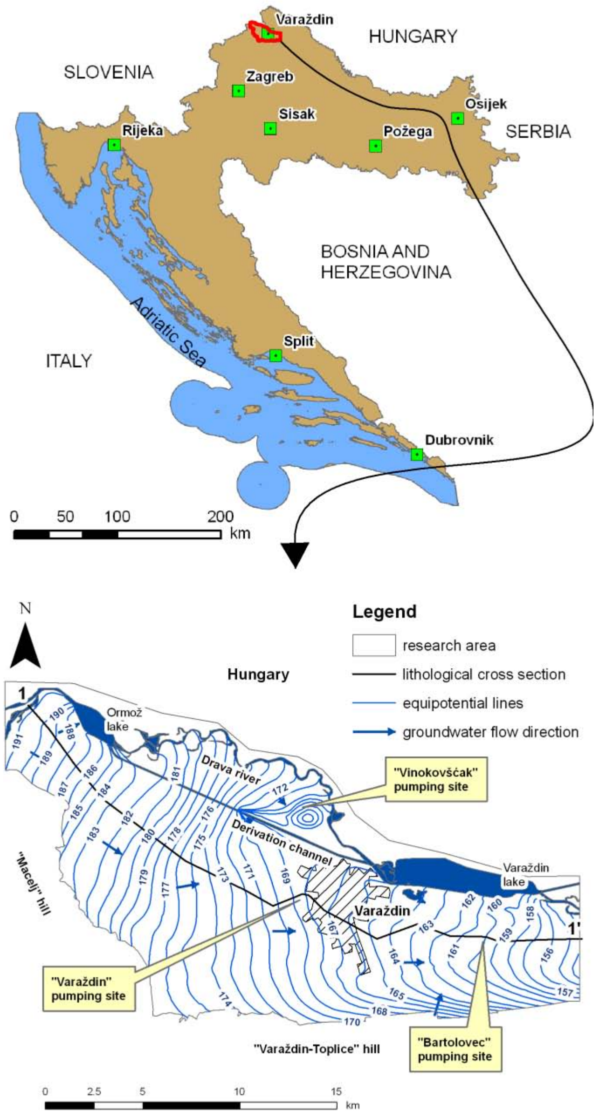

Figure 1. Location map showing equipotential lines and groundwater flow direction.

It is quite developed region where agricultural production is among the most important economic branches. Groundwater accumulated in the Drava alluvial aquifer represents valuable natural resource. As a result of favourable natural conditions, three pumping sites ("Varaždin", "Vinokovšćak" and "Bartolovec") have been developed for the purpose of drinking water supply. The natural quality of groundwater complies with the provisions of the Regulation on health safety of drinking water (OG 47/08), but during the years inadequate land use management took its toll, which became obvious in 1970s when high concentration of nitrates in groundwater was noticed for the first time. Today, high concentrations are observed in the first aquifer and, as a consequence, groundwater abstraction from the first aquifer at "Varaždin" pumping site has recently been terminated. This work was initiated to examine the nitrates behaviour in the first and the second alluvial aquifer of the study area.

HYDROGEOLOGICAL SETTING

The aquifer is composed of gravel and sand with variable portions of silt (Babić et.al., 1978; Urumović, 1971; Urumović, et.al., 1990). It is formed during Pleistocene and Holocene as the result of accumulation processes of the Drava river (Prelogović, Velić, 1988). In the north-westernmost area its thickness is less than 5 meters (Fig. 2). Going downstream the aquifer thickness gradually increases and reaches its maximum of roughly 105 meters in the eastern part of investigated area. It is noticed that particle sizes change going from the north-western part downstream, i.e. the size of gravel and sand particles gets gradually smaller as result of energy decrease of the Drava river. In accordance with variation of the particle size the values of hydraulic conductivity vary in the range from 100 to 300 m/day. In the central part, near Varaždin town, a tiny aquitard appears dividing the aquifer in two hydrogeological units (Fig. 2).

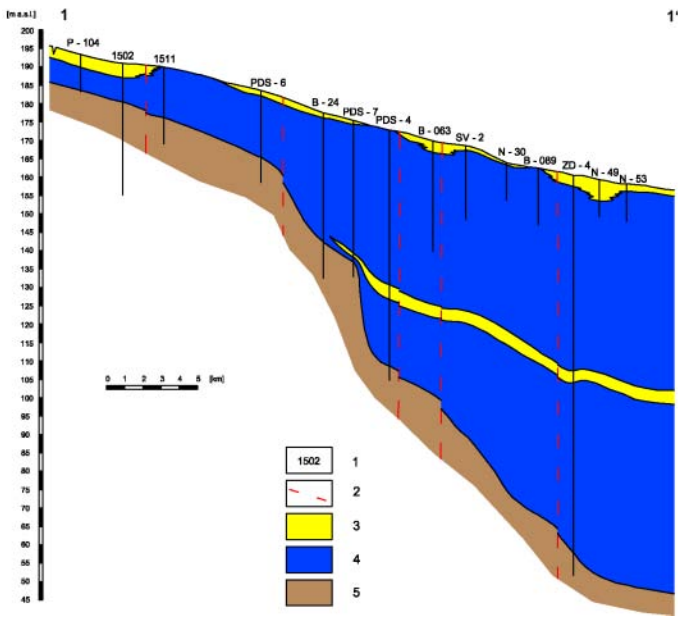

Figure 2. Lithological cross section. 1 — borehole; 2 — supposed fault; 3 — aquitard; 4 — aquifer; 5 — impermeable rocks.

It has regional significance and can be tracked even downstream of investigated area. It is composed of clay and silt and its thickness does not exceed 5 meters. The covering layer of the first aquifer is not continuously developed. In central part and near the Drava river it rarely exceeds two meters, while often there is no covering layer at all. Such conditions are favourable if they are considered from the aspect of aquifer recharge, but on the other hand tiny or non-existing covering layer composed of clay, silt and sand particles mixed with various content of organic matter, makes the aquifer quite vulnerable.

The aquifer is unconfined except its marginal part in the vicinity of "Varaždin-Toplice" hill where, locally, the covering layer gets thicker, at some places more than 10 meters. The recharge of the first aquifer occurs by means of precipitation infiltration and percolation of surface water, while the lower aquifer is recharged by the slow percolation of groundwater through aquitard.

The general groundwater flow direction is NW-SE and is parallel to the Drava river (Fig. 1). It is noteworthy that the piezometric head distribution and the flow net have been significantly changed consequential to building of two accumulation lakes for hydropower plants. Namely, prior to this intervention the groundwater had flown towards the Drava river where the aquifer had been drained and most of the recharge had been achieved by infiltration of precipitation. After construction of the Ormož and Varaždin accumulation lakes, the regional flownet changed leading to percolation of the water from the lakes to the aquifer. Besides, the groundwater levels increased leading to washing out of nitrates from unsaturated zone.

METHODS

In various hydrological conditions water samples were taken from wells and surface waters - Drava river, lakes, gravel pit (Figure 3).

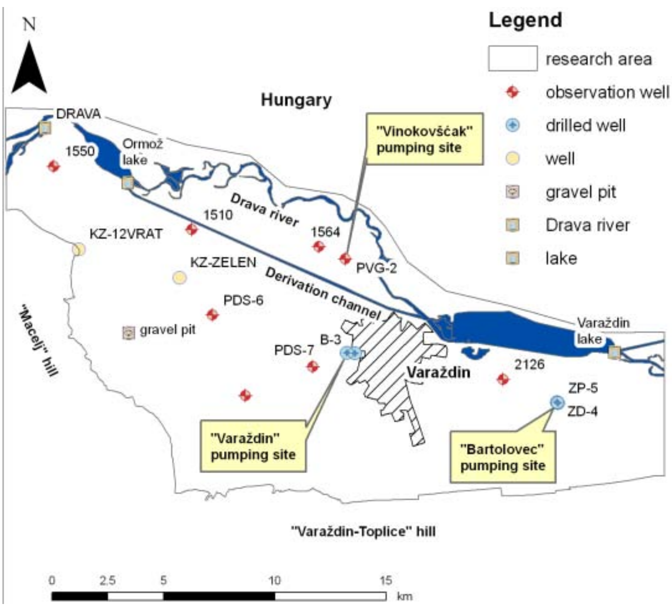

Figure 3. Sampling sites.

Prior to taking water samples from individual springs, the following parameters were measured "in situ" by probes of WTW company: EC, TDS, T and pH content in waters. At the Hydrochemical Laboratory of the Department of Hydrogeology and Engineering Geology — Croatian Geological Survey, the concentrations of the basic anions and cations were measured. The content of chlorides, sulphates and nitrates were measured by ion chromatograph of the LabAlliance company, whereas the concentrations of orthophosphates and ammonium were measured by the spectrophotometer DL/2010 of the HACH company. The concentrations of calcium, manganese, sodium and potassium were measured by the atomic adsorber of the Perkin Elmer company. The content of HCO_3^- was determined by titration. The results for ions were processed using the Netpath software. Data quality was further assessed using the charge balance between the sum of cations and anions (expressed in meq/l), which was always <±5%. Also, periodical chemical analysis made by VARKOM was used for interpretation.

RESULTS AND CONCLUSIONS

According to the chemical composition, groundwater from the Varaždin aquifer belongs to the $CaMg\text{-}HCO_3$ hydrochemical type. This is the primary water type which is principally derived from dissolution of carbonate minerals (calcite and dolomite) that compose the aquifer.

The pH of the analyzed water samples varies from 6.96 to 7.94 (slightly acid to alkaline). The EC values vary from 596 to 720 μS/cm and depend on amount of dissolved solids in water. Nitrate concentrations vary from 3 to 89 mg/l (Fig. 4, 5). The highest value was measured in groundwater from the catchment area of Varaždin pumping site. In the most samples from the first aquifer of Varaždin pumping site, measured concentrations of nitrate are over the MPC value. Nitrates concentrations from the wells located at the catchment areas of Vinokovšćak and Bartolovec pumping sites, vary from 3 to 38 mg/l in waters (Figure 4).

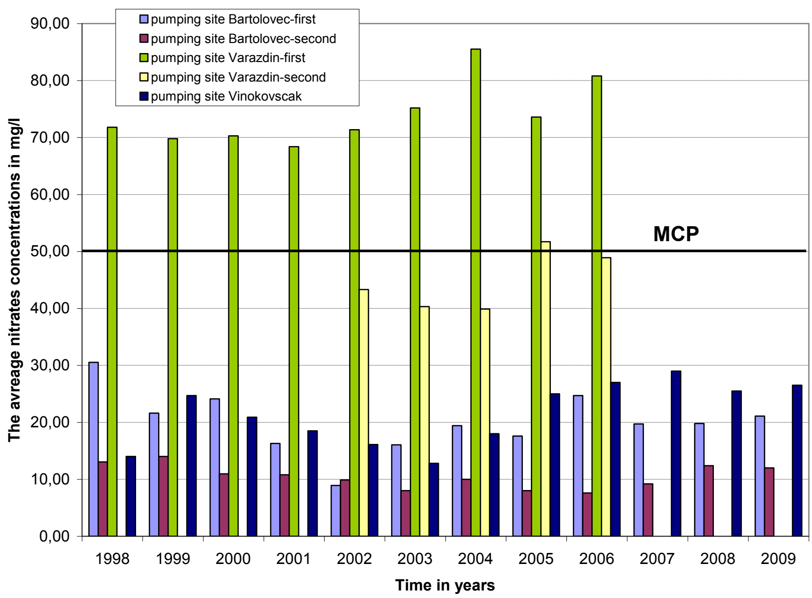

Figure 4. Distribution of average nitrates concentrations over 11 year period at pumping sites of Varaždin area.

In piezometer PDS-7 (near Varaždin pumping site) concentrations of nitrite are high, while, at the same time, concentrations of nitrate are low (Fig. 5). Nitrate contamination is generally high in oxygenated aquifers where nitrate is relatively stable and mobile, while nitrate can be naturally attenuated by denitrification under reducing aquifer conditions (Edmunds, Walton, 1983; Trudell et al.,1986; Frind et al.,1990; Postma et al.,1991; Geyer et al., 1992; Canter, 1997; Hamilton, Helsel, 1995; Pauwels et al., 2000; Böhlke, 2002; Jang, Liu, 2005; Thayalakumaran et al., 2008; Kim et.al., 2009). The redox state of an aquifer can be changed by the variability of geologic and geochemical properties and may determine the spatial distribution and biogeochemical behavior of nitrate and other redox-sensitive species. For example, reducing conditions required for denitrification can be facilitated within a silty aquifer where organic matter (as an important electron donor) is abundant and groundwater flow is retarded (Postma et al., 1991; Smith et al., 1991; Starr, Gillham, 1993; Robertson et al., 1996; Chae et al., 2004a; Thayalakumaran et al., 2008; Kim et.al., 2009). Such conditions are present in the surrounding area of the piezometric well PDS-7. Generally higher concentrations of nitrite were measured in water samples taken in the vicinity of the Varaždin pumping site, while they are low in other catchments.

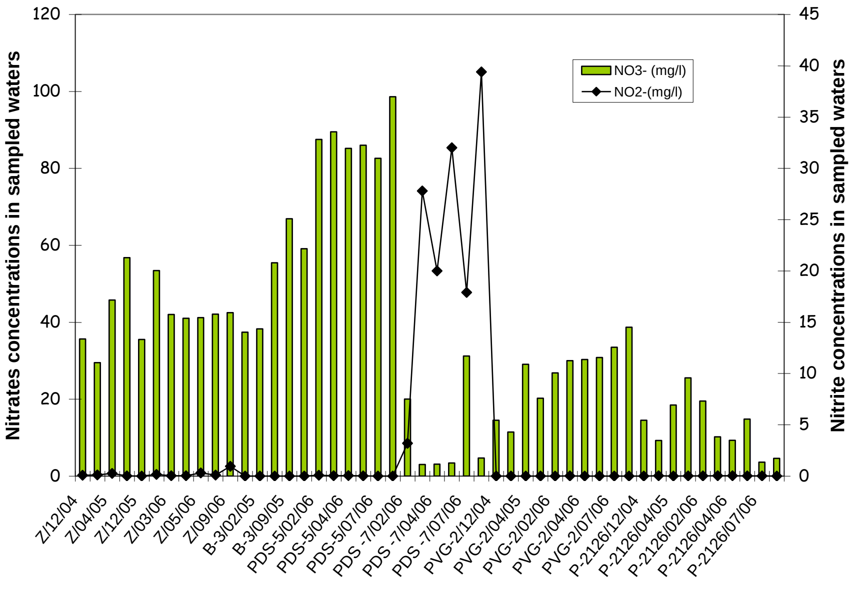

Figure 5. Distribution of nitrates and nitrite in monitored waters.

Ammonia and orthophosphate concentrations are higher in the water samples from wells located in catchment area of Varaždin pumping site then on the other sampling locations. The reasons for higher values of parameters in the groundwater from the first aquifer in the catchment area of Varaždin pumping site compared to the ones obtained for the water samples in the catchment areas of Bartolovec and Vinokošćak pumping sites area are: the lack of covering layer, thinner aquifer, numerous poultry farms as well as intensive cabbage production. Other values of chemical parameters measured in groundwater from the second aquifer are mostly under MPC levels.

The excessive concentrations of nitrates in groundwater from the shallow aquifer at the catchment area of Varaždin pumping site led to gradual decreasing of groundwater abstraction rate and directed the majority of abstraction to the other pumping sites — Bartolovec and Vikonovšćak, where concentrations of nitrate still do not exceed the MPC values. It's necessary to make improvements in agricultural production, as well as in Varaždin infrastructure, in order to reduce concentrations of contaminants in groundwater and enable sustainable groundwater management and development of the entire region.

ACKNOWLEDGEMENTS

The research was carried out in the framework of the research project of the Croatian Ministry of Education, Science and Sports: Basic hydrogeological map of Croatia. The authors wish to express their gratitude to VARKOM for the data which are used in this paper.

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abstract id: **382**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **Modeling nitrate transfer in an alluvial aquifer for estimating tendencies and short and medium term evolution of groundwater quality**

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keywords: nitrate, groundwater, geochemistry, modelling

INTRODUCTION AND CONTEXT

The objective of the project was the modelling of nitrate transfer from soil to the outflow of an alluvial aquifer. The model will permit to estimate tendencies and evolution of NO_3 concentration in groundwater under various socio-economical scenarios. The multi-tools study included the use of environmental tracers to calculate water and pollutant transit time within the alluvial aquifer, geochemical data for the evaluation of the groundwater-surface water interaction, 1D modelling of nitrate transfer from soil to groundwater through the unsaturated zone, 2D modelling for the estimation of the nitrate transport within the aquifer and socio-economical assessment of agro-environmental measures that would permit a change in groundwater nitrate concentrations.

The studied site of about 260 km^2 is located in the eastern part of France, in a region dominated by maize crop (Fig. 1).

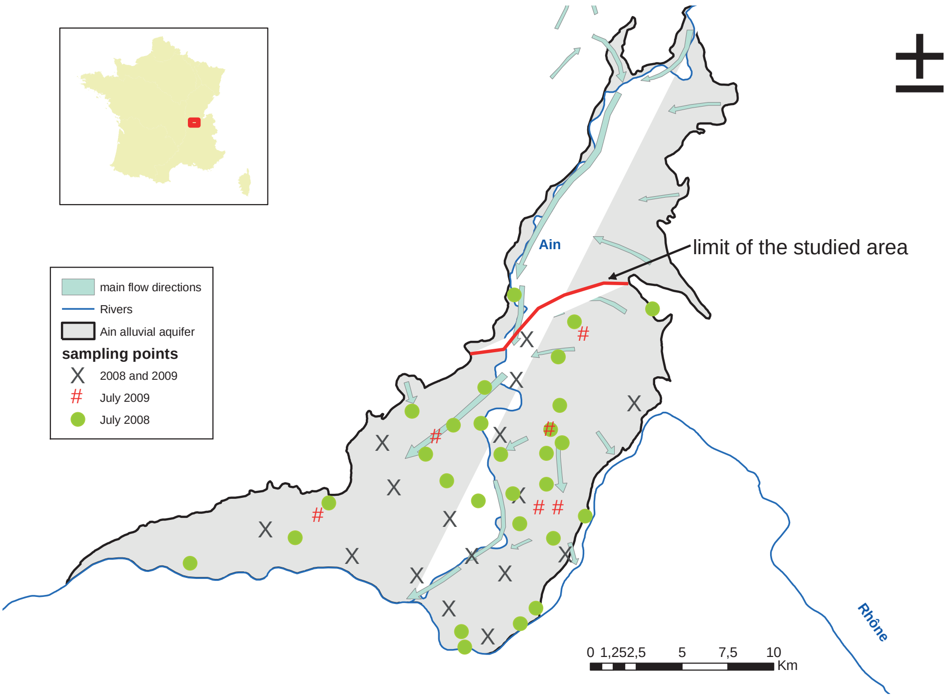

Figure 1. Localisation of the studied area – the Ain River alluvial plain, France.

The studied area covered the southern part of the groundwater body FRGW3676 untitled Alluvial Ain River plain. The plain is crossed by the Ain River and bordered by the Rhône River. The Ain River is considered to be isolated from the alluvial plain. Water and solutes exchanges may occur only in a narrow flooding area close to the river bed. The Rhône River is the natural aquifer exsurgence. The aquifer is mainly recharged by precipitation but also received water from the Dombes plain (North-West and West), intensively cultivated and from the Bugey and Jura karstic Mountains (North-East and Eastern part).

The alluvial aquifer is mainly used for drinking water of small size towns and for irrigation.

RESULTS AND DISCUSSION

Geochemical data

Two field sampling campaigns carried out in July 2008 and July 2009 permitted the collect of ground and surface water for the analyses of major and trace dissolved ions, δ^{2}H, δ^{18}O, CFC-11, CFC-12, CFC-113, SF_6, ^{3}H (Fig. 1).

Groundwater is of HCO_3-Ca type. Nitrate concentrations of groundwater vary from 5.2 mg·l^{-1} to 84.6 mg·l^{-1}. The northern part of the alluvial aquifer presents lower nitrates concentration. The highest NO_3 concentrations are measured in the south-east part of the aquifer in Loyettes sector.

Stable isotope data (δ^{18}O, δ^{2}H) was analysed at 23 groundwater wells and the two major Rivers crossing the area, the Ain and the Rhône Rivers (Fig. 2a). The local meteoric line (LML) is represented by Thonon-les-Bains precipitation (AIEA/WMO GNIP station). This meteorological station is located 150 km s upstream the alluvial plain in a mountainous region. Topographic and geographic data explained relatively depleted δ^{18}O and δ^{2}H values of "local" precipitation. The Worldwide Meteoric Water line (WML) is δ^{2}H = 8·δ^{18}O +10 (Craig, 1961). The Rhône River is influenced by the Alps snow melting and high altitude precipitation and surface water is therefore showing low stable isotope values. Water of the Ain River is from the Jura Mountain and aquifers discharged. Isotope data of this water are closed to the alluvial groundwater values.

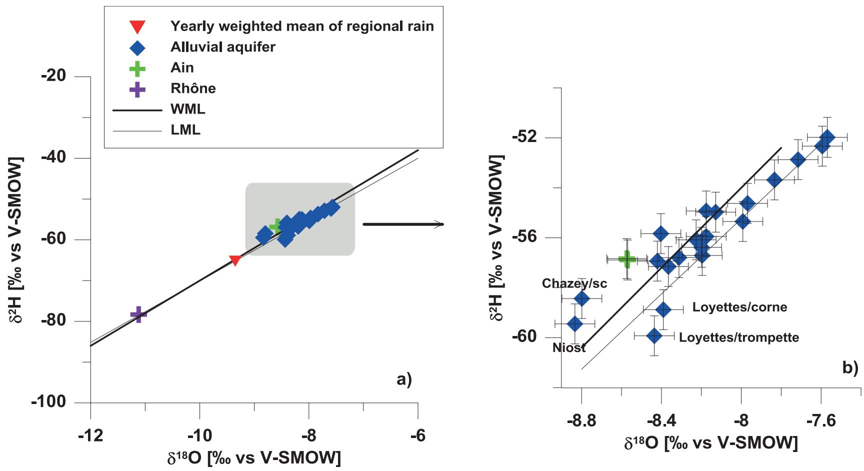

Figure 2. δ18O and δ2H of samples collected in 2008 in the alluvial aquifer, Ain and Rhône Rivers and weighted mean of regional rainfall collected at Thonon-les-Bains.

In the Figure 2b the two points representing the Ain River upstream and downstream are indistinguishable. Groundwater is plotted along the local meteorological line except for 4 points. At Loyettes south east part of the plain maize cropping is covering large areas and irrigation is needed from May to September and intensively from June to August. In July, sampling period, it is possible that the two wells Loyettes/corne and Loyettes/trompette were influenced by irrigation return. The two groundwater samples with highest deuterium excess are not drilled in the morainal and Miocene formations.

Stable isotope data is confirming that the Ain River is quite independent to groundwater. The aquifer presents a high hydrodynamic heterogeneity due to glacio-fluvial sediment deposits of varied granulometry and lithology.

Age-dating using CFC-11, CFC-12, CFC-113, SF_6 and ^3H gave a mean recharge date of 5 to 10 years.

Modelling nitrate tranfer and hydrodynamics

The transfer of nitrate from soil to groundwater thought the unsaturated zone is estimated using a global model called BICHE developed by the BRGM (Thiéry, 1990). The data on N cycle (amount of N used, plant needs, soil nitrogen mineralization, and N mineralization from vegetal crop residues) is coupled with a global hydrological model using ETP and precipitation (Fig. 3).

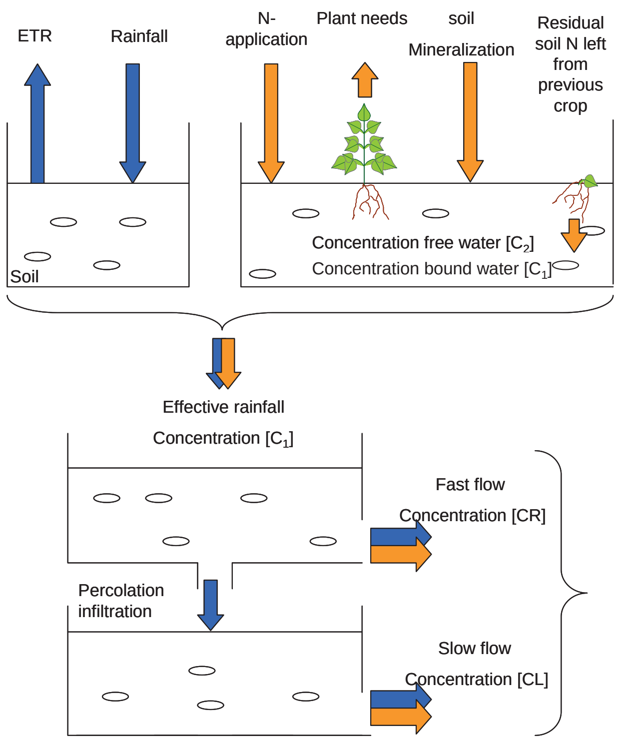

Figure 3. Structure of the BICHE model (from Thiéry, 1990).

The collect of data from as much as possible years was necessary for nitrate transfer modelling.

Data of nitrate concentration in groundwater is usually available from 1991 up to now. Frequency, duration and nitrate variability and concentrations vary within the numerous monitoring stations available in the studied area (Fig. 4).

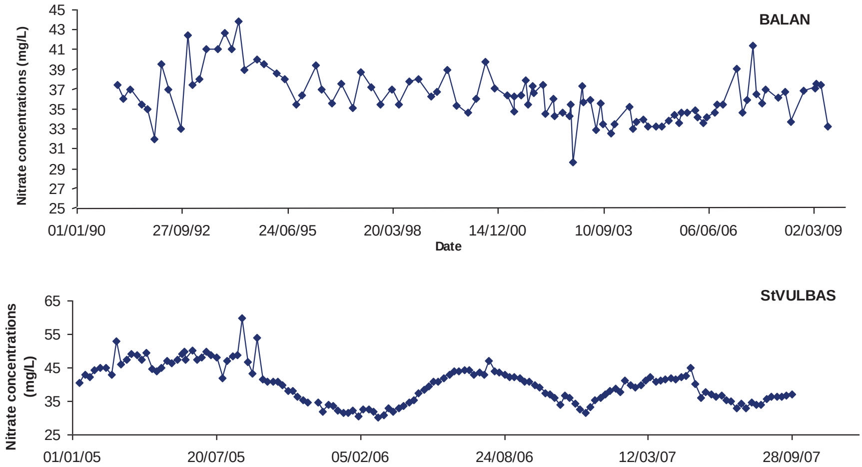

Figure 4. Nitrate concentrations in groundwater at two monitoring stations.

Thirteen more representative chronicles were selected for modelling purposes.

The hydrological input parameters (P and ETP) are the same than the ones used for the hydrodynamical modelling. The N cycle information is reconstituted from information given by the literature (Yara, 2004), agricultural enquiries, farmers' registry and soil and agricultural institutes.

Calibration and validation of the model (Fig. 5) was done using a great amount of data of various origin and type. This is a necessary step in order to use site specific modelling.

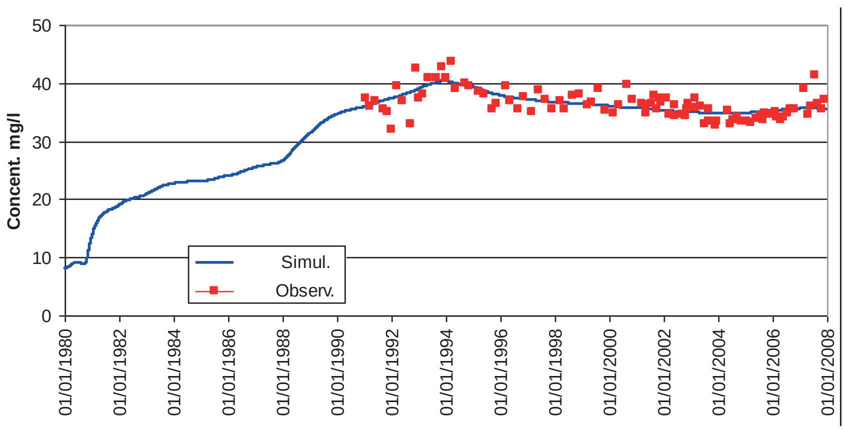

Figure 5. Nitrate transfer simulation using BICHE and observed concentration of nitrate in groundwater at site.

The hydrodynamic and hydrodispersive modelling of the entire alluvial plain was performed using MARTHE calculation code (Thiéry, 2004). It was calibrated on 8 years period at a 10 days time step, from 1999 to 2007. Results of the transitory regime calibration are satisfactory and allowed the use of this model for nitrate transfer estimation. For that purpose the 1D BICHE model outputs (flux of nitrate to the aquifer through time) was used as an entry of the 2D nitrate transfer modelling within the alluvial aquifer. In order to obtain spatial information, 12 homogeneous sectors were defined. Each sector has similar agricultural practices and hydrodynamic behaviour. For each sector it exists, at least, one chronicle of nitrate concentration in groundwater.

The coupled models is being used to assess the efficiency of various scenarios proposing changes (or not) in agricultural practices (crop type and fertilizer use).

The scenarios were prepared based on socio-economic studies considering today's practices and near future (< 2027) changes in land use and land management practices. Various scenarios were prepared after discussions with local stake holders and only four contrasted ones were finally selected. Such experiments have been conducted in other sites and using various calculation codes site specific (e.a. Krause et al., 2008) or simplified methods (e.a. Jackson et al, 2008).

Dating and modelling

Dating groundwater at a sampling point location means: determine the elapsed time (or residence time) from the time the water goes underground and became isolated from the atmosphere (i.e.: during its infiltration into the soil from precipitation or any other type of surface water) until it is removed/collected. The information obtained on the age of the water, and therefore its turnover time, is useful for management of aquifers.

There are two methods to estimate the age of groundwater. The first is based on the hydrodynamics of the system studied (Metcalfe et al., 1998). But the difficulty lies in the spatial distribution of permeability field that is generally known that in some points. On the other hand, it requires a set of sufficient data in order to achieve a satisfactory calibration model. This implies an uncertainty on the velocities and ages calculated. A second approach called "direct" is based on the use of tracers, geochemical or isotopic. In shallow aquifers, tracers most commonly used are events tracers that are related to a sudden or continuous contribution in the underground environment (^{3}H, ^{85}Kr, CFC, SF_6, ...). Their introduction into the natural environment dates from the twentieth century. For these compounds few studies seek to compare independently the hydrodynamic and tracers approaches. The use of both methods of dating can make a "feedback" to improve understanding of the conceptual model. This comparison could provide valuable information on the hydrogeological understanding of the Ain alluvial plain.

However, the question arises of the physical meaning of "ages" obtained by the models of geochemical dating. Knowledge of an apparent age does not necessarily imply knowledge of a residence time of water. In this study we evaluated the limits of different models for estimating residence time obtained by the use of event-tracers. Comparisons will be made using the following hydrodynamic models; discretized type, global or developed black box.

Different approaches are possible for the comparison of tracer and hydrodynamical models. The first approach is to reproduce the contents of CFCs and SF_6 by modelling as tested for the study of a shallow aquifer in Germany (Duke et al., 1993). A multi-tracer approach improved modelling results in reducing uncertainty and enhanced the importance of CFC-113 adsorption. A second approach compared the ages obtained by CFC age-dating and residence time obtained by modelling. This method was used in a shallow sandy aquifer in Maryland (Reuilly et al., 1994). A first level calibration using various tracers ^{3}H, CFC-11, CFC-12 highlighted the phenomenon of water mixing. A second level of calibration taking into account the results obtained using the CFC-dating led to the improvement of the age and the conceptual model.

In addition to these two methods, we will test a third approach consisting in entering CFC data in the hydrodynamical models in the aim of simulate its comportment in the system.

CONCLUSIONS

The system of the alluvial Ain river plain is an ideal study site for the use of tracers CFCs given the fast transfer velocities and known hydrodynamical characteristics. Using data ^{3}H, CFCs and SF_6 and the hydrodynamic model validated on observed hydrodynamic perspective of this study are:

- Determine the properties of conservation and solubilization of tracers in the unsaturated and saturated zones,
- Judge the relevance of the geochemical approach and try to improve it by using the hydrodynamic model coupled to solute transport,
- Comparing the information obtained using the hydrogeological and geochemical models to enable a better definition of "age" of water and its meanings,
- Validating hypotheses and results obtained in the nitrate transfer modeling.

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abstract id: **383**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **Evaluation of nitrate residue norm by estimation of process factors for groundwater, Flanders, Belgium**

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keywords: nitrate, Belgium, groundwater table interpolation

This contribution discusses a methodology for the estimation of a process factor for phreatic groundwater for the evaluation and differentiation of the current nitrate residue norm in Flanders, Belgium. The goal is to differentiate this norm for different crops, soil textures and hydrogeological homogeneous zones (HHZ). The process factor is an empirical factor, which summarizes all changes to the nitrate concentration between the moment when the nitrate residue leaves at 90 cm depth the soil profile in autumn and the measured nitrate concentration in phreatic groundwater. Since 2004 phreatic groundwater quality is systematically followed up by the Flemish Environmental Agency (VMM) (Eppinger, 2005) by way of analysis of samples from 2107 piezometers.

In the methodology eight HHZ's are selected, which are contrasting in soil texture, cover all agricultural regions and have different vulnerability with respect to exceeding the nitrate limits in shallow phreatic groundwater. A map of the groundwater table has to be obtained for the selected HHZ's. Groundwater table observations however, are scarce and irregularly distributed in space and time. Geostatistical interpolation methodologies like kriging correctly represent the spatial structure of the data and are exact predictors at the locations of observation. However it often fails to capture the patterns in groundwater table map, which result from hydrogeological flow systems. In this study, the Bayesian Data Fusion (BDF) framework (Bogaert, Fasbender, 2007) is used to combine a kriging interpolation with the results of a simplified groundwater flow model. The BDF is applied to Flanders to create a groundwater table map with a spatial resolution of 25 by 25 m^2. To evaluate the performance of the proposed methodology; a leave-one-out cross validation procedure is applied. It is shown that the BDF methodology produces a groundwater table map, which is exact in the observation locations and represents well the groundwater flow system. It is shown that the methodology outperforms both the kriging interpolation and the groundwater model in predictive capabilities.

Once a groundwater table map has been created, the flow line through a given point x,y in the study area is derived using a simple backward particle tracking algorithm. The flow line is defined as the path following the highest gradient over the simulated phreatic surface, starting at the given position x, y and ending at the water divide. Furthermore we can now calculate the location of infiltration for any piezometer at a certain depth in the phreatic aquifer (Cook and Böhlke, 1999). The uncertainty on the exact location of the infiltration point is further calculated by taking into account the spatial variability of the transmissivity. Deriving the standard deviation of the infiltration point in both the longitudinal and lateral direction along the flow line and solving the equation for the bivariate distribution $g(x,y, \rho_{xy})$, we delineate an elliptic area with a certain statistical probability around the calculated infiltration point, in which the real infiltration point is located.

The integral form of the Darcy-Buckingham equation is used to estimate the effective field capacity of the unsaturated zone. Using pedotransfer functions, yearly estimated groundwater recharge from WetSpass (Batelaan, De Smedt, 2007) and the estimated groundwater level unsaturated flow times are estimated. By means of an analytical solute transport model (Toride et al., 1993), the mean nitrate concentration in the percolated water is calculated. With the methodology the process factor can now be estimated for all piezometers as the ratio of weighted over the elliptical area average nitrate concentration in the percolation water at 90 cm depth and the nitrate concentrate in the uppermost oxidized filter. This is further used to link and evaluate the nitrate concentration with the land use in the infiltration area.

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IAH 2010
Krakow

abstract id: **402**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **New contributions on the presence of ions nitrate and nitrite in the region of the Coast of Hermosillo, and Valley of Sonora River, to the Northwest of Mexico**

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keywords: groundwater Sonora, Hermosillo aquifer, water quality, Sonora nitrates

INTRODUCTION

The coast of Hermosillo aquifer is located to the southwest of Hermosillo city between the coordinates 28°14' and 28°57' of latitude North and 111°15' and 111°45' of length West of Greenwich, includes an approximate surface of 3200 km^2 (Fig. 1). It is an exorreic basin located to the northwestern of Mexico, limited to the east by the recharge area of the valley of the Sonora River, and to the west with the Gulf of California.

Figure1. Location of the study area.

In December 2005, and April and December 2006, and December 2009, we got nitrate and nitrite ions concentration and were analyzed on 35 (nitrite) and 50 (nitrate) water samples collected from wells, springs, surface and irrigation waters of the coastal aquifer and its recharge zone in the valley of the Sonora River (Fig. 2). The study area follows a transversal line from west to east of 160 km since the Gulf of California to the upgradient of the Sonora river basin.

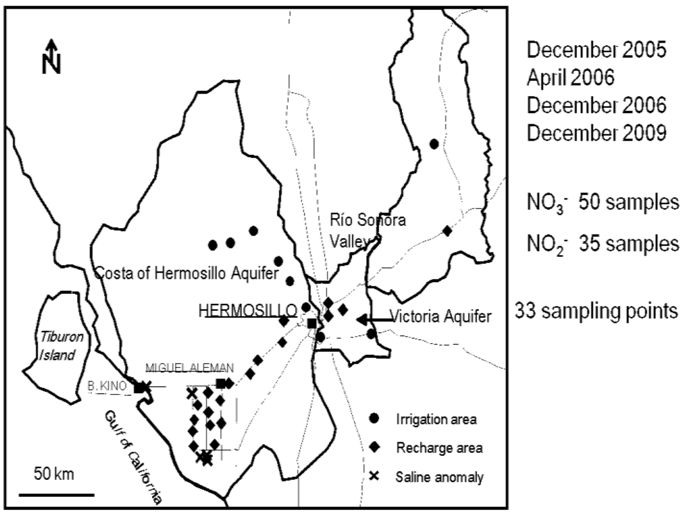

Figure 2. Sampling location.

THE PROBLEM

Groundwater from the Costa de Hermosillo aquifer has been used extensively for irrigation by over the past 60 years. The cultivation area reached 120,000 Ha in 1967 and actually this area has been reduced in no more than 40,000 Ha. Also it is well known the groundwater response in quantity and quality because of the over pumping in the aquifer area; the result was a large depression cone and contamination of the groundwater system by the sea water intrusion in more than 32 km inland. In this escenary it is possible to imagine that the intensive application of $(NH_4)_2SO_4$ fertilizers and raw sewage (untreated domestic effluents), made possible the increasing in concentration of highly conservative compounds in the groundwater system, such as nitrate, which has been observed in a regional scale. Steinch et al. (1998) reported important excess of nitrate content in the Costa de Hermosillo aquifer, with values up to 17 mg/L reached in 1995.

RESULTS

In 2005 and 2006 we noted three categories: 1) 1.2–99.94 mg NO_3^-/L and 5.99–12.15 mg NO_2^-/L in groundwater and surface water from the recharge zone; 2) 6.35–38.52 mg NO_3^-/L and 0.11–10.47 mg NO_2^-/L in groundwater from agricultural areas where the intensive irrigation takes place; and 3) 0.00–114.49 mg NO_3^-/L and 13.93–22.67 mg NO_2^-/L in groundwater, in zones where the high salinization due to seawater migration has occurred.

High concentration of nitrate ions in all types of analyzed water (especially in the recharge and saline intrusion zone) showed that anthropogenic pollution influence on the natural chemical water cycle in all groundwater systems of Costa de Hermosillo and nitrates are now high conservative, still increased groundwater components. Additionally very high concentration of nitrite ions (comparing to irrigation water — 0.33–0.77 mg NO_2^-/L) implies that reduction and/or strong evaporation processes could be responsible for containing this very harmful form of nitrogen in groundwater and surface water of Costa de Hermosillo region.

We continue working with the interpretation of our new chemical results from December 2010 (samples in lab), we want to observe the evolution and verify or to confirm the actual conditions. Unfortunately the generated environmental impact will require ability to modify agronomical practices since it will have a high social and economic cost and several decades to give back to revert the water quality conditions.

abstract id: **427**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **Identification of nitrogen long term trends at regional scale in Seine-Normandie groundwater (France) linked to CFC-age determination, water table variations and agricultural practices**

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keywords: nitrate, groundwater, trend, datation

INTRODUCTION

The European Union (EU) has adopted directives requiring that Member States take measures to reach a "good" chemical status of water resources by the year 2015 (Water Framework Directive: WFD 2000/60/CE). In order to achieve the environmental objectives for the Seine-Normandie groundwater, or to justify the non achievement of these objectives, a large body of water table time-series and nitrate data (available from 1945 to 2009) is analysed. Coupled with CFC-age determination (Baran et al., 2007; Cook and Solomon, 1997), recent geostatistical treatment applications are performed on water table and nitrogen time-series to identify hydrodynamic behaviours and nitrate trends at regional scale.

HYDRODYNAMIC AND NITROGEN BEHAVIOURS

The detailed dataset available for the whole superficial aquifers of Seine-Normandie basin is used to evaluate tools and to propose efficient methodologies for identifying and quantifying past and current trends. The temporal piezometric behaviour of each aquifer is defined using geostatistical analyse of water table time-series. This method requires the calculation of an experimental temporal variogram that can be fitted by a theoretical model valid for a large time range. The identification of contrasted behaviours (short term, annual or pluriannual water table fluctuations) allows a systematic classification of the superficial aquifers. The same treatments are performed on the nitrate time-series after filtrate them. This approach allows the identification of different behaviours in response of agricultural diffuse pollution at regional scale.

TREND ANALYSIS

Trends are determined based on nitrate time-series. But the dataset shows too many irregularities to justify traditional time-series approaches such as linear regression or Pearson regression. The non-parametric Mann-Kendall (MK) test is a robust statistical trend detection test that does not require verification of the normality of the dataset (Aguilar et al., 2007). Moreover, this test seems adequate as it is less sensitive to missing or outlier data than a simple linear regression test (Stuart et al., 2007). The trend analyses are decadely partitioned in order to detect possible trend reversals along the studied period.

The trend identification is also spatialized by the use of the Kendall Regional (KR) test on homogenous zones characterized by their geology, their agricultural practices and their hydrodynamic behaviour. The KR test, quite similar to de MK test, consists of a creation of a virtual global borehole constituted with all the boreholes located in the homogenous zone (Broers and Van Der Grift, 2004). This test allows the identification of regional trends, even in the zones in which nitrate time-series are too small to detect punctual trend.

To complete the study, CFC measurements have been carried out in 2009 throughout the Seine-Normandie basin in order to estimate the pollutant transfer time in each aquifer. The CFC apparent ages give information on the possible lags between the changes in agricultural practices and the appearance of effects in groundwater quality. Causes of trend reversals are not determined with the statistical analyse, but nitrate and water table time-series cross analyses give a brief replies on the possible positive correlation between these two variables. The evolution of the concentrations in nitrate in superficial aquifers may depend on a combine effect of the change in agricultural practice and the evolution of the water table.

ACKNOWLEDGMENTS

Authors gratefully acknowledge the Seine-Normandie Basin Agency for partially funding these researches.

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abstract id: **436**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **Assessment of nitrogen compound contaminations in shallow groundwater southern part of the Groundwater Body no. 53**

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keywords: groundwater pollution, nitrate, agricultural area

Results of the chemistry research of shallow groundwater belonging to south part of the Groundwater Body no. 53 were reviewed in this paper. The study area, which spreads on a surface of about 76 sq.km, is located in the upper part of the river Osownica catchment. It is an upland unit, typical for central Poland (Fig. 1), where agricultural use dominates (Kondracki, 2002). Chemistry studies of groundwater and surface water were conducted in years 2006–2009.

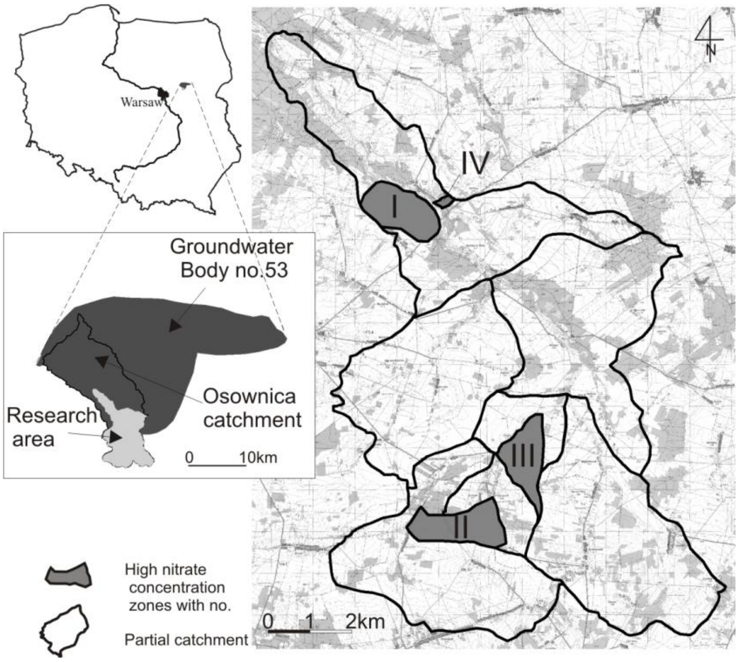

Figure 1. Location of the research area in the background of Groundwater Body no. 53.

The aim of this case study is an assessment of present state of shallow groundwater pollution by mineral nitrogen compounds, especially nitrate, which high concentration was detected in Warsaw WIOŚ monitoring point in Pniewnik (in 2004 established as an area especially vulnerable for pollutions of agricultural origin), (Regulation, 2004). Groundwater Body no. 53 was classified as threatened by not achieving standards contained in The WATER FRAMEWORK DIRECTIVE WFD (2000/60/EC), (Report, 2008).

Results of shallow water sampling (to the depth of 11 m) confirmed high nitrate compound contamination. Consequently, on the basis of groundwater chemistry monitoring in: springs, dug wells, piezometres and sampling probes, four zones were separated (as area groundwater pollution source), where nitrate concentrations exceed upper range of natural hydrogeochemical background.

Three zones (I–III) are characterized by significant fragmentation of agricultural use land groups and intensively conducting of agricultural farming, fourth (IV) is located in the neighborhood of municipal waste landfill, which operation affects negatively on groundwater quality. Lack of forest grounds and mid-field aggregations of trees and bushes in the zones I–III, leads to leaching and pollution migration, emerging as a result of field fertilization by organic and mineral nitrogenous fertilizers. This process is the most intensive during groundwater recharging by waters from spring melting of snow cover, the least intensive during period of vegetation ending, while low groundwater table level and while lack of infiltration recharge exists, which cause seasonal changeability of groundwater threat by nitrogen compounds pollution. In spring period values of average concentrations in mentioned areas are: for nitrate — 22.67 mg NO_3/dm^3, for nitrite — 0.12 mg NO_2/dm^3, for ammonium ion — 0.05 mg NH_4/dm^3, in autumn period: for nitrate — 16.86 mg NO_3/dm^3, for nitrite — 0.08 mg NO_2/dm^3, for ammonium ion — 0.39 mg NH_4/dm^3.

Actions related to agricultural farming also lead to contamination of deeper aquifer, recognized as head useful aquifer in this region (zone III). This phenomenon is documented by long standing observations conducted by District Station of Sanitary Epidemiological Inspection in Mińsk Mazowiecki, which has monitored groundwater intake for rural water supply system in Czarnogłów. Nitrate concentration in this intake waters have been holding steady at level 20–25 mg NO_3/dm^3 since 2002.

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abstract id: **442**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **Quality of shallow groundwaters of Hoshangabad city, Madhya Pradesh, India and its suitability for domestic and irrigational purposes, an rural environment appraisal**

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keywords: water quality, shallow groundwater, domestic use, irrigation use

Water is a precious gift of nature to human beings. Water is needed not only for domestic use but also for the growing needs of any nation for its better agricultural growth.

Hoshangabad is a holy city, situated near the river Narmada. Residents living near the river, use shallow groundwater for drinking as well as for irrigation purposes.

The main objective of the present study is to assess and evaluate the water quality of shallow groundwater of Hoshangabad city and its suitability for domestic and irrigation purposes. In the present study, the hydrochemical investigation is restricted to the major ions' concentration like Ca, Mg, Na–K–CO_3, HCO_3, Cl, NO_3 etc. In order to assess the water quality, 18 (Eighteen) shallow groundwater samples were collected from the different shallow aquifers of the Hoshangabad city and analyzed by using the methods as proposed by APHA (1995).

The experimental values of water samples suggested that most of the waters are slightly alkaline due to the presence of Carbonates and Bicarbonates. The pH values of water samples varied between 7.5–7.9. EC values were in the range of 650–2200 micromohs/cm at 25°C. The calcium hardness and magnesium hardness values ranged from 84 to 210 mg/l and 52 to 203 mg/l respectively. Total dissolved solids and total hardness values of water samples are well within the permissible limit as per the guidelines proposed by WHO, ICMR and BIS. Calcium and Magnesium are the two major constituents amongst the cations and it varies from 28 to 72 mg/l and 5 to 30 mg/l respectively. The conc. of sodium and potassium varies from 36 to 62 mg/l and 1.6 to 5.4 mg/l respectively. The carbonate is absent or present in traces. Bicarbonate is the important anion and it varies from 80 to178 mg/l. Chloride and Sulphate, conc. varies from 28 to 148 mg/l and 10 to 41 mg/l respectively. The Nitrate and Phosphate conc. varies from 10 to 41 mg/l and 0.07 to 0.42 mg/l respectively.

A variety of graphical representation methods are used to classify water. In the present study, Piper Trilinear Diagram (1944) and Modified Trilinear Diagram by Romani (1981) are used to classify the shallow groundwater. The concentration of major cations and anions has been converted to me/l and percentage reacting values of each ion have been computed and plotted in Pipers Trilinear Diagram and Modified Trilinear Diagram. The presentations of chemical analysis data in Pipers Trilinear Diagram reveal that the hydrochemistry of majority of shallow groundwaters are dominated by alkaline earth, weak acids and carbonate hardness, over 50% of which is temporary in nature. The chemical analysis data plotted in modified Trilinear diagram reveals that the majority of shallow groundwaters fall in the field C-1 and A-1, which shows that the shallow groundwater belongs to calcium-bicarbonate type.

In order to evaluate the agricultural water quality, various irrigational specifications have been suggested by various workers. In the present study, irrigational specifications as proposed by Asgar et al. (1936), Kelley et al. (1940), Eaton (1950), U.S. Soil Salinity Staff Diagram (1954), Wilcox (1955), Paliwal (1972), and Ayers and Westcot (1985) have been used to assess the suitability of shallow groundwaters for irrigational purposes.

Asgar et al. (1936) has suggested the salt index as a parameter for evaluating the quality of irrigation water. Salt index is negative for all good waters and positive for suitable waters. In the present study, the values of all the shallow groundwater samples are negative indicating the suitability of water for irrigation purposes.

Sodium problem in irrigation water can be evaluated on the basis of Kelly's ratio. If this ratio is below one, water is suitable. If this limit is in between one and two, the water is marginally suitable and if this ratio is beyond two, water is unsuitable. In the present study, the majority of shallow groundwater sa mples have less than one Kelly's ratio, indicating the suitability of water.

Eaton (1950) proposed that the indirect effect of carbonate and bicarbonate on water quality and it is expressed in terms of Residual Sodium Carbonate (R.S.C.). As per the guidelines of US Soil Salinity Laboratory Staff (1956), the majority of shallow groundwater samples have RSC more than 1.25 which clearly suggests that the water is safe for irrigational purposes.

When the EC and SAR values of shallow groundwater samples of the area were plotted in the US Soil Salinity diagram, it clearly indicate that the shallow ground waters showing no sodium hazard and the water belongs to good category.

As per Wilcox classification diagram based on EC and Soluble Sodium Percentage (SSP), the shallow ground waters fall in "Good to Permissible" class.

As per Paliwal (1972), the magnesium hazard is likely to be developed in soil when this ratio exceeds 50%. In the present study the value of index of magnesium hazard is less than 50% which clearly indicates that the shallow groundwater samples can be profitably applied for irrigation.

Ayers and Westcot (1995) proposed modified water quality guide lines based on Sodicity, Toxicity and Salinity. A comparison of EC, SAR, TDS, Cl, and NO_3, values of shallow groundwaters with the values of the parameters as proposed by Ayers and Westcot, reveals that the majority of shallow groundwaters belongs to "Slight to Moderate Restriction" category.

On the basis of various water quality guidelines proposed by BIS, WHO and ICMR, it is suggested that the majority of shallow groundwaters are found suitable for drinking purposes. On the basis of the various irrigational specifications such as Salt index, Kelly's Ratio, Residual Sodium Carbonate, Sodium Adsorption Ratio and Magnesium ratio it can be concluded that the majority of shallow groundwater samples are quite suitable for irrigational purposes. However, marginal and "slight to moderate restriction" water can be used for irrigation after proper management and selection of crops.

abstract id: **444**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **Factors of pesticide influence on groundwaters, using example of Lijevce polje**

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keywords: use and protection of groundwater, pesticides, GIS analysis, EU Directive

Lijevce polje is situated in north Bosnia and Herzegovina (B&H), and represents one of the most significant areas in B&H in which the agriculture is most represented. At the same time, the area of Lijevce polje represents a very populated area, in which the ground waters are used as the sole resource of water.

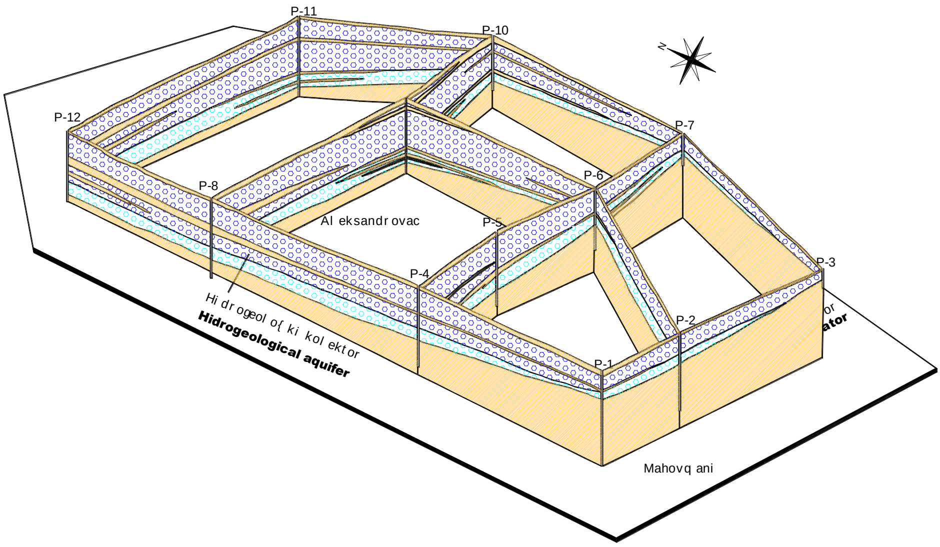

Figure 1. Block diagram of terrain South Lijevce polje.

The given area is a tectonic trench filled with alluvial sediments of the rivers Vrbas and Sava. The thickness of the alluvial sediments varies from 8 to 35 m. In these sediments are formed intergranular types of unconfined aquifer.

The source of recharging the ground waters are surface water flows, as well as infiltration of atmospheric waters. The filtration coefficient of the alluvial sediments is of 1×10^{-2}m/s, which puts this area in the area with the most perspective for a global water resource in B&H. Based on ortho-photo shots the areas of fields for agriculture have been identified, where the agro-chemicals are mostly used. The aim of the paper was to establish the state of ground waters, as well as the areas in which there is a contamination, as well as the factors to be analyzed in a general case, when it comes to the use of pesticides in an ecologically sensitive area. Using available hydrogeological data the vulnerability of the ground waters was defined, using the GIS methodology.

The vulnerability of the ground waters with the isohypses, the direction of the underground flow, as well as the land usage chart was basis for space stratification and defining locations of groundwater sampling. On the most sensitive locations the samples were taken and 20 active substances (pesticides) regularly used on the given area were examined.

At the site Lijevce polje examined 35 samples of ground water. In addition to 20 active substances (pesticides) analyzed the following parameters: pH, temperature, dissolved oxygen, water turbidity and conductivity.

Groundwater sampling was conducted expert team of Project, and the analysis of pesticides in water samples was made by the Agricultural Institute of Banja Luka.

The results of the analysis established five locations with high MDK content of pesticides, in comparison with the EU Directive 98/83/EC.

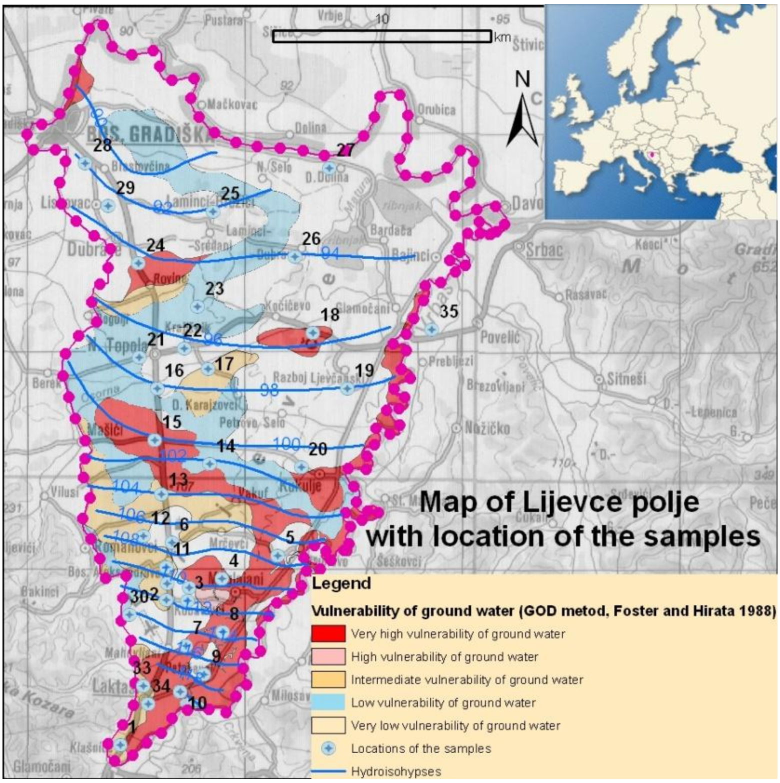

Figure 2. Map of Lijevce polje with location of the samples.

Based on the obtained results we can conclude the following:

1. compound gamma-BHC with concentration of 0.08 mg/l was found in sample No. 2. Place of sampling Kobatovci;

2. compound atrazine was found at the following sampling locations:

- Location of sampling Aleksandrovac (sample No. 6) concentration of 0.22 mg/l,
- Location of sampling Borac (sample No.12) concentration of 0.10 mg/l,
- Location of sampling Laminci (sample br.23) concentration of 0.10 mg/l,

3. alahlor compound with concentration of 0.10 mg / l was found in the sample No. 4 position sampling Srijem,

4. metolahlor compound was found in the following sampling locations:

- Location of sampling (sample no. 2) Kobatovci with concentration of 0.10 mg/l,

- Location of sampling (sample no. 6) Aleksandrovac with concentration of 0.10 mg/l.

Such results point to the conclusion that the impact of pesticides in ground water directly depends on the use of pesticides and the concentration used. Namely, in Aleksandrovac (sample 6) and Srijem (Paragon 4) downstream of the vulnerable areas, pesticide residues were found in ground water, which was expected if we know thet the upstream section is an intensive agricultural production. On the other hand, at the site of Al (sample 12), Laminici (sample 23) and Kobatovci (sample 2) hydrogeological environment is defined as less vulnerable due to the hydrogeological characteristics. The presence of residues of pesticides in these locations are directly linked to the dose of pesticide and way of using. Potential causes of unlogical presence of pesticide residues may be improperly packaging waste pesticides which often ends up in abandoned gravel pits or channels in the area Lijevce polje.

For the purpose of monitoring groundwater quality is necessary to establish a monitoring network of piezometar. Network of piezometar should develope in accordance with the defined groundwater vulnerability.

Out of the natural factors the vulnerability of ground waters was defined as characteristics of a hydrogeological environment and soil characteristics of the surface protection layer. Not least less important, human factor is present through present use of the land, and certainly the mode of use (dosage) of the agrochemicals. As a result of the research, education of population using pesticides in the production process was defined, in accordance with the space category of vulnerability and the culture being cultivated.

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abstract id: **494**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **Risk of pesticide pollution to groundwater — a case study to identify threatens to groundwater**

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keywords: pesticides, leaching, groundwater, modelling

In the project "Groundwater and Dependent Ecosystems: New Scientific and Technological Basis for Assessing Climate Change and Land-use Impacts on Groundwater (GENESIS)" coordinated by Bioforsk, the objective is to integrate new methods, concepts and tools for the revision of the Ground Water Directive and better management of groundwater resources. By case studies in different climatic regions various land use pressures are studied.

Recent research indicates that a major part of diffuse pesticide pollution originates from minor areas, "hot spots". Both micro topographical conditions and soil properties will influence where these "hot spots" are situated. In areas with cold winters below zero, large water quantities can be collected in terrain depressions during periods with frost in the soil, followed by rapid infiltration and transport of large water amounts down to groundwater in spring (Kværner et al., 2005). In Norway the most important groundwater resources are located in alluvial deposits along the rivers. Such areas are used for intensive cereal and potato production, and groundwater investigations demonstrate that diffuse pesticide pollution from agriculture is a major threat to these aquifers (Eklo et al., 2002). The case study in Norway is Grue located along the Glomma River in Hedmark County, north-east of Oslo. The area is situated above a deep basin filled with marine deposits beneath a top layer of fluvial sediments. The deposits consist mainly of sand with a top layer of flood plain sediments of silt and sand. The thickness of the unsaturated zone varied between 1.8 and 5.9 m. The mean groundwater recharge is estimated to be 300 mm year^{-1}. The velocity of the groundwater flow has been < 40 cm day $^{-1}$ at a hydraulic gradient of 0.2%. The main crops in the area are potatoes and cereals.

To identify threatens to groundwater pollution MACRO_GV (Lindahl, 2005) has been used simulating the movement of pesticides used in potatoes and cereals. The simulation set-up and output from the tool is similar to the FOCUS (2000) groundwater scenarios. Output consists of simulated average yearly leaching concentrations (20-year simulation) at one meter depth, and the long-term average concentration. Relevant soil parameters needed for the MACRO-GV simulations were extracted from the Norwegian Soil Data Base for 13 soil types in the Grue area. The results from the simulations with herbicides used in spring cereals are given in table 1–3. The applied dose of the pesticide represents the highest legal dose (NAD). The risk classes are based on the combination of simulated concentration and hydrological classes of the soil type.

Table 1. Soil types and selected properties.

	ATm4	AFs5	FOs5	TLt5	KMk5	KGl5	KLr5	TKi5	THg5
WRB-unit	Haplic Arenosol	Endogleyic Arenosol	Gleyic Fluvisol	Umbric Fluvic Cambisol	Endostagnic Fluvic	Fluvic Cambisol	Endostagnic Fluvic	Fluvic Stagnosol	Fluvic Stagnosol
Org. C (%)	1-2	2-3	3-5	>5	2-3	1-2	2-3	2-3	2-3
Influence of water	None	Gr.w. >50cm	Ground w.	Surface w.	Surf.w. >50cm	None	Surf.w. >50cm	Surface w.	Surface w.
Hydrological class	A	B	B	B	B	A	B	B	B

Table 2. Risk of herbicide leaching to groundwater from different soil types according to table 1.

Trade name	Active ingredient	Soil types ATm4	AFs5	FOs5	TLt5	KMk5	KGl5	KLr5	TKi5	THg5	Dosage (NAD)
Actril 3-D	Ioxynil	1	1	1	1	1	1	1	1	1	3 l/ha
	Dichlorprop - P	4	4	4	4	4	4	4	4	4	
	MCPA	1	1	1	3	2	1	1	1	1	
Ally 50 ST	Metsulfuron - methyl	4	3	3	3	3	4	3	3	3	0.012 kg/ha
Ally Class 50 WG	Metsulfuron - methyl	4	3	3	3	3	4	3	3	3	0.05 kg/ha
	Carfentrazone - ethyl	4	3	3	3	3	4	3	4	3	
Ariane S	Fluroxypyr 1-methylheptylester	4	3	3	3	3	4	3	4	3	2.5 l/ha
	Clopyralid	4	4	4	4	4	4	4	4	4	
	MCPA	1	1	2	3	3	1	1	1	1	
Roundup ECO	Glyphosate	1	1	1	1	1	1	1	1	1	4 l/ha
Express	Tribenuron - methyl	4	3	3	3	3	4	3	3	3	1 tabl./0.5 ha
Harmony Plus 50 T	Thifensulfuron - methyl	1	1	1	1	1	1	1	1	1	0.015 kg/ha
	Tribenuron - methyl	4	3	2	2	3	4	3	3	2	
Hussar	Mefenpyr - diethyl										0.2 kg/ha
	Iodosulfuron - methyl	3	2	2	2	2	3	2	2	1	
MCPA 750	MCPA	4	1	3	4	4	4	1	4	3	4 l/ha
Optica Mekoprop - P	Mecoprop - P	4	2	3	3	3	4	3	3	2	3 l/ha
Primus	Florasulam	1	1	1	1	1	1	1	1	1	0.1 l/ha
Puma Extra	Fenoxaprop - P - ethyl	1	1	1	1	1	1	1	1	1	1.2 l/ha
	Mefenpyr - diethyl										
Starane	Fluroxypyr 1-methylheptylester	4	4	4	4	4	4	4	4	4	2 l/ha

Table 3. Risk classes based on hydrology and pesticide concentrations.

	Concentrations (µg/L) simulated with MACRO_GV				
Hydrological class	< 0.001	0.001 - 0.01	0.01 - 0.1	0.1 - 1	> 1
A	1	2	3	4	4
B	1	1	2	3	4
C	1	1	1	1	1

1 = no risk
2 = low risk
3 = moderate risk
4 = high risk

Hydrological classes. A: Well-drained soils (natural drainage) with no drains or no gley features within 100 cm depth. B: Moderately well drained soils with gley features within 100 cm depth and poorly drained soils with gley features directly below the topsoil, or soils that have drains. Hydrological class C: Poorly drained soils formed on massive clays or shallow soils on hard rocks.

ACKNOWLEDGEMENTS

The project is financed by EU's 7th Framework program and Norwegian Research Council.

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abstract id: **496**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **Groundwater quality in the coastal aquifer system of Korinthos Prefecture (Greece)**

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keywords: Korinthos, quality, intrusion, groundwater, coastal aquifer

GEOLOGICAL AND HYDROGEOLOGICAL CONDITIONS

The study area is situated in the northern coastal part of Korinthos Prefecture and the geological structure of it, is presented in Fig. 1. An aquifer system occurs in the recent basin deposits, which consists of unconsolidated material, namely sands, pebbles, breccias and fine clay to silty sand sediments, characterized by a high degree of heterogeneity. Recent and older fluvio – torrential deposits originating from the streams-rivers that flow across the study area disrupt the lateral continuity of these sediments, the thickness of which varies from 30 m to 70 m and exceeds 100 m along the deposits of the river Asopos (Koumantakis et al.,1999a).

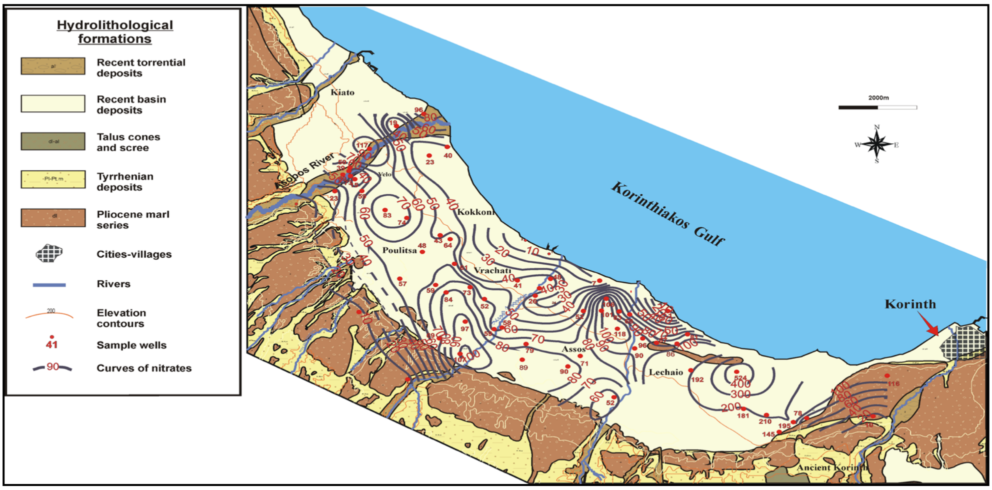

Figure1. Hydrogeological map of study area.

From a hydrogeological point of view the system consists of an unconfined phreatic aquifer superimposed on successive confined or semi-confined aquifers. Within the secluded thyrrenian conglomerate blocks overhanging aquifers of low potential may develop. Despite the documented heterogeneities however, it is suggested that on a regional scale a uniform aquifer may be considered on the basis that observed lithological anomalies are not extensive and most groundwater level measurements are indicative of a single piezometric surface. Mean hydraulic gradient as measured from the compiled piezometric map is $i = 0.006$. Transmissivity and storage coefficient values vary between $T = 2\times10^{1}–9\times10^{2}\ m^{2}d^{-1}$ and $S = 0.2–5\times10^{-2}$ respectively in the finer deposits (Koumantakis et al., 1999; Hionidi et al., 2001).

HYDROCHEMISTRY

Sixty two groundwater samples collected from boreholes and dug wells in two periods in November 2008 and in May 2009, were analyzed for major ions, nitrites and ammonia.

The average pH of groundwater is 7.4, thus indicating a slightly alkaline type. Electrical conductivity varies between 1000–6800 μS/cm and this is probably indicative of saline intrusion along the coastal areas of the studied system. The average value of TDS is between 750–4500 mg/l. The highest conductivity and TDS values are related to seawater intrusion as a result of the intensified exploitation (Panagopoulos et.al, 2001). Chloride concentration shows increase values because of the intrusion. Nitrates are noticeable throughout the entire region due to the extended use of fertilizers with particular high values in specific areas (Lecheo and Ancient Korinthos). The Wilcox diagram and the piper plot show the quality and the water type of groundwater. Groundwaters are of bad quality because of the salinity. The quality of waters is degrading in comparison to last decade; the intrusion is extended in the area and the water table level has significant fall.

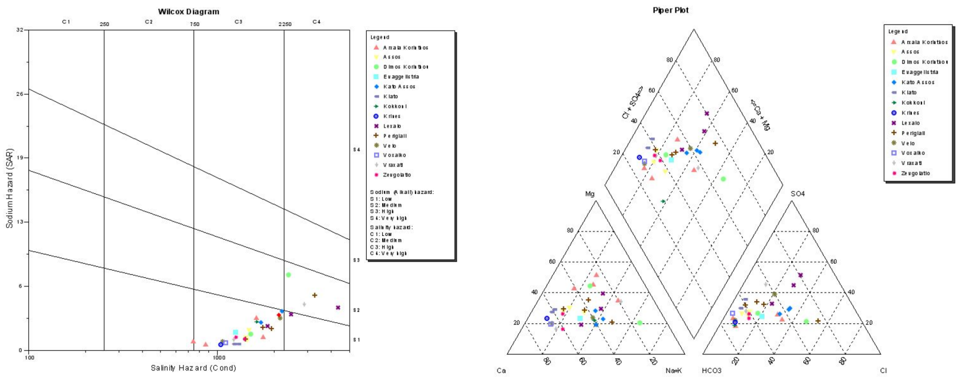

Figure2. Wilcox diagram and Piper Plot.

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abstract id: **509**

topic: **1**
Groundwater quality sustainability

1.4
Groundwater quality and agriculture

title: **Natural radionuclides concentration in sandy soil and groundwater**

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keywords: natural radionuclides, groundwater, agricultural activities

Soil is a very dynamic ecosystem of particular importance since, once contaminate, the soil acts as a potentially long-term source of environmental contamination of food, water and air. Twenty eight (cultivated and uncultivated) sandy soil samples from 14 locations and 14 underground water samples were collected from a farm in Hail region, middle region of Saudi Arabia. This study aim at evaluating the relationship between the agricultural activities in sandy soil and the underground water quality. Concentrations of U, Th and K (total and leachable) in soil and water samples were measured using ICP-MS. After 25 years of agricultural activities, the average concentrations of natural radionuclides in sandy soil did not show an obvious variation that could be due to the high filtration rate and low absorption capacity, i.e. low clay and organic matter contents, of sandy soils. Concentrations of natural radionuclides in the underground water seem that did not affected by agricultural chemicals and fertilizers due to high depth (about 600 m) of the underground water aquifer.

1.5 | Groundwater quality and mining

abstract id: **138**

topic: **1**
Groundwater quality sustainability

1.5
Groundwater quality and mining

title: **Implementation of a pump and treat system at Britannia mine north of Vancouver, British Columbia**

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keywords: pump and treat, seawater intrusion, mine tailings, groundwater modeling, FEFLOW

A pump and treat system was installed at the Britannia Mine located 50 km north of Vancouver in British Columbia (Figure 1), where a dissolved metal-laden plume associated with mine tailings and waste rock discharges to Howe Sound (Zawadzki et al., 2006). Pre-remediation mass flux associated with the groundwater pathway was estimated to be approximately 10 kg/day of dissolved copper and 16 kg/day of dissolved zinc which, together with surface water releases (O'Hara and Azevedo, 2008), resulted in the site being one of the largest point sources of metal pollution in North America discharging to a marine environment.

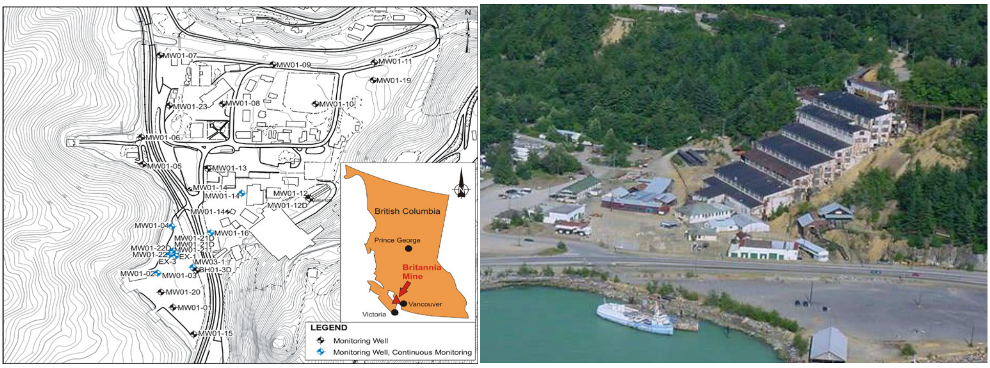

Figure 1. Site Location and Aerial View of Britannia Mine in 2005.

Hydrogeological conditions at the site are very dynamic due to tidal induced changes in hydraulic heads (approximately 2 m per tidal cycle up to 35 m away from the shoreline) and seasonal changes in the hydraulic gradients resulting from high precipitation (approximately 2.5 m/year) occurring primarily as rainfall in winter. The interpretation of site conditions is further complicated by the presence of freshwater/seawater intrusion which is also affected by daily and seasonal changes in groundwater flow conditions, and that is characterized by a highly diffuse transition zone resulting from these changes. Lastly, the presence of a major transportation corridor and old infrastructure associated with mining complicates the design and implementation of the remedial works.

Data collected during initial phases of system operation indicated that mine waste and sediments of the Britannia Creek alluvial fan were more heterogeneous than previously thought, and that a zone of higher permeability in the northern portion of the fan was responsible for an unexpected saltwater ingress into some pumping wells. A density-dependent numerical hydrogeological model of the site that was previously developed using FEFLOW (Diersch, 2009) and that simulated the freshwater plume transport and sea water intrusion was updated, and then used to optimize the wellfield. Optimization in this instance is to capture as much of the freshwater plume as practicable without inducing seawater intrusion to levels where the discharge water could not be treated. Model simulation trials indicated that pumping from two additional wells located in an inferred zone of higher permeability may improve system performance (Figure 2). Initial testing of the newly installed wells confirmed the presence of a higher permeability zone, and suggested that pumping from these wells increases overall plume capture.

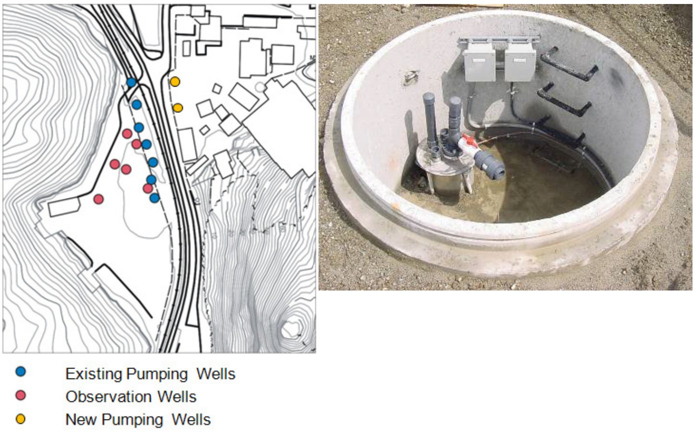

Figure 2. Pump and Treat System Components and Typical Wellhead Completion.

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abstract id: **176**

topic: **1**
Groundwater quality sustainability

1.5
Groundwater quality and mining

title: **The effects of Takht Coal Mine (Minoodasht, Iran) on the groundwater quality**

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keywords: coal mine, groundwater quality, Takht Mine

INTRODUCTION

Coal is one of the important sources of energy and an essential material in many industries (Wolela, 2007). The total coal deposit in the world is about 1060 MT, e.g. 5 times more than petroleum deposit. Iranian coal deposit is estimated to be 11.3 MT, %1.1 of the world deposit (Worldcoal). From an environmental point of view, coal mining is one of the notable sources for groundwater pollution. Extraction tunnel effluent and drainages from the coal and tailing depots are three possible way of releasing the pollutant into the environment in the vicinity of coal mines. Since in many cases sulfate minerals accompany coal layers, tunnel effluent are usually acidic and thus, carry heavy metals (Laus et al., 2007). Pyrite, marcasite, and pyrotite are the major sulfide minerals in coal. These minerals have the highest oxidation rate and play the main role in acidic mine drainage production (Butler et al., 2000). In some cases, neutralizing agents such as lime and dolomite exist in the area which cause increase in pH and causes the production of natural alkaline mine drainage (NAMD). This augmentation in pH consequently causes the precipitation of heavy metals although this does not affect the concentration of sulfate (Butler et al., 2000; Arthur et al., 1999). It is reported that total dissolved solids (TDS) in the mine drain could be controlled by complexes of iron and aluminum oxides. Adsorption of dissolved cations and anions in mine drains onto those complexes is completely dependent to pH. Increment of pH causes elevation of cation adsorption and precipitations while it decrease the anion adsorption and increase in anion solubility (Smith, 1999). A comprehensive study of open coal mines in the USA showed that quality characteristics of surface runoff and groundwater resources in the mining area were remarkably worsened. TDS, TSS, calcium carbonate, and heavy metals showed the highest increment in downstream of the mines (Laus et al., 2007). AMD effluent from Siti coal mine in Shanxi Province, Northern China, was held responsible for considerable augmentation in trace soil elements and sulfate ion in the soil downstream of the mine (Zhao et al., 2007).

This research dealt with the effects of coal extraction from Takht Coal Mine, southeast of Minoodasht, north of Iran, on the quality of the groundwater resources in the area.

METHODS AND MATERIAL

Samples were taken from the surface and subsurface water resources, both upstream and downstream, of the mine, extraction tunnel effluent, and tailing drainage in order to measure the physicochemical characteristics of water through pH, EC, concentration of cations (calcium, magnesium, and sodium) and anions (bicarbonate, chloride, sulfate, phosphate, and nitrate).

RESULTS AND DISCUSSION

The pH was measured at 8.41 and 8.12 in tunnel extraction effluent and tailing drainage. This finding indicates the presence of natural alkalinity mine drainage (NAMD) in the area. The field investigations disclosed that the mine is located in Shemshak calcareous formation. It can be interpreted by the geochemical characteristics of the area that neutralized the primary acidic mine drainage (AMD) into NAMD. NAMD is responsible for increment in pH of groundwater from 7.23 in upstream to 7.58 in downstream. pH in upstream runoff of the mine elevated from 8.21 to 8.29 in downstream runoff and 8.31 in downstream river. Entertainment of extraction tunnel effluent and tailing drainage with high concentration of calcium, magnesium, and sodium ions (68–120, 51–35, 160–402 ppm respectively) caused elevation in the concentration of these ions in the groundwater that in downstream were 2.7, 2.8, 4 times higher than upstream (Fig. 1). Also, coal mining doubled the concentration of magnesium and sodium ions in the downstream runoff in compare with upstream(Fig. 2).

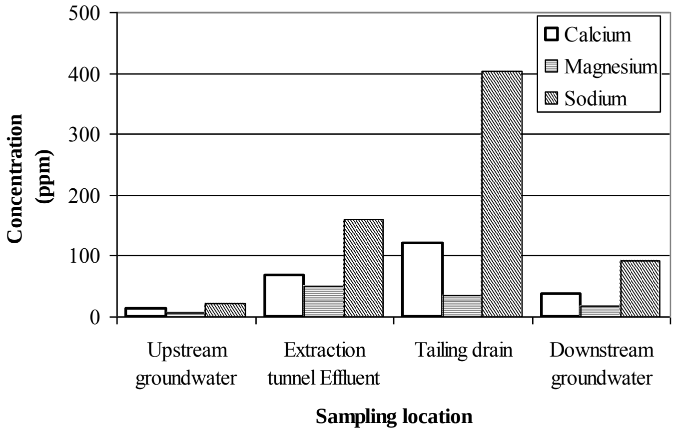

Figure 1. Cation concentrations in the groundwater, tailing drain, and tunnel effluent.

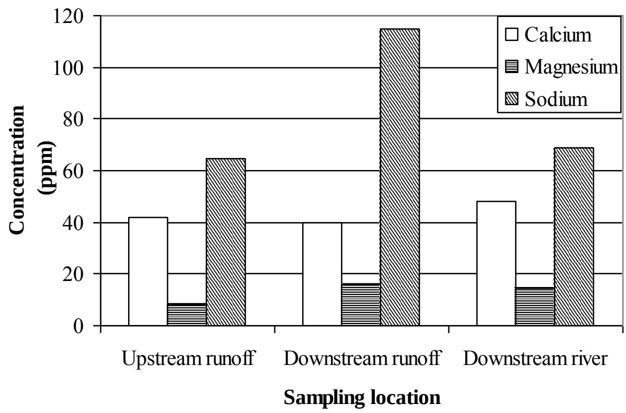

Figure 2. Cation concentrations in surface water.

The total concentration of anions was 2.15 meq/L in upstream groundwater which reached to 7.2 meq/L in downstream groundwater. This remarkable change in groundwater quality was due to the entering anions into the groundwater from tunnel extraction effluent and tailing drainage which contain sulfate (292.8–936 ppm), bicarbonate (378.2–305 ppm) and nitrate (114.1–868 ppm), (Fig. 3).

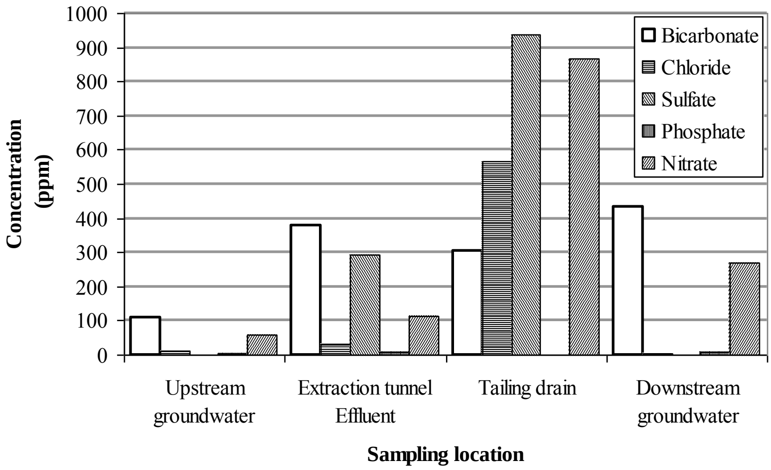

Figure 3. Anion concentrations in the groundwater, tailing drain, and tunnel effluent.

Mining also is responsible for increasing the concentration of bicarbonate and sulfate ions in downstream runoff. The total anion concentration increased from 5.35 meq/L in upstream runoff to 8.17 meq/L in downstream runoff and to 6.5 meq/L in the downstream river (Fig.4).

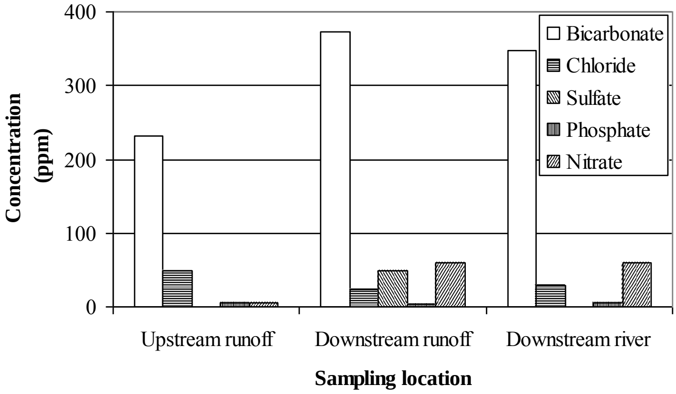

Figure 4. Anion concentrations in surface water.

CONCLUSION

It can be concluded that in the case of release of the NAMD with a pH of 8.41 into the environment, the augmentation in the concentration of calcium, sodium, magnesium, sulfate and bicarbonate are the major effects due to coal mining on the groundwater and surface water quality. Due to alkaline condition of the water resources in the region, it is predicted that the mining activities can increase the concentration of those heavy metals that have high solubility in basic solutions which opens the door for the further investigations.

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abstract id: **177**

topic: **1**
Groundwater quality sustainability

1.5
Groundwater quality and mining

title: **Assessment of the arsenic contamination in groundwater in Hired Gold Mine Zone (Northwest of Nehbandan, Iran)**

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keywords: arsenic contamination, groundwater, Hired Gold Mine

INTRODUCTION

Mineralization in mining zones, as one of natural complex deformations in primary rocks, is responsible for the release, concentration and spill of many heavy and toxic elements as well as metalloids into the water and soil bodies. Generally, gold deposits accompany metallic sulfide minerals and their oxidized products such as pyrite, arsenopyrite, chalcopyrite, sphalerite, limonite, and quartz. Arsenic, cadmium, and antimony minerals usually exist in gold deposits and thus, arsenic pollution is always a concern for these areas (Edinger et al., 2007). Distribution of arsenic in aquatic systems is controlled by pH and Eh (Takeno, 2005). By increasing pH, the concentration of As in water is elevated. Anions such as carbonate, phosphate, and sulfate also affect the mobility of arsenic in water (Villaescusa, Bollinger, 2008). Millions of people suffer from arsenic pollutions, usually with geogenic sources, around the world. Reports indicate several arsenic pollution symptoms in human due to exceeding level of arsenic in drinking water in Bangladesh, Argentina, Taiwan, Mexico, India, and the USA (Borgono et al., 1997; Chen et al., 1994; Del Razo et al., 1990; Dhar et al., 1997; Deschamps et al., 2005; Lasate, 2002). There are six areas in Asia where the groundwater is highly polluted with arsenic, namely, Cambodia, Laos, Pakistan, Myanmar, Vietnam, and Nepal (Zeng, 2003). Arsenic pollution can be accounted for diabetes, kidney disease, cardiovascular diseases, skin lesions, and cancer (Katesoyiannis, Katesoyiannis, 2006; Lackovic, Nikolaidis, 2000). Gold mines can change the concentrations of the heavy metals as well. For example Baba and Gungor (2002) reported that gold mines may cause an elevation on the concentration of Pb and Cd in groundwater. The present research aimed to evaluate the effects of gold mineralization on the arsenic pollution in the groundwater resources in the Hired tin-gold exploration zone, north-west of Nehbandan, Iran.

DESCRIPTION OF THE STUDY AREA

Hired is a mining area located between 59°8'00"E and 59°15'00"E and 31°54'00'' and 31°59'00'' N with the total area of 97 km^2. Hired Gold intrusion recently has been accepted as a gold mine. Gold mineralization has been identified in four areas, targets 1 to 4, when the biggest and most important one is Target 1. Mineralogical studies confirm the existence of arsenopyrite as a major mineral in the east of Target 1. Also, a high level of arsenic anomaly was observed.

MATERIALS AND METHODS

To determine the effects of gold mineralization in the quality of the groundwater resources, samples were taken from five qanats and four wells throughout the region and the pH was measured in site. Rock samples were taken for microscopic studies. The concentrations of arsenic in water and rock samples were determined by ICP-MS techniques in the lab.

RESULTS AND DISCUSSIONS

Microscopic studies disclosed the abundance of arsenopyrite accompany with pyrotite and chalcopyrite in the rocks (Figs. 1 and 2). Chemical analysis of the rocks showed that the concentration of arsenic in rocks increases toward south (gold mineralization zone) and ranges between 2.6 ppm and 1835 ppm (Fig. 3).

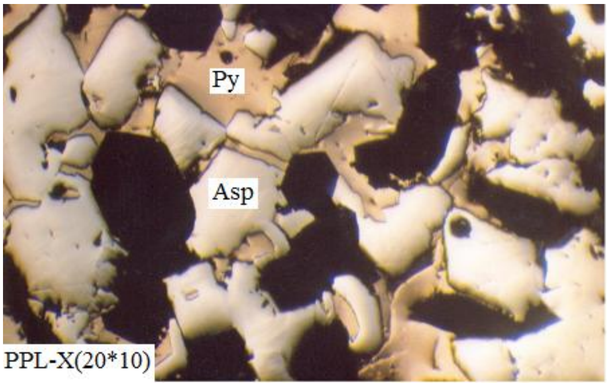

Figure 1. Arsenopyrite (Asp) accompanying pyrotite (Py).

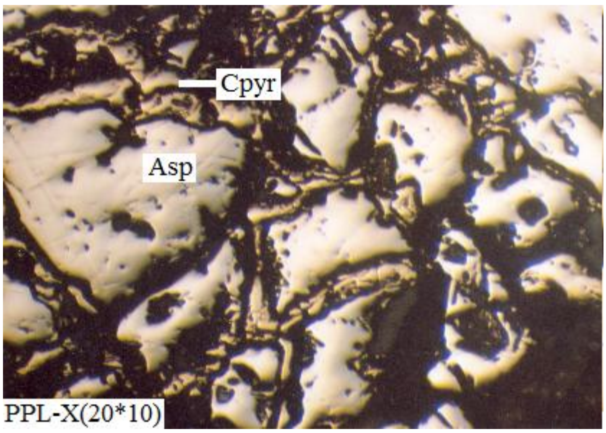

Figure 2. Arsenopyrite (Asp) accompanying chalcopyrite (Cpyr).

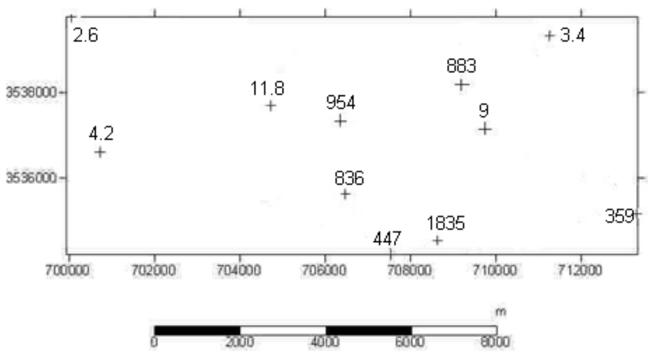

Figure 3. Distribution of the concentration of arsenic in the rocks throughout the region (in ppm).

The pH in wells and qanats of Abrikheh, Rahimi, Shoorabeh, Alizadeh, Golchin, Lakatoo, Noori, Hematabad, and Hired was recorded at 7.92, 7.80, 7.75, 7.75, 7.33, 8.13, 7.4, 7.45, and 7.57 respectively (Tab. 1).

Table 1. The pH of the groundwater resources in Hired Gold Exploration Zone.

Sample Location	pH
Abrikheh Well (S6)	7.92
Rahimi Qanat (S5)	7.80
Shorabeh Qanat (S1)	7.75
Alizadeh Well (S10)	7.75
Golchin Well (S2)	7.33
Lakatoo Well (S3)	8.13
Noori Qanat (S9)	7.40
Hematabad Qanat (S8)	7.45
Hired Qanat (S4)	7.57

The concentration of arsenic was as high as 1426.2, 101.8, and 37.3 (in ppb) in Lakatoo, Abrikheh, and Rahimi respectively as shown in Figs. 4 and 5. The results also indicate a direct correlation between pH and arsenic concentration in water. The highest concentration of arsenic occurs in Lakatoo (1426.2 ppb) which has the highest pH (8.13). Concentrations of arsenic in Hematabad, Hired, Shoorabeh, and Rahimi qanats and Alizadeh, Abrikheh, and Lakatoo wells are 1.1, 1.3, 1.9, 3.7, 2.2, 10.2, and 142.6 times more than the allowable limit for drinking water.

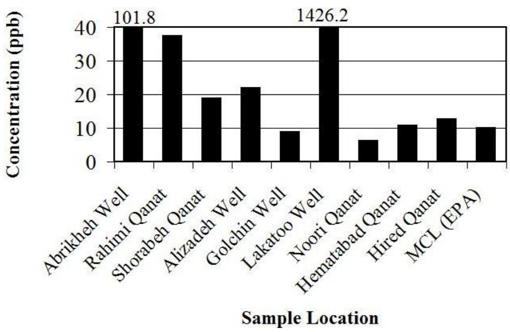

Figure 4. Concentration of arsenic in the groundwater resources in Hired Gold Exploration Zone.

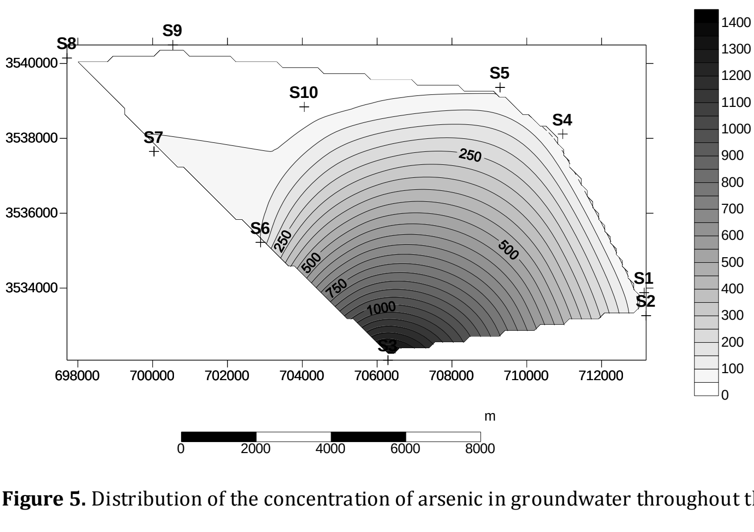

Figure 5. Distribution of the concentration of arsenic in groundwater throughout the region (in ppb).

The high level of EC (ranges from 3800 μS in Abrikhe Well to 13040 μS in Hematabad Qanat) along with the high concentration of arsenic makes the groundwater resources of the region unsuitable for drinking water. In terms of distribution of the concentration of arsenic in groundwater, 4 zones could be identified (Tab. 2). Concentration of arsenic is highest in south-west and north-east of the region.

Table 2. Distribution of As in the mineralization area.

Zone	Sample Location	Position	Avg. As Concentration (ppb)
1	Abrikheh Well and Lakatoo Well	SW	764.00
2	Shorabeh Qanat and Golchin Well	SE	13.70
3	Hired Qanat and Rahimi Qanat	NE	25.00
4	Hematabad Qanat, Noori Qanat and Alizadeh Well	NW	9.96

The highest concentration of arsenic is detected in Zone1, which is charged by groundwater from Targets 1 and 3. The only zone with allowable level of arsenic is Zone 4, located in North West of the region. Arsenopyrite (FeAsS) is the main arsenic mineral in all zones which shows a high anomaly in the gold exploration zone, thus, it can be the main source of arsenic in groundwater.

CONCLUSION

The effect of Hired Gold Mine on the groundwater quality in the whole region was verified through correlation between the arsenic minerals and the concentration of arsenic in groundwater. The highest level of arsenic was detected in Lakatoo Well and Abrikheh (1426.2 and 101.8 ppb respectively). Groundwater in the whole region is highly polluted and it is not suitable for drinking. The concentration of arsenic in rocks showed the same trend and augmented southward. Since the current situation is due to natural geological condition, extreme care should be taken before any attempt for extraction and mining activity in order to prevent more problems in water quality.

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abstract id: **236**

topic: **1**
Groundwater quality sustainability

1.5
Groundwater quality and mining

title: **Determination of processes affecting groundwater quality in coastal aquifer of Puri City using multivariate statistical analysis**

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keywords: principal component analysis, hierarchical cluster analysis, groundwater quality, Puri city

INTRODUCTION

Determination of processes affecting groundwater quality in a coastal aquifer is very complex. The variability of the parameters is linked to various biological, physical and chemical processes taking place in the aquifer such as: organic matter degradation/ aerobic respiration, iron reduction, cation exchange, mixing of salt water with fresh water etc. In order to characterize water quality of a place, it becomes necessary to collect large dataset of water quality parameters. Due to effects of multiple processes on a water quality parameter as well as the collection of large dataset of parameters, it becomes difficult to interpret relationships among the parameters and it is not possible to interpret the governing biogeochemical processes. Multivariate statistical analysis has been used in recent years to provide a quantitative measure of relatedness of water quality parameters and to suggest the underlying processes in groundwater aquifers. Recent studies have confirmed the usefulness of multivariate analysis techniques for (i) evaluation and interpretation of groundwater quality data sets (Singh et al., 2009), (ii) providing insight into the processes (Machado et al., 2008; Báez-Cazull et al., 2008), (iii) identifying critical water quality issues and possible sources of pollution/ polluting processes (Sargaonkar et al., 2008; Kumar, Riyazuddin, 2008) and (iv) interaction of river water/groundwater and groundwater mixing (Reghunath et al., 2002).

In this paper, the multivariate statistical analysis such as principal component analysis (PCA) and hierarchial cluster analysis (HCA) were applied to the data sets of chemical analysis of groundwater samples collected in two seasons (one set in November 2006, after monsoon rain and another set in June 2007, before monsoon), to elicit hidden processes affecting groundwater quality in the coastal aquifer of Puri city in Orissa.

Study area

The study area is a 16 km^2 urban area of which the Puri built up area occupies about 10 Km^2 and the remaining land surface is almost vacant. Most of the vacant land surface constitutes two groundwater well fields which supply domestic water to Puri city. The city is located on the coast of Bay of Bengal in Orissa. The aquifer beneath is sandy and unconfined, having depth of about 40 m and lies on a thick clay layer. Thin clay layers are also found in isolated lens and patches at shallow depths within the unconfined aquifer. The area receives rainfall during monsoon season (2nd week of June to October).

METHODOLOGY

Water Quality Parameters and Data Analysis

The water quality data of Puri city were obtained from two sampling seasons. In the first sampling season in November 2006, after monsoon rain, groundwater samples were collected from 51 numbers of tube wells and production wells scattered all over the city area and two groundwater well field areas. In the second sampling season in the first week of June, before rain, water samples were collected from 43 numbers of tube wells and production wells from the city area as well as two groundwater well field areas. The water samples were analysed for chemical parameters at NEERI laboratory following Standard Methods. The eleven water quality parameters considered for multivariate statistical analysis are pH, total dissolved solid (TDS), alkalinity, Na, K, Ca, Mg, Fe, SO_4, NO_3 and Cl. Before performing PCA and HCA, the parameters in the data sets were tested for normality. The distribution of all parameters in the two data sets was found non-normal except for pH, which fits normal distribution. In order to avoid the problem of difference in scale, i.e., range of values and unit, among the water quality parameters, the parameters were standardized using z-score: $z = (y_i - \hat{y})/s$, where $\hat{y}$ is the average value of a parameter in the sampling season and s is its standard deviation. The software SPSS Statistics 17.0 was used for data standardization and multivariate statistical analysis.

Principal Component Analysis

The PCA is performed to reduce the large data set of variables, i.e. water quality parameters, into few factors called the principal components which can be interpreted to reveal underlying data structure. The maximum number of principal components is equal to the number of variables. But, only few factors based on Kaiser criterion, i.e., principal components having latent root or Eigen value greater than one, are retained in the analysis. The factor loadings matrix is rotated using varimax orthogonal rotation to maximize the relationship between the variables and some of the factors. This rotation results in high factor loadings for the variables correlated in the factor and low loadings for the remaining variables. The suitability of the data set for PCA is tested by Kaiser-Meyer-Olkin (KMO) and Bartlett's tests. KMO is a measure of sampling adequacy and indicates the proportion of variance which might be caused by underlying factors. A high value (close to 1) indicates usefulness of PCA. The Bartlett's test of sphericity indicates whether correlation matrix is an identity matrix, which indicates that variables are unrelated.

Hierarchial Cluster Analysis

HCA is useful to group water quality parameters into clusters so that parameters within a cluster are similar to each other but different from those in other clusters. HCA is an unsupervised pattern recognition technique and uncovers intrinsic structure or underlying pattern in a data set without making a priori assumption about the data in order to classify the parameters into clusters based on their similarities. In HCA clusters are formed sequentially, starting with the most similar pair of variables and forming higher clusters step by step. The process of cluster formation is repeated until a single cluster containing all the variables are obtained. The result of clustering is seen visually as a dendrogram. The HCA of the standardized data set using Ward's method based on Euclidean distance was performed to classify the parameters into clusters based on their similarities. This method was found to provide best dendrogram of meaningful clusters with the proximity of clusters measured in a rescaled distance cluster combine.

RESULTS AND DISCUSSION

Hydrochemistry of major ions

The physico-chemical analysis of groundwater samples in the two sampling seasons indicates that the dominant major cations are Mg^{2+}, Ca^{2+}, Na^{+} and K^{+} and the dominant anions are HCO_3^{-}, Cl^{-} and SO_4^{2-}. The water quality parameter concentrations vary across space and time in the two sampling seasons (NEERI, 2008; Vijay et al., 2009).

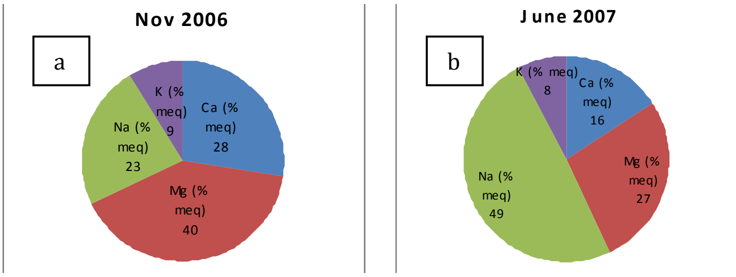

Figure 1. Changes in chemical facies (average value of cations in % milli-equivalent) in groundwater samples in a) post-monsoon (Nov 2006) and b) pre-monsoon (June 2007).

The average concentrations of major cations in two sampling periods are shown in Figure 1. The concentration of Na^+ ions are observed greatly increased in pre-monsoon along with reduction in concentration of Mg^{2+} and Ca^{2+} ions. The concentration of parameters appears to be affected by several geochemical processes occurring in the aquifer. The aquifer is recharged by monsoon rain each year during second week of June to end of October. Dilution and freshening is a predominant process during this period. The intrusion of sea water occurs in summer due to favourable hydraulic condition. Sea water intrusion and freshening of groundwater occur in a cyclic manner and have influence on the chemistry of groundwater quality parameters.

Principal Component Analysis

In the post-monsoon data set, four factors were found significant having Eigen values greater than unity and together they account for 73% of the variability of the data set. In the pre-monsoon data set, four factors were found significant having Eigen values greater than unity and together they account for 81% of the variability of the data set. The factor loadings obtained after varimax orthogonal rotation from the two data sets are given in Table 1.

Table 1. Varimax orthogonal rotated factor loadings from principal component analysis of water quality dataset of post-monsoon (Nov 2006) and pre-monsoon (June 2007).

Parameter	Factor 1 (27%) Post-monsoon	Factor 1 (35%) Pre-monsoon	Factor 2 (24%) Post-monsoon	Factor 2 (19%) Pre-monsoon	Factor 3 (12%) Post-monsoon	Factor 3 (15%) Pre-monsoon	Factor 4 (10%) Post-monsoon	Factor 4 (12%) Pre-monsoon
Fe	-0.269	0.039	-0.095	-0.197	0.156	-0.004	**-0.809**	**0.870**
pH	-0.464	-0.075	0.040	-0.068	0.185	**-0.861**	**0.606**	-0.039
TDS	**0.841**	**0.832**	0.441	0.367	0.080	0.302	0.028	0.150
Alkalinity	0.306	0.195	**0.855**	0.483	-0.089	0.040	0.132	**0.681**
Na	0.295	0.255	**-0.526**	**0.848**	**0.581**	0.038	0.099	-0.050
K	0.302	0.236	**0.794**	**0.878**	0.093	0.121	0.145	0.011
Ca	0.183	**0.564**	0.361	0.134	**0.534**	**0.685**	0.059	-0.043
Mg	0.156	**0.843**	**0.765**	0.268	0.148	0.088	-0.039	0.192
SO4	**0.845**	**0.856**	0.284	0.245	-0.104	0.333	0.039	0.014
NO3	0.250	**0.742**	-0.029	0.131	**-0.733**	-0.319	0.117	0.047
Cl	**0.928**	**0.848**	0.146	0.116	0.060	0.338	0.066	0.014
Interpretation of Processes	Dilution of saline and fresh water	Mixing of saline and fresh water/ Anthropogenic pollution	Mineral dissolution	Cation exchange	Weathering/ Anthropogenic pollution	Mineral precipitation	Organic matter degradation/ Iron reduction	Organic matter degradation/ Iron reduction

The factor loadings include both positive and negative loadings. Loadings close to ±1 indicate a strong correlation between a variable and the factor. Loadings higher than ±0.75 are considered strong correlation, loadings between ±0.5 to ±0.74 are considered moderately correlated and loadings approaching 0 indicate weak correlations (Liu et al., 2003). Based on the significant factor loadings, each factor has been assigned a process which the significant variables are likely to be associated within the factor. The processes which have been interpreted from the factor loadings of each factor are given in Table 1.

In the post-monsoon sampling period, in Factor 1, the variables with strong loadings are TDS, SO_4 and Cl. This factor explains 27% of the variability in the data set. The process assigned to this factor is dilution of groundwater since the concentration of the parameters chloride and sulphate is very much reduced due to recharge effect of rain water as compared to the concentration of these parameters in pre-monsoon, i.e., summer samples. Factor 2 explains 24% of the variability and is highly correlated with parameters alkalinity, K and Mg. This factor is interpreted as mineral dissolution factor. The K and Mg ions are released to groundwater due to dissolution of minerals bearing these ions during recharge of aquifer by rainfall. Factor 3 accounts for about 12% of the variance of the data set and includes Na, Ca and NO_3 parameters which are moderately correlated to the factor. The concentration Na is reduced in recharge process. The sign of NO_3 is negative. Two distinct processes are interpreted, weathering and anthropogenic pollution. The Ca concentration is increased due to weathering or dissolution of calcite minerals such as lime stone which is abundant in the study area. The other process is interpreted as anthropogenic pollution due to presence of NO_3 in this factor, which has its origin from on-site sanitation in the study area. Due to dilution, concentration of NO_3 is reduced. Factor 4 accounts for 10% of variability and has loadings of Fe and pH. The loading of Fe is strong and negative and the loading of pH is moderate and positive. The opposite sign of pH indicates that its value is decreased due to dissolution of Fe by microbial degradation aided by the presence of organic matter from sewage in the aquifer. This process is very complicated and needs detailed study.

In the pre-monsoon sampling, Factor 1 accounts for 35% of variability and includes TDS, SO_4 and Cl, Mg and NO_3. The loadings of TDS, SO_4, Cl and Mg are very strong and that of NO_3 is moderate. Two processes are interpreted, mixing of saline sea water with fresh groundwater and anthropogenic pollution. During summer season, without recharge, lowering of groundwater table occurs and the saline water front moves landward due to lower ground water head. In the mixing zone, mixing of saline water with fresh groundwater increases concentration of SO_4 and Cl parameters. The parameter NO_3 indicates pollution of groundwater by domestic waste water infiltrating from the on-site sanitation systems. The Factor 2 accounts for 19% of variability and includes parameters Na and K which are strongly correlated to this factor. The process attributed to this factor is called cation exchange. Factor 3 accounts for 15% of variability and rendered two parameters Ca and pH of which Ca has moderate loading and pH has strong negative loading. The process interpreted is called mineral precipitation, i.e. precipitation of calcium in groundwater onto the aquifer material, i.e. sand. Factor 4 accounts for about 12% of data variability and rendered two parameters: Fe, strongly correlated and alkalinity, moderately correlated with Factor 4. This factor is identified as organic matter degradation/ iron reduction process. The microbial degradation of organic matter in the aquifer is associated with iron reduction.

When sea water intrusion occurs, ion exchange process is said to take place. In this process, Na^+ ions present abundantly in sea water are adsorbed on the exchanger surface, i.e. the clay layer.

The Ca^{2+} ions previously present in the exchanger surface are exchanged with Na^{+} ions and Ca^{2+} ions are released to the groundwater (Appelo, Postma, 2005). The groundwater becomes calcium chloride or magnesium chloride type. During recharge of aquifer by rain, i.e. freshening of aquifer, groundwater becomes rich in Ca^{2+} and Mg^{2+} cations and HCO_3^{-} anion due to dissolution of calcium and magnesium bearing minerals present in the aquifer. Flushing takes place during this period and by the process of reverse ion exchange process, Na^{+} ions present in exchanger surface are replaced by Ca^{2+} ions. So, groundwater becomes rich in Na^{+} ions and calcium bicarbonate type water converts to sodium bicarbonate type water. With more flushing, sodium bicarbonate type water converts to calcium bicarbonate type water. But, in the study area, in pre-monsoon samples, concentrations of Na^{+} and K^{+} were found increased and concentrations of Ca^{2+} and Mg^{2+} reduced compared to their concentrations in post-monsoon samples. The increase of Na^{+} and K^{+} concentration in pre-monsoon samples can not be explained by cation exchange process since Ca^{2+} and Mg^{2+} concentrations in water samples are supposed to increase when ion exchange process takes place. The reduced concentrations of Mg^{2+} and Ca^{2+} in pre-monsoon can be explained by precipitation process. Due to mixing of sea water and cation exchange process, calcium and magnesium ions reach super saturation state causing their precipitation (Chapelle, 1983). In the study area, cemented sandy strata probably due to calcium precipitation have been observed at 5 to 7 m depth near the beach. This observation supports the hypothesis of precipitation.

Hierarchial Cluster Analysis

HCA is a powerful data mining technique. In this study, the Ward's method with Euclidean distance provided visually meaningful dendrograms. The HCA of two data sets produced two dendrograms which are shown in Figure 2. The processes interpreted from factors and the clusters from two data sets are consistent.

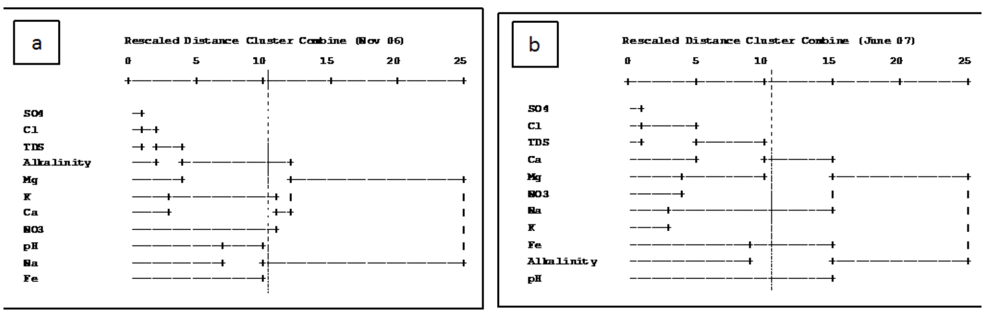

Figure 2. Dendrogram of a) post-monsoon (Nov 2006) data set and b) pre-monsoon (June 2007) data set

CONCLUSIONS

Groundwater quality data set of Puri city, Orissa in India collected during post-monsoon season of November 2006 and pre-monsoon season of June 2007 were analysed using two different multivariate statistical techniques such as PCA and HCA. In PCA of two standardized data sets, four factors were obtained from each data set with varimax rotation. Though exploratory in nature, PCA reduced the two large data sets into two small matrices. The factors aided in the interpretation of geochemical processes occurring in the coastal aquifer. From post-monsoon data set, the processes interpreted from four factors are dilution of groundwater, mineral dissolution, weathering with anthropogenic pollution and organic matter degradation with iron reduction. The processes interpreted from four factors in pre-monsoon data set are mixing of saline and fresh water with anthropogenic pollution, cation exchange, mineral precipitation and organic matter degradation with iron reduction. In each of the two data sets, HCA with Ward's method produced four grouping of variables. The interpretation of the processes by PCA and HCA are consistent. The present study validated usefulness of the PCA and HCA techniques to interpret complex geochemical processes in a coastal aquifer.

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abstract id: **296**

topic: **1**
Groundwater quality sustainability

1.5
Groundwater quality and mining

title: **Hydrogeological studies in diapiric-layering salt formations: The case of the East of Catalonia Potassic Basin**

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keywords: aquifer, contamination, salt, mine, subsidence

INTRODUCCION AND GEOGRAPHICAL SETTING

The Catalan Potassic Basin (CPC), located 70 km NW from the City of Barcelona (Fig. 1), is usually described as a part of a regional tick regressive-sedimentary EbroTertiary Basin that includes marine, evaporitic-transitional and continental facies, overlying by no-consolidated quaternary alluvial sediments and affected by Alpine-related tectonics structures (faults and folding). The main rivers in the CPC are the Llobregat and Cardener. The current hydrogeological knowledge of the area is poor and it is basically restricted to the shallower formations (less than 50 meters depth).

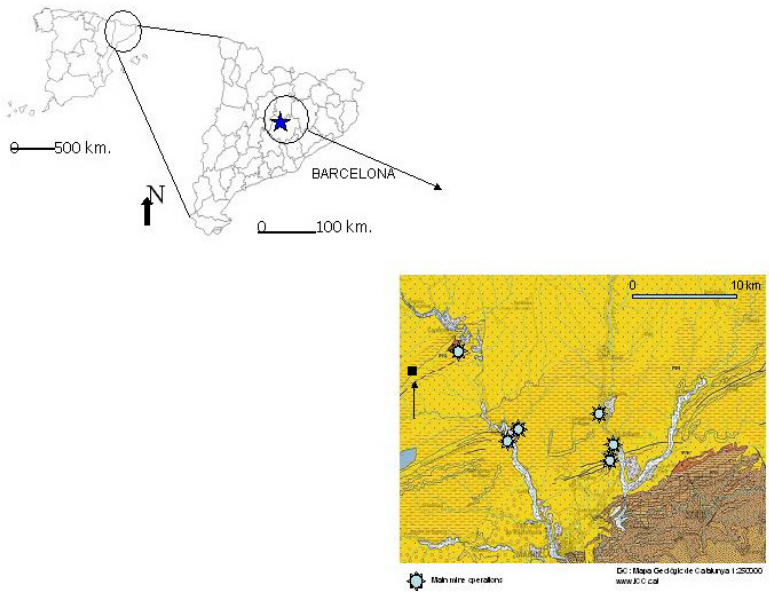

Figure 1. Geographical and Geological map of the Study Area showing the main mine works after ICC, 19XX. Geological map legend: Grey: alluvial unconsolidated Quaternary formations. Yellow: upper Paleogen Formation (Eocene-Oligocene). Brown: lower Paleogen Fm.

The natural salinity of the quaternary alluvial aquifer is low and it is mainly related to the salinity of the river and the lateral groundwater inflow from the Tertiary aquifers. In the Tertiary aquifers salinity seems to increase with depth. The piezometric relation between these two aquifers also controls the hydrogeological and chemical behavior in the Basin. Both aquifers, specially the alluvial one, are used for urban supply or local irrigation, and the Llobregat River is the main recharge source for the Lower Valley and Delta aquifers, located 60km SE, that are an strategic reserve of fresh water for Barcelona Urban Area.

The intense underground mining activity used in the exploitation of K-salts (Silvite and Carnalite) in the CPC during the last century, has provoked the appearance of saline springs and/or the salinization of old ones (Fig. 2a), groundwater contamination mainly from dumps (Fig 2b) and probably, the existence of subsidence and dissolution sink holes areas (Fig. 2c).

HYDROGEOLOGICAL CONTEXT

The objective of the actual hydrogeological studies in the CPC area is focused on the characterization of the Tertiary and alluvial aquifer in order to define their conceptual model. To obtain this information several investigation wells and piezometers with different depths were drilled and geophysical testified in both aquifers to obtain information of: groundwater levels, hydraulic parameters, hydrogeochemical compositions, thermal gradients and isotopic signatures.

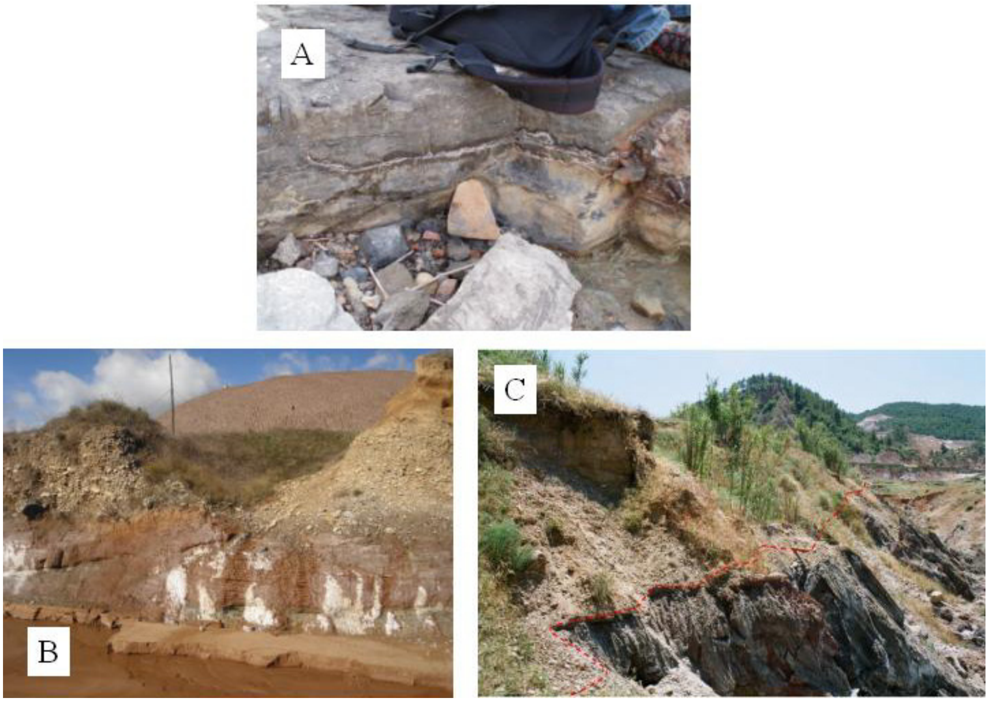

Figure 2. A) High salinity groundwater flowing across the Carbonate Tertiary fracture system and related white halite crystallizations (Sallent). B) Salt dumps, composed mainly by halite, with minor concentrations of K-chloride minerals, and mud flotation tails with organic compounds (VOC's and SVOC's). C) The existence of underground potash mining provoked, in some areas, subsidence and collapse problems were groundwater plays a critical role, e.g. part of the Cardener alluvial meander in the locality of Cardona, collapsed in 2002 due to a salt cavern generated in its base.

Regional piezometric context of the Tertiary formations described a general N-S, NW-SE flow in the area (Fig. 3), but several local singularities must be considered:

- The existence of preferential flow across the main fracture zones that locally modify the general distribution of the hydraulic gradient. In some of these areas (e.g. Llobregat River, in Sallent) the piezometric level could be periodically higher than the river bed surface level.
- Permanent main rivers (Llobregat and Cardener) and their second or third order ephemeral tributaries are the principal drain systems of the alluvial and Tertiary aquifers.

The distribution of the hydraulic parameters showed lower transmissivity in Tertiary formations (T from 0.1 from 15 m^2/d) and higher ones in alluvial sediments (T from 1 to 400 m^2/d). Otherwise, the trasmissivity in fractured Tertiary areas could reach 1 or 2 orders of magnitude higher than the regional average.

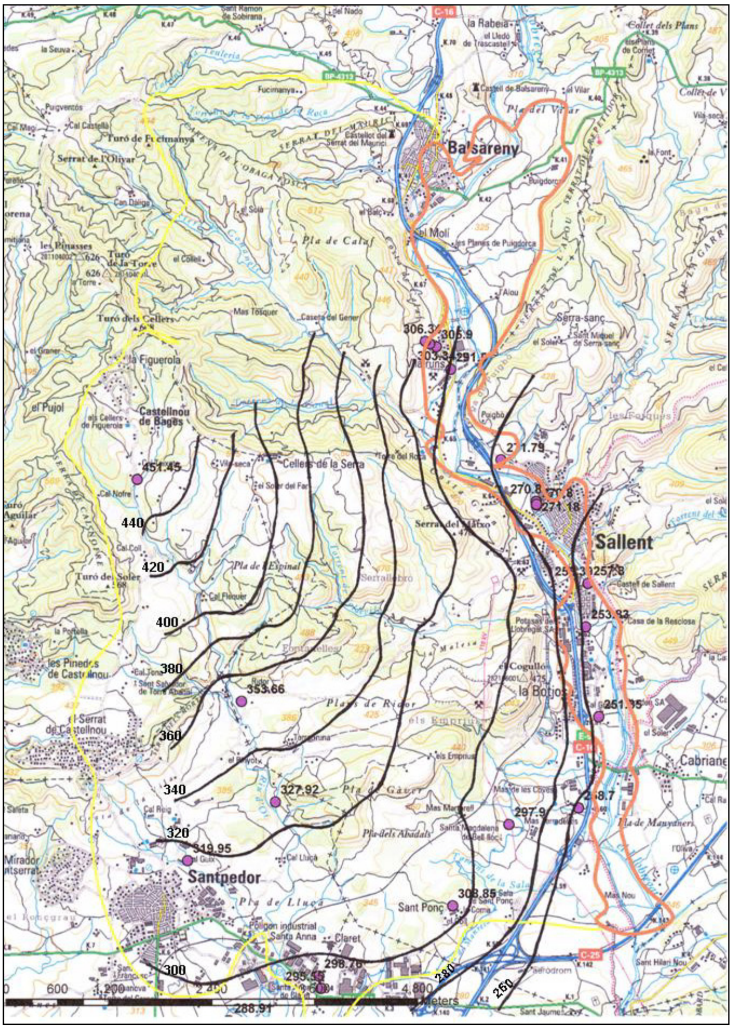

Figure 3. Piezometric regional map of the Tertiary formations in Llobregat-CPC area (composed partially with data from Escorcia, et al., 2009).

The hydrogeochemical and isotopic studies revealed a regional fresh water input in the shallow Tertiary and alluvial aquifers, and their coexistence with two main salinization sources:

- A saline natural source related to the Eocene marine salt layers that showed an increase in salinity with depth across the Tertiary formation,
- Anthropogenic saline point sources related mainly with K-mine dumps, and the rest of mine installations (usually associated with VOC's and SVOC's compounds). In that context, the influence of the saline plumes is basically found in the shallower levels of the aquifers.

The ratio between K and Cl is useful to fix other hydrogeological controls. The K-Chloride minerals (Carnalite and Silvite) solubility is higher than Halite solubility (Fig. 4) and also they are minor components of dumps.

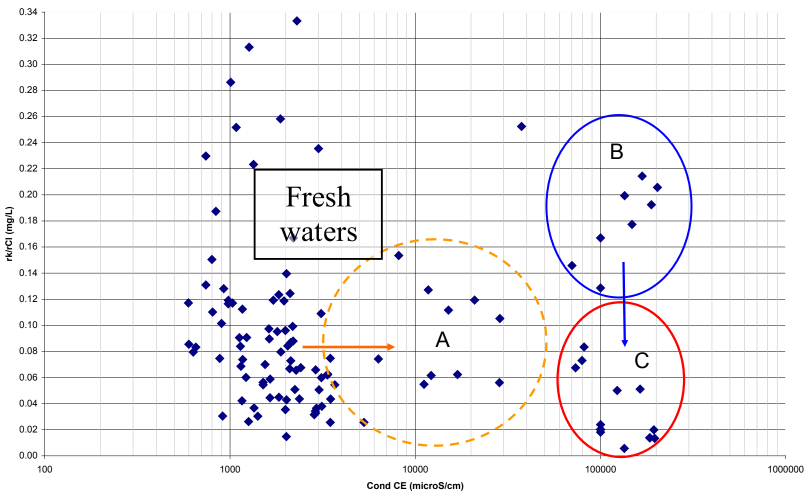

Figure 4. rK/rCl .vs. EC. Group A: fresh regional waters partially affected by salinization. Group B: saline groundwater not affected by selective removal of K (water recharged from actual dumps or Tertiary regional deep water circulating along K-rich formations), Group C: saline groundwater affected by selective removal of K-rich minerals (water recharged from old dumps or preferential flux along regional faults).

This difference produces two main effects in the area:

- The existence of a rK/rCl specific signature related to the age of the dumps, where old dumps have lower rK/rCl than the new ones,
- The probable difference in these indexes between the regional deep flow, and a more localized preferential flow, with higher rK/rCl, governed by regional Alpine faults systems, from the deep Tertiary aquifer towards the surface.

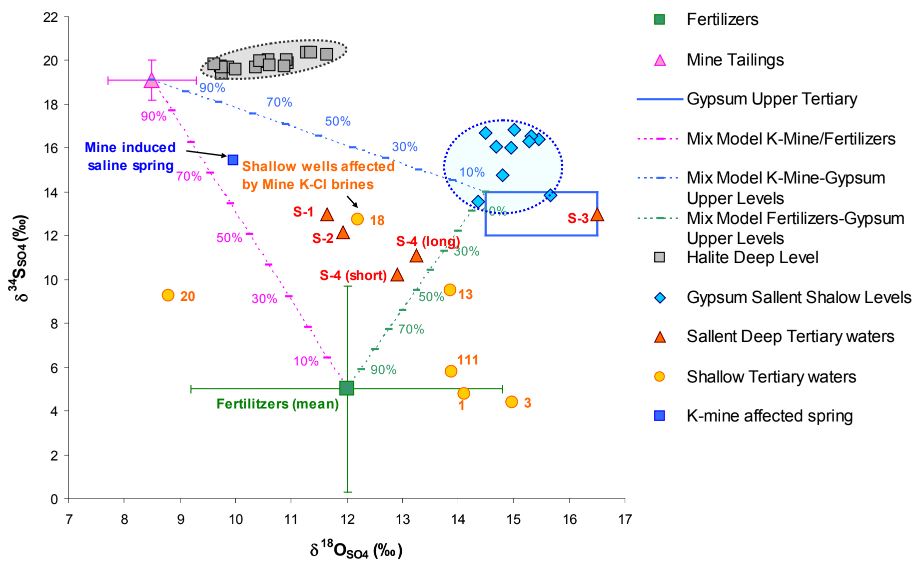

Figure 5. $\delta^{34}S$–$\delta^{18}O$ plot indicating the salinity origin, according to Otero and Soler 2002, 2003.

Dissolved sulfate isotopic composition has been demonstrated as a tool to distinguish the origin of salinity in the CPC (Otero, Soler, 2002; 2003). Sulphate isotope composition of shallow Tertiary waters indicates that salinity is the result of a mixing within natural sulphate and sulphate form fertilizers; only in the case of two wells (indicated in figure 5) it is clear the influence of mining activity. In the case of deep Tertiary wells, well S-3 shows that salinization is from natural interaction mixed with sulfate from fertilizers used in the area. In deep wells 1 and 2, salinity is the result of a fluid mix from natural interaction with the upper levels of Tertiary materials, sulfate from fertilizers and Halite-Potassic levels. In these wells is not possible to distinguish between natural interaction with sedimentary rich-potassium levels and mining lixiviates who show the same isotopic signature.

CONCEPTUAL MODEL

Recharge from rain infiltration is the main input of water in CPC Tertiary aquifers, that is complemented by lateral groundwater inputs, basically from their north limit. The general behavior of this aquifer is a typical multilayered one. The porosity seems basically secondary, where the water flows by strata discontinuities or major order faults. The Tertiary aquifer regional hydraulic parameters are low, with T around 0.01 to 1 m^2/d. Otherwise, the existence of Alpine faults provoke a local increment of hydraulic conductivity in these formations, that in some assays could be two orders of magnitude higher than regional values. In these faults areas, an augment of the vertical thermal gradient of water in wells, compared with the regional ones is also detected.

Rivers are the main natural drainage system of the Tertiary aquifer. The most part of groundwater are fresh, with no important Cl^- or Na^+ concentrations and moderate quantities of SO_4^{2-}, but point and diffuse saline springs exist, related to contamination from mine dumps and/or natural piezometric regime. In these second group, the main occurrences seem to appear in the Llobregat River in Sallent, and in the upper part of Conangles River (2 km North from Sallent city) related in both situations with faults. Hydrogeochemically, the Tertiary aquifer shows a vertical distribution of salinity, with deeper levels showing increasing Cl, Na or K concentration and decreasing NO_3, compared with shallower ones. This vertical distribution is locally modified by the contamination provoked by the mining installations, with high salinity plumes moving across the upper Tertiary formations and, if the geological and piezometric conditions are favorable, using the same preferential pathways than the regional flow, producing in some cases the salinization of historic fresh springs.

The combination of faults or other type of discontinuities, and the existence of preferential flow in these zones, have probably induced or accelerated problems of instability and surface collapsing of some old Potash Mines in the CPC. In some cases, engineering solutions have been proposed. In others, preventive actions have been taken.

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abstract id: **344**

topic: **1**
Groundwater quality sustainability

1.5
Groundwater quality and mining

title: **Influence of runoff and ground water inflow in the stratification developed in the Concepción pit lake (Iberian Pyrite Belt, Spain)**

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keywords: acid mine water, pit lake, meromictic, Iberian Pyrite Belt

INTRODUCTION

The Concepción mine, located in the northeast of Huelva province (Iberian Pyrite Belt, Spain), was exploited by underground mining and opencast since 1853. In 1874, the opencast exploitation went up to the 6th floor of the underground mine by means of five banks (Fig. 1). Water was extracted through a tunnel by gravity, which was connected with the 9th floor and had its exit close to river Odiel (Fig. 1). Ground water generated between the 9th to 12th floors was pumped toward this tunnel. The mine was abandoned in 1986. In the 1990´s, this tunnel was sealed and provoked underground mine flooding reaching the upper mining pit, which in 1993 was still not flooded. The pit was excavated in a stream bed, therefore chemistry and stratification of developed pit lake, is partially influenced by runoff contribution from a basin of 0.39 km^2, as well as inflow of water from underground mining. Nowadays, the dimensions of the pit lake are 280 × 60 m and 16 m of depth, with a volume of ~72,500 m^3. The lake level is regulated by an exit through an adit mine, which generate an acid mine drainage. Ground water chemistry can be studied through three mining shafts. The shaft-1 is inside of the pit lake, the shaft-2 in the pit slope and the shaft-3 is out of it, but both flooded too.

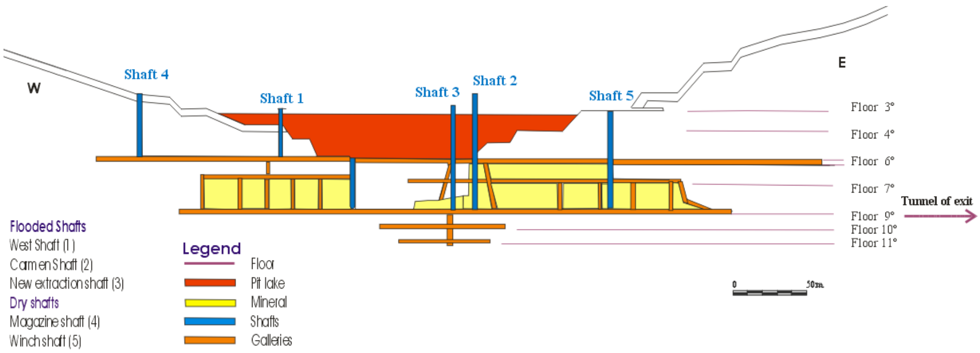

Figure 1. Sketch of underground mining and opencast in Concepción mine.

This study presents the processes that are involved in the stratification and chemistry of this pit lake, such as the inflow of metal-sulphate laden ground water from flooded shafts and galleries, the pit geometry and dilution process due to important runoff contribution.

RESULTS AND DISCUSSION

The pit lake is acidic, presenting high concentrations of sulfate and metals (Fe, Al, Zn, Mn and Cu). The vertical profiles of physico-chemical parameters and water chemistry obtained in Concepción pit lake have showed a permanent chemical stratification (Fig. 2), therefore was classified as meromictic during the hydrologic year 2008–2009, differentiating two layers with different density: 1) a thick superficial layer of ~10.5±1.5 m depth, pH 2.5–3, EC 1–2 mS/cm (oxygenated mixolimnion), this layer represents ~90% total volume of the lake, and 2) a thin bottom layer from ~10.5±1.5 m to 16 m depth (anoxic monimolimnion), which presents a chemical and thermal gradient with the depth, with pH from 2.5 to 4 and EC from 2 to 6 mS/cm. Between both layers is located a permanent chemocline.

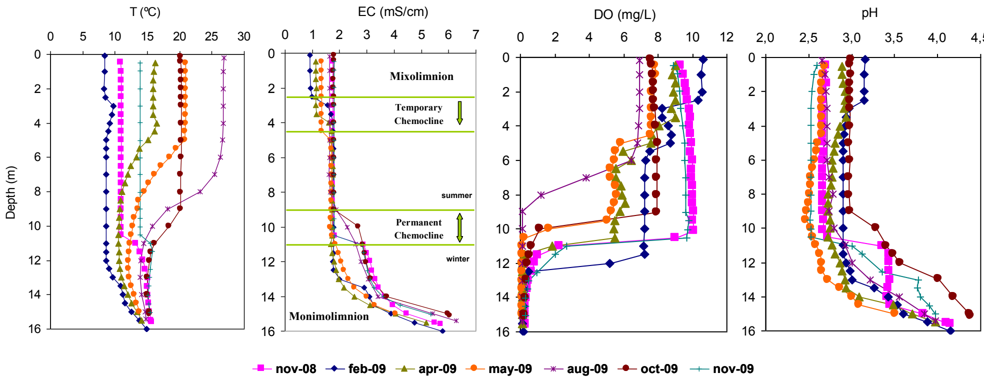

Figure 2. Depth profiles of temperature (T), electric conductivity (EC), dissolved O_2 (DO) and pH in the mining pit lake of Concepción.

In November 2008, a homogeneous mixolimnion was showed in the vertical profile (Fig. 2), but in February 2009 was recorded an upper thin layer (~3 m depth) less dense (EC <1 mS/cm), which was developed by runoff contribution during intense episodes of rain between January and February (rainfall ~220 mm), developing a temporary shallow chemocline (ectogenic meromixis). From February to May, EC and thickness was increased due to its mixing with lower layer. This shallow chemocline disappeared in August 2009, favoured in the last months by evapoconcentration. Moreover, the water lost by evaporation is partially compensated for the inflow of ground water, which induces the rise of permanent chemocline to 9 m of depth, while in winter it is situated to 12 m of depth. In this period, the level variations of lake have been lower to 1.1 m, therefore the chemocline really moves between winter and summer.

abstract id: **347**

topic: **1**
Groundwater quality sustainability

1.5
Groundwater quality and mining

title: **Seepage field simulation and contamination characteristics analysis in Xinfeng coal mine, China**

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keywords: seepage field, flow model, groundwater, Xinfeng coalmine, contamination

The Feflow software was selected to simulate the behavior of groundwater flow and pollution transport of Hanhui aquifer and Taihui aquifer in the Xinfeng coalmine. This model simulates three-dimensional groundwater flows by using finite-element techniques and contamination concertration trend. The model domain is divided into 9480 nodes, making a total of 15 417 cells in each layer and covering 10 km^2 of the model area.

ANALYSIS OF GROUNDWATER FLOW

The effect on pollutants dispersion is of real significance, analyzing of groundwater flow under different pump rate in aquifer. Under different pump rate of 1200m^3/d, 1700 m^3/d, 2200 m^3/d in limestone of upper Taiyuan Formation ,the groundwater flow of aquifer are shown in Figure 1 and 2. The results indicate that the flow of water is gradually centralized towards wells. The phenomenon is due to the variety of water table caused by different water outflow.

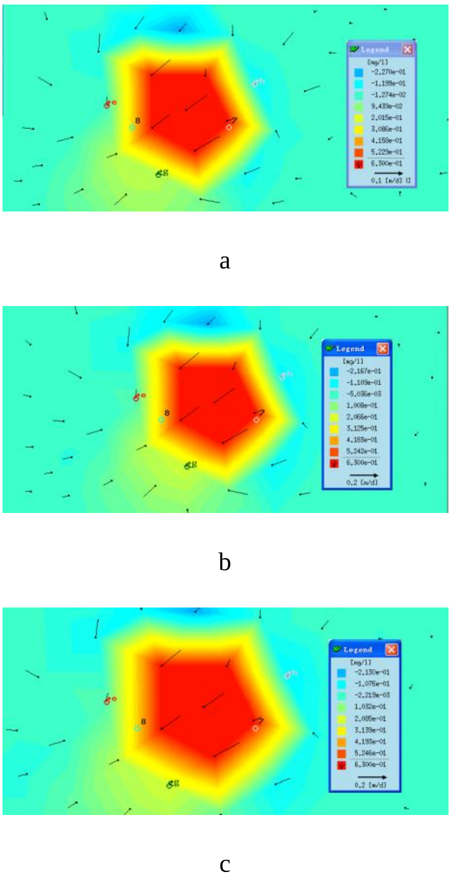

Figure 1. Ranges of Fe dispersion at pump rate of 1200 m^3/d (a), 1700 m^3/d (b)and 2200 m^3/d (c).

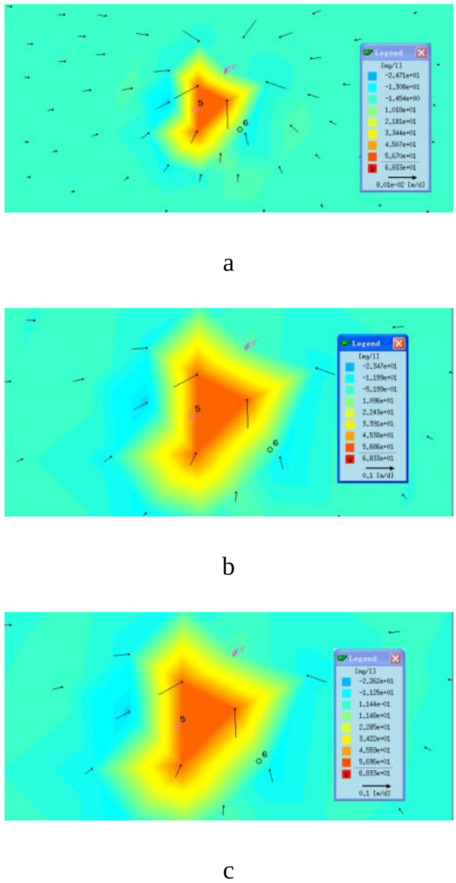

Figure 2. Ranges of SO_4^{2-} dispersion at pump rate of 1200 m^3/d (a), 1700 m^3/d (b)and 2200 m^3/d (c).

When the pollutants dissolved in water, it will have a definite range of pollutants dispersion. The range will change when the pollutants dispersion is effected by the outside factors such as time, water pump rate etc. Under different pump rate of 1200m^3/d, 1700 m^3/d, 2200 m^3/d in later five years, the range of pollutants dispersion of Fe^{3+} and SO_4^{2-} is shown in Figure 1 and 2. The results indicate that the range of pollutants dispersion is enlarged with dispersion speeding, when pump rate increasing. It is also shown that the concentration of pollutant is decreased gradually in the central of contaminative zone, while the pollutants disappear nearby the pump wells. The reason is that the pollutants are diluted by water flush and dispersion with water flow increasing.

The pollutants concentration of Conc. obs well No. 5, 6 and 7 at different rate of pump is simulated. The simulation figure is omitted because of limit of maximum length.

It is shown that concentration of SO_4^{2-} in all observation well is decreasing along with the rate of pump increase. When the rate is 1200 m^3/d, the concentration curves of Conc.obs well 10 and 8 are nearly parallel; when the rate is 1700 m^3/d, the concentration curves of Conc.obs well 10 and 8 are intersectional on 1374th day, and the concentration of SO_4^{2-} in Conc.obs well 10 decreases more rapidly than in Conc. obs well 8; when the rate is 2200 m^3/d, the concentration curves of Conc. obs well 10 and 8 are intersectional on 1240th day, and the concentration of SO_4^{2-} in Conc. obs well 10 decreases much more rapidly than at the pump rate of 2200 m^3/d.

Anyhow, the concentration of SO_4^{2-} in Conc. obs well 10 and 8 are lower than the initial concentration. The decrease is due to water outflow. The pollutants are discharged largely in the aquifer, although a lot of them are dissolved in the water. So a small quantity of pollutants can disperse in the aquifer. In addition, it is possible that the pollutants are diluted by water with pollutants dispersion. Therefore, the real reason is needed a long term of observations to certificate.

ACKNOWLEDGEMENTS

This work has been supported by national basic research program of China, Research on basic theory about the mechanism of water in rush and its prevention in coal mines.

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abstract id: **367**

topic: **1**
Groundwater quality sustainability

1.5
Groundwater quality and mining

title: **Restoration and revitilization of the area of the abandoned mine pit Suvo Rudiste on Kopaonik, based on the example of the construction of the water intake and water collector for multipurpose use of the mining waters**

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keywords: Kopaonik, restoration and revitalization, mining waters

INTRODUCTION

Kopaonik, a mountain in the central part of southwest Serbia (280 km from Belgrade) and the belonging protected area of the National Park (established in 1989) represent a unique natural whole. However, in spite of the fact that Kopaonik was given priority in regards to new development of mountainous area in Serbia and the fact that it deservedly carries the epithet of the 'first' mountain that has the necessary spatial capacity to enable the return of humans to nature, upon which we have returned en masse, it has in return received a powerful blow or clearly stated, has experienced grave consequences. Namely, on the roof of Kopaonik, more precisely below its highest peak, the peak of Pančić (2017m a.s.l.) and in the immediate vicinity of the tourist resort, lies an abandoned surface and underground excavation site "Suvo Rudište" (1970 m a.s.l.), upon which, after an extensive ore exploitation, all the activities have died down about twenty years ago. The previous mining activities in the greater area of the Suvo Rudište mine have devastated the immediate area of the extensive exploitation in its entirety, as well as the surrounding area that has been, due to its current state and appearance, excluded from the current borders of the NP Kopaonik. At the height of 1740 m a.s.l., in the vicinity of the tourist resort, the mining waters are flowing out from the underground part of the pit in the quantity of 10–30 l/s, polluted with iron, manganese, copper, zinc, nickel and cadmium. The mining stream, since the abandoning of the mine, has been completely devoid of all living things, because the proscribed restoration and revitalization of the underground facilities and hallways has not been done. However, it is of import to note, that during the time of the active mining operations, the same groundwaters were used, and their quality regularly inspected, for the fulfillment of needs for drinking water of the mine personnel and the two nearby hotels. This directly implies that the groundwater quality within the mining facility at the place of operation complied with the Act of water quality.

Due to the all aforementioned and the growing needs to bring the analyzed area back to its purpose a Study of feasibility and the Project of restoration and revitalization of the abandoned mine Suvo Rudište was done. The project stipulated the restoration of the surface dig and the part of the underground facilities, the intake of the mining waters from the underground area of the dig, their treatment until the desired quality was achieved, and then the pumping into the area of the surface dig Suvo Rudište, which would serve as a multi-purpose water collector, of volume 300.000–350.00 m^3.

THE DESIGN SOLUTION FOR THE SYSTEM OF WATER INTAKE STRUCTURE AND THE WATERCOLLECTOR

The ore deposit "Suvo Rudište" on Kopaonik during the phase of intensive exploitation was mined in two different ways, and consisted of the surface dig and the underground pit exploitation.

The underground part of the mine was opened with a main mine at the height of 1740 m a.s.l. (simultaneously the lowest point), divided vertically into five basic horizons that are linked by a system of transport and transit haulway rooms, a network of roads on the horizon itself, a network of exploratory hallways, bars for the transport of mined materials, and a network of trimming hallways and other auxiliary rooms. The main transport mine — horizon at 1740 m a.s.l., is simultaneously a main road, a room for drainage, a hallway of the main entry air current for ventilation, a room for fixtures, telecommunications etc. Apart from the main mine there were four other links – surface exits. The entire length of the pit facilities at the level of mine at

1740 m a.s.l. (the mine and the lateral hallways) is around 1820 m, of an average width of 2.2 m, respectively of the entire area of 4004 m^2 or volume 8808 m^3. The general assessment, based on the conducted research, is that the underground facility is stable and secure and there are no significant cave-ins. At the end of the mine and the lateral hallways several exploratory wells were done in the effort to define and follow the body of the ore. The groundwaters under pressure and further free fall towards the exit are the ones that stand out from all the wells with a full profile. An important characteristic connected to the phenomena of the presence of groundwaters within the mine, is that the body of ore was grasped by the mine that is simultaneously the lowest point in the underground, so that the entire drainage is gravitational, without pumps and energy utilization. The present quantities of groundwaters that are flowing out from the underground hallway at the height of 1740 m, are originating from the water sources along the cut sediment zones as well as the mentioned research wells. In the mine, at five points, there are appearances of permanent sources of groundwaters, and three have been regulated and smaller reservoirs with the volume of around 3 m^3 have been built, from where the intake waters were transported by a set-up pipeline to the one-time consumers at the surface of the mine, two nearby hotels, and for the pit, more precisely the mining drilling and blasting, with the aim of reducing dust. The flow of groundwaters within the main mine varied within the limits from 300 l/min to 1500 l/min or from Q_{min} = 5 l/s to Q_{max} = 25 l/s (measured during the time of active operations of the mine) while the water quality for the water supply, was controlled and approved by the authorized health institutions. From the aspect of hydrogeology in the wide area of the main mine and the surface dig "Suvo Rudište", conditions are such that there is no objective danger of any major water penetrations from the surface of the terrain that could endanger the stability of the underground facilities. The position and the height of the mine already enable the drainage of the groundwaters of the immediate perimeter in a natural way, and are gathered within the mine and flow out of the same due to gravity at 1740 m a.s.l.

The surface dig was opened as the depth-type with tiers and spiral transport routes at the dig, respectively between the tiers. The dig due to operations reached at its deepest section the height of 1870 m and considering the existence of activities in the part of the underground horizon underneath the dig itself at the height of 1865 m, there was a violation of stability in the disturbed section and a minor cave-in of the ceiling above the underground hallway at 1865 m. The depth of the dig has reached approximately 100 m, the length of the longer axis is 350 m, and of the smaller 220 m, and the entire dig is of an ellipsoid — amphitheatre shape. The condition of the rock mass within the dig is good, without any signs of subsidence and slides of larger proportions. The tier planes, the passages for communications, from the northern side of the dig have already began losing their original shape and the purpose of the traffic, while on the southern side they remain in good condition and could still be used for transport with minor improvements. Vegetation at the surface dig is practically non-existent. Considering the present configuration of the dig and the condition of the rock mass, the dig is not endangered with any potential peril and that can be confirmed by the fact that from the day of its closure till today the terrain has been stable.

FLOW-OUT REGIME AND WATER QUALITY

At the point of the flow out of mining waters from the main mine of "Suvo Rudište" mine, more precisely at about 50 m downstream where the flow is concentrated, the Thompson's weir for the measurement of the flow, was constructed. The mining waters are gathered at the lowest point of flow-out at 1740 m a.s.l. and are via the existing (active mine) main hallway evacuated to the surface of the terrain. The catchment area starts from the height of the peak of Pančić at 2017 m, up to the level of the main mine at 1740 m — the point of the mining waters flow-out, or at about 250 m of the height difference of the border area of the basin of about 3 km^2. In the following tables the representation of several year of observations of the mining waters flow-out regime and mining water quality is given.

Table 1. The representation of the abundance of the mining waters from the main mine at 1740 m a.s.l. (2004–2007).

Year/ Month	*"Water source of mining water"*, measurements Q (l/s)											
	I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**
2004	14.5	15.0	15.5	16.0	16.0	15.0	14.0	14.0	14.0	13.5	13.5	13.5
2005	14.0	15.0	15.0	16.0	18.0	18.0	18.0	22.0	22.0	18.0	16.0	15.0
2006	14.0	13.0	14.0	14.0	14.0	15.0	18.0	15.0	18.0	19.0	15.0	14.0
2007	13.0	12.0	13.0	14.0	15.0	18.0	19.0	20.0	21.0	19.0	16.0	15.0

The results gathered of the chemistry of the mining waters from the main mine at 1750 m a.s.l. indicate an increased concentration of certain elements — Fe, Mn, Cu, Ni and Zn (Table 2) while the microbiological indicators are within accepted limits.

Table 2. The results of the chemistry and microbiology of the mining waters testing.

	mg/l		mg/l		mg/l		mg/l	Pb (mg/l)	<0.001
HCO_3	24.4	Ca	23.2–30.2	P	<0.010	Ni	0.042	Cd (mg/l)	<0.001
SO_4	50.0	Mg	4.4–5.4	SiO_2	12.2	Li	0.003	T (°C)	6.0
Cl	3.3	Na	2.2–3.3	B	<0.1	Rb	<0.01	pH	6.25–7.5
NO_3	1.54	K	0.7	Fe	2.25–3.36	Zn	2.0	M (mg/l)	120–155
NO_2	<0.01	NH_4	<0.05	Mn	0.82–1.23	Cu	0.094	$KMnO_4$ (mg/l)	1.0–1.3

THE DESIGN SOLUTION FOR THE SYSTEM OF WATER INTAKE STRUCTURE AND THE WATERCOLLECTOR

In accordance to all the discoveries and the existing infrastructural facilities on the location of the abandoned mine Suvo Rudište, the following conceptual solution for the provision of large enough quantities of accumulated water for different purposes is given as inevitable. The complete hydro-technical system "Suvo Rudište" on Kopaonik would consist of the following parts (Figures 1 and 2):

- The groundwater source – water intake structure,
- The facility for groundwaters treatment,
- Pumping stations 1 at the height of 1740 m a.s.l. and a high pressure transport pipeline up to the water collector,
- The water collector within the area of the surface dig "Suvo Rudište",
- Pumping station 2 within the future water collector.

The water intake – of groundwaters, will be conducted in the existing, main mine at the height of 1740 masl, in the regime of gravitational outflow. The total measured capacity is Q_{min}=12 l/s and Q_{max}=25 l/s, so that the water intake itself is designed as a combination of a vertical entry shaft (of a large diameter) and an underground water gate — water intake structure (laterally anchored within the main rock) for the stopping and accumulation of groundwaters, with pumping aggregates for further transport of the waters towards the treatment facility installed within it.

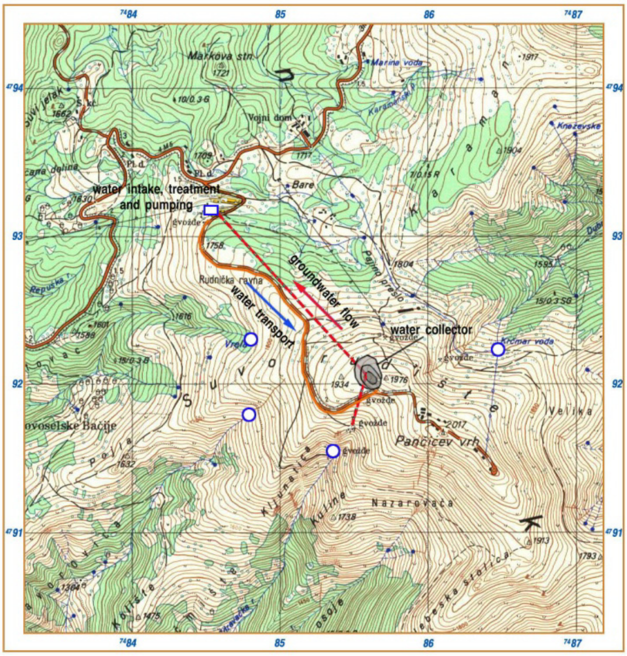

Figure 1. Objects disposition in the “Suvo rudiste” surroundings.

The mine groundwater is burdened with increased concentrations of iron, manganese and several oligo-elements and toxic heavy metals as: zinc, cadmium, nickel and copper. This is low mineralized water with a slightly lowered pH when compared to the drinking water, and is micro-biologically safe. Beneath the area of the water intake structure, the groundwater, mining water is further transported to the system for quality improvement — station treatment. It is designed that the process of deferrization and demanganization (with a minimal reduction of the copper, zinc, nickel and cadmium content) is conducted. During this treatment no external substances — chemicals are used outside of the facility, meaning, a true “green technology & green engineering” is in question.

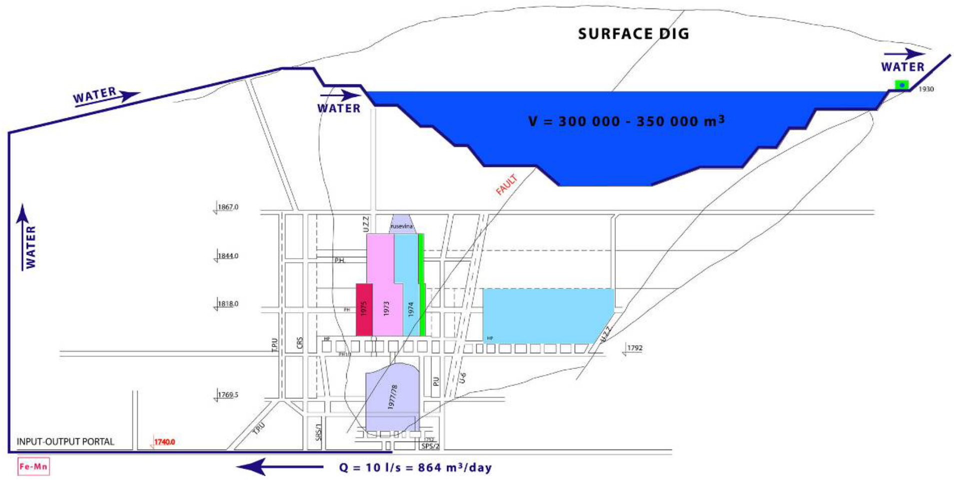

Figure 2. The design solution of water intake structure and watercollector.

The water that was collected and prepared would be, via an installed pumping station, further transported along the existing bypass route towards the peak of Pančić (the entire length of 2300 m) and would be enclosed within the existing ambience of the surrounding area without disturbing the said area. The transport itself of the groundwaters would be done by pump aggregates and via a high-pressure pipeline in the conditions present on Kopaonik.

During this same period, paralleled to the previous operations, the process of cleaning, preparing, concreting (Torkret method) and lining via a geo-membrane of the surface dig Suvo Rudište (preparing of the water collector) would be conducted, during which the accumulation of the intaken waters and the treatment of groundwaters is planned.

ASPECTS OF BRINGING THE FACILITY AND THE ENVIRONMENT INTO ACCORD

A high assessment of the area eligibility is reached through the proposed solution of the land restructuring and the use of resources, due to the opening and return to its purpose of this part of Suvo Rudište for the programs of presentation and resource utilization, recreational — skiing – hiking, educational and other facilities. The possibilities of expansion of the borders of the protected area to the southern parts of Kopaonik are opened, in the direction of Leposavić municipality, i.e. the percentage of the entire protected area in Serbia is increased (that being one of the relevant conditions for the joining of Serbia to the European Union).

With planned construction of the water intake structure and with the treatment of the mining waters, the negative physico-chemical contents of the groundwaters (Fe, Mn, Zn, Ni and Cu) will be removed, which will create the conditions for the renewal of the eco-system in the mentioned watercourses that is now significantly in peril. It can be stated that this area has the elements of a "rock desert". By building the suggested system, the restoration of the soil via biotechnical measures will be done — mass covering of the eroded areas, stabilization of loose slopes of the abandoned mine and prevention of further degradation; more precisely the improvement of the entire area and its increased closeness to other humane contents.

The biological diversity in the closer and wider area of "Suvo Rudište" — one of the highest zones of Kopaonik was destroyed by exploitation and opening of the mine surface and the slag deposit. The conditions for gradual revitalization of the biological diversity and the return of autochthonous sorts as well as the enrichment of the landscape are created by the construction of the facility and the implementation of the biotechnical measures.

CONCLUSION

Considering that on the territory of Kopaonik two significant elements of the development of Serbia can be found, and are interconnected (one protected — the National Park Kopaonik and the second, tourist – developmental, mountain resort of Kopaonik), it is of a national importance for the Republic of Serbia that the two segments mentioned mutually correspond and participate in the presentation and promotion of Serbia and its assets, with the adequate protection and securing of the area. The suggested Project is an adequate example where the mutual functions can be aimed towards the fulfilment of the national domain interests for Kopaonik and the Republic of Serbia.

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abstract id: **406**

topic: **1**
Groundwater quality sustainability

1.5
Groundwater quality and mining

title: **Waters and minerals in weathering zone of polymetallic deposits of Miedzianka-Ciechanowice and Stara Góra, Sudetes Mts, Poland**

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keywords: weathering of minerals, Sudetes Mts, geochemical modelling

The investigation are carrying in dumps which are remains after some mines worked on polymetallic deposits. The first is Miedzianka-Ciechanowice situated in the Czarnów Schist Formation which is mainly composed of mica-schists and amphibolites. This tectonic unit is a part of eastern metamorphic cover of Karkonosze granitic pluton (Rudawy Janowickie Mts.). Two types of ores build this deposit: the massive magnetite-pyrite-pyrrhotite ore connected with skarns and ore veins with polymetallic mineralization. In weathering zone of this deposit about 70 of secondary minerals occur. Waters samples were collect on dump of old "Neu Adler" mine (closed in 1925). On the dump occur fragments of amphibolites and shists. Polymetallic mineralization contain rich assamble of ore minerals (native silver, löllingite, saflorrite, pyrite, arsenopyrite, chalcopyrite, galena, sphalerite, tetrahedrite-tennantite and other sulphosalts of Cu and Pb. Calcite, fluorite and barite occurs as a barren minerals.

Different groups of supergene minerals are products of weathering processes. Paragenesis of copper secondary minerals is the most popular. Malachie, langite, brochantite, devilline and chrysocolla create coatings on the weathering Cu ore minerals. The second associations contains arsenates of Fe, Zn, Co and Cu such as scorodite, erythrite and Co-bearing köttigite. The third paragenesis of secondary minerals contain hydrozincite and gypsum. Diversity of parageneses of supergene minerals reflects variable geochemical conditions in different parts of the "Neu Adler" mine. Parental solutions for the minerals of the second paragenesis were enriched in Fe, Zn, Cu and As, originated from alteration of polymetallic ore mineralization. Presence of scorodite shows, that pH of the crystallization environment was very low.

The polymetal deposit of Stara Góra is located within Radzimowice village (Kaczawskie Mts.). The quartz-sericite and quartz-sericite-graphite schists exposed in this area are cut by rhyolites, rhyodacites and trachytes intrusions and also by polymetall ore veins. Ore veins contain pyrite, arsenopyrite, chalcopyrite, sphalerite, thetraedrite, bournonite, boulangerite, galena and other ore minerals. Quartz, rhodochrosite, siderite, dolomite, ankerite, and calcite are barren minerals. Mining activity was stopped in Radzimowice area at 1957. Near old mine is located numerously waste dumps contains primary and secondary arsenic minerals. Very intensive processes of alteration of ore and barren minerals took place in old adits and on waste dumps. Oxide iron hydroxides, sulphates, carbonates and arsenates are the products of these processes. The water samples were collected on the dump in place where was store material from arsenopyrite ore vein. Scorodite, kaňkite and pitticite are very popular secondary minerals in this place. Scorodite and kaňkite are associated with jarosite and gypsum. Small amounts of malachite, base copper sulphate and aragonite are present to.

Groundwater samples are taken thanks to ceramic and Teflon-quartz Eijkelkamp and Prenart probes from depth 30–120 cm. It were measured temperature, pH, conductivity and redox potential of water. After that in laboratory its chemical composition were investigated. These waters are very strong mineralized (till about 10 g per liter) and acidify ($3<pH<7$). Knowing primary and secondary minerals occurred in dumps and chemical composition of groundwater in weathering zone of these dumps carried out geochemical modelling using PHREEQC code. Results of speciation modelling shows tendencies to precipitation secondary minerals and to dissolve primary minerals. Inverse modelling shows quantitative and qualitative effects of this processes.

ACKNOWLEDGEMENTS
Researches are supported by the Polish Ministry of Science and Higher Education grant (N N307 065934).

abstract id: **476**

topic: **1**
Groundwater quality sustainability

1.5
Groundwater quality and mining

title: **Chemical composition of groundwater of the pleistocene burried valleys in the area of selected sand pits in the Upper Silesia — Poland**

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keywords: Pleistocene aquifers, buried valleys, hydrogeochemical processes, mining drainage

The main purpose of the following research was the identification of processes and factors determining the chemical composition of groundwater from Pleistocene buried valleys in the area of sands extraction in the Upper Silesian region (southern Poland, fig. 1). Aquifers of Pleistocene structures under consideration are unconfined, built of sands and gravels of average thickness about 40 m, locally divided by silts and clays into two or three hydraulically connected layers, and underlaid mainly by low permeable deposits of Upper Carboniferous and Neogene. Groundwater in Pleistocene buried valleys in natural conditions is characterized by a low mineralization and good quality. Over 40 years of intensive mining drainage connected with the activity of Maczki-Bór, Kotlarnia and Kuźnica-Warężyńska sand pits has disturbed hydrodynamical conditions in the Pleistocene buried valleys, caused both longlasting lowering of the groundwater table (about 30 m at the maximum) and spreading of the depression cone. The character of the Biała Przemsza and Bierawka rivers was changed from gaining into losing. Nowadays, extraction of sands in the Upper Silesian region comes to an end. Kuźnica Warężyńska sand pit was changed into an artificial lake in 2006. The west part of Maczki-Bór sand pit is filled up with coal mining wastes and the east part of Maczki-Bór sand pit as well as the mining area of Kotlarnia sand pit are going to be flooded. The hydrodynamical changes described above as well as land use influence the quality of groundwater from the examined aquifers.

Processes and factors controlling the chemical composition of groundwater in the investigated Pleistocene aquifers were identified on the basis of an analysis of archival materials and data gathered during fieldwork and laboratory research carried out in years 2007–2009 as well as on the basis of results of geochemical modeling by using PHREEQC codes. The composition of groundwater in the examined area is strongly dependent on the anthropogenic factors such as changes of the groundwater level or pollution sources as well as on the geogenic factors such as the occurrence of pyrite and organic matter in the Pleistocene buried valleys. Increased SO_4^{2-} and Fe^{2+} concentrations and a slightly acidic pH (about 6.0) in groundwater from observation wells in the area of the depression cone of Maczki-Bór and Kotlarnia sand pits might suggest the occurrence of simultaneous processes of pyrite oxidation, calcite dissolution and gypsum precipitation (Kaźmierczak et al., 2009). On the other hand, the chemical composition of groundwater in the area of Kuźnica Warężyńska artificial lake is determined by processes initiated by an increasing level of the water table, e.g. gypsum dissolution, what results in equal molality of Ca^{2+} and SO_4^{2-} in groundwater (Jakóbczyk et al., 2009). Higher concentrations of Ni^{2+} (up to 0.112 mg/l) in groundwater from the area of the flooded sand pit Kuźnica Warężyńska than in groundwater from other pits (on average about 0.02 mg/l of Ni^{2+}) might suggest the occurrence of manganese oxides dissolution. During the aforementioned processes, elements such as Ni^{2+} and Cd^{2+} are released from deposits into groundwater. Saturation of groundwater in the area of all the investigated pits with respect to hematite and goethite can serve as evidence of precipitation of these minerals. The quality of groundwater in the Pleistocene buried valleys is greatly determined also by the presence of anthropogenic sources of pollutions, especially in the area of Maczki-Bór sand pit. Leakage from landfills, unsewered settlements and agricultural areas as well as polluted surface water of losing streams result in an increased mineralization of Pleistocene groundwater. TDS reaches up to about 6000 mg/l in the area of Maczki-Bór sand pit. Concentrations of many ions are also increased, e.g. SO_4^{2-} (up to 1850.0 mg/l) Cl^- (up to 2198.0 mg/l), Na^+ (up to 1846.0 mg/l), B^{3+} (up to 2.25 mg/l) and nitrogen compounds (NO_3^{2-} up to 57.25 mg/l and NH_4^+ up to 20.0 mg/l). The variability of the chemical composition of groundwater from the Pleistocene buried valleys under research can be connected with over-lapping impact of different factors and chemical processes in time and space.

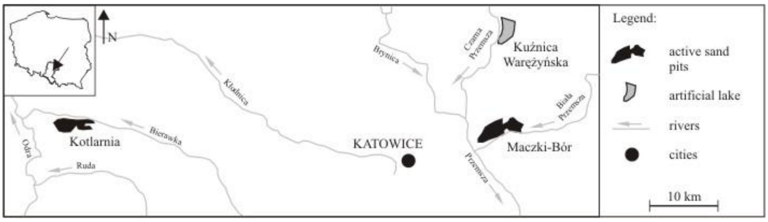

Figure 1. The location of open sand pits in the Upper Silesian region.

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abstract id: **477**

topic: **1**
Groundwater quality sustainability

1.5
Groundwater quality and mining

title: **Damming of water inflows in the western section of the "Wieliczka" Salt Mine as an example of one of the methods used for eliminating water hazards in salt mines**

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keywords: Miocene, Wieliczka rock salt deposit, water hazard, water dams

Water hazard as well as the methods of its control in salt mines must be considered in a different manner than in other areas of mining mineral resources.

This results from that fact that salt is easily dissolved in saline mineral waters. Even the proverbial drop of salt water can have a catastrophic impact for the mine's existence.

In the history of Polish salt mining there are known cases of water penetrating into a mine and its complete flooding. In 1907, two mines were completely flooded in Inowrocław, and in 1911 the shaft Wapno I in Wapno, in 1977 the salt mine in Wapno was also flooded (Lisiecki, 2007). These mines had exploited the Cechsztyn deposits on salt diapirs which are surrounded by rock formations strongly aquiferic and usually under full hydrostatic pressure.

The saline deposits existing in the pre-Carpathian depression belonging to the Miocene formation are less endangered by flooding than the Cechsztyn deposits in central Poland. This is due to their specific geological structure, the impermeable loam existing in the vicinity, and the relatively shallow deposition leading to the fact that the hydrostatic pressure of water inflowing to the mine is not as high (Tarczyński, Batko, 1961).

In spite of this, in the past, water penetrated into the mine and could have caused catastrophic consequences. In such a manner water forced its way through into the Wieliczka Salt Mine between the years 1868–1879, to the Kloski traverse at level V and the Colloredo traverse at level IV (Wójcik, 1992).

Miners have developed methods combating water hazards occurring in salt mines during the many centuries of their experience with floods.

The basic safety rule is not to allow water access into the mined excavations. Therefore, all drilling and mining works should be performed with greater care and in strict compliance with regulations for conducting works in water hazard conditions. Whereas the basic condition for the correct management of mining and drilling works is both the good knowledge of the geological structure of the deposit as well as its environment. In the past, however, mining works were not always conducted with full consideration of water hazards. Especially when it comes to corridor excavations where exploratory drilling works were not always conducted before executing drilling works and the used drilling equipment was not fitted with tools allowing efficient closing of drilled waters.

From among the many methods applied for liquidating water hazards the most efficient one is the method for damming inflows. However, to apply this method certain conditions have to be fulfilled:

- the orogen in the area of the inflow must be well examined,
- a small perforation of the orogen with mined excavations in the area of the inflow.

The flooding of the western border of the Wieliczka Salt Mine may serve as a good example to present, on the one hand, the mistakes in the art of mining which in effect lead to the penetration of water into the mine, and on the other hand, the existence of favourable geological and mining conditions for constructing water dams. In this part of the mine, the deposit was cut with several corridor excavations (Fig. 1). In August 1959, while working in the western section of the mine, at the end of level VI, during the process of executing a horizontal test bore 6-67 towards the north, the water bearing layer was drilled causing water to penetrate into the salt mine at a max. volume flow of 58 m³/h.

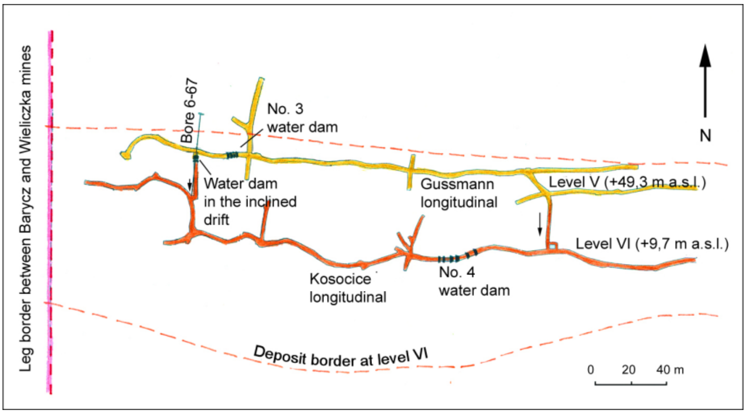

Figure 1. Location of water dams no. 3 and 4 in the western section of the Wieliczka Salt Mine.

The NaCl contents in the inflow was between 200–290 g/dm³ (Sękiewicz, Markowski, 1963).

Protective works were immediately executed aimed at limiting the inflow, i.e. decreasing the water hazard in this section of the mine.

The outflow was closed off by means of water dams (Fig. 1):

- Loam and concrete dam (No. 4) built in the Kosocice longitudinal at level VI,
- Concrete dam built in the inclined drift between levels V and VI,
- Block-loam-concrete dam (no. 3) constructed in the Gussmann longitudinal at level V (Fig. 2).

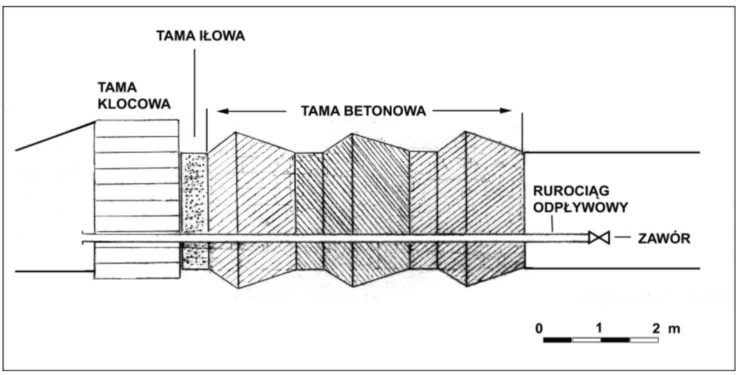

Figure 2. Structure section of the block-loam-concrete water dam in the Gussmann longitudinal (Level V).

Dam no. 3 was built due to the appearance of leaks in the dam located in the inclined drift and due to the insufficiency of the applied cementing processes.

Virtually, it was never possible to maintain the tightness of the dams for a longer period, and therefore, the dams have undergone cement tightening processes several times. A pipe system has been constructed at dam no. 3, level V, and dam no. 4, level VI, with fitted valves and manometers checking the pressures of the brine behind the dams (Sękiewicz, Markowski 1963). The pressure, until December 1961, at dam no. 3 was maintained between 0.20–0.25 MPa; at dam no. 4 between 0.63–0.85 MPa. Then, the pressure began to rise between reaching max. value 2.18 MPa (dam no. 3) and 2.65 MPa (dam no. 4), and then gradually began to drop coming at present to 0.42 MPa (dam no. 3) and 0.81 MPa (dam no. 4) (Water dam control book, 1965–2009).

The water dam complex at levels V and VI, in the western section of the mine, can be considered as efficiently closed off from inflows to the mine if not for the problem of the control pipeline system which is susceptible to corrosion. At present, the best solution seems to be the tight liquidation of the system connected with the liquidation of the Kosocice and Gussmann longitudinal sections, while the pressure behind the dams can be checked at the surface by means of a piezometric bore.

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IAH 2010 Krakow

abstract id: **479**

topic: **1**
Groundwater quality sustainability

1.5
Groundwater quality and mining

title: **Hydrogeology monitoring results obtained at the "Wieliczka" Salt Mine following the elimination of water inflow in the Mina traverse at Level IV**

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keywords: Wieliczka Salt Mine, Mina traverse, water inflow, hydrogeology monitoring

The threat of water is considered the biggest natural hazard to the Wieliczka Salt Mine. Currently, this threat is posed by water inflows called mine leaks. The sources of these leaks are the Chodenice layers localized in the northern part of the salt deposit. Hydro-geological monitoring consists of measurements of water capacity inflow and chemical testing. Isotopic investigations are also performed, as well as gravimetrical measurements in the northern border zone of the deposit. Gravimetrical measurements have been conducted temporarily, since the emergency inflow to the Mina Gallery on Level IV. This inflow, during 1992–2007, was considered as the biggest hazard for the mine and to the city of Wieliczka. Results of the monitoring concluded, that after closure of inflow to the Mina Gallery, the quantity and quality of other mine inflows (Fornalska 2 Gallery on Level VII and Z-32 Chamber on Level VI) have not changed. Observations of pressure in the D-2 and D-3 drain holes and water level in the B-3 piezometer indicate that water levels in the deposit are returning to pre-1992 levels. This process has also been confirmed by gravimetrical measurements.

Monitoring of hydro-geological phenomena, within which measurements of the efficiency of all registered water inflows to underground excavations and also chemical analysis of incoming waters, is conducted. Hydro-geological phenomena observed in the excavations of the Wieliczka Salt Mine called mining leakages are natural inflows of brine from behind the deposit or brines circulating within the deposit, due to inaccurate intake of inflows on the higher levels of the mine (Brudnik et al., 2006).

The dimensional layout of all hydro-geological phenomena registered on mining maps indicates (Brudnik et al., 2006):

- the occurrence of leakages of the lowest salinization in the northern border of the deposit;
- the presence of NaCl unsaturated leakages in the vicinity of the northern border of the deposit and in the region of under-saline layers occurrence;
- the localization of leakages of the highest capacity in the vicinity of the northern border of the deposit;
- the presence of numerous leakages of high NaCl salinization over 300g/dm^{3}and diverse capacity in the central part of the deposit.

Table 1. presents a sheet with mine leakages on several levels with a specification of the range of their capacity, according to data from 31.12.2009

Table 1. Leakage sheet in the Wieliczka Salt Mine.

Inflow volume [dm^3/min.]	**Number of leakages on mining levels**										**Total number of leakages**
	I	IIh	IIl	III	IV	V	VI	VII	VIII	IX	
< 0,1	26	13	16	17	9	12	4	2	1	1	**101**
0,1 - 1,0	3	4	4	9	10	3	11	6	3	-	**53**
1,0 - 10,0	1	-	-	1	2	-	1	1	-	-	**6**
> 10,0	-	-	-	-	-	-	2	1	-	-	**3**
Total	**30**	**17**	**20**	**27**	**21**	**15**	**18**	**10**	**4**	**1**	**163**

Hydro-geological conditions of the “Wieliczka” deposit, showed in details in the hydro-geological documentation (Górka et al., 2009) indicate that the highest inflows to the mine are supplied by the sandy Chodenice layers, classified as of Middle Miocene origin, occurring in the northern forefield of the rock salt deposit. A number of these inflows, in time of their formation, had a catastrophic character endangering the mine's existence.

These leakages appeared in the Kloski and Colloredo traverses on levels V and IV in the 19th century and to the 6-67 hole in the Kosocice longtitude on level VI, to chambers Z-32 on level VI and Fornalska 2 on level VII and also to the Mina travers on level IV in the 20th century.

Inflows to the Kloski and Colloredo traverses are seized at present in the Regis longtitude on level VI, and their total capacity does not exceed 3 dm^3/min. Whereas the inflow to the 6-67 hole has been dammed by means of water dams nr. 3 in the Gussmann longtitude on level V and nr. 4 in the Kosocice longtitude on level VI.

The largest active inflows are at present inflows captured under the Z-32 chamber on level VI and in the Fornalska-2 chamber on level VII.

In October 2007, after a 15 year old period of conducting protective works in the Mina traverse, the valves on drainage holes, used for water seizure, have been closed. This inflow, symbolized in the mines leakage evidence as WIV-27, supplied by the Chodenice layers, was considered the most dangerous water inflow into the underground excavations of the "Wieliczka" Salt Mine in the years 1992–2007. The pulsative character of this inflow differentiating from a few to a few thousand dm^3/min. and the variable content of solid fractions elevated by water, maximum 1593,16 g/ dm^3, caused danger to the safety of the underground "Wieliczka" Salt Mine and to the city located above the mine (Garlicki, Wilk, 1993).

Protecting the mine from the water inflow into the Mina traverse was aimed at constructing a dam against water consisting of timber, clay and concrete segments closing the periphery of the excavation, drilling drainage bores D-1, D-2 and D-3 enabling water drainage from behind the dam and also sealing the orogen with the hole injection technique in order to generate a spatial bowl sealing the peripheries of the Mina traverse (Gonet et al., 1997).

Completion of works aiming at sealing the orogen surrounding the peripheries of the Mina traverse allowed to liquidate the drainage hole D-1 and then to close the valves on the drainage holes D-2 and D-3 (Bromowicz, Brudnik, 2007). Complete closure of the water inflow into the Mina traverse was the result of the undertaken measures.

After closing the water inflow into the Mina traverse the inflows in the Fornalska 2 chamber and beneath chamber Z-32, symbolized as WVI-16 and WVI-32 in the mining leakages register, have the largest share in the total inflow into the underground excavations of the Wieliczka mine.

In 2006, ergo before closing the inflow into the Mina traverse, those inflows constituted jointly 54% of the total natural inflow into the mine's excavations, which totalled in 202.566 m^3. In 2008 those inflows represented 81 % of the total natural inflow, amounting 135.834 m^3, whereas in 2009 these inflows presented 80 % of total natural inflow amounting 134.028 m^3.

Analysis of conducted measurements of the capacity of inflows in the Fornalska 2 chamber and beneath the Z-32 chamber and also of chemical determination allow to state that closing the water inflow into the Mina traverse did not cause changes in those inflows. The dimension of the inflows in the Fornalska 2 chamber and beneath the Z-32 chamber uphold within the limits registered before closing the water inflow into the Mina traverse (Fig. 1).

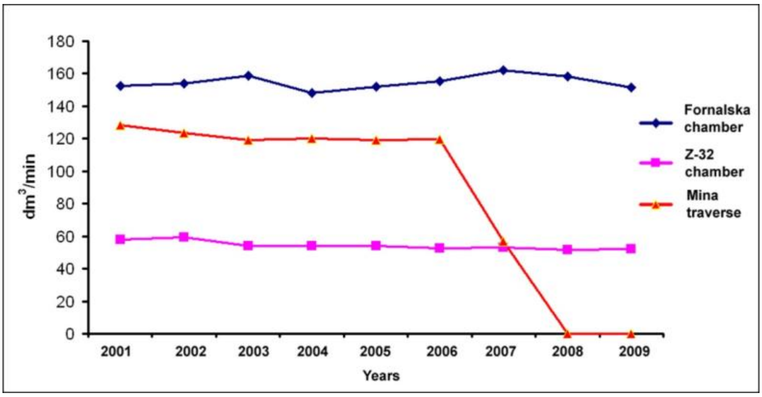

Figure 1. Average dimension of the water inflow into the Fornalska 2 chamber, the Z-32 chamber and into the Mina traverse in the years 2001 – 2009.

A similar tendency is noticed in reference to salinization of these inflows. No significant changes of NaCl content in the inflow into the Fornalska 2 chamber and in the inflow into the Z-32 chamber are observed (Fig. 2).

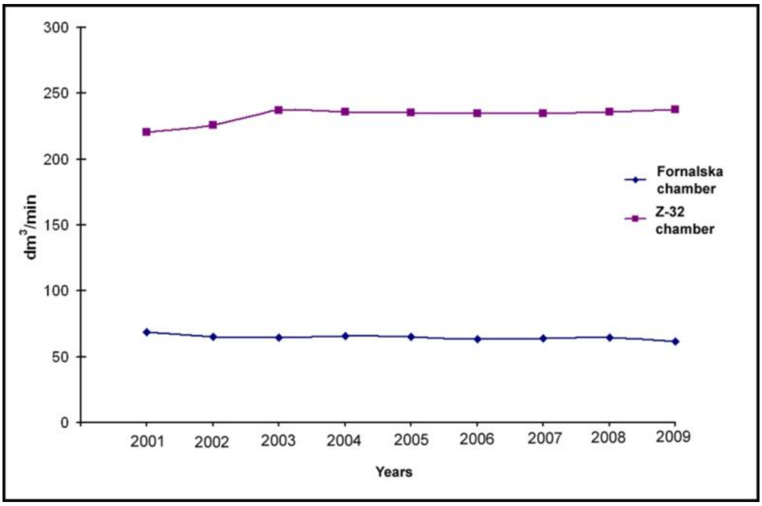

Figure 2. Average NaCl content in the inflow into the Fornalska 2 chamber and the Z-32 chamber in the years 2001–2009.

Registration of pressure changes observed on manometers built on closed drainage holes D-2 and D-3 is conducted within the hydro-geological monitoring in the Mina traverse, whereas from the surface level measurements of the water table in the piezometric bore B-3 are conducted. This bore registers changes of the position of the water table within the sabulous Chodenice layers formations located in the northern forefield of the Mine traverse.

Readings of the pressure of manometers installed on the drainage holes D-2 and D-3 have shown its rapid growth after closing the inflow in the Mina travers and stabilization on the level of 1,5 MPa (Fig. 3).

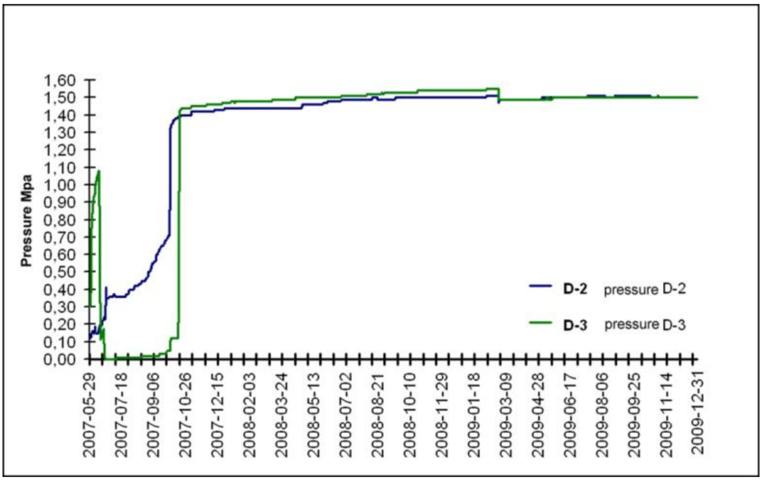

Figure 3. Pressure changes registered on drainage holes D-2 and D-3 and in the Mina traverse in the period 29.05.2007–31.12.2009.

Rapid growth of pressure indicates lack of free spaces in the sealed orogen area on the northern forefield of the Mina traverse. On the other hand stabilization of pressure indicates complete restoration of the level of waters in the orogen to the condition from before 1992. This state is confirmed by measurement data from registering the position of the water table in the piezometric bore B-3 (Fig. 4).

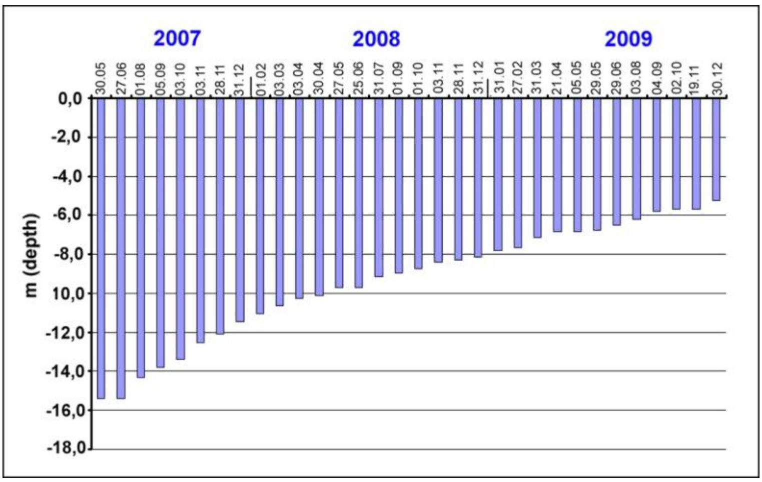

Figure 4. Position of the water table in the piezometric bore B-3 in the period May 2007–December 2009.

The state of restoration of the water level has been proved with gravimetrical research conducted on the northern forefield of the deposit in the area of the Mina traverse in the years 1992-2007 (Madej et al., 2008). Gravimetrical research conducted in 2006 and 2007 have shown the restoration of state of the orogen in the area of the Mina traverse forefield to the state from 1992. The research proved the thickening of the orogen in depleted areas due to water inflow into the Mina traverse. The area closest to surface of the orogen was influenced by this process in particular (Madej et al., 2008).

The results of hydro-geological monitoring conducted in the Wieliczka mine, indicating lack of relevance between the closure of the water inflow into the Mina traverse and the dimension of the inflow and NaCl salinization of the main mining leakages supplied as the inflow in the Mina traverse by the Chodenice layers, are convergent with the results of isotopic research conducted annually since 1973 on water sampled from mining excavation inflows (Zuber, Duliński, 2004). The authors of this research claim that there is a large number of water subsystems in the Chodenice layers, which despite the presumably existing general hydraulic link, are clearly separate.

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abstract id: **480**

topic: **1**
Groundwater quality sustainability

1.5
Groundwater quality and mining

title: **The impact of old mine shafts on the accumulation of water in mined excavations and terrain surface based on the example of the Górsko shaft in the "Wieliczka" Salt Mine**

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keywords: Miocene, salt mine, mine shafts, water hazard, terrain deformation

The issue of water inflow to the Górsko shaft and the problems arising due to the accumulation of waters in the nearby excavations of the mine as well as the geological and engineering phenomena occurring on the surface in the surroundings of the shaft is most interesting. The waters migrating in this shaft and around it were not considered as a direct hazard to the existence of the Wieliczka undergrounds, however, their movement and the changes of volume and NaCl saturation caused a necessity to capture and pump them to the surface. The waters migrating for centuries washing out the soil (the phenomena of suffusion) and leaching saline formations together with the process of tightening of post-exploitation excavations caused mining subsidence and the destruction of the building at the fore-shaft.

The Górsko shaft was dredged to the depth of Level I, in the first half of the 17th century, and completed during the administration of the salt-works administrator, Andrzej Górski, probably in 1622. The excavations located nearby at Level I were established in the 17th and 18th centuries. The shaft was dredged in the 19th century, at first to the Level II lower, and then, in the period to 1836, to Level IV (Charkot, 2003).

In the 1890s and first decade of the 20th century the shaft housing was reconstructed. In 1899 the wooden *kleta* (housing) was changed to a brick structure in the shaft building. The cable railway constructed in 1902 was extended to the shaft in the years 1912 – 1914 from the nearby Psia Górka sand pit and from 1914 sand was lowered into the mine and used for filling the excavations. This process was continued after the break caused by World War I until the outbreak of World War II (Müller, 1935; Charkot, 2003).

In 1954 the Górsko shaft was filled in to the depth of ca 6 metres below ground level (Charkot, 2003). The geological profile of the shaft indicates the existence of Quaternary formations forming as clay dust and loam dust, and then the following successive formations of loam and gypsum zone, boulder deposit with loam-and-saline rock (called *zubry*) and blocks of green salt, and from the height of the Level II lower into the depth of the orogen–stratiform deposits (Fig. 1), (The book of water hazard control in inactive shafts at the Wieliczka Salt Mine, Hrebenda 2005).

The hydrogeological conditions of the orogen, in the area of the shaft, and the phenomenon which occurred on the surface impact on the creation of Quaternary formations, including the existence of soils susceptible to suffusion. It was difficult to pass this layer during the process of dredging the excavation in the 17th century. The inflow at that time was defined as significant. Therefore, it became necessary to drill a drainage well in the vicinity of the shaft connected with it to the underground corridor, so-called *stuła* (Charkot 2003). Also, accumulating water in the region and the geological and engineering process taking place in the orogen may have had their impact on the stream flowing by the shaft and the surface affecting subsidence of the Słaboszów chamber, established in 1698, located a few dozen metres to the west from it (Kolasa, Kubik 1983).

The water outflows of from the Górsko shaft where first observed at the shaft bottom of Level III (Fig. 1). On the map „The Inflow of Ferocious Waters" (this was the name of mine outflows) of Level III at the shaft bottom leak no. 63 is noted of a flow rate equal 1.59 l/dm^3. The map, which is not dated, depicts the situation of the excavation in the 1930s. According to the observations made between the years 1943–1944 there was an existing inflow at the flow rate of 0.66–2.0 dm^3/min. at the shaft bottom of Level III , which in the years 1948–49 was registered at a flow rate of 1,5 dm^3/min. (Ferocious inflows in the Wieliczka mine).

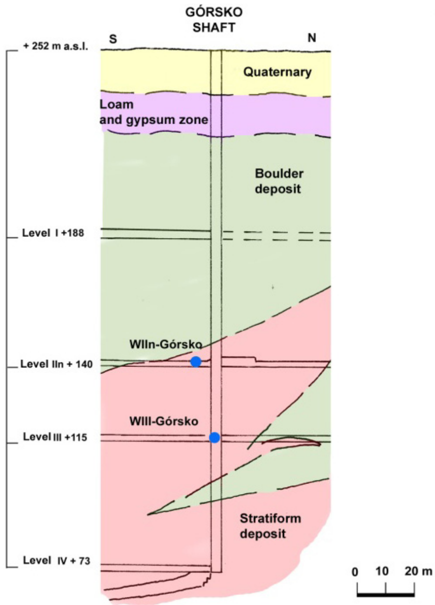

Figure 1. Geological profile of the Górsko shaft. Prep. by J. Przybyło, 2010.

After filling in the shaft in 1954 the registered inflows at the shaft bottoms were characteristic for their different flow rates from droplets to ca 2 dm^3/min. as well as changes in the flow route. The leaks associated with the shaft were observed in the area of the shaft bottom in the Level II lower and III. The shaft bottoms at Levels I and IV are not accessible.

At present no significant hydrogeological phenomenon at Level III is noticed in the spot where the inflow was noted in the 1940s. The brines are received in the lower section of Level III known as WIIn-Górsko in the area of the shaft bottom (Fig. 1), (The book of water hazard control in inactive shafts at the Wieliczka Salt Mine). It is also possible, that the brine from the shaft migrates along the ceiling of the bedded deposits to the Fryderyk August chamber (leak WIIn-8) located to the south from it. In both these areas the condensation of fully saturated brine is observed (Leak register of the mine).

The building of the shaft bottom, in respect to the surrounding area, is located in a basin, what causes the flow of precipitation waters towards it. The terrain surrounding the shaft is systematically settling, as registered, on average 13 mm/year. A slight subsidence of the terrain was noted in the shaft area at the end of the 1970s, and, in the 1980s, a subsidence of the level of the material filling the shaft pipe was noticed.

Cracks were noticed on the fore-shaft building in December 2002, and at the beginning of 2003 – intensified settlement. These phenomenon caused the execution of protecting works in January and February 2003, which included the liquidation of the empty space around the shaft to the depth of 3 metres, and the empty 16-metre space in the shaft pipe which was performed to limit the inflow of water to the shaft. In effect, the execution of these works resulted in slowing the motion of terrain settlement in the area of the shaft (Stawarczyk, 2003).

The work plans aimed at protecting the Wieliczka Salt Mine include further sealing of the orogen in the close vicinity of the Górsko shaft, which is conditioned by preserving the historic infrastructure of the shaft, the fore-shaft building and shaft tower.

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abstract id: **499**

topic: **1**
Groundwater quality sustainability

1.5
Groundwater quality and mining

title: **Unscrambling the mine dewatering riddles in highly inter connected multiple mine workings in the Donbass Coal fields, Ukraine**

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keywords: dewatering coal mines, interconnected mines, pumping shafts, planning, mine closure and control, mine water quality

Over the past century of coal mining in the Donbas Basin of eastern Ukraine, significant environmental changes have taken place, not least among them the dewatering of water saturated strata between the coal bearing seams.

The Donbas Basin is one of the major late Palaeozoic coal and methane provinces in the world. The accumulation of coal in the Basin is associated with recurring swampy coastal-marine plains, large peatbogs, transiting to shallow marine environments which resulted in accumulation of thick (up to 14 km) paralic coal-bearing Carboniferous (post-Early Visean) formation, containing more than 300 coal seams and intervening sandstones. In the Middle Carboniferous, marine limestone layers deposited in shallow sedimentary conditions, recur at regular intervals of 10–100 m, and sometimes lie directly on coal seams. The Basin hosts significant economic accumulations of coal, methane and metals, and is, in fact, one of the most intensively exploited in the Europe (Privalov et al., 2002).

The mines of the Donbass region operate at depths ranging between 220 and 1400m and the average coal mining depth is 620 m. Approximately 53% of the coal mined from the Donetsk Basin is from depth less than 600 m, and the remaining is exploited from the intervals of 600–900 m, and from 900–1,200 m. Ten mines operate at depths of 1,000 m. Generally the Carboniferous sequence contains from 10–14, to 30–40 workable seams. Major coal reserves are accumulated in coal seams with thickness of 0.6 to 1.0 m.

Aquifers in the Donbass Coalfield Basin are found in of the Quaternary deposits, at times confined by low permeability beds, and although yields are insignificant they are recharged through rainfall. Based on the example of Komsomolets Mine, major aquifers within the Palaeozoic sequence occur in the sandstone and limestone of the Carboniferous formations. Water abundance of the aquifers reduces with increasing depth, although this is counteracted by the permeable fractured zones. Coal strata occurring at depths greater than 500 to 600 meters are essentially water-free. The Chemical composition of waters changes from Ca–HCO_3, Ca–Mg–HCO_3 and Ca–Na–HCO_3 (at depths of up to 100 meters) to Cl–HCO_3 Na–Cl–SO_4 (deeper than 600 meters). Total dissolved solids increase with depth from 1300 mg/l to 1800 mg/l to 2000 mg/l to 2500 mg/l. In Skochinsky Mine, in the western part of the Basin, mineralisation may rise to 9000 mg/l.

Due to the intensity of the mining within the region, and the proximity of mine workings, over the years, access shafts and roadways between the mines have become interconnected. While the dewatering for individual mines was initially planned to provide dry working conditions for each mine, the interconnections now mean that the dewatering has to take account of groups of several mines. Further, within such a group iof mines, some have been exploited to completion and have ceased operations, others are still operating deeper or laterally displaced seams. With mine closure there is a preponderance to also reduce water pumping costs; however due to the interconnected nature and the fact that some mines are under State control, while others are in the process of being divested, the mine dewatering requirements have become increasingly complicated. The sub surface environment of mine shafts, roadways and long walls, is dewatered by collecting the aquifer water in series of underground storage tanks and then progressively pumping the water to higher elevations, finally pumping the water to the surface. As the restructuring of the Coal Sector in Ukraine proceeds, there is a requirement to make assessments of how to manage the very complicated system of dewatering.

This paper will illustrate the situation found in the mine dewatering system from Miuskaya closed mine, located close to the town of Snieznoye, which is the centre for pumping to maintain the dry working conditions for several other currently working mines, such as Lutugina, Udarnik, Sniznianskaya, Woskhod and Remonskaya. The setting is the closed syncline of the Chistyakowo–Snieznianska sub basin, in which the hydraulic connections through the full vertical sequence is schematically illustrated in Figure 1. The plan of the location id illustrated in Figure 2.

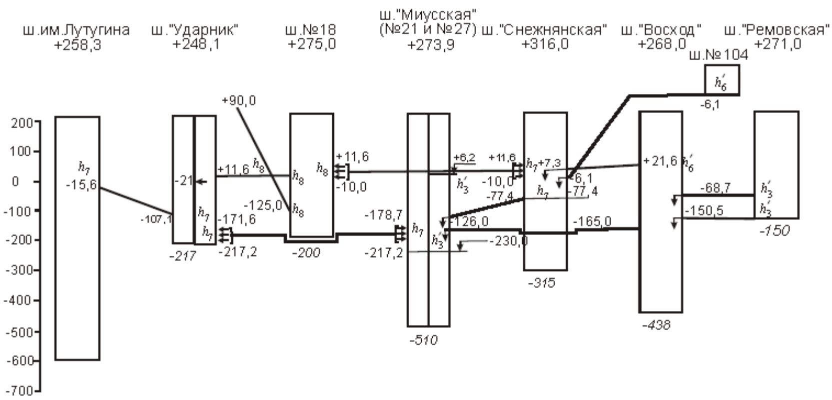

Figure 1. Schematic section of the interconnected mine dewatering system based around pumping from Miuskaya closed mine.

The Miuskaya mine shaft forms the main dewatering system for the whole complex of mines. The Remonskaya mine roadways are connected to the Wozkhod system, and the shallow aquifers feeding to the *h3* coal seams are discharged into it. Wozkhod is connected to Snizniansakaya, which receives 125 m^3/h of the flows. Between 40 to 60 m^3/h arises from within Sniznianskaya, which is connected into the Miuskaya shafts. Mines no #21 and #27, shown on the plan (Figure 2) yield about 790 m^3/h; the source of this large inflow is thought to be the fault that intersects the basin and the series of aquifers that are interspersed in the vertical section.

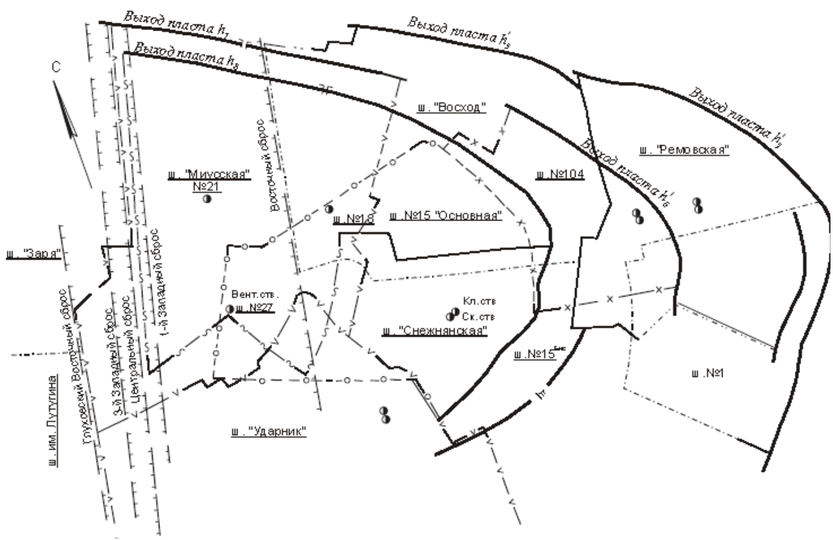

Figure 2. Plan of the Chistyakwo-Snieznianka closed syncline, showing mine locations.

The paper will discuss the assessment of the whole of the dewatering system and the solutions that have been adopted. Measures to reduce the volume of pumping, allowing the hydraulic levels to rise to acceptable depths without endangering the operations of working mines will be presented. Finally, a discussion of some of the institutional & management barriers to the operations of the Coal Sector will be outlined, as they affect the sound management of the environment.

1.6 | Groundwater monitoring

IAH 2010
Krakow

abstract id: **134**

topic: **1**
Groundwater quality sustainability

1.6
Groundwater monitoring

title: **Groundwater level monitoring: the ideal network versus reality**

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keywords: groundwater, monitoring, water levels, network, conceptual modelling

INTRODUCTION

The Environment Agency is the environmental regulator for England and Wales, with a duty to manage water resources to ensure that sufficient water is available to meet the needs of people and the environment. To fulfill this duty, the Environment Agency monitors the environment by collecting and analysing a wide variety of data, and by regulating the use of water through a system of abstraction licences. At the heart of the Environment Agency's monitoring programme is a national network of over 6,000 boreholes (see Fig. 1) from which data on groundwater levels are collected regularly. This network has grown up over time, responding to changes in the roles and functions of the Environment Agency and its predecessors, which are in turn responding to changes in legislation and other business drivers. This paper describes a fundamental review of the national groundwater level monitoring network for England and Wales, which is approaching its conclusion.

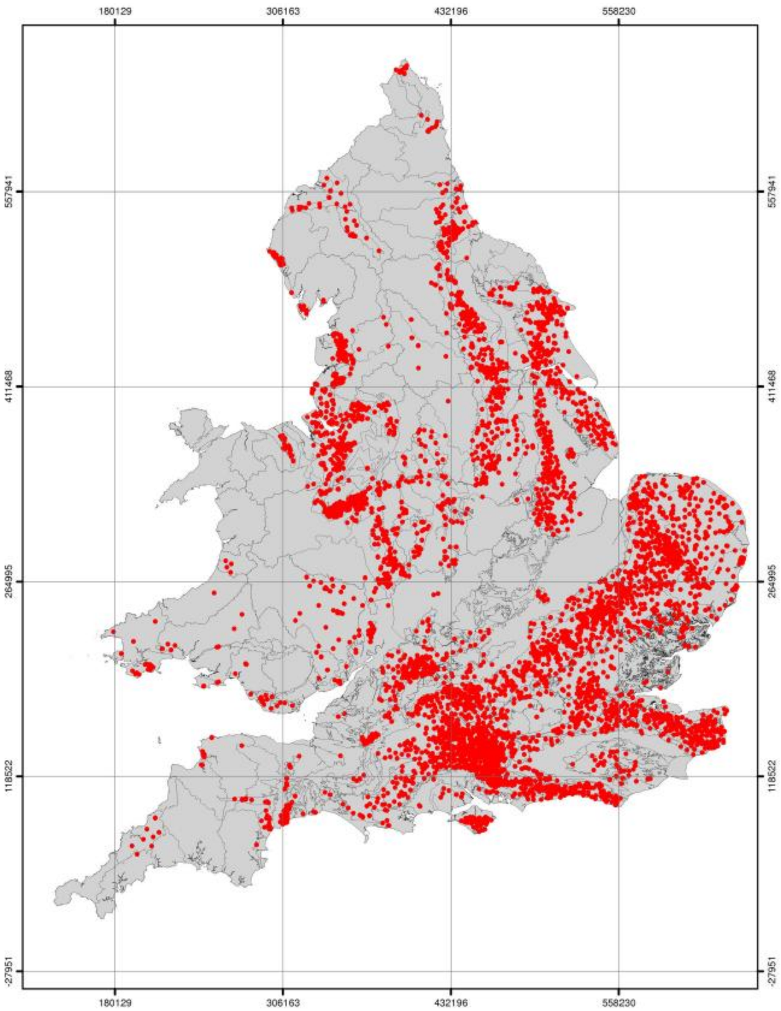

Figure 1. Locations of groundwater level monitoring sites in England and Wales.

KEY OBJECTIVES FOR A NATIONAL MONITORING NETWORK

It is essential that the Environment Agency monitor groundwater levels, and that this should be done in an efficient and coordinated manner. The key objectives for the national groundwater level monitoring network are to:

- Contribute to the fulfilment of the Environment Agency's principal roles as environmental regulator and monitor of the state of the environment.
- Comply with its duties under UK and international (mainly European) legislation.
- Comply with its non-statutory commitments and environmental initiatives.
- Evaluate, protect and manage groundwater resources quantitatively and qualitatively.
- Provide groundwater level data across England and Wales on a consistent basis.
- Define the behaviour of and identify trends in all aquifers (with early warning of low water levels, groundwater flooding and minewater rebound; identification of over-abstraction and impacts of climate change).
- Identify links between groundwater, surface water and ecosystems, and thus feed into other monitoring programmes (groundwater quality, river flows, wetland status, etc).

WHAT DO GROUNDWATER LEVELS REALLY TELL US?

The European Water Framework Directive (2000/60/EC) is one of the key legislative drivers for the collection of groundwater level data. The wording of the Directive suggests that groundwater level is the main parameter to be used when assessing the quantitative status of groundwater bodies. However, we need to understand what groundwater levels are really telling us. When interpreting groundwater levels, we need to be aware of the following:

- *Head not flow:* groundwater levels measured in monitoring boreholes indicate the hydraulic head, or potential, at that point. Groundwater flows cannot be measured directly in situ, and have to be inferred from hydraulic gradients and aquifer properties. The same observed groundwater levels could mean very different things (see Fig. 2).

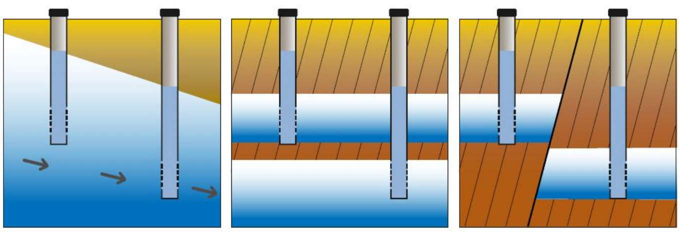

Figure 2. Different interpretations of the same groundwater levels.

- *Beware of open holes:* in a layered aquifer system, the groundwater level measured in a monitoring borehole that is open to several aquifer layers is ambiguous, because it provides no information about the actual head in any one layer or the vertical hydraulic gradients between the layers.
- *Changing levels:* a groundwater body is part of a dynamic system that is responding to changing inputs to and outputs from the system, often with a time lag between change and

response. Falling groundwater levels do not necessarily indicate over-abstraction, because there might be natural multi-year cycles.

- *Pegged levels:* groundwater levels in a monitoring borehole may be pegged or anchored, if, for example, the borehole is next to a major surface water body or aquifer discharge area. This could give a false impression of the 'health' of the aquifer.
- *Karst:* in aquifers such as karstic limestone where the majority of flow takes place in discrete fractures, fissures and conduits, it is most unlikely that the groundwater level measured in a monitoring borehole will yield useful information about the aquifer as a whole, even if it intersects a flow conduit. Spring discharges provide a much better indicator in these circumstances. This also applies to some low-permeability aquifers.
- *Saline intrusion:* long-term saline intrusion can occur even without an alteration in flow direction in a coastal aquifer, because of the density differences between saline and fresh water. Using groundwater levels alone to infer flow directions will not lead to a full understanding of how the aquifer system is behaving.

It is therefore essential that we interpret groundwater level data in the light of a good conceptual model of how the groundwater system operates, including the influence of vertical hydraulic gradients. It is also essential that we interpret groundwater level data alongside other data, such as spring flows, river stages, wetland water levels and water quality data.

CRITERIA FOR AN 'IDEAL' MONITORING NETWORK

The existing groundwater level monitoring network in England and Wales is not yet ideal. There are still gaps in the network, duplication of monitoring points, and incomplete information about the key characteristics of some monitoring points. The questions are: What would the ideal groundwater level monitoring network look like? How do we adapt or refine the existing network so that it is closer to the ideal? In answering these questions, we need to be realistic about the resources available for monitoring, the uses to which the data will be put, and the benefits to be gained from an efficient network. In other words, the network needs to be cost-effective, risk-based and targeted at the areas of concern, while at the same time avoiding bias in network coverage, which could give a false impression of the state of the environment. The criteria for an 'ideal' national network can be described as follows:

- The national groundwater level network must be 'fit for purpose' and able to answer policy and operational questions relating to the national groundwater resource.
- The questions are defined by the business drivers, which will change, so there must be a mechanism for the network to adapt, in response to the changing drivers.
- All data should be collected for a well-defined reason, and if the reason is no longer valid at a certain monitoring point, then data collection at that point should stop.
- All data collected should be quality controlled, with a feedback loop for dealing with quality issues, quickly, so that only high-quality data are archived, and we can have confidence in our historical datasets.
- The data should be stored in easily-accessible national databases, which can be linked to other types of data (such as groundwater quality and aquifer characterisation data), to build up a complete picture of the groundwater system.

- We should use the data that we are collecting and understand what the data mean. We should be able to add value to the raw data by processing and analysis.
- We need to identify and maintain monitoring points and datasets for long-term purposes such as detecting the impacts on groundwater of climate change.

DESIGN OF AN EFFICIENT MONITORING NETWORK

If we define what the most efficient groundwater level monitoring network would look like, we can compare that to the existing network, and refine the existing network by filling in gaps and removing duplication. Network design can be considered in terms of three aspects:

1) Distribution of groundwater level monitoring points: In an efficient network, groundwater level data should be available at enough points in the aquifer system to enable us to understand the key hydrogeological processes that govern the way the system works and the way in which it responds to pressures and management interventions. It is helpful to use the 'recharge-pathway-discharge' concept (analogous to the 'source-pathway-receptor' concept from the field of groundwater protection). The aim is to have groundwater level monitoring points in the following places:

- Where the recharge gets into the system. This is likely to involve fairly shallow boreholes that monitor the water table and its response to recharge events.
- Where groundwater leaves the system, either as natural discharge to rivers, wetlands, the sea or other aquifers, or in the form of abstractions.
- In sufficient places to define the 'structure' of the hydrogeological pathway between the recharge area and the discharge areas or points. This is where information on vertical hydraulic gradients is most likely to be useful.
- Where there is a legal requirement to monitor groundwater levels, for compliance with licence conditions, for example.
- In one or more places that are unaffected by abstraction and other anthropogenic influences. Interpreting 'pure' signals from such sites is much easier than having to naturalise hydrographs. This is important for drivers such as climate change.

There is an understandable tendency to concentrate monitoring points in areas that are under pressure, which, for example, are 'At Risk' of not meeting Water Framework Directive objectives. More monitoring is certainly needed in those areas, but at the same time we must avoid introducing bias into the network when reporting on the overall state of the environment. Otherwise, undue weight will be given to the 'problem' areas.

2) Frequency of groundwater level monitoring: In an efficient network, groundwater level data should be collected at each of the monitoring points at a frequency that enables us to understand the key processes that govern the way the system works and the way in which it responds to pressures and management interventions. The required frequency may be different at each monitoring point, and they should be assessed individually. This is because different types of aquifer behave in different ways, with the storage coefficient being the key hydraulic property that influences an aquifer's response to transient events, such as recharge or abstraction (although transmissivity also plays a part).

3) Quality of groundwater level monitoring data: When considering the overall quality of groundwater level data, four aspects need to be taken into account:

- *Measurement accuracy:* If a water level is obtained by manual dipping, the reading is normally quoted to the nearest 0.5 cm. The typical accuracy of water level readings from pressure transducers is 0.05% of the full range of the instrument. This level of accuracy is perfectly adequate for most hydrogeological purposes.
- *Data acquisition:* Correct procedures should be established and followed for measuring groundwater levels, setting up dataloggers, recording manual data and retrieving data from dataloggers. Common sources of error include using different local datums.
- *Quality control before archiving:* It is important to quality control data before archiving, to correct issues such as data outliers and unexplained steps or gaps in the time series.
- *Cleaning up historical data:* Many hydrogeological studies depend on the retrieval of historical data from archives, but if those data have never been checked and cleaned up, then their value is greatly diminished. Significant effort may be required to clean up historical groundwater level data, but this is an investment for future studies.

REFINING THE EXISTING NETWORK

The Environment Agency is refining the existing groundwater level monitoring network by implementing a process that consists of the following elements:

a) National business rules: These are being developed and applied nationally, and cover the aspects of spatial design (distribution of monitoring points), frequency of monitoring, and quality control of monitoring data, as just described. In addition, national business rules are being developed on network governance, covering the following:

- *Responsibility:* The national groundwater level monitoring network should have one central owner with nominated regional owners, so that responsibilities for and custodianship of the data are clear.
- *Training:* Hydrometric staff and any other monitoring staff who dip boreholes will be trained in all the correct procedures, so that they reach the required level of capability, and so that procedures are applied consistently. Internal users of groundwater level data will also be trained in the added value that can be gained from the data.

b) Network reviews: These will be undertaken at two levels, strategic and annual:

- *Strategic network reviews:* will be undertaken on a 6-year cycle, to ensure that the network delivers high-quality groundwater level data for use by internal and external customers. The strategic review checks whether there have been any changes in our conceptual understanding of any part of the groundwater system that would necessitate changes in the monitoring network; whether any new business drivers have appeared (new legislation, for example) that require new monitoring boreholes; and whether any monitoring boreholes are now redundant.
- *Annual network reviews:* will be undertaken to ensure that data quality is consistently high; that basic information about individual monitoring points is up to date; that protocols on frequency of data collection are being applied consistently across all regions; and that the

data being collected are fit for purpose (including consideration of the frequency of monitoring in relation to aquifer behaviour).

c) Regional implementation plans: These are perhaps the most important part of the process because it is at regional level that most of the hard work of implementing the findings of the reviews takes place (the Environment Agency divides England and Wales into eight regions). The structure of a regional implementation plan can best be described in the form of a Table 1.

Table 1. Structure of regional implementation plan.

	Component	Comments
1	Conceptual modelling	Develop a conceptual model for each groundwater body, using the best available information.
2	Spatial design	Design the optimal distribution of monitoring points, taking into account the identification of which specific national and local business drivers are relevant to the region.
3	Monitoring frequency	Decide the optimal monitoring frequency at each site.
4	Quality control	Implement the correct quality control procedures, including correcting quality issues in archived data.
5	Network comparison	Compare the existing network to the most efficient network, to identify gaps in the network or superfluous monitoring points.
6	Regional strategy	Prepare a regional groundwater level monitoring strategy, describing the results of Components 1 to 5 (which together constitute a strategic review at regional level).
7	Action plan	Prepare a detailed plan, directly linked to the regional strategy, of how to adapt or refine the existing regional network. This will include information to support the annual regional capital expenditure bids.
8	Annual review	Undertake annual network reviews, as described above, and take action as necessary.
9	Repeat strategic review	Repeat the strategic network review on a 6-year cycle. Note that this includes updating the conceptual models of the groundwater bodies, in the light of new information obtained during the review cycle.

IAH 2010
Krakow

abstract id: **170**

topic: **1**
Groundwater quality sustainability

1.6
Groundwater monitoring

title: **Characterising groundwater dynamics in Western Victoria using Menyanthes software**

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keywords: groundwater, time series modeling, climate, land use, system memory

Water table across much of the western Victoria, Australia have been declining for at least the last 10–15 years, and this is attributed to the consistently low rainfall for these years, but over the same period of time there has been substantial change in land use, with grazing land replaced by cropping and tree plantations appearing in some areas. Hence, it is important to determine the relative effect the climate and land use factors on the water table changes. Monitoring changes in groundwater levels to climate variables and/or land use change is helpful in indicating the degree of threat faced to agricultural and public assets. The dynamics of the groundwater system in the western Victoria, mainly on the basalt plain, have been modelled to determine the climatic influence in water table fluctuations. Previously, linear regression analysis was used to estimate trends in individual bores in the study area and thereby predict areas most at risk from shallow or rapidly rising groundwater (Pillai, 2003).

In this study, a standardized computer package *Menyanthes* (Von Asmuth et al., 2002) was used for quantifying the influence of climatic variables on the groundwater level, statistically estimating trends in groundwater levels and identify the properties that determine the dynamics of groundwater system. This method is optimized for use on hydrological problems and is based on the use of continuous time transfer function noise model, which estimates the Impulse response function of the system from the temporal correlation between time series of groundwater level and precipitation surplus.

In this approach, the spatial differences in the groundwater system are determined by the system properties, while temporal variation is driven by the dynamics of the input into the system. Results of 80 time series models are summarized in Table 1, with the model output parameter values characterized by their moments. The zero-order moment Mo of a distribution function is its area and M1 is related to the mean of the impulse response function. The relation is M1/Mo. It is a measure of the system's memory. It takes approximately 3 times the mean time (M1/Mo) for the effect of a shower to disappear completely from the system.

Overall, the model fitted the data well, explaining 89% (median value of R^2) of variation in groundwater level using the climatic variables (rainfall and evaporation) left without significant trend (-0.046 m/yr, on average), which is within the range of variable input standard error.

The average estimated system response (memory to disappear) is 5.2 years which is less than by $1/10^{th}$ of the previously estimated time using Ground Water Flow System approach (Coram et al., 2000). The average Mo is 1.45 m, which means that a precipitation of 365 mm/yr will eventually lead to a ground water level rise of 1.45 m on the location.

The Menyanthes result is compared with HARTT (Hydrograph Analysis and Time Trends) method (Ferdowsian et al., 2001). The trend and Mo estimate using Menyanthes and HARTT show comparable result. From a time series analysis there is no indication that the groundwater table was rising/falling due to changes in landuse, at least not during the observation period.

Table 1. Statistical analysis results and model parameter estimates (median value).

Aquifer	Trend (m/yr)	Mo (m)	3×Mo/M1 (yrs)
Basalt	–0.046	1.45	3.4
Deep lead	–0.047	1.4	6.5
All bores	–0.046	1.45	5.2

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IAH 2010
Krakow

abstract id: **198**

topic: **1**
Groundwater quality sustainability

1.6
Groundwater monitoring

title: **DNA-microarrays for monitoring natural attenuation of emissions from abandoned landfill sites in contaminated groundwater plumes**

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keywords: microarray, natural attenuation, groundwater, monitoring, 16S rRNA

Degradation of contaminants by microbial communities in soil and groundwater is the main activity in natural attenuation. Due to the complexity of the emitted organic components, natural attenuation of contaminated groundwater plumes from abandoned landfill sites can be evaluated only to a very limited extent by instrumental analysis.

The influence of pollutants on growth characteristics as well as composition of microbial communities in groundwater has been confirmed by denaturing gradient gel electrophoresis (DGGE) of PCR-amplified marker-gene fragments such as the 16S rRNA gene (Röling et al., 2001). Until today, PCR-DGGE is the method of choice to generate genetic fingerprints for comparison of microbial communities involved in degradation of a variety of contaminants. PCR-DGGE has some major disadvantages: It is strictly site-dependent and does not facilitate identification of microbial communities involved in degradation of contaminants and, therefore, the precise monitoring of natural attenuation.

Over the past years developments in the field of microbial ecology improved considerably. The application of DNA-microarrays in the area of marine biology as well as soil- and water ecology facilitated the analysis of microbial communities on species-level by specific detection of microbial rRNA-genes (Loy, 2005; Peplies, 2004). These findings led to the assumption that DNA-microarray-technology is applicable for monitoring natural attenuation of contaminated groundwater. Compared to other methods, which are state of the art in molecular biology, the potential to analyze a large number of parameters in parallel is a major advantage of DNA-microarrays. Based on known probe-sequences the composition of microbial communities can be analyzed on any taxonomic level.

To overcome the limitations of PCR-DGGE and to apply the benefits of DNA-microarray technology to environmental analytics, a 16S rRNA directed DNA-microarray for the analysis of microorganisms, which have been detected in soil and groundwater, was designed (Kühn et al., 2009). The main objective in microarray-design was to detect as many microorganisms as possible with a minimal number of probes. Therefore a higher taxonomic level was selected to detect bacterial families instead of single species. Since more than 90% of the existing prokaryotes are still unknown, a microarray for the detection of microorganisms on species level is not applicable for routine monitoring of natural attenuation.

The DNA-microarray facilitated the simultaneous detection of Bacteria and Archeae in groundwater for the first time ever and confirmed results obtained with PCR-DGGE. Furthermore the composition of microbial communities in tested groundwater-samples could be assessed. It could be shown that the Bacteria to Archeae ratio is a function of the groundwater contamination. DNA of sulfate-reducing bacteria from the families *Desulfobacteraceae, Desulfobulbaceae, Desulfovibrionaceae* and others could be detected in every analyzed groundwater sample. The fraction of sulfate-reducing bacteria is significantly increased in contaminated groundwater samples and therefore a marker for contamination. In contrast to the ubiquitously prevailing sulfate-reducing bacteria, DNA of methane-producing Archeae from the families *Methanobacteriaceae*, *Methanomicrobiaceae* and *Methanosarcinaceae* can be detected in contaminated groundwater exclusively. Hence, a detailed analysis of methane-producing Archeae provides a marker for contamination of ground water.

Due to the selection of defined microorganism families and the PCR-parameters chosen for the amplification of 16S rRNA Genes the analytical significance of the developed DNA-microarray is somewhat limited. In spite of the limitations mentioned above, combined with determination of microbial concentration, the family-specific DNA-microarray facilitates quantitative and functional statements regarding the composition of microbial communities in groundwater and therefore the evaluation of natural attenuation of contaminations along the downstream flow from abandoned landfill sites

ACKNOWLEDGEMENTS

This work was funded by the German funding priority KORA of the BMBF (Federal Ministry of Education and Research).

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abstract id: **233**

topic: **1**
Groundwater quality sustainability

1.6
Groundwater monitoring

title: **Optimizing a monitoring concept for a Riverbank Filtration Site**

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keywords: monitoring, riverbank filtration, water supply

INTRODUCTION

Bank filtration as a natural or technically induced process of groundwater recharge marks a crucial interface where surface water affects subsurface water resources. Large quantities of infiltrated surface water have a high impact on hydraulic, chemical and biological conditions in adjacent shallow aquifers. At riverbank filtration (RBF) sites, these conditions show significant spatial and temporal variations due to the dynamic behavior of the river stage. The composition of abstracted raw water is a result of these conditions and the numerous processes involved, but is also affected by the mixing of bank filtrate with land-side groundwater. Thus, a thorough monitoring of the whole catchment area is required to provide the information necessary to ensure maximum safety as well as efficiency in well field and treatment plant operation.

At an existing RBF site an extensive monitoring program which was executed in the past 15 years was analyzed. The main purpose of this work was to identify potentials for reducing effort and costs while assuring a level of information that satisfies legal requirements as well as demands for risk and operation management. The general concept of the monitoring program at this site is to treat the catchment as a part of the multi-barrier system in the drinking water production process. The potential of the soil and the surface water body to remove or reduce undesired substances from water present barriers and monitoring can be considered as a tool to manage the function of these barriers. This concept was retained. However, the analysis of the existing data led to a re-evaluation of sampling frequencies and parameters of the monitoring system and, eventually, to adjustments. To guarantee a high level of objectivity, statistical methods were applied where possible.

SITE DESCRIPTION

The waterworks Torgau-Ost is located at the River Elbe in Saxony, Germany. Its catchment, consisting of 42 vertical wells, stretches over a length of about 6 kilometres along the south-west bank of the river (Fig. 1).

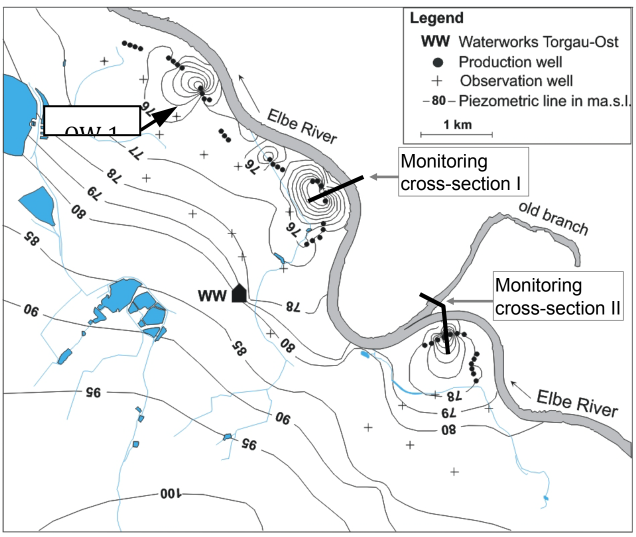

Figure 1. Catchment of the waterworks Torgau-Ost (Grischek, 2003).

The average distance between the wells and riverbank is 300 m. The aquifer with an average total thickness of 50 metres is formed by Pleistocene deposits overlain by Holocene river gravels and covered by a top layer of meadow loam (Grischek et al., 1998). It can be considered as a three-layered aquifer with varying geohydraulic properties. The hydraulic conductivities of the rather thin upper and lower aquifers are significantly higher than the conductivity of the dominating middle aquifer (Fig. 2).

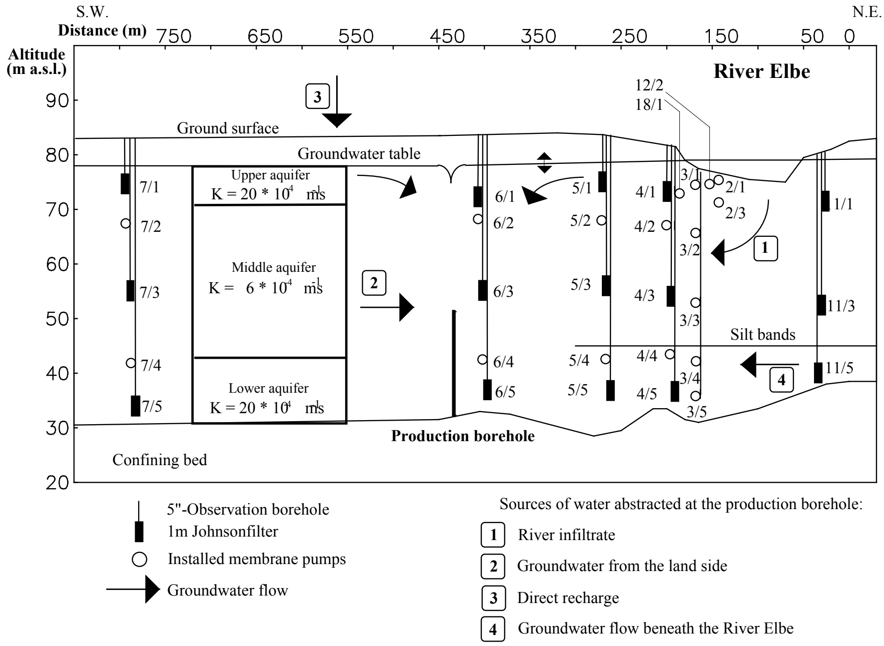

Figure 2. Monitoring cross-section 1 (Grischek et al., 1998).

Overall production rates of the waterworks usually vary within the range of 50000–80000 m^3/d with single well abstraction rates of approximately 150 m^3/h. The maximum production capacity exceeds 100,000 m^3/d. Depending on operational regime and river stage, bank filtrate can account for 20 to 60 % of the abstracted raw water. A significant groundwater flow beneath the river also has been found in field investigations and by numerical groundwater flow modeling as well.

MONITORING DATABASE

Several research projects have been conducted in the past to investigate different aspects of RBF (e.g. Grischek et al., 1998; Trettin et al., 1999; Krüger et al., 2006). In this context 120 observation wells had been installed across the entire catchment area (Fig. 1 and 2) on both sides of the river Elbe. Among these two monitoring cross-sections to observe the flow of bank filtrate (Fig. 2) allows for depth-oriented water sampling. During the past 15 years a substantial database has been generated. Data resulted from regular measurements of water table and in-situ parameters, water analyses, including trace compounds, and from several field experiments. Regular measurements and sampling have been conducted manually in intervals ranging from weeks to years as well as continuously using data loggers.

GENERAL MONITORING CONCEPT

The general concept of monitoring at this RBF site was designed according to the monitoring principles as applied at contaminated sites. Its structure is shown in Fig. 3.

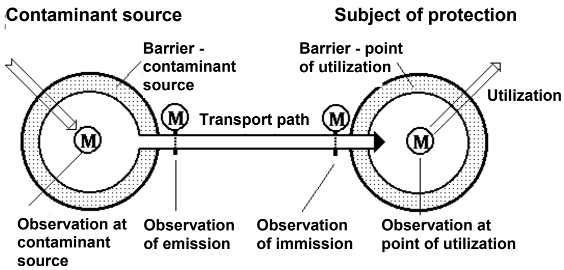

Figure 3. General structure of the monitoring of a potential endangering contaminated site (Nestler, 1999).

At a RBF site there exist basically two potential sources of endangering contaminations, namely diffuse and point contamination sources on the land-side and the river as a linear source for constant or temporary highly concentrated contamination. On the land-side the covering loam meadow and the aquifer itself act as barriers, whereas the topsoil is substituted by the river and its capacity for self-cleaning, dispersion and dilution processes on the bank filtrate side of the catchment. For the abstracted water the treatment in the waterworks presents the final barrier in drinking water production. The refinement of the elements of the monitoring structure, as presented in Fig. 3, lead to a modified structure for a RBF site as given in Fig. 4.

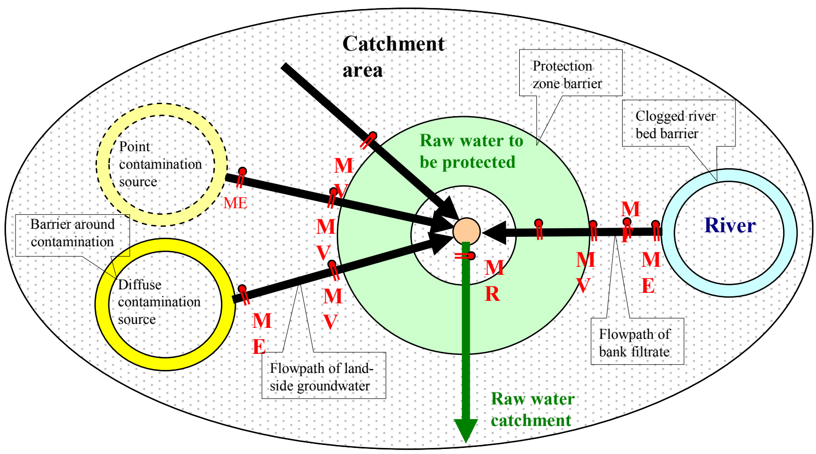

Figure 4. Structure of the monitoring of a RBF site (Grischek et al., 2010).

The observation points, as named in Fig. 4, are distinguished according to their relevance for the water supplier:

- MR — observation of abstracted raw water,
- MV — observation for early warning at boundary of protection zone of catchment,
- ME — observation at point of emission of contaminant,
- MF — observation of impact of operational actions on raw water quality.

DATA ANALYSIS

A 3-D groundwater flow model for the catchment of the waterworks Torgau-Ost was provided by the water company and used to determine the residence times of groundwater from each observation well to the production wells for average abstraction rates. Based on the residence times and considering a minimum advance warning time of 1 year, as well as a minimum sampling frequency of 2 years for maintenance reasons, sampling frequencies could be enlarged. Existing data sets were used to prove the sufficiency of longer sampling intervals. Trends derived from total sets of data (all samples included) for significant parameters were compared to the trends which result from a decreased number of samples, considering only the samples that would have been taken when applying the newly defined sampling intervals. No significant deviations were found. An example is given in Fig. 5.

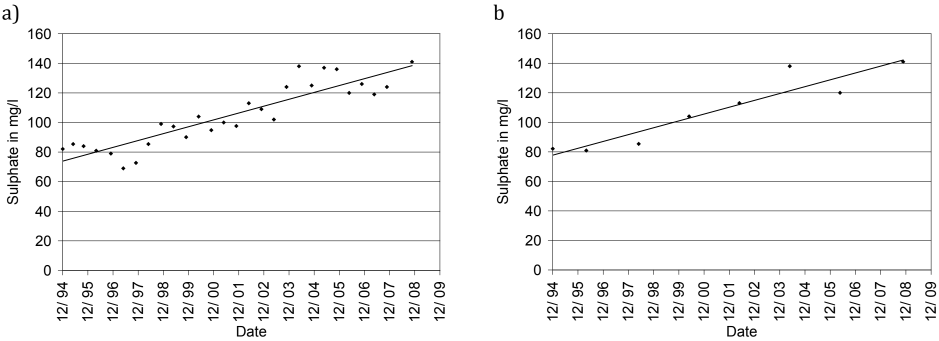

Figure 5. Trend for sulphate concentration in observation well OW 1 (see Fig. 1) from a) all samples; b) decreased number of samples.

Descriptive statistical parameters, mean and median value, standard deviation, minimum, maximum, and 10% and 90% percentile were used to identify parameters which showed constantly negligible or acceptable concentrations. For these parameters low input and/or sufficient protection by the mentioned barriers can be assumed. Hence, they were removed from the parameter spectrum for the regular monitoring and will be checked only randomly.

For the parameters nitrate, sulphate, DOC and iron a linear regression analysis was conducted to identify significant linear trends at a 95 % level of significance. Furthermore, trends were evaluated visually to classify them according to the trends shown in Fig. 6. Both procedures served the purpose of identifying trends which require further attention due to unexplainable behaviour or strongly increasing concentrations.

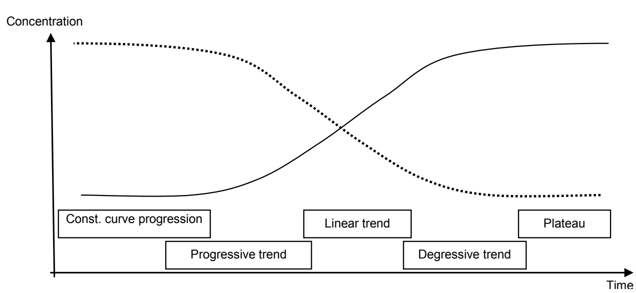

Figure 6. Schematical trend curves.

The two existing monitoring cross-sections (Fig. 1) were compared and tested for supplementary information with regard to the aims of the optimized monitoring program. For observation points at comparable distances to the riverbank, concentration curves of significant parameters and curves of in-situ parameters, such as temperature and electric conductivity, were compared to evaluate residence times of the bank filtrate and degradation rates. It was shown that additional information derived from the second monitoring cross-section was not relevant for monitoring purposes. Thus, the second cross-section, which was built for RBF research, could be excluded from regular monitoring.

Table 1. Example of results (significantly decreasing trends and visual evaluation).

Observation well	Depth	Parameter	Mean M [mg/l]	Standard deviation s [mg/l]	Annual decrease [% of M]	Visual evaluation of trend
G_506	upper	Sulphate	259	78.4	–5.0	Linear
	medium	DOC	3.0	0.24	–1.2	Linear
G_508	upper	Sulphate	297	80	–5.1	Degressive (decreasing, Plateau: 200 mg/l)
G_512	medium	Iron	3.76	2.65	–9.7	Degressive (decreasing, Plateau: 3 mg/l)

MONITORING OF TEMPORARY RIVER POLLUTION

The possible case of a contamination of the river water due to accidents requires special consideration. Because of the short residence times of the riverbank filtrate of < 100 days in the upper layer of the aquifer, spills present the highest potential risk for the catchment. That is why a monitoring and evaluation strategy was developed, including additional experiments and modeling to be conducted to support the risk evaluation based on monitoring results (Grischek, 2003). The basis of this concept is an event-based sampling of the water beneath the riverbed using membrane pumps (see 2/1, 2/3, 12/2 in Fig. 2).

CONCLUSIONS

The multi-barrier concept has been demonstrated to be a useful base for a monitoring program at a RBF site. Groundwater flow modeling and statistical data analysis are essential tools for an objective evaluation of an existing monitoring program. At the waterworks Torgau-Ost, a significant reduction of monitoring effort and costs was achieved and the sufficiency of information gained was proven. Furthermore, an action plan for the case of river water pollution was developed to provide efficient monitoring and evaluation of the impacts on the catchment. The modification of the monitoring program does not lead to a static schedule of sampling but must be considered as a dynamic process. Monitoring results will be continuously reviewed and in case of divergent tendencies, the monitoring program modified.

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abstract id: **258**

topic: **1**
Groundwater quality sustainability

1.6
Groundwater monitoring

title: **Optimization of groundwater quality monitoring network using information theory and simulated annealing algorithm**

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keywords: monitoring network, information theory, optimization, entropy, simulated annealing

INTRODUCTION

Assessment and optimization of groundwater quality monitoring networks is an important and difficult task and should be carried out in terms of different criteria. While the problem of assessing the cost of network operation do not create any problems from the methodological point of view, a choice of quantitative criterion for assessing the network quality is not as clear. The main goal of the monitoring system is to produce data for statistical analysis. Thus, one of the evaluation criteria should be the amount of information that the monitoring network is able to provide to the control system. The network should be evaluated by the test that measures whether the amount of information obtained from monitoring meets the expectations. If we assume that the monitoring network is a signal communication system capable of providing environmental information, we can use the entropy-based criteria, derived from the Shannon information theory (Shannon, Weaver, 1949). The fundamental criteria derived from this theory are: (1) the value of marginal information entropy, which is a measure of the amount of information containing in the data in a location of sampling point, and (2) the value of transinformation (mutual information) which measures the amount of information shared between each of two sampling points. Marginal information entropy uses probability distribution functions to measure the randomness (or uncertainty) of a random variable. Transinformation can be interpreted as an index of the stochastic dependence between the random variables corresponding to groundwater quality data recorded in different sampling points of monitoring network and shows the reduction of uncertainty included in one variable due to the knowledge of the other variable.

Some methods relating to Shannon information theory were developed to assess monitoring networks. Harmancioglu and Alpaslan (Harmancioglu, Alpaslan, 1992) have shown application of the information theory into water quality monitoring network design in the context of multi-objective optimization. The results were highly promising as the benefits of a monitoring network were defined quantitatively in the terms of information gain measured by entropy. Mogheir and Singh (Mogheir, Singh, 2002) used the entropy-based criteria to quantify the information produced by ground water monitoring network and combined it in the cost-effectiveness analysis. Recently Masoumi and Kerachian (Mogheir, Singh, 2002) used the discrete entropy theory, C-means clustering method and fuzzy set theory to optimal redesign of groundwater quality monitoring network of the Tehran aquifer. The measure of transinformation was used to find the optimal distance between the monitoring wells.

This paper presents a methodology of assessing and optimizing groundwater quality monitoring networks which takes into account the value of transinformation. This criterion allows to assess the redundant information in the network containing in the series of the same water quality parameter observed at different control points. Since the formulated problem of the monitoring network optimization is a complex combinatorial problem, which is hardly solvable by means of classical algorithms, a heuristic algorithm of simulated annealing is proposed, which allows one to find a satisfactory sub-optimal solution. The proposed methodology was applied to optimize the groundwater monitoring network of contaminant reservoir "Żelazny Most" located in the West-South part of Poland which receives post-flotation contaminants originating from copper ore treatment (Duda, Witczak, 2003; Kucharek, Treichel, 2007). This reservoir has been classified as one of the worlds biggest industrial waste disposal site.

INFORMATION ENTROPY MEASURES

The base term of the information theory introduced by Shannon (Shannon, Weaver, 1949) is entropy *H(X)*. It allows to describe quantity of information coming from random variable. If *X* is a discrete random variable with the probability distribution $p(x_i)$, i = 1, 2, …, *N* then marginal entropy *H(X),* that measures information quantity which comes from observation of *X*, can be calculated as follow:

$$H(X) = -\sum_{i=1}^{N} p(x_i)\log p(x_i) \tag{1}$$

If the probabilities $p(x_i)$ are low, the entropy value is high. The maximum value of entropy equal to *log(N)* is reached for uniform probability distribution $p(x_i) = 1/N$ for i = 1, 2, …, *N*.

There are three additional types of entropy measures associated with stochastic dependency between two random variables *X* and *Y* (Harmancioglu, Alpaslan, 1992; Kucharek, Treichel, 2007; Mogheir, Singh, 2002): joint entropy, conditional entropy and mutual entropy called transinformation. The joint entropy *H(X, Y)* measures a total information content in both *X* and *Y* , and is a function of the joint probability distribution $p(x_i, y_j)$. The total entropy of two independent random variables is equal to the sum of their marginal entropies. When *X* and *Y* are stochastically dependent, their joint entropy is less than the total entropy of these variables. Conditional entropy *H(X / Y)* is a measure of the information content of *X* which is not contained in the random variable *Y*. It represents the uncertainty remaining in *X* when *Y* is known. The transinformation *T(X, Y)* is another entropy measures which measures the redundant or mutual information between *X* and *Y*. It is defined as the information content of *X* which is contained in *Y*. It can also be interpreted as the reduction of uncertainty in *X*, due to knowledge of variable *Y*.

$$T(X,Y) = T(Y,X) = \sum_{i=1}^{N} \sum_{j=1}^{N} p(x_i, y_j)\log \frac{p(x_i, y_j)}{p(x_i)p(y_j)} \tag{2}$$

where *X* and *Y* are two discrete random variables defined in the same probability space with probability $p(x_i)$ and $p(y_j)$, respectively.

The approach developed here consists in assessing the reduction in the joint entropy of two or more variables due to the presence of stochastic dependence between them. This reduction corresponds to the redundant information in the series of the same water quality parameter observed at different control points. Thus a criterion of evaluation of the groundwater quality monitoring network will be the value of transinformation. Minimization of this objective function could be achieved by an appropriate choice of the number and location of sampling points.

GENERAL CHARACTERISTICS OF THE DATA SET

The reservoir "Żelazny Most" was establish in 1974 as a landfill of copper ores flotation tailings and nowadays is one of the world's largest industrial waste disposals. It occupies an area of approximately 1400 hectares. The landfill is surrounded by a protective zone ranging from about 500 to about 1500 meters from the dams. Groundwater quality monitoring network includes 278 data points in which the water quality of first groundwater level is observed. Depending on the plan at some points the measurement is conducted three times a year and at others once every four years.

Following an analysis of the data set, three of variables were chosen for further study: Cu [mg/dm^3], Na [mg/dm^3] and Cl [mg/dm^3]. Data include 55 measurement points, where tests were performed for 10 years, from 1996 to 2005. In the first stage of the analysis the results of measurements are used to calculate basic descriptive statistics (see Table 1 for some examples). Based on analysis, it was found that as time increases the average concentrations of pollutants in groundwater increases and higher maximum values are met. Data distributions are asymmetrical, as evidenced by the coefficient of skewness and significant difference between the mean and median. In addition, each year a number of outliers is detected. The calculated basic statistical parameters are confirmation of the general upward trend due to the continuing expansion of the landfill.

Table 1. The descriptive statistics for the chloride contamination [mg/dm^3] in ground-water of the first water level around the disposal site "Żelazny Most" in 2002–2005.

Statistics	Cl_2002	Cl_2002a	Cl_2003	Cl_2003a	Cl_2003b	Cl_2004	Cl_2004a	Cl_2005
Mean	2 785.9	2 732.8	3 138.6	3 060.6	3 292.6	3 793.3	3 630.0	3 673.3
Standard error	403.8	396.4	417.0	421.0	416.8	447.9	427.2	503.0
Quartile1 (25%)	71.3	60.15	68.8	72.6	72.85	80.4	139.95	144.85
Median	1 865.0	1 556.0	2 584.0	1 971.0	2 669.0	3 967.0	3 921.0	2 746.0
Quartile 3 (75%)	4991.5	4962	5266.5	5378.5	5467	6116	6048	6145.5
Standard deviation	2 994.8	2 940.1	3 092.3	3 122.1	3 091.0	3 321.4	3 168.1	3 730.4
Kurtosis	0.004	0.124	–0.397	–0.362	–0.603	–1.088	–0.793	0.205
Skewness	0.945	0.970	0.730	0.793	0.614	0.331	0.445	0.879
Range	10 206.6	10 201.1	10 328.3	10 329.1	10 143.4	10 992.3	10 505.0	15 216.3
Minimum	10.4	7.4	17.7	16.9	15.6	6.7	10.0	7.7
Maximum	10 217.0	10 208.5	10 346.0	10 346.0	10 159.0	10 999.0	10 515.0	15 224.0
Number of items	55	55	55	55	55	55	55	55
Confidence level (95.0%)	809.6	794.8	836.0	844.0	835.6	897.9	856.5	1 008.5

OBJECTIVE FUNCTION

In the next step of data analysis the values of transinformation were calculated. For all control points in the monitoring network and for three variables: Cl, Cu and Na transinformation was calculated using equation (2). The computing of marginal and joint probability distributions for each sampling points and for each variables was carried out by the mean of contingency tables (Mogheir et al., 2003). To take into consideration in the optimization problem all the investigated variables (Cl^- , Cu^{2+}, Na^+) the objective function was defined as the average of transinformation values determined for the pairs of sampling control points and for the subsequent concentration of all three ions Cl^- , Cu^{2+}, Na^+ :

$$J = \frac{1}{3M(M-1)} \sum_{s=1}^{3} \sum_{n \neq m} T_s(X_n, X_m) \tag{3}$$

where *s* is an index of the investigated variable (Cl^- , Cu^{2+}, Na^+), *n* and *m* are indices of sampling points, *M* is a number of sampling points.

Because the transinformation defines the amount of information contained in one variable (sampling point), which is also contained in another, the use of this criterion allows us to remove redundant information from the groundwater quality control system.

SIMULATED ANNEALING OPTIMIZATION ALGORITHM

Since the formulated problem of minimization of objective function (3) belongs to a class of complex combinatorial problems, which are hardly solvable by means of classical algorithms, a heuristic algorithm of simulated annealing (Kirkpatrick et al., 1983) was proposed, which allows one to find a satisfactory sub-optimal solution. This is a technique that attracted significant attention as suitable for optimization problems of large scale. At the heart of this method is an analogy with thermodynamics, specifically with the way that metals cool and anneal. The key parameter of the algorithm is the cooling schedule. Sufficiently high initial temperature in the initial phase allows the search through the entire search space. However, the speed and the way of lowering the temperature determines the speed of the algorithm. Too slow decrease in temperature can hamper the identification of the optimum by leaving too much freedom to search during a large number of iterations. On the other hand, if the temperature drops too quickly, the algorithm can easily stay at a local optimum, it will not have enough iterations to effectively search through the entire search space.

RESULTS OF OPTIMIZATION

In the order to improve the efficiency of the monitoring network around the disposal site "Żelazny Most" a number of optimization was performed. Calculations were carried out in several variations. We performed calculations for the scenario of whole groundwater monitoring network and for the option the network is divided into zones having regard to the ability or inability of the impact on each individual sampling points. Given the complexity of the phenomenon and the possibility of interactions between the various points the best results were obtained when considering all three ions (Cl^- , Cu^{2+}, Na^+), but maintaining the distinction between the eastern and western forefield.

In each variant of optimization the number of piezometers in the network was successively decreased. For each variant of reduction of the number of sampling points the simulated annealing algorithm calculated the optimal value of the objective function, which evaluates the informational value of the monitoring network, and defined the optimal configuration of the remaining network. Figure 1 shows the optimal configuration of the network designated in the optimization process for the variant of reduction of the network by 20%. It is worth to note that the criterion of transinformation for evaluating the amount of redundant information in the network ensures the stability of the solutions obtained in sequential variants. Sampling points removed from the monitoring network in the variant of a reduction by 10% are also removed from the monitoring network in the variant of a reduction of 20% and were still removed in the variant of a reduction of 30%. This means that the monitoring network reduction procedure can be performed sequentially.

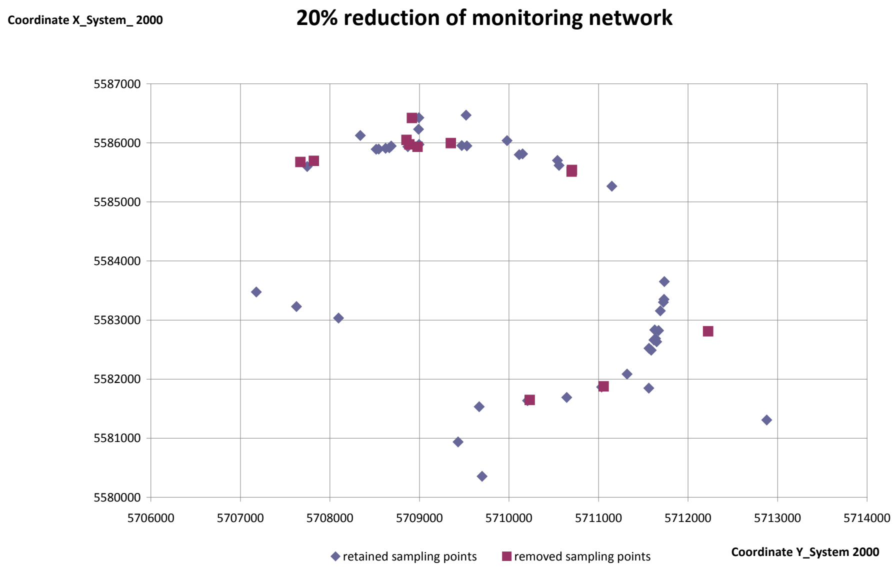

Figure 1. Removed and retained sampling points while reducing the monitoring network by 20%.

SUMMARY AND CONLUSIONS

The aim of this study was to increase the effectiveness of the groundwater quality monitoring network by reducing the number of piezometers while maintaining an acceptable amount of information available in the network. The methodology was applied to the monitoring network of the contaminant reservoir "Żelazny Most" which collects post-flotation contaminants originating from copper ore treatment. When analyzing the information value of the monitoring network, the data on ion concentration of chlorine, sodium and copper in the groundwater of the first water level are used. Different combinations of a number and locations of sampling points were evaluated using the measure of redundant information called transinformation. The simulated annealing algorithm was used to find a sub-optimal solution of the optimization problem. The results show that the proposed methodology can be effectively used for redesign and reorganization of the existing monitoring network and the best combination of sampling points considering minimal redundant information in the system could be selected.

ACKNOWLEDGEMENTS

This research was partially financed by Polish Ministry of Science and Higher Education, project number 1 T09D 010 30. The authors acknowledge KGHM Polska Miedź for providing data for this study.

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IAH 2010
Krakow

abstract id: **260**

topic: **1**
Groundwater quality sustainability

1.6
Groundwater monitoring

title: **Well bore cross-aquifer contamination**

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keywords: groundwater monitoring, cross-aquifer contamination, well purging, ambient well bore flow

ABSTRACT

Water quality tests were performed on two long-screened alluvial aquifer wells (15 to 30 m of screen) that are completed in a heterogeneous aquifer that exhibits extreme temporal water quality variability. When stressed the total dissolved solids (TDS) in one well decreased from 10,600 to 3,500 mg/L and in another well the TDS increased from 136 to 2,255 mg/L. Nested short screened monitoring wells were constructed in chemically distinct horizons affecting each well. Water level measurements and solute and isotopic samples were obtained from the production wells and the monitoring wells during a water quality test. Results of a time drawdown tests demonstrate transmissivity differences between horizons. Ambient water quality in the production wells and aquifer cross-contamination are controlled by well bore mixing due to head differences of as little as 0.01 m between chemically distinct horizons which are linked by the production well screen. During non-stress periods the ambient well bore chemistry is controlled by the horizon with the greatest hydraulic head, whereas during stressed conditions, horizon transmissivity controls the well bore chemistry. In one well aquifer cross-contamination, driven by an ambient head differential of 1.2 m, persisted until about 1,600 well bore volumes were purged.

INTRODUCTION

Production wells are often the primary source of temporal and spatial water quality and hydraulic head data. Such data are used to evaluate the origin, mixing patterns, stratification, and movement of groundwater; to describe the location, geometry, and migration of groundwater contamination; and to calibrate and verify groundwater flow and solute transport models. Because confidence in water quality data is critical, numerous purging and sampling protocols have been developed to help ensure representative water quality data, and considerable attention has been paid to monitoring well design.

Well purging is often needed because stagnant casing storage may not be representative of aquifer water quality. Non-representative water may result from chemical and microbiological induced changes in borehole water quality, internal ambient well bore flow and mixing, the affects of pumping rates and time, and the pump location (Barber and Davis, 1987; Martin-Hayden, 2000a, b; Martin-Hayden and Wolfe, 2000). If the aquifer is chemically homogeneous, well purging should result in a representative water quality sample. Sampling protocols include pumping until field parameters stabilize, evacuation of three or more well-bore volumes, low-flow purging, and calculations of purging times and volumes based on theoretical considerations (Barcelona et al., 1994; Barber and Davis, 1987; Boylan, 2004; Capel et al., 2002; Gibs et al., 1990; Hardy et al, 1989; Knobel, 2006; Robbins et al., 2005; Varljen et al., 2006).

Some aquifers have vertical and/or spatial chemical heterogeneity, thus attention has been paid to monitoring well design including long vs. short screen monitoring wells and discrete and multiport sampling devices (Britt, Tunks, 2003; Einarson, Cherry, 2002; Gibs et al., 1993). Long well screens (i.e., > ~ 2 to 3 m) can bias the sample by diluting water drawn from contaminated horizon(s) with water from non-contaminated horizons. Short screen wells and discrete sampling may bias the sample by either missing contaminated or non-contaminated horizons.

Internal and external factors can bias water quality samples obtained from heterogeneous aquifers. Well bores can induce cross-aquifer contamination in multilayered aquifers (Church and

Granato, 1996; Henrich, 1998; Meiri, 1989; Santi et al., 2006; Sloto, 1996; Sloto et al., 1992). Cross-contamination may occur with small hydraulic head or thermal differentials under ambient conditions (Elci et al., 2001, 2003; Reilly et al., 1989). Temporal solute variability may also result from physical and chemical heterogeneity in the aquifer and from skin effects (Church and Granato, 1996; Reilly and LeBlanc, 1998).

Although many processes which can bias well water quality have been investigated, previous work has focused on: 1) theoretical and modeling approaches (Barber and Davis, 1987; Elci et al., 2001, 2003; Lacombe et al., 1995; Reilly et al., 1989), and 2) laboratory and field experiments generally using low pumping rates (< 5 L s^{-1}), short time intervals (< 1 day), and low solute concentrations (< 100 mg L^{-1}) (Church and Granato, 1996; Hutchins and Acree, 2000; Martin-Hayden 2000b; Reilly and LeBlanc, 1998). Low pumping rates and short pumping intervals mean the travel distance for water drawn into the well bore is small and only a limited aerial extent of the aquifer is involved. Additionally low solute concentrations can make it difficult to chemically distinguish water bearing horizons, to fully evaluate well skin effects, and to identify cross-aquifer contamination.

Short well screens and multiport sampling designs are generally preferred over long well screens for water quality sampling and water level measurements. However, long-screened, production wells with high pumping rates, which may sample chemically heterogeneous aquifers, are often the only data source. Despite the numerous investigations of water quality bias associated with monitoring wells, the potential for water quality bias due to long-term pumping of high output, long-screen production wells is poorly understood.

Because long-screened production wells commonly draw water from heterogeneous aquifers, a critical question is what does water quality data from long-screened production wells in heterogeneous aquifers tell us about the aquifer? To examine this question two unconfined aquifer production wells, which are located in the San Luis Valley, Colorado (Figure 1) and which exhibit large temporal TDS variability, have been investigated.

GEOLOGIC AND HYDROLOGIC CONDITIONS

The San Luis Valley, a major agricultural area located in south-central Colorado (Fig. 1), contains approximately 2.5 x 10^{12} m^3 of groundwater within 1,800 m of the land surface (Romero and Fawcett, 1978). The 95 km wide and 170 km long valley was a closed basin from about 4.5 Ma until a few hundred thousand years ago, when the ancestral Rio Grande overflowed the basin and cut a channel through the San Luis Hills in the southern portion of the valley (Machette, 2004). The northern portion of the valley, known as the Closed Basin, remained a region of internal drainage. Mayo et al. (2007) designated the central portion of the Closed Basin as the ancestral sump due to methane (CH_4) evolving, high TDS groundwater in the unconfined and upper portion of the confined aquifer.

In the Closed Basin the ~ 30 m thick unconfined aquifer occurs in the upper part of the Pliocene-Pleistocene Alamosa Formation (Mayo et al., 2007). The Alamosa Formation, which consists of a series of discontinuous, lakebed clay, and other interbeds that are up to several hundred meters thick, also supports underlying confined groundwater systems (Emery et al., 1973; Hanna and Harmon, 1989; Huntley, 1976; Powell, 1958; Romero and Fawcett, 1978). Interbeds in the ancestral sump area include well-sorted fluvial deposits, fine-grained lake sediments, organic sediments, and evaporite minerals deposited in ancestral Lake Sipapu (Mayo et al., 2007).

In ancestral sump area, the U.S. Bureau of Reclamation constructed 170 long-screened (15-30 m of screen) production wells and 35 monitoring wells, known as SW and EW wells, respectively (Figure 1). The SW wells have a casing diameter of 0.28 m, a mean screen length of 16.6 m, and a mean well depth of 29.9 m. EW wells have a well casing diameter of 0.1 m, a mean screen length of 4.5 m, and a mean depth of 39.8 m.

Using SW and EW data maximum TDS concentrations in the ancestral sump are contoured on Figure 2. The waters have a maximum concentration of more than 44,000 mg L^{-1} and evolve from Ca^{2+} - HCO_3^- type water outside the ancestral sump (mean TDS 247 mg L^{-1}) to sump area Na^+ - HCO_3^- - SO_4^{2-} - Cl^- rich water (mean TDS 2,619 mg L^{-1}). The chemical evolution of the waters is described by Mayo et al. (2007).

METHODS OF INVESTIGATION

Thirty-five SW wells, with a maximum TDS greater than 300 mg L^{-1}, have exhibited TDS variability greater than 25 percent in response to pumping stress. In some wells the TDS increases during pumping and in other wells the TDS decreases during pumping. Absolute differences between minimum and maximum TDS for individual wells range from 52 to 14,394 mg L^{-1}. Wells exhibiting TDS variations are located along a linear trend (Figure 3), which corresponds to the locations of playa and organic rich environments in ancestral Lake Sipapu (Mayo et al., 2007). The combined effects of chemical stratification well bore mixing due to hydraulic head driven ambient well bore flow, and differential well bore inflows during pumping stress were suspected as the cause of temporal TDS variability.

Two production wells, SW-67 and SW-89 (Figure 1), were selected for study because they exhibit large temporal water quality changes in response to pumping stress (Figure 4). Low TDS in SW-67 corresponds to pumping periods, whereas low TDS in SW-89 corresponds to non-pumping periods (Figure 5). After periods of pumping concentrations of Na^+, HCO_3^-, SO_4^{2-}, and Cl^- decreased in SW-67, whereas concentrations of Na^+, Ca^{2+}, SO_4^{2-}, Cl^-, and HCO_3^- increased in SW-89 (Figure 4). The recorded TDS range in SW-67 is 1,030 to 15,427 mg L^{-1} and the recorded TDS range in SW-89 is 123 to 3,250 mg L^{-1}.

SW-67 and SW-89 are located about 10.5 km apart (Figure 1). The unconfined aquifer lithology is not continuous between the two wells. SW-67 lithology is dominated by finer grained sediments, whereas coarser grained sands are more common at SW-89 (Figures 6a and 6b). In both wells numerous thin clay and interbedded clay and sand horizons are encountered. Lithologic logs of wells located between SW-67 and SW-89 suggest that horizons commonly pinch over distances of a kilometer or more.

Using SW and deep boring lithologic logs, water levels, and geophysical logs several water-bearing horizons were identified at SW-67 and SW-89. At each well a series of nested monitoring wells were constructed in three distinct aquifer horizons traditionally considered and legally defined as part of the unconfined aquifer. At SW-67 a monitoring well was also completed in the upper part of the underlying unconfined aquifer. Seven monitoring wells were constructed near SW-67 and six were constructed near SW-89 (Table 1).

At SW-67 a combined 8.5-day time-drawdown pumping and water quality test, using observation well responses, was performed. During the test the pumping rate declined from 16.7 to 11 L s^{-1}. At SW-89 a 23-day water quality test was performed with a pumping rate that declined from 12.7 to 9.1 L s^{-1}. Pumping rates declined in response to falling water levels in the pumping wells (Figure 7). Because the wells contained permanently installed electric pumps, the impeller speed could not be increased to compensate for the declining pumping rates. Water levels were measured using an electrical sounder. Discharge water was conveyed 300 m from the pumping wells via pipeline and discharged into small ponds.

Solute, gas, and isotopic samples were collected prior to and at the end of each test. Pumping well water samples were collected from permanently attached sampling faucets. Each SW well has such a faucet because production wells are sampled at least twice a year. Prior to and at the end of the water quality tests samples were collected from the monitoring wells using a low volume pump. Samples were collected after at least 3 well bore volumes had been removed and the field parameters pH, temperature and conductivity stabilized. The purging protocol is considered adequate because the monitoring wells were designed to sample discrete water bearing horizons.

In addition to field parameters samples were collected for major ion and isotopic analysis (Table 2). Isotopic analysis included $\delta^{2}H$ and $\delta^{18}O$, $\delta^{13}C$, and $\delta^{34}S$. A wide range of solutes and isotopes were collected because it was uncertain which parameters would be most useful. Major ions and stable isotopes were collected to help distinguish geochemical horizons, ambient well bore mixing, and aquifer cross-contamination. The stable isotopes $\delta^{2}H$, $\delta^{18}O$, $\delta^{13}C$ and $\delta^{34}S$ were collected because they sometimes provide insight into geochemical horizons independently rock-water interactions that effect solute compositions. Major ion charge balance errors for SW-67 data are <3% and errors for SW-89 data are typically <5%. Because many confined and some unconfined aquifer waters exsolve gas, the gas was analyzed for C1-C5 (i.e., methane, ethane, propane, butane, pentane), CO_2, N_2, O_2, Ar, He, and H_2 content (Table 3). $\delta^{13}C$ and $\delta^{2}H$ were determined on CH_4, and $\delta^{13}C$ was determined on CO_2 to help determine the origin of the gas.

RESULTS

SW-67 and SW-89 Water Quality Tests

Water quality tests, which included observation well water quality sampling, were conducted at SW-67 and SW-89 in an attempt to better understand the relationship between TDS variability, pumping stress, and aquifer heterogeneity. SW-67 was pumped for 8.5 days and SW-89 was pumped for 23 days. Prior to the tests SW-67 and SW-89 were not pumped for 123 and 71 days, respectively. Beginning and end of test solute compositions are illustrated as Stiff diagrams in Figures 6a and 6b. During the tests SW-67 TDS declined from 10,600 to 3,530 mg L^{-1} and the TDS in SW-89 increased from 136 to 2,282 mg L^{-1} (Table 2). Water quality stabilization in SW-89 was not achieved until about 15 days of pumping (Figure 8). Similar temporal water quality data are not available for the 8.5 day test at SW-67.

At each pumping well the water bearing horizons are chemically stratified. Three distinct water types were identified: low to moderate TDS Na^{+} - HCO_3^{-} type water, elevated TDS Na^{+} - HCO_3^{-} - SO_4^{2-} type water, and elevated TDS Na^{+} - Cl^{-} - Ca^{2+} - SO_4^{2-} type water. Na^{+} - HCO_3^{-} type water occurs in horizons 1, 3, and 4 at SW-67 and in horizons 1 and 3 at SW-89. Na^+ - HCO_3^- -SO_4^{2-} type water occurs in horizon 2 at SW-67, and Na^+ - Cl^- - Ca^{2+} - SO_4^{2-} type water occurs in horizon 2 at SW-89 (Figures 6a and 6b).

Only the upper and lower horizons at each pumping well maintained stable chemical compositions during the tests. Changes in chemical compositions in horizons 2 and 3 at SW-67 and horizon 2 at SW-89 resulted from either pumping induce vertical leakage from an adjacent horizon or from the removal of water which invaded the horizon via the pumping well bore during non-pumping periods. Where no pumping induced vertical leakage occured, end of test monitoring well chemistries are assumed to be representative of the background solute compositions of the horizon.

Although an in depth analysis of the chemical evolution is beyond the scope of this investigation, a brief discussion of the chemical evolution will help to provide context for the observed chemical stratification. Diverse carbon histories are evidenced by HCO_3^- and $\delta^{13}C$ contents which vary from 0 to -12 ‰ (Table 2). End of test SW-89 horizons 1 and 3 have HCO_3^- concentrations ~ 1.3 to 3.7 meq L^{-1} and $\delta^{13}C$ ~ -12 to -9 ‰, that are typical of carbon acquired from soil zone CO_2 gas and the dissolution of soil zone carbonate minerals. Most end of test waters have $\delta^{13}C$ compositions of ~ -7 to -5 ‰, however SW-67 horizon 4 has a $\delta^{13}C$ of about 0 ‰. Possible explanations for the less negative $\delta^{13}C$ compositions include: 1) the acquisition of dissolved carbon during a different climatic time, or 2) the acquisition of CO_2 gas or H^+ from additional sources such as methanogenic reactions. δ^2H and $\delta^{18}O$ isotopic composition of SW-89 horizons 2 and 3, and SW-67 horizon 2 may suggest recharge during different climatic conditions than during the recharge of other waters or evaporation at the time of aquifer deposition (Figure 9). Both of these mechanisms could affect the $\delta^{13}C$ composition; however, neither mechanism would increase HCO_3^- to > 20 meq L^{-1}.

At SW-67, $\delta^{13}C$ of -7.4 ‰ or less combined with elevated HCO_3^- concentrations are accompanied by in situ production of methanogenic carbon. Methanogenic processes are described by Doelle (1969), Hunt (1979), Whiticar et al. (1986), and Wolin and Miller (1987). Evolving methane gas (CH_4) was evident during the SW-67 test from several monitoring wells (Table 3). The slight odor of HS^- gas occurs at SW-67, WS-89, and other unconfined aquifer wells. HS^- is a product of sulfate reduction and often associated with methanogenesis. Although the $\delta^{13}C$ composition of horizon 2 may suggest methanogenesis, the SO_4^{2-} content of this water is too elevated for appreciable anaerobic methanogenesis to have occurred. The apparent contradiction between the $\delta^{13}C$ and SO_4^{2-} may indicate that different chemical processes are occurring in different horizons. In summary elevated Na^+ and HCO_3^- contents are attributed to in situ H^+ driven - methanogenic - cation exchange – carbonate mineral dissolution mechanism, whereas low Na^+ and HCO_3^- contents are attributed to cation exchange.

The elevated SO_4^{2-} content of horizon 2 at both wells is attributed to gypsum dissolution. Gypsum dissolution as evidenced by the positive $\delta^{34}S$ compositions (Table 2). Sulfate from reduced sulfur sources (e.g., pyrite) typically have $\delta^{34}S$ values ~ 0 ‰, whereas sulfate from oxidized sources (e.g., gypsum) typically have $\delta^{34}S$ compositions >10 ‰ (Clark and Fritz, 1997). The idea of gypsum dissolution in SW-89 horizon 2 is also supported by gypsum saturation (gypsum SI = 0.01). The low SO_4^{2-} concentrations and very positive $\delta^{34}S$ compositions of SW-89 horizon 1 and 3 waters are attributed to the original sulfate content of the recharge waters. Most stream waters entering the Valley from both the Sangre de Cristo Range and the San Juan Mountains have very low SO_4^{2-} concentrations, however $\delta^{34}S$ data are only available for one stream entering the valley, thus correlation of $\delta^{34}S$ contents with closed basin groundwaters is problematic (Mayo et al., 2007). The elevated Cl^- at SW-89 horizon 2 most likely results from the dissolution of halite in the aquifer matrix.

δ^2H and $\delta^{18}O$ compositions suggest that some pre-test waters have been subjected to evaporation (Figure 9). Well bore evaporation may be responsible for some pre-test data, although all of the wells were capped. The data also suggest that end of test SW-67 horizon 2 and possibly SW-89 horizon 2 have been evaporated, whereas groundwaters in horizons above and below have not. The significance of the elevated TDS contents of horizons 2 at both wells and the potential evaporation water in SW-67 horizon 2 is that, under natural conditions, upward vertical flow from horizon 2 to horizon 1 has been limited. Under current conditions the vertical gradient is slightly downward from horizon 1 to horizon 2. When the idea of limited vertical flow is considered in light of the closed TDS contours (Figure 2), it is apparent that a zone or zones of stagnate or nearly stagnant groundwater exists in the subsurface. The lateral continuity of the elevated TDS horizons beyond SW-67 and SW-89 is unknown.

SW-67 Time-Drawdown Pumping Test

Unconfined aquifer vertical gradients are downward near SW-67, but the total head difference is generally less than 0.15 m (Table 1; Figure 10). However, in horizon 3 well 3A had a static head about 0.3 m less than the corresponding well 3B, possibly due a facies change between the two wells or vertical leakage from horizon 1. The confined aquifer antecedent water level (horizon 4) was about 1 m above unconfined aquifer levels indicating upward potential between the two aquifers. No discernable trends in antecedent water levels were measured in the 20 days prior to the test.

Results of the 8.5 day aquifer test are shown in Figures 11 and 12. Drawdown data for unconfined aquifer wells (horizons 1, 2, and 3) initially decreased in a straight-line fashion on a semi-log plot (Figure 11). During the test the rate of decline decreased after 200 minutes or less and water levels subsequently increased. The non-linear semi-log slopes are attributed to the declining pumping rate during the test, although facies changes and vertical leakage may also have been factors.

The rise above the static level in the confined aquifer monitoring well 4A (Figure 12) is a common response in Closed Basin upper confined aquifer wells that exsolve (CH_4) methane gas (Huss, 2004). The rise in water level is attributed to the Noordbergum effect which is the result of three-dimensional deformation of adjacent aquifer materials induced by pumping (Hsieh, 1996; Wolff, 1970).

The combined factors that drawdown occurred in each well in each horizon in response to pumping SW-67, horizon 1 drawdown was <0.3 m whereas horizons 2 and 3 drawdowns were several meters, drawdowns in the distant B-series wells were less than in the nearby A-series wells, and SW-67 is only screened opposite horizons 2 and 3 suggests that:

- horizon 1 is unconfined,
- horizons 2 and 3 are confined or semi-confined,

- water from horizon 1 enters the SW-67 well bore by vertical leakage into horizon 2,
- lateral hydrodynamic communication occurs in each horizon.

Understanding the potential contribution from each horizon to SW-67 is important for evaluating the time-drawdown data. The fact that the horizons are chemically stratified means that it should be possible to use the chemical compositions to help understand the contribution of each horizon to each other and to SW-67.

Assuming the SW-67 well completion isolates horizon 1 from the well bore, drawdown in horizon 1 results from SW-67 pumping induced vertical leakage. Examination of the SW-67 as built documentation and discussions with Rio Grande Water Conversancy personnel (Huss, 2004) supports this assumption. The fact that the post-test TDS of horizon 2 water is less than the end of test TDS and the TDS of both pre-test and end of test horizon 1 water is greater than the TDS of horizon 1 water suggests that ambient leakage from horizon 1 to horizon 2 is minimal. Head differentials between the two horizons of 0.01 to 0.03 m support this idea. Pumping SW-67 created downward head differentials of ~2 to 6 m which could readily induce vertical leakage from horizon 1 to horizon 2. The potential contribution of horizon 1 to horizon 2 during pumping was calculated assuming the final horizon 2 chemistry is a mixture of horizon 1 and pre-test horizon 2 waters. Calculations using SO_4^{2-}, Cl^- , and TDS suggest about 25% of end of test horizon 2 water is from horizon 1.

Mixing ratios were calculated in an attempt to evaluate contributions from horizons 2 and 3 to SW-67 during pumping (Table 4). Mixing calculations only used the A-series end of test results for conservative solute species (SO_4^{2-} and Cl^-) and the isotopic compositions ($\delta^{18}O$, $\delta^{2}H$, and $\delta^{13}C$). End of test compositions accommodates the effect of vertical leakage from horizon 1 to horizon 2. The A-series wells were chosen because they are close to SW-67 and their water chemistry can not have been impacted by water flowing near the B-series wells. For SO_4^{2-} and Cl^- the calculations suggest that horizon 2 could contribute ~22 to 34% of SW-67 discharge and that horizon 3 contributes most of the water discharging from SW-67.

Mixing calculations for the stable isotopes of water (i.e., $\delta^{18}O$ and $\delta^{2}H$) suggest that both horizon 2 and 3 could contribute ~ 50% of the water to SW-67. However, the value of the final $\delta^{13}C$ of SW-67 is less than the $\delta^{13}C$ value for water near A-series horizon 3 water, thus the calculated contribution from this horizon is listed as 100 % in Table 4. The $\delta^{13}C$ of water near the B-series horizon 3 well is -5.0 ‰ , which means the combined contributions of water from near the A- and B-series wells is consistent with the end of test SW-67 $\delta^{13}C$ composition. Therefore, based on $\delta^{13}C$ both horizons 2 and 3 could contribute to SW-67 discharge.

Although the chemical data suggest that during pumping horizon 2 contributes 30 to 40 %, horizon 3 contributes 60 to 70% of SW-67 discharge, the data also suggest that ~ 25% of horizon 2 water is from horizon 1. The uncertainty in contributions of from each horizon combined with the non-linear drawdown responses complicate the analysis of the SW-67 observation well time-drawdown data. Because of the uncertainty both analytical and numerical methods were used to analyze aquifer parameters using the time-drawdown data.

Analytical analysis involved curve matching with respect to delayed yield, vertical leakage, and boundary conditions by the methods described in Lohman (1978) and Batu (1998). Only horizons 2 and 3, which have direct hydraulic communication with SW-67, were analyzed by curve matching methods. The SW-67 pumping rate was apportioned between the horizons based on the calculated mixing ratios. Assigned Q contributions from horizons 2 and 3 are 27% and 73% of SW-67 discharge, respectively, and only the first 300 minutes of data were used. The 27 and 73% values were used to account for some water from the vicinity of the B-series wells. Aquifer parameters were calculated using leaky without storage log-log type curves. The drawdown data were also evaluated relative to other type curves. Using the Q apportionment method, calculated storativity (S) of horizons 2 and 3 are similar, ~3 to 6 x 10^{-4} and ~2 to 4 x 10^{-4}, respectively and calculated transmissivity (T) for horizons 2 and 3 were ~ 15 and 45 m^2 day^{-1}. The rate of vertical leakage between horizons 1 and 2 was not quantified.

Numerical analysis, using a radial flow model similar to Hoffmann et al. (1996), was performed on the fist 360 minutes of data by Halford (2009). The numerical model has the advantage that flow rates do not need to be assigned to specific horizons and all horizons can be analyzed simultaneously. Assumptions included vertical to horizontal anisotropy = 0.2, specific storage = 9.9 x10^{-6}, and Sy = 0.15. Calculated T values for horizons 1, 2, 3, and 4 were 10, 8, 84, and 67 m^2 day^{-1}, respectively.

Calculated T results using both analytical and numerical methods show similar patterns and are relativity consistent with each other. The results should only be viewed as 1st order approximations due to the numerous assumption used in the analysis. Results of the numerical analyses confirm that the transmissivity of horizon 3 is appreciably greater than the overlying horizons and that most groundwater discharging from SW-67 originates in horizon 3.

DISCUSSION

SW-67 and SW-89, which are open to heterogeneous aquifers, exhibit extreme water quality variability in response to pumping stress. Each well encounters water bearing horizons that are chemically distinct from each other. At each well site chemical differences between the horizons include concentration and in some instances chemical composition. Because pumping well water quality variability is associated with TDS differences between the horizons as well as temporal solute variability within some horizons, the water quality relationships between the pumping wells and the horizons are complex. Understanding this complexity is complicated by the fact that hours to days of well purging are required to stabilize water quality parameters in the production wells. Such purging times greatly exceed typical sampling protocols.

In order to sort out the factors responsible for the temporal water quality variability in the production wells several factors need to be evaluated: 1) the natural water quality in each horizon and the spatial distribution of this water quality, 2) water quality changes within horizons due to pumping induced head changes, and 3) water quality changes induced by ambient (i.e., non-pumping) cross-aquifer contamination via the pumping well bore. The following evaluation will only include analysis of SW-67 data, because only one horizon in SW-89 contains two monitoring wells. Two monitoring wells are needed to evaluate spatial relationships.

At SW-67 only horizon 1 monitoring wells have end of test compositions that are essentially unchanged from pre-test conditions and that are similar in both the A and B series wells. These waters are Na^+ -HCO_3^- type with a TDS of ~2,200 mg L^{-1}. The spatial and temporal consistency of pre-test and end of test compositions suggest chemical homogeneity in horizon 1 that has not influenced by pumping stress.

Horizons 2 and 3 monitoring wells exhibit both spatial and temporal chemical heterogeneity. Horizon 2 pre-test compositions in the A- and B-series wells are chemically similar (Figure 6a). The pre-test composition (Na^+ -HCO_3^- -SO_4^{2-} type water, TDS of ~13,000 mg L^{-1}) likely represents background conditions because: 1) significant natural vertical leakage from horizon 1 into horizon 2 is unlikely do to the small head differential between horizons 1 and 2, 2) horizon 3 water can not invade horizon 2 via SW-67 well bore due to the downward gradient, and 3) horizon 2 waters have the highest TDS. Mixing calculations, discussed above, suggest that the horizon 2 end of test compositions are diluted by a ~25% contribution from horizon 1 via pumping induced vertical leakage. The cause of the large TDS difference between end of test well 2A and well 2B waters may be the result of greater pumping induced vertical leakage from horizon 1 in the vicinity of the B-series wells than in the vicinity of the A-series wells. Lower TDS water beyond well 3B is unlikely for several reasons. The gradient from well 2A to well 2B is 0.007 suggesting horizon 3 ambient water occurring west of well 3B should be similar or more saline than water in encountered in well 2A. The pre-test horizon 2 compositions support this idea. Because prior to pumping the natural groundwater flow is toward well 3B, the TDS beyond the well prior to pumping should also be elevated.

Pre-test and end of test horizon 3 water in well 3A exhibits large compositional and concentration differences, whereas both the composition and concentration in well 3B were relatively stable during the test. In well 3A the end of test TDS declined from ~6,500 to ~700 mg L^{-1} indicating the invasion of substantial amounts of high TDS water into the horizon prior to pumping. Elevated TDS horizon 2 water is the most reasonable source of this water. Because the head differential between well 2A and 3A is very small, only 0.01 m, and only horizon 3 water in the vicinity of the A-series wells was affected, vertical flow in the SW-67 well bore is the most likely avenue for fluid migration between horizon 2 and horizon 3. Mixing calculations using pre-test well 2A and post test well 3A as end members suggest that ~ 50% of the water encountered in well 3A originated in horizon 2. The ~ 45 m thick clay zone separating horizon 4 from horizon 3 would limit vertical leakage from the confined to the unconfined aquifer.

The lateral extent horizon 2 water invasion into horizon 3 was evaluated by two methods: 1) calculation of the volume of water removed from horizon 3 during the water quality test, and 2) calculation of the radius of water invasion into horizon 3 from horizon 2 during a specified time. The volume of water removed calculation utilizes several simplifying assumptions: piston flow, aquifer porosity = 0.2, the pumping time required to remove mixed water from horizon 3 = 8.5 days, average pumping rate = 14 L s^{-1}, saturated thickness in horizon 2 = 7 m, horizon 3 = 10 m. Based on these assumptions the radius impacted in horizon 3 is ~ 35 m. The 8.5 day purging time was selected because this was the duration of the drawdown test. Using a shorter purging time would result in a small radial impact. It should be noted however, that a the pre-test solute composition in well 3B, located 22.5 m from SW-67, was slightly impacted water from horizon 2.

The water invasion estimate involved calculating the ambient flow rate from horizon 2 to horizon 3 via SW-67 well bore. The flow rate was then used to estimate the radius of water invasion. The flow rate calculation assumed horizons 2 and 3 satisfy the Theis assumptions. Assigned aquifer parameters, based on the results of the time-drawdown aquifer test were T= 18 m^2 d^{-1} and S = 0.2 for horizon 2, and T= 84 m^2 d^{-1} and S = 10^{-4} for horizon 3. Calculated ambient flow rates ranged from ~ 0.01 to 0.04 L s^{-1} depending on the assigned head differential.

Using the range of calculated ambient flow rates, the radius of horizon 3 affected and the minimum purging time require to remove the water invaded from horizon 2 were calculated. Assumptions included horizon 3 saturated thickness = 10 m, porosity = 0.2, inflow rate = 0.01 to 0.04 L s^{-1}, and pumping rate = 14 L s^{-1}. The calculated radius impacted after 1 year of ambient well bore flow is ~7 to 12 m, and the purging time required to remove horizon 2 water from horizon 3 ranged from ~ 4 to 24 hours. In addition to the uncertainty in the ambient flow rate calculations and the porosity of horizon 3, the calculations include the simplifying assumptions of piston flow from the well bore into horizon 3, and the regional gradient does not impact the shape of the plume (i.e., radial flow from the well).

The purging times calculated using the ambient flow rate method appears to be low based on field observations, and the 8.5 day purging assumed in method 1 is likely too long. Short term synoptic conductivity data are not available to better fix the necessary purging time for SW-67. SW-67 had only been idle for 71 days prior to the test. The time between pumping events would also greatly impact the purging time as the volume invasion water via ambient flow is proportional to time between pumping events. Synoptic TDS data collected during the 23 day SW-89 test (Figure 8) provides insight in potential purging times. At SW-89, which had only idle for 71 days prior to the test. During the SW-89 water quality test conductivity data were measured frequently (Figure 13). At SW-89, which had been idle for 123 days prior to the test, ~15 days of pumping at ~11 L s-1 were required to remove all invaded water.

CONCLUSIONS

Vertical stratification may affect water quality in sampled wells in the following manner. When the well is not under stress, groundwater from the horizon with the greatest hydraulic head flows into the well bore and displaces water from horizon(s) with lesser hydraulic heads. Water can move up or down the well bore, depending upon the direction of head differentials. Under non-stressed conditions, where the aquifer contains hydrochemically distinct or contaminated horizons, the water chemistry or contaminant concentrations in the well is dominated by the chemistry of the horizon with the greatest hydraulic head. If the well has not been pumped for some time, water from the horizon with the greatest hydraulic head will also move into and mix with groundwater in horizons with lower hydraulic heads.

Pumping removes the mixed groundwater from the well bore and contaminated horizons. Thus, after a well has been pumped for sufficient time the water chemistry in the well will represent the chemistry or contamination of each horizon mass weighted for its transmissivity. Numerous schemes have been developed to determine the pumped volume of water necessary to help ensure samples that are representative of the aquifer (Barcelona et al., 1994; Barber and Davis, 1987; Gibs et al, 1990; Hardy et al, 1989). The general idea in most schemes is that a limited amount of groundwater extraction is required to obtain representative water quality data. Inherent in this is the assumption that the influence of well-bore cross-contamination does not extend for a great distance into the aquifer. In most situations water quality differences between horizons are not great and the true extent of cross-contamination is difficult to quantify.

Because substantial water quality differences exist between aquifer horizons in this study, several observations regarding the potential meaning of water quality samples are possible from the San Luis Valley testing. At SW-89, where chemical stratification is not subtle and thus purging effects can be readily measured, the necessary purging volume greatly exceeded most protocols. The daily effects of pumping on solute compositions of SW-89 waters are illustrated in Figure 13. Similar data are not available for SW-67. Solute compositions increased steadily until about day 14-16 when compositions stabilized. This is equivalent to vacating about 1,600 well bore volumes before representative water quality was obtained. After chemical stabilization the representative water quality carries the caveat that is does not represent a single horizon, but it represents mixed water quality.

Observation well data from SW-67 and SW-89 demonstrate that well bore mixing in long-screened wells can result in appreciable aquifer water mixing away from the well bore under small head differentials. Thus, mixing can influence the solute, isotopic, and contaminant concentrations in nearby short-screened monitoring wells. Mixing of aquifer waters by invasion of water via the well bore is observed in well 3B (SW-67), at a distance of 22.5 m from the long-screened well pumping under a head differential of only 0.11 m.

Another critical issue is what does the water quality from a sampled well tell about the aquifer system? Water quality sampled from SW-67 and SW-89 provided only limited insight into subsurface conditions. The temporal water quality data did suggest well bore mixing from two or more horizons. However, the pumping well data did not suggest the existence of four hydrogeochemical horizons and it did not suggest chemical facies changes over short distances. For example, the $\delta^{13}C$ of HCO_3^- and the major ion compositions of end test SW-67 horizon 2 waters (i.e., 2A and 2B; Table 2) and the beginning and end of test TDS differences in SW-67 wells 3A and 3B are fundamentally different from each other indicating facies changes over a distance of less than 30 horizontal m.

Some monitoring well data also provided misleading information. For example, OW-3 (SW-89) has only 1.5 m of screen, yet the water quality and isotopic composition of samples at the beginning and ending of the 23-day test are fundamentally different (Figure 6B, Table 2). A similar conditions occurs in well 3A at SW-67 (Figure 8A) Daily sampling from SW-89 (Figure 13) indicate that a considerable volume of water, 1,600 well bores in this case, must be removed to eliminate cross-contaminated water for the aquifer system. Even in cases where the TDS did not appreciable change between the beginning and end of the test, such as well 3B (SW-67) fundamental isotopic and isotopic compositional changes occurred (Table 2).

Knowledge of aquifer lithology and aquifer parameters may provide little comfort in assessing the meaning of water quality data. The extent of chemical stratification and aquifer cross-contamination was not apparent from the borehole lithologic and geophysical data at SW-67 and SW-89.

Because chemical stratification is pronounced over relatively short vertical distances, the water quality variability in long- and short-screened wells in the San Luis Valley provides valuable insights into the impact of chemical stratification on water quality samples and on knowledge of the groundwater system gained from samples. Such insight is not readily apparent in groundwater systems where chemical stratification is not pronounced yet subtle differences occur. This is particularly true for groundwater contamination investigations where concentration differences as small as 0.001 to 0.01 mg L^{-1} may be critical. Such small values may be the difference between meeting or exceeding a water quality standard. As an example of how this critical difference may be important Capel et al. (2002) found that purging 3 well-bore casing may be adequate for major ion analysis but not for some inorganic constituents. In this case it is likely that different hydrostratigraphic horizons had similar overall water chemistry but not all horizons were nitrate and atrazine contaminated. Thus conventional purging stabilized field parameters, but either cross-contamination or organic constituents remained or other factors affecting the reliability of purged samples remained.

Results of this investigation suggests that: 1) in relatively low TDS groundwater cross-aquifer contamination may persist appreciably longer that previously thought and that typical well purging techniques may not result in representative water quality sample, 2) in long-screened production wells cross-aquifer contamination is common, although it may not be readily apparent when the solute concentrations of the various horizons are similar, and 3) it may not be possible to obtain a non-biased water quality sample. Therefore, the question remains. You've sampled the well, so what do you now know about the aquifer? Clearly thoughtful consideration is required when collecting, interpreting, and evaluating water quality results from long-screened wells in heterogeneous aquifers.

ACKNOWLEDGMENTS

Special thanks to Allen Davey of Davis Engineering Services, and Ralph Curtus and Fred Huss of the Rio Grande Water Conservation District for their help and financial assistance. The paper benefited greatly by reviews from Gary Weissmann and an anamous reviewer. I am particularly grateful for the review, comments, and assistance of Keith Halford in revising the pump test data analysis.

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abstract id: **266**

topic: **1**
Groundwater quality sustainability

1.6
Groundwater monitoring

title: **Groundwater flow and recharge in the Doñana aquifer system (Huelva, SW Spain) from temperature profiles in boreholes**

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keywords: groundwater, flow, recharge, temperature, Doñana

INTRODUCTION

Ground average temperature depends on long–term, local average ground surface temperature and the geothermal vertical gradient. This is not only influenced by deep heat sources and the thermal properties of water–containing materials but also by groundwater flow rate, due to the large heat capacity of water. The influence of downward vertical recharge from the surface (or upward vertical discharge from the depth) is here considered as a 1–D problem between two constant temperature boundaries, one in the ground surface (the average of seasonal and diurnal variation) and the other in depth. This is the Bredehoeft and Papadopulos (1965) steady state problem, that now is considered here under non–steady conditions when there is a sustained sudden change in surface (or in depth) temperature (Custodio et al., 1996). This is applied to the Doñana area, in southwestern Iberian Peninsula, between the Guadalquivir and the Tinto–Odiel rivers marshes.

A recent morphological and hydrogeological description of the Doñana areas can be found in Custodio et al. (2009). It is the largest seminatural area of Western Europe and holds a 3000 km^2 aquifer system. The territory was unhabited due to the very poor eolian sand soil cover, the marshes and a large number of lagoons and wetlands. There is a very long, almost untouched coastal area only developed for shell–fish capturing, except for two recent, localized, large tourist resorts. The area was promoted for irrigated agriculture in the 1970s using local deep groundwater from a coarse layer below thick fluvio–marine sand formations. It also holds a large protected area as national and natural parks.

Groundwater studies are available since the late 1960s and especially from the late 1970s. In the 1980's a dedicated groundwater monitoring network, with point piezometres open at different depths. Detailed numerical modelling has been carried out. Studies included a temperature borehole logging survey.

HEAT TRANSPORT IN A SATURATED POROUS MEDIUM

The heat balance in a water–saturated porous medium can be given as:

$$-\mathrm{div}J_D - \mathrm{div}J_A + F = \frac{\partial}{\partial t}(c_g^v\theta) \qquad (1)$$

where:

J_D = conductive heat flow = –K grad θ	$[EL^{-2}T^{-1}]$
J_A = advective heat flow = $\rho_w c_w \theta$	$[EL^{-2}T^{-1}]$
F = heat source term (negative if it is a sink)	$[EL^{-3}T^{-1}]$
t = time	[T]
c^v_g = ground volumetric heat capacity = (1–m) $\rho_g c_g + m\rho_w c_w$	$[EL^{-3}K^{-1}]$
θ = temperature (assumed the same for ground and water)	[K]

for the following parametres:

K = ground thermal conductivity	$[EL^{-1}T^{-1}K^{-1}]$
k = hydraulic conductivity (permeability)	$[LT^{-1}]$

q = groundwater flow = –k grad h (Darcy's law)	[LT^{-1}]
h = groundwater head (for a homogeneous fluid)	[L]
ρ_w = water density (assumed homogeneous)	[ML^{-3}]
c_w = water specific heat (assumed homogeneous)	[$EM^{-1}K^{-1}$]
ρ_s = solid density	[ML^{-3}]
c_s = solid heat capacity	[$EM^{-1}K^{-1}$]
m = volumetric porosity	[––]

E=energy; L=length; T=time; K=temperature; M=mass [$E=M^2K^{-2}$]; ––=dimensionless.

It is assumed a saturated ground (the vadose zone is thin); otherwise k, c_g and h will depend on saturation, which is a fraction of porosity (m).

Ground thermal conductivity depend on solid properties and groundwater flow. Then it is a combination of solid thermal conductivity (Fourier's law) and the thermal effect of water diffusion and dispersion (Fick's law), and increases with water flow. In the application q is assumed constant; then K will be considered constant but with a value higher than the mere thermal condutive one.

1–D SOLUTION FOR TWO BOUNDARY CONSTANT TEMPERATURES AND SURFICIAL WARMING

For the vertical (1–D) heat transport through the ground between the surface –with an average long–term temperature θ_o– and a deep constant temperature due to a relatively fastly renovating aquifer –with an average long–term temperature θ_f– when there is vertical flow in between –in what is considered a relative aquitard–, through a saturated medium (the vadose zone is assumed of negligible thickness), Bredehoeft and Papadopoulos (1965) found a well known solution, that has been used to determine steady state recharge rates by applying different plots (Cartwright, 1975).

The substitution of natural vegetation for pasture land and agricultural plots, or for suburban areas, is often accompanied by soil warming. Be Δt_o this increase, the current average value over previous average temperature. At depth z_f the ground temperature is kept constant, θ_f. If there is a vertical recharge q, assumed constant, with no heat source (F=0), the 1–D solution of the vertical heat transport in the ground (Custodio et al., 1996), for a coordinate system z (downwards from the soil surface, z=0 down to z=z_f) and θ (temperature) along time t from the moment the $\Delta\theta_o$ change is introduced (t=0) is:

$$\theta(z,t) = (\theta_o + \Delta\theta_o)\frac{\exp(\beta z/z_f) - e^{\beta}}{1-e^{\beta}} + \theta_f\frac{1-\exp(\beta z/z_f)}{1-e^{\beta}} - \\ -\Delta\theta_o \exp(\beta z/z_f)\sum_{n=1}^{\infty}\left[\frac{n\pi}{\lambda_n}\left(\exp(-a\lambda_n t)\sin\frac{n\pi z}{z_f}\right)\right] \qquad (2)$$

being: $\beta = q\frac{\rho_w c_w}{K} z_f$ [dimensionless]

$\lambda_n=(n\pi)^2+\beta^2/4$ [dimensionless]

$$a=\frac{K}{\rho_g c_g z_f^2}$$ [T^{-1}] ; $\rho_g=(1-m)/\rho_s+m\rho_w$ (bulk density)

When $\Delta\theta_o=0$, no change in the soil surface temperature, the solution of Bredehoeft and Papadopulos (1965) for the steady state (t=∞) effect of recharge in the ground temperature is obtained:

$$\theta\ z\ =\theta_o\frac{\exp\ \beta z/z_f\ -e^{\beta}}{1-e^{\beta}}+\theta_f\frac{1-\exp\ \beta z/zf}{1-e^{\beta}} \tag{3}$$

DATA AND PARAMETERS

Temperature logs of point piezometric boreholes are available from the 1990's. They were carried out with a potable device with sensitivity 0.1°C and measurements every 1 m, down to 150 m in the deepest boreholes.

Thermal properties of local ground materials are not available. Then, values from the literature (e.g. Matthess, 1982) have been used, considering possible dynamic effects of water transport on the thermal conductivity in the stratified sands between the surface and the deep gravel and coarse sand layers, the preferentially exploited aquifer layers. See Table 1.

Table 1. Adopted values for parametres based on Matthess (1982), and other published values, for the local stratified fluvio–marine medium–fine silica sands.

Total porosity (measured)	m = 0.35	—
Dynamic thermal conductivity	K = 2.8	W m^{-1} K^{-1}
Water head capacity	c_w = 4000	J kg^{-1} K^{-1}
Water density	ρ_w = 1000	kg m^{-3}
Solid head capacity	c_s = 800	J kg^{-1} K^{-1}
Solid density	ρ_s = 2300	kg m^{-3}
Ground bulk density (calculated)	ρ_g = 1800	kg m^{-3}
Ground volumetric capacity (calculated)	$C_g = 2.96 \times 10^6$	J kg^{-1} K^{-1}
Ground thermal diffusivity (calculated)	$a_g = 0.946 \times 10^{-6}$	m^2 s^{-1}

Near the coastal area, the sand (a relative aquitard with respect the bottom coarse layer) has a thickness of z_f=50 to 100 m and recharge is 150 to 200 mm/a (Custodio et al., 2009).

With Table 1 values and for z_f=100 m, q=200 mm/a, results are β=0.227 and $\ln(\beta/z_f)$=0.0010, which means a small vertical thermal disturbance with respect the linear thermal gradient for steady temperature.

The annual temperature oscillation in depth, the most penetrating one, is less than 0.1ºC –the temperature probe sensibility– at about 15 m, which is almost no affected by local recharge rate under present circumstances (Custodio et al., 1996).

RESULTS AND DISCUSSION

For a constant recharge, q, with a sudden temperature increase $\Delta\theta_o$ after t=0 the water front penetrates q/m per unit time. The thermal front is delayed due to heat exchange with the ground to attain thermal equilibrium; the penetration is q $\rho_w c_w / c_g^v$. The thermal front is smoothed out due to thermal conductivity, the more the greater is the front age; if t is the front age, the 68% of temperature values ($\pm\sigma$) is inside $\Delta z = \pm(2\ a_g\ t)^{1/2}$.

The piston flow vertical rates of propagation are:

- for recharge water v=q/m=2,86q
- for the sustained surface thermal change v'=q $\rho_w c_w / c_g^v$ =1,38q.

The Δz values are:

t, years	1	3	10	30	100	(300)
±Δz, m	7.8	13.5	25	43	78	(135)

When β is small (the thermal profiles are close to linear) $\Delta\theta_o$=1°C, Figure 1 shows the thermal perturbation penetration (in this case θ_o=18°C, θ_f=21°C, z_f=100 m) versus recharge rate for $\Delta\theta_o$=1°C and v/v'=2. This penetration is a slow one.

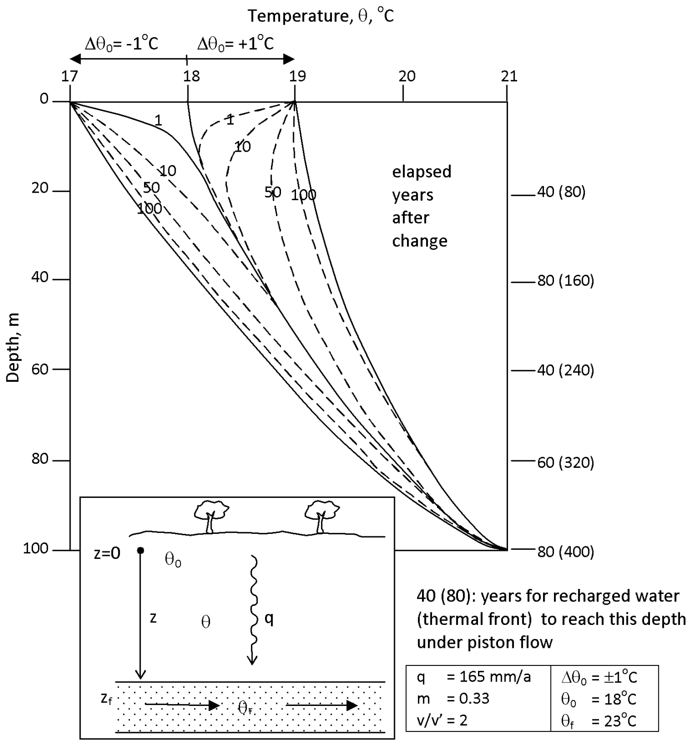

Figure 1. Calculated temperature logs for a sudden surface change $\Delta\theta_o$ of ±1°C from a previous average steady state value of θ_o=18°C in the ground surface and θf=21°C.

In the area of Doñana being considered the main land use perturbations correspond to rather well defined activities, such as introduction of large eucalyptus tree plantations in the 1940s and irrigated areas, colonization and tourist resorts in the 1970s, or respectively about 50 and 20 years with respect the date of the temperature logs (1995). This is indicated in Figure 2.

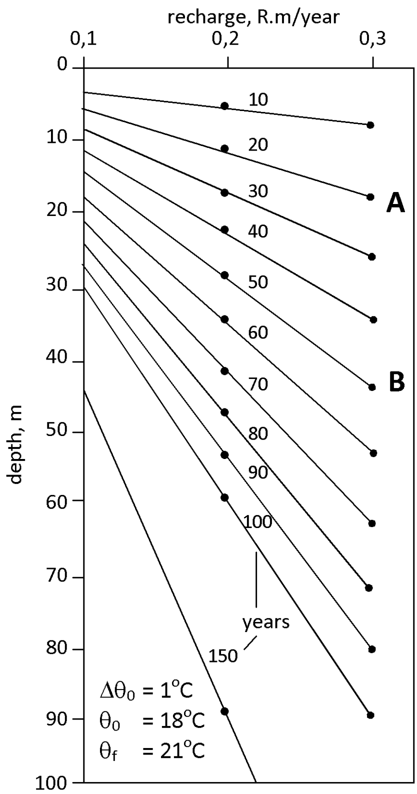

Figure 2. Calculated penetration of a sudden surface temperature change moving at half the recharge water penetration rate, for $\Delta\theta_o$=1°C, θ_o=18°C, θ_f=21°C, z_f=100 m, considering recharge rate and elapsed time. A=irrigation project; B=eucalyptus plantations.

The actual $\Delta\theta_o$ is not known since it depends on difficult–to–quantify influences of forestation, irrigation (mostly in winter with warm groundwater or cool water stored in large basins, depending on the area and variable along time) and urbanization.

CONCLUSIONS

Land use changes may be accompanied by sustained average temperature changes in the ground surface. They slowly propagate downwards when recharge is mostly vertical due to preferential groundwater flow in depth. Penetration is the compound of heat dynamic conduction and advection. The result is that temperature logs may differ from the expected vertical gradient, even considering the recharge effect. Even if actual temperature change is poorly known, the penetration of the disturbance points to the magnitude of recharge.

ACKNOWLEDGEMENTS

The closed form solution here used was obtained with the help of Dr. R. Juanes, of the University of A Coruña. Temperature logs were carried out by the Groundwater Group of the Ground Engineering Department, Technical University of Catalonia (UPC), Barcelona, with the help of the Geological and Mining Institute of Spain and the Guadalquivir River Authority. This is part of CICYT research project REDESAC (CGL2009–12910–C03–01).

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abstract id: **268**

topic: **1**
Groundwater quality sustainability

1.6
Groundwater monitoring

title: **Application of sustainable development idea for optimization of groundwater monitoring on petrol stations**

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keywords: sustainable development, groundwater monitoring

INTRODUCTION

Nowadays, more than 6500 petrol stations operate in Poland and each is a potential object which can impact on many susceptible parts of the environment. Spillage from fuel tank or pipelines makes soil and groundwater most endangered site and this are subjects of every monitoring system. It also could be realized what is the real level of influence and what is real land requirement to keep safety. In this paper consideration about petrol station influence was support on studies of sample station located in central Poland and was analyzed regarding environment and petroleum pollutants properties.

THE STRATEGY OF THE SUSTAINABLE DEVELOPMENT

The first definition of the sustainable development was originally formulated by Hans Carl von Carlowitz (1713) and it deal with forestry industry. This eighteenth century right described the way of husbanding the forest, depend on cutting out only as many trees, as many can grow in the same place, so the forest would not be liquidate and always allow to rebuilt itself.

Global definition of sustainable development was translated from Carlowitz and defined by the United Nations World Commission on Environment and Development ("Brundtland Report"), as "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" (United Nations World Commission on Environment and Development., 1987). Following prof. Jonathan Smith from the University of Sheffield, this is interpreted as those actions which, having regard to social, environmental and economic factors, and to short and term-term issues, maximize the overall benefit (Smith, 2009).

The strategy of the sustainable development concern:

- stimulating the processes of the development, as so to affect on the environment at the lowest degree,
- successive eliminating of economic actions that are harmful for environment and people's health,
- promoting the ways of "environmental friendly" management,
- accelerating actions of restoring the environment to the proper state.

Generalize the strategy of the sustainable development has defects:

- companies growing costs connected with the "environmentally friendly" policy
- higher prices of the products compare with the prices offered by the states not warning the principles of the sustainable development.
- setting- back the several areas of the economy
- development of the unethical business consist on using the items based on the environmental protection policy.

The strategy of the sustainable development pressures on keeping permanency of all processes, underplay local authorities capacity and still very general, described as social-economic development in which integration process of political, economical and social actions occurs and natural balance and constancy of basic natural processes are maintained.

Unfortunately, last few years European economic was dented because of changing economic reality and also soundness of all generally accepted principles. Everybody has to face up the growing crisis and its effects. Finding the way to react President J.M. Barroso at his presentation of to the Informal European Council of 11 February 2010 remarked that “Economic realities are moving faster than political realities” that is the one of main problems which many companies have to clash with. In opposition he pointed to three priorities should be the heart of Europe 2020:

- Smart growth – developing an economy based on knowledge and innovation.
- Sustainable growth – promoting a more resource efficient, greener and more competitive economy.
- Inclusive growth – fostering a high-employment economy delivering economic, social and territorial cohesion.

Barroso also said „The exit from the crisis marks the passage to the different economy from the exit from the crisis to the durable reconstruction, and not the return to the situation from before the crisis”.

That idea was spreading earlier by The Sustainable Remediation Forum – UK (SuRF-UK), which is a multi-stakeholder initiative to develop a framework for sustainable remediation, which involves incorporating sustainable development principles in remediation (Pazdro, Kozerski, 1990). Established in 2007, it has involvement and support from industry, service providers, government agencies and academies.

SuRF-UK has defined sustainable remediation as the practice of demonstrating in terms of environmental, economic and social indicators, that an acceptable balance exists between the effects of undertaking remediation activities and the benefits the same activities will deliver (Pazdro, Kozerski, 1990).

In a wider context the SuRF-UK framework is applicable to any assessment of sustainable remediation or ground water monitoring, and it was drafted to be consistent with the requirements of the most recent draft of the EU Soil Protection Framework Directive, which required an assessment of environmental, social and economic considerations in selecting a sustainable remedial solution.

The purpose of cited views and ideas is to create initiative like the SuRF-UK, to discus, find new solutions and to generate framework for actions, also in Poland, which involves incorporating sustainable development principles in monitoring decision-making in case of supposed side effects of soil and groundwater contamination.

In the time of crisis we are forced to re-define many aspect of our activity. Profits, collaboration, competitions, development, costs, directions for future actions should not be steady. In this new situation also authorities are forced to re-define their expectations. Local authorities must fulfil new regulations in which new situation will be taken into consideration. All of us must use new ideas coming from “knowledge based economy” (Wrzecioniarz et al., 2010). Academics should help, using their specific knowledge, to reduce cost connected with environmental outsourcing and also to reduce the investors costs to grow up whole economy and let it be competitive in comparison to another companies which not fulfil specific environmental restrictions. There is strong need to find common point of collaboration and proceed to enlarge "sustainable collaboration area" as much as it is possible (Fig.1).

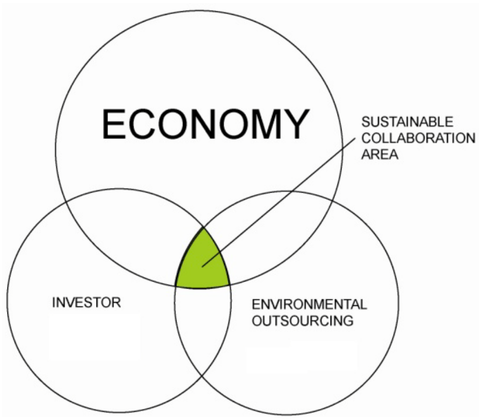

Figure 1. Sustainable development in recent years.

SUSTAINABLE DEVELOPMENT IN GROUND WATER ANALYSIS

The idea is to transfer the philosophy of SuRF-UK presented by prof. Smith and co-authors in this conference to more aspects of environmental protection actions. In reference to prof. Smith, re-definition is based on:

- Simple foundations are not always proper. Talking about influence on environment safety should contain all information about specific of this natural elements like soil and water character and properties.
- Minimization – optimization means in the strategy of the management to maximize benefits. Optimization doesn't mean minimization without subsistence high-level protection for environment, it's an action based on knowledge and technology in opposition to maximization means just for framework and ordinary actions.
- Considering the problem should be precede on all-embracing analysis (Pazdro, Kozerski, 1990).

It's hardly resisted on sustainable development UN definition and the idea was continued by SuRF-UK, formed that balance between actions and benefits is possible.

This redefined sustainable development ideas are applied for practical problems connected with monitoring of the influence of petrol stations to environment. It means to take kind of protection policies that could minimize of threats thereby minimize of the preventive repair costs. Reduction of sustainable development costs should take place on the basis knowledge and best available practice connected with specific hydrogeological know-how.

APPLICATION OF SUSTAINABLE DEVELOPMENT IN EUROPE

The upgrade idea of sustainable development was describe on the examples from Germany and Hungary. In several cases reduction of contamination of soil risk was conducted by natural attenuation and frequency of required groundwater monitoring visits were reduced.

German conception of reducing the risk of the pollutants is based on the process enabling the natural reduction of contaminating medium in the soil environment (NA – natural attenuation) (Solecki, 2005; Stupp, 2007, 2008). The biological schedule of BTEX (benzene, toluene, ethyl petrol, xylol) in the result of the redox reaction based on the microorganisms. Second level is modeling and prognosis the propagation of the pollution medium in soil environment, analysing the physical and chemical propriety of contamination and the influence of the soil parameters on the migration character.

Hungary applies similar solutions, where local authorities agree to cut a frequency of monitoring. In the 2009, 4 proposals of the monitoring reduction at the petrol stations were announced, one of them was approved, so it cause 25 percent reduction of monitoring cost.

Hereinafter in this paper more detailed solution will be presented for Poland.

Oil derivatives in ground

Considering ground and water pollution it's should be understood that no ground has the equal properties but every state can be recognize and described by characteristic ratios. Water and soil proprieties mainly determinate spreading of pollution, so the environment and its hydrogeological ratings determine protecting actions should be taken. Risk management should firstly establish that simple, basic questions to estimate time and place of predict contamination, different in various area.

Petrol and other petrochemicals concentrate in the soil environment as a liquid, create thin layer on the first groundwater table surface or in dispersed form in unsaturated and saturated zone. Its transport from the point of the injection begins when infiltrating in vadose water zone soil environment initially vertical, where it is partly contained by filling the pores of the soil and sorption. Areal spreading of pollution and speed and time which its reach the piezometer mostly depends on the groundwater level and the hydrodynamic (ratios) relations of the shallow groundwater stream. In fact, the migration of the contamination medium runs over water table surface, in line with a direction of the groundwater run-off. Linking the liquid character and filtration flow, the process of moving petrochemicals can be refer to the process of the groundwater flow. The physical proprieties of the soil and the physical proprieties of the liquid have the main leverage for these phenomena.

The frequency of groundwater monitoring should be mainly based on the contamination filtration speed in the specific soil conditions. It should verify all hydrogeological condition of local area, mainly to recognize filtration properties of soil which could be vulnerable for contaminant factors.

ANALYSIS FOR EXEMPLARY PETROL STATION IN POLAND

The exemplary area of the petrol station in located in Sieradz, central part of Poland. The soil profiles are typical for most subsoils in this part of Europe and it's determined by last quaternary glaciation. It's posed by bedding clay with sand and sand with clay. Local in the profile there are fluvioglacial sediments which formed one thin layer of fine sand, about 2 meters deep. This is unconfined aquifer with small flow rate. Contain to its genesis it's non-continious bed and has about 2 to 5 meters of thickness. Soil fine-grained type and thinckness of the aquifer couses that hydromagnetics flow is very finite, so the possibility of migration of the contamination is finite as well.

Velocity of water in porous medium can be refer to liquid petrochemics contamination. Calculations one can bring back the soil to the speed of the migration of contaminant stepping out in the liquid form. This phenomenon describes Darcy's law.

$$v = k \cdot I$$

v - seepage velocity [m/s]
k - hydraulic conductivity [m/s]
I - hydraulic gradient [-]

Evaluating the velocity of the groundwater flow, firstly the hydraulic conductivity should be remarkable as resultant of soil graining and also physical properities of liquid.

$$k = K \frac{\gamma_r}{\eta_r}$$

k - hydraulic conductivity [m/s]
K - intrinsic permeability [m^2]
γ_r - specific weight of U95 petrol [N/m^3]
η_r - dynamic viscosity coefficient of U95 petrol [Ns/m^2]

In calculations here, the physical properities of specific weight and dynamic viscosity of benzine were assumpted as a contamination medium. Specific weight amount 72610 N/m^3, and the value of dynamic viscosity of petrol is 0,06 Ns/m^2.

The transmissivity coefficient of the mid-compacted fine sand which formed aquifer amount from 1 to 10 darcy. For calculations the enlarged value assumed 10 darcy, that is $0{,}987 \cdot 10^{-11}$ m^2.

So, the hydraulic conductivity is $1{,}19 \cdot 10^{-5}$ m/s, equal 1,03 m/d.

$$I = \frac{\Delta h}{l}$$

I - hydraulic gradient [-]
Δh - distinction of piezometric head
l - flow distance

The hydraulic gradient defines the change of the height of groundwater table which is established on known distance, in exemple for Sieradz, between piezometers P1 and P2. The way of groundwater flow is about 55 m. Average all results of seasonal piezometric table fluctuation of multiannual observation, disparity of piezometric table is 0,77 m. The hydraulic gradient amount to 0.014.

$$v = k \cdot I$$

v - seepage velocity [m/s]
k - hydraulic conductivity [m/s]
I - hydraulic gradient [-]

Substituting the values of the hydraulic conductivity and hydraulic gradien the velocity of the groundwater flow is about $1{,}67 \cdot 10^{-7}$ m/s, so that is 0,0144 m/d.

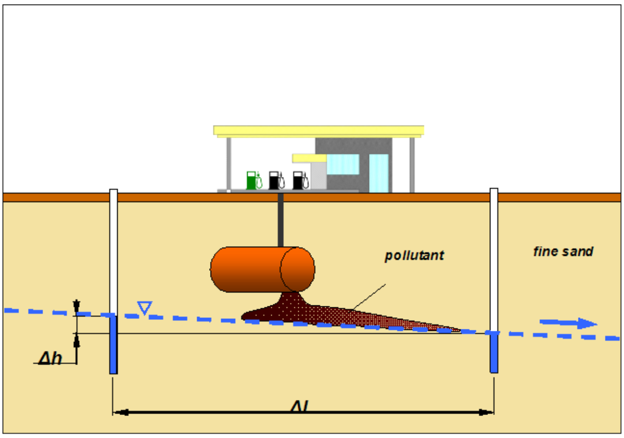

Figure 2. Migration of pollutant scheme.

In connection with the character of the soil, water movement is not homogeneous, which is caused by the pores in it, which have diiferent size, form and often are unconnected. The parameter of the effective porosity termed this feature and it is always smaller than the total porosity of the soil about 10-40%. For find sand described in the profile of this area the value of effective porosity is 0,2. Having the value of effective porosity and accounts the apparent velocity of the flow, the actual velocity of moving contaminetion medium could be compute.

$$V = \frac{v}{n_e}$$

V - average seepage velocity [m/s]
v - seepage velocity [m/s]
n_e - effective porosity

The velocity of the pollution liquid substance which is transport was calculated to 26,28 meters a year. Resting on groundwater levels from observation wells it can be infer that the water flow rate has SW direction. Basing on detailed site map minimum distance from the edge of the tank and other petrol devices, which can conaminate ground, is amount about 32 m from the P2 piezometer, which is located on the way of water flow.

Analyzing only the calculations of the aquifer flow velocity using the simplified Darcy's equation it should be noticed that petrochemicals also undergo natural biodegradation or sorption process. So that can be infer contamination medium from petrol tank couldn't reach to the piezometer in shorter time than one year. Moreover, all petrol station service carries on reservoir balance so the petrol wastage and pollution hazard could be noticed quicker then the monitoring does.

The monitoring of the first groundwater table, which is the mostly vulnerable for contamination causes by the working petrol station, is extremely necessary for environment safety and equilibrium. It supplies information about the quality of water, table fluctuation, and first of all it could recognize contamination endangering bound up with oil derivatives.

All the processes have to deal with are microscale, local problems, going on a small area, involving petrol station parcel, so it mainly whittle down the high-level risk of this human activity. At advantage land conditions to protection activities can be limited, but still based on strict, reliable and recurrent monitoring.

RISK ASSESSMENT

In analysis of approaches to prevent soil contamination an important common problem is how to assess the risk of a local activity of petrol station or already contaminated site. There is no such a thing as "universal risk assessment", because the way these problems should be answered can be very different. For local sources the risk should be assessed is associated with certain activities, technological abilities, failure range but mostly with soil condition of a land. The probability of a spill or leakage and, in the end, transport of a hazardous substance in soil and groundwater is the main problem in the assessment.

Unfortunately, there is still a strong need for uniform analysis and research procedures focus on environment protection actions with conform to universal directions of sustainable development. There is a wish for minimize risk in the name of sustainable development without identification of all conditions it could occur and which can influence on endangering scale.

Every taken action has to be oriented as much as possible to the objective of the monitoring. Sampling and analysing to get a better understanding of the possible effects of a contamination is important rather than getting an idea only about concentrations of a certain substance, without any notion of possible transport, risks and potential effect of hazardous substances. Practical boundaries, such as the time and space available to carry out remediation, could also limit the range of possible interventions.

The risk management should be re-oriented and, following EU Soil Framework Directive working groups: "(…) costs to be proportionate to environmental and social benefits" (Smith, 2009). Most pollution protect concepts have an environmental impact themselves, for example emissions of volatile fuel combustion products or energy consumption. Every steps, not only protection jobs, should be based on knowledge from simple qualitative methods to multi-criteria analysis of media involved in bio-process to amount the social, environmental and economic benefits to attain the aim. A scope of assessment methods based on a series of indicators are available to inform the decision-making units and start discussions to identify the optimum solution.

Sustainability assessment is possible, but it has to be done a framework to allow balanced decision making in the environment protection strategy.

CONCLUSION

The definition of sustainable development is still actual and many parts of human activity, not only environmental protection actions, is determined by rules which were described over 20 years ago. Following authorities and changing European economic situation we need to re-define of sustainable development in the day of the crisis, discuss and trying to use new conceptions, knowledge and keeping effectiveness and competitiveness. The main point is not to minimize safety measures at the cost of benefits, but to optimize preventive and repair actions to minimize the risk.

The risk assessment is main thing which should by analyses for local activity of petrol station or already contaminated site. In hydrogeological practice there is no such a thing as "universal conditions", so that there is no "universal risk assessment", because the way these problems should be answered can be very different.

On the basis of described ideas 30 sites located in Poland were selected to the preliminary program of costs reduction. Specific hydrogeological conditions of petrol stations areas are described and calculation were prepared. In 6 locations the amount of inspections are reduced. Local authorities were informed and the idea of cost reduction was also presented to the polish government (Chief Inspector for Environmental Protection). The program will be applied soon to the hydrogeological practice.

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abstract id: **275**

topic: **1**
Groundwater quality sustainability

1.6
Groundwater monitoring

title: **Optimizing groundwater monitoring networks using the particle swarm algorithm**

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keywords: particle swarm optimization, monitoring network, traveling salesmen problem, groundwater

INTRODUCTION

Quality and quantity monitoring networks are essential tools for the effective management of groundwater resources but the costs of monitoring well installations and sampling can prove prohibitive. The challenge is to obtain adequate water quality and quantity information with a minimum number of wells and sampling points, a task that can be approached objectively and effectively using numerical optimization methods. One recently developed optimization approach involves particle swarm optimization (PSO), a population based stochastic optimization technique that was inspired by the social behavior observed in bird flocks and schools of fish. The system is first initialized with a population of randomly generated particles (i.e. potential solutions); thereafter, searches for optima are conducted iteratively. However, unlike genetic algorithms, PSO has no evolutionary operators (e.g. crossover and mutation) and instead, potential solutions "fly" through the problem space by following the current optimised particles. To demonstrate the effectiveness of the PSO approach, the particle swarm algorithm was used to optimize an existing network of 57 monitoring wells located in the Astaneh aquifer in the north of Iran. The traveling salesperson problem (TSP) analogy was used to represent the existing condition and PSO was used to solve the problem and thereby provide the optimal solution.

TRAVELING SALESPERSON PROBLEM

The TSP is one of the most intensively studied problems in computational mathematics and involves finding the shortest itinerary between a series of cities under the condition that each city may be visited only once. In TSP, the distance between cities and the order of visiting are important. However, in the application of PSO to the optimization of monitoring networks, the distance between wells and the order visited are not directly related to the objective function and problem constraints. Distances between wells do, however, affect the accuracy of the water level estimation.

PSO-TSP ALGORITHM

In this algorithm, the particle selects a well to visit based on the relative importance of that well compared to its neighbors. The objective function is designed to minimize the overall data loss in the optimized monitoring network. It can be quantified using the root mean square error (RMSE) for each well where a constant number of wells is considered. The function is:

$$\min Z = \sqrt{\frac{\sum_{i=1}^{m}\left(\frac{WT_{est,i} - WT_{act,i}}{\min(WT_{est,i}, WT_{act,i})}\right)^2}{m}}$$

where $m = S_{goal}$, and represents the total number of wells that should be eliminated as selected by the user, $WT_{act,i}$ is the observed (or "actual") groundwater level in eliminated well i, $WT_{est,i}$ is the estimated groundwater level in eliminated well i based on observations in neighboring wells.

The results of the optimization showed that the number of observation wells in the Astaneh aquifer monitoring network could be reduced from 57 to 42 without any significant loss of information. The root mean square error (RMSE) for the final optimized network was 0.322 m.

Fig. 1 shows a comparison between potentiometric contours generated using 57 monitoring wells (solid line) and 42 monitoring wells (dashed line).

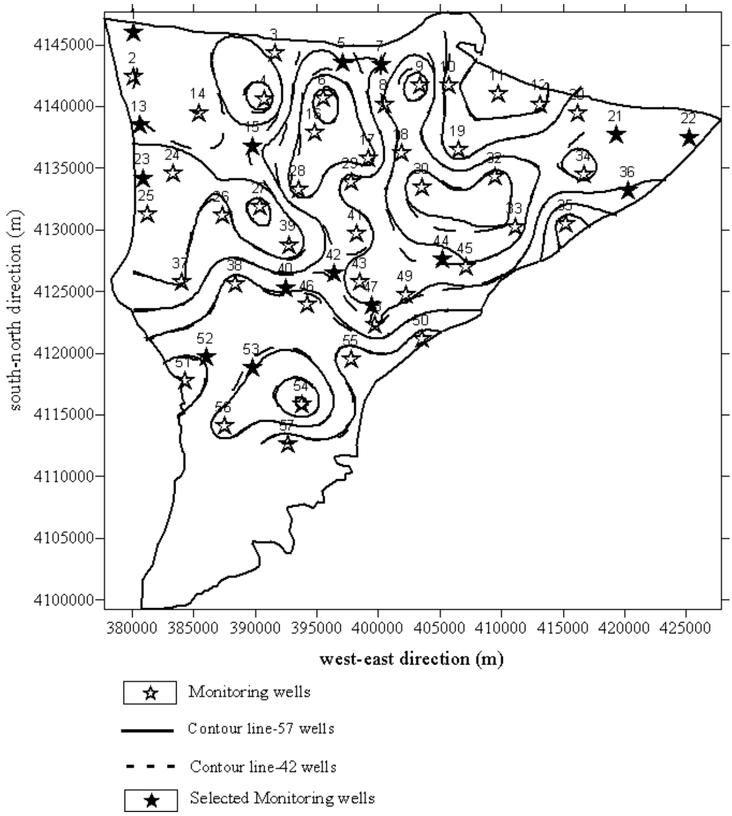

Figure 1. Comparison between groundwater levels using 42 and 57 wells.

abstract id: **293**

topic: **1**
Groundwater quality sustainability

1.6
Groundwater monitoring

title: **Hydrogeochemical monitoring in a coastal aquifer subject to an intense seawater abstraction. The case of the River Andarax delta (Almería, SE Spain)**

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keywords: coastal aquifers, seawater intrusion, monitoring network, desalination plant

INTRODUCTION

The delta of the River Andarax is situated on the coastal strip of the Detritic Aquifer of the Lower Andarax (Almería, SE Spain). The delta aquifer deposits consist of 100 m thickness of alternating sands, gravels and lutites. The desalination plant installed in this delta aquifer abstracts a large volume of seawater from coastal boreholes. A monitoring network was designed close to the water collection area, consisting of three piezometer clusters (PI, PII and PIII), 500 m apart, each including four simple piezometers: one that is slotted over its entire permeable length, and the remaining three with a 1–2 m slotted section at particular depths in the zones of fresh water, salt water and mixing. The piezometers in each cluster are positioned at different depth, depending on the position of the fresh and salt water bands in each monitoring group (Jorreto el al., 2009).

The fully-slotted piezometers were sampled in order to characterize the hydrochemistry of the area. Samples were taken at different depths corresponding to the fresh water band (12–15 m depth), band of transition (25–30 m deep) and saline band (38–55 m deep). The remaining piezometers were sampled over their slotted length. Overall, 22 samples were taken.

RESULTS AND DISCUSSION

The waters sampled from the piezometer network exhibit varying salinity (6.8 to 51.8 mS/cm) and a chloride facies, typical of a coastal aquifer with marine intrusion. Such wide variability in the different piezometers allows the hydrogeochemical zoning of the aquifer (fresh water, mixing zone seawater) to be determined. However, this zoning was not recorded in the fully slotted piezometer (PII1), sampled at five different depths. This piezometer gave relatively low ion contents compared to the others, except for nitrate, which was higher. Samples from this piezometer also showed a narrower dispersion than the other piezometers studied (Table 1). The homogeneity of the water from the five sampling depths in piezometer PII1 implies a salinity similar to that taken from the shallower, individual piezometer where the water was less saline (9.7 mS/cm). This homogeneity is interpreted as being a consequence of the abstraction of seawater in the boreholes closest to PII1, which must be affecting the situation of the interface in this piezometer. As seawater is abstracted, the interface descends – this phenomenon is detected from the temperature and electrical conductivity of water in the fully slotted piezometers. (Jorreto et al., 2006; Jorreto et al., 2009). As a result, the salinity of the water column in the borehole becomes close to that found in the upper aquifer levels.

Table 1. Means and standard deviations of ion content (mg/L) and electrical conductivity (mS/cm) in the fully slotted piezometers.

		EC	Ca	Mg	Na	K	Cl	HCO_3	SO_4	NO_3	Br	Sr
PI1	Standard Deviation	22.3	58	539	6285	188	9759	160	802	20	27	2
	Mean	37.1	511	956	9437	255	14669	365	2591	23	41	8
PII1	Standard Deviation	4.2	21	83	853	21	1564	3	97	12	4	0
	Mean	13.1	430	352	2399	49	4130	344	1602	83	11	5
PIII1	Standard Deviation	20.8	235	568	5794	146	10389	36	867	53	29	4
	Mean	32.2	786	946	7956	174	14438	337	2690	41	40	11

ACKNOWLEDGEMENTS

This work was undertaken within the framework of project CGL2007-63450/HID funded by the Spanish Ministry of Science.

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abstract id: **325**

topic: **1**
Groundwater quality sustainability

1.6
Groundwater monitoring

title: **Environmental and hydrogeological monitoring of sites contaminated with light petroleum products**

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keywords: estimating monitoring, special monitoring, controlling monitoring, light petroleum products, risk

CONCEPTION AND GOALS OF MONITORING

Monitoring of sites contaminated with light petroleum products (LPP) represents the system of observations on qualitative and quantitative changes of LPP plumes in the subsurface in order to reveal and estimate LPP state, volume and transformation, predict LPP spreading and prevent LPP impact on soil, surface water and groundwater for estimation of environmental state and development of preventing or remedial actions.

The goals of monitoring are elaborated at the stage of research. Monitoring design must answer the following questions: 1) which characteristics and parameters are monitored; 2) which number of sampling points and their allocation is necessary; 3) which models are used to predict LPP migration.

Since LPP are immiscible fluids and can migrate in the subsurface as a liquid, a gas, an emulsion, being dissolved in water and retained in soil, monitoring of LPP contamination is rather specific and different from monitoring of groundwater contamination with dissolved chemical substances. Observation wells do not represent levels and thickness of LPP lenses on a groundwater table as well as a volume of LPP retained in unsaturated soils.

Up to date most of research into monitoring of groundwater contamination concern dissolved contaminants. In Ukraine problems of monitoring of the subsurface contaminated with LPP were examined for individual territories not taking into consideration general characteristics of petroleum product migration in the subsurface, estimation of their volume, state and transformation, and potential remediation.

Monitoring conception at different stages of research including *estimating*, *special* and *controlling* monitoring is developed.

ESTIMATING MONITORING

Estimating monitoring is carried out during research into determination of subsurface contamination rate and environmental threat. Works are carried out into four stages:

- Distribution of contaminants in space and lithological and hydraulic properties of the subsurface are estimated by rapid field methods.
- Monitoring of the subsurface is carried out to estimate dynamics of contamination and detect LPP destruction and its rate.
- Dynamics of contamination is estimated, and contamination spreading is predicted taking into account natural biological degradation.
- Risk for objects exposed to contamination is determined.

Main goals of the first stage are to establish a contamination source and objects exposed to contamination, delineate a contamination plume in subsurface air, soil and groundwater, and determine a volume of LPP in the subsurface. This stage is finished by a conceptual scheme of subsurface contamination.

The main task of the second stage is to establish stability, increase or reduction of LPP mass in the subsurface. If LPP mass decreases, it is necessary to determine the cause of this (volatilization, sorption, dispersion, or biodegradation). Geochemistry data are collected to corroborate biodegradation. In case of biodegradation concentrations of electron acceptors (oxygen, nitrates, sulfates, Fe^{+3}, etc.) decrease within a contaminated plume while concentrations of metabolic co-products (Fe^{+2}, Mn^{+2}, methane, etc.) increase. High correlation between electron acceptors, electron donors, and co-products indicates that LPP mass decreases due to biodegradation.

All components of contaminated subsurface (soil, subsurface air, and groundwater) are monitored. Stable contamination plumes and plumes with a limited migration potential are monitored during one year. Maximum term of monitoring is three years to determine stability or decrease of a contamination plume. Quarterly measurements enable to represent the influence of seasonal groundwater fluctuations, precipitation, etc.

Subsurface air is monitored periodically by means of gas survey. The unsaturated zone with residual LPP is monitored periodically by sampling. Observation wells are installed within a lens of LPP and a zone of dissolved LPP (Figure 1).

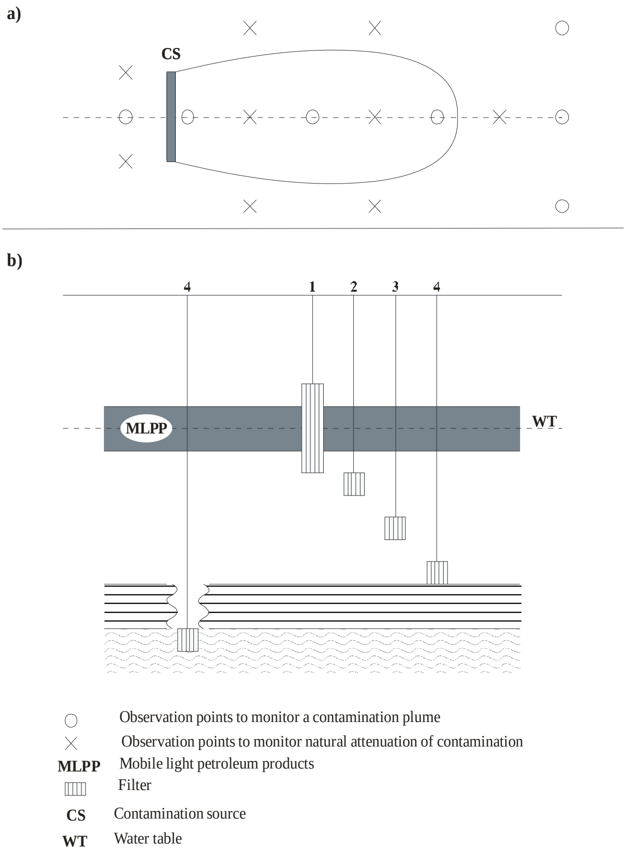

Figure 1. The location of observation points: a) within a real or potential contamination zone, b) in an observation point.

The rate of LPP biodegradation is estimated by decrease of LPP mass or concentrations using either calculation dependences in simple conditions or mass transport models in complex conditions.

Risk is determined for objects exposed to contamination, which is attended by a threat to human health, fauna and flora due to accumulation of contaminants in soil, air, surface water and groundwater. Such objects are water-supply wells, surface water reservoirs, agricultural lands, air in places of human activity where contaminant concentrations exceed extremely limited concentrations.

The method of risk determination is based on predictions of extreme conditions by groups of parameters within possible errors accelerating and decelerating the process of contamination. Boundary values of contamination time t_{min} and t_{max} are calculated. It can be accepted as a range of possible values $R = t_{max} - t_{min}$ with an arithmetical mean $\bar{t} = (t_{max} + t_{min})/2$ and a mean-square deviation $\sigma = R/\alpha_n$ where α_n is a tabulated value depending on a number of estimations, and a probable error value $\Delta t_\rho = 0.6745\sigma$.

An arithmetical mean value of contamination time $\bar{t}$ with an error Δt_ρ is used to determine risk. If $\Delta t_\rho \leq T/2$, where T is time defining a degree of risk, parameter values are reliable. Otherwise parameter values are unreliable and it is necessary to carry out added research to reduce a range of parameter errors.

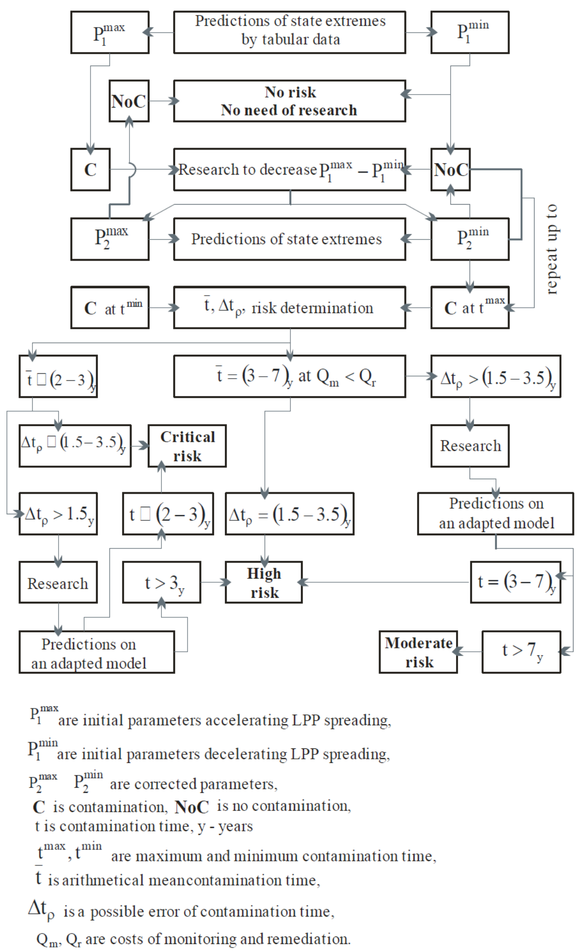

Figure 2. The scheme of risk determination.

Crisis situation and critical, high, moderate, and low risks are defined. In a crisis situation LPP concentrations are already exceed extremely limited concentrations (ELC) during estimating works. If LPP concentrations are less than ELC at an extreme parameter error it is no risk for an object. Figure 2 demonstrates the scheme of risk determination.

SPECIAL MONITORING

Special monitoring is carried out at the stage of prospecting and remediation when there is a critical or high risk of contamination for an object. A part of the subsurface where contamination spreads is studied.

The tasks of prospecting are to specify parameters of the subsurface, a volume of contamination, and the effect of natural biological degradation, choose and test remediation methods.

Parameters describing the possibility of LPP extraction, the effect of bioventilation and microbiological activity are determined by means of test pumping in all observation wells, estimation of gas permeability in soil and testing of oxygen consumption by microorganisms. Water table fluctuations are studied including a long-term rise or decrease, seasonally compensated or relatively stable water table. A soil organic analysis determines the presence and composition of LPP and physical soil properties (grain size, bulk density, porosity, and moisture) enable to identify subsurface air movement through soil.

Concentrations of BTEX (benzene, toluene, ethylbenzene, and xylene) and total hydrocarbon concentrations are determined in groundwater and subsurface air. LPP boiling points are analyzed, which enables to establish the role of volatilization.

During remediation monitoring is carried out to determine the efficiency of remediation and correct a volume and rate of works. Measurements and sampling are carried out every month or quarterly depending on velocity of remediation.

CONTROLLING MONITORING

Controlling monitoring of contamination plume spreading is carried out in the subsurface when there is a moderate or low risk of contamination for an object in order to prevent a high risk.

Location of controlling observation points (COP) depends on dynamics of a contamination plume. If a contamination plume increases and an object is contaminated in 7–10 years (moderate risk), COP are located perpendicularly to a central line of the plume at the distance of contamination movement in 2–3 years (Figure 1a). As soon as a contamination plume approaches, COP are relocated at the same or corrected distance.

Controlling monitoring is also carried out within a compliance zone of objects that are potential sources of contamination in order to reveal contamination as soon as possible (Ognianik et al., 2006). LPP concentrations must not exceed ELC at the boundary of a compliance zone, which is controlled by the state regulators. Otherwise, the enterprise must pay a fine.

The problem lies in the fact that observation points are projected when there the aquifer is not contaminated yet. Qualitative and imitation approaches are developed to solve this problem (Loaiciga et al., 1992; Meyer, Brill, 1988 but they are not efficient.

We propose to locate observation points in the most sensitive nodes of mass transport models, taking into consideration boundary conditions, dispersion, sorption, biodegradation, etc. At this, relative contaminant concentration C_c=1 is specified at contamination source and C_c=0 at the boundary of a compliance zone. Obtained concentrations in parts of unity indicate node sensitivity to contamination. Node sensitivity is

$$W_j = \sum_{j=1}^{n} C_j$$

where C_j is relative contaminant concentration at j-realization of its outflow. Observation points are located in the most sensitive nodes. The problem is defined as

$$\max Z = \sum_{j \in J} W_i x_i \quad \text{given} \quad \sum_{j \in J} x_j \geq P$$

where j is an areal index of observation point location; J is a range of potential observation point location; x_j = (0,1): 1 — if an observation point is in a sensitive node, 0 — otherwise; P is a number of observation points defined as $\Sigma_{j \in J}\, q_j\, x_j \leq$ R, where q_j is the cost of installation of j observation point; R < S + (Q_c – Q_o) are reasonable money resources, S is the sum of a possible fine; Q_c is the cost of remediation within a compliance zone; Q_o is the cost of remediation within an optimal zone.

This approach was tested on the case study of the location of observation points near a sewage pond.

CONCLUSION

- Monitoring of sites contaminated with LPP, which are immiscible fluids, is rather specific.
- The system of monitoring includes estimating, special and controlling monitoring.
- During estimating monitoring LPP distribution in components of the subsurface, transitions, rate of biodegradation are determined. The final result of estimating monitoring is risk determination for objects exposed to contamination. The method of risk determination is proposed.
- Special monitoring is carried out at the stages of prospecting and remediation when there is a critical or high risk of contamination for an object. The main tasks are to specify LPP volume, choose and test a remediation method. Monitoring data are used to identify mathematical models imitating remediation to optimize it.
- Controlling monitoring of contamination plume spreading is carried out in case of a moderate or low risk of contamination for an object and also within a compliance zone of objects that are potential sources of contamination. The location of observation points in the most sensitive nodes of the mass transport model is shown provided that costs for monitoring network location and remediation in an optimal zone must be mush less than a fine and costs for remediation in a compliance zone.

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abstract id: **328**

topic: **1**
Groundwater quality sustainability

1.6
Groundwater monitoring

title: **Variability of chemical composition of groundwater at the Miocene aquifer in the Poznań-Gostyń fault graben region (Poland)**

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keywords: groundwater chemistry, the Miocene aquifer, ascent of water, fault graben

INTRODUCTION

The water supply system in the Region of Wielkopolska (Poland) is to a large extent based on the Miocene aquifer. However, the use of water from this aquifer is difficult due to a significant variability of chemical composition of water related to the occurrence of dispersed organic matter within the sand water-bearing formations as well as to the present and paleohydrogeological conditions of water circulation systems (Górski, 1989). One of the main hydrogeochemical anomalies is connected with the Poznań-Gostyń fault graben, developed longitudinally in the Mesozoic basement of the Miocene aquifer. The fault graben region is marked by the occurrence of active hydraulic tectonic faults, with deep circulating water ascending from the Mesozoic basement which consists mainly of weakly permeable carbonate and mud formations of the Jurassic and Cretaceous periods. The ascent of water is also noticeable in the outcrop belt of the Lower Jurassic deposits consisting of sand and mud.

The problems of variable water chemistry in the Miocene formations in the Wielkopolska Region and the relations of water chemistry to the current and paleohydrogeological conditions of water circulation were discussed in papers by Błaszyk (1966), Pawuła (1975), Przybyłek (1986), Górski (1989), Górski, Przybyłek (1996), Przybyłek et al. (2000), Dąbrowski et al. (2000). The above mentioned papers were mainly based on archive hydrochemical data and they did not concern the analysis of microcomponents. This paper is based on current analyses comprising the microcomponents which have not been analysed so far, or which have been studied only in the region of Poznań (Siepak et al., 2006; Siepak et al., 2007).

The aim of this study was: (1) the determination of the current state of water chemistry of the Miocene aquifer, with emphasis on microcomponents; (2) the characteristics of hydrochemical zones against the background of groundwater flow and geological structure; (3) the use of the results of physicochemical parameters determinations of the studied water, and especially of the microcomponents, in the identification of groundwater ascent from the Mesozoic to the Miocene aquifer in the zone of the Poznań-Gostyń fault graben.

MATERIALS AND METHODS

Study area

A part of the groundwater Miocene aquifer in the area of the Poznań-Gostyń fault graben (Wielkopolska, Poland) was selected for the study. In the north, the study area is limited by the parallel length of the Warta River, and its southern borderline is the Barycz Old Valley. The western and eastern borderlines were defined arbitrarily and they have no structural reference. The western borderline runs 10 km west from Leszno, while the eastern borderline runs 20 km east from Gostyń (Figure 1).

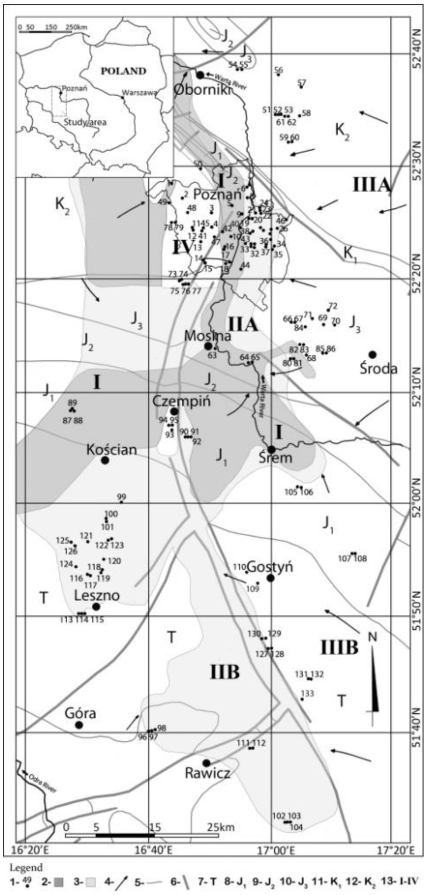

Figure 1. The occurrence of zones of anomalous salinity and colour of water at the Miocene aquifer against the background of the main structural elements of the Mesozoic basement. 1 — sample collection points; 2 — the zone of water colour >80 mg Pt/L; 3 — the zone of chloride content >20 mg/L; 4 — the main directions of the Miocene aquifer groundwater flow; 5 — stratigraphic borders; 6 — faults; 7 — Triassic; 8 — Lower Jurassic; 9 — Middle Jurassic; 10 — Upper Jurassic; 11 — Lower Cretaceous; 12 — Upper Cretaceous; 13 — hydrochemical zones (see the text for description).

Hydrogeology

Three water-bearing layers (lower, middle and upper) can be distinguished within the Miocene. The layers combine to create one aquifer to the west from Poznań (Dąbrowski et al., 2007). The lower layer consists of the lower Miocene sands with the thickness of approximately 30–40 metres. Between the lower and upper water-bearing layer there is a carbonate series with silts, in which the middle water-bearing layer occurs. It consists of fine, dusty, locally middle-grained and coarse sands with the thickness of 1 to 50 metres. The upper water-bearing layer consists of fine-grained and dusty sands of the middle and upper Miocene (so called adamowskie layers sands). Their thickness amounts to approximately 20–40 m (maximum up to 80 m) (Dąbrowski et al., 2007).

The recharge of the Miocene aquifer results from the process of percolation of water from the Quaternary aquifers. The process occurs especially in the places of decreased thickness of isolation layers, also where the layers of Poznań silts were glaciotectonically disturbed and locally, in the places of hydraulic contact through hydrogeological windows, which were formed as a result of erosive cuts in Poznań silts in the areas of buried valleys (Przybyłek et al., 2000; Dąbrowski et al., 2007). The ascent flow of water from the lower basement occurs in the deepest parts of Miocene formations, where basement deposits of good permeability occur and along some hydraulically-active tectonic faults. The natural regional discharge zone of the discussed groundwater is the Warsaw-Berlin Old Valley, the Barycz Old Valley and the Warta Valley.

Sample collection

The groundwater samples from the Miocene aquifer were collected for physicochemical analysis from 133 wells. The measurements of water temperature, pH reaction, redox potential, electrical conductivity and dissolved oxygen were taken directly on the research site. The measurements were taken using the *MULTI 197I* (WTW, Weilheim, Germany). The colour and alkalinity were also determined on the research site. The water samples were collected in Nalgene® (Rochester, USA) polyethylene bottles (LDPE). Depending on the determined water quality indicators, the samples were fixed with HNO_3 or $CHCl_3$ (Merck, Darmstadt, Germany). After the collection, the samples were stored at 4°C.

Chemical analysis

In order to determine the anions (Cl^-, SO_4^{2-}, F^-, PO_4^{3-}, NO_3^-) and the cations (NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}), Dionex DX-120 ion chromatograph (IC) (Dionex, USA) was used. The determinations of Fe, Mn Cr, Cd, Cu, Zn, Pb and Ni were performed by atomic absorption spectrometry with flame atomization (F-AAS) using an Aanalyst 300 apparatus produced by Perkin Elmer (Perkin Elmer, Norwalk, CT, USA). As, Sb and Se were determined by atomic absorption spectrometry combined with the hydride generation technique (HG-AAS) using a Varian apparatus (Spectra 280FS, Varian, Australia). Be, V and Mo were determined by the technique of inductively coupled plasma with atomic emission detection (ICP-AES); the system consisted of the spectrometer Jobin-Yvon Model 170 Ultrace (Jobin-Yvon, Longjumeau, France). Ag, Al, Ba, Li, Tl, Ce, Cs, La, Nd, Pr and Sm determinations were performed using the technique of inductively coupled plasma with mass spectrometry detection (ICP-MS), using a 7500ce apparatus produced by Agilent (Agilent Technologies, Inc. Headquarters, USA). Hg content was determined by cold vapour atomic fluorescence spectroscopy (CV-AFS) using Millennium Merlin Analyzer 10.025 (PSAnalytical, England).

The determinations of total alkalinity were performed by the titration of the 0.1 mol/L HCl water sample against methyl orange as an indicator. The obtained results were verified based on the ion balance. The difference between the sum of cations and anions did not exceed ± 5%.

RESULTS AND DISCUSSION

The general characteristics of groundwater chemistry at the Miocene aquifer

The groundwater of the Wielkopolska Miocene aquifer is marked by weakly acidic to weakly alkaline pH reaction (from 6.20 to 8.08). Electrolytic conductivity ranges from 387 μS/cm to

2140 μS/cm, and TDS from 193 to 1049 mg/L. A characteristic feature of the groundwater at the Miocene aquifer is its variability in terms of colour intensity and chloride concentrations (Figure 2A). The regions of very high colour intensity are noticeable (>80 mg Pt/L, and even as large as several thousand mg Pt/L), as well as those marked by very low colour intensity (<20 mg Pt/L) — Figure 1. The water marked by high colour intensity and increased salinity occurs zonally, and its origin is related to the flow of the deep circulation water from the Mesozoic basement through tectonic faults and/or formations with increased permeability in the basement (Lower Jurassic formations). High colour intensity occurs in these parts of the discharge zones where the water from the Mesozoic basement had difficulties flowing to the surface discharge zones. On the other hand, the low concentrations of colour are characteristic for the regions where the conditions for intensive water exchange existed. The zones of water colour intensity overlap with the salinity zones (Figure 1). The water hardness, from 1.14 to 12.9 mval/L, is marked by clearly regional variability. The lowest hardness is observed in the zones of water ascent from the Mesozoic basement, and the highest – in the areas of recharge from Quaternary aquifers and the zones where water flows to the discharge zones (transit zones). Significant variability of macrocomponents concentrations in terms of Na^{+}, Ca^{2+}, Mg^{2+}, Fe and SO_4^{2-} was observed (Figure 2A), while in the case of microcomponents, clear variability of concentrations for F^{-}, Al, Ni, Pb, Cu, Cr, Ba, Hg, Mo, Li and Se was stated (Figure 2B). Such clear differences were not observed for V, Cd, Be, Ag, Tl or Cs.

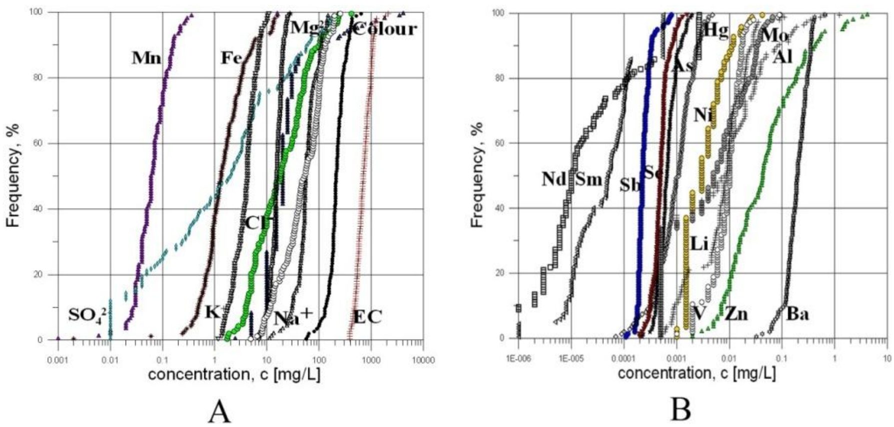

Figure 2. Cumulative frequency curves for selected macro-components (A) and micro-components (B)

Hydrochemical zonality

Based on the spatial distribution of hydrochemical parameters, and especially of colour, Cl^{-}, Mn and hardness, taking into consideration the geological structure of the Mesozoic basement and hydrodynamic conditions, four hydrochemical zones marked with the Roman numbers I to IV (Figure 1) were separated in the study area. The variability of water chemistry in the zones was presented on the Piper diagram (Figure 3).

Zone I comprises the area of water with high colour intensity (>80 mg Pt/L). The zone stretches along the Szamotuły structure and the Poznań fault. It also comprises the outcrop belt of Lower Jurassic in the region of Wielichowo-Śrem (Figure 1). It is the area where, due to the hindered exchange conditions of water discharged from the Mesozoic basement, high colour intensity of water occurs and increased concentration of chlorides (>20 mg/L) as well as the lowest hardness (<4 mval/L) may be observed, and the concentration of manganese amounts (<0.1 mg/L). This zone is clearly marked by microcomponent concentrations higher than in the other zones. These are especially the concentrations of As, Sb, Se, Cu and, less significantly of Pb, Ni and Cr. The concentrations of iron are also higher. The occurrence of increased concentrations of these parameters should be linked to the enrichment of the ground environment and groundwater in humus substances.

Zone II comprises the areas where, similarly to zone I, the water ascent from the Mesozoic basement occurs (Figure 3), but the water colour intensity does not exceed the anomalous limit (>80 mg Pt/L). In some parts of this zone, the discharge of water from the Miocene to the Quaternary aquifer may be observed. The features distinguishing this zone are: the concentration of chlorides >20 mg/L and relatively low hardness, generally <5 mval/L. In terms of micro-components, similarly to zone I, the increased concentrations of Li, Al, Mo, Cr and Hg may be observed. The zone comprises the areas marked by varied conditions of water ascent from the Mesozoic basement. In the northern part (from Poznań to Czempin), the recharge originates mainly in the Lower Jurassic formations. In the southern part (from Czempin to Rawicz), the recharge originates in the Triassic formations. The difference also concerns the conditions of water circulation. In the northern part, the zone of ascent is relatively narrow. The water here flows to the Quaternary in the Warta Valley. In the southern part, the water ascending from the Triassic basement moves south-west to the discharge zone in the Warsaw-Berlin Old Valley. As a result, zone II was divided into IIA and IIB (Figure 1). Certain differences may be observed in the water from these zones in terms of macro- and microcomponents. Lower concentrations of Cl^- in zone IIB are observed, while the concentrations of SO_4^{2-} are slightly higher. In relation to microcomponents, the concentrations of Al, Mo and Hg are much higher in zone IIB than in zone IIA.

Zones IIIA and IIIB comprise the areas of the Miocene recharge from the upper aquifers, as well as of the water transit to the discharge zones. The central parts of the recharge zones are located east- and southwards from the studied area. Thus, in the analysed area, water typical for the transit zones prevails (Figure 3). It is marked by chloride concentration <20 mg/L, hardness higher than 4 mval/L and manganese concentration >0.1 mg/L. The division into zones IIIA and IIIB was made considering the different conditions of water recharge and flow to the north and south of the Warsaw-Berlin Old Valley. In the basement of zone IIIA, the Upper Jurassic and Cretaceous deposits occur, while in zone IIIB the Triassic and lower Jurassic deposits occur (Figure 1). The water chemistry in zones IIIA and IIIB is similar both in relation to macro- and microcomponents. However, the hardness, SO_4^{2-} and Ca^{2+} concentrations are much higher in zone IIIB. In terms of microcomponents, the whole zone III is marked by the higher concentrations of Ba in relation to I and II zones.

Additionally, zone IV was separated in the region westwards from Poznań. The zone is located between the areas of water marked by high colour intensity. It is a small area, where the water chemistry is mainly determined by the direct, limited, recharge from the upper aquifers. The water chemistry in this zone is similar to zones IIIA and IIIB, but a smaller leakage of filtration from upper aquifers is observed here. The water chemistry in this zone to the largest extent reflects the hydrogeochemical conditions of the Miocene deposits environment.

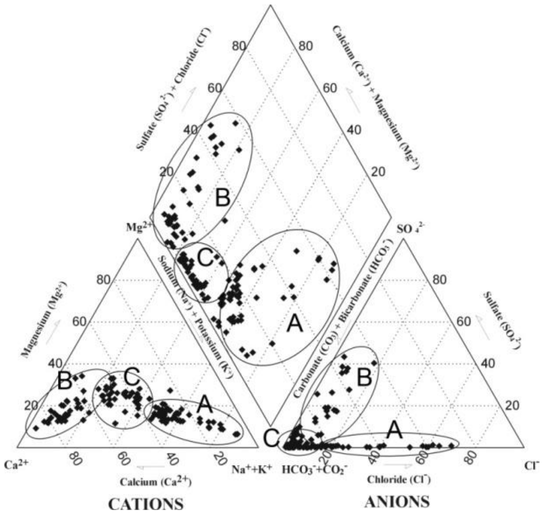

Figure 3. The Piper diagram with the marked points located: A — discharge zones of water ascending from Mesozoic basement (zone I, IIA and IIB), B — zones of recharge from Quaternary aquifers and transit (zone IIIA and IIIB), C — zone of limited recharge from Quaternary aquifers (zone IV).

CONCLUSIONS

Based on the obtained study results, the following conclusions may be drawn:

- The chemical composition of the Miocene aquifer in the Wielkopolska Region in the area of Poznań-Gostyń fault graben and the Szamotuły structure is marked by high variability, especially in terms of colour intensity, chlorides, hardness and manganese.
- The chemistry of water in the studied region is mainly formed as a result of the ascent from the Mesozoic basement and the recharge from the Upper Quaternary aquifers.
- The ascent of water from the Mesozoic basement is mainly observed in the hydraulically-active zones of tectonic faults and in the outcrop zone of the Lower Jurassic formations.
- In the area of ascent recharge from the Mesozoic basement, the water of the Miocene aquifer is marked by the increased concentrations of Cl^- (>20 mg/L), Mn (<0.1 mg/L) and low hardness (mostly lower than 4 mval/L). In terms of microcomponents, the increased concentrations of Al and Li are stated.
- In the area of ascent recharge, the zone marked by anomalously high colour intensity (>80 mgPt/L) may be distinguished. The zone has been formed paleohydrogeologically and occurs in the parts where the transit of water discharged from the Mesozoic basement to the surface discharge zones was hindered. Apart from the increased Cl^- concentrations and low hardness and Mn, the water with high colour intensity is marked by the increased concentrations of Fe, As, Sb and Se and, to a smaller extent, of Pb, Cu, Ni and Cr.
- In the zones where the chemical composition of water at the Miocene aquifer is formed due to the influence of the recharge from the Quaternary aquifers, the water is marked by the low concentrations of Cl^- (<20 mg/L). On the other hand, higher hardness (>4 mval/L), Mn concentrations (>0.1 mg/L) and, locally SO_4^{2-} concentrations may be observed. In terms of microcomponents, the increased concentration of Ba may be stated.

ACKNOWLEDGEMENTS

The research was financed from the 2006–2008 research fund as a project No. N305 074 31/2944 of the Ministry of Science and Higher Education.

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abstract id: **329**

topic: **1**
Groundwater quality sustainability

1.6
Groundwater monitoring

title: **Hydrogeochemical zoning in the delta of the River Andarax (Almería, SE Spain)**

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keywords: seawater intrusion, monitoring network, detritic aquifer

INTRODUCTION

The delta of the River Andarax occupies the coastal section of a detritic aquifer that extends along the central sector of the valley. It comprises Quaternary alluvial and deltaic deposits, together with Plioquaternary fluviodeltaic sandy and silty conglomerates. This is a free aquifer but the presence of lutitic beds in the delta gives rise to local, confined sectors. The piezometric surface show wide variations as a function of rainfall and surface water flow in the River Andarax (Sánchez-Martos, 1997). A desalination plant is located near the coast, taking seawater from a number of coastal boreholes (Fig. 1, 2).

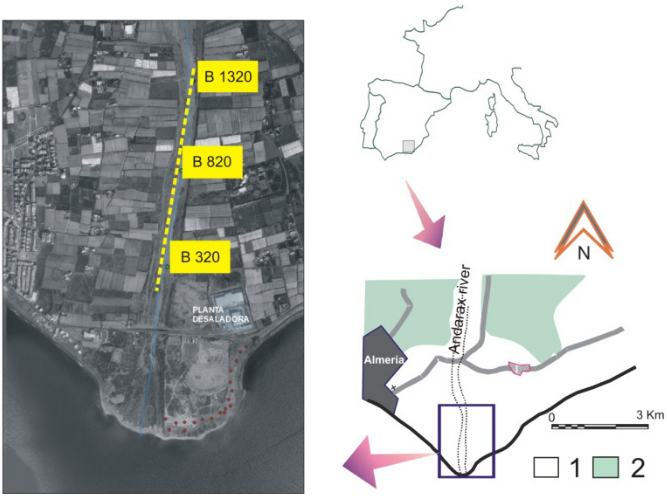

Figure 1. Situation of the river Andarax delta indicating the observation boreholes (B-320, B-520 and B-1320) situated in the river bed. The white dotted line indicates the position of the cross-sections represented in Figure 2. 1 — Quaternary deposits (gravels, sands and silts); 2 — Pliocene deposits (marls and sandy silts).

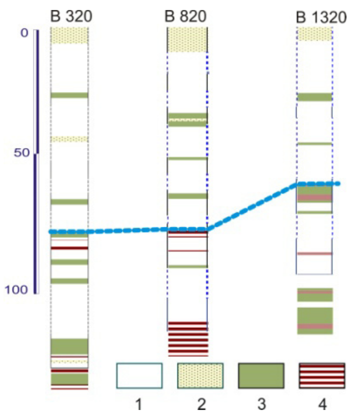

Figure 2. Transverse geological section as indicated in Figure 1 by the white dotted line. 1 — Heterometric sands and gravels; 2 — Gravels, sands and clays; 3 — Fine sands and silts; 4 — Lutites.

The geological series comprising the delta aquifer has been described on the basis of three borehole logs, drilled to a depth of 110–130 m. These deposits are basically coarse detritic deposits: gravels with sandy intercalations and small cemented beds that are continuous over the three boreholes logged, and which serve as a reference for separating the aquifer units. The upper unit is quite homogeneous, consisting of sands and medium-coarse gravels. The underlying unit has a more heterogeneous lithology, mostly medium and coarse gravels but with more abundant sand and silt layers than in the upper aquifer, which are locally cemented. Between 100 and 120 m depth appear some very fine sands, marly silts with remains of bioclasts, with local occurrences of highly plastic blue silts containing some clay (Sánchez Martos et al., 2007; Jorreto et al., 2009).

The aim of this study is to demonstrate the difficulties that arise when studying the hydrogeochemistry of highly complex and variable coastal detritic aquifers, where there are frequent changes of facies in both the vertical and horizontal planes. These difficulties are compounded by the presence of saline deposits and levels of varying permeability, all of which contribute to the presence of different water types with varying salinity and highly contrasting geochemical evolutions.

DATA

Data were collected from different depths in three boreholes in the bed of the river Andarax (Figure 1), over two surveys in April 2006 and June 2009. Sampling was preceded in each borehole by a series of tests to determine suitable sampling depths in the three bands: fresh water, freshwater-seawater interface and salt water.

RESULTS AND DISCUSSION

Vertical zoning was confirmed on the basis of electrical conductivity logs, with salinity being used to differentiate the three bands of fresh water, freshwater-seawater interface and salt water. The thickness of the freshwater zone ranges from 25–35 m, diminishing towards the coast. The thickness of the freshwater-seawater interface was between 20 and 30 m in the boreholes furthest from the sea, narrowing markedly towards the coast where is was slightly less than 10 m. The salt water zone began at a depth of between 40 and 50 m (Sánchez Martos et al., 2007; Jorreto et al., 2009). The physico-chemical data describe a zonation coherent with the data from the borehole logs: fresh water (electrical conductivity less than 6 mS/cm, with a sodium-calcium chloride-sulphate facies), freshwater-seawater interface (salinity from 15–30 mS/cm, sodium chloride facies) and saltwater (salinity of 45–57 mS/cm, sodium chloride facies (Tab. 1).

Table 1 Summary of the main characteristics of the three water bands. Concentrations are in mg/L, E.C.: electrical conductivity (S/cm), (1): mean (2): standard deviation.

Zone	Data	E.C.	Na	K	Ca	Mg	Cl	NO_3	SO_4	HCO_3	B	
Fresh water	5	4.3	499.0	20.1	286.1	158.8	768.3	71.5	987.6	374.2	0.8	(1)
		0.9	206.0	7.3	60.9	25.7	408.5	9.1	54.1	14.4	0.0	(2)
Interface	9	17.4	2679.7	52.7	564.0	497.8	5349.8	41.4	1438.5	348.6	1.0	(1)
		8.6	1334.9	29.0	363.3	261.8	3122.9	12.7	255.8	30.6	0.3	(2)
Salt water	8	52.0	9933.6	363.4	796.2	1346.8	19379.5	0.5	2634.8	348.7	4.2	(1)
		4.5	1401.9	67.8	631.1	134.9	1758.0	0.0	272.9	51.1	1.3	(2)

The water in the fresh water band contained the highest nitrate concentrations, varying from 60–70 mg/L. The Andarax delta is an area of intensive agriculture, and this favours elevated nitrate concentrations. Nitrate concentrations in the samples representing the freshwater-seawater interface were lower (23–54 mg/L), and they were practically zero in the saltwater band.

Samples corresponding to the freshwater-seawater interface had diverse chemical compositions (Tab. 1) due to the variety of processes associated with fresh water-seawater mixing. Considering chloride as a conservative ion, these processes were identified by plotting the relationships between Cl-Na and3 Cl-Mg and showing the theoretical line of mixing between fresh water and seawater (Figure 3).

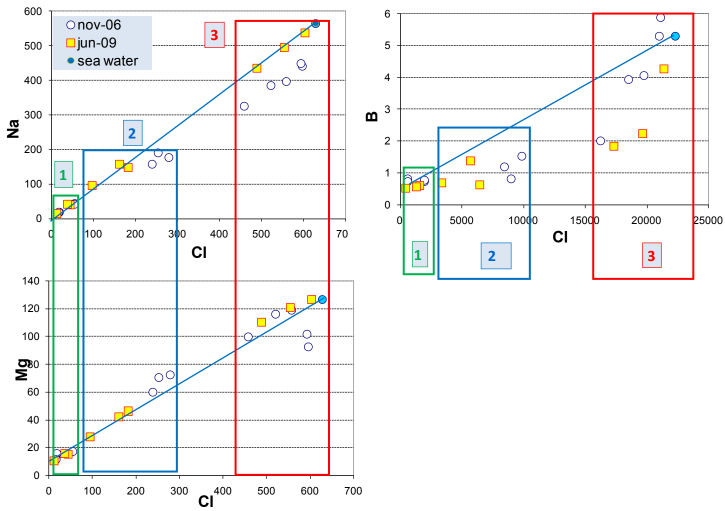

Figure 3. Ratio of Cl/Na (meq/L) Cl/Mg (meq/L) and Cl/B (mg/L). The composition of seawater and the theoretical line of mixing between fresh water and seawater are shown. Three types of water are defined: (1) fresh water, (2) freshwater-seawater interface y (3) salt water.

Figure 3 shows the deviation in sodium content from the theoretical line of mixing that indicates a deficit, represented by the blue line. In terms of the relationship between Cl and Mg (Figure 3), there is a series of points that do not fall along the line of theoretical mixing, which indicate an ”excess” of Mg. This Mg excess and Na deficit can be interpreted as due to ion exchange, which modifies the chemical composition of the mixing water. The same process is observed between Cl and B, where boron concentrations are less than expected for a mixture of fresh water-seawater. This ion exchange and ion absorption of Li and B has been studied for the Andarax delta (Sánchez Martos et al., 2002), in addition to the content of $\delta^{11}B$, which is attributed to differential enrichment caused by the absorption of boron by the lutitic aquifer matrix. Ion exchange causes a decrease in the B/Cl ratio (Morell et al., 2008). These ion exchange processes are indicated in Figure 4, where it can be seen that they especially affect the sampling points corresponding to salt water and the freshwater-seawater interface. These points exhibit a marked similarity with seawater, except in terms of the cations Mg and Na), which show slight variations up or down.

Analysis of the two surveys separately highlights clear differences between them (Figure 4). Data collected in November 2006 are more variable, with lower values recorded at the points corresponding to “fresh water”, as well as at points in the freshwater-seawater interface.

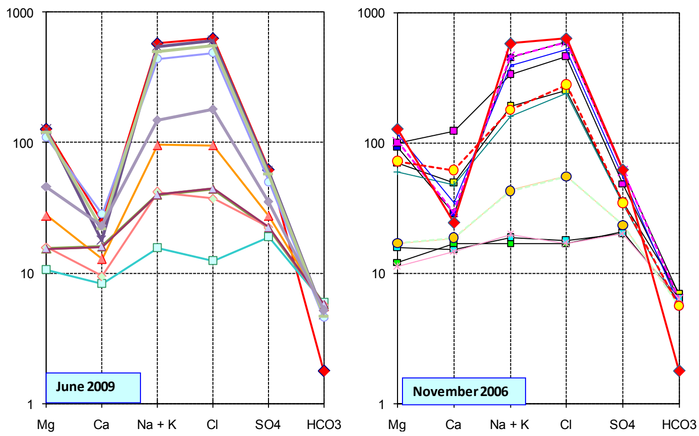

Figure 4. Schoeller Berkaloff diagram, showing chemical data for the two surveys separately.

The chemistry of the deeper and more saline samples taken in June 2009 is more homogeneous (interface and salt water), and indicates a composition very similar to that of seawater. This homogeneity is linked to the exploitation of seawater by the desalination plant, which began to operate continuously during 2009. This collection of seawater mobilized the water in the salt-water band and modified the potentials and salinity (Jorreto et al., 2009), thus reducing the variability in the water chemistry of the interface and giving rise to ion ratios very similar to that of seawater.

FINAL CONSIDERATIONS

To understand the hydrogeochemical processes taking place in coastal detritic aquifers, various tools are required (detailed surveys of the borehole column, and electrical conductivity and temperature logging), and a monitoring network must be in place to take borehole samples at different depths. This is fundamental because the aquifers undergo frequent changes in facies that lead to the development of levels with different permeability. Added to this, the presence of salt deposits of marine origin significantly affects the hydrogeochemical evolution of the water, making it more difficult to elucidate the hydrogeochemical processes that are directly related to marine intrusion. In the Andarax delta, several ion exchange processes have been identified that are a consequence of the lutitic intercalations in the aquifer matrix, including boron. Ion exchange occurs especially in the deeper, more saline bands, and so this is where the variability of the water is greatest.

One final comment is that the homogeneity of the deeper waters is probably a consequence of the seawater collection by the desalination plant, whereby the water in the deepest band exhibits ion ratios very similar to that of seawater.

ACKNOWLEDGEMENTS

This work was undertaken within the framework of project CGL2007-63450/HID funded by the Spanish Ministry of Science.

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abstract id: **422**

topic: **1**
Groundwater quality sustainability

1.6
Groundwater monitoring

title: **Groundwater quality in Pomeranian region in the light of monitoring surveys**

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keywords: groundwater quality, Pomerania Region, monitoring surveys

Groundwater monitoring is one of the most important tools in groundwater protection and management. Monitoring system is regulated by polish Water Law consistent with European Union Water Framework Directives. Groundwater monitoring investigations are very important for hydrogeological research thanks to long term and cyclic observations including wide range of analysis.

In Pomeranian Voivodeship (total area 18 293 km^2 — around 6% of the Poland territory) monitoring is run from 1991 (country monitoring) and from 1995 — regional monitoring. In 2004 when the Water Frame Directive has been implemented, the observation system has been changed into diagnostic, operational and investigative monitoring and it is run in groundwater bodies. In Pomeranian Voivodeship there are 19 groundwater bodies and 13 of them are located entirely in the range of the voivodeship. Diagnostic monitoring is led in order to assess and verify anthropogenic changes in groundwater quality and also to indicate areas where long term changes in the chemical composition occur. On the basis of the results, the investigative monitoring is planned.

Operational monitoring serves to assess the state of groundwater quality in the region.

In Pomeranian region the monitoring is run in three multiaquifer formations: Quaternary, Tertiary and Cretaceous. In most areas the chemical composition of groundwater is good and stable, although in urban areas some undesirable changes has been observed. There are also areas where groundwater quality is poor mainly due to increased concentrations of chlorine and fluoride ions. Such a poor quality is observed mainly in the region of Vistula River Delta and also in some areas in the northern part of the region.

abstract id: **457**

topic: **1**
Groundwater quality sustainability

1.6
Groundwater monitoring

title: # The grounds for determining additional index parameters in the monitoring process of water environment in the vicinity of municipal waste landfills

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keywords: municipal waste landfills, water quality, specific index parameters

THE AIM OF THE STUDY

Municipal waste landfills classified as other than hazardous or neutral frequently constitute a direct or indirect threat for the soil and water environment. Contamination of the environment results from malfunctioning or inadequate conservation of landfills which are still both in and out of operation. Old landfills constitute a threat for the environment as they frequently have no artificial sealing at the bottom of the facility, the only basal sealing is constituted by substratum horizons. Municipal waste landfills which may not be adapted to comply with legal requirements in force should be closed down and their negative impact on the environment eliminated. Conditions connected with the location of each landfill and methods of conserving and inspecting it have to be individually identified and adjusted.

Monitoring the impact zones of individual sites is the basic element of inspections carried out in order to determine safety levels. The range of monitoring and its frequency are subject to legal regulations, however it is crucial to select additional specific parameters characteristic for individual landfills in order to include them in the programme of control studies. Studies of leachate from municipal waste landfills and environmental monitoring carried out by the authors of this paper earlier indicate that such sites may contaminate waters to an extent which exceeds prescribed values (Klojzy-Karczmarczyk et al., 2003; Brudnik et al., 2006; Witkowski, 2009).

According to regulations currently in force it is obligatory to monitor among other things water pH, electrical conductivity and selected metals. However, these parameters and their variability may in some cases go unnoticed or may result from the impact of other facilities and their values are the effect of overlapping of various anthropogenic or natural factors. Additional indicators for the purposes of soil and water monitoring potentially impacted by municipal waste landfills should be determined based on an analysis of landfill specificity and of a study of selected environmental parameters (e.g. the composition of leachate water and surface water) in the potential impact zone of a given facility.

STUDY RESULT INTERPRETATION

The existing facilities and their actual impact on the environment have been analysed. Over the period of several years the authors have conducted studies of the quality of surface waters and groundwaters in the vicinity of several landfills where deposited municipal waste is obviously a contaminant.

In the presented paper the quality of surfaces water and groundwaters were analysed in the impact zone of two municipal waste landfills currently in operation in Małopolska region and one landfill which is out of operation Podkarpacie region. The authors are of the opinion that the obtained study results and an analysis of partial archive data have allowed to indicate the necessity of establishing additional contamination indices around municipal waste landfills. They should be considered specific indicators, characteristic for the surrounding areas of such landfills.

The quality of surface water was analysed in the impact zone of a municipal waste landfill located in Małopolska region, not far from Krakow, on a salt post-mining site. The landfill is situated in a natural depression and partially in a hollow resulting from ground subsidence due to the leaching of rock-salt mined until late 1990s. The potential source of contamination of the water environment in the discussed area is connected with the operation of municipal waste landfill and particularly with two closed down phases of its operation. Potentially migrating leachate constitutes a source of water contamination in the catchment basin of the river Malinówka adding to contamination resulting from former salt mining. The two first operating phases of the landfill have no additionally sealed base but have already been reclaimed. The phase which is currently in operation has been protected with additional synthetic insulation (Brudnik et al., 2006).

The results of studies conducted between 2008 – 2009 around the landfill indicate that the surface water is contaminated with chlorides and organogenic compounds which confirms indices recognised as characteristic. Figure 1 presents the variability of characteristic contamination indices of the river Malinówka waters in the potential impact zone of the landfill in locations above and below the facility. In the location below the landfill, an increase of electrical conductivity of water corresponding to mineralisation and ammonia nitrogen and chloride content has been clearly observed.

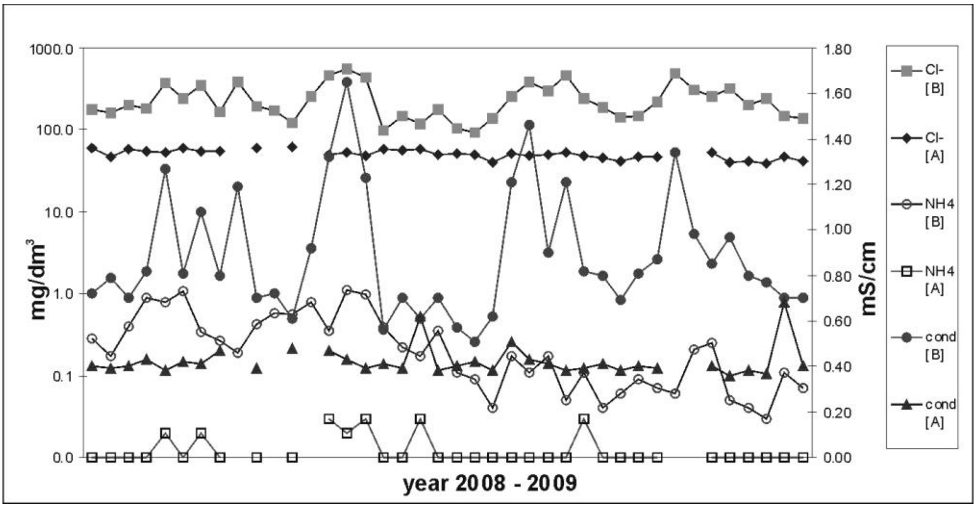

Figure 1. The changing values of characteristic surface water contamination indicators in the impact zone of a municipal waste landfill (A – site located above the facility; B – site located below the facility).

In the course of the river Malinówka water analysis, concentration of indices regarded as obligatory in the monitoring process has also been determined. Over the period of the last two years no increase of any of these parameters has been observed at the location below the landfill and these values are generally low, often below the detection level (fig. 2, table 1). Based on concentrations of parameters which are regarded as obligatory, it may be considered that there is no negative impact of the municipal waste landfill on the surface water environment. What is puzzling however, is the increase of electrical conductivity at the location below the landfill. This increase is doubtlessly the result of a measured chloride concentration in surface waters, which in this case, may indicate the existence of a negative impact of the analysed landfill.

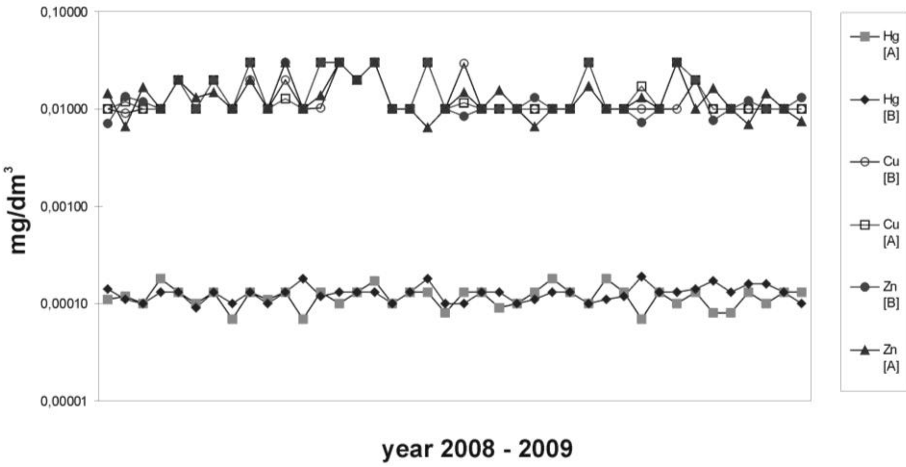

Figure 2. Obligatory indicators parameters in surface waters in the municipal waste landfill impact zone (A – site located above the facility; B – site located below the facility).

The quality of groundwaters was analysed in the impact zone of two municipal waste landfills located in two different regions. The access to the investigated environment in case of groundwaters is technically difficult, therefore the number of groundwaters quality measurements is significantly smaller than the number of surface water measurements presented above.

The municipal waste landfill located in the Małopolska region is an operating facility. It comes in contact with Carboniferous period deposit outcrops, and is naturally unprotected from leachate penetration. However, the landfill has been sealed with synthetic material (bentonite padding and HDPE foil geomembrane).

Groundwaters quality studies conducted between 2008 – 2009 indicated a general increase of electrical conductivity in the study borehole located at the outflow of these waters (Fig. 3).

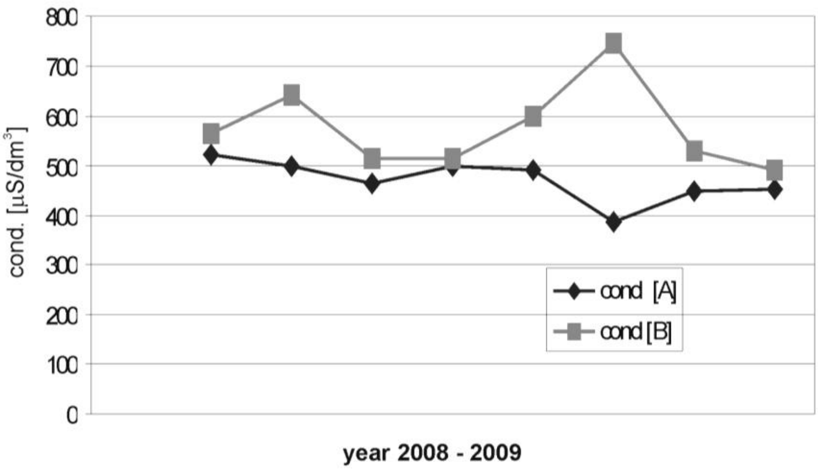

Figure 3. Electrical conductivity in groundwaters in the impact zone of municipal waste landfills (A – observation borehole at inflow; B – observation borehole at outflow of water from the landfill).

The concentration of indicators regarded as obligatory, indicated no increase at the same observation borehole (table 1). Studies of additional characteristic indicators were not conducted. It is therefore not possible to establish the reason for increased mineralisation of water leaching from the landfill area.

Table 1. Water environment contamination indicators in the impact zone of municipal waste landfills.

index	surface WATERS		groundWATERS			
	Malinówka stream*		Quaternary aquifer**		Carboniferous aquifer ***	
	above landfill	below landfill	at inflow	at outflow	at inflow	at outflow
OBLIGATORY INDEX PARAMETERS						
electrical conductivity of water [μS/cm]	416	879	no	no	470	575
[pH]	1.07.1958	1.07.1989	1.06.1995	1.07.2014	1.07.1930	1.07.1941
chromium [mg/dm³]	<0.01	<0.01	no	no	<0.01	<0.01
zinc [mg/dm³]	0.025	0.031	no	no	<0.01	<0.01
cadmium [mg/dm³]	<0.001	<0.001	no	no	<0.001	<0.001
copper [mg/dm³]	0.02	0.03	no	no	<0.005	<0.005
lead [mg/dm³]	<0.01	<0.01	no	no	<0.005	<0.005
mercury [mg/dm³]	0.00015	0.00015	no	no	<0.001	<0.001
ADDITIONAL INDEX PARAMETERS						
chloride [mg/dm³]	46	238	26,5	29,6	no	no
ammonium ion [mg NH_4^+/dm³]	0.01	0.09	no	no	no	no
nitrate ion [mg NO_3^-/dm³]	1,78	2,85	4,54	8,95	no	no

no – not determined

* - landfill in the vicinity of Krakow, research between 2008 – 2009; mean values

** - landfill in Podkarpacie region, research between 2002 – 2003; mean values

*** - landfill in Małopolska region; research between 2008 – 2009; mean values

The municipal waste landfill located in Podkarpacie region is out of operation. Studies were conducted between 2002–2003 while it was still in operation in a period when there were no binding legal regulations on monitoring studies. The landfill is located in a natural hollow, in an old river-bed meander. Quaternary sediments in the form of compact loam underlain with river sand are the direct substratum of the landfill. Miocene shaly mud-stone is the substratum of quaternary sediments. The landfill has not been sealed with synthetic material, so there is a potential leachate migration and therefore a real threat to groundwaters environment. There are no natural surface streams in the vicinity. Currently the landfill dome is being sealed and the site is being reclaimed.

Figure 4 presents the variability of indice parameters in groundwaters of the first water-bearing horizonl in the impact zone of the closed landfill. The study was conducted to obtain additional parameters considered by the authors of the work as specific indicators. In each of the investigated series of samples there is a marked increase in chlorides and nitrates in each of the two observation boreholes located at water outflow from the landfill. Other parameters were not determined, however on the basis of the obtained results of chloride and nitrate concentration, negative impact of landfill on the groundwaters environment may be concluded.

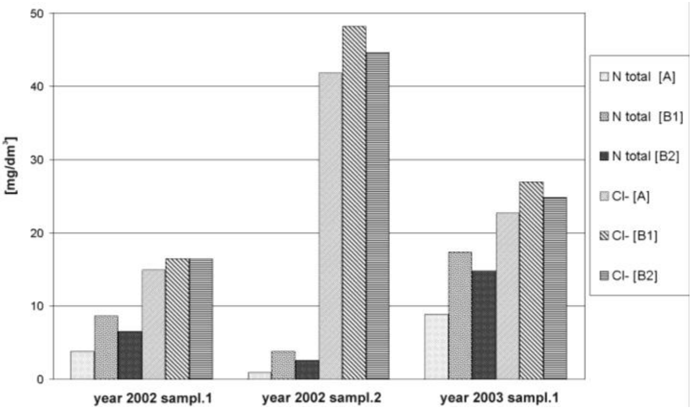

Figure 4. Variability of characteristic indicators of groundwaters contamination in the impact zone of municipal waste landfill (A – observation borehole at inflow; B – observation borehole at outflow of water from the landfill).

Table 1 contains concentrations of indicators considered obligatory and specific, characteristic for the quality of water environment in the potential impact zone of municipal waste landfill. The table contains average values for all the samples gathered in the subsequent periods from the three analysed landfills.

CONCLUSIONS

Studies have indicated that there is a close relationship between the location of landfills and areas with increased characteristic parameters which have not been selected for obligatory analysis. Undoubtedly chlorides and nitrogen compounds are among specific indicators of possible negative impact of municipal waste landfills on the soil and water environment and they may not be neglected. The results of studies conducted in the impact zones of the existing facilities therefore justify the necessity to extend the scope of monitoring studies. The studies extended in such a manner reflect the actual threats for the environment.

ACKNOWLEDGEMENTS

The authors would like to thank the Management of the landfills for providing materials for research and analysis.

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abstract id: **471**

topic: **1**
Groundwater quality sustainability

1.6
Groundwater monitoring

title: **Impact of currently remediated industrial waste disposal sites on groundwater quality in the area of Tarnowskie Góry (Southern Poland)**

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keywords: groundwater quality, monitoring, industrial waste

The region of Tarnowskie Góry constitutes a perfect example of negative environmental impact caused by casually locating waste site that takes into account no environmental considerations. In the considered area, there are the biggest in Poland industrial (chemical) waste disposal sites (of a former chemical plant) covered an area of over 27 ha with about 1.4 million tonnes of wastes. This situation together with the naturally high groundwater vulnerability to pollution has resulted in a progressing degradation of water quality in the multi-aquifer system (two Quaternary porous aquifers and two Triassic karst–fissured ones) Locating the wastes in the watershed area has additionally complicated the situation leading to multidirectional contamination spreading. Both Quaternary aquifers are a transit type being a source of recharge of lower Triassic aquifers. Horizontal flow in the Triassic aquifers is predominant while within the upper one (Muschelkalk) weak downward component is also observed. Natural groundwater flow pattern is modified by active wells.

The mentioned sites have been systematically monitored since 1999 (Rubin, Witkowski, 2002). The groundwater quality monitoring network has been subjected to multiple modifications and in 2004 consisted of 42 observation wells which monitor the Quaternary (20 wells) and the Triassic (22 wells) aquifers (Fig. 1).

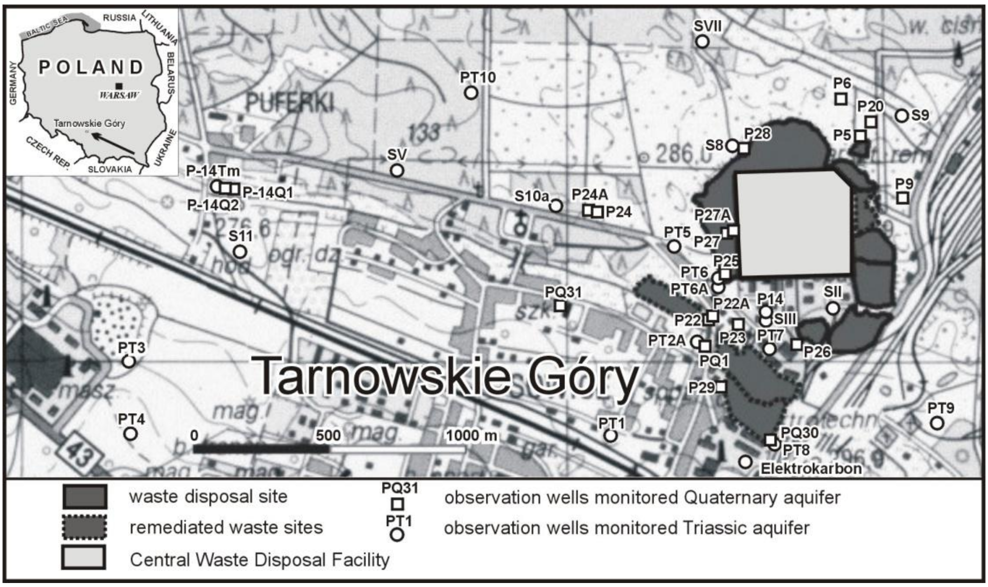

Figure 1. Location of the waste disposal sites and groundwater quality monitoring network.

Groundwater quality of the Quaternary aquifers is very changeable but generally highly contaminated (TDS — up to about 3000 mg/dm^3, Cl — up to 868 mg/dm^3, SO_4 — up to 1130 mg/dm^3, B — up to 275 mg/dm^3, Ba — up to 722 mg/dm^3, Sr — up to 30.6 mg/dm^3). Groundwater of the Triassic aquifers is generally less contaminated. Significantly contaminated water (even locally more than in Quaternary aquifer) has been noticed in the top part of the Mushelkalk in the area of waste disposal sites and adjacent downgradient areas (up to about 1 km from sites) (TDS — up to 2150 mg/dm^3, Cl — up to 275 mg/dm^3, SO_4 — up to 630 mg/dm^3, B — up to 116 mg/dm^3, Ba — up to 1.6 mg/dm^3, Sr — up to 1.25 mg/dm^3) (Rubin, Witkowski, 2003). Better quality water in base parts of the Mushelkalk in the area of considered sites and at the distance up to about 2 km downgradient from them has been observed. Water of better quality was observed in base parts of the Muschelkalk aquifer in the area of the considered sites and at a distance of up to about 2 km downgradient from them (TDS — up to 694 mg/dm^3, Cl — up to 78,8 mg/dm^3, SO_4 — up to 127 mg/dm^3, B — up to 1.49 mg/dm^3, Ba — up to 0.1 mg/dm^3, Sr — up to 0.327 mg/dm^3) Groundwater of the fourth lowest aquifer (Roethian) have been practically uncontaminated by the considered facility (TDS — up to 306 mg/dm^3, Cl — up to 41 mg/dm^3, SO_4 — up to 67 mg/dm^3, B — up to 0.47 mg/dm^3).

The high concentration of boron has been perceived as particularly dangerous since it reached 275 mg/dm^3 in the Quaternary aquifer, and 116 mg/dm^3 in the Triassic one. This critical situation resulted in closing of many water intakes situated nearby. Therefore a complex remediation of that area together with gradual removal and relocation of wastes to the new built lined Central Waste Disposal Facility has been begun in 2001.

In the course of ten years from 1999 to 2009 a general improvement of groundwater quality of the Quaternary aquifer and some relative stabilisation of the groundwater quality of the Triassic aquifer were observed. A significant differentiation in contaminants migration intensity has been observed within the Quaternary and Triassic aquifers depending on water flow direction.

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IAH 2010
Krakow

abstract id: **478**

topic: **1**
Groundwater quality sustainability

1.6
Groundwater monitoring

title: **Integrated monitoring of sources pollution — point sources pollution in Slovakia**

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keywords: point sources pollution, groundwater quality, database integrated monitoring, industry pollution, Slovakia

Problems of point sources pollution in groundwater gained ground following requirements of Water Framework Directive 2000/60/EC in Slovakia. One of the main aim of the Water Framework Directive (WFD) is an achievement of good groundwater/surface water status to the year 2015.

Integrated monitoring of pollution sources is one of the main tools for groundwater chemical status evaluation within the point pollution sources. The main component of this tool is database with the same name. Integrated monitoring of sources pollution database is created and operated by Water Research Institute, Bratislava, Slovakia (www.vuvh.sk) in cooperation with JTS s.r.o. Bratislava, Slovakia.

An achievement of good groundwater/surface water status to the year 2015 is a need for a greater integration of qualitative and quantitative aspects of both surface and groundwaters, taking into account the natural flow conditions of water within the hydrogeological cycle. Point sources pollution are one of the biggest risk for groundwaters because of its area density, variety of chemical contaminants which can deteriorate groundwater status and also its incorrect and inaccurate localization.

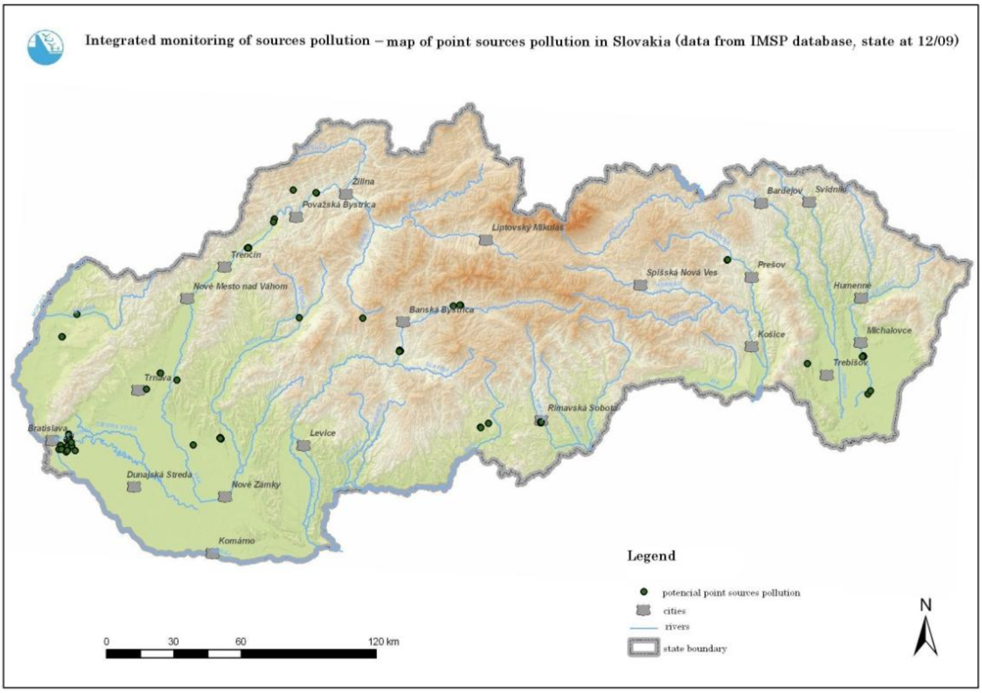

Figure1. Integrated monitoring of sources pollution.

Very good method to obtain data from different groundwater monitoring of industrial areas, wasting sites, is creation of own database, where these data can concentrate. Development of the Integrated monitoring of sources pollution database have started in 2006 as a simple MS Access database. Data was imported manually via native MS Access background. Further development consisted in testing activity via web application (www.vuvh.sk) which enable to input data directly from potential polluters from whole Slovakia.

On the ground of higher performance, comfort, safety and Multilanguage support we had to change over to more professional environment of relational database – OpenSource Community environment with Linux operating system, Ingres database environment with Apache web server and Glassfish/Sun Java Application Server.

Quality data from Integrated monitoring of sources pollution database are basement for evaluation of groundwater chemical status in Slovakia. First step is classification of the locality to the groundwater body and definition of chemicals substances which are dangerous for this groundwater body.

We will evaluate with statistical method, comparing with threshold values of chemical substances in specific groundwater body, comparing with legislative values and environment in specific area. Another step is risk analyses and proposal for remedial measures which will provide a good groundwater status in specific locality to 2015.

IAH 2010
Krakow

abstract id: **511**

topic: **1**
Groundwater quality sustainability

1.6
Groundwater monitoring

title: **Monitoring of the impact of agriculture on groundwater in Latvia**

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keywords: groundwater, monitoring, agriculture

ABSTRACT

The objective of the study is to investigate the overall status of groundwater table fluctuations and quality to evaluate possibility to use groundwater monitoring results for evaluation of the efficiency of good agricultural practice.

Groundwater monitoring is a part of state water monitoring program in Latvia. For agriculture, the risk is related to leaching of nutrients and pollutants to the shallow groundwater. Groundwater regime and balance plays significant rule in agricultural lands as part of water cycle and surface and subsurface interaction.

INTRODUCTION

Groundwater resources, especially shallow ones are sensitive to contamination and other anthropogenic factors. Most intensive farming is developed in Zemgale region where area of agricultural land reached up to 80% of total land use.

Fluctuations of groundwater level in an unconfined aquifer in agricultural land depend on many factors: subsurface drainage, physical and chemical soil properties, soil water balance, slopes and, infiltration and percolation processes. At present groundwater monitoring (quantity and quality) in agricultural land has been carried out by Latvian Environment, Geology and Meteorology Centre (LEGMC) and Latvia University of Agriculture (LUA). LUA have three monitoring stations, which are located in different types of soil and intensity of farming. Monitoring of groundwater level in Latvia at three agricultural run-off monitoring stations in 10 observation wells started in year 2006.

GROUNDWATER LEVEL MODELLING

Conceptual groundwater level model METUL by Krams and Ziverts (1993) was calibrated using measurements of the daily groundwater level fluctuations for the period 2006–2009. This model is site oriented two-dimensional mathematical model based on daily weather data (temperature, precipitation, and relative humidity).

Water balance for model calibration is from three parts: estimation of snow cover, estimation of active soil zone of moisture balance and estimation of groundwater balance together with capillary fringe. Necessary parameters in each part for groundwater balance calculations are required. For snow cover estimation parameters are air temperature of daily average below which snow accumulation begins, air temperature of daily average above which snow ablation begins, evaporation coefficient from snow and two empirical coefficients, which characterize the intensity of the snowmelt and the water contribution from the snow.

For active soil zone moisture balance estimation parameters are water storage of the active soil zone at the beginning and the end of the day (mm), rain and snow melt water (mm/day), evaporation from active soil zone (mm/day), evaporation from groundwater surface (mm/day).

For groundwater and capillary water zone parameters are capacity of empty ground pores at the beginning and the end of the day (mm), recharge of groundwater (mm/day), evaporation from groundwater surface (mm/day), three runoff components: surface, drainage, groundwater (mm/day) (Krams and Ziverts, 1993).

GROUNDWATER QUALITY

The groundwater quality in the agricultural run-off monitoring stations has been measured during 2006 – 2009. In the climatic conditions of Latvia the pollutant threshold values for groundwater bodies (50 mg l^{-1} of nitrate) was not observed today. Observed data shows water quality in three parts of soil profile: small catchment area (surface water bodies) drainage field and groundwater aquifer level (Figure 1). One of the important future tasks is to organize comprehensive national groundwater monitoring network covering both confined and unconfined aquifers.

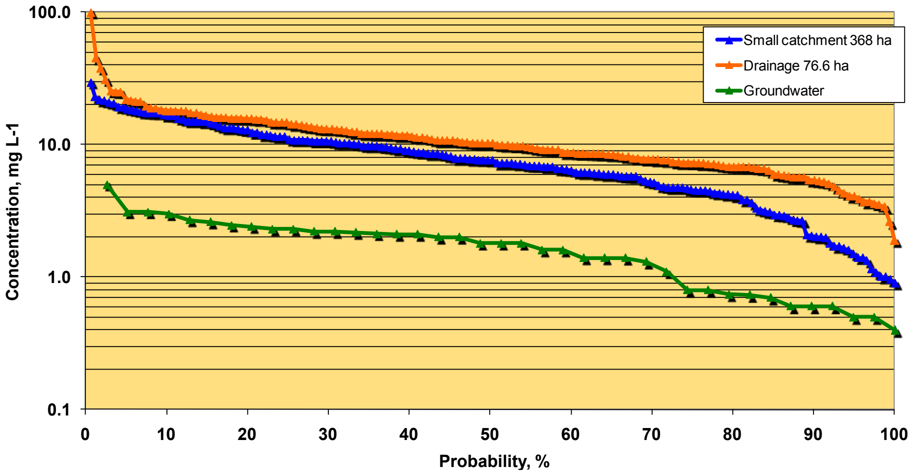

Figure 1. Cumulative probability distribution for Ntot concentration in monitoring station Berze.

DISCUSSION

In each territory, groundwater development conditions are different and depended on following regularities: soil type, geological structure of ground layers, hydrophysical conditions etc. All mentioned parameters for groundwater level modelling are taking into account. Observed data are required to transform as model recognize them and all parameters must known before modelling.

However, the impact on the groundwater watertable in Latvia mostly depends on precipitation amount. Characteristic seasonal fluctuations in groundwater level in mentioned monitoring stations from 2006 – 2009 were observed (Figure 2). High groundwater level in autumn, spring and lowering of the groundwater levels in summer time is typical for soils in Latvia.

Modeling results shows correlation between modeled and observed data. To be able to compare mentioned data curves use determination coefficient R^2. The coefficient of determination, R^2, is useful because gives the proportion of the fluctuation of one variable that is predictable from the other variable (Steel and Torrie, 1960). Three and two year period is not enough for determination of hydrological processes but it is sufficient for trend analyses in mentioned monitoring stations and prediction of future purposes. Further research will be based on groundwater modeling results from three monitoring stations (case study area). Groundwater level simulations using METUL for prediction of groundwater levels in future are expecting. All determine parameters and compliances will be applied to another territory and soil type in future. If soil type or hydrogeological conditions are different necessary to take into account new parameters.

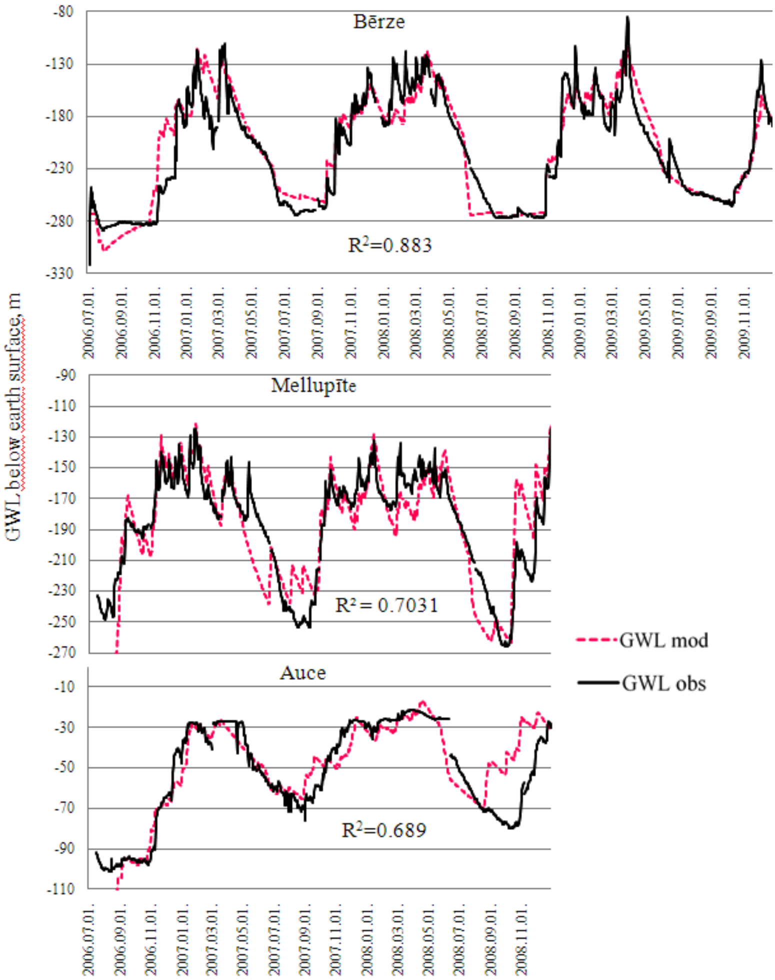

Figure 2. Observed and modeled groundwater level fluctuations 2006 – 2009 in LUA monitoring stations.

CONCLUSIONS

Determination of soil properties and meteorological conditions are the key purpose for groundwater level simulations based on METUL model. A result shows good determination correlation between observed and modeled data in Berze and Mellupite stations (Figure 2). In Auce monitoring station compliance between observed and modelled data are lower. For best compliance in Auce monitoring station are necessary to reconsider used parameters and add new ones depending on hydrogeological, hydrological and soil type conditions in mentioned area. Introduce in groundwater model METUL new calibrated parameters depending on groundwater aquifer conditions. Risk for groundwater quality conditions in mentioned monitoring sites are depending mostly on drainage water contamination. Drainage runoffs in agricultural areas are contaminated by biogenic elements from agricultural production.

ACKNOWLEDGEMENTS

This work has been supported by the European Social Fund within the project „Establishment of interdisciplinary scientist group and modelling system for groundwater research".

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IAH 2010 Krakow

abstract id: **526**

topic: **1**
Groundwater quality sustainability

1.6
Groundwater monitoring

title: **Uncertainty involved in sampling process and its influence on the overall performance of groundwater quality monitoring**

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keywords: groundwater monitoring, QA/QC programme, sampling uncertainty

The most important European Union directives concerning groundwater quality – 2000/60/WE (Water Framework Directives) and 2006/118/WE – say that uncertainty identification and estimation is an important part of the overall groundwater monitoring results interpretation. Uncertainty is the most important parameter describing measurement quality. Also other international standards, e.g. PN-EN ISO/IEC 17025, show that we have to consider all sources of uncertainty rising during different part of procedure, starting from sampling procedure, sampling collection, preservation and transport to laboratory and sample analysis.

Uncertainty assessment procedures have been concentrated only on analysis yet. But many different researches prove that sampling process is very often important source of uncertainty influencing final result and general quality of results achieved during water quality monitoring. The part of uncertainty associated with sampling process can account for 50–90 percent of total uncertainty. Acquaintance of different source and cause of uncertainty growing during sampling process is very important when we want to obtain reasonable results of our investigations. We cannot discount any contribution in total uncertainty.

The best way to achieve satisfying (low) level of uncertainty is to carry on extended quality assurance/quality control (QA/QC) program. During this quality process control samples are collected: duplicate and blank samples. The number of these control samples shouldn't be less than 10% of all normal samples. The analysis of duplicate samples gives us information about uncertainty associated with sampling and analytical process. The analysis of field blank samples says about practical limit of detection for all analysed elements and compounds. The good laboratory practice and properly performed QA/QC program can decrease total uncertainty value and identify main sources of uncertainty. This the most important in the case of sampling which has usually the largest contribution of total uncertainty. The knowledge of uncertainty sources let us minimize its influence and eliminate the biggest contributions by refining whole sampling procedure and source of errors elimination.

ACKNOWLEDGEMENTS

This work was partially supported by AGH-UST 18.18.140.585 and 10.10.140.585.

abstract id: **532**

topic: **1**
Groundwater quality sustainability

1.6
Groundwater monitoring

title: **Natural radionuclides in drinking water supplies**

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keywords: drinking water, natural radionuclides, Upper Silesia

INTRODUCTION

Groundwater from different aquifers is often used as a source of a drinking waters at many locations. It is usually stated, that such water supply are more safer for the public due to smaller possibility of contamination as surface ones. On the other hand, waters from underground reservoirs are containing more minerals usually, together with natural radionuclides. We were interested in investigation of the water purification processes, as radionuclides may be accumulated in the waste materials produced during water treatment.

For the preliminary investigations, eight different water supplies were taken into account, five of them were underground ones, while 3 others were surface water supplies. The latter ones were investigated to compare the balance of natural radionuclides in treatment processes, which in all of the cases were similar. The simplified description of the treatment method is following. At first gravel/sand filters have been used for the removal of mechanical suspention, afterwards the oxidation of the water has been applied in most of the cases to remove iron, manganse and sulphur (a co-precipitation or adsorption of natural radionuclides may occur at that stage). The sediments, containing iron hydroxide and manganese dioxide were filtered again at the gravel filters and finally a chlorine was added to the as the desinfecting agent. From time to time gravel filters are backwashed for the removal of the residues. Sludges are transported to the sedimentation tanks, where iron hydroxide and manganese dioxide are settled, together with adsorbed or co-precipitated natural radionuclides. Naturally occurring radionuclides can accumulate in these sludges enhanced concentrations, therefore these waste materials should be considered often as NORMs. Most abundant radionuclides, present in sludges are usually radium isotopes (Ra-226 and Ra-228). Due to some reports, elevated concentrations of radium are observed in waters with low oxygen content (Vornehm, 2009), which parameter can be correlated with hydrogeological conditions in the aquifer.

Level of acceptable radioactivity in the drinking water is regulated or recommended by different legal acts of recommendations. In the USA, the EPA regulation (EPA, 2001) was established for Ra-226 concentration as a permissible level 5 pCi/l (0,185 Bq/l). If concentration of radium is exceeding 3 pCi/l (0,111 Bq/l) measurements of Ra-228 concentration must be done. When radium concentration is above the permissible level, than the water treatment must be done for removal of radioactive nuclides. On the other hand, recommendation of the WHO (WHO, 2004) are following. At first the gross alpha and beta activity should be screened and in case, if gross alpha activity is below 0,5 Bq/l and gross beta activity doesn't exceed 1 Bq/l, such water can be used as a drinking water. Only in cases, when those values are higher as recommendations, analysis of particular radionuclides should be done. In European Union, the Drinking Water Directive (Drinking Water Directive, 1998) has been issued, followed by the Radon in Water Directive (Directive 2001/928/Euratom, 2001), regulating radon issues in drinking water supplies. Drinking Water Directive requirements are following – the only directly mentioned radionuclide is tritium H-3, which permissible level is 100 Bq/l. For all other radionuclides following provision is applied, that the total dose due to ingestion of radioactivity (called Total Indicative Dose — TID), shouldn't be higher as 0,1 mSv/year. Conversion factors from ingestion to dose were published in Euratom Directive (Euratom, 1996), in which whole population has been divided into six age groups, characterised by different conversion factors. In the Radon in Water Directive, recommended level of radon is established at level 100 Bq/l while permissible level is as high as 1000 Bq/l. Additional requirement of that Directive is the monitoring of Pb-210 and Po-210 when the recommended value is exceeded.

SAMPLING

Eight different water supplies, located in Upper Silesia region, were taken into preliminary investigations, five of them were underground ones, while 3 others were surface water supplies. In each of the cases, the raw water samples were taken, before any treatment and at least one sample of drinking water, after full treatment. The volume of particular water sample was 20 l, to have enough sample for preconcentration and measurements of all required radionuclides. Sampling has been done in August and September 2009 in the Upper Silesia Province in southern Poland. In three cases also sludges have been sampled from the water treatment installations, in which waters from underground were treated. The usual amount of the sludge was 2 liters, to enable gamma spectrometry of the sample.

RESULTS

20 samples of raw and treated waters have been take into analyses as well as 3 samples of sludges. Measurements of natural radionuclides in waters have been performed and results are shown in Table 1. Results of measurements for tritium, strontium and cesium were very low, usually below the detection limit for the particular analysis, therefore are not shown.

Analysis of results of natural radionuclides in water samples is showing the following pattern, that concentrations of all these radionuclides in waters from surface supplies are low (see samples 3, 5 and 11). It is different for samples from underground wells (samples 7, 9, 14, 15, 17 and 19). It can be seen, that concentrations of particular natural radionuclides can vary a lot and it is related to the conditions in particular aquifers.

During sampling three samples of sludges were taken for the analysis. Samples were measured with application of gamma spectrometry and results are presented in Table 2.

Table 2. Results of measurements of natural radionuclides in sludges from water treatment installations – results in Bq/kg of the dry mass.

No	Sampling site	Ra-226	Unc. 2 δ	Ra-228	Unc. 2 δ	Ra-224	Unc. 2 δ	Pb-210	Unc. 2 δ	U-238	Unc. 2 δ
1.	Konopisko (water No. 7 and 8)	2390	340	1496	76	366	28	345	44	360	90
2.	Dąbrowski (water No. 14 and 13)	1630	160	982	51	425	27	104	19	< 150	-
3.	Zwonowice (water No. 19 and 20)	905	45	510	25	108	15	55	15	< 160	-

It can be seen, that all of the sludges are showing enhanced activities of natural radionuclides. Most important radionuclides are radium isotopes, co-precipited and adsorbed on the sediments, while uranium U-238 was found only in one of the samples, probably being the effect of the uranium adsorption on the iron hydroxide. The presence of Ra-224 and Pb-210 is either a reason of its co-precipitation from the water, or more probably it is due to ingrowth of decay products of Ra-226 and Ra-228 in the sludge.

Table 1. Results of investigations for water samples

		Radium isotopes				^{210}Pb		Uranium isotopes			
			mBq/l				mBq/l		mBq/l		mBq/l
No.	**Sampling site**	**^{226}Ra**	**δ ^{226}Ra**	**^{228}Ra**	**δ ^{228}Ra**	**^{210}Pb**	**δ ^{210}Pb**	**^{238}U**	**δ ^{238}U**	**^{234}U**	**δ ^{234}U**
1	Tychy – treated water	<1,1	-	<6,6	-	<3,2	-	0,10	0,09	0,10	0,09
2	Pszczyna - treated water	<1,1	-	<6,6	-	<3,2	-	<0,05	-	<0,05	-
3	Goczałkowice – raw water	<1,1	-	<6,6	-	<3,2	-	1,01	0,32	1,18	0,35
4	Dziećkowice- treated water	<1,1	-	<6,6	-	<3,2	-	0,64	0,15	0,92	0,19
5	Dziećkowice – raw water	<1,1	-	<6,6	-	<3,2	-	0,99	0,18	2,19	0,31
6	Mikołów – treated water	<1,1	-	<6,6	-	<3,2	-	0,36	0,10	0,56	0,14
7	Konopisko – raw water	27,9	3,0	18,9	10,0	3,3	3,3	0,76	0,16	7,02	0,79
8	Konopisko - treated water	12,6	2,0	<6,6	-	4,0	3,3	0,15	0,04	0,42	0,07
9	Niegowonice raw water	60,2	5,0	12,7	10,0	5,7	3,4	11,48	0,82	18,70	1,29
10	Niegowonice treated water	60,9	5,0	<6,6	-	5,1	3,3	11,27	0,65	18,31	1,03
11	SUW Maczki raw water	<1,1	-	<6,6	-	<3,2	-	8,72	0,62	14,33	0,97
12	SUW Maczki treated water	<1,1	-	<6,6	-	<3,2	-	6,55	0,55	11,76	0,92
13	Dąbrowski treated water	25,8	3,0	65,6	20,0	3,5	3,3	4,59	0,57	11,75	1,26
14	Dąbrowski raw water	33,8	4,0	88,0	20,0	3,6	3,3	3,56	0,37	9,11	0,81
15	SUW Bielszowice raw water	42,1	4,0	48,0	20,0	3,7	3,3	3,87	0,48	8,39	0,89
16	SUW Bielszowice treated water	15,3	2,0	17,8	10,0	<3,2	-	3,70	0,34	8,26	0,66
17	Łabędy raw water	17,0	2,0	13,3	10,0	3,3	3,3	31,60	2,44	58,23	4,41
18	Łabędy treated water	11,2	2,0	8,7	7,6	3,3	3,3	34,19	2,52	60,77	4,40
19	Zwonowice raw water	5,0	1,5	<6,6	-	<3,2	-	0,09	0,05	0,25	0,05
20	Zwonowice treated water	<1,1	-	<6,6	-	<3,2	-	0,08	0,05	0,11	0,05
		LLD	^{226}Ra=	1,1	mBq/l	LLD ^{210}Pb	3,2	mBq/l	LLD ^{238}U=	0,05	mBq/l
		LLD	^{228}Ra=	6,6	mBq/l				LLD ^{234}U=	0,05	mBq/l

DISCUSSION

Results of investigations are showing, that the treatment of the raw water for the producing the drinking water may lead to the creation of sludges with enhanced natural radioactivity. On the other hand, far more important is the concentration of radionuclides in the drinking water after purification. The drinking of the water with elevated content of natural radionuclides may cause the increase of the effective dose for the population.

It can be clearly seen, that in some cases estimated annual doses are higher as 0,1 mSv/year. It also became obvious, that there are two critical groups in the population — babies and teenagers, for whom the number of cases, when the value 0,1 mSv/year has been exceeded was significant. In contrary, for adults we found no examples of the exceeding of the Total Indicative Dose limit. It means, that applying the WHO approach, all of investigated waters would be classified as a drinking waters. This point is very crucial, as application of the approach accordingly to EU Directive is leading to different conclusions. It means also, that relying on the screening method of gross alpha and gross beta activity may cause the underestimation of the annual dose.

CONCLUSIONS

1. Analyses of water samples, taken from different water supplies, are showing following pattern — usually concentrations of radionuclides in surface waters are low, while in waters from underground wells natural radiunuclides are often present.
2. Screening method for the assessment of radioactivity of the drinking water, it means measurement of gross alpha and gross beta activity is appear to be inadequate for this purpose, especially for underground waters.
3. The most important radionuclide, taking into considerations a dose for the population, is radium isotope Ra-228. The critical age groups are babies and adolescents.
4. In our opinion, a different approach should be applied for the monitoring of waters from surface supplies and underground ones. For surface waters the screening might be good enough to classify these waters.
5. For the monitoring of underground waters, the monitoring should be based on measurements of the most important natural radionuclides — Ra-228, Ra-226 and Pb-210, additionally uranium isotopes are sort of important ones, if gross alpha activity is high.
6. More attention must be focused in the future on investigation of sludges, as till now these waste materials are disposed into the environment without any measures againt the environmental pollution.
7. Additionally radon concentration in waters from underground water supplies should be monitored and mitigated, if necessary.

ACKNOWLEDGEMENTS

Investigations have been made with use of the instrumentation, received within the frame of the project, supported by European Fund of Regional Development, entitled "Development of the research capabilities for revitalisation of the post-industrial areas" Nr: OIG.02.01.00-24-045/08, This project is allocated at the Central Mining Institute within Operational Programme „Innovative Economy", period 2007-2013, Priority 2. Infrastructure of R+D sphere, Activity 2.1. Development of institutions of high research potential.

INNOWACYJNA GOSPODARKA NARODOWA STRATEGIA SPÓJNOŚCI
GŁÓWNY INSTYTUT GÓRNICTWA
UNIA EUROPEJSKA EUROPEJSKI FUNDUSZ ROZWOJU REGIONALNEGO

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1.7 | Groundwater policy and legal aspects

abstract id: **399**

topic: **1**
Groundwater quality sustainability

1.7
Groundwater policy and legal aspects

title: **Proposed procedure to evaluate the chemical status of groundwater bodies**

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INTRODUCTION

According to Article 5 of the water framework directive (WFD, European Commission, 2000) all member states are required to conduct a study determining the impact of human activity on the status of groundwater. In accordance with the deadlines defined in the WFD, the first analysis of pressures and impacts was to be completed in December 2004. This analysis of pressures and impacts should be reviewed and updated in each European river basin district by December 2013, and thereafter every six years.

The aim of this work is to propose a procedure to evaluate the impact on the chemical status of groundwater bodies, which may be a procedure to be used in the review to be completed in 2013 in all European river basins.

ENVIRONMENTAL OBJECTIVES

Preliminary considerations

An impact occurs when a given body of water fails to meet the environmental objectives that the directive sets out in Article 4. This leads to the conclusion that as a preliminary step towards the identification of impacts on the chemical status of groundwater bodies, it is necessary to review the environmental objectives of groundwater bodies.

Groundwater bodies

The objective that the WFD establishes for groundwater bodies is to achieve a good chemical and a good quantitative status by 2015. The parameters that should be used to evaluate the chemical status of groundwater bodies are electrical conductivity and the concentration of pollutants (Tab. 1).

Table 1. Definition of good groundwater chemical status according to the WFD.

Objective	Parameters	Criteria	Reference
Good chemical status	Conductivity	Not indicative of saline or other intrusion	Annex V, section 2.3
	Concentration of pollutants	Do not exhibit the effects of saline or other intrusions	
		Do not exceed the quality standards applicable under Directive 2006/118/EC	
		Do not result in failure to achieve the environmental objectives nor any significant diminution of quality of associated surface waters	

In order to achieve good chemical status, the electrical conductivity must not indicate the existence of salinisation or other types of intrusions, and concentrations of pollutants must be below the quality standards (maximum permissible concentrations) established in Directive 2006/118/EC (Groundwater Directive, European Commission, 2006). Furthermore, the chemical and ecological status of surface water bodies and ecosystems that directly depend on the groundwater body should not be deteriorated (Tab. 1).

PROPOSED PROCEDURE TO EVALUATE IMPACTS ON GROUNDWATER CHEMICAL STATUS

Background

The documents of reference that have been used to establish this methodology are the following: water framework directive, guidance document nº 3 on the analysis of pressures and impacts (European Commission, 2003) and the manual for the identification of pressures and analysis of impacts on surface waters, drawn up by the Spanish Ministry of the Environment (2005, unpublished data).

The objective of an impact assessment on the chemical status is to identify all the chemical substances or physicochemical parameters that can cause a groundwater body to not meet its environmental objectives. Therefore, the list of pollutants and indicator parameters considered to assess impacts should be as extended as possible.

Impact classes proposed

Two types of impacts are proposed in this work: an *important* impact and a *slight* impact. Consequently, the result of an impact assessment may be one of the following four options: a) *important* impact, b) *slight* impact, c) *no impacts reported* and d) *no data found*.

An *important* impact will be present when one of the parameters used to assess the chemical status does not meet the quality standard. The *slight* impact is reserved for those cases which do not exceed the quality standard, however the concentration or value of the parameter considered indicates that the natural status of a water body has been altered due to human activity. If neither of these cases applies, the water body will be defined as *no impacts reported*, and where no data is available for evaluation, the classification *no data found* will be assigned.

Impact assessment on the chemical status of groundwater bodies

The requirements for a groundwater body to have a good chemical status can be summarised into the following:

- 1. No evidence exists of salinisation or seawater intrusion.
- 2.The concentrations of contaminants do not exceed the quality standards set in the Groundwater Directive (Directive 2006/118/EC).
- 3. The chemical or ecological status of surface water bodies and terrestrial ecosystems that depend on these groundwater bodies do not deteriorate.

Table 2. Parameters and criteria for assessing the impacts on the chemical status of groundwater bodies. (All concentrations are expressed in μg/l unless otherwise indicated).

	Impact		
Parameter	**Slight**	**Important**	
1. Electrical conductivity	Upward temporary evolutions		
2. Chloride			
3. Sodium			
4. Sulphate			
5. Nitrates	20-50 mg/l	>50 mg/l	
6. Pesticides	Presence	>0.1 (indiv.)	>0.5 (total)
7. Alachlor	Presence	MA>0.3	>0.7
8. Anthracene	Presence	MA>0.1	>0.4
9. Atrazine	Presence	MA>0.6	>2.0
10. Benzene	Presence	MA>10	>50
11. Brominated diphenylether	Presence	MA>0.0005	
12. Cadmium: <40 mg/l CaCO3	-	MA>0.08	>0.45
40-50 mg/l CaCO3	Presence	MA>0.08	>0.45
50-100 mg/l CaCO3	>0.45	MA>0.09	>0.60
100-200 mg/l CaCO3	>0.60	MA>0.15	>0.90
≥200 mg/l CaCO3	>0.90	MA>0.25	>1.50
13. C10-13 Chloroalkanes	Presence	MA>0.4	>1.4
14. Chlorfenvinphos	Presence	MA>0.1	>0.3
15. Chlorpyrifos	Presence	MA>0.03	>0.10
16. 1,2-Dichloroethane	Presence	MA>10	
17. Dichloromethane	Presence	MA>20	
18. Di(2-ethylhexyl)-phthalate	Presence	MA>1.3	
19. Diuron	Presence	MA>0.2	>1.8
20. Endosulfan	Presence	MA>0.005	>0.010
21. Fluoranthene	Presence	MA>0.1	>1.0
22. Hexachloro-benzene	Presence	MA>0.01	>0.05
23. Hexachloro-butadiene	Presence	MA>0.1	>0.6
24. Hexachloro-cyclohexane	Presence	MA>0.02	>0.04
25. Isoproturon	Presence	MA>0.3	>1.0
26. Lead and its compounds	>10	MA>7.2	
27. Mercury	Presence	MA>0.05	>0.07
28. Naphthalene	Presence	MA>2.4	
29. Nickel and its compounds	>10	MA>20	
30. Nonylphenol	Presence	MA>0.3	>2.0
31. Octylphenol	Presence	MA>0.1	
32. Pentachloro-benzene	Presence	MA>0.007	
33. Pentachloro-phenol	Presence	MA>0.4	>1.0
34. Polyaromatic hydrocarbons:			
(a) Benzo(a)pyrene	Presence	MA>0.05	>0.10
(b) Benzo(b)fluor-anthene	Presence	MA: Σ>0.03	
(c) Benzo(k)fluor-anthene			

	Impact		
Parameter	**Slight**	**Important**	
(d) Benzo(g,h,i)-perylene	Presence	MA: Σ>0.002	
(e) Indeno(1,2,3-cd)-pyrene			
35. Simazine	Presence	MA>1	>4
36. Tributyltin compounds	Presence	MA>0.0002	>0.0015
37. Trichloro-benzene	Presence	MA>0.4	
38. Trichloro-methane	Presence	MA>2.5	
39. Trifluralin	Presence	MA>0.03	
40. (a) Total DDT	Presence	MA>0.025	
(b) P,p-DDT	Presence	MA>0.01	
41. Aldrin	Presence	MA: Σ>0.01	
42. Dieldrin			
43. Endrin			
44. Isodrin			
45. Carbon tetrachloride	Presence	MA>12	
46. Tetrachloro-ethylene	Presence	MA>10	
47. Trichloro-ethylene	Presence	MA>10	
48. Chloro-benzene	Presence	MA>20	
49. Dichloro-benzene	Presence	MA>20	
50. Ethyl-benzene	Presence	MA>30	
51. Metolachlor	Presence	MA>1	
52. Terbuthylazine	Presence	MA>1	
53. Toluene	Presence	MA>50	
54. 1,1,1-Trichloro-ethane	Presence	MA>100	
55. Xilene	Presence	MA>30	
56. Cyanides	Presence	MA>40	
57. Fluoride	>1.0 mg/l	MA>1.7 mg/l	
58. Arsenic	10-50	MA>50	
59. Cupper: ≤10 mg/l CaCO3	>2.5	MA>5	
10-50 mg/l CaCO3	>11	MA>22	
50-100 mg/l CaCO3	>20	MA>40	
>100 mg/l CaCO3	>60	MA>120	
60. Total chromium	>10	MA>50	
61. Chromium VI	>1	MA>5	
62. Selenium	>1	MA>1	
63. Total zinc: ≤10 mg/l CaCO3	>6	MA>30	
10-50 mg/l CaCO3	>40	MA>200	
50-100 mg/l CaCO3	>60	MA>300	
>100 mg/l CaCO3	>100	MA>500	
64. Total phosphorus	>12	>50	
65. Biological oxygen demand	>2.5 mg/l	>4.0 mg/l	
66. Ammonium	Presence	>0.5 mg/l	
67. Phosphate	Presence	>0.5 mg/l	

"MA": mean annual concentration; the other values are expressed as maximum allowable concentrations

Table 2 shows the list of the 67 physicochemical parameters proposed in this work to identify the impacts on the chemical status of groundwater bodies, as well as the threshold values proposed to define the *slight* and *important* impacts.

Salinisation or seawater intrusion

Four physicochemical parameters are proposed to identify the existence of an impact made by salinisation or seawater intrusion (parameters 1 to 4 in Tab. 2): Electrical conductivity, Chloride concentration, Sodium concentration and Sulphate concentration.

The criteria proposed to identify an impact by salinisation or seawater intrusion are based on the existence of increasing trends over time with respect of any of these parameters. Given the difficulty of establishing a single quantitative threshold to differentiate between the *important* and *slight* impacts, a distinction based on the following characteristics of increasing trends is proposed: number of control points showing an upward trend, number of physicochemical parameters showing an upward trend and clarity or evidence of trends.

Quality standards established in Directive 2006/118/EC

Two quality standards are established in Annex I of this directive related to the concentration of nitrate (50 mg/l) and pesticides (0.1 µg/l for a single pesticide and 0.5 µg/l for the sum of pesticides). These quality standards are proposed to identify the existence of an *important* impact given that going over this limit would imply that a groundwater body fails to reach the good chemical status (5 and 6 in Tab. 2). Furthermore, it is necessary to define another threshold value to identify the existence of a *slight* impact. In the case of nitrate, a compound that can be found naturally in water, it is proposed to define a *slight* impact when the concentration is between 20 and 50 mg/l. With respect to pesticides, which are substances that do not come from natural sources, it was decided to consider its mere existence in water as evidence of a *slight* impact.

Surface water bodies and associated ecosystems

One of the requirements of the WFD for a groundwater body to have a good chemical status is that the status of associated surface water bodies and dependent ecosystems does not deteriorate by its action.

Many groundwater bodies have been defined in aquifers that discharge through one or more springs that in many cases feed rivers and lakes, which, in turn, can constitute surface water bodies. Consequently, a deterioration in the status of this groundwater would result in a deterioration of the quality of surface water bodies and associated ecosystems. For this reason, it was considered necessary to include in the list of parameters used to assess the chemical status of groundwater bodies, those parameters which are necessary to evaluate the chemical status of surface waters. These substances are numbered from 7 to 65 in Tab. 2.

The parameters 7 to 47 in Tab. 2 were obtained from the Directive 2008/105/EC on environmental quality standards in surface waters (European Commission, 2008), which defines quality standards that set maximum permissible concentrations allowed in surface water for 41 substances. These maximum concentrations or quality standards are expressed in two different manners: as average annual values and as maximum allowable concentrations. In this proposal, surpassing these concentrations is considered as evidence of an *important* impact since they will prevent an associated surface water body to reach a good chemical status.

In regards to *slight* impacts, the 41 substances have been grouped into two types: those that are not naturally found in water (all of them except for cadmium, lead and nickel), and those that can originate from both natural sources as well as polluting activities. In regards to those not naturally found in water, it was decided that their mere presence in water is indicative of a *slight* impact, and with respect to cadmium, lead and nickel (numbers 12, 26 and 29 respectively in Tab. 2), a *slight* impact is present when concentrations surpass 10 µg/l for lead and nickel, and 0 to 0.9 µg/l (depending on water hardness) for cadmium. In the case of lead, the value corresponds to the maximum concentration recommended by the World Health Organization (after Baird, 1999), whilst values of nickel and cadmium have been established within the framework of this work as no previous information was found.

Substances from 48 to 63 in Tab. 2 were obtained from the Royal Decree 995/2000, of 2 June, which defined the quality objectives for certain pollutants (Official [Spanish] State Gazette, *BOE* No. 147, 20.6.2000). The maximum concentrations established in the Royal Decree have been interpreted as indicating the existence of an *important* impact. In regards the thresholds that identify the existence of a *slight* impact, its estimate is calculated using the following three criteria:

- For chemical substances that do not have a natural origin, their mere presence in the water reflects the existence of a *slight* impact (cells with the term "Presence" in Tab. 2).
- In the case of arsenic (number 58 in Tab. 2), which unlike the above substances can have a natural origin, the threshold considered was 10 µg/l which is the maximum concentration recommended by the World Health Organization (after Baird, 1999).
- Concentrations assigned to the parameters fluoride, copper, total chromium, chromium VI, selenium and zinc to detect a *slight* impact have been established within the framework of this work.

Finally, the substances 64 and 65 (total phosphorus and biological oxygen demand respectively) were obtained from Annex VIII of the WFD and thresholds considered were taken from the guidance document on the analysis of pressures and impacts elaborated by the European Commission (European Commission, 2003).

Other Pollutants

Ammonium and phosphate (parameters 66 and 67 in Tab. 2) are not included in the definition of good chemical status for groundwaters, however they can be found in other parts of the WFD (section 2.4.2 of Annex V and Annex VIII of the WFD). Therefore, both ammonium and phosphate have been considered in the list of parameters used to assess the chemical status of groundwater bodies.

Their mere presence in groundwater has been interpreted as indicative of a *slight* impact since they rarely have a natural origin, whereas concentrations greater than 0.5 mg/l are indicative of an *important* impact (value established within the framework of this work).

CONCLUSIONS

This work presents a methodology for assessing the impacts on the chemical status of groundwater bodies. The proposed procedure has been developed on the basis of the environmental objectives of the WFD for groundwater bodies. Following this, criteria based on a series of physicochemical parameters and threshold values were established, arising from their respective environmental objectives, from which the existence of an impact has been determined. Finally, two possible classifications to define the impact on groundwater have been established in function of their magnitude, *slight* and *important*.

ACKNOWLEDGEMENTS

This work forms part of project CGL2008-04938 of DGICYT, the Research Group RNM-308 of the Andalusian Government and the associated unit IGME-GHUMA ''Unidad de Estudios Hidrogeológicos Avanzados''.

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1.8 | Economic tools to protect groundwater

abstract id: **353**

topic: **1**
Groundwater quality sustainability

1.8
Economic tools to protect groundwater

title: **The use of economic tools to protect groundwater in South Africa**

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keywords: groundwater, protection, value, economic, failure to protect

Protection of groundwater is one the more difficult activities to promote as it has no visible outcomes and will compete for the same human and financial resources as housing, roads and education projects with visible and almost immediate return on investment. Part of this problem is that municipal managers do not realize the value of the groundwater, know how to protect it or what the benefit would be if they do protect it. These questions must be addressed if we ever hope to have resources allocated for the protection of groundwater sources. Economic tools can be used to promote the value of groundwater and justify the cost of protection.

The value of groundwater is evaluated here as a natural and renewable resource by its role: (a) As human right contributing basic needs to improve security of life, health, and safety; (b) As a resource providing value through abstraction for domestic, agriculture, or industrial use and emergency preparedness; (c) As a contributor to surface water resources, used to generate economic value; (d) Contributing to the environment we live in through insitu value creating land stability, supporting terrestrial and aquatic ecosystems as well as cultural and recreational opportunities; (e) As carrier of contaminants to constitute a risk pathway.

The typhoid outbreak in Delmas, South Africa in 2005 can be regarded as an example of failure to protect a groundwater resource and is evaluated by comparing the costs associated with the incident and the cost to protect the groundwater source. Total economic cost due to the contaminated drinking water is estimated at R7 million, while the estimated cost to protect and manage the resource would have been about R3 million. The total economic benefit of protecting the resource was found to be significantly less than the total economic cost incurred due to the failure to protect.

1.9 | Sustainable management of groundwater

abstract id: **122**

topic: **1**
Groundwater quality sustainability

1.9
Sustainable management of groundwater

title: **Effect on the groundwater recharge and the springwater restoration by infiltration facilities**

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keywords: infiltration facility, groundwater recharge, springwater restoration, artifical recharge experiment

INTRODUCTION

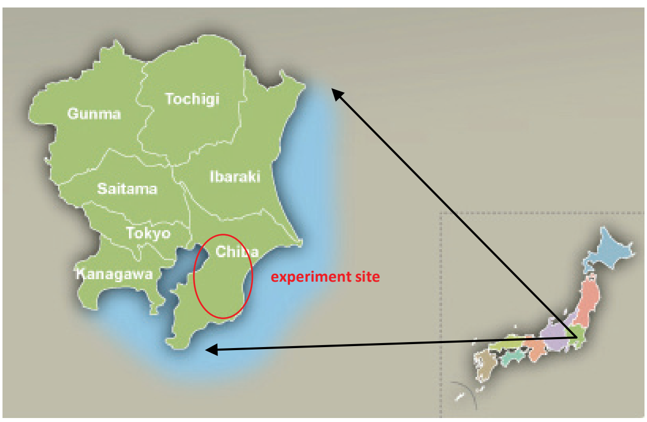
Increase of impermeable surface of roofs, road pavement, etc. with urbanization around catchment basins has been causing the decrease in the quantity of rainwater infiltrating to the ground. As the result, decrease in groundwater level, dryness of spring water and not only decrease of the ordinary flow but also increase of stormwater runoff in urban rivers has been occurring. Therefore, the national and local governments have been cooperating to take the action to install the rainwater infiltration facilities at any space in the basin.

It is well said that infiltration facilities have the effect on groundwater recharge, improvement of the base flow in the river and springwater restoration as well as the reduction of stormwater runoff. However, although there are several numerical simulation researches to learn the effects of infiltration facilities in Japan (for example Jia et al., 2000), proving data of those effects based on the observed data has been very limited. Especially, as for the effect on groundwater recharge, improvement of the base flow in the river, spring water restoration by the infiltration facilities installed in shallow depth, there are some difficulties to prove its effectiveness based on the observed data because the spread of the infiltration facilities doesn't catch up with urbanization in the huge basin area. Therefore, it is unclear how water from infiltration facilities installed in shallow depth infiltrates to aquifer layer and how much its effects in quantitatively.

As the result, it becomes an urgent ongoing problem to install the infiltration facilities in effectively with limited budget in government body. Therefore, here is an attempt to learn those effects by installing real size of infiltration facilities and a system for hydrological measurement system to estimate the effects of facilities, at the comparatively narrow catchment area for the existing spring water where located at urbanized area near the capital of Japan, Tokyo.

SELECTION OF EXPERIMENT SITE

It is very important how to select an experiment site to satisfy the purpose, such as condition of infiltration area (proportion of natural and residential area), installed place, recharge water, flow direction of groundwater etc. Since major purpose of the experiment is to confirm the amount of groundwater recharge and spring water restoration with infiltration facilities, the experimental site was selected under considering of the following viewpoints.



http://www.japan-i.jp/explorejapan/kanto/index.html

Figure 1. Location of experiment site.

- Natural area should be a little and residential area should be a large in the catchment area because it is difficult to know those effects if the natural area is large.
- Public facilities should exit at near spring so that the infiltration facilities are installed easily.
- Recharge water should be available at near experiment site.
- Existing well should be a lot at around experiment site so that the direction of the groundwater flow can be almost estimated widely by using the water level of the wells.
- There are no steep slopes just near the facility installed place because it can cause the instability of slope.

As the result, Minowa spring basin located at Ichikawa city in Chiba prefecture was selected as an experiment site (Fig.1). The Minowa spring was situated at residential district which was constructed as Minowa land readjustment project. The plateau is can be considered as recharging area for the Minowa spring and its width can be estimated as about 30,000m^2. The top of the stratum at the plateau is filled with a volcanic as called Kanto loam up to a depth of 5-6 meters from the surface. Under the Kanto loam area, a Narita sand layer of fine sand is laid. The hydraulic conductivity of Kanto loam layer and Narita sand layer is about 4.0×10^{-4} cm/s and 2.0×10^{-4} cm/s respectively.

Wakamiya elementary school which apart about 120m in horizontal distance form the Minowa spring is selected as experiment site to infiltration facilities (Fig.2). According to the estimation results of flow direction by groundwater levels of the surrounding existence wells, it can be confirmed that infiltrated water flow to the direction of Minowa spring.

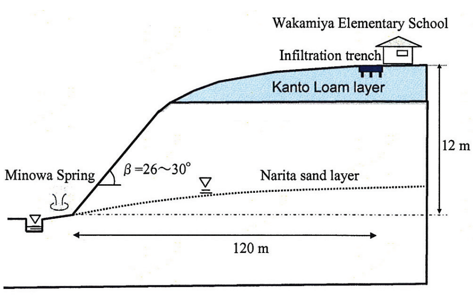


Figure 2. Positional relation of experiment site (Wakamiya elementary school) and Minowa spring.

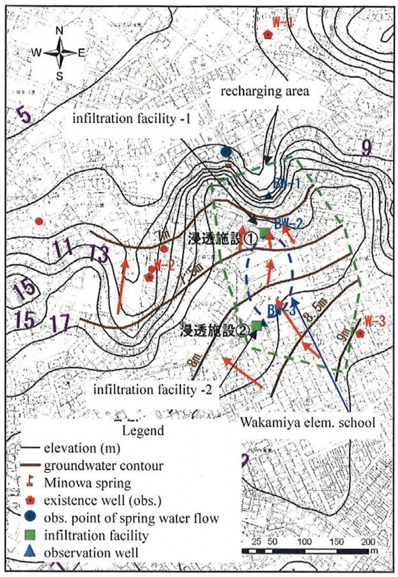


Figure 3. Topography and groundwater contour around Minowa spring

INFILTRATION FACILITIES AND MONITORING FACILITIES

The infiltration facilities which were installed at Wakamiya elementary school were the following two types.

Infiltration facility-1

The facility is composed by one trench (width 0.5 m, height 0.6 m, length 4.4 m) and three holes (15 cm in diameter and 1.0 m in depth) as shown in Figure 4. According to the calculation results by using proposed method of [Association for Rainwater Storage and Infiltration Technology] (Guideline for rainwater storage and infiltration technology — investigation and planning edition 2000), estimated infiltration capacity is about 2.0 m^3/hr.

Infiltration facility-2

The facility is composed by three holes (18 cm in diameter and 2.8 m in depth) and each hole is connected by porous pipe, as shown in Figure 5. Infiltration capacity is estimated to be about 0.77 m^3/hr.

Each facility was installed by using handed digger and small backhoe as shown in Photo 1 and Photo 2. Each facility was connected with roof drainage pipe as shown in Photo 3 and Photo 4.

At the experiment site, groundwater level, spring water flow rate and soil moisture are being measured and the monitoring facilities can be described as Table 1 and Photo 5.

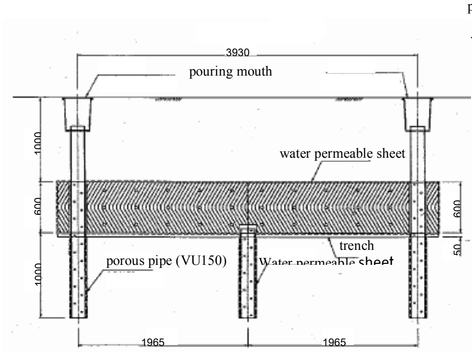


Figure 4. Structure of infiltration facility-1.

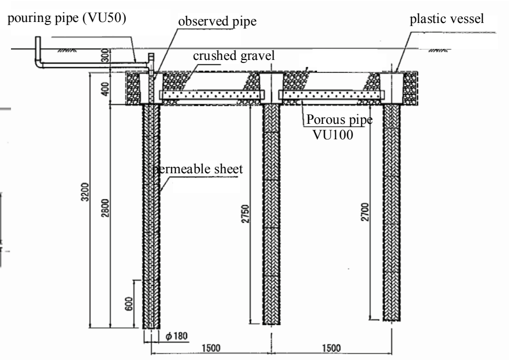


Figure 5. Structure of infiltration facility-2.

Photo 1. Installation work for facility-1.

Photo 2. Installation work for facility-2.

Photo 3. Connection of infiltration facility and cullis water pipe (facility-1).

Photo 4. Connection of infiltration facility and cullis water pipe (facility-2).

Table 1. Monitoring facilities.

Measurement item	Observation point	Location	Well type	Target of monitoring	Measuring method
water level	W-1	lowland part	existing well	groundwater behavior at lowland part	piezometer
	W-2	near at slope	existing well	to monitor instability of slope	piezometer
	W-3	plateau part	existing well	groundwater behavior at plateau part	piezometer
	BW-1	near at Minowa spring	newly setup	groundwater behavior at near of spring	piezometer
	BW-2	near at infiltration facility-1	newly setup	groundwater behavior at near of facility-1	piezometer
	BW-3	near at infiltration facility-2	newly setup	groundwater behavior at near of facility-2	piezometer
	infiltration facility-2	inside of infiltration facility-2	newly setup	amount of water storage inside facility	piezometer
spring water	Minowa spring	discharged channel	to know change of spring water flow rate		v-notch
soil moisture	SW-1（200cm）	near at infiltration facility-2	to know change of soil moisture		ADR
	SW-2（400cm）	near at infiltration facility-2			

Existing well (W-2) Newly setup well (BW-2) V-notch

Photo 5. Close view of some of monitoring facilities

Photo 5. Close view of some of monitoring facilities.

Since main target of this investigation was to know the quantity of groundwater recharge and spring water restoration, there were no investigation for the change in the chemical composition of ground- and spring water.

RECHARGING EXPERIMENT

Recharging experiment were carried out by artificial recharging and natural recharging (rainfall). Artificial recharging experiments were carried out four times as shown in Table 2. Here, the recharge water used in experiments was tunnel drainage water and tap water from Wakamiya Elementary School. Because of the experiments works were conducted at school premise, it was difficult to conduct longtime artificial recharge. Therefore, pouring water was stopped when it was confirmed that infiltrated water reach to groundwater surface and then groundwater level rose up.

Table 2. Detail conditions of artificial recharging experiment.

No.	Recharging facility	Recharge water (m^3)	Recharge method	Recharge period	Water source	Cullis (roof) water	Rise up of groundwater at nearest obs. well
1	facility-1	108	intermittent (day time)	5 days	tunnel drainage water	no	7 cm
2	facility-1	142	continuance (day&night)	5 days	tap water	no	8 cm
3	facility-2	170	continuance (day&night)	8 days	tap water	no	9 cm
4	facility-1 facility-2	252 103	continuance (day&night)	7 days	tap water	no	10 cm

Next, natural recharging is now being carried out during rainy season by investigation [how much groundwater level at near of facility rise up and how much amount of spring water increase during rainfall].

Results of experiment No. 2 and No. 3 are shown in Fig. 6 and Fig. 7 respectively. In the former case of experiment No. 2, groundwater level at the nearest point of BW-2 rose up 8cm during recharge period and those of rose up of groundwater level during experiment No. 3 at point BW-3 was 9 cm. Even though rainfall was occurred during experiment, the rise up of groundwater level has stayed in about 1cm at plateau part during rainfall, and so it can be considered that the influence of rainfall during recharge period is small and most of rise up of groundwater level is the effect of recharge water.

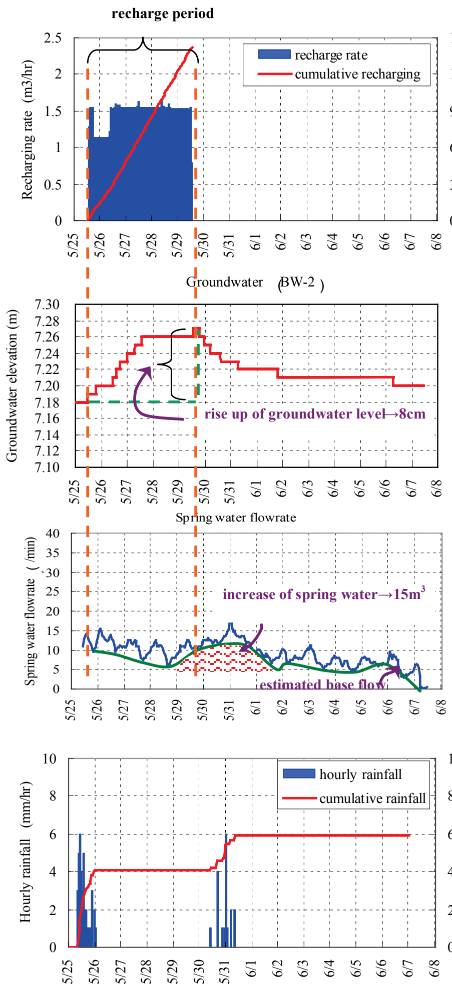


Figure 6. Results of artificial recharging experiment (experiment No.2).

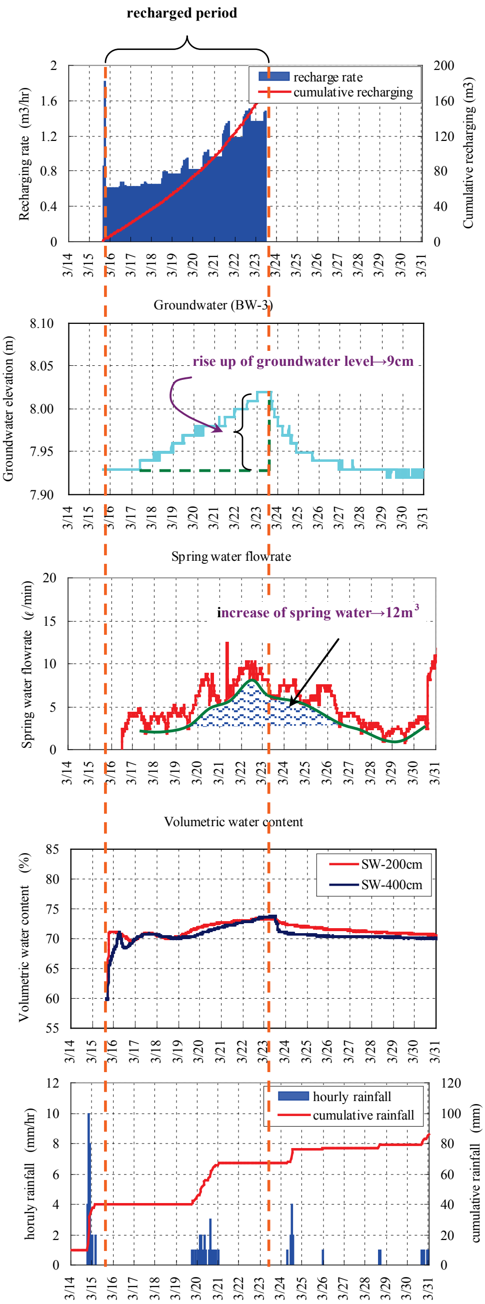


Figure 7. Results of artificial recharging experiment (experiment No.3).

Next, increase amount of spring water during recharge period were 12-15m^3 but it was difficult to estimate how much influence of rainfall was included.

To understand the mechanism of effect of recharge water, 2D and 3D of saturated and unsaturated infiltration analyses were carried out. Details of analyses will be omitted in this paper because of space. It will be introduced at another opportunity. Figure 8 to 10 show the simulation results of groundwater level and spring water during recharge period. It is difficult to get completely agreement between calculated and observed results but it can be evaluated as approximately agreement. That means, the effect of infiltration facility for groundwater recharge and spring water restoration can also be recognized by simulation results.

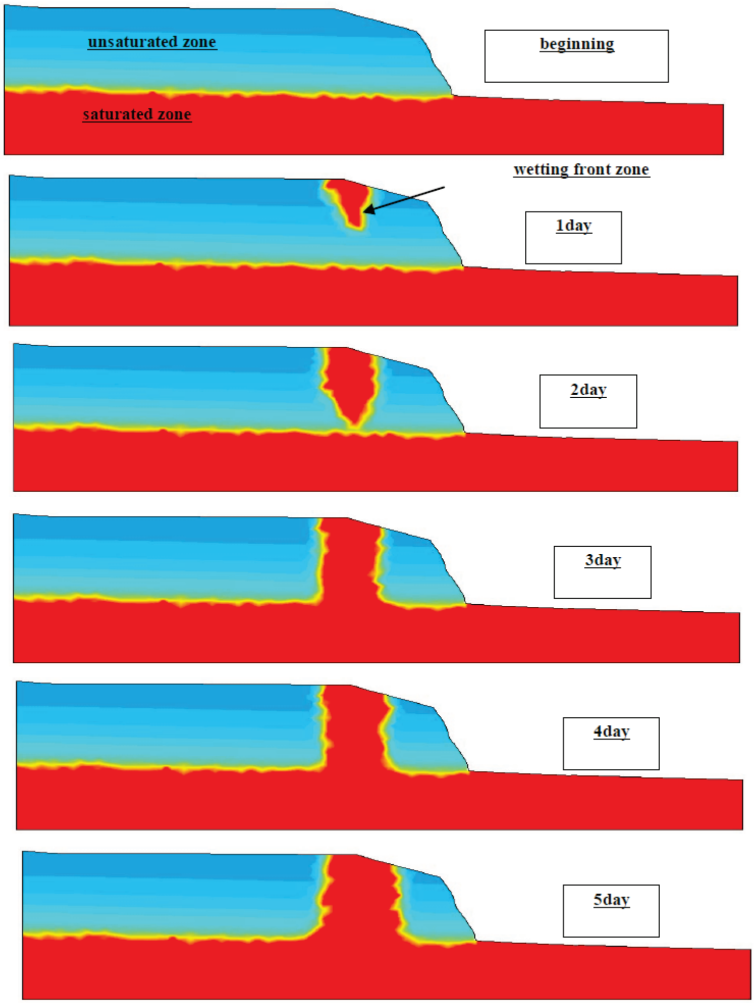


Figure 8. Seepage flow analyses.

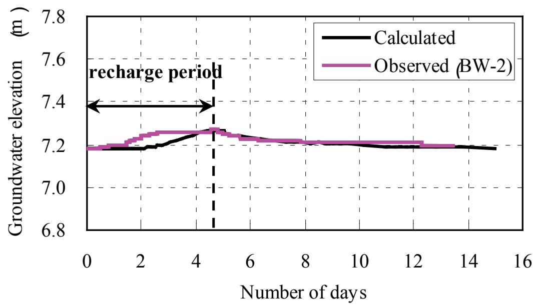


Figure 9. Simulation results (groundwater level).

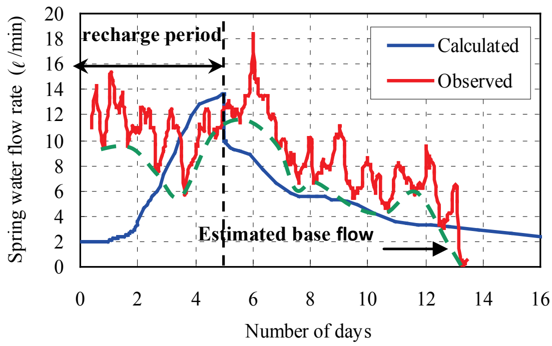


Figure 10. Simulation results (spring water).

CONCLUSIONS

According to analyzing the results of a series of artificial recharging experiment, it is clear that the effectiveness on the groundwater recharges and the spring water restoration by the infiltration facilities has been verified.

An effective infiltration pattern and the effective arrangement of infiltration facilities in the catchment basin should be considered in detail in order to decide the priority of the implementation in practice. For this study, the authors carried out 3D saturated and unsaturated infiltration analyses. The results will be introduced in the next opportunity.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the cooperation by Ichikawa City Chiba Prefecture on carrying out the experiment.

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abstract id: **194**

topic: **1**
Groundwater quality sustainability

1.9
Sustainable management of groundwater

title: **Sustainable source development and quality management in endemic fluoride affected area — case study from Southern India**

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keywords: fluoride, artificial recharge, rainwater harvesting

Presence of fluoride in groundwater poses a health hazard in many semi-arid tropical parts of the world which includes India also. Andhra Pradesh state in INDIA is one of the states which have more than 7000 habitations with excess fluoride in drinking water supply based on groundwater. Several defluoridation methods have been deployed but all these high technology based treatment ended up with several constraints like inavailability of chemicals, electricity, skilled man power and improper sludge disposal treatment.

In this paper the results pertaining to a simple and replicable approach of rainwater harvesting and artificial recharge for in-situ dilution of groundwater fluoride and sustainability over a small area of ~2sq.kms in Nalgonda District of A.P. was attempted for creating safe drinking water source for fluoride endemic villages. Through hydrological and geophysical integration, suitable artificial recharge strategies were adopted and the groundwater fluoride concentration of > 3.5 mg/l over the study area was brought down to < 1.5 mg/l which is appreciably within the WHO norms for drinking water standard. The sustainability both in terms of quantity and quality over the subsequent years are being monitored before initiation of water supply to the villages.

Site suitability and proper understanding of the subsurface through an integrated approach of near surface geophysics and hydrological investigations can enable in solving the problem of excess fluoride in drinking water supply over similar geomorphological terrain.

abstract id: **229**

topic: **1**
Groundwater quality sustainability

1.9
Sustainable management of groundwater

title: **Climate change and groundwater vulnerability in the Czech Republic**

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keywords: climate change, groundwater, Czech Republic

INTRODUCTION

In case of development according to climate change scenarios, the flow as well as baseflow characterising the groundwater discharge will decrease in future. The quantification of groundwater regime is therefore necessary for rational groundwater management. The aim of this paper is therefore to show the options for groundwater regime quantification by using examples of hydrological regime in Polická basin (Metuje River basin), which is area characterised by deep groundwater circulation, and in Divoká Orlice River basin upstream from Klášterec n. O. water gauging station, which was selected as an example of area characterised by relatively shallow groundwater circulation in the crystalline geological formations.

STUDY BASIN AND METHODS

Study basin

A hydrogeological study was focused on comparison of hydrogeological conditions in Policka basin and in Divoká Orlice River basin (Fig. 1). Polická basin is hydrogeologically closed Cretaceous formation. The system on an area of 240 km^2 is formed by 3 main aquifers. Depths of the cretaceous layers of the aquifers exceed 200 m. For these conditions, the calculation of water balance and its simulation are fully reliable. Its closing site is monitored by Hronov water gauging station located on the Metuje River. Its part, the Adršpašsko-Teplická formation is also hydrogeologically closed due the Skalský fault enclosing the hydrologic head of the aquifer. The streamflow is monitored by Teplice nad Metují water gauging station (M XII) located at its closing site.

Figure 1. Site Polická basin and Divoká Orlice River basin.

The area of Divoká Orlice River basin upstream from Klášterec n. O. is 155 km^2, which corresponds approximately to the area of the Metuje catchment in Polická basin, but it is formed by crystalline deposits and therefore its hydrogeological conditions are quite different. It is mostly mountainous catchment with high precipitation (annual precipitation exceeds 1100 mm while it is only 732 mm in Polická basin), which allows frequent replenishment of groundwater. The maximum groundwater storage is approximately from 40 to 50 10^6 m^3 but consequently to high slopes in relation to the erosion bases the available storage is about 10% of the maximum volume.

Bilan water balance model

Modelling changes in groundwater level was conducted using the hydrological model Bilan developed by T.G. Masaryk Water Research Institute, p.r.i. Input data of Bilan model include primarily time series of monthly precipitation, temperature and relative air humidity. The model simulates time series of monthly potential evapotranspiration, actual evapotranspiration, infiltration across the land surface and recharge from the soil to the aquifer. The output of the model includes monthly series of water storages in the snow pack, soil and aquifer. All these hydrological variables apply to the whole catchment. Furthermore, three runoff components, i.e. surface runoff, interflow and base flow (groundwater discharge) are calculated at the outlet of the catchment. The eight free parameters of the Bilan model are calibrated by minimising the differences between simulated and observed outflow from the basin.

RESULTS

Polická basin

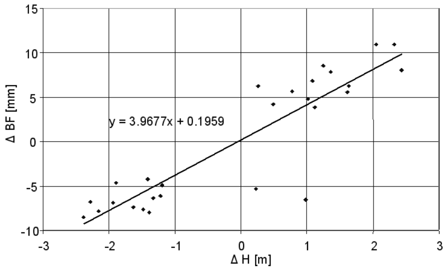
First, the simulated baseflow was compared with the baseflow determined by using the separation equation based on interrelationship between the flow regime and groundwater levels. The fit between the results was good and therefore the groundwater storage simulated by the model could be used in further steps. Interesting experience was that of the five boreholes used for derivation of separation equation, VS3 Adršpach borehole (situated in the formation above Skalský fault) produced the best results for both of the water gauging stations. For Teplice nad Metují water gauging station it is not surprising. But in the second case, the catchment above the Skalský fault represents only 30% of the basin of the Hronov water gauging station. It indicates that the borehole used for flow separation as an indicator of groundwater regime need not necessarily represent the real variability in groundwater levels.

The following step was focused on derivation of the relationship between the variability in the groundwater storage (groundwater flow) and changes in groundwater levels. For reliable derivation of real changes in groundwater levels, relatively uninterrupted data series from the period 1976 to 1990 were available from 8 boreholes for Teplice n. M. water gauging station (with the catchment of 89 km^2) and 10 boreholes for Hronov station (with the catchment of 240 km^2).

Mean values of changes in groundwater levels in the periods when groundwater storage changed substantially were used for derivation of the general relationship between the groundwater level and simulated water storage. The knowledge of hydrogeological areas of individual boreholes was insufficient for derivation of their weights for calculation of mean changes in groundwater level and therefore identical weights were used. The results showed that the relationship derived for data from VS3 borehole was most suitable for estimation of groundwater deficit (Figures 2). It is important with respect to the fact that the operational monitoring in the majority of other boreholes has been already finished.

The calculated results were compared with groundwater storage values (the groundwater storage over the erosion base level) derived for the basins by using a mathematical model, which was developed by Milický and Uhlík (2001). The groundwater storage values are 24 x 10^6 m^3 for the Teplice n. M. station and 79 10^6 m^3 for Hronov station.

a) derived at Teplice n. M



b) derived at Hronov

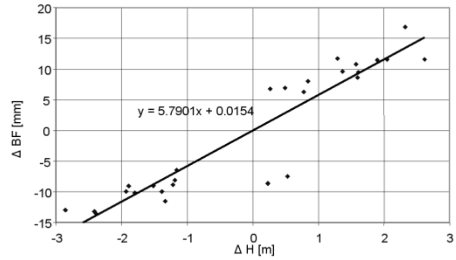


Figure 2. Relation between change in groundwater level in the VS 3 Adršpach borehole (Δ H) and change in groundwater storage (simulated baseflow) derived for the basin of the Metuje River at Teplice n. M (Δ BF) and at Hronov (Δ BF) , period 1974-1990.

For Teplice n. M. station the largest simulated decrease in groundwater storage in the evaluated period was 9.0 mm or 0.80 10^6 m^3. The relevant mean decrease in groundwater level ΔH is 2.21 m. Similar results were derived for Hronov station: 17.04 mm – 4.09 10^6 m^3, ΔH = 2.94 m.

It can therefore be concluded that the largest groundwater decrease in the observation period is small compared to the large groundwater storage in the Adršpašsko-Teplická formation. The maximum decrease was 3.3% of the storage for Teplice n. M. station and 5.2% of storage for Hronov station.

In addition to the observation period (1976–1990), the groundwater storage was also compared with its decrease in dry year 2004. The decrease in groundwater storage for Teplice n. M. station was 6.48 10^6 m^3, i.e. 27% of the whole storage, and 29.44 10^6 m^3, i.e. 37% of the storage for Hronov station. Figure 3 shows permanent decrease in groundwater level during the latest years. In 2004, the groundwater level was 2.26 m below that in 2002. It corresponds approximately to the annual groundwater flow (base flow) but on the other hand it represents only 5% of the whole storage. The situation is not therefore critical for the current conditions (the groundwater levels in 2005 exceeded by 15 their maxima in 2004). However, warning conditions would occur if the trends from the latest 3 to 5 years continue in future as suggested by climate change scenarios.

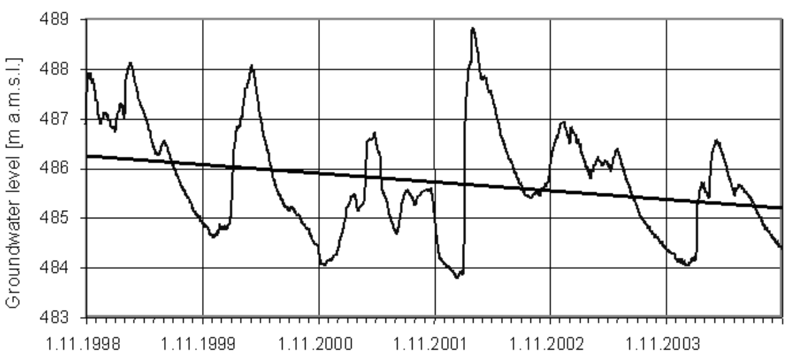


Figure 3. Trend in groundwater level in the VS 3 Adršpach borehole, period 1999-2004.

Divoka Orlice river basin

For the assessment of the natural storage capacity of the catchment we have derived relationships between decrease in the groundwater storage (simulated by the water balance model) and decrease in yields of three observed springs.

The maximum yields of mountainous springs are influenced by surface runoff and interflow, this effect was eliminated by using the method developed by Kille (Figure 4). The resulting spring yields permitted derivation of the relationship between the spring yields and decrease in groundwater storage, which was applicable in practice (Figure 5).

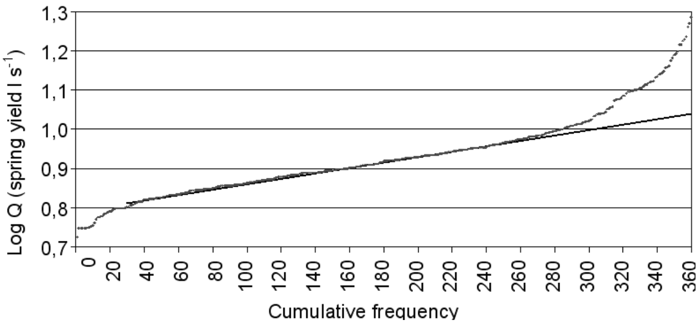


Figure 4. Separation of baseflow by using spring yield (Kille method), Klášterec n. O. water gauging station, spring no. PP0043, monthly values from the period 1971-2000.

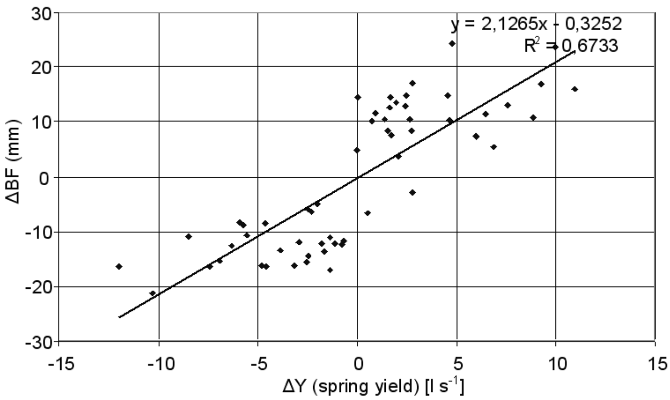


Figure 5. Relation between change in spring yield (spring no. PP0043) and change in groundwater storage (simulated baseflow) derived for the basin of the Divoká Orlice River at Klášterec n. O., period 1971-2000.

Maximum decrease in the groundwater storage in the period from 1971 to 2000 was 22 mm, which is 3.41 10^6 m^3.

The interesting fact is that for minimum groundwater storage the simulated flow was 0.42 m^3s^{-1} (2.7 l $s^{-1}km^{-2}$), which is consistent with values given in a report on Hydrological Conditions of the Czech Republic (Q_{355} = 0.44 m^3 s^{-1}). The mean groundwater flow simulated by the water balance model and also derived from the relationship with spring yield is 1.05 m^3s^{-1} (6.8 l s^{-1} km^{-2}), which is 33% of total runoff. These values are also consistent with long-term characteristics (CHMI, 1982).

A comparison of the maximum decrease in groundwater storage (3.41 10^6 m^3) and estimated available storage (from 4 to 5 10^6 m^3) shows that groundwater contribution to the flow is almost exhausted and the groundwater would not have any additional compensation effect in case of climate change.

Changes in regime of groundwater recharge and groundwater flow are predictable by using low flow tails of runoff hydrographs, whose initial parts are reduced relevantly to a decrease in groundwater level derived by the presented method.

CONCLUSION

The quantification of groundwater regime is indispensable for the purpose of groundwater management planning. In the present study we have determined the active storage of groundwater (the groundwater storage over the threshold of corresponding erosion base) for two pilot water gauging stations on the Metuje River, Teplice n. M. (89 km^2) station and Hronov (240 km^2) in Police Cretaceous basin (geologic formation characterised by deep circulation and high accumulation of groundwater), and for Klášterec n. O. (155 km^2) water gauging station situated on the Divoká Orlice River in the Orlické Mountains (crystalline geologic formation with shallow groundwater circulation). The groundwater storage was determined by the use of water balance model for the periods of decreasing flows, when the only component of the total runoff is baseflow. The results of the study showed that deficits in active storage of groundwater are acceptable even in extreme situations in the Cretaceous layers while in the mountain crystalline formations the groundwater storage can be fully exhausted. In addition, the decrease of groundwater storage would be considerable in both basins, if the recent trend in climate conditions continues as suggested by the climate change scenarios. The study included also derivation of relationships between changes in groundwater storage and changes in groundwater level in Cretaceous deposits of the Polická basin and between changes in groundwater storage and spring yields in the crystalline formations. It was shown that quantification of the groundwater regime should be included as a component of all water management schemes.

ACKNOWLEDGEMENTS

This paper was prepared from the results of the research project on Refining of current estimates of impacts of climate change in sectors of water management, agriculture and forestry and proposals of adaptation measures (project No. SP/1a6/108/07) sponsored by Ministry of the Environment of the Czech Republic.

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IAH 2010
Krakow

abstract id: **232**

topic: **1**
Groundwater quality sustainability

1.9
Sustainable management of groundwater

title: **Pollution of groundwater in shallow aquifers – a critical moment in Uganda**

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keywords: pollution, slums, contamination, groundwater, aquifer

INTRODUCTION

Ground water is the main and safest sources of drinking water and other domestic use for the people of Uganda. However water contamination within the densely populated lowlands (swamps) threatens the livelihood of the inhabitants.

About 60% of the inhabitants of Kampala reside in such areas with very little formal structure, therefore here people depend on polluted springs for drinking water.

Bwaise slum is one of such areas which we are going to look at in this paper. It has a very shallow water table some time up to the surface of the ground and not greater than 1.5 m.

In this area the pit latrine is the main technology used and no proper dumping of the solid waste garbage.

Bwaise is in perI-urban Kampala about 4km in the north, it fringes on the lowland of Lake Victoria with a population density of about 27000 people per square kilometer.

This situation leads to the contamination of the water in the area posing serious threats epidemics of water borne diseases lie chorale diarrhea which has led to lose of life.

Due to pit latrine, solid waste management and sullage dumps, the animal yards and car washing bays and garage the studies put the concentration of coli form at 1-16 × 10^7 cfu/1000 ml, nitrate at 0.10-779 mg/l and phosphorous at 0.001-13 mg/l.

Of all these the main pollutant is pit latrine.

However the bedrock is about 30m below the clay containing clean water in the fracture network. The problem is the technology and fund to be able to extract this clean water for the community to use.

The problem of contaminating the ground water has been helped by the following reasons:

Over population the

The population density as already stated is 27000 people per square kilometer which is one of the highest in the country. Typical of the peri-urban development in low land (swamps) with the water table just on the surface of the ground. The inhabitants mainly use on site septic tanks and pit latrine coupled with damping the solid waste in the area. This means that the waste products get direct contact with the ground water which is the source of drinking water in the area for more than 90% of the inhabitants.

Ignorance

Most of the inhabitants of the area are semi or illiterate therefore have no access to information, so many are not aware of the dangers of poor sanitation in the areas.

Being illiterate means that the written literature is useless to them. And further still attending sensitization programmes might be very difficulty as some are always busy with work and even believe that these are for literate community members. Well as such programmes could help to inform them on the dangers of consuming untreated and contaminated water.

Poverty

The inhabitant of the place are poor people living in congestion, therefore cannot afford appropriate sanitation facilities such as flash toilet which would suit the areas with high aquifers. Some cannot even afford the pit latrine and have no space for it. These therefore resort to flying toilets (defecating in a polythene bag and through it away at night). This means littering the whole areas with feacal materials as each home is throwing to the other.

Luck appropriate technology

The residence luck the appropriate technology applicable in order to protect shallow aquifers when designing water and sanitation schemes in the area. Having access to only pit latrine technology does not help the situation when the best technology would have been either ecosan or flash toilet for a swampy area.

Culture

As such areas attract too many low income earners, therefore bringing in people of all walks. Hence collecting different cultures which have many negative attitudes towards good water sanitation behaviours.

Some cultures believe that pregnant women must not use pit latrine and others know that feaces from babies have no harm. Others believe in drinking water without a simple treatment such as boiling.

Government policy

The government's failure to dully plan for peri-urban areas mainly in swamps. And to make matters worse its corrupt official fail to implement the laws so that these areas are developed according to plan. By law the wet lands are supposed to be preserved as filters for the contaminated water before getting to Lake Victoria.

However many government officials turn a blind eye to these development which has lead to a number of catastrophes such as floods further more contaminating the ground water, leading to diseases like cholera.

Land Tenure system

The land ownership in the country also does a lot to promote these problems as it encourages the unrealistic development of the area. This is because in some instance the land is owned by two people the land lord and the scoter if there is a disagreement the development is of area is affected.

The economic activities

Some of the economic activities in the area pollutes the ground water such as oil from garages, detergent from the washing bays and waste products from brewing. Given that these activities are not using advanced equipment they end up leaving the waste products to go to the streams or bear ground which contaminate the ground water. And they actually take no trouble to have remedies to the problem and the government supervision is not sufficient.

Negligence

Some people are just negligent in that they have been sensitized on the water and sanitation good practices. And they are fully aware of dangers of using polluted ground water. However they end up doing the same. They even fail to pass on the information to the neighbors because of the I don't care attitude.

Alcoholism and drug abuse

Given the nature of the inhabitants, there is a lot of alcoholism and drug abuse, turning the people into nuisance hence defecating and urinating any where. They dump the waste materials in wrong spots which contaminate the water.

However the situation can be saved so that this contaminated water can be rendered usefull for consumption in the area for the inhabitants. The following must be addressed properly in order to mitigate situation.

Flexibility of the design

A flexible design which is appropriate and can be adopted by the community should be thought. It must be easy for the local technicians to construct and must be affordable to most of the inhabitants so as to solve this problem effectively. In this case an ecosan toilet technology is best for this situation if the users are sensitized to appreciate its application and advantages.

Insitutional and funding options

The funding of the water and sanitation schemes should be made relevant to the prevention of polluting the ground water in the area. Funding should be made adequate for both the hardware and software in order to solve the problem of operation and maintenance of these facilities to be done by the community or end users.

Participatory implementation

All the stake holders must be involved in all stages of the planning for a water and sanitation scheme, so as to listen their views as they could be very useful in solving the problems as they are aware of the background of the area, therefore could provide very useful information in the design of the scheme.

Social Cultural dimension

The people in the area should forge a common way of behavior to suit the area they are living in concerning the water and sanitation attitudes. For example irrespective of their different cultures they must adopt those which suit shallow aquifers in order to stay in this are healthy.

Sufficient hygiene education and Health aspect must be addressed

The community members should be sensitized about the dangers of unhygienic behavior which lead to the contamination of the ground water in their community. They must be informed the effect of contaminating the drinking water to their healthy and the diseases which attack them and some times kill some of them.

Environment concern

The environment degradation behaviour and the effect of the people activities in the area to the climates should be addressed. The community members should appreciate their contribution to the problems which affect them in their daily life. And also teach them how to mitigate.

Land requirement

An appropriate land laws and policies which would avoid double ownership so as to give confidence to who ever is on the land to fully develop it without fear for the good of the area. This will help to curb the pollution of the ground water problems caused by land ownership in the country.

CONCLUSION

Pollution of ground water in Ugandan is at critical moments due to population explosion as many people are settling in swamps which are low land with high aquifers.

Unless all the stakeholders come on board shallow aquifers in Ugandan will be polluted because there is no filter, hence multiplying the problem to all water sources e.g lake Victoria.

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abstract id: **256**

topic: **1**
Groundwater quality sustainability

1.9
Sustainable management of groundwater

title: **Sustainability of river bank filtration**

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keywords: river, bank, filtration, sustainability, clogging

INTRODUCTION

River bank filtration (RBF) is a process during which surface water is subjected to subsurface flow prior to extraction from vertical or horizontal wells. The raw water discharged from the production well consists of a mixture of infiltrated river water and groundwater recharged on the landside catchment. From a water resources perspective, RBF is normally characterised by an improvement in water quality (Kuehn, Mueller, 2000). Therefore, RBF is a well-proven treatment step, which at numerous sites is part of a multi-barrier approach to drinking water supply. Grischek et al. (2002) report about the extensive application of RBF along the European rivers Danube, Rhine, and Elbe. In the United States, RBF is receiving increased attention especially with regard to the removal of parasites and the prevention of disinfection by-product precursors (Ray et al., 2002; Tufenkji et al., 2002).

RBF in Germany provides about 8% of drinking water supplies. The city of Duesseldorf, situated on the River Rhine, is entirely supplied with drinking water from RBF. In the Rhine basin, more than 20 million inhabitants receive drinking water which is directly or indirectly derived from river water, mostly via bank filtration. In the city of Dresden public water supply on average relies on up to approximately 32% bank filtrate and 66% surface water from reservoirs.

HISTORY OF RIVER BANK FILTRATION IN DUESSELDORF AND DRESDEN

In the summer of 1866, there were 57 cases of cholera in the urban area of Duesseldorf. About half of those who contracted the disease died. This forced the town council to adopt a resolution to construct and operate a waterworks. The English engineer William Lindley was called in to provide expert advice on the choice of location and planning of the technical equipment. The first well field at Flehe of Duesseldorf, on the banks of the River Rhine, was put in operation for the first time on May 1, 1870 and has been continuously used since then till the present day. Up to that point in time, the population had obtained water from rainwater storage tanks, as well as from open and pumped wells. In the following years, the increasing water demand had to be met. Driven by the increasing population and the industrial water demand, the extension of the water supply was the main task. In the period between 1948 and 1956, the water requirement almost doubled. While the increasing demand could be met by the continuous development of well fields, the simultaneous decrease of the river water quality posed an additional challenge (Eckert, Irmscher, 2006).

In Dresden, there exist three RBF waterworks. The first waterworks, the Dresden-Saloppe Waterworks was built between 1871 and 1875 on the bank of the River Elbe. Drain pipes were installed near the river bank to abstract raw water. Due to geological boundary conditions, more than 90% of the abstracted water is bank filtrate. Today, the waterworks is still in operation and produces up to 12,000 m^3/d for industrial water supply.

Increasing water demand at the end of the 1880s exceeded the capacity of the Dresden-Saloppe Waterworks. In 1891, the city council assigned the building officer, Bernhard Salbach, to write an expert's report on the future water supply of the city. Salbach proposed building a test well on the left bank of the river, which abstracted 4,000 m^3/d in 1891. Four more wells were completed in 1893 resulting in a total water abstraction from the left bank of 20,000 m^3/d. Wells were connected using a siphon pipe and a collector well. Between 1896 and 1898, the second waterworks, the Dresden-Tolkewitz Waterworks, was constructed. A further rise in water demand resulted in the construction of four more wells and a second siphon pipe in 1901 to raise the capacity to 40,000 m^3/d. In the 20th century, the number of wells was again increased and the water treatment facilities improved. Between 1919 and 1928 a third siphon pipe with 39 wells was built. A significant decrease in the water demand after the reunification of Germany in 1989 allowed for the closure of the well fields in April 1992 in order to plan a general reconstruction of the waterworks. After intensive construction works, the Dresden-Tolkewitz Waterworks and the well fields were put into operation again in February 2000. The maximum capacity is now 35,000 m^3/d.

RIVER WATER QUALITY

During the first 80 years (1870–1950), the quality of the river water in Germany permitted the production of drinking water without further treatment; the well water had only to be disinfected. After 1950, the quality of the river water began to deteriorate gradually. Increasing quantities and insufficient treatment of effluents from industry and communities caused a noticeable drop in the oxygen concentration of the river water. The consequence of this and the increasing organic load in the river water changed the redox situation in the adjacent aquifer from the prior aerobic to anoxic conditions. It became necessary to treat the pumped raw water to remove iron, manganese and ammonium in addition to organic micro-pollutants. At many sites, subsequent technologies such as ozone treatment, biological filtration or granular activated carbon (GAC) adsorption were established. Increased contamination of surface waters with persistent organic compounds threatened the use of bank filtrate for drinking water purposes.

Furthermore, spectacular industrial spills underlined the need for sanitation measures and pollution control. On November 1, 1986, a fire broke out in an agrochemical storage facility of a chemical plant in Basel, Switzerland. Insecticides, herbicides and fungicides were carried into the adjoining River Rhine with the fire-fighting water. The effects on the river were serious. On the stretch of the Rhine up to the Middle Rhine region, the entire stock of eel was destroyed. Other species of fish were also affected and damaging effects were detected on fish food organisms up to the mouth of the river Mosel. The question then arose, whether such a wave of poison could simultaneously contaminate the water source in the adjacent aquifer. This accident has given fresh impetus to the improvement of pollution control on the Rhine and was the reason for projects aimed at understanding and managing the effects of accidental shock loads on RBF plants (Sontheimer, 1991).

In the Rhine valley, the water pollution was caused by rapidly growing industrial activities and increasing density of urban settlements after World War II (Friege, 2001). In the 1950s and 1960s, sewage systems in the destroyed cities had been built prior to waste water purification plants leading to increasing pollution of the rivers. The oxygen concentration in the river Rhine decreased continuously until the beginning of the 1970s. A low point was marked by an enormous death rate of fishes in 1969, caused by the insecticide Endosulfan accidentally released by the chemical industry and resulting oxygen concentration of less than 4 mg/L (Friege, 2001). Despite the low river water quality in the middle of the last century, drinking water supply based on RBF remained possible. The attenuation processes during RBF made a significant contribution to ensuring safe drinking water production. After pollution control and sanitation measures were undertaken, oxygen concentrations reached saturation at the beginning of the

1990s. The higher oxidation capacity together with a lower oxygen demand in the infiltrating river water led to more efficient natural attenuation processes within the aquifer. This enabled the waterworks to reduce their treatment expenses.

A similar situation has to be reported for the River Elbe. The industries along the Upper Elbe River valley previously discharged a wide range of organic contaminants into the river. Hence, together with urban sewage, the dissolved organic carbon (DOC) comprises a complex mixture of easily degradable and refractory substances. In addition to the industrial effluents, paper mills, cellulose processing plants and the pharmaceutical industry played an important role in the 1980`s. From 1988 to 1990 the average DOC concentration on the left bank of the River Elbe at Dresden-Tolkewitz was 24 mg/L and the UV-absorbance at a wavelength of 254 nm was 55 m^{-1}. Along a flow path length of approximately 100 m at a cross-section at Dresden-Tolkewitz, the DOC concentration was reduced to about 20% of the input concentration (Nestler et al., 1991). Problems with bank filtrate quality occurred due to the high load of organic pollutants, foul taste and odour, and the formation of disinfection by-products. Results from 17 measurements in 1991/92 at a cross section at Dresden-Tolkewitz showed a mean DOC concentration of 6.9 mg/L in River Elbe water and 3.4 mg/L at an observation well near a production well. From that, a reduction of DOC concentration of about 50% can be seen as an effect of RBF processes. Investigations in 2003 at the same cross section included 7 samples. In 2003 the mean DOC concentration in River Elbe water was 5.6 mg/L and 3.2 mg/L in bank filtrate at the same observation well sampled in 1991/92. The mean DOC concentration in raw water from all wells was found to be 2.6 mg/L as a result of mixing with groundwater. These results show that the period of strong pollution of Elbe river water did not limit the further use of the Dresden-Tolkewitz site.

CLOGGING OF RIVER BEDS

A very important aspect of the sustainability of river bank filtration is the effect of particulate organic matter which can intensify clogging of the riverbed and significantly reduce the well yield. The proportion, and thus volume, of pumped bank filtrate strongly depends on riverbed clogging. Clogging is the formation of a layer on top of or within the riverbed which has a lower hydraulic conductivity and reduces the flow rate of the filtrate through the riverbed. It is the result of the infiltration and accumulation of both organic and inorganic suspended solids, precipitation of carbonates, iron- and manganese-(hydr)oxides and biological processes. Erosive conditions in the river and floods limit the formation of a clogging layer by disturbing the riverbed via increased flow velocity and shear stress. The permeability of clogged areas varies with the flow dynamics of the river. There are not only variations in the pressure head between the river and the aquifer but also remarkable variations in the concentration of suspended solids in the river water. The concentration of suspended solids in the River Rhine varies from 10 to more than 400 mg/L with an average concentration of less than 40 mg/L. Highest values appear in periods of rising water levels following storm events. Due to difficulties in determining the thickness of the clogging layer, the term leakage coefficient (L) is introduced, which is defined as hydraulic conductivity of the clogging layer in metres per second divided by the thickness of the clogging layer in metres. Under specific conditions, the leakage coefficient can be calculated for RBF sites using water levels in the river and two observation wells positioned between the river and the production borehole using an analytical solution. Otherwise it has to be determined by calibration procedures in groundwater flow modelling. Based on water levels and known pumping rates, the leakage coefficients of the River Rhine and the River Elbe at Duesseldorf and Dresden, respectively, have previously been determined for different river stages and measuring campaigns and compared with former data.

A first field study of the riverbed adjacent to the Flehe Waterworks was done in 1953 and 1954 with a diving cabin. In 1987, a second study of the riverbed at the Flehe Waterworks was carried out. This investigation revealed a zone of almost 80 m which had a fixed ground and was entirely clogged by suspended sediments (Schubert, 2002). The expansion of the clogged area is limited especially by bed load transport in the river. In regions with sufficient shear force, the deposits are whirled up and removed. The zones at the Flehe site are characterised by a different permeability. The infiltration occurs mainly in the middle of the river.

At Dresden-Tolkewitz, a significant decrease in groundwater levels was observed between 1914 and 1930 and attributed to riverbed clogging by suspended materials caused by increased infiltration rates since 1901. In the 1980s strong river water pollution caused by organics from pulp and paper mills in conjunction with high water abstraction led to unsaturated conditions beneath the riverbed, especially at the Dresden-Tolkewitz Waterworks. However, investigations of riverbeds using a dive-chamber showed that the material responsible for the pore clogging in the gravel bed consisted of up to 90 % inorganic materials (Heeger, 1987). Heeger calculated a leakage coefficient of about 1×10^{-4} s^{-1} for the riverbed without bank filtration and a mean value of 5×10^{-7} s^{-1} at RBF sites in and around Dresden. After improvement of river water quality from 1989 to 1993, the hydraulic conductivity of the riverbed increased. In 2003, groundwater flow modelling was used to test former assumptions about groundwater flow towards the production wells and clogging of the riverbed. From model calibration, a reliable leakage coefficient of 1×10^{-5} s^{-1} was determined.

Looking at the long-term operation of the waterworks, it is clear that the observed clogging of the riverbed did not result in the closure of wells under the existing erosive conditions in the river. After a period of additional organic pollution and observed slime on the riverbed surface (assumed to act as an organic outer clogging layer) there is a marked recovery of hydraulic conductivity in the riverbed.

CONCLUSIONS

Two examples from Germany — from the Lower Rhine region and the Upper Elbe River — have been presented where river bank filtration has been employed for more than 130 years. During this time the RBF systems were able to overcome extreme conditions with respect to poor river water quality, and to withstand spills in the rivers. Drain pipes at the Dresden-Saloppe Waterworks have been in operation for more than 130 years whilst four production wells at the Dresden-Tolkewitz Waterworks had to be replaced only after 60 years. In Dresden, severe clogging of the riverbed occurred in the 1980s mainly due to high loads of organics from pulp and paper mills upstream. Following improvement of river water quality in the 1990s, no problems with riverbed clogging or foul taste and odour have been encountered.

Field studies are part of ongoing efforts to establish the risks of river bank filtration and to obtain knowledge of the best practice for sustainable operation of bank filtration plants. Raw water quality and treatment are optimised by managing specific mixing ratios of bank filtrate and land-side groundwater. Pumping rates can be reduced to get longer retention times in the aquifer and higher attenuation rates of organic compounds. No indication of a decrease in attenuation capacity of the aquifer over time was observed. Long-term experiences and results of the evaluation of historic and recent data and of investigations using modern modelling tools strongly indicate that RBF is a sustainable water resource for water supply in Germany.

The authors see enormous potential for wider use of RBF worldwide, especially given that the removal of microbial pathogens from surface water through RBF would be a crucial factor (Ray, 2008; Sandhu et al., 2010). Thus, it could serve as a preferable alternative to direct river water abstraction. At a minimum, bank filtration acts as a pre-treatment step in drinking water production. In some instances, it can serve as the final treatment just before disinfection. Good quality drinking water is not only a long-term benefit of RBF, but also leads to reduced medical costs and improved productivity for the consumer. Bank filtration also serves as an asset to water suppliers by way of capital cost reduction through lower maintenance, improved reliability of source water and enhanced community supply by lowering the total dissolved solids concentration. Nevertheless, the application and adaptation of RBF is very much site-specific and demands careful investigations into hydrological, hydrogeological, hydrochemical and hydrobiological conditions, especially clogging of river or lake beds and redox reactions in the aquifer.

ACKNOWLEDGEMENTS

The authors are grateful to the German Federal Ministry for Education and Research (BMBF, IND 08/156) and the Ministry for Science and Art, Saxony (grant no. 475316002512007) for funding RBF research projects.

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abstract id: **261**

topic: **1**
Groundwater quality sustainability

1.9
Sustainable management of groundwater

title: **Use of detention storage and managed aquifer recharge to buffer water quality variability for drinking supplies**

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keywords: water quality, attenuation, dispersion, contaminants, pathogens

Bank filtration has long been valued for water quality improvement and buffering of stream water quality changes that occurs in the aquifer between the stream and the water recovery well. The aquifer also plays a valuable role in producing drinking water supplies for a range of other managed aquifer recharge methods where source water is highly variable in quantity and quality, such as urban stormwater. In such systems some form of stormwater detention is required to allow time for recharge which occurs at a much slower rate than the rate of urban runoff during storm events. This detention storage also has the effect of mitigating some of the variability in quality, and in parallel with diffusive processes in aquifers can lead to a significant reduction in peak and mean concentrations of contaminants. The capability to monitor water in transit through the system can verify whether these "natural" treatment systems are effective and that residual risks are acceptable. Although aquifers are traditionally valued for their storage capabilities, it will become increasingly obvious in urban areas that both their treatment potential and their buffering capacity will be essential to establishing non-traditional water supplies. Public confidence with recycled water supplies also correlates closely with the natural processes that aquifers endow. These factors should create demand for better characterisation of urban aquifers to sustain water supplies in places where climate is drying and/or population is growing. This paper draws on several Australian case studies to illustrate these concepts and even puts a value on these treatment processes by comparing them with alternative engineered treatments that have the same effect.

abstract id: **277**

topic: **1**
Groundwater quality sustainability

1.9
Sustainable management of groundwater

title: **Quality and quantity status and risk assessment of groundwater bodies in karst areas of Croatia**

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keywords: karst aquifers, groundwater body (GWB), groundwater quality and quantity, Water Framework Directive (WFD), Croatia

INTRODUCTION

Karst aquifers developed in south-western and southern part of Croatia occupy an area of approximately 26,750 km^2 of the total national territory (Figure 1). They are built mostly from karstified carbonate rocks that belong to the macro-structural unit "*Dinarides*" which extends along the northwest–southeast direction, from Slovenia through Croatia and Bosnia and Herzegovina to Montenegro. Karst aquifers in Croatia represent almost the half of total available amount of water in the country. For karst areas and economically developed coastal area these aquifers are the only sources of drinking water. One part of the Croatian karst areas belongs to the Adriatic Sea catchment, and other part to the Black Sea catchment.

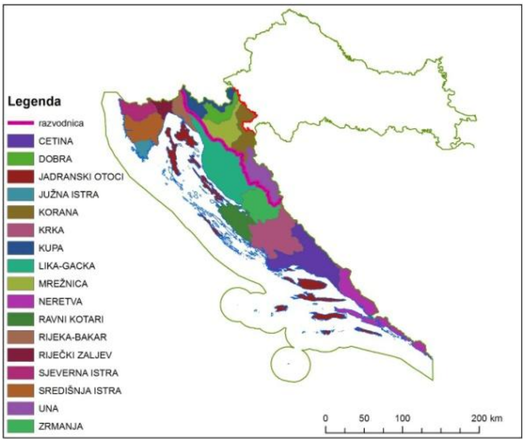

Figure 1. Groundwater bodies in Croatian karst area.

Basic characteristics of Dinaric karst aquifers are specific surface and subterranean relief, large catchments rich in precipitation (up to 4000 mm per year), low retentive capacity of karstified underground, rapid subsurface flows, periodic flooding of karst fields, appearances of large karst springs, multiple discharges and sinking of waters within the same catchment, long periods of drought, lack of covering layers and significant sea influence in coastal aquifers. All this facts makes karst aquifers naturally highly vulnerable that requires special protection measures if we want to preserve the quality and quantity of water in them. Only 2% of the total groundwater reserves are used for water supply of karst areas and almost 25% of the total reserves is accumulated in a numerous of surface accumulations and used for hydro power plants. Due to the complex needs of groundwater characterization according to European Water Framework Directive (hereinafter WFD), in Croatian karst area has been delineated 17 groundwater bodies (hereinafter GWB): 12 in Adriatic, and 5 in Black Sea catchment area. For purely practical reasons Adriatic islands are included and observed as one GWB, although each island functions as a separate unit. A large number of karst catchments in Croatia extend into neighbouring Slovenia and Bosnia and Herzegovina (hereinafter B&H), which open the need for joint research and management of transboundary water bodies. Towards the Croatian south, the number of transboundary GWB units is increasing, so in the most southern part of Croatia there are practically placed only discharges zones, while the most of catchments areas are in B&H.

An assessment of quantitative and qualitative status of GWBs is conducted during the characterization of GWBs according to WFD (WFD, 2000).

CHARACTERISATION OF GROUNDWATER BODIES

Impact and pressure and risk analysis were performed using a European approach described by COST project 620 (EU COST 620, 2004), which consists of three phases: analysis of natural vulnerability, hazard analysis and risk analysis.

Analysis of natural vulnerability of aquifers is based on geological structure, estimation of karstification degree, slope of terrains and quantity of rainfalls. This analysis separates areas with different levels of natural vulnerability. The final result is *Vulnerability map*, which is extremely useful in determining the sanitary protection zones of water supply sources.

Hazard analysis includes the development of databases for point and diffuses (agriculture) pollutants. The final result is *Classified maps of hazards*, which shows the location and weighted values of each pollutant. Special attention is paid to the impact of agricultural activities, because the chemical analyses of water in some regions have shown significant impact of agriculture on groundwater resources. *Risk map* is achieved by overlapping of Vulnerability and Classified hazard maps.

Qualitative status assessment (hereinafter QUAL) has performed individually for each GWB, according to chemical analysis of waters from 55 karst springs that are included in the *National monitoring network*, and according to detailed analysis of individual water supply springs in period 2000–2007.

For QUAL were used following basic parameters (WFD, 2000): dissolved oxygen, pH, electrical conductivity (hereinafter EC), nitrates and ammonia, and additional groundwater parameters such as free CO_2, water temperature (hereinafter T), orthophosphate, turbidity, Fe, Mn, mineral oils, As, Cd, Pb, Hg, chlorides, sulphates, trichloroethylene and tetrachloroethylene. Specific characteristics of karst aquifers in Croatia and elsewhere in the world are high groundwater velocities, relatively short residence time of groundwater and rapid hydrology and water quality changes in short time intervals. It is interesting to note that exceptional quality of water on karst springs is often during the long summer dry periods. This indicates the great and importance role of epikarst and unsaturated zone of karst aquifer, which prevent infiltration of contamination in the saturated parts of karst aquifer. Heavy rainfall after a long dry period causing strong and relatively short-term pollution of waters on karst springs. During these events several water quality parameters exceed the maximum allowed concentrations values (hereinafter MAC). Another major problem, especially of coastal karst aquifers, are occasional sea water intrusions deep into the coastal aquifers during the summer dry periods and water supply exploitations of these aquifers in terms of labile fresh water–salt water relationships. Illustrative parameters for QUAL of karst groundwater in Croatia are nitrates. In the central part of Croatian karst area (mountainous area) values of nitrate are of very low values and have constant uniform trend. Due to that, it is an indicator of humanly untouched GWB that is characteristic for sparsely populated Dinaric mountainous area. On the other hand, in Dinaric border areas, on Istrian Peninsula, the situation is much different. Although the nitrate values are in most cases still within MAC (on average 46.35 mg/L NO_3^-), they are yet very close to this limit. The reason for this is a much stronger agricultural activities on Istrian Peninsula. MAC of pH for drinking water is in range 6.5 to 9.5. Within this range are all analysis used during the characterization of GWBs, but in border parts of mountainous Dinaric area trends of pH show considerably decreasing values. Such trend is commonly associated with microbiological and chemical processes in natural systems as a result of pollution. But, in the case of Istria and Ravni Kotari regions it can also be partly an indicator of regional contaminant transport of acid rain from industrialized northern Italy.

The major problem of coastal and island karst aquifers in Croatia is also periodical or permanent sea influence on freshwater systems. During the first half of the 20th century for water supply needs numerous water springs were captured in coastal area and on islands, and in that time this water quantities were adequate for local population needs.

However, population growth and tourism development have caused increased demand for drinking water and existing water supply springs have become increasingly exploited. Increased fresh water exploitation has caused gradual increasing of salinity on these springs, and nowadays many of them are already out of service. This problem is especially significant on the islands where fresh water gradually disappears and today only three large islands (Cres, Krk, Vis) have their own fresh water resources. Water supply on other island is either associated with mainland water supply systems with undersea water pipelines, or islands have small devices for desalination of salted water or only water tanks. Increased fresh water exploitation is also the reason of increasing EC trend in coastal area and on islands.

QUAL analyses of karst groundwater in Croatia showed two GWB that have significant water quality problems in accordance with established criteria of EU WFD. Those are GWB "*South Istria*" and GWB "*Ravni Kotari*" (Figure 3 — left). GWB "*South Istria*" has problem with nitrates and chlorides that are increased during a summer dry periods, due to uncontrolled exploitation of water for agriculture purposes (Biondić et al., 2009). GWB "*Ravni Kotari*" has the biggest problem with sea water intrusions deep into the land that cause higher chloride concentrations on water supply wells. Fresh water resources on the Adriatic islands are also influenced by sea water, and because of that their QUAL status is "*potentially bad status*".

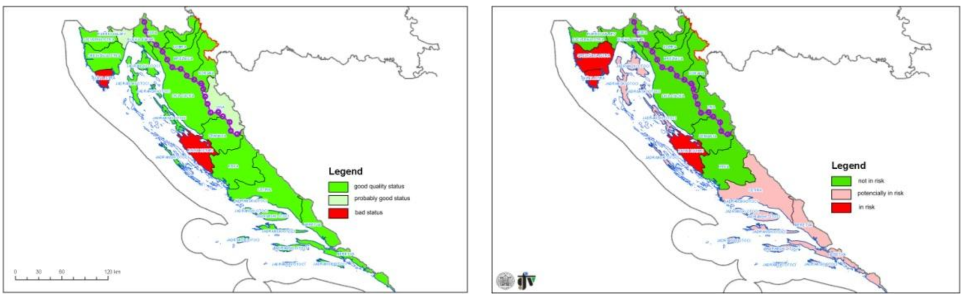

Figure 3. GWB qualitative status (left) and qualitative risk (right).

Under QUAL was also performed risk assessment based on analyses of trends for the specific parameters. The boundary condition of "at risk" is 75% of the allowable reference value at the end of the following reporting period, end of 2015. With this methodology GWB "Central Istria" also has the status "at risk", i.e. very big part of the Istrian Peninsula, entered the zone of high alert and needs for significant improvement of the qualitative status of groundwater. The risk assessment also includes the fact that most of transboundary GWBs have their recharge areas in the neighbouring countries (Slovenia and B&H). The problem is uneven water policies between these countries and Croatia, and because of that these GWBs are put in the category "potentially at risk" (Figure 3 — right).

In Quantitative states assessment (hereinafter QUAN) four comparative analysis (that included effects of anthropogenic changes in recharge, groundwater flow and discharge) have been applied: (1) analysis of GWBs water balance, with particular attention to the effects of exploitation of groundwater on viability of surface flows, (2) surface flow analysis, (3) impact analysis of quantitative relations in GWBs on terrestrial ecosystems and (4) analysis of sea water intrusion into coastal aquifers. For the purpose of QUAN analyses data period 1961–1990, with 567 stations, has been used. For the spatial coverage of boundary areas data from 85 stations in neighbouring countries also has been used.

Estimations of mean annual discharges have been made by frequently most used models of Turc and Langbein, and a comparison with the measured hydrologic data on several tested GWBs (Horvat, Rubinić, 2006). The relevant results were obtained by using Langbein method. According to approximated water balance calculation for Croatian karst areas, karst aquifers have a total volume of about 590 m^3/s of available water reserves per year, of which about 481 m^3/s per year inflows from neighbouring countries, mostly with Neretva River in the southern part of Croatia.

Effect of exploitation of groundwater for water supply on karst springs has a significant impact only during summer dry periods, when the maximum amount is taken, while the natural discharge is reduced to a minimum.

Most of the waters from karst catchments are used to generate electricity. Constructed accumulations in high zones of karst areas halt high water waves; thereby also reduce the risk of flooding of karst fields and valleys, from where the largest rivers in karst are drained to the Adriatic Sea or to the Black Sea catchment. Artificial accumulations have caused significant damage to environment when they were built, due to changes in natural conditions. But because of projected losses in their beds, nowadays they have a useful function and they increase flows of karst springs and streams during summer dry periods. For the period 1961–1990 estimated average amount of runoff from the Croatian karst areas toward Adriatic coast is about 420 m^3/s, adding inflow of 435 m^3/s from B&H. On natural way (springs, rivers) into the sea discharges about 210 m^3/s, and hydropower facilities discharges into the sea about 200 m^3/s. Even 445 m^3/s (52%) is hydrological uncontrolled groundwater runoff into the sea. Therefore, Dinaric karst area, which is drained toward Adriatic Sea, provides enormous amounts of fresh water, which nowadays freely drain into the sea, and can be used in the first place for Croatian needs (water supply of islands), but also for eventual commercialization of a part of those reserves in future market of water in the Mediterranean area.

Previous hydrological analysis shows that in the observed thirty year period is reduced water balance in Dinaric karst in Croatia for about 10%, and probably in the neighbouring countries whose water gravitate toward the Adriatic and Black Sea catchment, too. However, the water regime with today's used volume is not yet threatened so much to cause major problems in a whole area. Problems are only locally, during summer dry periods, when the exploitation is maximised and karst aquifer natural recharge minimised. This is particularly related to the maintenance of important ecosystems along karst rivers. However, water reserves are renewable and already first higher rainfalls after dry periods compensate all possible water deficits created by long term droughts.

QUAN analysis has shown that two GWBs have “bad status” (“South Istria” and “Ravni Kotari”), and two due to insufficient data for these areas and assessment of researchers “probably bad status" ("North Istria" and "Neretva"). Except these GWBs with "bad status" or "possibly bad status" assessment of quantitative risk expends this list to GWB "Rijeka–Bakar" and GWB "Adriatic Islands" due to sea water intrusions and its effect on groundwater, which caused occasional stronger salinisation of water supply springs (Figure 4).

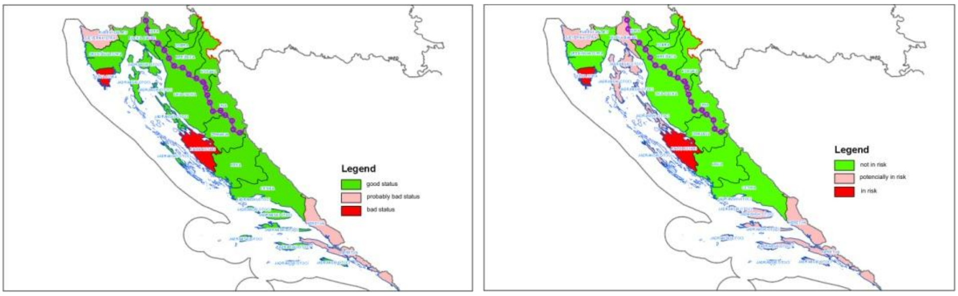

Figure 4. Quantitative status of GWBs (left) and quantitative risk of GWBs (right).

FINAL CONCLUSIONS

WFD as a strategic document for the organization of management and protection of water resources in the European Union to prevent degradation of water resources, effective protection, mimprovement of aquatic ecosystems and sustainable use of highly sensitive natural resources. Risk and states assessment of GWBs is a basic document for further monitoring of water resources value in the member countries and candidate countries for the EU membership. In the Croatian Dinaric karst region has been delineated 17 GWBs, of which 12 are in the Adriatic, and 7 in the Black Sea catchment. Analyses of pressures and impacts, qualitative and quantitative status of groundwaters, analysis of groundwater dependent ecosystems and risk assessment has been done for each GWB. Special attention is given to the monitoring network expand, because for further characterization of risk or potential risk there are not enough relevant data.

General assessment of the qualitative and quantitative status of GWBs in the Croatian Dinaric karst area is good status, which confirms that the Adriatic region has high-quality water resources in sufficient quantities for their own development, but also for the future commercialization of the Mediterranean region too. Problems with waters are registered in two GWBs, but with the possibility of alternative sources for water supply. Status "*at risk*" due to the high content of nitrate and occasional intrusions of sea water has two GWBs ("*South Istria*" and "*Ravni Kotari*"), and several GWBs have status "*the potential risk*": "*Rijeka – Bakar*", "*Adriatic islands*" and "*Neretva*" due to occasional sea water intrusions, and GWB "*Cetina*" and "*Neretva*" due to transboundary conditions and problems – the inability to control the recharge areas.

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abstract id: **290**

topic: **1**
Groundwater quality sustainability

1.9
Sustainable management of groundwater

title: **Sustainable management of groundwater through percolation tanks in semi-arid, basaltic terrain in Western India and the Role of UNESCO-IUGS-IGCP project GROWNET**

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keywords: semiarid region, artificial recharge, India

INTRODUCTION

Volcanic terrain in western India comprises of Basalts, also known as the Deccan Traps and covers an area of about 500,000 sq kms. It is the largest exposure of volcanic rocks in the world. Sustainable management of percolation tanks or percolation tanks is closely related to the survival of about 15 million farmers and an equal number of cattle, living in the semi-arid basaltic plateau in western India. Here the Monsoon rains are restricted to a few rainy days between June and September. It is therefore, necessary to harvest the monsoon runoff into small percolation tanks in mini-catchments, by constructing earthen bunds on small streams and allowing the stored water in the tanks to percolate and recharge the ground water body.

Activities related to maintaining the efficiency of such tanks have been listed as "best practices" on the website of UNESCO-IUGS-IGCP Project "GROWNET" for which the Author is the Project Leader. NGOs have an important role to play in ensuring sustainability by ensuring active participation of the villagers.

NATURAL FEATURES

The importance of Percolation tanks is more pronounced in the semi-arid basaltic terrain of western India, because people and cattle need the water stored in the tanks or tanks for their mere survival. The rainfall in this region is erratic and takes place in the four months of the Monsoon season (June-September). During the rest of the year, comprising four months of winter and four months of summer, people need the stored surface water and ground water for their crops, domestic use and for the cattle. Due to the high evaporation rates of surface water in the summer months, storage in a ground water reservoir is a preferred method in this region. In order to augment this storage, runoff water in several seasonal streams in an area is impounded by constructing earthen bunds across the streams. Percolation tanks are formed during the Monsoon season, behind such bunds. This water percolates during the four months of the winter season (October-January) and by the beginning of summer the tank becomes dry.

Another important socio-economic factor, favoring construction of percolation tanks in the drought-prone, semi-arid region is that during a drought year construction of an earthen bund across a stream gives employment to about 1,000 to 1,200 men and women, for 6 to 8 months.

EFFICIENCY AND SUSTAINABILITY OF A PERCOLATION TANK

A percolation tank has two efficiencies, the storage efficiency and the percolation efficiency. Storage efficiency is the ratio of the volume of water stored in the tank to the volume of runoff water available from the catchment during the rainy season. This efficiency could be close to 100% in the initial stage, but as the tank bed gets silted-up every year, storage efficiency declines. This decline is represented by increase in the volume of water flowing over the spillway. Percolation efficiency is defined as the ratio of the volume of water percolated to the volume of water stored. The overall efficiency is the product of the above two efficiencies.

Location of the bund across the stream in relation to hard-rock topography, is important. If the tank behind the bund has a rocky bed, percolation rates are extremely slow and the very purpose of creating the tank is defeated. Vertical bores are then drilled in the rock and blasted to create artificial fracture porosity. Silting of the tank-bed is also undesirable, as it reduces both the storage and percolation efficiencies. It is, therefore, necessary that when the tank bed dries in summer, beneficiary farmers bring their bullock-carts to the tank, remove the silt. The amount of silt received in the tank in each rainy season could also be controlled by promoting watershed development and soil conservation activities like contour bunding of farms, contour trenching on hill slopes, gully plugging, afforestation, grassland management, etc., in the watershed of the tank. All such activities related to watershed development and sustainability of the Percolation Tanks have been listed as 'best practices' on the website www.igcp-grownet.org. Project GROWNET (Ground Water Network for Best Practices in Ground Water Management in Low-Income Countries) has been approved by UNESCO-IUGS-IGCP for global dissemination of "best practices" over the Internet, for replication elsewhere (Limaye, Reedman, 2005).

CONCLUSIONS

1. Percolation tanks or tanks are of vital importance for the survival of about 15 million farmers and an equal number of cattle, living in the semi-arid basaltic terrain in western India. Regular de-silting of the tank bed is essential for improving the storage efficiency and the percolation efficiency of a percolation tank.
2. Long term sustainability can be achieved by adopting watershed development activities in the catchment area of a percolation tank. In the semi-arid region, precaution must, however, be taken to select only those species of trees, bushes and grasses for afforestation, which have very low transpiration.
3. At present, the percolation tanks are constructed by the Government, under drought relief programs or minor irrigation schemes. Locations are selected without much consideration of local hydrogeological features. Provision for regular de-silting of the tank-bed, is also not made. Non-Governmental Organizations (NGOs) and Community Based Organizations (CBOs), therefore, play a vital role in ensuring sustainability of percolation tanks.
4. UNESCO-IUGS-IGCP Project "GROWNET" (Ground Water Network for Best Practices in Ground Water Management in Low-Income Countries) is a humble step in promoting water harvesting structures like percolation tanks, for achieving sustainability of ground water supply for domestic and irrigational use in semi-arid volcanic terrains.

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IAH 2010
Krakow

abstract id: **323**

topic: **1**
Groundwater quality sustainability

1.9
Sustainable management of groundwater

title: **Efficient groundwater management approach for North ThangLong and Quang Minh Industrial zones — Hanoi, Vietnam**

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keywords: hydrology, hydrogeology, Holocene aquifer, Pleistocene aquifer

INTRODUCTION

The study area is about 50 square km and is located on northern part of Hanoi, Vietnam. The area covers a segment of Red river with Thang Long industrial zone in south and a segment of Ca Lo river with Quang Minh industrial zone in north. The climate of area is humid tropical monsoon by hot and wet summer (from June to October) and cold and dry winter (from November to May). The annual relative humidity is 84% by rainfall of max 1532 mm and min. 948mm. The area is elevated of 5-10 m above sea level. The topographic and geomorphologic evolution of this area has been performed in the period from the end of Pleistocene to the Holocene, corresponding with 5 depositional cycles of sedimentary formations (An 1996, Dy 1998).

HYDROLOGY

Major rivers flowing in the area include the Red river in south and Ca Lo river in north. These rivers have very large discharge which varies by seasons in the year. The content of alluvium *terra-rossa* in Red river is 1.5 kg/m^3 of water, it does mean about 100 mln ton/year of transport. The water level is changing between dry season and rainy season about 10m. The Red river in Hanoi is blocked by two dikes on both sides. Within the space of 60 years the water level of Red river in Hanoi rised up of 1m (An, 1996; Nghi, Toan, 1991).

The quality of water in the Red river and Ca Lo river is generally good up to now. The total dissolved solid content (TDS) is low (<0.2g/l). The water is of calcium bicarbonate type, with pH equaled 7–7.5. The electrical conductivity EC is equal to 15–20 mS/m. The water level sensibility changes season by season. In the flood season (August-September) it is usually 4–6 m higher than the land surface of area.. Thus, Hanoi has a dense and diverse hydrographic system, which not only provides abundant water resources but also serves well as a water way transportation and drainage of the city as well as is a tourist attraction. However, so far due to various reasons, the surface water potential has not been exploited appropriately for domestic water supply. On the other hand, due to large amount of wastewater discharged to them, the small rivers and lakes are being more and more polluted.

GEOLOGICAL FORMATION

During the Quaternary period, the land of studying area has been created through transgressions and regressions of the sea in 5 depositional cycles from the Early Pleistocene to the Late Holocene (see tab. 1).

Table 1. The depositional cycles of Quaternary.

Cycle	Age	Sedimentary materials
5	Late Holocene	Various genesis such as alluvial, alluvial-marine sands
4	End of Pleistocene and beginning of Holocene	Marine genesis, mainly composed of clay and clayed silt of greenish gray
3	Late Pleistocene (Q_1^3vp)	fine sediments as well as silt sand, clayed silt
2	middle-late Pleistocene (Q_1^{2-3}hn)	coarse grained sediments as well as cobble, gravel, coarse sand to finer sand
1	Early Pleistocene	Pebbles, gravel coarse sand (thickness 70-140 m)

There are different opinions on the subdivision of the Holocene stratigraphy in the Red river delta plain (Hori et al., 2004, Nghi, Toan, 1991). The bases consist of the oscillation of the sea-water levels and the stages of cultural development during Holocene. But the fluctuation of sea-water levels is one of important factors playing the main role in the process of development history of Holocene. According to the research results of many authors the Flandrian marine transgression is the highest one at the approximate time of 6,000 yr. BP (Dy, 1998). After this event, the marine regression began to happen. After that, the shoreline began to remove seawards, and the sedimentary environment transformed from lagoon-estuarine to deltaic one. This is the reason for considering the 6,000 yr. BP point of time as boundary between Early and Late Holocene.

HYDROGEOLOGY

On the basis of stratigraphy of 3 wells — OW1, OW2 and OW3 made in studying area by the end of July 2008 (Fig.1b) there are two aquifers (Fig. 2). Holocene aquifer (Qh) is exposed on the surface, widely and continuously distributed from Red river to Ca Lo river.

a) b)

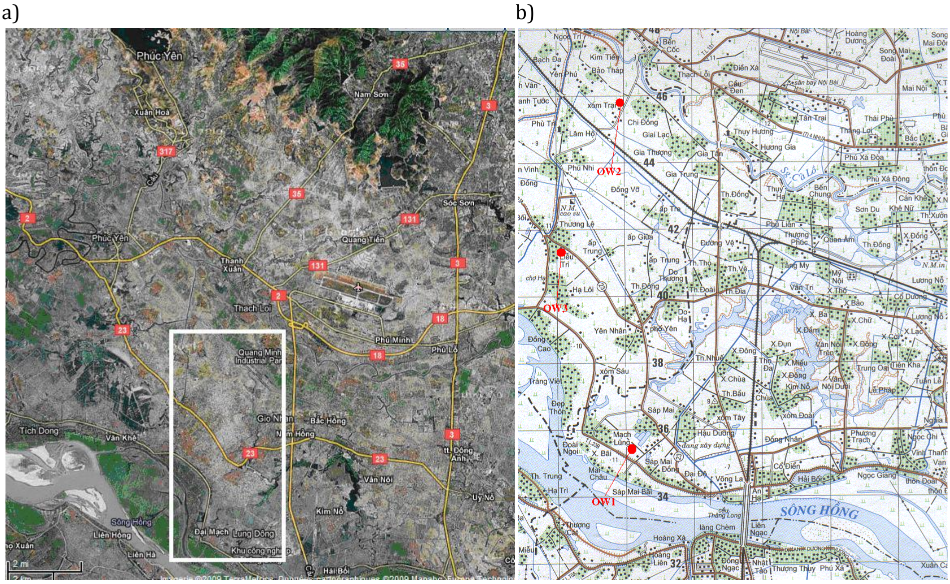

Figure 1. (a) Location of studying area in NW Hanoi, Vietnam. (b) Location of wells OW1, OW2 and OW3 in the studying area.

The water bearing formations consists of 2 sequences: the upper sequence is composed of sandy clay, clayey sand, with low permeability, by thickness to about 10m. The lower sequence is composed of sand with various grain sizes, in some place mixed with the gravel at the bottom, by average thickness of 9-10m. The depth to the groundwater level is 5-5.5m below the surface. It does mean that mainly rainwater, irrigation water and river water recharge to the aquifer during the rainy season. But, during the dry season, groundwater from this aquifer will be discharged to the river and to the underlying aquifers. The groundwater in the Qh aquifer is fresh, with TDS usually below 0.5g/1, mainly of calcium- bicarbonate type. The iron content in the water in most of the area is 0.4 to 10mg/l. The manganese content is 0.2- 2mg/l, the ammonium content is ranging tens of mg/l. The electrical conductivity is 40 mS/m. This aquifer is significant for small-scale water supply (for domestic using). The rural people usually dig wells and drill shallow and small diameter boreholes for extracting the groundwater from this aquifer.

Pleistocene aquifer (Qp*)* is the lower aquifer which distributed all over studying area. The depth to the top of the aquifer is 20-30m. Between two aquifers is one confining layer Q_1^3vp (Fig. 2).

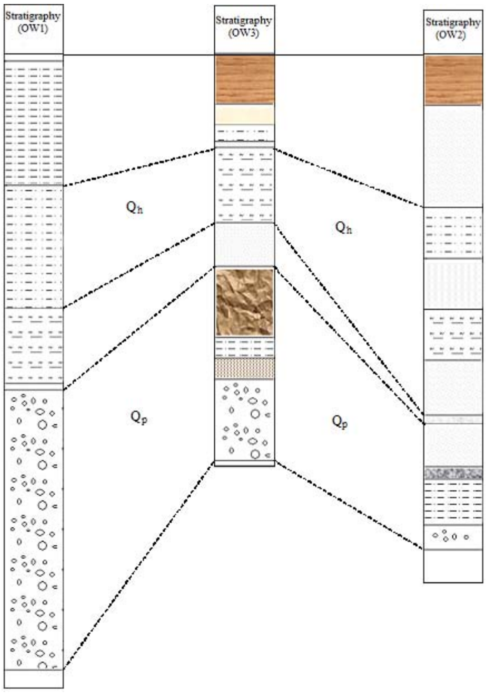

Figure 2. The location of Holocene aquifer, Qh and Pleistocene aquifer, Qp by 3 wells stratigraphy OW1, OW2 and OW3 in the studying area.

The aquifer Qp is pressure with thickness from few m to 60 m and increasing from N to S by coarse sand, gritstone, gravel with low TDS and with water level from few to tenth m. The source for Qp mainly from rainy water from surrounding region Red river delta and from hydrogeological windows. Between the aquifers and the rivers, there is the close hydraulic connection by the observation water level from OW1, recently. The water bearing formation is composed of sand mixed with cobble and gravel of the thickness of 25–35 m. The groundwater in the Qp aquifer is fresh, with TDS 0.3 g/l, mainly of calcium-bicarbonate type. The iron content in the water is 10 mg/l and manganese content is 2 mg/l. Due to its high productivity the Qp aquifer is being intensively abstracted and is the main source of water supply for the area. This aquifer is not much exposed to direct pollution but pollutants can move from the Holocene aquifer (Qh) into it through hydraulic windows. Our project continue monitoring of 3 wells for future forecasting.

Regarding on hydrogeological conditions in the studying area, one can take remarkable conclusions to the Red river delta region, in general. The Qp aquifer is the largest in the Red river delta of Vietnam. The study on relation between the rain water, Red river water (surface water) and groundwater in Hanoi area, through isotope data from 2002 to 2005 year shows interesting information about the recharge of water from Qp aquifer to the Red river. The $\delta^{18}O$, δD and tritium T values were proved to the surface water (Red river) being the result a mixing of precipitation and groundwater (Bono et al., 2004). The existence of T in the all of wells in Qp proved mixing between water from this aquifer and modern water. As we know that tritium's symbol is T or ^3H, also known as Hydrogen-3 which is a radioactive isotope of hydrogen which contains one proton and two neutrons. Tritium is a naturally occurring radioactive form of hydrogen that is produced in the atmosphere when cosmic rays collide with air molecules, but tritium radiation does not travel very far in air.

Isotope data from Hanoi rainy water, Red river water, Hanoi groundwater and rainy water from Hong Kong and Kunming rainy stations in southern part of China are presented in (Tab. 2).

Table 2. Isotope content in rainy water for some stations (annual) after report of the Institute of Nuclear Technology – Hanoi.

Station	TritiumT(TU)	$\delta^{18}O$ (%o MOW)	δD (%o SMOW)	Date
Hong Kong	1.72 ÷ 3.69	-1.91 ÷ -9.0	-5.3 ÷ -61	2002
Kunming	4.4 ÷ 17.7	-0.67 ÷ -17.51	-20 ÷ -90	2002
Hanoi rainy water	0.98 ÷ 4.65	-1.4 ÷ -9.8	-6.76 ÷ -77.42	2002-2005
Red river water	1.78 ÷ 8.5	-7.18 ÷ -9.77	-46.43 ÷ -66.62	
Hanoi aquifer Qh	<1 ÷ 5.8	-4.21 ÷ -9.1	-41.0 ÷ -66.60	
Hanoi aquifer Qp	<1 ÷ 5	-5.14 ÷ -8.9	-41.4 ÷ -56.0	

The content T in Hong Kong and Hanoi is ranging from 1.0 to 10.0 TU, but T is higher in Kunming (south China). The content T of Hanoi rainy water is lower than in the Red river water and the phase is lower about 1 month (depend of changeable of season N to S from rainy to dry 1 month) and the T content in rainy water and in the Red river water is increasing by time.

As we know, the flow of Red river water begins from the South China, where T content of rainy water is 2 or 3 times higher than in Hanoi. On the way to Hanoi the Red river water is supplied by rainy and groundwater and it is why in the Red river water in Hanoi T content is lower. The age of water from aquifer Qp is about 10,000 years.

During 2007-2008 we collected 6 samples of water from 6 stations in our study area and around which are presented in table 3. The distance between location of H1 (Red river right bank –W) and H2 (Red river right bank-E) is 5 km and the location between H3 (Calo river left bank-W) and H4 (Ca Lo river left bank-E) is also 5 km. The location of H5 (Dai Lai reservoir) is about 25 km north of studying area. The location of H6 is located of well OW1.The result of the analysis of water for anion and cation in mg/l is presented in table 3.

Table 3. The results of analysis for water by N. Hida and his collaborators in June and September 2008.

Station	Cl	NO_3	SO_4	HCO_3	Na	K	Mg	Ca	$\delta^{18}O$ (%o)	δD (%o)
H1	1.865	3.072	9.038	96.894	3.057	1.606	4.841	29.376	-8.1	-54.6
H2	2.761	2.933	11.939	118.971	4.526	1.686	6.068	32.629	-8.8	-61.7
H3	12.496	5.417	23.537	110.385	8.897	7.000	6.318	34.710	-6.5	-32.1
H4	10.795	10.118	23.277	121.424	7.152	6.905	6.698	39.775	-5.1	-35.7
H5	3.257	1.311	6.258	15.945	2.363	0.920	1.448	4.713	-2.4	-28.3
H6	4.671	3.826	2.806	160.672	15.842	1.913	5.542	36.949	-7.3	-51.0
OW1	1.510	2.650	0.252	112.838	8.206	3.970	4.346	21.654	-7.2	-49.5
OW2	1.835	0.151	1.882	63.778	6.917	2.640	2.807	10.640	-6.5	-47.6
OW3	—	—	4.720	—	—	8.095	—	—	-5.8	-42.0

The groundwater level is changing by time (Fig. 3). It is lower in dry season from March to May and higher in rainy season on July. The time of observation is short, but influence of surface water to groundwater can be observed by OW1 well in the study area. The groundwater level of OW1, OW2 and OW3 wells is changing by time. The values of conductivity of OW3 well water are higher than OW1 and OW2 in the same time. The temperature of groundwater from all wells is approximately constant.

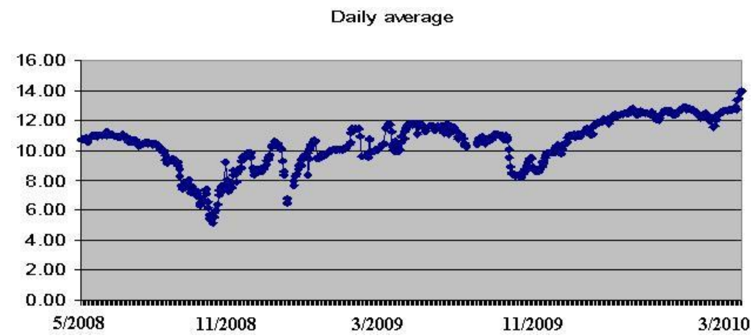

Figure 3. The groundwater level observation of OW1 from May 1, 2008 to March 15, 2010.

CONCLUSIONS

There are two aquifers in the study area on the basis of geological section of wells OW1, OW2 and OW3 stratigraphy. Holocene aquifer (Qh) is shallow and highly polluted but Pleistocene aquifer can be considered as potential groundwater aquifer. They are connecting by hydraulic windows.

The differentiation of geological structure and geochemical characteristics of the sediments causes the difference in hydrological features of the study area. The relationship between geochemical characteristics of the sediments and groundwater quality in the study area is rather close and there is relationship between groundwater and surface water from Red river and Ca Lo river.

Because of rapid development of the industrial zones in the study area the monitoring of groundwater changing is necessary in nearest future.

ACKNOWLEDGMENTS

This study is supported by JSPS Grant-in-Aid for Scientific Research (B), No.19401002 in 2007-2010.

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abstract id: **352**

topic: **1**
Groundwater quality sustainability

1.9
Sustainable management of groundwater

title: **Uzbekistan karizes and use of ancestors experience on building groundwater gallery**

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keywords: kariz, gallery, operation

INTRODUCTION

At present time water supply at the expense of groundwater is carried out mainly by the water well intakes which use is limited by deficiency of the electric power. Therefore search of areas on which groundwater gallery operation is possible, allowing at operation to reduce electric power expenses, is the important problem for Republic Uzbekistan. Its decision will allow to improve essentially water supply of the population by potable water, to reduce electric power expenses at water intake operation. The way of the decision of this problem sees in partial transition to groundwater gallery operation, on those areas where their use will be the most effective.

Centuries-old experience of use of groundwater gallery (foggara, kariz, qanat) show on high efficiency of operation of such constructions. High vocational training of ancient builders of these constructions unmistakably defining a position of the most watery aquifers, underground constructions carrying out building in difficult engineering-geological and hydro-geological conditions amazes and admires at application only manual skills and groundwater providing a conclusion to a surface. At the heart of building of such constructions lay, intuitively exact engineering calculations. Experience of our ancestors on water supply of the population at the expense of groundwater, especially in arid areas of Republic Uzbekistan, can be successfully applied and in modern conditions.

KARIZES: HISTORY AND THE PRESENT

Outstanding achievement of hydraulic engineering since the most ancient times are groundwater galleries which in Central Asia and on Caucasus name the kariz, in Iran – the qanats (Wulff, 1988), in Africa – the foggara. Karizes were known in Assyria, Babylonia and ancient Persia, were used by Romans in Syria, then Turks in Asia Minor. They meet in Central Asia and Transcaucasia, on Near and Middle East, the North Africa and the Central Asia. In Uzbekistan kariz water supply in foothill areas was carried out since the most ancient times till 60th years of the XX-th century. So in Kushrabat area in village Aktepa there is a kariz ligament constructed at the time of Abdullahan II (1534–1598) from a dynasty Shejbanides. In Uzbekistan karizes are most extended on northern and southern slopes of Nurata mountains, especially often meet round the cities of Gazgan and Nurata. Here them is more than 100 karizes ligaments, some of which in total length more 6500m. Karizes are traced and now in the form of linearly extended relief low; radial lows from these lines; partially remained observant pits, and as places of possible exits of pits on a surface. The top part of some karizes ligaments is developed divergently in the form of the fanlike branches consisting of several galleries, incorporating more down in one gallery. Sometimes only two branches incorporate. Among them are kariz “Dushoca” in Gazgan city and kariz “Kalta” at a foot of the Nurata marble deposit. Action principles karizes are opened on the results of modern field investigation. The hydrogeological section along kariz operating earlier on a district “Akkula” is showing in Fig. 1.

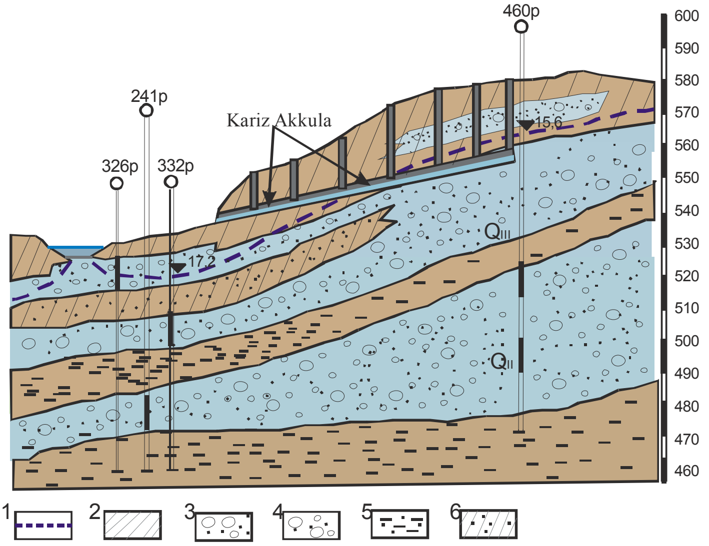

Figure 1. Schematic section along kariz Akkula of Nurata valley. 1- water table, 2- clay, 3- gravel, 4- gravel with sand, 5- loam, 6- sandy clay.

From this section it is clear that kariz collected water of their top most permeability aquifer in Pleistocene sediments (Q_{III}) and deduced it in Upper Quaternary horizon. Operation most permeability aquifer in Pleistocene sediments is characteristic for all karizes, operating earlier in the Nurata valley. Decrease in a aquifer permeability with depth for area Nurata valley is showing in Fig. 2. So at water yield to 15 L/c on the top aquifer their reduction to 6L/c on depths 100-150m and to 2L/c on depth 200m and more is observed.

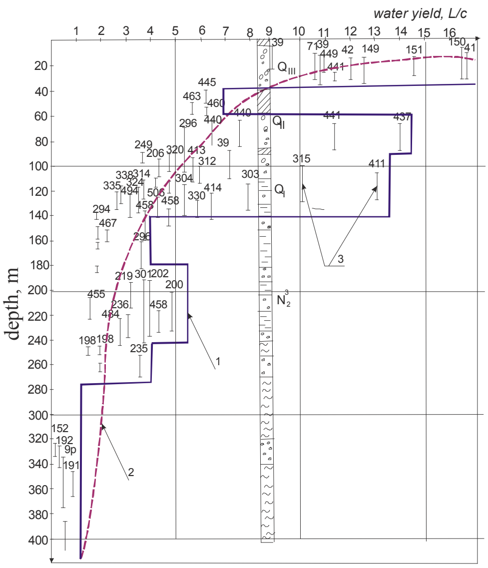

Figure 2. Integral graph showing relationship between change of deposits water yield q(L/c) and their depth for area Nurata valley. 1 – conditional sketch of deposits water yield; 2 – trend of relationship between in water yield at depths; 3 – well filter.

As a rule karizes are confined to a basic recharge source of Nurata valley groundwaters - a river Bigljarsaj which on all extent completely loses a superficial run-off during the short spring period. Only in separate years abounding in water its superficial run-off falls outside the limits a valley in desert Kyzyl Kum. Geological activity of paleoriver Bigljarsaj has generated Quaternary sediments which as a whole form the Nurata aquifer of fresh groundwater. Under discharges Nurata karizes it is possible to divide into three groups: watery — more 100 L/c; averages — 10-100 L/c; the least watery — less 10 L/c. So for example, the discharge Kalta's kariz makes to 40 L/c. Now extraction of groundwater of the Nurata deposit is carried out by wells which has lowered groundwater heads on all Nurata valley. It was reflected in activity remained karizes which are partially drained and abandoned now.

OPERATING EXPERIENCE OF GROUNDWATER GALLERIES

Making use of ancestors experience on building karizes and modern achievements of hydrogeology, in Uzbekistan are made works directed on building horizontal groundwater galleries. Examples operating horizontal groundwater galleries in Uzbekistan are: gallery of Sarycheku for water supply of mountain-metallurgical industrial complex; a gallery of Akkishlak for drinking water supply in upper courses of the river of Kata-Uradarja; a gallery in desert Central Kyzyl Kum.

The gallery of Sarycheku represents gallery shallow location, drilled in Paleozoic fractured rock in which roof faces of two operational wells settle down (Fig.3). Wells are equipped by the filter on top Quaternary aquifer. Through filters groundwater arrives in wells on which trunk flow down in gallery. Groundwater the pump established in a observation pit, moves from galleries to directly consumer.

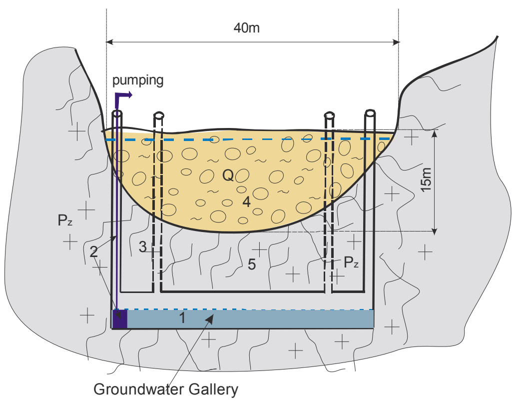

Figure 3. Schematic section along Groundwater Gallery Sarycheku. 1 — gallery, 2 — pumping from observation pit, 3 — filtration well, 4 — Quaternary aquifer, 5 — Paleozoic sediments.

The gallery discharge changes from 4 to 15 l/c. In a freshet seasons the gallery discharge increases, and in dry season for increase in the expense of the artificial lake for recharge aquifer is created. The geophysical works spent here have shown that capacity of permeability alluvial deposits makes no more 8м. Capacity of Paleozoic (Pz) crust of weathering is estimated in 30m. Fractured these deposits shows on a possible groundwater filtration on cracks that is the most probable in a narrow strip of modern development of a Paleozoic valley (Nagevich, Chebotareva, 2009).

The groundwater intakes construction of this kind operates in desert Central Kyzyl Kum. It is intended for drainage of the aquifers which are lying down on Paleozoic sediments. There is passed mine and drift from it on depth nearby 270м from an earth surface for this purpose. The drift it is passed in Paleozoic fractured sediments. From a surface of the earth to a drift roof there are drilled some tens wells. They open a total thickness of all aquifers above Paleozoic sediments and provide running off of groundwater of these aquifers in drift. Mine groundwater outflow of such design has provided drainage of a part of aquifers on depth to 110-120m from an earth surface. The groundwater outflow expense made in the beginning of its work to $1m^3/c$ and has gradually decreased to $0,2m^3/c$. Building of this drainage construction has been in details proved by the previous hydrogeological researches.

Absence of such purposeful researches can lead to negative results: an example from a groundwater gallery of Akkishlak for drinking water supply in upper courses of the river of Kata-Uradarja (Fig.4). Here trench was excavated by depth in 3-4m and extent several hundreds meters. In trench are put perforated pipes of the big diameter 1000mm, which were overhand fallen asleep earlier extracted by soil.

Figure 4. Groundwater gallery of Akkishlak in upper courses of the river of Kata-Uradarja.

However groundwater drainage was not reached, and gallery turned out to be dry on all its length. This area belongs to a narrow modern valley of the mountain river. The top Quaternary aquifer is characterized by a high permeability (water yield have made 18-25 L/c at drawdown to 6m, the hydraulic conductivity - 5-25m/d). However depth groundwater table makes 8-10m from a flood plain surface. Low on a depth Cretaceous limestone, clay, sandstones lie down. Sandstones are characterized by a low a permeability (water yield have made less 1L/c at drawdown more 20m), but has high artesian heads (near to an earth surface). The wells drilled in flood plain of the river on this Cretaceous aquifer, are artesian. Pumping rate their very low less 0,01L/c. Hydrogeological investigation on this area has been executed under a groundwater well intake on the top water-bearing horizon. Such hydrogeological system is reflected in Fig.5. However the developed incorrect illusion about permeability all aquifers, including and a zone of aeration by capacity to 10m, has led to unreasonable recommendations about building of superficial groundwater gallery. This example convincingly testifies to an obligatory hydrogeological substantiation of building of groundwater gallery.

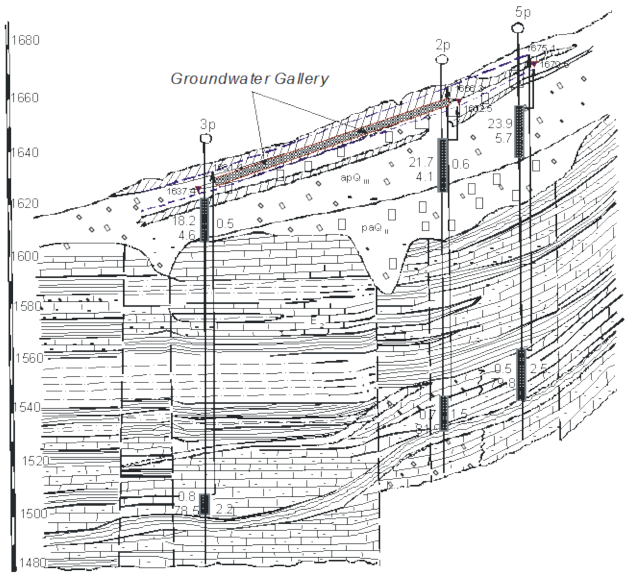

Figure 5. Schematic section along groundwater gallery of Akkishlak.

THE CONCLUSION

Groundwater gallery can be maintained in following conditions:

- foothill plains (kariz type);
- river valleys;
- channel lenses;
- low-power seasonal rivers.

Objects of researches at the decision of a question of groundwater gallery application are: A – areas of alluvial and proluvium sediments; B-areas of a local congestion of groundwater (Nagevich, Chebotareva, 2010). A areas characterized by following characteristics: to hallow groundwater table; high aquifer properties; high quality water. B areas of a local congestion of the groundwater, belong to proluvium deposits of temporarily currents rivers in foothill zones. The groundwater of small productivity aquifer (to 10 L/c) can be successful operation and is deduced on a surface without application of the pump equipment and the electric power.

Leaning against the modern techniques, experience and knowledge of hydrogeological aquifer properties building of gallery both deep hole similar karizes, and shallow horizontal hole, is quite possible. Certainly expenses for their building will essentially above, and the time of recovery of outlay of constructions is much longer, than at wells water intakes constructions. However profitability gallery water intakes constructions at operation allow to consider them as alternative to wells water intakes constructions.

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abstract id: **365**

topic: **1**
Groundwater quality sustainability

1.9
Sustainable management of groundwater

title: **Water resources management in the bottled water business**

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keywords: water resources management, water resources protection, bottled water, Nestlé

INTRODUCTION

Water is the source of all life, but while we tend to think of this as an abundant, inexhaustible resource, the fact is that less than 1% of all water on Earth is in a form usable by humankind. In dealing with the water challenge, it is clear that everyone must have a role. Governments have to take the lead, both as policy makers and through their fundamental duty to see that basic services are provided for their people. We need to look for ways and mechanisms, whether policy or market-based, that protect the world's water resources as well as access to water, but also to ensure each and everyone's responsibilities as water users.

Today, on a global scale, agriculture represents 70% of the world's withdrawal of freshwater; industry represents 20% and domestic use 10% (Shiklomanov, 2000). Nestlé uses about 0.004% of the world's freshwater consumption (Figure 1). Our bottled water business uses 0.0009% (Nestlé, 2007).

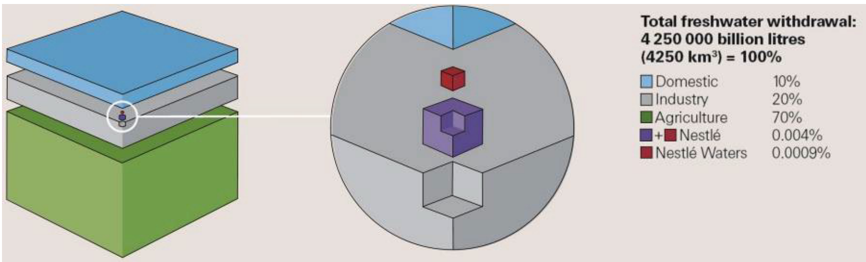

Figure 1. Total freshwater withdrawals worldwide 2006 (Déprés et al., 2005; Global Water Futures, 2005).

FOR A SUSTAINABLE APPROACH

The observation is simple and final: without water, life is impossible for plants, animals and human beings. As one of our essential natural riches, water is a right that is renewable, exhaustible and scarce – and each drop of it is precious. That is why Nestlé Waters always keeps environmental protection in mind as it continues to expand its activities. Every day, the company pursues an active policy in line with its flagship concerns: water resources, packaging and transport, health and wellness. Protecting our water sources (wells or natural springs), their recharges areas and their biodiversities has always been a priority for Nestlé Waters.

Nestlé Waters is the world's leader in the bottled water business. We operate 103 factories in more than 35 countries and produce different categories of bottled water: natural mineral water, natural spring water, drinking water. With more than 500 water sources (wells or natural springs), Nestlé Waters has always considered their management as a strategic activity.

The definition of sustainable development most currently referred to is that defined by the (United Nation's) Brundtland Commission (UN, 1987): "*Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs*". As such, the term covers not only the environmental aspects of development but an overall economic, social, and environmental thinking that takes into account the short and long-term as well as local and global dimensions.

Sustainable development is also a key concept in water management. According to Global Water Futures (GWF, 2005), "sustainable solutions" for the withdrawal of water resources generally exhibit three characteristics:

- First, they are strategic. Water is a strategic resource, meaning it is vitally important to human prosperity, economic development, environmental health, and political and geopolitical stability. The most effective solutions will recognize this importance and leverage the different roles water plays in each of these areas.
- Second, sustainable solutions are innovative. Innovation can stem from not only entirely new solutions, but also new applications and mixes of past solutions.
- Finally, sustainable solutions are effective over the long-term. Long-term solutions not only extend the lifespan of solutions implemented today, but also leverage the next generation of innovations and successes in an ever-rising upward spiral.

Strategic, innovative, long-term approaches will be necessary to solve the global water challenges of both today and tomorrow. Businesses can take many actions – individually, collectively, and in partnership with others – to address the evolving water challenges (WBCSD, 2006).

WATER RESOURCES MANAGEMENT

Protecting groundwater resources is critical to the ecosystems and communities where we live and work. In a given geographical area, Nestlé Waters seeks out and manages water sources in a sustainable way.

Therefore, we support science based legislation that treats all water users equally. We always comply with local legislations and sometimes exceed them, if they are considered to be insufficient, by applying our own internal quality standards.

Water resources exploration

The water resources exploration phase is a crucial step in a new project. To assess the local water resources context some studies are performed by an external specialised company to collect all the key information on hydrogeology, quality, quantity and legislation. Based on this study, the location for the research area of a new water source is defined. Afterwards some geophysical investigations can be performed to optimize the drilling of an exploration well or the building of a natural spring catchment. In Figure 2 we can see the result of exploration conducted in Italy. By carrying out this investigation, we have been able to increase significantly the natural flow rate of the spring. The water quality around the catchment is secured by installing impermeable geotextiles.

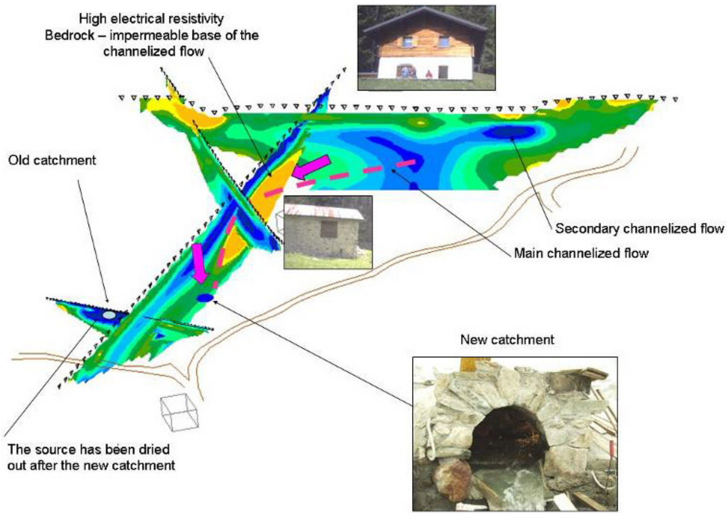

Figure 2. Application of Electrical Resistivity Tomography method (Suena spring, Italy).

Water resources monitoring

Continuous interpretation of monitoring data allows us to rapidly detect any noticeable deviation in terms of quality or quantity. This then allows us to implement immediate actions to avoid additional degradations.

If no immediate reaction is taken, degradations may lead to a major intervention in the catchment, such as renovation or cleaning. It may also lead to a water shortage and then a temporary production stop or even the permanent loss of a source. Water resources management in the bottled water business has to be very reactive and well coordinated with the instantaneous production needs.

In Nestlé Waters, our water sources are monitored on a continuous basis (Figure 3). Different parameters are analysed and consolidated: water level, flow rate, conductivity, temperature, turbidity, rainfall. This list can be adjusted according to the site specifications. On top of that, a regular quality monitoring system (chemistry and microbiology) is implemented from the water sources to the filling machines including water transportation via pipes, water storage tanks and water treatment processes.

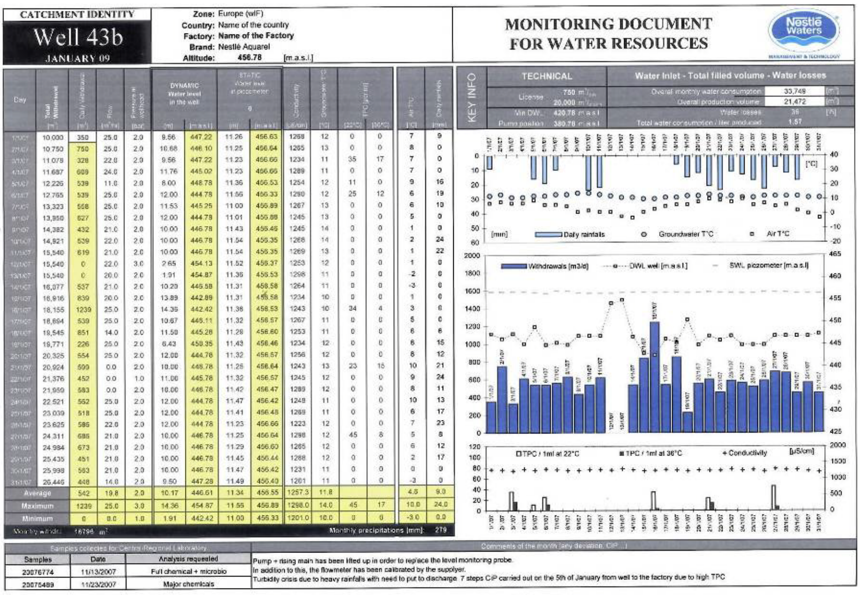

Figure 3. Water resources monitoring sheet.

Water resources equipment

Based on the category of the finished products (natural mineral water, spring water, drinking water) and according to the legislation, some specific technical standards are applied. They depend mainly on the types of water treatment that are allowed.

In the bottled water business, it is possible to define water resources as our DNA. To ensure the water quality over the long term, the drilling operations are performed under strict hygiene conditions. All the equipment (rigs, pipes, pump, cables, and sensors) that will be in contact with the groundwater must be cleaned and disinfected carefully before any use.

The equipment that is installed in a well (casing, screens) or a natural spring is made of stainless steel. The pipes that transport the water from the sources to the factory comply with the food grade standards (stainless steel or high density polyethylene).

The materials used for the surface equipment (wellhead) in the catchment building are also made of stainless steel. Its design (connections, welding) minimizes the retention zones favourable to biofilm development. The equipment design (flow meter, pressure, air-vent, sampling valve) minimizes the time needed in case of maintenance. It avoids production stops and minimizes the risk of microbiological cross-contamination during the operations. Our standard wellhead equipment gives us the possibility to perform a disinfection loop in case of temporary quality deviation.

Water resources security

Water resources security is an important part of our strategy. Measures are implemented against all voluntary or accidental actions. It means the protection of the immediate environment and catchment equipment, and the protection of a wider area where human activities could also impact the water (transportation, storage and treatment).

Security at the water sources is conducted using passive and active measures. A motion sensor is installed in each catchment to detect the presence of any unauthorised person. Additional measures can occasionally be put in place in case of alert: automatic stopping of the pump, automatic diversion of the water flow to discharge.

The security of monitoring wells must be considered case by case from a hydrogeological perspective. Security measures have to be proportional to the potential negative impact caused by pollution occurring on a specific monitoring well with regard to the water sources used for bottling: the shorter the distance/travel time from monitoring wells to the sources used for production, the greater the active measures to be adopted.

WATER RESOURCES PROTECTION: AGRIVAIR METHODOLOGY

Nestlé Waters is working to protect and manage water resources around the world, especially in the Vosges region of France, where our biggest bottling plant produces 4 Natural Mineral Waters such as Vittel or Contrex (Figure 4).

Figure 4. Agrivair location.

Had the risk not been identified early, the development of intensive farming would have been a threat to the future quality of water resources. To this end, the company is engaged in a number of efforts throughout the area with the cooperation of government and local communities.

In the 1980s, a four-step methodology was especially developed and implemented (Perrot-Maître, 2006):

- Understand the farming systems and why farmers do what they do;
- Analyze conditions of changing farmers practices and behaviour;
- Experiment, test, and validate in farmers fields the management practices necessary to reduce the nitrate threat;
- Research tools and indicators to support the change.

In 1992, a partnership was developed with INRA (National Institute for Agronomic Research) to investigate these opportunities in the form of a wide-scale, multidisciplinary research programme involving historians, sociologists, economists, agronomists and zoo technicians. The programme resulted in the creation of Agrivair, a subsidiary of Nestlé Waters, and a veritable "driving belt" in charge of implementing INRA proposals.

The Agrivair concept can be summarised as a 360° approach to protect groundwater resources (Nestlé Waters, 2007):

- Elimination of corn cultivation (nitrates and water consumption)
- Composting manure
- Maximum 1 cattle unit/hectare/year (i.e. 1 dairy cow)
- No pesticides
- Putting in place an alfalfa-based cultivation turnover
- Balancing the animals intake
- Put farms buildings in accordance with standards.

For example, the use of pesticides is totally banned in the groundwater protection area. Agrivair keeps ladybugs a natural enemy of crop-damaging insects, and releases them in farm fields when the harmful insects appear.

A thermal weed killing system was also implemented in the golf courses, public gardens and along the railways and roads. Through technical and economic support, Agrivair also encourages the use of organic fertilizers in place of chemical fertilizer. Agrivair's forest management programme maintains a balance of trees that maximizes the nitrates the trees extract from the soil. In other words, Agrivair thins some trees so that young ones can grow.

By agreeing to adopt new, environmentally protective practices, the farmers concerned made a contractual commitment to following Agrivair specifications in the form of a notarised deed of minimum 18 years. This programme based on a strong scientific background created a win-win situation for both parties (Table 1).

Table 1. Costs and benefits of the Agrivair programme.

	Costs	Benefits
Farmers	■ No direct financial cost but high transaction costs: cost of learning new practices and participating in identification and testing of practices and incentive system, and negotiations	■ Secured long term farming ■ Cancelling of short-term and long-term debt ■ Additional land
Nestlé Waters	■ Land acquisition ■ Farm equipment ■ Farm compensation ■ Agrivair operations (which is at least partially self financed).	■ Eliminated business risk ■ (1 billion bottles per year). ■ Sustainable water resources management

The question of whether or not the investment was economically justifiable was raised early in the process. INRA demonstrated that under the assumption that one hectare of well-managed pasture produced 3,000 m3 of mineral water every year; the scheme was economically feasible (INRA, 1997).

Today, 92% of the recharge area (~10,000 hectares) have been converted to the programme and respect every clauses of the Agrivair contract. But the farmers are not the only people involved in the protection of the groundwater. Agrivair has widened the scope of its strategy to include in its project all the players present in the area.

The entire programme was essentially a "learning-by-doing" experiment. It was the ability to "think outside the box", brought by the multidisciplinary INRA team (and later Agrivair), and the active participation of farmers in identifying and testing alternative practices, that made the experience a success.

The successful long-term partnership with a public research institution was also a key element of success. Without it, Agrivair would not have been able to develop the programme and validate recommended practices scientifically. There was at the time a "strong political support to make the experience successful, to a certain extent regardless of the overall costs" (Déprés et al., 2005). Much was at stake not only for Nestlé Waters but also for the municipality, which benefited from the employment created by the business and the tax revenues on Natural Mineral Water.

The Vittel case study illustrates the difficulty in establishing "Payment for Ecosystem Service" (Millennium Ecosystem Assessment, 2005). Agrivair had to go negotiate a series of legal, regulatory, social, technical, political and administrative hurdles before a successful partnership between Vittel and the local community could be established. It also illustrates the complexity of technical issues: how to calculate individual payments and estimate opportunity costs, as well as political issues such as the importance of other actors in influencing the bargaining process, and the rivalry within the farming community.

CONCLUSIONS

The growing stress on the world's water resources has further increased awareness about the importance of good water resources management and planning. Being as sustainable as the communities where we operate, everyone needs to take part in ensuring the sustainability of water resources (policy makers, industry, agriculture and individual consumers). Water supply is a global issue that has to be managed locally.

It is evident that there is no standard response for an international company like Nestlé Waters that has local operations in more than 35 countries. Each factory sets its own specific context. Still, beyond the technical and hydrogeological considerations, being able to pose the right questions, and show willingness to also understand the wider socio-economic context should be a good step forward on the road of responsible water management.

Most of the time, the scientific knowledge necessary to protect our resources over the long term is available. What is necessary above all is the maintenance of an open approach to the problem.

The Agrivair programme in Vittel has undertaken these challenges for the past decade. Nestlé Waters is now starting to act similarly all around the world (France, Argentina, Switzerland, Spain, Turkey, Italy, Mexico). This approach respects the definition of “sustainable solutions” in water management being strategic, innovative and over the long term. It perfectly reflects our vision of sustainable development, which is based on a profitable business model that serves consumers while respecting humankind and the environment.

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IAH 2010
Krakow

abstract id: **374**

topic: **1**
Groundwater quality sustainability

1.9
Sustainable management of groundwater

title: **Groundwater protection used for human consumption. Conceptual frame of the safeguard zones**

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keywords: groundwater, protection, safeguard zones, Water Framework Directive, geographical information system

ABSTRACT

Groundwater is a basic source of supply for populations and for other activities related to the human development. For this, it is necessary to establish suitable protection measures in order to achieve the good status of groundwater bodies intended for human supply according to the requirements of the Water Framework Directive (WFD).

In this work a conceptual frame is defined for the delimiting safeguard zones in the groundwater bodies destined to human consumption according to the requirements of the WFD. It is necessary to create a methodology that considers the distribution of water body abstraction points, hydrogeological criteria, evaluation of pressures and vulnerability, also considering the wellhead protection areas of abstraction points among others. The processing and analysis of these data by means of a Geographical Information System (GIS) will allow the establishment of safeguard zones in groundwater bodies.

As a general protection measure, the first advances, in Spain, in the development of a methodology to delimit safeguard zones are presented here.

INTRODUCTION

The protection of water has become one of the high-priority environmental objectives in the European Policies with the entry into force in the year 2000 of the Water Framework Directive (WFD), Directive 2000/60/EC of the European Parliament and of the Council (European Union, 2000), and the Directive 2006/118/EC of the European Parliament and of the Council, in the year 2006 (European Union, 2006), regarding the protection of groundwater against pollution and deterioration. Groundwater constitutes a basic resource in Europe which is demonstrated in countries such as Austria, Germany, Italy or Denmark where more than 70% of the population's water supply comes from groundwater (Martinez Navarrete et al., 2008).

The need to make the socioeconomic activity compatible with the safeguard of the groundwater quality has been approached historically by means of the zoning of the territory made by the characterization of the environment. Since protection strategies have delimited wellhead protection areas (source) and the intrinsic vulnerability has been evaluated to the pollution of the aquifers to protect the resource. These figures of protection are of great utility but they must be combined with other factors to provide to the groundwater bodies of a suitable protection.

In this work a conceptual frame is defined for the delimiting safeguard zones in the groundwater bodies destined to human consumption according to the requirements of the WFD. This figure of protection is equivalent to "wellhead protection areas" of the groundwater bodies destined for the human consumption according to the article 7.3 of the WFD.

Once the propose zoning is made, it is necessary to analyze and to integrate these protection areas in the different policies with incident in the land management. Therefore it should be accompanied by a guide of recommendations and restrictions in relation to installation of new human activities, conditionings to subject to pressures or location of new captations for supply.

SAFEGUARD ZONES AS A MEASURE OF PROTECTION

The "safeguard zones" are areas (that can be established optionally as stated in the WFD) whose scope focuses on measures to protect groundwater with the aim of avoiding the deterioration of water quality and reducing the level of purification treatments required for human water consumption. This is a highly recommendable option as it has been extensively used for the delimitation of numerous water bodies in several Member States.

They are therefore equivalent to "wellhead protection areas" of groundwater bodies intended for human consumption according to article 7.3 of the WFD. The size of the "safeguard zones" can be highly variable; in many cases they will be smaller than the groundwater body and several "safeguard zones" can coexist in the same water body as well as extend outside of it, which for example occurs with karst materials due to their characteristics and the location of their recharge zones. On the other hand, "safeguard zones" can correspond to the entire extension of a groundwater body or surround the wellhead protection areas of existing abstraction points (Figure 1) (Jiménez Madrid et al., 2008).

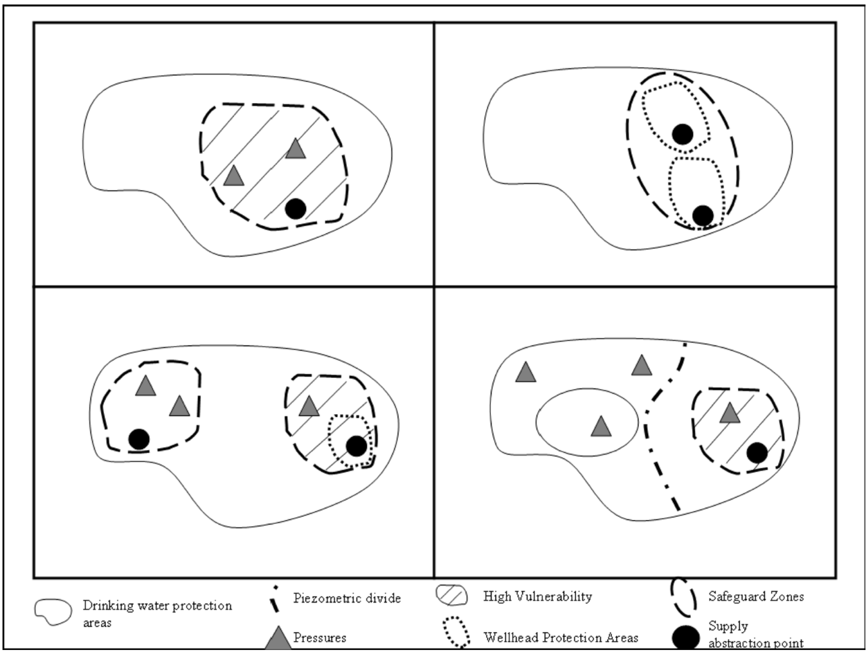

Figure 1. Possible configurations of safeguard zones.

In order to be able to apply these considerations to a large number of groundwater bodies, as is the case in Spain, it is advisable to use a methodology that specifically considers the contamination risk when delimiting safeguard zones. (Jimenez Madrid et al., 2008, 2010). To achieve a global protection, priority measures should be considered as follows:

- Water supply abstraction points: The location and characteristics of groundwater abstractions intended for human consumption are analysed (according to the requirements of the WFD: > 0.1 L/s or serves 50 persons).
- Previously established wellhead protection areas for abstraction points intended for water supply.
- Established wellhead protection areas for mineral waters.

- Information referring to purification treatments (as a reference point to prevent its possible contamination resulting from pressures).
- Intrinsic vulnerability of groundwater bodies to contamination.
- Pressures on groundwater bodies and risk evaluation.
- Definition of aquifer recharge zone boundaries.
- Establishment of monitoring networks in protected areas, by selecting representative abstraction points intended for human consumption, to verify the fulfilment of article 7.3 of the WFD.
- Groundwater body piezometric levels and flow directions.
- Effects of seawater intrusion.

The analysis of each of these parameters and their joint assessment through GIS tools will allow the establishment of a conceptual framework for the development of a methodology to delimit safeguard zone boundary lines as a global protection measure of groundwater bodies intended for human consumption.

Once the proposal of safeguard zone boundaries has been defined, it is necessary to draft a recommendations and restrictions guide in relation to the introduction of new activities, conditioning factors of existing pressures or location of new abstraction points. In order for the protection measures to have a positive effect, they should be included in the urban regulations and other regional policies affecting the land use.

FIRST ADVANCES IN SPAIN

In order to define safeguard zones in all groundwater bodies used for human consumption, a collaboration project is being carried out in Spain between the Ministry of the Environment and Rural and Marine Affairs and the Geologic Survey of Spain. Preliminary results contemplate four possible zones in groundwater bodies:

- A. Safeguard zone with heavy restrictions
- B. Safeguard zone of future prevention
- C. Safeguard zones not established
- D. Safeguard zone with moderate restrictions

The zones to be established will be defined in different phases with an increasing degree of complexity and precision in the work required. In this work we present the preliminary results obtained after the application of the first phase of work. In the First Phase (Table 1) each groundwater body used for human consumption will be analysed in its whole extension, to identify which of the 4 zones proposed (A, B, C, D) can be distinguished in them, according to the vulnerability pressures analysis.

For the vulnerability analysis of groundwater bodies crossing territorial boundaries within Spain, the COP method (Vías et al. 2006) has been used for carbonate aquifers and the reduced DRASTIC index (DGOHCA and IGME, 2002) for intergranular porosity aquifers. These obtained vulnerability classes have been sorted into in two groups (Table 1).

Table 1. Criteria for the delimitation of safeguard zones in Spain (First Phase).

CRITERIA FOR THE DELIMITATION OF SAFEGUARD ZONES			
VULNERABILITY (V)		**PRESSURES (P)**	
Group	**Score**	**Group**	**Score**
COP: Range between 0-1 = HIGH	2	Existence of pressures in the scope of the groundwater body	4
COP: Range between 1-15 = LOW	1		
Reduced DRASTIC: Range between 72-156= HIGH	2	Nonexistence of pressures in the scope of the groundwater body	2
Reduced DRASTIC: Range between 16-72 = LOW	1		
Zone A (V + P = 6): High vulnerability and significant pressures.			
Zone B (V + P = 5): High vulnerability and insignificant pressures.			
Zone C (V + P = 4): Reduced vulnerability and insignificant pressures.			
Zone D (V + P = 3): Reduced vulnerability and significant pressures.			

Existing pressures in each groundwater body have also been evaluated obtaining a layer in which they are all projected and overlaid according to the criterion set out in Table 1. Finally, using GIS tools, the joint analysis of both factors was carried out by adding the scores given to the vulnerability and pressures and thus cataloguing the entire extension of the groundwater body.

RESULTS

Figure 2 show the first results obtained in the Intercommunal Basins of Spain inside the project carried out in Spain between the Ministry of the Environment and Rural and Marine Affairs and the Geologic Survey of Spain.

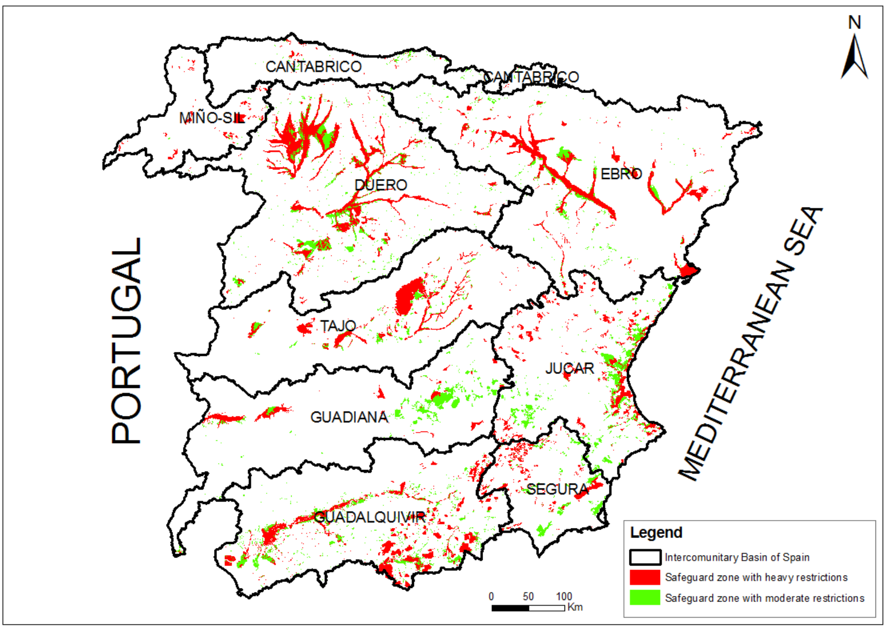

Figure 2. First results in intercommunitary river basins of Spain.

The safeguard zone type A occupy on 5% of the surface in all the Basins except in the Guadalquivir and Segura Basins where they spread for over more than 10 % of the territory (Table 2).

Table 2. % occupation of the territory of the safeguard zones type A in the different Basins.

BASIN	% OCCUPATION
DUERO	5,75 %
TAJO	2,49 %
MIÑO-SIL	1,54 %
SEGURA	10,21 %
JÚCAR	5,21 %
EBRO	5,75 %
GUADIANA	2,49 %
CANTÁBRICO	1,54 %
GUADALQUIVIR	10,21 %

CONCLUSIONS

The protection of groundwater used for human consumption is one of the high-priority environmental objectives of the Water Framework Directive. The establishment of safeguard zones as a global measure of protection for groundwater bodies intended for human consumption is an advisable option to comply with the requisites imposed by the WFD.

An initial methodological approach has been developed for the delimitation of safeguard areas which is divided in several working phases. In this work, we present the preliminary results obtained after the application of the first phase of work. In the first phase the evaluation of intrinsic vulnerability to contamination and the existence of pressures are considered.

Once the proposal of safeguard zone boundaries has been defined, it is necessary to elaborate a recommendations and restrictions guide and they should to be included in the urban regulations and other regional policies affecting the land use.

In future phases of works it will be necessary to contemplate other factors that allow the characterisation of safeguard zones of groundwaters used for human consumption with more accuracy.

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abstract id: **448**

topic: **1**
Groundwater quality sustainability

1.9
Sustainable management of groundwater

title: **Comparison of common and new methods to determine infiltration rates in Lake sediments**

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keywords: infiltration rates, methods, lake bank filtration

INTRODUCTION

For more than 100 years, rivers and lakes have been used as a source for bank filtration in Europe. Due to its proven efficiency in pathogens and persistent contaminants removal many developing countries such as Brazil, India and Egypt have also used this system for drinking water supply in the last few years. The amount of riverbank filtered water used for public supply is dependent on the stream bed permeability, in addition to other factors such as pumping rate, river elevation, water viscosity and stream bed thickness. Fischer *et al.* (2005) reported that the proportion and the volume of bank filtrate strongly depend on riverbed clogging. The deposition of fine grained sediments on the stream bed normally happens during low stream velocities. In addition, algal growth in higher temperatures can result in the deposition of organic matter on the bottom of the stream. This causes the increase of the streambed thickness, while consequently decreasing the bed permeability. During lower temperatures the water viscosity increases, thus reducing the water flow through the sediments. The increased flow velocity during floods causes cleaning of the river bed and re-suspension of the sediments, thus the thickness of the stream bed is assumed to decrease and bed permeability to increase.

Interest in analyzing infiltration rates has increased because of the necessity of water management at sites with high abstraction rates as well as sites with decreasing abstraction rates. At the same time, a variety of techniques and methods has been developed to examine and monitor infiltration. An improved understanding of the connection between surface and groundwater is viewed as an important prerequisite to effectively managing these resources (Sophocleos, 2002).

This study provides a comparison of new and common techniques to determine infiltration rates. Methods using Rn-222 (Macheleidt et al., 2006), fluorescent tracers such as melamine resin particles and air-dried FPOM from alder leaves (Gunkel et al., 2009), temperature and the use of monitoring wells and seepage meters (Rosenberry and LaBaugh, 2008) will be discussed and compared.

DESCRIPTION OF METHODS

Three of the most commonly used methods to calculate or directly measure groundwater flow will be described in the first section, with new methods described later. All of them are useful to determine infiltration rates under specific conditions.

Common methods for infiltration studies

Segment Approach Method

In this method, the shore-line of the superficial water is divided into segments (Figure 1). The number of segments depends on the number of observation wells. Hydraulic conductivity and the gradient between the well and the surface water are determined for each shore-line and consequent observation well. This method considers the area of a vertical plane (A), which consists of the length of the shore-line segment (m) multiplied by the thickness of the aquifer (b). The amount of water that passes through each the vertical plane is calculated by the Darcy's equation (Equation 1),

$$Q = KA\frac{h_1 - h_2}{L} \tag{1}$$

where Q is the flow through the vertical plane (L^3/T), K is the horizontal hydraulic conductivity (L/T), A is the area of the vertical plane (L^2), h_1 and h_2 are the hydraulic head difference between the observation well (h_1) and the surface water (h_2) in (L), and L is the distance from the observation well to the shore-line (L). The net flow is calculated using the sum of flows to and from the surface water. The infiltration rates for each of the sections are obtained also using equation 1.

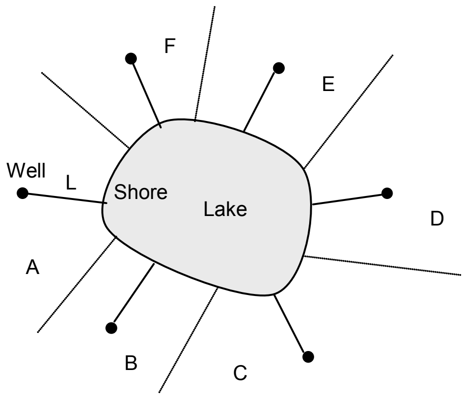

Figure 1. A segmented lake based on positioning of near-shore water-table wells. Adapted from Rosenberry et al., 2008.

Seepage Meter

This method is one of the most commonly used for measuring the infiltration rate directly in the sediment-water interface. It consists of the use of a cylinder attached to a plastic bag partially filled with a known amount of water. The cylinder is submerged in the water and placed in the sediment of the water body. The plastic bag is attached to the chamber and the change in volume is measured (Figure 2). The volumetric rate of flow through the part of the bed covered by the chamber is obtained. To calculate the infiltration rate, it is necessary to divide the volumetric flow rate by the area covered by the cylinder.

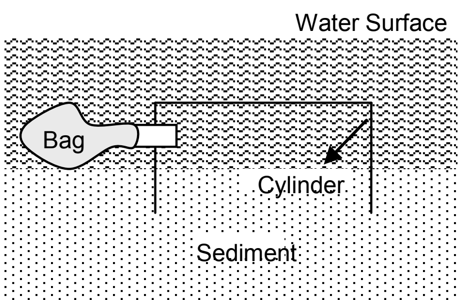

Figure 2. A typical seepage meter to estimate infiltration rate. Adapted from Rosenberry et al., 2008.

Temperature

The continuous exchange of water between the surface and groundwater provides an opportunity to use heat as a natural tracer to estimate infiltration rates indirectly. The use of heat as a tracer relies on the measurement of temperature gradients. Water and sediment temperature can be measured either directly by using a probe driven into the ground or indirectly by measuring water temperature at different depths in an observation well. In both cases it is necessary to use a probe connected to a data logger that can be programmed to read the parameter at least daily. More exact measurements will read the parameter every hour.

Many models of heat and groundwater transport have been developed. One of them was developed for cases where pore water velocities are sufficiently high and heat transport by conduction is negligible when compared to heat transport by advection. For this case, pore water velocity, v (m/s) is calculated by equation 2:

$$\mathrm{v} = \mathrm{v}_T \frac{1}{\theta}\frac{Cs}{Cw} \tag{2}$$

Where v_T is the vertical velocity of the temperature peak down into the streambed sediments (m/s), θ is the percent volumetric water content, C_S is the volumetric heat capacity of water, and C_W is the bulk sediment (both in $J/(m^3\ K)$).

In order to estimate infiltration rates, a computer modelling program from the U.S. Geological Survey called VS2DH has been used, where streambed temperature profiles are defined as input. This two-dimensional simulation code is based on inverse modelling to match simulated temperatures against measured temperatures to estimate heat and water fluxes into or out of the streambed.

Infiltration Chambers

In situ infiltration rates can also be determined by using special plexiglass chambers. The plexiglass is pressed into the sediment and connected (without pressure) to a plastic bag, which is previously filled with a known amount of water. After a period of 24 hours, the plastic bag is retrieved and reweighed. The infiltration rate can be determined by equation 3,

$$IR = \frac{Q}{A} \rightarrow where \rightarrow Q = \frac{V_i - V_f}{t} \tag{3}$$

where IR is the infiltration rate (m/h), Q is the flow (m^3/h), A is the cross sectional area of the infiltration chamber (m^2), V_i is the initial volume of the bag (m^3), V_f is the final volume of the bag (m^3) and t is the exposition time (h).

New Methods for infiltration studies

Fluorescence labelled tracers

The fluorescent labelling method is normally used as a tool for the investigation of particle transport in sediment interstices but can also be utilised as a method of infiltration rate analysis (Gunkel et al. 2009). In this procedure, melanine resin particles (which are produced by a private company) are labelled with 7-amino-4-methylcoumarin (AMC). The fluorescing MF-AMC particles have a blue colour (λex 360 nm / λem 429 nm), a density of 1.5 g cm^{-3} and a hydrophilic surface charged positively by amino groups. The particles are delivered in aqueous medium and are used for studies in microfine particle transport.

In addition, fluorescein-5-isothiocyanate (FITC) fluorescent labelling (λex 560 nm / λem 529 nm) (produced from a private company as well) is also a method that allows the study of vertical particle transfer in sediments. The application of this fluorescent can be utilised in natural organic substrates from the sampling site or for analysis of the biological decomposition of particulate organic material. In both fluorescent methods the recovering rate of the tracer is analysed at different depths in order to investigate the infiltration rate.

The restriction of this method is the need of sophisticated materials such as fluorescent tracers and microscopes equipped with UV lamps. The use of incorrect filters can cause errors in detecting the colour of the fluorescent particles in the sediment. Particle agglomeration can also be a problem when the samples are not ultrasonicated. Furthermore, the ingestion of FITC-labelled particles by invertebrates can occur, and severe clogging can hinder the vertical transport of the fine resin particles.

Radon-222

Radon-222 (^{222}Rn) is an inert natural gas found in different concentrations in groundwater and superficial water. It is the natural decomposition product of the radioactive ^{226}Ra, which also exists in the soil. In groundwater it is in equilibrium with ^{226}Ra, but in surface water its high volatility prevents its presence. As a consequence, it can be used as a natural tracer to estimate infiltration rates indirectly, based on its equilibrium concentration and retention time. For the application of this method, the homogeneity of ^{222}Rn emanation in the soil is assumed.

The restriction of this method is in the local sedimentary stratification, which can influence the equilibrium concentration of ^{222}Rn. In addition, the volume of gas in the saturated upper zone of the aquifer can influence the concentration of ^{222}Rn and its measurements.

CONCLUSION

Table 1 shows some positive and negative aspects for the methods described before. The selection of the method to estimate infiltration rates depends on availability of material, field site conditions, streambed grain distribution, etc. In general, all field measurements must be conducted at many locations in the river/lake bed to obtain reliable data for infiltration rates.

Table 1. Brief comparison between common and new methods.

Method		Positive Aspects	Negative Aspects
Common Methods	Seepage Meter	It is a direct measurement of infiltration rates; Possibility of having a good idea of the real distribution of the flux; Well suited for calm and shallow water settings (Rosenberry and LaBaugh, 2008).	Badly suited for surface water with strong hydraulic movement; Very soft and rocky sediments might are not adequate; Dense vegetation interferes in the measures (Rosenberry and LaBaugh, 2008).
	Segment Approach Method	It is possible to quantify flow between groundwater and surface water; Interesting for homogeneous aquifers; It is possible to have a general idea of the aquifer characteristics (Rosenberry and LaBaugh, 2008).	No information about infiltration rates at a specific area. Large numbers of monitoring wells needed.
	Temperature	Heat is a natural tracer free from issues of contamination associated with the use of chemical tracers; Well suited for investigations of stream/groundwater exchanges; Temperature data are immediately available as opposed to most chemical tracers (Rosenberry and LaBaugh, 2008).	Very low hydraulic gradients and/or extensive clay-textured streambeds can affect the temperature measurements (Rosenberry and LaBaugh, 2008).
	Infiltration Chambers	Infiltration rates can be measured *in situ* and it is relatively fast to obtain the measured results; It is relatively easy to handle; Low costs for building.	Badly suited for surface water with strong hydraulic movement; Rocky sediments might are not adequate; Dense vegetation might interferes in the measures.
New methods	Radon-222	It is a natural gas found in different concentration in groundwater and superficial water; Possibility of having a good idea of infiltration rates regimes (Macheleidt et al., 2006).	High volatility of Rn-222 when in contact with atmosphere; Demands specific sampling; Expensive Rn analyser needed; Sedimentary stratification can influence the concentration of Rn-222 (Macheleidt et al., 2006).
	Fluorescent Labelled Tracers	It is a possibility of measuring infiltration rates by labelling natural organic substances from the sampling site (Gunkel et al., 2009).	High costs for fluorescent particles; Severe clogging can limit the resin passage through the sediment; Ingestion of tracers by invertebrates; Particle agglomeration (Gunkel et al., 2009).

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IAH 2010
Krakow

abstract id: **517**

topic: **1**
Groundwater quality sustainability

1.9
Sustainable management of groundwater

title: **Sustainable groundwater management in the North China Plain: main issues, practices and foresights**

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keywords: groundwater management, groundwater overexploitation, scenario analysis, the North China Plain, dualistic model

The North China Plain in this paper denotes the Hai River Plain, the north part of the Vast North China Plain, as shown in Fig.1. It is the political center and the economically- developed region of China, including 5 cities or provinces of Beijing, Tianjin, Hebei, Henan and Shandong, with an area of 131000 km^2. The groundwater aquifer system in the North China Plain belongs to the Quaternary geological system, and the unconfined aquifer system can be classified into 3 types, i.e., the mountain-front alluvial and diluvial plain of abundant groundwater, the eastern alluvial and lake-formed plain of semi-abundant groundwater and the coastal alluvial and sea-formed plain of weak groundwater.

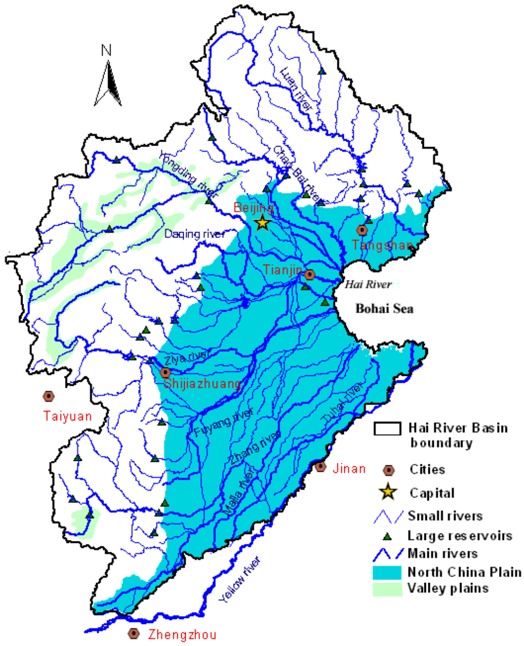

Figure 1. The North China Plain and the Hai River Basin.

Main groundwater issues in the plain are summarized, which include groundwater level declining (Fei et al., 2007), geological-environmental issues due to the overexploitation, groundwater pollution, drying up of river channels, shrinking of wetlands and decreasing of flow into the Bohai Sea. The followed is an introduction to the management practices conducted in the plain, which includes groundwater overexploitation control, water-saving, slightly-saline groundwater utilization, artificially recharging of groundwater aquifer and public participation.

Based on the above basic information, main issues and management practices, foresights and desired measures for the sustainable groundwater management in the plain are discussed by analyzing 9 scenarios using a dualistic model, in which hydrological conditions, water saving measures to reduce water use, groundwater use reduction and water diversions from the Yellow River and the Yangtze Rriver. It is concluded that the groundwater aquifer restoration in the plain is not optimistic in a short period, integrated implementation of technical, administrative and legal measures is desired to realize safe exploitation of groundwater in the plain and to increase the river flow into the Bohai Sea in 2020 above all things, and to restore the deteriorated groundwater system in the following decade subsequently.

MAIN GROUNDWATER ISSUES

Groundwater overexploitation

With the water use increase in the North China Plain, the groundwater overexploitation occurred in some area in 1970s. The groundwater overexploitation area gradually spread since then, and the accumulated overexploitation amount has been over 90 billion m^3 at present in which about 50% is from the shallow groundwater and the remaining 50% is from the deep groundwater. In 2004, the overexploited groundwater amount was 6.12 billion m^3, accounting for 30% of the total groundwater use in the plain. The total water use was 29.42 billion m^3, and 69% was from the groundwater with 16.25 billion m^3 from the shallow fresh groundwater (salinity <2g/L), 0.34 billion m^3 from the shallow brackish groundwater and 3.67 billion m^3 from the deep groundwater. The urban groundwater use and the rural groundwater use accounted for 1/3 and 2/3 of the total groundwater use respectively (He, 2006).

In the shallow groundwater system, the total overexploited area has reached 59600 km^2, with 11 big funnel-shaped groundwater depression areas. The deepest funnel was located at the southern Shijiazhuang with the maximum depth below the land surface of 52.3 m, and the maximum depth below the land surface in Beijing was 35 m (He, 2006). Because of the long-term overexploitation, the groundwater in the unconfined aquifer systems in the northern Tanshan, the southwestern Beijing and the Heibei plain in the front of the Taihang Mountain has been used up. As an example, Fig.2 shows the annual variation of groundwater level in the funnel center in Shijiazhuang city.

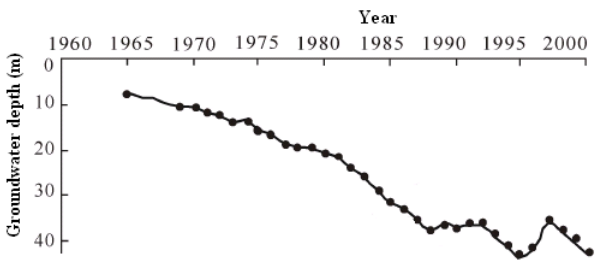

Figure 2. Annual variation of groundwater level in the funnel center in Shijiazhuang city.

In the deep groundwater system, the total overexploited area has reached 56100km^2, mainly distributed in Cangzhou and Hengshui of Hebei province, Tanggu and Hangu of Tianjin city, and Dezhou of Shandong province. The deepest withdrawl depth at the funnel center of Tianjin has been over 105 m. If the declining trend continues, the aquifer water will be exhausted and over 30 million people will be threatened by no groundwater supply.

Geological-environmental issues caused by groundwater overexploitation

The groundwater overexploitation has caused the following four main geological-environmental issues (HRWCC, 2002): 1) Regional land subsidence. Based on observations, area with the accumulated subsidence of over 500 mm reached 8200 km^2 in 1990, and 13700 km^2 in 1995. 2) Geological disasters. The declined groundwater level has caused over 200 cracks of land and river dikes in the plain, mainly distributed in Tianjin, Tanshan, Langfang and Baoding cities. A crack length has a range of several meters to 1000 m, the crack width is from 1 cm to 200 cm, and the biggest depth is 10 m. 3) Seawater intrusion. The overexploitation in the coastal area caused the seawater intrusion into the fresh groundwater aquifer system. The most seriously impacted district was the alluvial area of Yang river and Dai river in Qinghuangdao city. The seawater intruded distance toward inland was about 6 m to 8 m, and the area was over 50 km^2 in 1993. Tianjing city is also threatened by the seawater intrusion. 4) Deep groundwater quality deteriorated by the moving down of the brackish groundwater front. The main influenced area reaches Hengshui and Cangzhou cities of Hebei province. For instance, in Cangzhou, the area with 10 m moving down of the brackish groundwater front was about 1959 km^2.

Groundwater pollution

Based on the investigation and assessment of groundwater in the Integrated Water Resources Planning of the Hai River Basin (Ren, 2007), the ratio of the polluted groundwater aquifer area (i.e. the groundwater quality is worse than the Class III) to the plain area is 76.4%. The monitoring and assessment results show that 41.7% of the polluted groundwater aquifer is originated in the human activities, with the lightly polluted area of 34496 km^2 and the seriously polluted area of 27892 km^2. The main pollution items are NH_3-N, salinity, COD-Mn, NO_3-N and NO_2-N. The three main reasons of the groundwater pollution are attributed to the infiltration of surface water polluted by urban and industrial wastewater, the infiltration of agricultural irrigation water including manure and chemicals, and the untreated industrial castoff and urban garbage (Zhang, 2006).

Drying up of river channels and shrinking of wetlands

The groundwater overexploitation reduced the river base flow from the groundwater drainage and even made the river water recharge the groundwater. Together with the dam construction in upstream mountain areas (31 large dams with a total volume of 24.9 billion m^3), many downstream river channels in the plain were dried up almost through a whole year, which further caused the desertification of river beds and sediments. River channels of Yongding, Hutuo, Zhanghe, Cihe and Shahe have become the source area of sandstorms in the plain.

The natural wetland area in 1950s was 9000 km^2, but the sum of natural wetland area plus reservoir-formed water surface area is only 3852 km^2 at present. Baiyangdian, the biggest wetland had become dry for many years in 1980s, and now it relies on the water diversion from the Yellow River.

The runoff discharge into the Bohai Sea has greatly decreased. It reduced from 11.6–24.1 billion m^3 in 1950s–1970s to 2.7–6.9 billion m^3 in 1980s–1990s. Due to the reduction of river water into the sea, the sedimentation issue at river mouths/estuary becomes quite serious, and the ecosystem in the river mouth area has been seriously damaged.

MANAGEMENT PRACTICES

Control of groundwater overexploitation

Control of groundwater overexploitation is the most important measure at present to prevent the aquifer system from a further deterioration. In 2007, the Ministry of Water Resources of China (MWR) worked out the Groundwater Exploitation Reduction Scheme for the Water Supply Area of the South-North Water Transfer Project, with the North China Plain as its main part. In 2004, the Ministry of Water Resources of China and the State Environment Protection

Agency of China (SEPA) jointly carried out a program called Integrated Water Resources and Environment Management in the Hai River Basin (the executive period: 2004–2010) at the support of the Global Environment Fund (GEF) of World Bank. The program includes a project called Strategic Study for Sustainable Groundwater Exploitation and Administration of Water Rights and Well Permits in the Hai River Basin (abbreviated as SSG hereafter), and a pilot project called Well Permits and Administration of Water Rights in Cheng'an county (abbreviated as PPG hereafter).

Water-saving

Agriculture is dominant in the groundwater users in the plain. Therefore, the water-saving is the main concern in the plain. The following agricultural water-saving practices were promoted in the plain: 1) turnover of traditional crops to different fitting ones, i.e., reducing the ratio of the highly water-consumed grain crops like winter wheat while increasing the ratio of the lowly water-consumed cash crops like cotton (with plastic film covered on farmland); 2) water use gauging facilities for well irrigation area; 3) small plot irrigation with low-pressure pipes; 4) application of micro-irrigation techniques like dripping irrigation; and 5) spreading of water-saving irrigation.

For industrial and domestic water uses, new ideas were put on adoption of water-saving facilities to reduce water leakage of pipes, toilet flashing water use, consumption of circulation cooling water of industries, and reuse of treated wastewater.

Utilization of slightly-saline groundwater

The slightly-saline groundwater is defined as the groundwater with salinity higher than 2 g/L but lower than 3 g/L, which has a total amount of 1.7 billion m^3 in the plain. Because of serious water shortage in the plain, some regions had tried the utilization of slightly-saline groundwater to replace the deep groundwater exploitation. A pilot project in Guantao County was established (IHRH & WCBGC, 2009).

Artificial recharging of groundwater system

Artificial recharging experiments for groundwater system were also carried out in the plain (Han, 2001). The first example is about an experimental site in the downstream Chaobai river channel, in which 9 weirs (width: 300–400 m, height: 3–5 m) were constructed from 1984 to 1998 to use the discarded flood from the upstream Miyu reservoir to recharge the overexploited shallow groundwater. The second example is about a site in the downstream Yongding river channel in 1981, which included artificial recharging to both shallow groundwater and deep groundwater. The third example is about a site in the Tianjin city in 1980, which artificially recharged to deep hot groundwater.

A recent example is well injection experiment for the planned groundwater reservoir in the Futuo river (i.e. upstream of Ziya river) reach in Shijiazhuang city. The experiment was carried out on 20 August 2009, lasting for 17 days and recharging 18 million m^3 water discharged from the upstream Huangbizhuang reservoir. In the experiment site, 12 observation wells of 50 m deep were prepared in the recharging zone, and 40 monitoring wells were drilled in the outside impacted zone.

Public participation

At the support of the World Bank GEF program mentioned above, the public participation in water resources use management in the well irrigation districts were enhanced through introduction and dissemination of Water Users Associations (WUA) and Community Driving Development (CDD). In addition to the above mentioned Cheng'an County, 4 counties of Guantao, Feixiang, Linzhang and Shexian (see Fig. 3) also implemented the WUA and CDD establishment.

FORESIGHTS

The fact of the serious groundwater issues, though many management experiments have been practiced, to restore the deteriorated groundwater system in the North China Plain is still a big challenge. Because of a close connection between surface water system and groundwater one, an integrated management of both systems is desired. What will be the future vision of water resources in the region?

We developed a natural-artificial dualistic water cycle model (2008) in combination with a distributed hydrological parameter model, a groundwater numerical model, a water resources allocation model and a multi-objective decision-making model, and they applied the model to analyze 9 scenarios of water resources development in the Hai River Basin in 2005, 2010 and 2020 (see Table 1) with due regard to socio-economic and environmental water demands, water-saving measures, hydrological conditions, groundwater overexploitation control, preferable river discharge into the Bohai sea, the South to North Water Transfer (SNWT) projects and the Water Transfer from the Yellow River (WTFYR).

Table 1. Scenarios of Water Resources Development in the Hai River Basin (unit: $10^8 m^3$)

Planning year	Scenario	Hydrol. series	Precip.	Overexploited groundwater	Water into sea	SNWT Middle Route	SNWT East Route	WTFYR
2005	actual	2005	1558.5	78.0	24.9	0	0	37.3
2005	S1	1980–2005	1596.2	80	35	0	0	46.2
2010	S2	1980–2005	1596.2	53	35	0	3.65	46.4
	S3		1596.2	53	55	0	3.65	46.4
	S4		1596.2	53	55	56.4×50%	3.65	46.4
	S5	1956–2005	1695.4	53	93	56.4×50%	3.65	46.4
2020	S6	1980–2005	1596.2	0	55	58.7	14.2	47.0
	S7		1596.2	0	93	58.7	14.2	47.0
	S8	1956–2005	1695.4	0	93	58.7	14.2	47.0
	S9	1980–2005	1596.2	0	35	58.7	14.2	47.0

Applying the analyzed results on the basis of 9 scenarios, through a intensive water-saving and reducing groundwater abstraction, it is possible to realize the target of reducing 1/3 groundwater overexploitation and increasing river water into the Bohai Sea to 5.5 billion m^3 besides guaranteeing the economic water use (S4 in Table 2). However, the target of zero groundwater overexploitation is difficult to realize a case of scenario (S6 in Table 2), which requires to reduce 9.5 billion m^3 of drawing groundwater, and 8.2 billion m^3 of the consumed groundwater. In addition to water-saving policy in agricultural groundwater use, large amount of agricultural groundwater use in well irrigation districts will need to be changed into surface water, which poses the requirement for constructing a lot of water dams, water conduits and water-distributing facilities. Who will pay for the required heavy investment? This is closely related to action of new national and local government policies in the light of a deliberate study.

Therefore, a good management of groundwater resources is desired through control of groundwater abstraction, more intensive water-saving, efficient utilization of SNWT and WTFYR water, and integrated implementation of technical, administrative and legal measures.

CONCLUSION

As a reaction of rapid socio-economical development and irrational water resources development in the North China Plain, serious groundwater issues occurred in overexploitation, geological-environmental troubles, groundwater pollution, drying up of river channels, shrinking of wetlands and decreasing of water flow into the Bohai Sea. National projects to settle those problems were committed to field experiments, such as control of groundwater overexploitation, water-saving, utilization of slightly-saline groundwater, artificial recharging of groundwater aquifers and public participation. However, tested experiments on analyzed results along feasible scenarios showed still a big challenge to restore the deteriorated groundwater system in the North China Plain. Integrated implementation of technical, administrative and legal measures can meet to realize safe exploitation of groundwater in the plain and to increase river discharge into the Bohai Sea in 2020 at first, and to restore the deteriorated groundwater system in the following decade.

ACKNOWLEDGEMENT

The research got financial supports from the National 973 Program of China (2006CB403404), the NSFC (the National Scientific Foundation of China) Project (50721006), and the GEF-Haihe Project of KM Application System Development in the Hai Basin (HW7-17).

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1.10 Decision support tools for sustainable groundwater management

abstract id: **136**

topic: **1**
Groundwater quality sustainability

1.10
Decision support tools for sustainable groundwater management

title: **Development of pedotransfer functions to estimate annual groundwater recharge rates in countries of the Arab region**

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keywords: percolation rate, groundwater recharge rate, pedotransfer functions, soil water balance, Arab countries

INTRODUCTION

Within the framework of the technical cooperation project "Management, Protection and Sustainable Use of Groundwater and Soil Resources" between the Arab Center for Studies in Arid Zones and Dry Lands (ACSAD, Damascus/Syria) and the Federal Institute for Geosciences and Natural Resources (BGR, Hannover/Germany) a Decision Support System (DSS) for water resources management was developed and applied in two pilot areas, the Zabadani Basin in Syria and the Berechid Basin in Morocco (Droubi et al., 2008). The DSS has been built by the combination and linkage of three components, a project database, a groundwater flow model (MODFLOW2000; Harbaugh et al., 2000) and a user-friendly water evaluation and planning software (WEAP; Stockholm Environment Institute 2005). For running the MODFLOW model water flows from soil to groundwater have to be determined because the percolation rate from the soil acts as one of the main input variables.

On a regional scale reliable estimates for annual values or long term means of the percolation rate from the soil are needed for quantitative water resources management. Conventionally precise information about movement of water in the unsaturated zone can only be obtained from lysimeter data, soil-hydrological measurements or process-based simulation models such as SWAP (Kroes et al., 2003). To avoid high costs of field measurements and limitations in the availability of model input parameters robust methods such as empirical equations and nomograms are needed. To characterize this kind of approaches Wessolek et al. (2008) use the term "hydro-pedotransfer functions" (HPTFs). They are based only on input variables that can be determined easily or are available from existing databases.

Exemplary for Germany HPTFs to predict long term means of the percolation rate from soil were developed by Wessolek et al. (2008). The authors used a simulation model of the soil water balance to calculate actual evapotranspiration and percolation for different climatic regions, soils and land use classes. The spectrum of site variations included four soils with different water storage capacities, six groundwater levels, sixteen climate stations whose climate parameter values can be viewed as representative of the climate regions of Germany, and four land use types [cropland (with the typical succession of grain and root crops), grassland, coniferous forest, and deciduous forest]. These conditions resulted in simulation runs for 57,600 years on a daily basis. The results of all the scenarios were analyzed by multiple regression statistics and equations were derived, from which reliable estimates of the target variable can be calculated. These HPTFs were used to compile a nationwide map of the annual percolation rate from the soil within the framework of the new Hydrological Atlas of Germany (HAD) (BMU 1998, 2001, 2003). A goal of this investigation is to adapt this methodology to semi-arid climatic conditions so similar results can be obtained for locations in a Mediterranean environment.

MATERIALS AND METHODS

The same methodology as described above was used to develop similar nomograms or empirical equations for countries of the Arab region. For simulating the soil water balance the CROPWAT model (Clarke et al., 1998) was used. CROPWAT is a decision support system developed by the Land and Water Development Division of FAO for planning and management of irrigation. CROPWAT is meant as a practical tool to carry out standard calculations for reference evapotranspiration, crop water requirements and crop irrigation requirements. Additionally CROPWAT offers plant physiological coefficients for 36 agricultural crops (crop coefficient Kc, rooting depth, depletion fraction, and yield response factor). All calculations are based on a daily soil water balance using various options for water supply and irrigation management conditions. From the soil scientist's perspective percolation beyond the lower boundary of the root zone equals groundwater recharge.

The CROPWAT software as well as the CLIMWAT database is available from the FAO homepage via download. CLIMWAT 2.0 offers observed agroclimatic data of over 5000 stations distributed all over the world. CLIMWAT provides long-term monthly mean values of seven climatic parameters as required for CROPWAT applications. For this investigation data from 188 meteorological stations from eight Arabic countries (Morocco, Algeria, Tunesia, Libya, Egypt, Jordan, Lebanon, Syria) were used. Typical kinds of land use of the Mediterranean environment were taken into consideration. Five soils were compared, varying in the total available water capacity of the uppermost meter (40, 80, 120, 160, 200 mm). For all simulation runs a fixed amount of surface runoff is assumed, i.e. precipation in Fig. 1–2 means effective precipitation or net input.

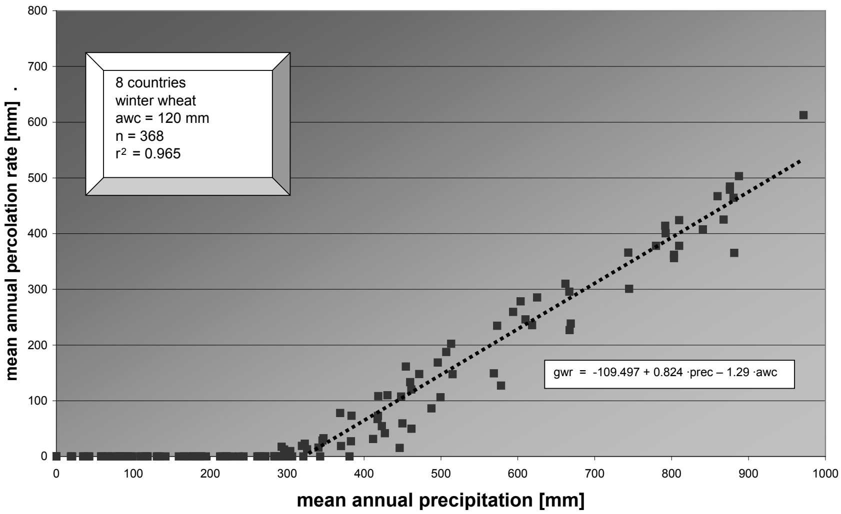

Figure 1. Annual percolation rate as a function of annual precipitation for land use type "winter wheat" and derived regression function.

First approach: preliminary pedotransfer functions derived from CROPWAT results for three kinds of land use under natural conditions

In Table 1 results for three kinds of land use (winter wheat, citrus trees, pastureland) are compared, and only natural conditions without irrigation are taken into consideration.

In order to predict mean annual percolation rates by HPTFs linear models based on precipitation and available water capacities are adequate. Based on the correlation coefficients in Table 1, the accuracy of these HPTFs is generally high. Accuracy in this context refers to correspondence between simulation model and pedotransfer function. Highly precise estimates of the target variable can be obtained on the basis of easily available soil, crop and climate information. Nomograms were developed for specific crops and varying soil properties and for specific locations and varying kinds of land use. An exemplary visualization of such a model and the derived regression equation is given in Figure 1. In the case shown, groundwater recharge from percolating water does not take place if effective precipitation is below a threshold of ≈ 300 mm.

Table 1. General conditions and summarized results of the first case study.

Land use type	Area	Target variable	Database	Statistically significant input variables	Correlation coefficient
Pastureland	8 countries	ETact	n = 940	Prec, awc	$r^2 = 0.929$
		GWR	n = 495	Prec, ETpot, awc	$r^2 = 0.930$
Winter wheat	8 countries	ETact	n = 940	Prec, awc	$r^2 = 0.912$
		GWR	n = 555	Prec, awc	$r^2 = 0.939$
	Syria	ETact	n = 220	Prec, ETpot, awc	$r^2 = 0.919$
		GWR	n = 185	Prec, awc	$r^2 = 0.968$
Citrus trees	8 countries	ETact	n = 940	Prec, awc	$r^2 = 0.922$
		GWR	n = 490	Prec, awc	$r^2 = 0.932$
	Syria	ETact	n = 220	Prec, ETpot, awc	$r^2 = 0.925$
		GWR	n = 170	Prec, awc	$r^2 = 0.960$

(ETact: actual evapotranspiration; GWR: groundwater recharge; Prec: precipitation; ETpot: potential evapotranspiration; Irrig: irrigation; awc: soil available water capacity)

Advanced approach: pedotransfer functions derived from model simulations based on the dual crop coefficient concept

The CROPWAT model applied in the first case study is based on the single crop coefficient concept, where differences in the crop canopy and aerodynamic resistance relative to the reference crop of the FAO Penman Montheith method are accounted for within the crop coefficient Kc. The Kc coefficient serves as lumped parameter for the physical and physiological differences between crops. Kc integrates the relationships between evapotranspiration of the crop and the reference surface and summarizes all factors influencing evaporation and transpiration. Therefore CROPWAT's use is restricted to the period of growth. In a second, more sophisticated approach Kc is split into two factors that separately describe the evaporation (Ke) and transpiration (Kcb) components. All relevant algorithms were published as part of the FAO Irrigation and Drainage Paper No. 56 "Crop Evapotranspiration" (Allen et al., 1998). Within the framework of the second case study the dual crop coefficient concept was applied to improve derived pedotransfer functions. In particular the following modifications were implemented:

- the dual crop coefficient concept was applied to calculate evaporation from bare soil before and after the period of growth and within its initial phase,
- the spectrum of typical Mediterranean crops was extended to olive trees and vegetables,
- CROPWAT-internal parameter settings were substituted by region-specific plant coefficients,
- the effects of irrigation were taken into account; generally irrigation up to maximum demand without yield reduction was simulated,
- expert knowledge about region-specific agricultural practices (sowing dates, irrigation practices, ...) was incorporated.

The second case study is restricted to Syria (44 meteorological stations) and includes six land use scenarios. Three crops under rainfed agriculture (wheat, barley, olives) are compared with three crops under irrigation (wheat, citrus trees, peas as an example for small vegetables). Based on the correlation coefficients in Table 2, mean annual percolation rates can be predicted by HPTFs very precisely.

Table 2. General conditions and summarized results of the second case study.

Land use type	Length of growing season	Sowing/ planting date	Period of potential evaporation	Statistically significant input variables for estimating GWR	Correlation coefficient
Winter wheat	240 days	1st Nov	155 days	Prec, awc	$r^2 = 0.957$
- no irrigation -					
Barley	160 days	1st Dec	225 days	Prec, awc	$r^2 = 0.967$
- no irrigation -					
Olives	270 days	1st Mar	125 days	Prec, awc	$r^2 = 0.951$
- no irrigation -					
Winter wheat	240 days	1st Nov	160 days	Prec, ETpot, Irrig	$r^2 = 0.989$
under irrigation					
Citrus trees	365 days	(whole	60 days	Prec, ETpot,	$r^2 = 0.957$
under irrigation		year)		Irrig, awc	
Vegetables	100 days	1st Apr	285 days	Prec, ETpot,	$r^2 = 0.999$
under irrigation				Irrig, awc	

(Prec: mean annual precipitation; ETpot: mean annual potential evapotranspiration; Irrig: irrigation; GWR: groundwater recharge; awc: soil available water capacity).

Regression models for rainfed cropping use only precipitation and soil available water capacity as independent variables while regression models for irrigated agriculture additionally integrate information on potential evapotranspiration. Outside desert areas in eastern parts of the country, the negative correlation between precipitation and potential evapotranspiration in Syria is not very strong; areas with high rainfall can be characterized by low evapotranspiration rates in the Antilebanon mountains as well as by high evapotranspiration rates on western slopes of the coastal range. For that reason estimated groundwater recharge as a function of precipitation only shows more variation under irrigated conditions. The distinction between rainfed and irrigated agriculture can also be found in Fig. 2: thresholds for the beginning of groundwater recharge in terms of annual precipitation are generally higher for non-irrigated crops than for crops that depend on irrigation in summer.

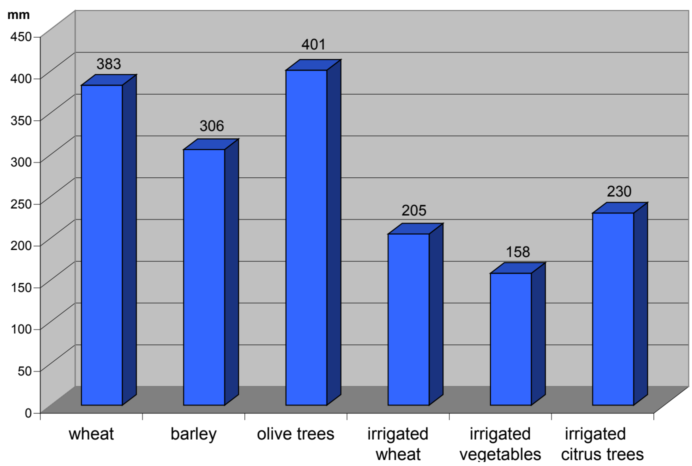

Figure 2. Minimum annual precipitation necessary for groundwater recharge for six agricultural crops in case of moderate soil available water capacity.

Another influencing factor is the crop itself: transpiration losses by crops with shallow rooting depths and short vegetation periods such as small vegetables are low in comparison to perennial crops with deep root zones such as olives. Against this background the following order of mean annual groundwater recharge under standardized conditions along land use types can be derived from model simulations: olive trees < wheat < barley < irrigated citrus trees < irrigated wheat < irrigated vegetables. (Hydro-) pedotransfer functions that require only easily available soil, crop and climate information as presented here can serve as a useful tool to provide reliable estimates of the groundwater recharge rate for most of typical land use types in Syria.

OUTLOOK/NEED FOR ACTION

Simulation results of the soil water balance following the dual crop coefficient concept were validated on the basis of measurement results from single test sites in southern Syria and Tunisia (Jabloun et al., 2008). By interpreting results from (hydro-) pedotransfer functions up to now some limitations have to be noted:

- The amount of surface runoff has to be known and was neither simulated by models nor empirically estimated.
- Results are not valid for groundwater affected soils with shallow water tables and capillary rise towards the root zone.
- Results are based only on long-term monthly mean values of agroclimatic data.
- All (hydro-) pedotransfer functions have to be furthermore validated on the basis of available measurements from test sites.

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abstract id: **145**

topic: **1**
Groundwater quality sustainability

1.10
Decision support tools for sustainable groundwater management

title: **The extent of the unconfined aquifer based on the Dempster-Shafer theory on the example of postglacial sandur area**

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keywords: Dempster-Shafer, accuracy, unconfined aquifer, nonparametric maps, decision support tool

INTRODUCTION

The extent of hydrogeological elements are represented in the cartographic studies based on the point or exploration performed in the field. With respect to distances, those limits are of probable course, more or less similar to the real boundary. Error assessment of graphic presentation of the hydrogeological elements, such as extent of aquifer has not been expressed in values yet. Hydrogeology cartography offers diversified studies, due to the reliability of data used. It is connected with the accuracy and likelihood of estimation of the extent of groundwater bodies and their amounts. Information about reliability of hydrogeologic studies is especially useful to readers from other speciality. Maps with nonparametric scale gives the reader easy readable data about quality of source information from area of research.

In the environmental studies, the proper use of the information (or the lack of the information) leads to searching for way to represent this kind of data. It is argued that the application of Boolean logic (the all-or-nothing system) in the GIS design causes some problems (Leung, Leung, 1993).

THE MAIN OBJECTIVE

The main study objective was to evaluate the probability that the shallow unconfined aquifer could be found in each pixel location in a surface represented in the studied area. The shallow aquifer is here defined as the aquifer of minimum 2 [m] thick, and at the depth less than 15 [m] from surface.

THE AREA OF RESEARCH

The research area in the east part of the Pomeranian Lakeland in Poland was chosen for testing this procedure (Figure 1). This area lies within border of sheet of Geological map. The relief of the studied area is characterized by forms of fluvioglacial from the last (Veichselian) glaciation. The main form is outwash sediments (the Wda sandur) and in little part a moraine plateau (Figure 1). Only Cenozoic water bearing strata have been recognized within the log wells. The Pleistocene water bearing layers form the major aquifer for the studied area. It consists of one unconfined aquifer and two or three confined aquifer.

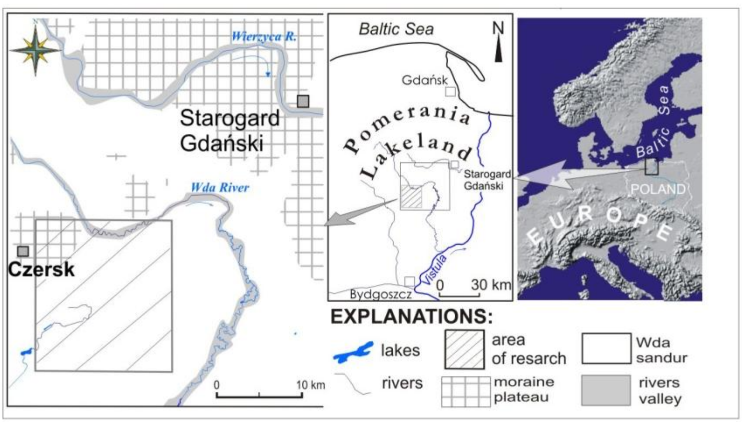

Figure 1. The location of the study site.

The hydrogeologic recognition of research area is weak. In study area there are 25 “hydrogeological recognition pixels” where drilled wells exist with logged geology profile and hydrogeologic parameters (Figure 2).

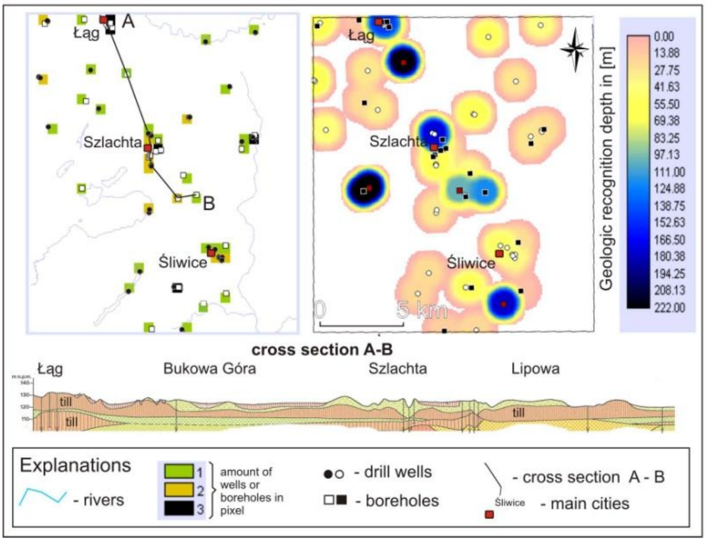

Figure 2. Location of “hydrogeological recognition pixels” on the research area (on the left), geologic recognition depth (on the right) and cross section (Trzepla, Drozd, 2005) (below).

METHODOLOGY

The Dempster-Shafer theory is an extension of Bayesian probability theory (Shafer, 1976). This theory makes a distinction between probability and ignorance and it allows for the expression of ignorance in uncertainty management (Lee et al. 1987; Klir, Yuan, 1995). By using the “belief functions” to represent the uncertainty of hypothesis, the theory releases some of the axioms of probability theory. The resulting system becomes a superclass of probability theory. Unlike Bayesian probability analysis, D-S theory explicitly recognizes the possibility of ignorance in the evaluation, i.e. the incompleteness of knowledge or evidence in the hypothesis (Eastman, 1999).

The research objective was performed on IDRISI raster based software program. In IDRISI, the BELIEF module can be used to implement the Dempster-Shafer theory. BELIEF constructs and stores the current state of knowledge for the full hierarchy of hypotheses formed from a frame of discernment. BELIEF first requires that the basic elements in the frame of discernment be defined. As the basic elements are entered, all hypotheses in the hierarchical structure will be created in the hypothesis list. For each line of evidence entered, basic probability assignment images (in the form of real number images with a 0–1 range) are required with an indication of their supported hypothesis.

The development of knowledge base

The research question guides us to define the frame of discernment — it includes two elements [present] and [absent]. The hierarchical combination of all possible hypotheses, therefore, includes [present], [absent] and [present, absent]. We are most interested in the result generated for the hypothesis [present] which mean existing of unconfined aquifer. The final results produced for the hypothesis [present] are dependent on how all evidence relate together in the process of aggregation.

Given knowledge about existing boring wells, dug wells and given expert knowledge about the occurrences of aquifers, each evidence is transformed into a raster layer representing likelihood that an unconfined aquifer exists. The aggregated evidence produces results that are used to predict the presence of an aquifer and evaluate the impact of each line of evidence to the total body of knowledge.

Several pixel maps of elements which confirm or deny the occurrence of the only unconfined aquifer were prepared for this study. At the beginning, each map included separately: point or area data in a scale 0 and 1. In the next stage, the information on each map was changed in order to work out membership functions. As a result, the pixel map with values from 0 to 1 was obtained. Finally, all the maps (information layers) were put to the BELIEF module and probability map was compiled regarding Dempster-Shafer theory.

Data input for the unconfined aquifer

To analyze the extent of the unconfined aquifer there is a need to collect the information about boring wells (as the best indicator of aquifers, or it's lack), dug wells and more indirect evidence of occurrences for the unconfined aquifer (springs, rivers, lakes, the area of extent of alluvial or outwash deposits). There is high probability that the unconfined aquifer will be inside or close to these forms.

For estimating the extent of the unconfined aquifer in a probabilistic scale the following data was selected:

- location of boring wells and boreholes from database of Hydrogeological Map of Poland (Herbich, 2005; Fert et al., 2005, Prussak, 2000). The geologic profile of wells or boreholes was taken from Central Hydrogeological Data Bank (Cabalska et al., 2005);
- location of dug wells from supplement of Hydrogeological Map of Poland – first groundwater horizons (Jankowski, Walczak, 2005);
- area of the extent of the moraine plateau and outwash (from Detailed Geological Map of Poland 1:50 000);
- course of main rivers and boundary of lakes.

CREATING PROBABILITY MAPS (FUZZYFICATION)

The stage of fuzzyfication is a procedure, which allows for converting a discrete/dichotomic image (binary map or bitmap) into pixel images (pixel map) with a probabilistic scale (from zero to one). The reliability of the obtained maps depends on the applied parameters of fuzzyfication controlled by a membership function. For this study the following assumptions were taken:

Membership function for boring wells

Wells are the best point markers of the aquifer. The point map with locations of the wells (with unconfined aquifer) were converted to raster (pixel) image and all the pixels in which well (or wells) were located, obtained the value: one. Also for these features, the area in the close vicinity of the wells should obtained high likehood of occurrence of an aquifer.

Radius of 300 [m] was used around pixel representing drill wells, so the pixel values representing probability of unconfined conditions are high in the close area and decreased down to the level of the background (Figure 3). The above distance was established subjectively as the optimal one after analyzing the hydrogeological conditions from the research area.

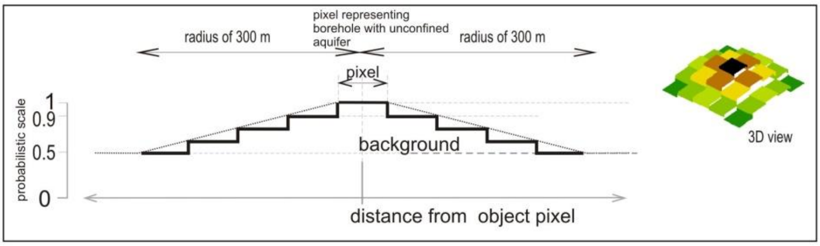

Figure 3. Graph of the membership function for drilled wells with unconfined aquifer.

Membership function for wells and boreholes with lack of unconfined aquifer

The value "0" was assigned for the pixels where boreholes exist and unconfined aquifer is not noticed. In the vicinity of those pixels, probability increases from "0" to the value of background for the range 300 [m] (Figure 4). The above distance was established subjectively as the optimal one after analyzing the geological and hydrogeological conditions from the research area.

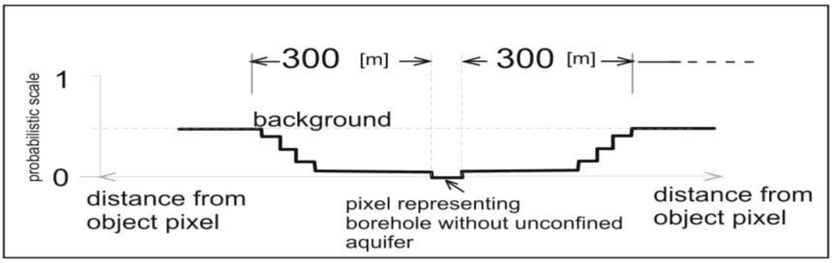

Figure 4. Scheme graph of the membership function for boreholes and drill wells without an unconfined aquifer.

Membership function for the area of outwash sediments and moraine plateau

In the research area of the extend the unconfined aquifer is associated with fluvioglacial outwash. The area of the outwash extent was digitized from the Detailed Geological Map of Poland in a scale 1:50 000 (Trzepla, Drozd, 2005; Ber, 2005). The rest of the area was classified as a logic negation, which means the area without sand sediments on the terrain surface (i.e. moraine plateau). Arbitrarily the value "0.8" was assigned to all the pixels which represent the area of outwash sediments and the river valley. For the remaining area a constant value "0.3" was established *a priori*.

Membership function for area in the vicinity rivers and lakes

Rivers and lakes are hydrologic objects with frequent connection to the aquifer, especially the unconfined aquifer. Close to a river or a lake there are often sand sediments with the aquifer, therefore, this vicinity to water indicates the plausibility for the aquifer. Only rivers that are longer than 5 km and lakes with the area bigger than 1 ha were analyzed.

After data analysis, the author found that there should be higher likelihood (the value of about 0.8) in the zone 100 [m] from the river bank or lake shores.

Stage of calculating

After processing data in the BELIEF module a set of maps was generated. These were maps of the degree to which evidence provided concrete support for the hypothesis (belief) and the degree to which that evidence did not disprove the hypothesis (plausibility). The probabilistic map of the extent of the unconfined aquifer in a research area was shown on the Figure 5.

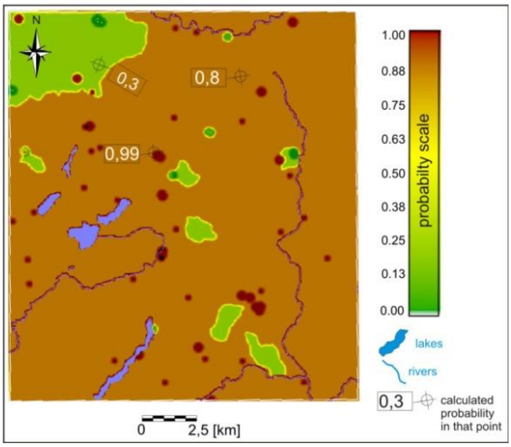

Figure 5. The probabilistic map of the extent of the shallow unconfined aquifer in a research area.

SUMMARY AND CONCLUSIONS

The limits of geological and hydrogeological structure presented on the cartographic studies contain often significant errors due to poor geologic and hydrogeologic recognition. The purpose of the methodology presented here is to produce a probabilistic information layer of the extent of the unconfined aquifer in the study area (Figure 5). It is an attempt to use Dempster-Shafer theory in hydrogeology. Taking into account the fuzzy set theory, the author calculates probability occurrence of shallow unconfined groundwater based upon hydrogeological elements (especially drilled wells and dug wells). Additional information for the probabilistic map are derived from hydrological and geomorphological investigations. The accuracy of such map is largely determined by the established membership functions.

The generated maps may be regarded as a supplement to a classic set of information concerning hydrogeology and which provides a new form of a map layer. The statistical description of the pixel value on the result map may be used for the assessment of reliability of hydrogeological model and as decision support for sustainable groundwater management.

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abstract id: **195**

topic: **1**
Groundwater quality sustainability

1.10
Decision support tools for sustainable groundwater management

title: **Decision support system for the multi-objective optimization of bank filtration systems**

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INTRODUCTION

Within the European project TECHNEAU (www.techneau.org) the Berlin Center of Competence for Water (KWB) is investigating bank filtration (BF) and adjusted post-treatment as a managed aquifer recharge (MAR) technique to provide sustainable and safe drinking water supply to developing and newly industrialised countries. One of the tasks within the project is the development of a Decision Support System (DSS) to assess the feasibility of BF systems under varying boundary conditions such as: (i) quality of surface and ambient groundwater, (ii) local hydrological and hydrogeological properties (e.g. clogging layer) and (iii) well field design (distance to bank) and operation (pumping rates). Since the successful, cost-effective implementation of BF systems requires the optimization of multiple objectives such as (i) optimizing the BF share in order to maintain a predefined raw water quality, (ii) maintaining a predefined minimum travel time between bank and production well and (iii) achieving cost-efficiency of different well field design and operation schemes, all these objectives need to be addressed within the DSS.

METHOD

The DSS was programmed with the software MATLAB® (The MathWorks, 2009a) and compiled as stand-alone version by using the MATLAB® Compiler™ (The MathWorks, 2009b). Each of the above listed objectives can be addressed within the DSS, of which the conceptual structure is divided into four steps. In the first step the user has to specify representative substance concentrations of both, surface water and ambient groundwater. This data set is then used in the second step to calculate the potentially hazardous substances, by comparing each input substance concentration against the corresponding threshold value derived from either the German Drinking Water Ordinance (TrinkwV, 2001) or the Drinking Water Guideline of the World Health Organization (WHO, 2008). In a third step the 'optimal' BF share range is calculated using the conservative mixing approach for each potential hazard substance (local 'optimum') as well as for all substances (global 'optimum'). In the fourth step, different well field designs (number of production wells, distance to bank) and operation scenarios (pumping rates) can be simulated with the BF Simulator (Holzbecher et al. 2008, Rustler et al. 2009), in order to find an optimum well field design and operation scheme, for which the above identified 'optimum' BF share can be obtained. Since the BF Simulator also calculates minimum travel time, depression cone and infiltration length these data could can also be used as additional optimization objectives (multi-objective optimization).

RESULTS AND CONCLUSION

The DSS was tested with data from the Palla well field in Dehli/India (Rustler, Boisserie-Lacroix, 2010). It proved to be a good qualitative tool to identify and learn about the trade-offs a decision maker has to make due to the (i) inherently competing nature of different objectives (e.g. high BF share and minimum travel time > 50 days) and (ii) the inherent uncertainty connected with the high natural variability of boundary conditions (e.g. clogging layer). Since both characteristics can be addressed within the DSS it helps to add transparency and reproducibility to the decision making process. An additional advantage is that its application requires only low effort concerning time, money, and manpower. Thus the application of the DSS is recommended to accompany decision making processes especially in developing and newly industrialised countries where data availability and low financial budgets are usually the major burden for the application of more complex, data-demanding decision support tools.

ACKNOWLEDGEMENTS

The authors thank Céline Boisserie-Lacroix, for the extensive testing of the DSS. The project TECHNEAU at KWB was funded by the European Commission (Contract Number: 018320) and Veolia Water.

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abstract id: **213**

topic: **1**
Groundwater quality sustainability

1.10
Decision support tools for sustainable groundwater management

title: # Characterization of hydraulic head distribution and recharge area delineation: Application of the water table fluction method on the Lusaka Plateau, Zambia

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The carbonate and schist aquifers on the Lusaka Plateau are amongst the highly exploited aquifers in Zambia. Legitimate use of groundwater on the Lusaka Plateau include domestic, irrigated agriculture and industrial. Groundwater abstraction in these aquifers accounts for 50% of the piped water supplied to Lusaka city and 100% for most private users that depend on the unconfined upper aquifers. Protection of groundwater associated with surface water and dependent terrestrial ecosystems is not currently feasible due to limitations in the existing legislation. Groundwater data and information deficit is one such a challenge that has created considerable uncertainty concerning the effects of present pumping and has also limited the development of hydrological as well as hydrogeological models to explain the dynamics of water resources inflows to and outflows from the Lusaka Plateau. The absence of legislation to assure sustainable groundwater utilization and management, prompted the Ministry of Energy and Water Development (MEWD) through the Department of Water Affairs (DWA) to adopted the Water Table Fluctuation Method (WTF) to understand the required protection of the various uses of groundwater on the Lusaka Plateau in the context of Integrated Water Resources Management (IWRM). A groundwater monitoring network was designed and observation boreholes progressively constructed in the unconfied aquifers. These are now used as a groundwater management tool for taking the hydraulic head as a directly measurable property in the upper unconfined aquifers. Preliminary analysis of the changes in the hydraulic head over time facilitated the delineation of the main recharge area, various transmissive zones and identification of production boreholes for use as part of the monitoring network to continuously assess the groundwater quality status. Determination of groundwater flow, assessment of the yearly recharge and identification of areas affected by high abstraction is now possible. The fundamental premise is that the upper water table aquifers provides a source of fresh water for various uses and a valuable storage of groundwater. Initial efforts are directed at creating awareness amongst groundwater users on the yearly variability of recharge, the declining water table observed within the city boundary and the need to keep as well as provide groundwater abstraction records. Furthermore, involvement of private drillers in the collection of relevant groundwater data and information is another aspect aimed at improving the information deficit. Based on the WTF principles, intial steps in the delineation of zones for restricted and controlled groundwater abstraction has been achieved to accommodate policy development as well as future active groundwater management for long-term sustainability.

abstract id: **226**

topic: **1**
Groundwater quality sustainability

1.10
Decision support tools for sustainable groundwater management

title: **WEAP-MODFLOW as a Decision Support System (DSS) for integrated water resources management: Design of the coupled model and results from a pilot study in Syria**

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keywords: decision support system, water resources management, Arab Region, MODFLOW, weap

INTRODUCTION

The situation of the water supply in the Arab region is characterized by water scarcity and, at the same time, by increasing demand caused by population growth as well as expanding economy and agriculture. Furthermore, climate change models predict even more severe conditions in the water sector, associated with rising temperatures and decreasing precipitation. The decision makers have to respond to the most urgent questions: How will the water balance change in time and which action is required to achieve a sustainable water supply?

To answer these questions an integrated approach is obligatory. In addition to the evolution of the availability of water resources and of the demands, the whole social, economic, cultural and environmental framework has to be taken into account. To understand such a complex interacting system and the outcomes of any changes, a Decision Support System (DSS), based on computational models, renders assistance.

Within the framework of a technical cooperation project, ACSAD and BGR, supported by the SEI (Stockholm Environment Institute), have jointly worked on the development, application and dissemination of a DSS software for water resources management (Droubi et al., 2008). This system has been successfully applied in several pilot areas in the Arab region, e.g. in the Zabadani Basin, Syria.

WEAP-MODFLOW DECISION SUPPORT SYSTEM (DSS)

The DSS itself is a software product that gives the user the capability to calculate and visualize the time-dependent behavior of a hydraulic system, if one or many of the system's parameters change. The modeling components are a combination of the two preexisting software products: MODFLOW and WEAP. MODFLOW, developed by the U.S. Geological Survey (Harbaugh et al., 2000), numerically solves the three-dimensional groundwater flow equation for a porous medium by using the finite-difference method. It is based on Darcy's law for laminar flow and the conservation of the water volume. The water evaluation and planning system WEAP (http://www.weap21.org) has been developed by the SEI (Yates et al., 2005). Based on groundwater and surface water balances in a catchment, subcatchment or landuse class level, WEAP calculates current and future demands as well as the development of the resources.

A dynamic link between WEAP and MODFLOW has been developed. For each time-step, results of the one model are transferred as input data to the other (Fig. 1). Groundwater recharge, abstraction rates, and river stages are calculated by WEAP. This data act as boundary conditions for MODFLOW, which calculates hydraulic heads, storage volumes and flows in the groundwater system. These values are used in turn by WEAP.

Contrary to MODFLOW, WEAP does not take into account any spatial relationship. In order to ensure that WEAP results address to MODFLOW cells correctly and vice versa, a linkage has been developed, which acts like a dictionary between the two models.

Thus, river-groundwater interaction, spring discharge or recharge as well as management constraints regarding the groundwater head or discharge can be considered (Al-Sibai et al., 2009).

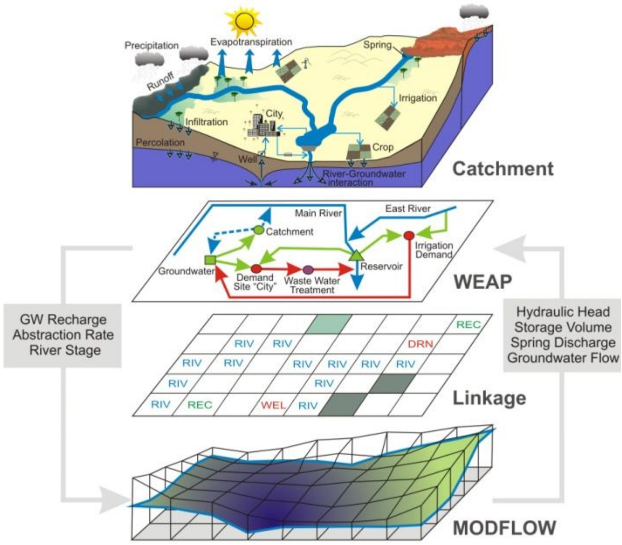

Figure 1. Schematical setup of the WEAP-MODFLOW DSS.

The calibrated DSS provides the capacity to investigate, compare and evaluate various water management scenarios. Future constraints, as changes in demography, economy, climate, landuse, irrigation efficiency, or return flow, can easily be taken into account. The results are visualized as graphs, maps, and tables. They depict the impacts of the scenarios on the water balance in a whole watershed or in detail, e.g. in terms of hydraulic heads, flow rates or irrigation amounts. Thanks to the coupling with MODFLOW, the reactions and dynamics of the groundwater system, discretized in time and space, can be predicted and evaluated.

The WEAP-MODFLOW DSS has been improved continuously. Recent developments aim at the integration of the simple particle tracking model MODPATH (Pollok, 1994), the optimization of abstraction rates and pumping allocation with consideration of water quality, drawdown and cost, and an additional soil water balance model called MABIA (Sahli, Jabloun, 2005). MABIA is based on the FAO-56 dual crop coefficient approach. It provides the use of real world field data as well as FAO reference parameters.

PILOTSTUDY ZABADANI BASIN, SYRIA

The Zabadani Basin is located in the Antilebanon Mountains in the NW of Damascus, Syria. It covers an area of about 140 km^2. Geomorphologically and hydrogeologically it can be divided into three NNE-SSW trending blocks (Fig. 2): 1) the Chir Mansour Mountain range in the W, reaching up to 1884 m a.s.l., characterized by faulting, intensive karstification and very high transmissivities; 2) the Zabadani graben, ranging from 1080 to 1400 m a.s.l., with moderate transmissivities; 3) the Cheqif mountain range in the E, reaching up to 2466 m a.s.l., with minor karstification and high transmissivities.

In the basin rises the Barada River representing the only perennial stream in the region. The mean annual rainfall is about 700 mm. About 48,000 people are living permanently in the area; however, during summer time the population increases significantly due to tourists.

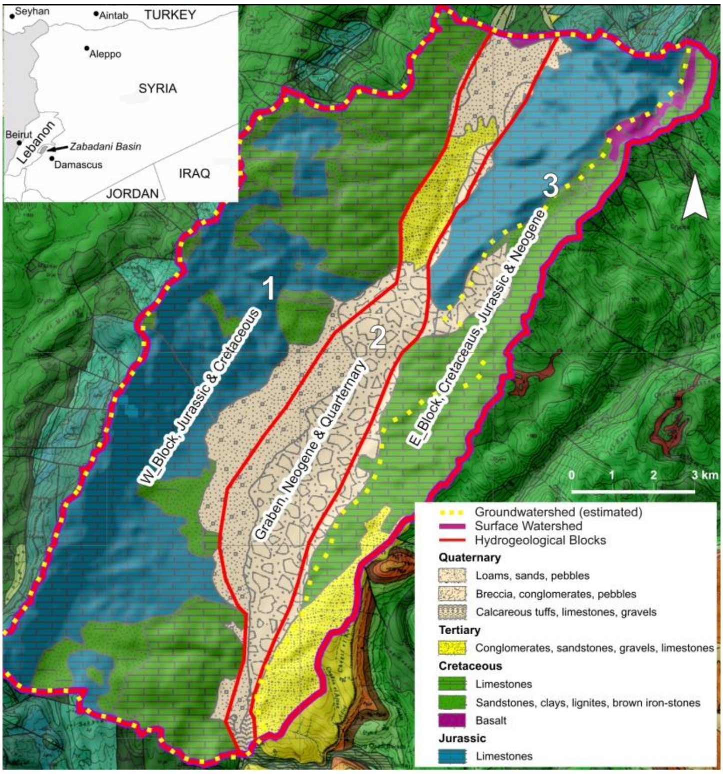

Figure 2. Location and geology of the Zabadani Basin.

In the Zabadani Basin exists already a water competition between local drinking water suppliers, Damascus water supply authority as well as agriculture and touristic activities. Since the very beginning of the project, a steering committee has been set up, integrating all relevant stakeholders into the DSS development, data acquisition and future scenario planning.

The numerical MODFLOW groundwater flow model of the Zabadani Basin consists of 10,044 cells, each with an equal length and width of 200 m. The regional aquifer has been subdivided into three layers, which have different hydraulic properties but are hydraulically connected. The anisotropic permeability varies in the range between 0.01 to 60.0 m/day, mainly according to the type of formation, density of lineaments and dipping of the formation. The boundaries have been set as no flow Neumann boundaries, except in the south where groundwater inflow is assumed. Groundwater recharge is calculated by WEAP, applying a soil water model on 48 landuse classes. Groundwater abstractions from well fields for domestic use and from rural wells for irrigation are considered. Furthermore, surface water-groundwater interactions at the Barada River and Barada spring have been modeled by Cauchy boundary conditions.

Since the hydrological year 2004/2005 was a year with an average precipitation leading to full recovery of the groundwater table after the winter rains, it was used for steady state and transient calibration of the hydraulic properties and the groundwater inflow from the south in order to fit the Barada spring discharge and the measured groundwater heads.

The WEAP21 software was used to build a planning and evaluation model, which then has been linked to the MODFLOW groundwater flow model as component of the DSS. Within WEAP, the basin has been divided into 11 subcatchments, based on the location of the major drinking water well fields and surface watersheds. In addition to areal data, climate data are also assigned at subcatchment level. In the next step, each subcatchment was further subdivided into respective landuse classes. Irrigation pattern, crop coefficient, leaf area index, root zone conductivity and soil water capacity values have been assigned to them. The basis for the landuse mapping was provided by aerial photographs, geological information (Kurbanov et al., 1968) and data from ministries as well as local farmers. Figure 3 depicts the WEAP schematic with integrated nodes as demand and supply sites as well as the connections between them.

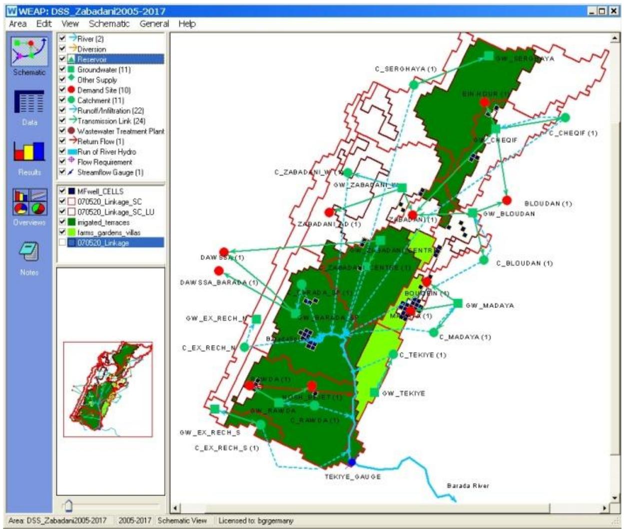

Figure 3. WEAP schematic of the Zabadani Basin (screenshot).

With the linked WEAP-MODFLOW model realistic surface-, soil- and groundwater balances as well as hydraulic heads for the reference year 2004/2005 could be calculated. The results can be visualized by WEAP at different scales in various charts, tables and maps, as shown in Fig. 4 exemplary.

Based on this initial model setup, different scenarios have been investigated dealing with realistic assumptions on domestic and agricultural demands as well as influences of climate change. As an example, results of two scenarios are depicted in Fig. 5. For scenario A, the demand of drinking water has been doubled whereas the irrigation demand has decreased by 30%, assuming population growth on one hand and a change to drip irrigation on the other hand. Influences of climate change are considered in scenario B, based on predictions of the climate model ECHAM4. Here, preliminary calculation results of daily precipitation data have been compared for two thirty year time periods (1961–1990 and 2070–2099). By averaging the yearly precipitation in the two time periods, a decrease in precipitation of twenty percent can be derived. This decrease was applied to the planning scenario 2005–2017 in order to see on an even shorter time scale the impact of climate change.

Both scenarios lead to a negative water balance within the basin. As a consequence of this, groundwater drawdown can be expected.

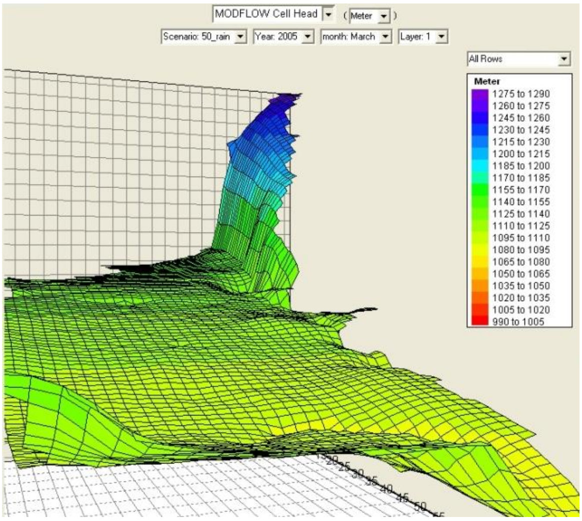

Figure 4. WEAP-MODFLOW DSS result: Hydraulic heads in the Zabadani Basin.

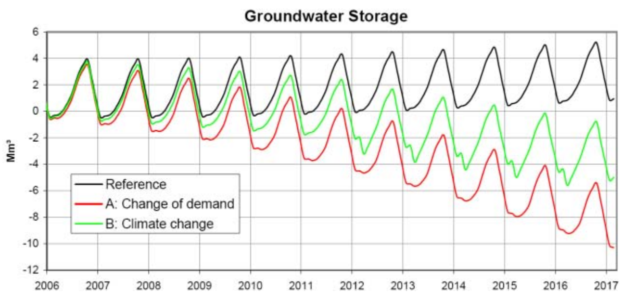

Figure 5. WEAP-MODFLOW DSS result: Comparison of scenarios.

CONCLUSIONS

Within the framework of a technical cooperation project, a user-friendly, inexpensive, efficient and easily shareable Decision Support System (DSS) for integrated water resources management has been developed incorporating MODFLOW and WEAP as modeling components. The user can manipulate inputs and evaluate and compare results of various scenarios with respect to current as well as future water management strategies in the target area, considering human activities (population growth, urbanization, domestic demand), agriculture (landuse, crop types, irrigation practices), climate impacts (climate change models, regional climate cycles), network characteristics (transmission link losses and limits, well field characteristics, well depths), and additional resources (artificial recharge, waste water reuse).

The results are visualized as graphs, maps and tables (hydraulic heads, water balances, etc.) and support the decision making process among relevant stakeholders and decision makers. The DSS has been successfully tested in the Zabadani Basin, Syria. For different water planning scenarios, realistic results (hydraulic heads, surface and groundwater balances, etc.) on different scales (MODFLOW cell, landuse class, subcatchment or catchment) could be calculated. The

DSS is already established in several institutions within the Arab region in Morocco, Tunisia, Palestine, Syria and Jordan.

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abstract id: **242**

topic: **1**
Groundwater quality sustainability

1.10
Decision support tools for sustainable groundwater management

title: **Field tests for subsurface iron removal at a dairy farm in Saxony, Germany**

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keywords: subsurface iron removal, decision tool

INTRODUCTION

Iron and manganese are commonly present in anoxic groundwater worldwide. High iron concentrations are not harmful to human and animal health, but can result in technical problems such as clogging of production wells, precipitation and incrustation in the water supply distribution systems, orange/brown colour and bad taste of drinking water.

Iron removal from groundwater can be accomplished in two different ways. The quality of raw water, the available financial resources and the philosophy of the water company are the main criteria in deciding on either of the groundwater treatment processes. The most common process is the treatment of groundwater on the surface (after abstraction). Another treatment process is the in-situ subsurface removal of iron from groundwater, using the Vyredox method (Hallberg, Martinell, 1976), Subterra (Rott, Friedle, 2000; Rott et al., 2002; Herlitzius et al., 2008) or Uneis methods (Eichhorn, 1985).

Subsurface iron removal is an ecologically sound in-situ oxidation treatment without chemicals. The operating mode is based on abstraction and infiltration between two or more vertical or horizontal wells (Fig. 1).

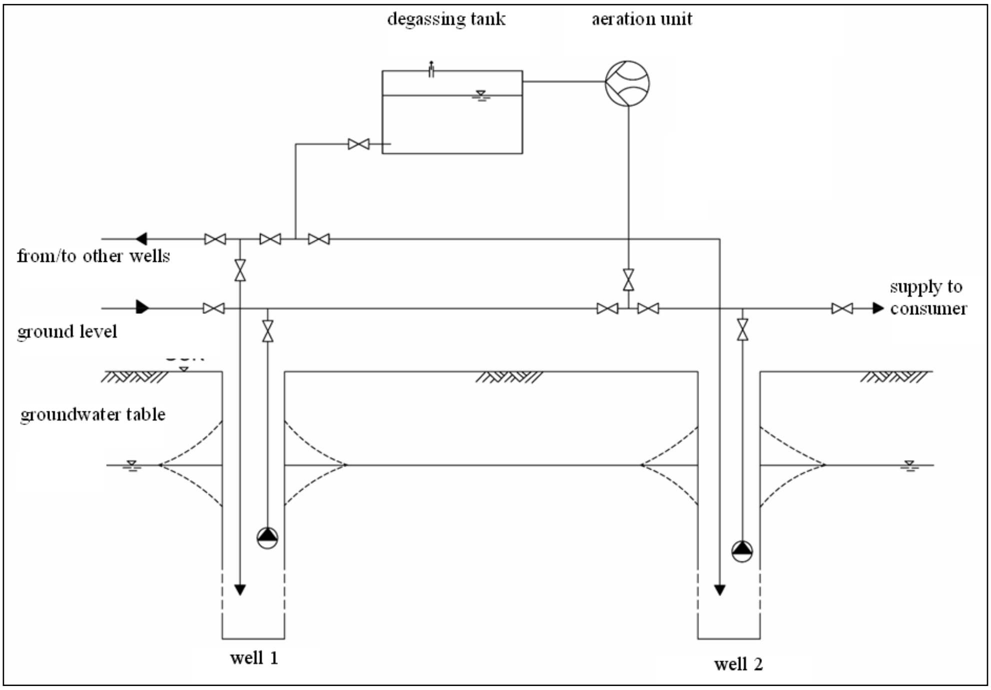

Figure 1. Illustration of subsurface iron removal with two vertical wells.

The applied technique includes the following steps:

1. Abstraction of groundwater from the first well, aeration of a portion of the pumped water and re-infiltration of the aerated groundwater containing dissolved oxygen into the second well (Fig. 1).

2. In the aquifer: Oxidation of the dissolved and adsorbed Fe(II), transformation of the soluble Fe(II) to its less soluble form Fe(III), formation and precipitation of iron(hydr)oxides providing further adsorption sites for Fe(II).
3. Abstraction of anoxic groundwater and removal of Fe(II) by adsorption onto iron(hydr)oxide in the reaction zone around the pumped well. The second well is used for abstraction and the first well is used for infiltration of aerated/oxygenated water.

The efficiency of this groundwater treatment process is calculated as the ratio of the volume of water infiltrated to the volume of water abstracted, which can range from one part infiltrated water to three to ten parts of abstracted water.

Through adsorption in the reaction zone, it is also possible to remove arsenic, manganese and dissolved organic carbon. Limitations of subsurface iron removal are low pH, low hardness, and high Fe(II), Mn(II) and ammonia concentrations.

In 2008, a mobile unit on a vehicle trailer was developed for pilot tests to determine the applicability of subsurface iron removal. The mobile unit contains an aeration unit for controlling the dosage of technical oxygen, a static mixing unit, a degassing unit, valves for discharge control and devices for continuous measurements of discharge, pH, temperature and electrical conductivity. The objective of this paper is to present a field test approach for subsurface iron removal, based on field investigations at a dairy farm in the state of Saxony, Germany. At the farm, the drinking water for the livestock is supplied by two groundwater abstraction wells.

STUDY SITE AND METHODOLOGY

The research site at the farm in Dobra is located in northern Saxony 40 kilometres from the city of Dresden. The Pleistocene sediments are underlain by greywacke with a thickness of 10-20 m. The sediments are fine to medium sands with a hydraulic conductivity of about 1×10^{-3} m/s. At the time of the experiment the water table was 1.5 beneath the ground surface, and the groundwater had a mean concentration of 10 mg/L Fe(II), 0.5 mg/L Mn, 0.1 mg/L ammonia and a mean pH of 6.5.

To conduct the field test for subsurface iron removal in Dobra, an existing old shaft well (PW 2) with a diameter of 2 m and depth of 5 m, and a new vertical well (PW 1) having a diameter of 125 mm and a depth of 14 m were used. Additionally, for measuring the dissolved oxygen concentration (O_2), electrical conductivity (EC) and pH in the reaction zone, two monitoring wells (MW 1 & MW 2) having a depth of 12 m were also installed at a distance of 5 m and 10 m from to the new vertical well PW 1 (Fig. 2). The mobile unit used in this study was developed at the Division of Water Sciences of the University of Applied Sciences Dresden.

The field tests were conducted from September to December 2009, with a total abstraction rate of 4.5 m^3/hour of which 1.2 m^3/hour was infiltrated. One test period consisted of a cycle of an abstraction from one well and infiltration into the other well. During the first testing period it was necessary to create a reaction zone with a water volume of around 300 m^3 and an O_2 concentration of 15-25 mg/L. In the first period the water was abstracted from PW 2 and infiltrated in PW 1. Using data loggers in the production and monitoring wells it was possible to measure the O_2, pH and EC automatically at regular intervals. Samples of the abstracted water were taken during all 7 test periods.

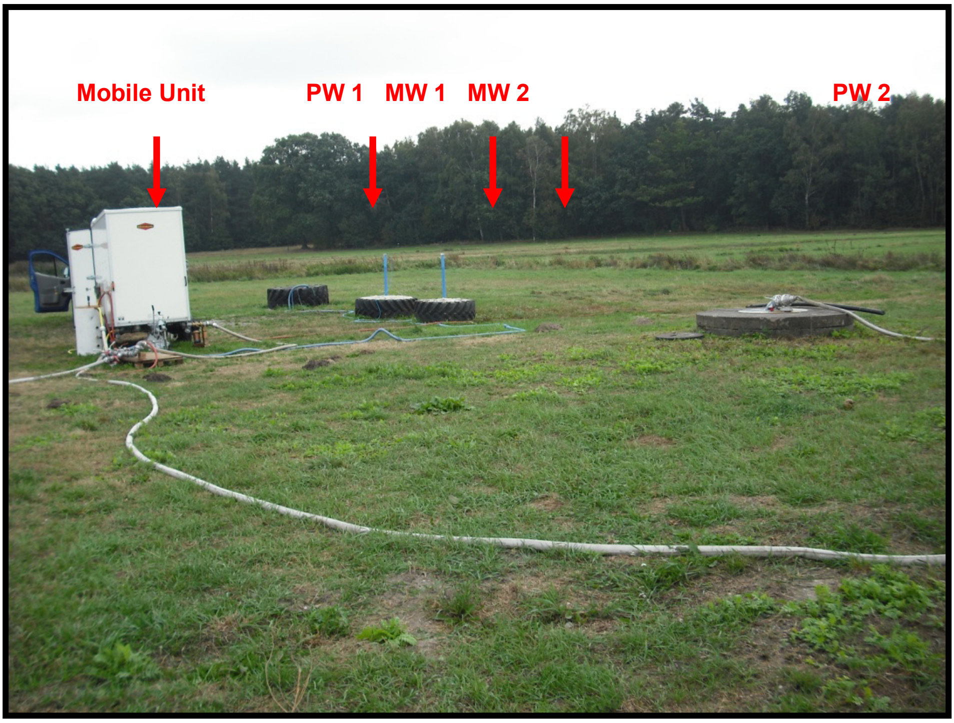

Figure 2. Mobile car unit for subsurface iron removal tests with production wells (PW) and monitoring wells (MW).

RESULTS

A tracer test to determine the size of the reaction zone around one well was conducted by measuring the EC and O_2 concentration. The infiltrated water containing 15-25 mg/L O_2 and a chloride tracer were injected in PW 1. O_2 and EC were measured in PW 1 and in MW 1 separated by a distance of 5 m. The results (Fig. 3) show a breakthrough of the injected tracer in MW 1 after 3.5 days, peaking at 1.3 mS/cm after about 4 days. A breakthrough of oxygen (from the oxygen-rich infiltrated water) was observed in MW 1 after about 7 days with a peak of 22 mg/L at 8.5 days.

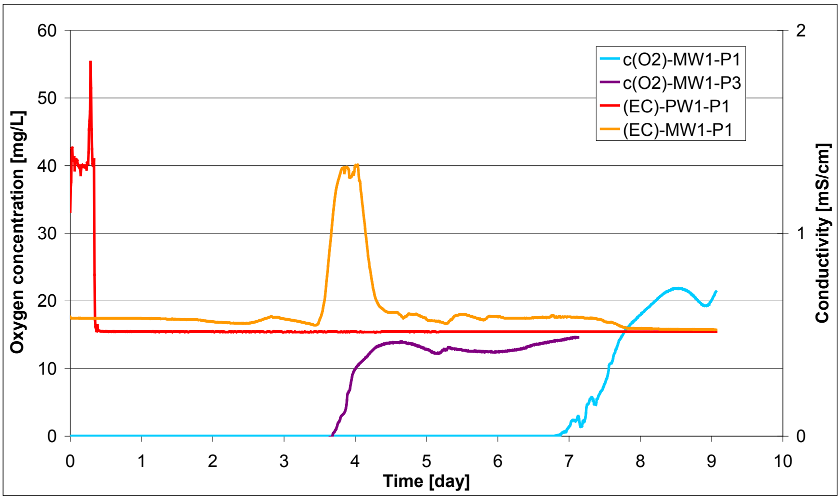

Figure 3. Oxygen concentration and electrical conductivity during the tracer test in the production well 1 (PW 1) and monitoring well 1 (MW 1) during period 1 and 3 (P 1, P 3).

The infiltrated volume before every abstraction was around 300 m^3 in both of the wells. The iron concentration of 10 mg/L at a depth of 14 m in PW 1 was less than 0.5 mg/L in three periods after an abstraction volume of 700 m^3 (Fig. 4). Figure 4 shows also that the iron removal in PW 1 is improving after subsequent periods of infiltration and abstraction.

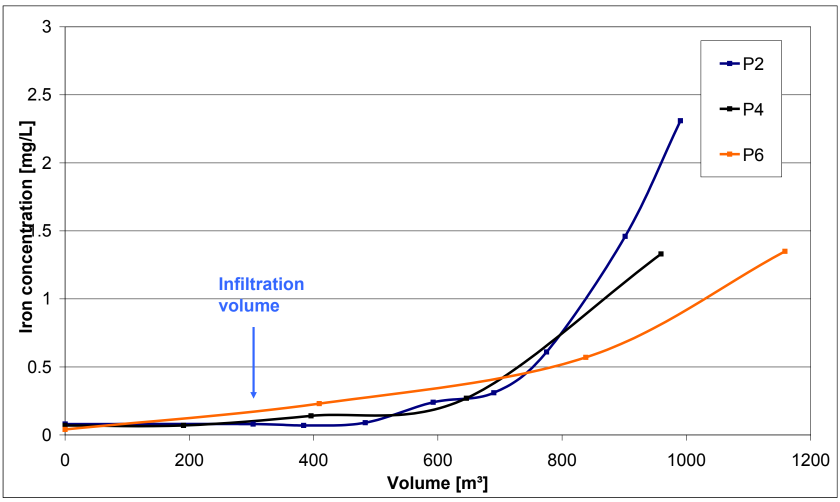

Figure 4. Iron concentration during abstraction in period 2, 4 and 6 at production well 1 (PW 1).

In PW 2 it was possible to lower the iron concentration from around 5 mg/L to less than 0.5 mg/L for an abstraction volume of up to 1200 m^3 (Fig. 5).

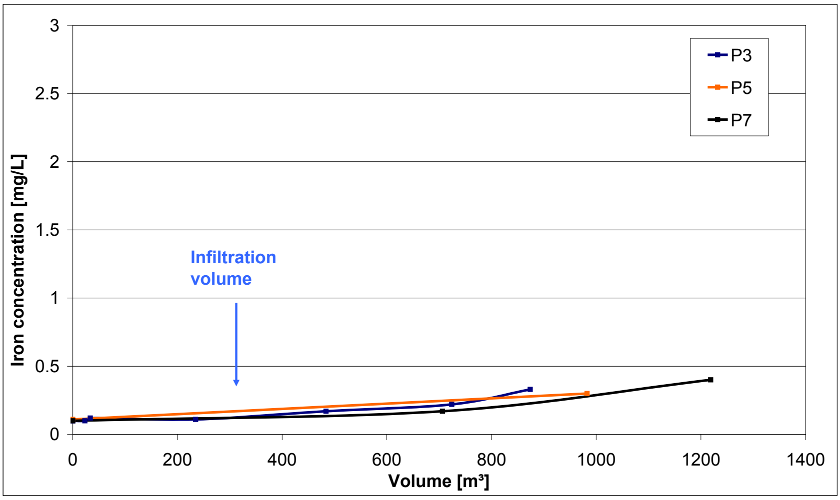

Figure 5. Iron concentration during abstraction in period 3, 5 and 7 at production well 2 (PW 2).

CONCLUSION

After application of the subsurface iron removal technique, an iron concentration of less than 0.2 mg/L (a 98% change from background) was achieved in the abstracted groundwater within one week. Results from a tracer test were used to determine the size of the reaction zone. The ongoing experiment provides data for different oxygen concentration in the infiltrate, the efficiency of iron removal and the oxygen consumption by other processes. Results will be used to choose an optimal subsurface iron removal treatment technique, especially in deciding on long-term subsurface treatment using aeration or technical oxygen. The mobile unit can be used to characterise site-specific aquifer conditions within one week and to determine whether subsurface iron removal can be successfully applied at a site.

ACKNOWLEDGEMENTS

The authors are grateful to the financial support of the German Federal Ministry of Education and Research (BMBF) to the project "Development of mobile modules for automated subsurface iron removal and well conservation" (BMBF 1735X07). The logistic support of the agricultural company Agrargenossenschaft Dobra is also gratefully acknowledged.

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abstract id: **295**

topic: **1**
Groundwater quality sustainability

1.10
Decision support tools for sustainable groundwater management

title: **Hydrogeological database, a decision support tool**

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keywords: hydrogeological database, GIS, barrier effect

INTRODUCTION

An Hydrological Data Base (HDB) allows to introduce, to store, to order, to manipulate and to manage important volume of diverse information. For this reason a good initial design determines its utilization and validity in the future. It is necessary to know the use that wants to give at HDB, information that is needed for working, necessary fields and the design — relation between different tables. The incorporation of HDB in a Geographic Information System (GIS) environment allows to store information as a collection of thematic layers.

FCIHS HDB is organized in a mother table which contains basic information in order that a point can be geoindexed (Figure 1). Hydrogeological, geological, chemical, etc. data are in different tables with a particular relation between them.

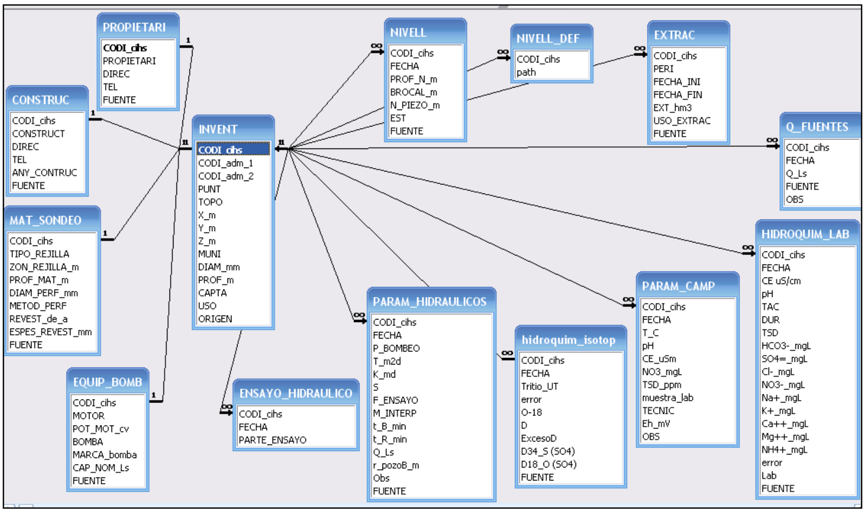

Figure 1. Relations between mother table and hidrogeological tables.

A methodology to validated information entry has been created during implementation and application phases of FCIHS HDB. These methodology of entry information is realized from a set of dichotomy keys. FCIHS HDB have been validated 20–25% of the existing information in the documentary corpus. These numbers represent 55000 hydrological information, corresponding to 6000 water points. FCIHS has elaborated graphical documents to visualize information about a point: its location, piezometric data, chemical record, tests of pumping – recovery, hydraulic parameters, etc.

In the FCIHS it is being used the potential of the BDH in multiple hydrogeological works. One of these are focused to prevent barrier effect of linear infrastructures (tunnels, long parking, etc.) in aquifers.

Barrier effect takes place when a construction work intercepts the lines of flow of one aquifer. The magnitude of its effect relates to the length of orientation and intersection of the lines of flow with regard to construction work. When both lines are orthogonal major variation of level is generated. A simple barrier can generate a relative ascent or decrease of the groundwater level. In both cases, it is very important to determinate and control the modification of the original flow that can generate a change of the quality of underground water.

METODOLOGY

Current condition of exploitation of the aquifer (without considering the consequences of its management under extreme droughts or avenues situations) and only with pre-existing infrastructures is the start point of this methodology. Two determining are defined: general and specific.

General determining is directly generated by the conditions of regional aquifer flow. It is based on the maintenance of the not saturated thickness of the aquifer and the current condition of hydraulic gradient. Humidity map, dryness map and average map are constructed to represent a three piezometric maps of climatic conditions of the aquifer. This climatic factor can express from the evolution of the piezometry historical levels of the zone. By obtained results, area is divided in different zones depending on the value of not saturated thickness zones. In aquifers with piezometers with historical record or with high degree of information, the threshold value will be obtained with the relation between the average value of not saturated zone and the piezometric oscillation (maxim and minim). Aquifers with low quantity of information, will consider that barrier valour will be a maximum threshold that corresponds of 25% effect of the aquifer not saturated local thickness zone.

Specific determining is associated with the presence or absence of urban zones, of humid zones, of landfills with residues, of wells and in the habit of concerning a sector of the study area. In case in which it is not present, general determining will only apply.

Tracing of underground infrastructures under urban zones can flood preexisting spaces that do not have efficient waterproofing. The methodology will be considered to be a threshold of alert the possibility of changing, for effect barrier, a minimum thickness of 3 m measured from the surface of the area. Depending on the value of general determining in the concrete water point it will be alerted.

In the humid zones there is designated a void variation of level in the limit of the humid zone or in the protective area of them.

Landfills with residues represent a risk of pollution if these intercept the local piezometric level. Generally, there is not known the vertical penetration of the same aquifer and only there is a suspect of the location of the landfills. For this reason in that methodology the criteria prevention is the generation protection zone (buffer) of 500 meters from the landfills area.

Wells represent a service of water capture that can be disturbed by the construction work. There is defined a protection radius of 100 meters from the water point.

APPLICATION IN A RIVERDELTA AQUIFER

A practical case took place in the superficial aquifer of Low Valley and Delta of the Llobregat river. Combination of piezometric map and topographic map allows to obtain the layers of thickness not saturated (Figure 1). Piezometry has been obtained of Model of Accumulation Impacts and from the control points of Catalan Water Agency (ACA) in the zone, considering three climatic conditions (humidity, dryness and averages). In this particular case we propose four general zones depending on the not saturated thickness for every climatic frame: zone A of not saturated thickness lower than 1 meters, zone B of not saturated thickness lower than 3 meters, zone C of not saturated thickness lower than 5 meters and zone D of not saturated thickness higher than 5 meters.

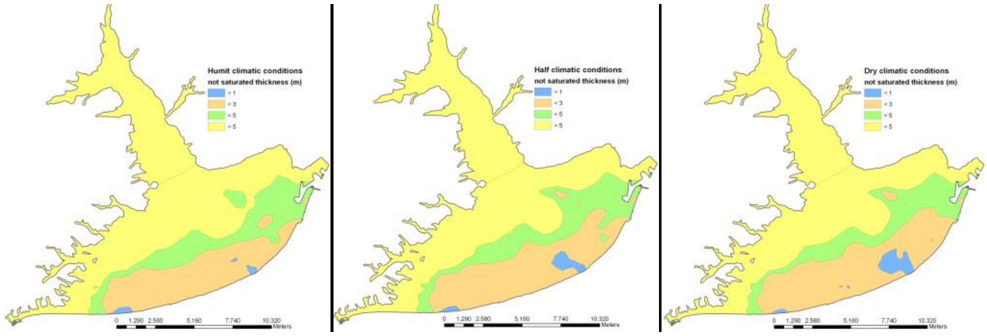

Figure 1. Layers of zoning not saturated thickness in dry, humid and averages climatic conditions.

Specific determining, combines the respective layers of information associated with the proximity to urban zones, to landfills with residues, to humid zones, and to wells.

The layer of urban zones includes different polygons associated with urban and industrial zones (Figure 2a). For this case, in urban areas where not saturated zone already is lower than 3 m, it would not be possible to allow additional ascents provoked by the barrier effect. If a zone has not saturated top thickness, there will be applied a level security of 25% of the difference between the not saturated local level and 3 m previously mentioned.

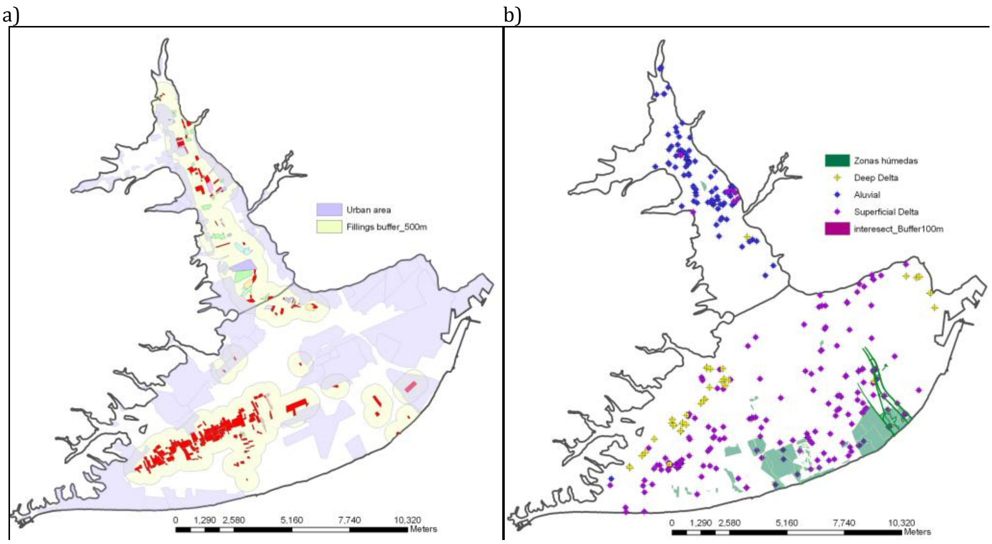

Figure 2. a) Layer of area of influence (500m) of fillings and distribution of urban area; b) Layer of wells and distribution of superficial waters and humid zones.

The layer of extractive activity landfills presents by different polygons associated with different information. From this layer there has been created a buffer of 500 m that corresponds to the area where influence of landfill is considered (Figure 2a).

Wells layer gathers the points inside the study area (Figure 2b). From this layer is created a crown of influence of 100 m that corresponds to a protective area of the wells.

In the layer of humid zones of the study area there are two humid zones: humid areas and reservations. there is defined the absence of variation of the level inside the bounding perimeter of humid zone as it is a humid area as it is a reservation area (Figure 2b).

General determining plus specific determining allows to impose the thresholds of the barrier effect depending on the value of not saturated thickness. With the creation of this new layer and overlapping the infrastructure is determined, the maximum admissible threshold from the zoning of the treated infrastructure (Figure 4).

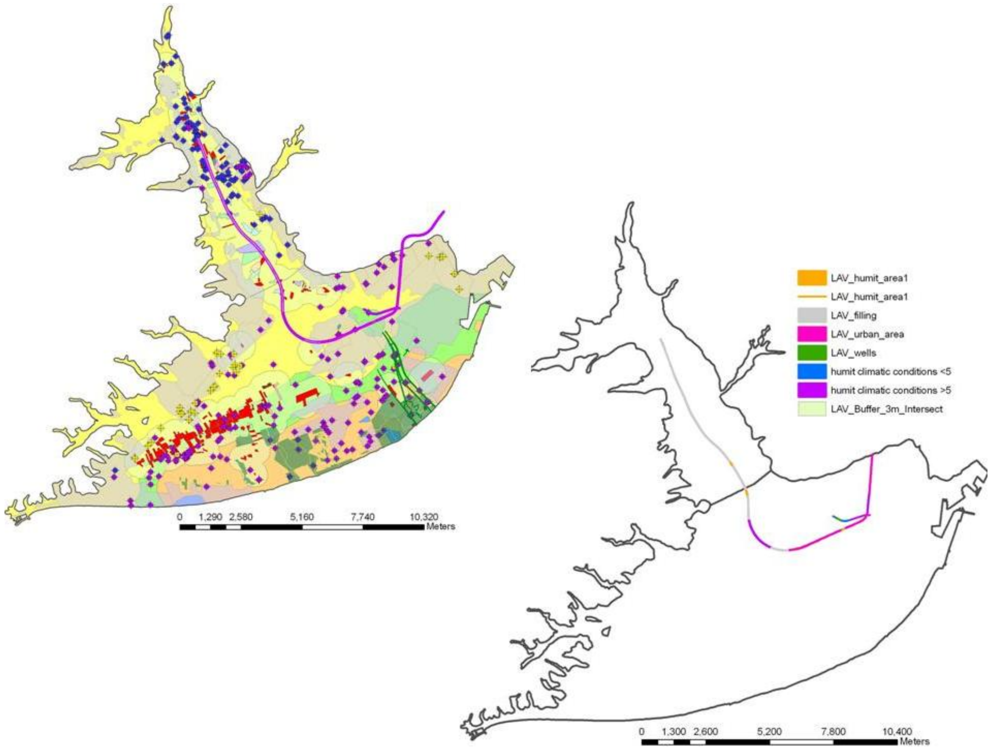

Figure 4. Integration of all layers, general and specific determining, in study area. See the tracing of the LAV divided into zones depending on the intersection with the different determining.

CONCLUSIONS

HDB is a tool to arrange hydrogeological information of a geoindexed form. It is an important management tool because:

(1) it allows to combine punctual and cartographic information in different formats,

(2) obtain different models of visualization and analysis hydrogeological information.

Precision of the results will depend on the degree of knowledge and accuracy of the different kind of data that form a part of the layers of information.

Methodology for determination admissible threshold of barrier effect tries to be a tool of great application and simple use in hydrogeological infrastructures projects.

abstract id: **310**

topic: **1**
Groundwater quality sustainability

1.10
Decision support tools for sustainable groundwater management

title: **Evaluation of piezometric trends by seasonal Kendall test in the alluvial aquifers of the Elqui river basin, North-Central Chile**

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keywords: piezometry, trends, Kendall test, Sen slope test, principal component analysis

Now more than ever there is a need to apply robust statistical methodologies to ensure the proper evaluation of water resources data in order to help the decision makers in the water resources planning and management. Graphing or mapping data for people to see is the easiest way to communicate trends, especially to a non-technical crowd.

In this paper a joint methodology using Seasonal Kendall test, Sen slope test and Principal Component Analysis (PCA) is used to detect and map monthly trends and their magnitude of piezometric time series from 1979–2008 obtained in 23 shallow wells in the alluvial aquifers of Elqui River situated in the central part of Chile. This is an arid area characterized by water resources scarcity where intense agricultural and mining activities occur.

An initial exploratory data analysis of the 23 piezometric historical time series observed in the alluvial aquifers of Elqui river show significant seasonal variations (intra annual), but also variations induced by the ENSO phenomenon (inter annual), depicting influences of climatic and anthropogenic factors. However from the simple look of these time series is very difficult to visualize regional and seasonal trends. From the results from the application of seasonal Kendall and Sen slope tests to the time series we conclude that the about 2/3 of the monitoring wells present significative downward trends with values of decrease of piezometry reaching an average of 0.049 meters per month. Only two time series analyzed show a small upward trend of about 0.029 m/month, the remaining ones present a no-trend behavior.

Reasons for these downward trends could be found in the significant decrease of precipitation rates especially in the rainfall months and the reduction of snowmelt. These trends are in consonance with similar decrease trends in streamflow rates in Elqui river water catchment.

Reasons for the upward trends observed in the wells in low plains can be found by the increase of aquifer recharge induced by irrigation return flows in these areas. In order to better visualize the relationships between wells a PCA was applied to the slope trend matrix. This analysis provides the calculation of two factorial indexes for each monitoring well, indicating the relative magnitude of trend and its monthly influence.

Trend maps are very useful tools for the decision-makers because they can reinforce the implementation of actions in areas where economic sectors (agriculture and mining) are important, managing water scarcity conflicts in an arid region such as Elqui river water catchment towards a monitoring network optimization.

Also in a scenario of impact of climatic change on water resources due to the expected reduction of precipitation and increase of snowmelt, these decision support tools can help in the implementation of the most adequate adaptation measures to climate change effects in the water resources management.

abstract id: **387**

topic: **1**
Groundwater quality sustainability

1.10
Decision support tools for sustainable groundwater management

title: **Development of a decision support system for water management in the Haouz-Mejjate plain (Tensift basin, Morocco)**

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keywords: surface water, groundwater, exploitation, management, Haouz plain

INTRODUCTION

This study presents the progress status of the Decision Support System (DSS) relevant to the integrated management and planning of the water resources in the Haouz-Mejjate plain (Fig. 1). The latter is the most important plain of the Tensift basin. It contains the city of Marrakech, a population of about 2.5 million of inhabitants, receives 2 millions of tourists a year and holds important agricultural lands extended on 170000 ha and producing citrus, vegetables, fruits, cereals and olives.

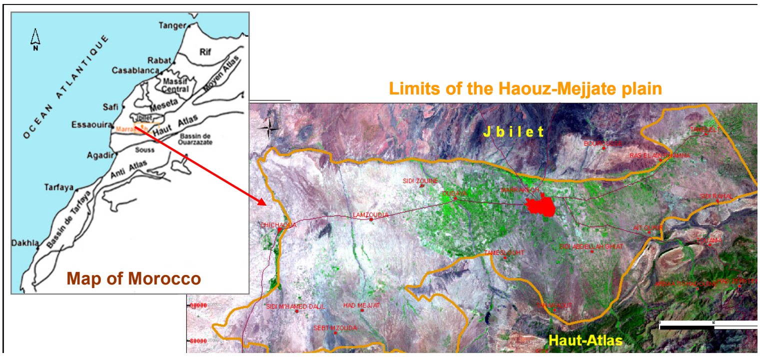

Figure 1. Location of the Haouz-Mejjate plain.

The DSS is the result of a fruitful cooperation between several public and research institutions. It is developed in the framework of a large technical cooperation program (AGIRE) jointly conducted for the Haouz case study by the GTZ (German Agency for Technical Cooperation) and ABHT (Agency of the Hydraulic Basin of Tensift). This program deals with technical, regulatory, institutional and public participation aspects of water management.

OVERVIEW OF WATER RESOURCES IN THE HAOUZ PLAIN

The Haouz-Mejjate basin, extended over an area of 6000 km^2, is part of a tectonic depression, filled by siliciclastic deposits (alluvial fans, fluviatile formations, etc.) of Neogene and Quaternary age. These sediments are brought from the High-Atlas Mountains by several rivers crossing the basin from south to north.

The climate is semi-arid, characterized by low rainfall with 250 mm as annual average (Fig. 2).

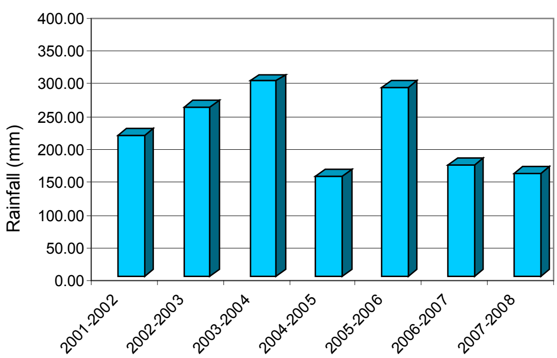

Figure 2. Annual rainfall (2001-2008).

The main rivers (Tab. 1) come from the High-Atlas Mountains and flow to the Tensift river (Fig. 3). Two dams are installed on the N'Fis river with a total storage capacity around 130 millions of m³ (130 Mm³).

Table 1. The main rivers of the Haouz plain.

River name	Watershed area km	Gauge Station		Operating date	Annual flow rate (m^3/s)
		Name	Number		
Tensift	10150	Abadla	1675/44	05/03/1969	5.36
Rdat	497,8	Sidi Rahal	44/54	03/10/1963	2,82
Zat	520,8	Tafériat	1562/53	09/02/1962	3,83
Ourika	491,1	Aghbalou	2089/53	04/04/1969	4,92
Rheraya	222,1	Tahanaout	1565/53	08/03/1962	1,59
N'Fis	1 651,2	Takerkoust dam	—	—	5,59
Assif el Mal	514,4	Sidi B. Othman	1976/53	14/11/1984	1,63
Seksaoua	565	Iloudjane	628/52	15/10/1974	1.57
Chichaoua	2200	Chichaoua	451/52	27/01/1971	—

The surface flow analysis shows a big interannual variability. The 10-years moving average graph highlights a decrease trend in surface flow during the four last decades (Fig. 3) due to the succession of drought periods.

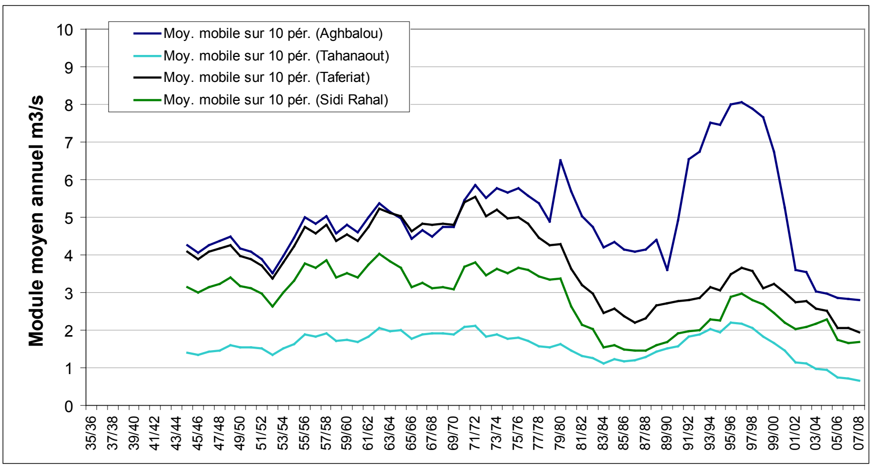

Figure 3. Ten-years moving overage of the main rivers flow.

The groundwater is provided by the unconfined aquifer of the Haouz-Mejjate for which the rivers play a role in recharge and discharge. The aquifer is heterogeneous because of the variability of the alluvial deposits. The aquifer thickness varies from 20 m at the north margin of the plain and in many overexploited sectors in the centre of the plain, to 120 m at the southern part where the bottom of the aquifer is deeper and the effects of exploitation are less significant. The groundwater is presently exploited by more than 20000 pumping wells, withdrawing about 300 to 400 Mm³/year. Consequently, during dry periods, the groundwater surface is lowered by a rhythm of 1m/year to 3 m/year in the most exploited zones.

To enhance the irrigation and alleviate the pressure on groundwater, additional surface water (80 to 180 Mm^3/year) is transferred from the hydraulic basin of Oum Er Bia bounding the Houaz to the East . The transfer is realised by a 120 km long channel, with a remote and automatic regulation.

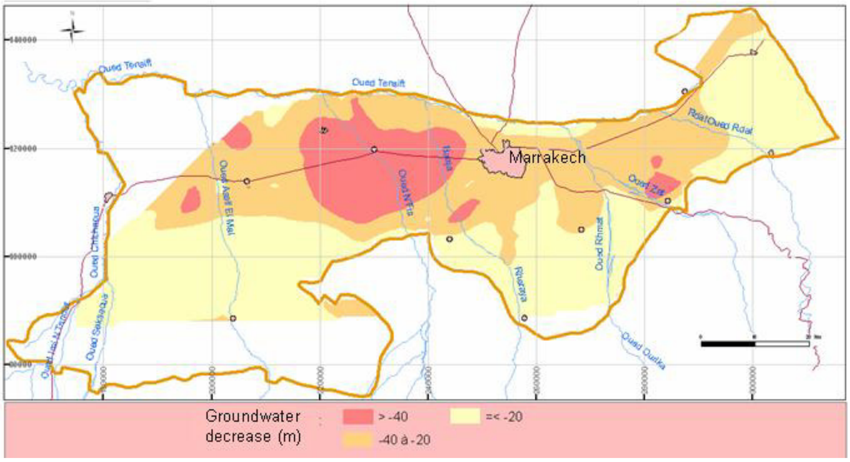

Figure 4. Groundwater decrease between 1972 and 2008.

DSS ARCHITECTURE

The Decision Support System (DSS) is devoted to integrated management of water resources in the Haouz-Mejjate plain. Its design answers to the principle of implementing inclusive and transparent sharing of ideas complemented by tools to structure, quantify and visualise the collective understanding and data, providing an informed basis of dialogue, exploration and decision-making (Tidwell, Brink, 2008; Cockerill et al., 2007).

From a technical side, the DSS of the Haouz-Mejjate aims to compare spatially and temporally sectorial water demands with regards to available surface and groundwater resources, to follow the evolution of water budgets and to develop scenarios for selecting futures management policies. Presently it is composed of the following tools:

- The GIS of the Haouz-Mejjate which organizes all the collected data and provides the shape files that are directly used as inputs to the models.
- SAMIR (Satellite Monitoring of Irrigation), a tool for the spatialization of the evapotranspiration using remote sensing. For the monthly monitoring of the evapotranspiration, this tool was modified for processing analogic satellite images (Abourida et al., 2010).
- WEAP (Water Evaluation and Planning system) model, a tool for integrated water resources planning. WEAP calculates water demand and supply information to drive mass balance model. It also evaluates water development and management options and takes account of multiple and competing uses of water systems.
- MODFLOW is the simulation model of groundwater flow. The model restitutes both the spatial and temporal variations in head charges and allows the calculation of the ground-

water balance. Through a dynamic linkage with WEAP, the model assesses the impact of the exploitation and the management options on the groundwater resources.

In the framework of the present project, the models are calibrated within the period 2001–2008. The data are collected and compiled at monthly time steps. The hydro-climate data consist of the monthly monitoring of 18 rainfall stations, 8 river gauge stations, 2 dams, the surface water deliveries to modern irrigation perimeters located in the middle of the plain, the surface water deliveries to traditional irrigation in the piedmont of the High-Atlas. The water demand data consist of the drinking water supplies and the agricultural water demand over the Haouz-Mejjate plain. These data will be supplemented by others concerning wastewater reuse of Marrakech and artificial recharge which still under study. Depending on the agricultural activities and the irrigation water source (surface or groundwater), the study area is divided into land use sectors that constitute the basic units of water budget calculation. These sectors are modeled currently in WEAP under 5 sub-catchments which are the territorial units for reflections and decisions on future water polices.

By the dynamic link between Modflow and WEAP, results of one model are transferred as input data to the other for each monthly time step. Via the WEAP interface the one can manipulate inputs and evaluate and compare results of various management scenarios.

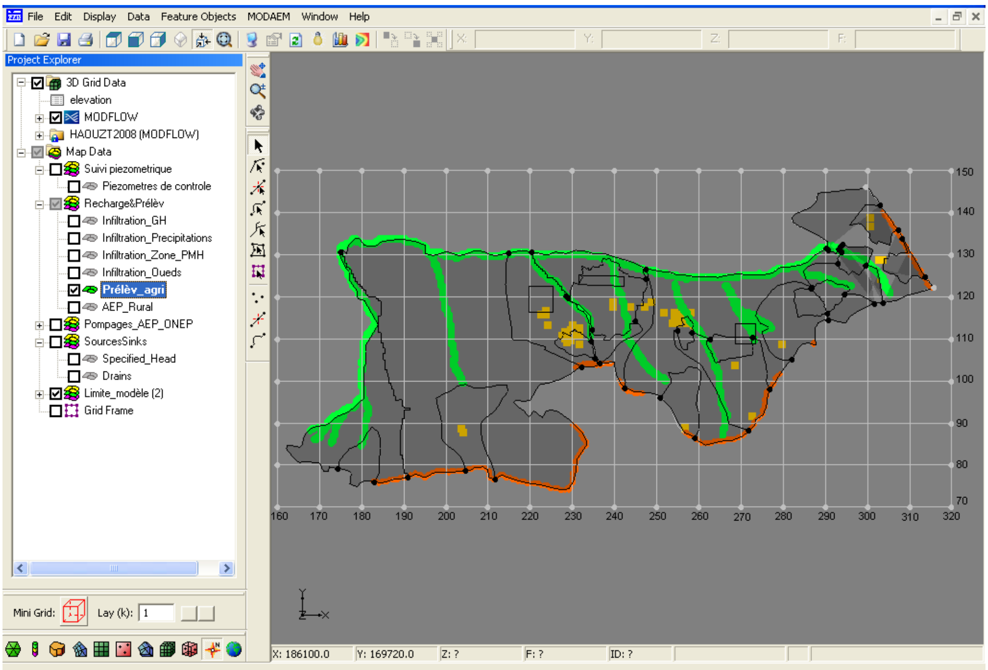

Figure 5. Modflow model of the Haouz aquifer: boundary conditions and land use zonation.

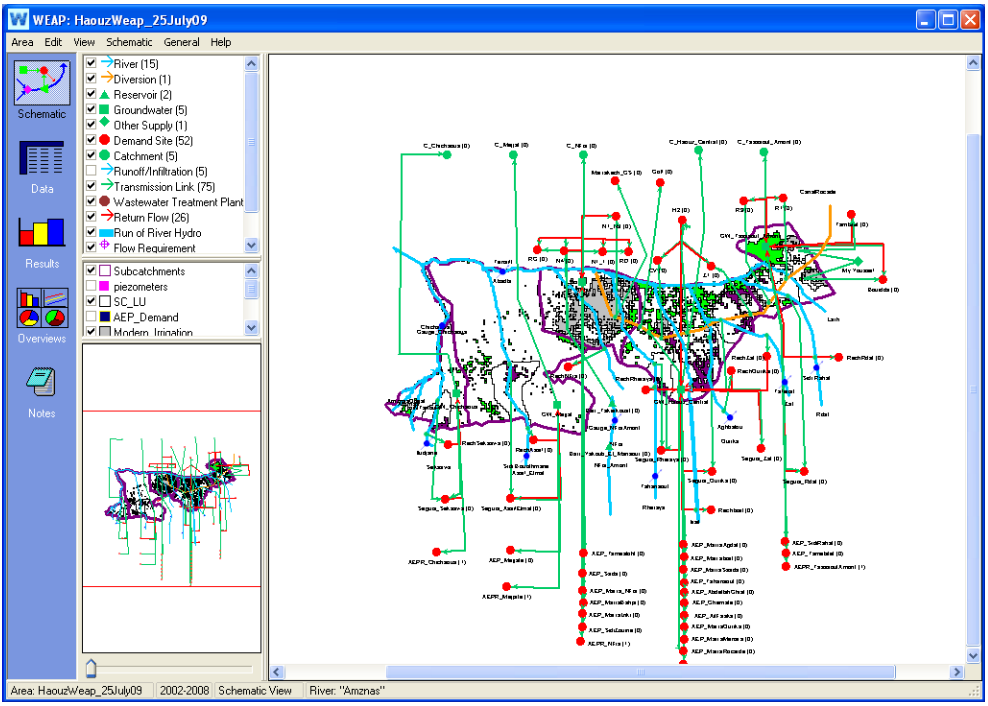

Figure 6. Weap model of the Haouz plain: water supplies and demands.

As a direct application, the DSS of the Haouz will be applied in the implementation process of the groundwater agreement of the Haouz being recently launched. In this framework, the DSS will be used to quantify and visualise, to the decision makers and stakeholders, the current status of groundwater exploitation and possible alternative scenarios of the future development.

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abstract id: **438**

topic: **1**
Groundwater quality sustainability

1.10
Decision support tools for sustainable groundwater management

title: **Potential of semantic wiki tools to organize interdisciplinary IWRM approaches**

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keywords: IWRM, decision support, knowledge management, Lower Jordan River Catchment

INTRODUCTION

Following the principles of Integrated Water Ressorces Management (IWRM), the impact of a planning scenario has to be collectively evaluated from various viewpoints, corresponding to the knowledge of experts in different domains as well as to the interests of various stakeholders. Thus, the developement of a comprehensive and interdisciplinary water ressources knowledge base is perceived as fundamental to integrated water resources assessment and consequent decision making (GWP, 2000). It is also recognised that contemporary knowledge management techniques can contribute to improving the performance and effectiveness of both capacity development (FAO & IPTRID, 2005) and knowledge sharing (Giupponi & Sgobbi, 2007) in the water sector, provided that there is a basic capacity in place to coordinate this approach. To handle this necessity, most IWRM projects carried out during the last years already had knowledge sharing initiatives on their agenda. The requirement for such a knowledge framework is tackled in current IWRM approaches in several manners: (i) Applied projects and case studies usually share multi-thematic databases and Information Systems to enable data access, transfer and comparability between their interdisciplinary modelling environments. (ii) Joint projects implement internet platforms for building and distributing thematic bibliographies as information portals on IWRM related topics (e.g. CAWaterInfo: http://www.cawater-info.net), or (iii) focus on supporting Capacity Building Networks in the IWRM environment (e.g.:

- CAP-NET: http://www.cap-net.org;
- GWPToolbox: http://www.gwptoolbox.org).

However, the direct support of IWRM decision processes in the planning practice through adequate knowledge management strategies is still lacking satisfactory consideration in state of the art aproaches on IWRM-Decision-Support-Systems (DSS).To adress this necessity it requires a knowledge management framework that enables experts, planers and decision makers to conduct specific queries for available and relevant information during the decsion process, directly adress critical knowledge gaps, feedback new information into the structure and continually evolve the knowledge base. In the domain of participatory knowledge management, Wiki-systems are considered as young and promising approach for collaborative and flexible knowledge-transfer (Wagner, 2004), which have become well-established in short term and are already successfully implemented in many coorporate environments (Hof, 2004; Swisher, 2004). Furthermore, the recent enhancement of the Wiki-technology through semantic concepts (Schaffert et al., 2008), enables additional functionality for the efficient use of Wikis as structured knowledge management tools (Oren et al., 2006).

The aim of this research is to explore the actual knowledge requirements of the IWRM decision process and analyse the potential of the semantic wiki technology as flexible knowledge management tool in a IWRM-DSS-framework. To support the theoretic findings, the presented approach is implemented as a prototype for a case study in Jordanian Wadi, a subcatchment of the Jordan Valley.

POTENTIAL OF SEMANTIC WIKIS TO ORGANIZE IWRM KNOWLEDGE

Wikis enable online interaction and collaboration in the form of web pages which can be edited and structured with a simple markup language by anyone who has appropriate access and a internet browser. Lately, wikis are also becoming popular for personal and organizational knowledge management as well, as they enable communication and collaboration, in opposition to only knowledge storage, common of many traditional knowledge management systems (Fuchs-Kittowski & Kohler, 2005). The success of wiki tools for collaborative information collection can also be observed by success and the relatively high quality of the Wikipedia encyclopedia (Giles, 2005).

Semantic Wikis combine properties of wikis (ease of use, powerful collaboration emphasis, strong linking) with Semantic Web technologies (semantic structuring of knowledge, linking with background knowledge models, logic reasoning). This results in access to the inbuilt structure of a wiki for logic reasoning, by annotating existing links with attributes that describe their meaning (e.g., a link from Karlsruhe to Germany could be annotated with "*located in*") (Schaffert et al., 2008). This feature can be used for enhanced navigation and semantic queries to contextual information.

There are different Semantic Wikis software recently under development which feature some similar and some unlike functionalities. For our study we chose the "Semantic MediaWiki" (SMW) project (Krötzsch et al., 2007), which originated from the AIFB Institute of the University of Karlsruhe as an open source extension to the well known MediaWiki implementation, but at this time has attracted a large developer and user community (http://www.semantic-mediawiki.org).

The SMW-framework has potential to support several critical knowledge management aspects for the implementation in an IWRM-DSS context:

- Strong support for collaborative work in a community of different domains.
- Possibility to gather, store and edit information in many types of rich content (e.g. text, data values, references, images, maps, files, videos ...).
- Possibility to establish and evolve the semantic structure of the IWRM knowledge elements flexibly, introduce new knowledge elements or change the properties of existing ones).
- Possibility to establish meaningful links between the knowledge elements.
- Enable free browsing but also structured queries for specific knowledge elements.

On the downside, some important shortcomings of the basic functionality for ready use in a IWRM-DSS environment have to be mentioned:

- Presentation capabilities do not support dynamic graphical representation of information elements, e.g. of a water balance scheme that dynamically represents its elements according to their data values, or the dynamic representation of the cause effect network for graphical browsing.
- Support for temporal and spatial variability of properties, e.g. in different scenario context, has to be represented by a workaround with multi-valued properties.
- Some missing semantic functionality, e.g. inheritance of properties from category to subcategory, which would enhance better ontology support.

However, due to the very generic building blocks of the SMW-software it seems feasible to implement some of the missing functionalities by developing supplementary extensions.

Further open questions are related to the prospective of integrating the Wiki structure with other IWRM-DSS elements (relational and spatial databases, system models and multi-criteria decision tools).

CASE STUDY

Study Area

For an extensive evaluation of the applicability of the SMW-software in the IWRM context we apply a prototype of the SMART Knowledge Management System for a Jordanian Wadi within the Balqa Governorate. The Wadi Shueib (Fig. 1), an eastern side wadi of the Jordan Valley near the capital Amman, is characterized by a steep relief with elevations ranging from -200 m bsl in the southwest up to 1240 m asl in the northeast. The climate in the wadi is semi-arid and classified within the Mediterranean climate zone with large seasonal and daily temperature variations (Bender, 1968). Precipitation is directly related to the terrain elevation, resulting in variations of annual rainfall from over 600 mm at the town of Salt in the northern part to less than 200 mm at the southern catchment outlet,with a maximum in the Winter months (Taa'ny, 1992). Potential Evaporation Rates in the area range from 1mm/d (winter months in the higher altitudes) to 8 mm/d (summer months in the southern part of the wadi).

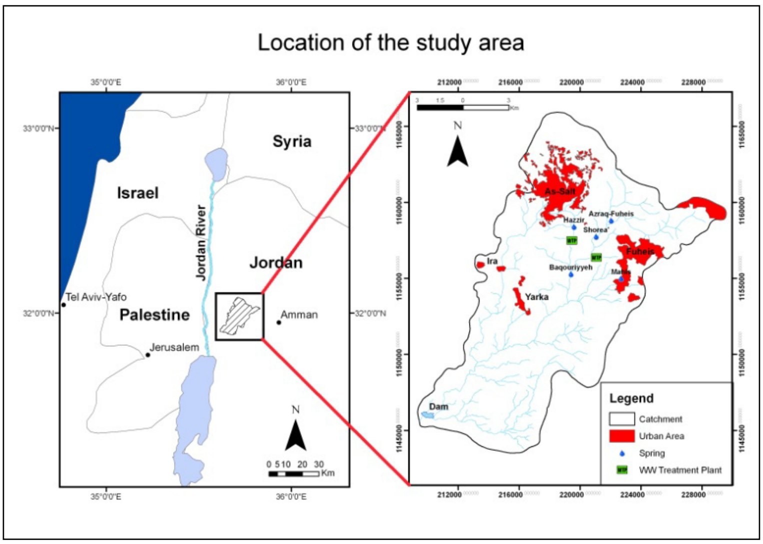

Figure 1. Overview over the Wadi Shueib catchment area.

The area comprises 5 larger municipalities (Salt, Fuheis, Mahis, Yarka, Ira) and several small hamlets with a total population of approximately 109472 people according to the last demographic census (DOS, 2004). The population density, as well as most agricultural activity is concentrated in the higher altitudes in the northern part of the Wadi.The dense drainage network of the escarpment discharges the periodic flush floods of the rainy season to the Jordan Valley floor. The baseflow in the main channel is perennial and comprises the discharge from several springs, the outflow of the two sewage treatment plants in Salt and Fuheis as well as some untreated sewage from the smaller municipalities (Ira and Yarka).

In 1968 a dam was constructed in Wadi Shueib at the outlet in order to catch up the flows, but falls dry during the summer months. The main water source in the Shueib area is ground water (pumped wells and springs) from the karst-aquifers.

The urgent issues for the water management in the Wadi Shueib are related to the municipal water supply, being the main user in this area. Due to microbiological and nitrate contamination, the available freshwater resources from the spring discharge are not used to their potential extent. The high rate of physical losses in the water infrastructure increases the supply need to cover the municipal demand by over 40%. To cover the municipal demand, water is imported at a rate of 2.2 MCM/a from the water supply of Amman. With regard to the high population growth in Jordan and the increasing living standards, this situation is likely to aggravate in the near future. The sewer coverage is only about 65%. Consequently, contamination of groundwater is widespread and in many cases contributes to the high coliform levels in spring waters mentioned above.

Water System Assessment in Wadi Shueib

The current state of the water system in the Wadi Shueib Area, its interrelation with other sectors and the existing deficits were compiled in a comprehensive review of available data from various related sector actors (MWI, WAJ, JVA), a broad range of literature sources and within interdisciplinary discussions with partners from governmental agencies, research facilities and development coorporation institutions. The findings resulted in a holistic water balance scheme, a problem analysis of causal relationships and the elaboration of potential response scenarios after the DPSIR (Driver, Pressure, State, Impact, Response) framework (OECD, 1993).

Implementation of the Case Study in the Knowledge Management Framework

However, as a typical matter of comprehensive information gathering processes in the IWRM domain, the assemblage left several data and information gaps, uncertainties as well as some inconsistencies, since

- some Data/Information were unknown or
- not available for review or
- were ambiguous as contributed from different sectors,
- investigations in the consulted data and literature sources originate from a broad time period (1990-2006), and it has to be assumed that the water system in the Wadi Shueib area has already been significantly changed during this period.

Thus, to continually improve the quality and to best reflect the actual state, it seems necessary that the available information is constantly reviewed by practitioners and researchers involved in the water sector of Wadi Shueib. Furthermore the decision and planning process of the possible response scenarios needs continuous input from the modelling and domain experts in order to close critical knowledge gaps. Therefore the comprehensive results of the water system assessment are in the process of being transferred into the knowledge structure of the SMART Knowledge Base with the Semantic Wiki software to be opened for the collaborative work process between the project partners.

CONCLUSIONS

This study has analysed the potential contribution made by a particular type of technology, a semantic wiki tool, to the development of a knowledge management framework for IWRM approaches. The assessment showed the theoretic suitability of the Semantic MediaWiki software to support several critical knowledge management aspects, especially the strong collaborative functionality and the high flexibility of the generic semantic structure. Furthermore, since based on the popular MediaWiki, the system embraces a large user and developer community which results in fast development (quarterly update releases and already over 1300 extensions available for the MediaWiki project: http://www.mediawiki.org). Development needs could be mainly identified in respect to presentation and visualization capabilities in order to enable dynamic graphics, and in respect to full semantic reasoning support. Further research is also necessary focussing on the integration possibilities of the Semantic Wiki approach within the larger IWRM-DSS framework.

The information gathered for the IWRM challenges in the Wadi Shueib catchment builds a solid use case for testing the implementation of the IWRM knowledge management prototype, which is the next step in the process of this study.

Probably the most advantageous characteristic of a Semantic Wiki approach in the IWRM-DSS context is the collaborative evolving nature of its structure and content, which resembles a constant peer review process where the target audience keeps on adding to the knowledge base that has been created.

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2 Groundwater and dependent ecosystems

2.1 Global climate change and water budget

abstract id: **157**

topic: **2**
Groundwater and dependent ecosystems

2.1
Global climate change and water budget

title: **Evaluation of evapotranspiration variation in the Draa basin using statistical and empirical methods (South-Eastern Morocco)**

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keywords: evapotranspiration, pan evaporation, parametric tests, non parametric tests, Draa basin (Morocco)

ABSTRACT

In arid and semi arid environment, water is an important limiting resource not only for its scarcity, but also its intermittency and unpredictable presence. In the Draa basin; water resources knows a decrease from the upstream towards the downstream which is translated by a decline of precipitation ratio (A mean of 270 mm in Agouim and 66.5 mm in Zagora) and an increase of evaporation (255 mm in Agouim and 360 mm in Zagora) and temperatures mean. Precipitation and evapotranspiration are the most important variables to diagnose the climate changes and their effects on the environment. The analysis of these climatic parameters seems important to understand and forecast the resources instability. The methodology adapted in this work is focused on the statistical analysis of evaporation time series. These analyses include the detection of trends via Mann Kendall test, the detection of Mean series change using a cumulative deviation and Student's t-test, and the cross correlation test to correlate the rainfall to evaporation time series.This study was conducted for 7 stations where six are located in the high Draa basin (Mansour-Eddahbi, Ait Mouted, Iffre, Agouim, Agouilal, Assaka) and Zagora station situated in the Middle Draa at a elevation of 707 m.a.s.l. The analysis outcomes reveal the existence of variations and change within the series; however, the size of this change seems difficult to prove.

INTRODUCTION

The Draa catchment climate is arid to semi arid; it is characterized by low precipitation rates which decrease with the elevation showing inter and intra annual variabilities. The evaporative power in the region knows a very remarkable increase because of the temperature degree which can reach up to 56°c as maximal extreme value in Tagounite station. The evapotranspiration is an important parameter of the water balance which influences the availability of water resources, particularly for the agriculture and which constitute a very rarely measured object. In the region of study, the quantification of the evaporated proportions is very difficult; In the Middle Draa aquifers; the groundwater level knows an important fluctuations, and the evaporation by capillarity process caused the lowering of water table. The global climate change can cause a variation in the evolution of the meteorological factors. The study main is to analyze the time series of the parameter of evaporation using parametrical and non parametrical tests for given periods. The data used comes from the principal hydro-equipped stations and they were chosen as the records spreads out over important periods without gaps.

SITUATION OF STUDY CATCHMENT

The high and middle Draa catchments are situated in the southeast of Morocco, it extends over a surface of 42000 km² and it is limited to the North by the south side of the High Atlas. This region is characterized by the climate aridity and water resources scarcity. The precipitations in this area constitute a main element of dam and aquifers refill (Fig. 1).

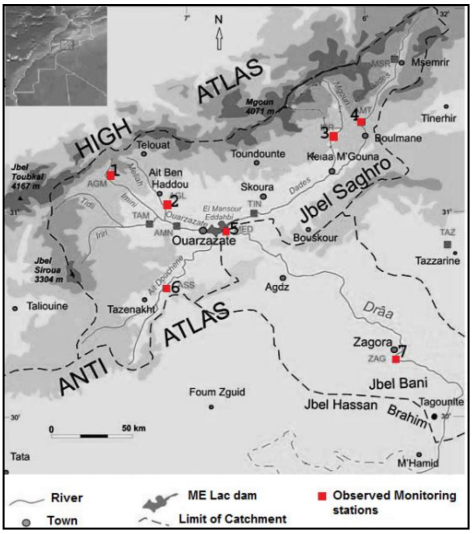

Figure 1. Situation of study area.

COMPARISON OF POTENTIAL EVAPOTRANSPIRATION TO LAKE EVAPORATION

Although the computation methods of evapotranspiration parameter are multiple; however, the evaluation of the real evaporated quantities values remains very difficult because of the interaction of several climatical and anthropological factors. The estimation of the potential evapotranspiration (ETP) in this work was based on the Thornthwaite empirical method which depends only on the effect of the climatic conditions and ignores that of the vegetation. This hypothesis is not precise, but the method of Thornthwaite was widely applied in hydrology, because of its low data requirements (only average monthly temperature data). The formula for the calculation of potential evapotranspiration is as follows.

$$E = 16C\,(10T_m/I)^{a}$$

E stands for potential evapotranspiration (in mm), ***C*** is the daylight coefficient, $\boldsymbol{T_m}$ is the mean monthly temperature (°C), ***a*** is an exponent derived from the heat index (***I***) and they were expressed by the following equations:

$$a = (67.5\times10^{-8}I^3)-(77.1\times10^{-6}I^2) + (0.0179I) +(0.492)$$

$$I = \Sigma\,(T_m/5)^{1.51}$$

The results obtained by this method were correlated to the lake evaporation which derives from the pan evaporation (class A) records. Pan evaporation is used to estimate the evaporation from lakes. There is a correlation between lake evaporation and pan evaporation. Evaporation from a natural body of water is usually at a lower rate because the body of water does not have metal sides that get hot with the sun. Most textbooks suggest multiplying the pan evaporation by 0.75 coefficient to correct this difference. The values of ETP and lake evaporation show increases for June, July and August (Figure 2). The important peaks are registered in July when the relative humidity shows the lowest values.

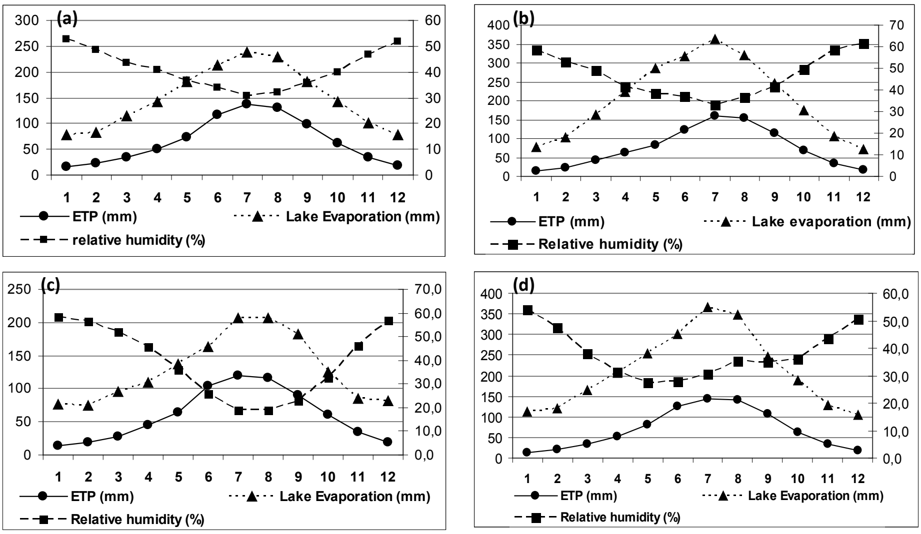

Figure 2. Diagrams representing mean monthly values of ETP, lake evaporation and relative humidity. (a) Iffre (b) Mansour-Eddahbi (c) Agouim (d) Ait Mouted.

The comparison shows a big similarity in the temporal variables evolution. As the volumes of waters transpired compared to those evaporated from lakes (Mansour-Eddahbi dam), channels are not important; the analysis of the volume recorded in hydrometric stations constituted the main objective of this study.

DETECTION OF EVAPORATION TRENDS: MANN KENDALL TEST

The evapotranspiration is a very important constituent in the water balance and the influence on the availability in water; essentially for the agriculture. The identification of evapotranspiration series trends in respond to climate change allows the estimation of the potential impact of climate change on the evapotranspiration. There are many parametric and non-parametric methods that have been applied for detection of trends (Zhang et al., 2006). Parametric trend tests are more powerful than non-parametric ones, but they require data to be independent and normally distributed. On the other hand, non-parametric trend tests only require the data be independent and can tolerate outliers in the data. One of the widely used non-parametric tests for detecting a trend in hydro-climatic time series is the Mann–Kendall test (Hirsch et al., 1982; van Belle and Hughes, 1984; Zetterqvist, 1991; Zhang et al., 2001; Burn and Elnur, 2002; Yue et al., 2002; Yue and Wang, 2002; Yue and Pilon, 2004; Burn et al., 2004; Zhang et al., 2005; Arora et al., 2005; Aziz and Burn, 2006; Gemmer et al., 2004; Zhang et al., 2006; Zhu and Day, 2005). The methodology adapted in this current study is based on the *Man Kendall test* associated with the technique of bootstrap. The trends analysis was made on 4 hydro-meteorological sites located on the high and middle Draa catchments. The values ***n*** of the temporal series (X_1, X_2, X_3, X_n) are replaced by their relative ranks (R_1, R_2, R_3, R_n). The statistical test is:

$$S = \sum_{i=1}^{n-1}\left[\sum_{j=i+1}^{n}\operatorname{sgn}(R_j - R_i\right]$$

Where: $\operatorname{sgn}(x) = 1$ for (x>0)

$\operatorname{sgn}(x) = 0$ for (x=0)

$\operatorname{sgn}(x) = -1$ for (x<0)

If the null hypothesis ***H₀*** is true, then ***S*** is normally distributed with: $\mu = 0$ and $\sigma = n(n-1)(2n+5)/18$. The Z test is thus: $Z = |S|/\sigma^{0.5}$. The positive value of ***S*** indicates an increase of the trend and vice versa.

The techniques of bootstrap are modern statistical methods of inference which demand an extensive computing calculation. The objective is to know some indications on a statistics: naturally, its estimation, but also the dispersion (variance, standard deviation), the confidence levels, and the hypothesis test. This method is based on simulations, as the methods of Monte Carlo, Bayesian method, the algorithm of Metropolis-Hastings, with the difference that the bootstrap does not require additional information and depends only to the available data in the sample. Generally, the bootstrap is based on «new samples» obtained by resampling from the initial sample. In resampling analysis, the original time series is resampled to provide many replicates of time series data of equal length as the original data. The time series data for each replicate is obtained by randomly selecting data value from any year in the original time series continuously until a time series of equal length as the original data is constructed.

Table 1. Mann Kendall test results with bootstrap (S: significant, NS: no significant).

	MEAN	MANN KENDALL TEST	CRITICAL VALUES (STATISTIC TABLE)			CRITICAL VALUES (RESAMPLING)			RESULTS
			a=0.1	a=0.05	a=0.01	a=0.1	a=0.05	a=0.01	
Agouim (1963-2004)	190.5	-2.872	1.645	1.96	2.576	1.626	1.875	2.633	S (0.01)
Ait Mouted (1964-1998)	285.9	-1.818	1.645	1.96	2.576	1.647	1.96	2.556	S(0.1)
Mansour-Eddahbi (1979-2005)	233.6	0.5	1.645	1.96	2.576	1.605	1.897	2.418	NS
Iffre (1964-2004)	206	-0.528	1.645	1.96	2.576	1.617	1.988	2.482	NS

The *Mann Kendall test* results presented in Tab.1 show the presence of significant decreasing trend at the significant level of 1% for Agouim and 10% of Ait Mouted time series, and an absence of trend in Mansour-Eddahbi and Iffre at the significance level of 10%.

DETECTION OF CHANGE IN THE EVAPORATION TIME SERIES

Most of water resources systems were based on the stationnarity of hydrology hypothesis. If this hypothesis of stationnarity is inadmissible, the current systems can be under or overestimated. The presence of trends and change in the hydro-meteorological series can be due to climate change, to the percentage of exploited lands (urbanization, deforestation), to the change of the resources management methods. The change of the temporal series can occur gradually, brutally or under a more complex form. He can affect the mean, the median, the variance or more other data aspects. The detection of change in evaporation data was made through two statistical tests: *Cumulative Deviation test* and *Student's t-test*.

Cumulative deviation

The cumulative deviation method is a parametrical test which examine if the mean in two parts of the same series are different for unknowing change time. The test supposes that the data are normally distributed. The purpose of this test is to detect a change in time series mean after *m* observations:

$$E(x_i) = \mu \qquad i = 1,2,3,......,m$$

$$E(x_i) = \mu + \Delta \qquad i = m+1, m+2,.....,n$$

Where $\boldsymbol{\mu}$ is the mean before the change and $\boldsymbol{\Delta}$ is the change of mean. The cumulative deviations of means are calculated as follows:

$$S_0^* = 0 \qquad S_K^* = \sum_{i=1}^{K}(x_i - \bar{x}) \qquad K = 1,2,3,......,n$$

And the adjusted and re-measured partial sums are obtained by dividing the values of $\boldsymbol{S_k^*}$ by the standard deviation:

$$S_K^{**} = S_K^* / D_x$$

$$D_x^2 = \sum_{i=1}^{n}\frac{(x_i - \bar{x})^2}{n}$$

The *Q* statistic test is:

$$Q = \max\left|S_K^{**}\right|$$

The test is calculated for every year; and the change point is indicated by the highest value.

Student's t-test

The Student's t-test is a non parametrical method which analyse if the mean for two different periods are different. The test supposes that the data are normally distributed. The *Student's t-test* is:

$$t = \frac{(\bar{x} - \bar{y})}{s\sqrt{\frac{1}{n} + \frac{1}{m}}}$$

Where $\bar{x}$ and $\bar{y}$ are respectively the mean of the first and the second period, ***m*** and ***n*** present respectively the number of observations in the first and the second period, ***S*** is the empirical standard deviation of ***m*** and ***n*** observations.

Results

The Student's t-test seems to be the easier and the most reliable statistical tool to test the distances between two data samples of different size.

The *Student's t-test* reveals in Tab. 2 the presence of mean change before and after the years of break:

- Iffre: the mean of 1964–1983 (Mean=*212*) and 1984–2004 (Mean=*200*) does not present any significant difference (a=0.1).
- Mansour-Eddahbi: the mean of 1979-1991 (Mean=*231*) and 1992-2005 (Mean=*235*) does not present any significant difference (a=0.1),
- Agouim: the mean of 1963–1983 (Mean=*212*) and 1984-2004 (Mean=*168.8*) is significantly different at the significance level of (a<0.01); the mean of the first period is bigger than the second.
- Ait Mouted: the mean of 1964-1980 and 1981-1998 does not present a significant difference.

Table 2.Results of cumulative deviation and Student tests *(S: significant, NS: no significant).*

		Tests values	Statistic table			Bootstrap			Results
			a=0.1	a=0.05	a=0.01	a=0.1	a=0.05	a=0.01	
Iffre	Cumulative deviation	1.459	1.131	1.261	1.502	1.113	1.238	1.492	S(0.05)
	student	1.459	1.684	2.021	2.704	1.729	2.045	2.646	NS
Mansour Eddahbi	Cumulative deviation	0.935	1.114	1.234	1.448	1.12	1.226	1.358	NS
	Student	-0.439	1.706	2.056	2.779	1.644	1.904	2.251	NS
Agouim	Cumulative deviation	1.721	1.132	1.262	1.504	1.15	1.268	1.493	S(0.01)
	Student	3.194	1.684	2.02	2.702	1.725	2.037	2.615	S(0.01)
Ait Mouted	Cumulative deviation	1.401	1.125	1.25	1.48	1.136	1.266	1.55	S(0.05)
	Student	0.401	1.692	2.034	2.732	1.598	1.867	2.306	NS

The comparison of the mean in two different periods by cumulative deviation test shows in Tab.2 a significant mean difference in the data series:

- In Iffre the data show a significant change at the significance level of 5%; the mean of 1964-1977 period is bigger than that of 1977–2004
- In Agouim, the data show a significant change at (a<0.01) ; the mean of 1963-1980 period is important than that of 1980–2004
- In Ait Mouted, the mean over the period of 1964–1990 is much important than that of 1990–1998 at the significance level of (a<0.05)
- The Mansour-Eddahbi data series does not present a significant change.

COMPARISON BETWEEN RAINFALL AND EVAPORATION DATA SERIES BEHAVIOUR

Distribution and dispertion of data

In probability theory and statistics, the coefficient of variation (*CV*) is a normalized measure of dispersion of a probability distribution. It is defined as the ratio of the standard deviation σ to the mean μ:

$$c_v = \frac{\sigma}{\mu}$$

The analysis of the variation coefficient shows in Figure 3.a, that the rainfall data are more scattered than those of evaporation. The normal statistical fluctuations give variations producing asymmetries. To distinguish between statistical and actual asymmetries, it is necessary to measure the distribution asymmetry. The most used asymmetry coefficient was the "skewness". Qualitatively, a negative skew indicates that the tail on the left side of probability density function is longer than the right side and the bulk of the values (including the median) lie to the right of the mean. A positive skew indicates that the tail on the right side is longer than the left side and the bulk of the values lie to the left of the mean. A zero value indicates that the values are relatively evenly distributed on both sides of the mean, typically but not necessarily implying a symmetric distribution. The study of the distribution of the series analyzed by the calculation of "Skewness" shows in Figure3.b a positive asymmetry for the rainfall variable; while the distribution of the evaporation data extend out towards negative values. The two parameters do not show a normal distribution.

The measure of the random rainfall and evaporation variables distribution show a positive asymmetry for the precipitation; while the distribution of evaporation spreads out towards negative values.

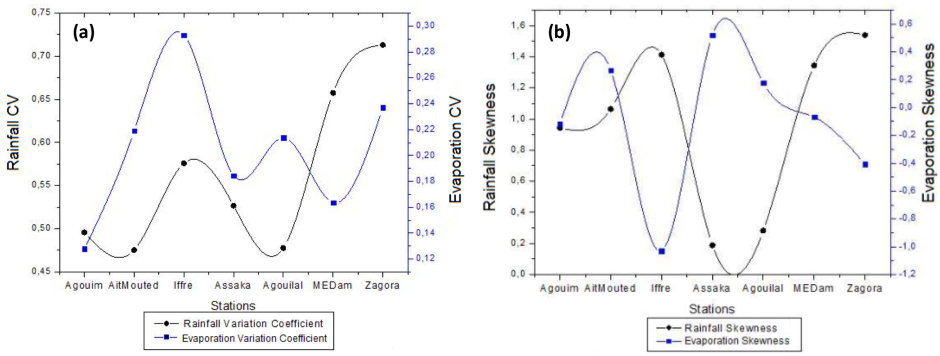

Figure 3. Statistical Comparison of the rainfall and Evaporation parameter. (a) Variation Coefficient. (b) Skewness.

Cross correlation test

The cross correlation is a standard method which aims at estimating the degree of correlation between two variables and the statistical meaning of the obtained results. The cross correlation is sometimes used in statistics to indicate the covariance *Cov (X, Y)* of random vectors *X* and *Y*; to distinguish this concept of the "covariance" of a random vector X, which is understood as being the covariances matrix of *X* coordinates.

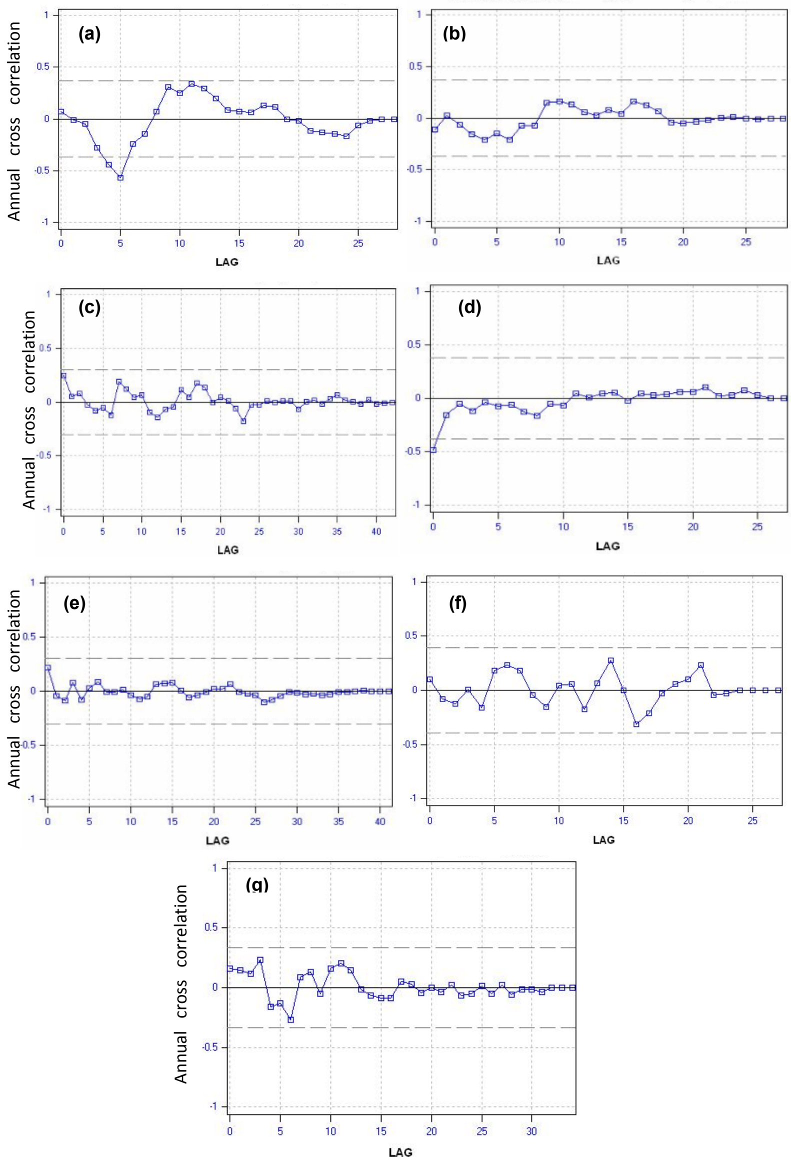

Figure 4. Diagrams representing the Cross-correlation between Mean annual rainfall data and the mean annual evaporation data measured according to Piche evaporometer. (a) Agouilal (b) Agouim (c) Ait Mouted (d) Assaka (e) Iffre (f) Mansour-Eddahbi (g) Zagora.

The mean annual evaporation data used in this analysis are measured according to the Piche evaporometer. The record's length of correlated series is variable according to data stations, the minimal period is 28 years, and the maximal period is 42 years. The results of the cross correlation test applied on seven stations show in Figure 4; a negative values and values close to 0 which can be explain by the fact that the evaporation and rainfall data are independent or conversely proportional.

CONCLUSION

Most water resources projects are designed and operated based on the historical pattern of water availability, quality and demand, assuming constantly climatic behaviour. The investigation of present and probable future climate change pattern and their impact on the water resources, appropriate adaptation strategies may be implemented. Rainfall and evapotranspiration are the most important parameter to diagnose the climate change and variation. In this current study, the statistical tests reveal the existence of change and variabilities in the time series values through decades but do not certainly prove the size of change which can be insignificant; Particularly for Mann Kendall test which do not expect the normal distribution of time series. According to the variation and change analysis tests, the evaporation time series tend to a diminution for the last decade. Indeed the climate of Morocco knew an important phase of aridity and especially that registered in 1980. The cross correlation between rainfall and evaporation has a tendency to be independent towards the upstream stations (values close to 0).

The application of Mann Kendall test on the mean annual evaporation showed homogeneity of the studied series with the presence of a decreasing trend for Agouim and Ait Mouted data series, while the series of Iffre and Mansour-Eddahbi do not present a significant trend. The Student's t-test does not show significant mean change except for Agouim where the evaporation during period of (1963–1983) presents a more important mean than that of the period of (1984–2004). The detection of mean change over two different periods according to the year of break via cumulative deviation test reveals a significant variation of mean which aims to decrease for the last twenty years. The comparison of the mean annual precipitation and evaporation series on various time intervals shows a conversely proportional relation between these two parameters which tend to be autonomous.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the member of the Regional office of agricultural development of Ouarzazate, the member of water resources service in Ouarzazate and the general office of hydraulics in Rabat. We deeply acknowledge the International Association of Hydrogeologists to accept the results of this study to be published during the 38 IAH Congress holding in Krakow 2010.

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IAH 2010 Krakow

abstract id: **366**

topic: **2**
Groundwater and dependent ecosystems

2.1
Global climate change and water budget

title: **A parallel groundwater regime and vegetation pattern analysis of the groundwater dependent ecosystems at the South Danube-Tisza Interfluve, Hungary**

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keywords: hydraulic regime, groundwater dependent ecosystem, climate change, hydrodynamic model

The investigated area lies on the Danube Tisza Interfluve where a gravity driven and surface morphology (topography) controlled groundwater flow regime occurs. The regional groundwater flow is orientated towards Danube and Tisza lowlands from the central ridge region.

At the region of interest there are several dune slack meadows which are groundwater dependent ecosystems, therefore the knowledge of groundwater systems is one of the most important aspects in the protection of ecologically valuable areas. The main goal of this study is to reveal the connection of hydrological backgrounds and vegetation pattern.

Two sites of about 100–100 ha large dune slack meadows were chosen for detailed botanical and hydrogeological investigation because of its unusual richness in protected plants. Both areas are involved in the Natura 2000 network. The studied areas are situated near to the midline zone of groundwater flow system regionally, but they bear marks of discharge zone locally. The vegetation was sampled along a 500 m long transect in one site and a 380 m long transect in the other site, respectively. The transects were positioned approximately along the line determined by observation wells, crossing stands of the relevant vegetation types. Coenological relieves were made in 5×5 m quadrates and the percentage cover of plant species was recorded in June, 2005 and 2009. It is understood that, the distinct hydraulic characters are the source of the different vegetation patterns in the studied areas. The different vegetation types can move on the surface according to groundwater level changes. If the groundwater level decreases significantly, the drought-resistant plants take the hydrophilic plants place.

Our study other aims to provide a prediction of shallow groundwater level changes as the effect of climate change resulted in lower precipitation and recharge rates on the study area. A common conceptual hydrogeological model has been created and tested.

There are some indications of regional drawdown; thus many formerly artesian wells today characterized by a static groundwater table lower than 10 m below the surface in vicinity of main recharge areas.

As a final result of the model we have been able to assign those areas where the biggest decline of water level due to happen. The hydrological changes, especially the decrease of groundwater compared with the observed vegetation map. The main result of this study is to reveal the connection of hydrological backgrounds and vegetation pattern.

abstract id: **371**

topic: **2**
Groundwater and dependent ecosystems

2.1
Global climate change and water budget

title: **Spatial and temporal changes in groundwater runoff development in the Nitra River Basin, Slovakia**

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keywords: groundwater, baseflow, drought, spatial and temporal changes, climate change

Changes in surface and groundwater extremes occurrence and their severity are observed more frequently in Europe in the end of the 20th Century and in the beginning of 21st Century (Hisdal et al., 2001; Briffa et al., 2009) in connection to climate changes (Bloschl et al., 2007). Methodology of streamflow and groundwater drought evaluation was published by Tallaksen and van Lanen Eds. (2004). A lot of local studies for various countries were published recently. Studies of streamflow drought in Slovakia were published by Majercakova et al. (1997), Demeterova and Skoda (2009), Fendekova et al. (2009), and by others.

Groundwater runoff spatial and temporal changes were studied in the Nitra River Basin (Slovakia) complemented by study of changes in selected physical and chemical parameters of surface and groundwater. Drought propagation through the hydrological cycle was studied starting with meteorological drought occurrence in four main sub-basins of the Nitra River Basin — in the Upper Nitra, Bebrava, Zitava and lower Nitra.

Parameters of surface and groundwater drought were derived using the threshold level method for streamflow and baseflow values, as well as for groundwater levels. Baseflow values in a daily step were calculated using the local minimum method for different length of N-day period (5–30 days) using the BFI+2 program (Gregor, 2008). Groundwater runoff estimated by method of Kille was used as a reference value.

Occurrence of groundwater drought periods was analyzed stressing the differences in surface and groundwater drought duration, as well as the time shift between the starting and ending dates. Spatial propagation of groundwater drought downstream the Nitra River basin, as well as temporal development of groundwater drought frequency was studied; being complemented by study of seasonal changes in basic physical and chemical parameters of the surface and groundwater.

Important differences between the groundwater drought occurrence in four studied sub-basins was proved, the increased occurrence of drought periods was documented since nineties of the 20th Century and in the period 2002–2008, being more severe in the lower part of the Nitra River Basin and in the Zitava River sub-basin.

ACKNOWLEDGMENTS

The authors would like to thank to financial support of EC FP6 Watch project (contract No. 036946), as well as the VEGA grant No. 1/0783/08. They also would like to thank to Slovak Hydrometeorological Institute for provided climatic and hydrological data.

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abstract id: **381**

topic: **2**
Groundwater and dependent ecosystems

2.1
Global climate change and water budget

title: **The impact of climate change on hydrological patterns in headwater catchments of Czech GEOMON network**

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keywords: headwater, hydrological modelling, regional climate model

INTRODUCTION

This paper is focused on changes in flow patterns due to projected climate change in micro-scales such as headwater catchments. The investigated Lysina (LYS, 0.27 km^2, 829–949 m a.s.l.) and Pluhův Bor (PLB, 0.22 km^2, 690–804 m a.s.l.) catchments are situated in the western part of the Czech Republic. Lesní Potok (LES, 0.70 km^2, 400–495 m a.s.l.) and Salačova Lhota (SAL, 1.68 km^2, 557–744 m a.s.l.) catchments are situated in the central part.

MATERIALS AND METHODS

The Brook90 model was used for hydrological modelling. Brook90 is a deterministic, process-oriented, lumped parameter hydrological model that can be used to simulate most land surfaces at a daily time step year-round (Federer et al., 2003). The model uses the Shuttleworth and Wallace (1985) method for separating transpiration and soil evaporation from sparse canopies, and evaporation of interception. Meteorological model input data for the studied catchments (minimum and maximum daily air temperature, daily precipitation depths, average daily wind speed and length of daylight) for the period 1961–2006 were taken from climatic stations of the Czech Hydrometeorological Institute (CMHI). Air temperature data were corrected based on a lapse rate, in order to represent the average catchment altitudes. Daily precipitation amounts were corrected by a factor calculated from the difference between average annual precipitation amounts measured by bulk precipitation collectors at the investigated catchments and precipitation amounts measured at CHMI climatic stations. Investigated catchments are equipped with water-level recorders, installed in combination with V-notch weirs. The calibration of Brook90 and validation of model performance were based on daily discharge data from the catchment outlets for the period 1990–2006 (Lysina, Pluhův Bor) and 1993–2006 (Lesní Potok, Salačova Lhota).

The climate model data used were obtained as a result of dynamical downscaling by the regional climate model RCAO (the Rossby Centre regional Atmosphere-Ocean model; Döscher et al., 2002). The RCAO model uses large-scale lateral boundary conditions from two GCMs: HadAM3H (Hadley Centre, United Kingdom; hereafter RCAO-H) and ECHAM4/OPYC3 (European Centre Hamburg Model, developed at Max Planck Institute for Meteorology, Germany, hereafter RCAO-E), each run with A2 and B2 emission scenarios. These future climate scenarios are based on the IPCC (Intergovernmental Panel on Climate Change) A2 and B2 SRES (Special Report on Emissions Scenarios) anthropogenic CO_2 emissions scenarios (Nakićenović et al., 2000).

Simulated daily maximum and minimum temperatures, daily amounts of precipitation, global radiation, and average daily wind speed were downloaded from the PRUDENCE project (Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects) (Christensen et al., 2007). These datasets are available for 0.44° grids (~50 km resolution) for a control period from 1961–1990 and a predicted period from 2071–2100.

Simulated RCAO atmospheric data for the control period (1961–1990) differed notably from measured data, and therefore had to be transformed for hydrological modelling purposes. We calculated a correction factors based on long-term monthly difference between RCAO climatic outputs and measured data in the control period. Under an assumption that it provides a local scale conditions correction, we used the factors for correction of the projected RCAO climatic outputs.

RESULTS

In general, Brook90 well reproduces the discharge conditions in the investigated catchments, including both individual flood events and long-term runoff. The correlation coefficient for the validation period (2000–2006) varied between 0.85–0.93 (r_{crit}= 0.2199, n= 84, p= 0.05) for monthly data and 0.67–0.73 (r_{crit}= 0.1966, n= 2557, p= 0.05) for daily data.

Annual runoff is predicted to decline by 6–90%, and impacts on the distribution of monthly flow are predicted to be significant, with summer-autumn decreases of 30–96% and winter increases of up to ~50% (for the higher altitude catchments) compared to mean flow from control period (Fig. 1). Concerning uncertainties in our study the selection of the GCM providing boundary conditions for the process of downscaling has larger impact on the projected hydrological change than the selection of emission scenario or RCM used for downscaling. The hydrological model in combination with future projected data is sensitive to change of leaf area index within the year influencing winter-spring evapotranspiration. This is probably due to anticipated shift in vegetation season.

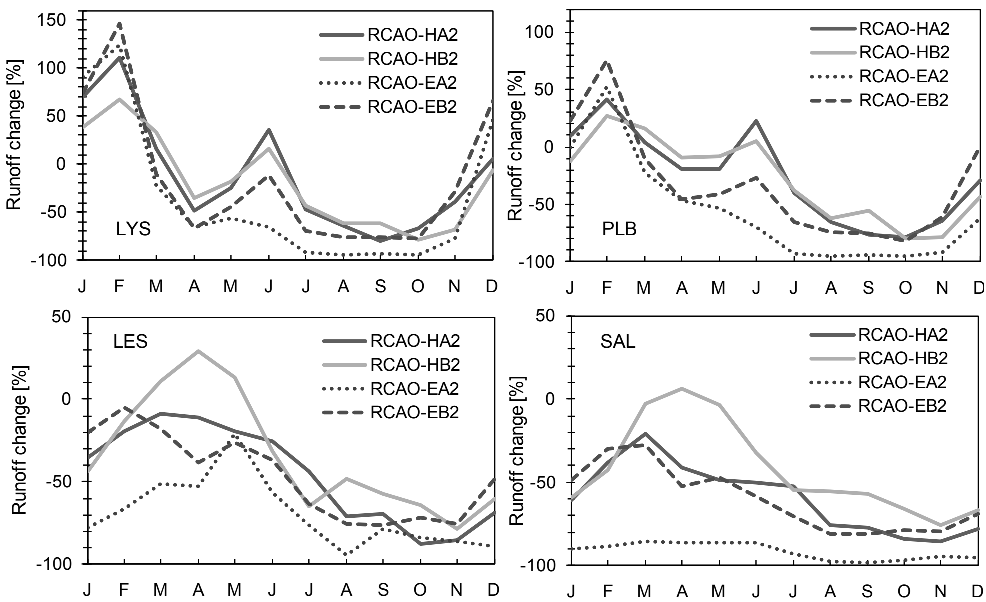

Figure 1. Mean annual cycle of runoff changes for Lysina (LYS), Pluhův Bor (PLB), Lesní Potok (LES) and Salačova Lhota (SAL). Changes between runoff were calculated using observed data for the control period (1961–1990, respective 1961–1990 for LYS and PLB) and future runoff in 2071–2100 was simulated based on bias-corrected RCAO outputs (using the HadAM3H and ECHAM4/OPYC3 with SRES A2, B2 scenarios).

CONCLUSIONS

The calibrated hydrological model Brook90 provides a suitable tool for the modelling of future changes in hydrological patterns in small-forested catchments.

The annual runoff is expected to decrease and the annual cycle will change significantly. Winter runoff is expected to increase, the runoff maxima will shift, and runoff in summer and autumn will decrease notably. The predicted declines in mean daily flows indicate that studied streams might regularly dry up for short periods in the summer and autumn that can be already recently seen at some locations.

ACKNOWLEDGEMENTS

RCAO climate data have been provided through the PRUDENCE data archive (EU contract EVK2-CT2001-00132). The research was supported by a grant of the Czech Ministry of Environment (VaV SP/1a6/151/07), by the Norway and the European Economic Area Financial Mechanisms (CZ 0051).

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abstract id: **465**

topic: **2**
Groundwater and dependent ecosystems

2.1
Global climate change and water budget

title: **The role of groundwater in enabling communities in sub-Saharan Africa to adapt to projected impacts of climate change on freshwater resources**

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keywords: groundwater, climate change, Africa, recharge, adaptation

For decades, communities across much of sub-Saharan Africa have overcome intermittent and sustained water scarcity by withdrawing groundwater from weathered crystalline rocks. Intensification of the global hydrological system brought about by climate change is projected to accentuate current inequities in the distribution of precipitation over the next century. Substantial uncertainty, primarily associated with the choice of GCM and estimation of evapotranspiration, severely constrains understanding of climate change impacts on terrestrial hydrology. Fewer but more intense rainfall events associated with a warming atmosphere heighten temporal variability in surface water resources and reduce soil moisture storage. Both of these projected impacts pose serious threats to regional food security let alone access to safe drinking water. Increased spatial and temporal variability in precipitation is expected to substantially increase reliance upon groundwater to meet domestic, agricultural and industrial water demands over the next few decades in sub-Saharan Africa. Recent evidence from ground-based observations including borehole hydrographs and river discharge records and satellite data (GRACE) reveal: (1) the dependence of direct recharge fluxes on heavy rainfall events exceeding 10 mm/day, (2) the localised extent of saprolite-saprock aquifer systems in their response to recharge and abstraction, and (3) substantial spatial variability in trends in total water storage (soil moisture, groundwater, lakes). These results highlight the role that groundwater can play in enabling communities to adapt to (1) more variable soil moisture and its associated impacts on food production, and (2) more variable surface water flows and their impacts on water supplies. The localised nature of saprolite and saprock aquifers underlying nearly half of sub-Saharan Africa compels small-scale groundwater-based adaptations to climate change. Apart from substantial uncertainty in groundwater resources at the local scale, technical and economic barriers continue to inhibit the widespread adoption of groundwater-based solutions for development and climate change adaptation.

abstract id: **502**

topic: **2**
Groundwater and dependent ecosystems

2.1
Global climate change and water budget

title: **Land use vs. climate change**

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keywords: land use, climate change, groundwater quality, groundwater quantity

There is an evidence for changes in the hydrological cycle that may be linked to changes in climate. And there is relation between land use and climate change. The long term changes in precipitation and temperature can cause the changes in land use. Land use activities exert pressure on water resources. The past and existing land use has impact on water resource quality and quantity. Regional development leads to conflicts between competing sectors and demands for safe water resources.

In the paper two different test sites will be describe and analyse:

- Ljubljana field, gravel aquifer that is the drinking water source and where urban land use prevail and
- Prekmurje Field, gravel aquifer where water supply and irrigation competed and where the agricultural land use prevail.

We'll try to find out the impact of climate change on water resources dependent system vs. changing land use and how to manage the system and what adaptations to climate change are implemented.

IAH 2010 Krakow

abstract id: **507**

topic: **2**
Groundwater and dependent ecosystems

2.1
Global climate change and water budget

title: **Factors and driving forces affecting water withdrawals in future**

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keywords: groundwater, water budget, emission scenarios, climate change

Limitation of possibilities of conflicts in water management in the European Union countries is mainly provided by the Water Framework Directive 2000/60/WE which created the framework of water policy in the European Union. It is characterized by elasticity in determination of goals, which should include environmental, social and economic aspects.

One of the elements, which has an influence for intensity of conflicts in water management, is climate changes. Among many existing definitions of „climate changes", the most adequate is following description: it is progressing process of both physical and chemical changes in the structure of atmosphere in which factors that cause this process lead to determination of new state of balance of all the climatic system in relation to the initial state.

The project „Influence of climate changes for environment, economy and society" regarding analysis of driving forces and factors that may have an influence for water uptake in the future.

The initiative of project „Influence of climate changes for environment, economy and society" (changes, effects and the methods of their limitation, conclusions for science, engineering practice and economic planning), acronym CLIMATE, which was taken by the Institute of Meteorology and Water Management in 2007, fulfils, in considerable range, the need of creating adaptive activities for climate changes. The project should be realized, in accordance to the schedule, in years 2009–2012, and its financing is also provided by the exploration part of the Operational Program Innovative Economy. The range of this project includes complex knowledge about climate changes and its negative impact for environment, economy and society. Within a framework of the project the solutions, which prevent this impact, should be elaborated, as well as, adaptive activities for new environmental conditions in important fields of economic and social life. Finally, the effects of realized program will become a scientific document, based on solid knowledge, results of which will be directly used by strategic government departments of the country for at least two time horizons: short and long-term.

Analysis, that were taken in the project, also concern future, balanced water resources management in Poland, especially driving forces and factors which may have an influence for water uptake in the future, depending on the path of economic development. Essential in this matter is interpretation of:

- influence of analysed path of Poland economic development for water demand and
- resulting from global economic development, the emission of gas causing greenhouse effect, which have an influence for climate changes, together with precipitation deciding about water resources.

In the CLIMATE project three economic scenarios were accepted as the basis for further consideration. They were elaborated by IPCC (International Panel for Climate Change) with code names accepted in *Special Report of Emission Scenarios* (IPCC Special Report): A1B, A2 and B1. More accurate information about accepted scenarios are included in mentioned report.

Analysed versions will be the basis for conclusions about future water demand in Poland and possible difficulties in realization of balanced development rules. Those versions will be specified, which means that it will be interpreted, how to adapt development trends to Polish conditions. Moreover, it is going to be necessary to interpret them in categories of influence for water demand, which will require assessment of future unitary water usage indicators.

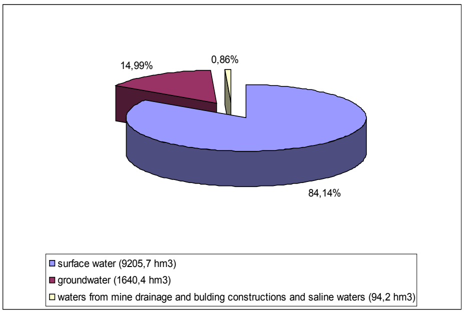

Figure 1. Structure of water uptake in Poland (in accordance to the Central Statistic Office).

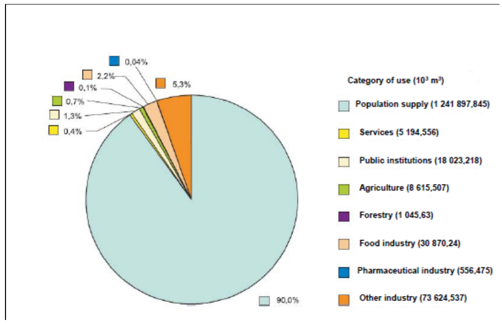

Figure 2. Diagram of usage structure of underground waters in Poland, according to the percentage uptake share registered in particular categories of usage in 2005; next to the categories total uptake is given (Frankowski et al., 2009).

The test of analysis of driving forces and factors that may have an influence for water uptake in the future was made in the groups, which are presented below.

Socio-economic development (economic growth — GDP gross domestic product, change of life conditions (standards), social trust (acceptance of changes, acceptance of expenditure growth), consciousness, ecological education, state policy concerning environmental protection, economic tools (charges, fines, the rule of repayment for water services, investment expenditure), none-economic tools (Integrated Water Resources Management, planning, determination of emission standards, determination of environmental standards)).

The path of economic growth is the basis for all the development scenarios prepared by IPCC. Basing on the water usage and economic data received from the Bank of Regional Data (BDR) and Central Statistic Office (GUS), it has been tested whether there is dependence between the value of GDP growth and water uptake. On the current stage of Polish economy development (after political transformation, industry modernization) this dependence was strongly limited. However, it does not mean that the path of economic growth will not have an influence for the value of water uptake. The influence will be noticed in fields such as conditions of life (improvement or deterioration), it will have an effect on state policy concerning usage of water resources and environment protection. Depending on the value of receipt to the state budget, investment expenditure will be determined, for example for new water-saving technologies.

Understanding climate changes, and simultaneously changes in water management, may be possible thanks to proper level of acceptance among citizens. In order to achieve this goal, one should take care of new educational programs. It is also important to organize process of society involvement properly. Adequate units should provide the information about climate changes, its effects and adaptive activities to as many receivers as possible: schools, offices. Therefore it will be necessary to prepare educational materials, organize trainings and, in schools, didactic lessons (education of children, youth, as well as, adults in the matter of climate and water resources). It will be also essential to co-operate with other more experienced countries. The example of such a country is France. Water agencies realizing water policy of the state, they also take care of promoting rational water resources usage.

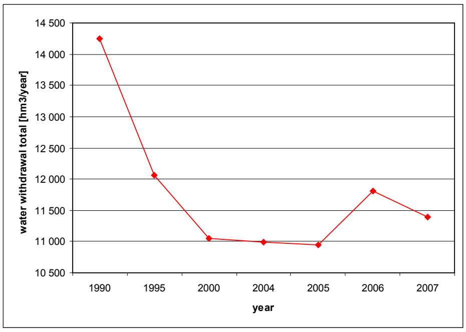

Figure 3. Total water usage in Poland in 1990–2007 (in accordance to the GUS).

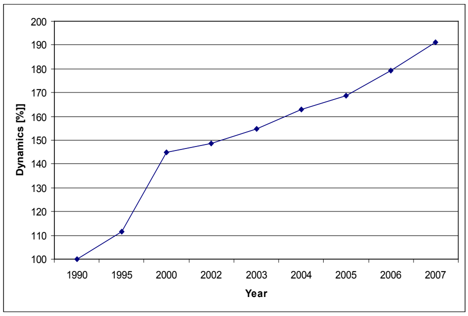

Figure 4. Gross Domestic Product (constant prices, year 1990 = 100%) in Poland in 1990–2007 (in accordance to the BDR and GUS).

Presently, water management is formed by following legal tools: juristic acts regulating aspects of planning and managing, administrative decisions including: water law permits, requirements for environmental parameters and standards of water usage for products and services. It may be assumed that the water price will be different in particular scenarios, however, it will be determined by GDP changes. Certain external factors, like distribution of income, may cause appearance of the new economic tools used for water management and lead to the modification of water law. Nevertheless, it may be presumed that implementation of the rule mentioned above will not be possible for particular water services.

Demographic development (population, life length, ageing of society, urban development).

Essential for water uptake, mainly groundwaters, will be demographic development of the country. Presently, water usage for communal purposes equals 99.6 1/M/d and it mainly comes from underground intakes (according to the GUS almost 70 % of water for communal purposes is uptaken from underground intakes). Global trends present population growth. In Poland, population decrease is forecasted, but for the size of water usage, following factors are also fundamental: life length, ageing of society and level of urban development. The income level will also have an influence and consequently life standard and the level of ecological education of society.

In last few years one can observe the quantity equalization process of water used in households located in urban developed and rural terrains. In households in urban developed terrains water usage for one consumer is falling and in 2008 it reached the value of 37.9 m^3/consumer/year (BDR data). However, in rural terrains one can observe contrary tendency — the growth of water usage for one consumer (33.7 m^3/consumer/year, BDR data), nevertheless, higher water usage still can be observed in urban developed terrains.

Changes of standard and lifestyle result in higher resources usage. Fundamental influence on water usage may have growing number of single households, in which water usage is higher than in households for several people (household for two people consumes 300 l water per day, whereas, single household consumes 210 l of water per day (European Commission, 2005)). Apart from development scenario this tendency will maintain.

Technological development (energetic economy, state policy concerning „technological progress", economic tools (subventions, public help, support of research programs), determination of water usage standards, as well as, electrical energy used by AGD, changes in industrial production technology (changes direction: growth, reduction of water absorption), state energy policy.

The size of future water usage in industry seems to be the biggest unknown, because it is very difficult to anticipate changes that may occur in industrial sector in the next tens of years, which industrial sectors will be dominating and how much water they will use. In spite of falling tendency in water usage for productive purposes, one can assess, that nowadays water absorption of Polish industry is still 2–3 times bigger than West-European industry (State Ecological Policy, 2009–2012), which means that in the future it is possible to achieve water savings in this national economy sector.

Among all industrial branches, nowadays, the biggest quantity of underground waters is used by food and pharmaceutical industry (properly 30 870.24 m^3 and 556.475 m^3, which is together 2.24% of underground waters uptake (Frankowski et al., 2009)). Those are industrial production branches that require good water quality, which is provided by underground waters. Economic development variant has fundamental influence on technological development of the state. Depending on the state budget, the values of investment outlays will be determined for new water-saving technologies, public help, support for research programs concerning innovation. Enumerated factors will have an influence on changes in industrial production technology, losses reduction, water recovery, changes in cooling technology and on direction of water absorption changes for one unit of created product. Also, the state policy in determination of standards of water and electrical energy usage for products and services will have an essential influence on future water uptakes.

Changes in agriculture (state policy concerning agriculture development, economic support of particular sectors of agricultural production through as for example additional payment system, rules of law which have an influence on changes in cultivation structure (energetic plants, biofuels, genetic modified plants), changes in irrigation of cultivation, measurement of uptakes).

According to the European Environment Agency (EEA) almost 24% of water in Europe is uptaken for agricultural purposes and only 1/3 of this water comes back to the water regions. Climate changes may determine deepening of excessive water resources exploitation resulting in decrease of its quality and growth of risk that salt water will mix with underground waters. It especially concerns coastal regions. Some of river and lake ecosystems dependent on water, can also suffer from water deficiency. Such a great water usage in agriculture may suggest bad functioning of price mechanisms. More frequent usage of intensive irrigation system by farmers together with better production efficiency only confirms this fact.

In 2005 about 0,8% (which is 9 661,137 thousand m^3) of underground waters uptake was used for irrigation in agriculture and forestry (Frankowski et al., 2009) (uptake for agriculture and forestry take 10% of total water uptake (State Ecological Policy, 2009–2012)). Essential for water uptake in agricultural sector will be the change in the method of irrigation which considerably depends on weather conditions and cultivation type. For future method of croplands usage the Common Agricultural Policy will have an influence and the system of extra charges for particular crops.

Considering the influence of agriculture for water uptake, what ought to be taken into account is growing amount of plants for energetic usage. Energetic cultivation needs more irrigation than many alimentary plants (plants for consumption), which may cause additional pressure for water resources.

CONCLUSION

Researches carried out in Institute of Meteorology and Water Management may be used for developing rules and structures of balanced managing of natural resources in Poland. Moreover, one should assess how great is the influence, that using those resources, have on environment, quality of life including progressing climate changes. Work is important, considering limitation of possible conflicts occurrence and developing adaptive activities, limiting damages caused as a result of possible climate changes. The path of economic development may determine changes in fields like life conditions, state policy concerning using of water resources and environment protection. Variance analysis will allow to take adaptive actions in economic and environmental policy. Researches carried out within a framework of CLIMATE project will allow to plan probable investment projects, which guarantee limitation of possible water deficiency. Furthermore, educational material will be developed, presenting sensitivity of water system for climate changes.

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abstract id: **519**

topic: **2**
Groundwater and dependent ecosystems

2.1
Global climate change and water budget

title: **Hydrological changes in the Mediterranean zone: impacts of environmental modifications (changing climate) in the Merguellil catchment (central Tunisia)**

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keywords: changing climate, arid zone, hydrodynamics, geochemistry, Merguellil catchment

INTRODUCTION

All around the Mediterranean Sea, the semi-arid climate and the fragmented environment (geology, topography, etc.) have led to high spatial and temporal variability in the different components of the water budget. Major fluctuations in hydrology are consequently observed from one year to another, but serious long-term changes are also the consequence of human modifications of the environment. The different studies performed in the Mediterranean region have produced a wide range of results in all aspects of the water cycle.

Tunisia provides many interesting examples of rapid hydrological changes. Its limited water resources are considerably exploited and shared between agriculture (82%), human consumption, tourism and industry, but the population rise—by a factor of 2.5 in the last 40 years—and the extension of irrigation have led to numerous local and regional conflicts. This study profited from the long-term hydrological survey conducted in central Tunisia, near the city of Kairouan, where one of the greatest aquifers in the country has been studied for four decades (e.g. Besbes et al., 1978; Ben Ammar et al., 2006). The present study was based on cross-checking of hydrodynamic and geochemical approaches and identified the drastic changes that have occurred in processes and in flows. The wide range of forms of these modifications may provide a useful framework for extrapolating or comparing with other Mediterranean regions where the causes and processes of changes are identical but observations rarer.

STUDY AREA

Wadi Merguellil is one of the three main temporary rivers reaching the Kairouan plain (Fig. 1).

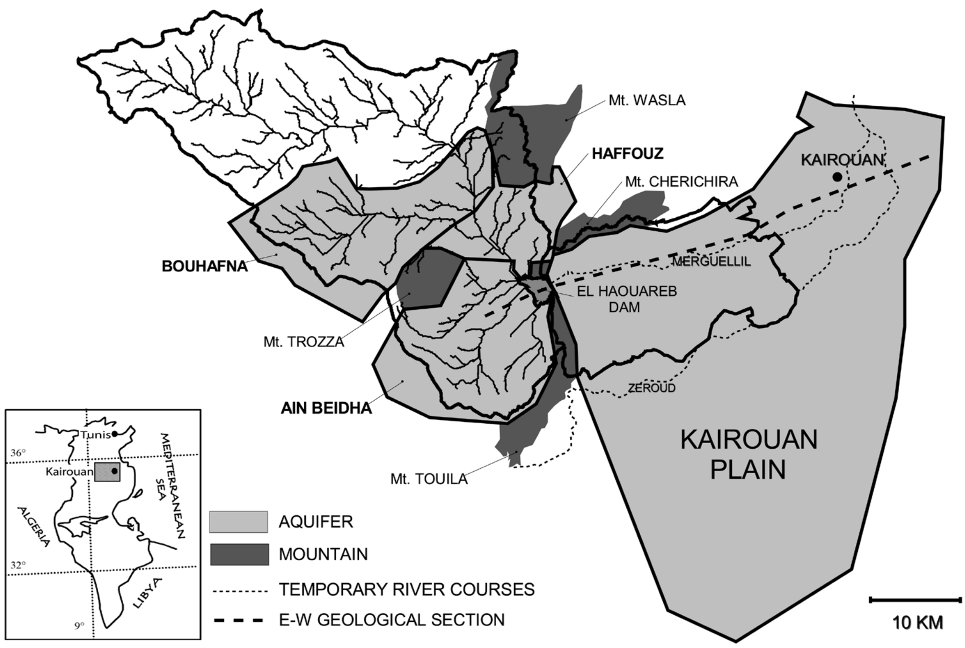

Figure 1. Location of the study area, limits of the upstream and downstream subcatchments and limits of the different aquifers.

The Merguellil upstream catchment (1200 km^2) is defined by the El Haouareb Dam built in 1989 over a rocky sill. It presents a hilly topography (altitude between 200 and 1200 m with a median elevation of 500 m) and has diversified conditions of geology, morphology, vegetation and land use. The Merguellil downstream catchment is part of the very large and flat Kairouan alluvial plain that extends over about 3000 km^2. Our research in the downstream part covered an area of 300 km^2 close to the dam, west of the city of Kairouan.

Three small connected aquifers (Aïn el Beidha, Bou Hafna, Haffouz-Cherichira) are located in the lower part of the Merguellil upstream catchment. Depending on the place and time, they interact with the drainage network in both directions (springs flowing into the river beds, floods recharging alluvium and linked aquifers). The Kairouan plain aquifer represents a much greater water storage capacity because of its horizontal extent and its thickness (up to 800 m of alluvium and colluvium). It was mainly fed by the infiltration of floods. Water table levels are regularly measured in more than one hundred piezometers. Completing the regular hydrodynamic survey started 40 years ago by the Tunisian Ministry of Agriculture, different cooperating institutes (e.g. IAEA, IRD, Universities of Sfax, Tunisia, and Paris XI, France) recently performed many physical and chemical field measurements (electrical conductivity, temperature, pH, alkalinity) and geochemical and isotopic analyses (major ions, ^{2}H, ^{3}H, ^{13}C, ^{14}C, ^{15}N, ^{18}O) in rivers and aquifers throughout the catchment.

CHANGE PROCESSES AT WORK

Climate variability

Previous studies in Tunisia showed that there is no statistical break in the long-term rainfall series of the 20th century (Sakiss et al., 1994). This was confirmed by Kingumbi et al. (2005), who analysed rainfall data in Tunis since 1901: the only break that appeared for six out of the 15 variables was in different years between 1948 and 1952. In Gafsa, located southeast of the Kairouan region, Kingumbi et al. (2005) did not find any break after 1961. However, within this long term steadiness, the high variability typical of the Mediterranean precipitation can be observed.

El Haouareb Dam

The El Haouareb Dam was built to protect the city of Kairouan against floods. Before then, the infiltration of the Merguellil floods in the river bed was the most important recharge of the Kairouan plain aquifer. For instance, in 1969, the rise in the water table induced by the catastrophic floods was higher than 10 m on the Merguellil side. Since 1989, the surface runoff of the Merguellil upstream catchment has been stopped by the dam. This water is now shared between infiltration through karstic fissures (the most important term), evaporation, pumping and releases. Water infiltrating beneath the El Haouareb Reservoir joins the groundwater flow from the Ain el Beidha Tertiary-Quaternary aquifer, goes through the karstic Mesozoic limestone of the El Haouareb sill and recharges the alluvial Plio-Quaternary aquifer of the Kairouan plain. There is no surface runoff downstream from the dam, except the very exceptional dam releases (less than 6% of the water stored by the dam, which was 304×10^6 m^3 in 16 years).

The reservoir dried up completely in 1994, 2000, 2001, 2002 and 2004. Infiltration to underlying aquifers was estimated from the daily measurements of the reservoir water level through an iterative calculation calibrated in depletion periods. Evaporation and rainfall were measured at the site of the dam. But the main cause of uncertainty in estimating water volumes is the silting up of the dam, which represented 20.5 × 10^6 m^3 over 17 years. A few very violent floods contribute most of the sediments and can abruptly change the relationship between the level, area and volume of the lake. In February 2006, we updated the reservoir budget since construction of the dam. Water stored in the reservoir comes from the Merguellil inflow (90%) and from the rain falling on the lake (10%). It is shared between infiltration (52%), evaporation (30%), pumping (12%) and dam releases (6%). The uncertainty of the total budget of the reservoir water is estimated at about 5%.

Water consumption

Because of its limited and unreliable spatial and temporal availability, surface water is of limited interest for regional development. When it exists, a small proportion of water in the El Haouareb Reservoir is pumped to a nearby large irrigation scheme (between 1 and 6 × 10^6 m^3 per year). In some small reservoirs of the upstream catchment, water is also pumped by 270 farmers but this represents a very limited consumption (an average of 10 000 m^3 per year per reservoir). In fact, most water is taken from the upstream and downstream aquifers. Groundwater is pumped for irrigation and to supply drinking water to the Kairouan region, but also to the Mediterranean coast where demand for water exceed local resources. During the last 10 years, the irrigated area increased by about 10% in the upstream catchment, and now covers 3500 ha (of which 670 ha are fed by small reservoirs). In the same period, the irrigated area in the plain increased from 3000 to 8800 ha. As a consequence, the number of boreholes in the thick alluvial Kairouan aquifer has increased continually in spite of the legal prohibition. Most of the boreholes are for private farms, while a few others with a high pumping rate are for public irrigation schemes or drinking water supplies. Official figures for agricultural water demand are significantly underestimated compared with the results of our detailed local field investigations. Overexploitation of the aquifer is reflected in the drop in the water table: between 0.25 and 1.0 m per year for the last two decades, depending on local values of pumping intensity and hydrodynamic characteristics. The Bou Hafna Oligocene aquifer in the upstream catchment is also overexploited (with a resulting drop in the water table of up to 30 m in 30 years).

IMPACT OF CHANGES IN THE KAIROUAN PLAIN AQUIFER

In the downstream part of the Merguellil catchment, the overexploitation of the Kairouan plain aquifer has led to a general drop of the water table. This could induce long-term changes in water quality by pumping older waters from deeper layers or reversing the gradient with the salt lake area downstream of Kairouan that is the natural outlet for the regional flow. But in fact the construction of the big El Haouareb Dam is by far the most important factor to be discussed, because of its many consequences upstream and downstream from the dam.

Because of the semi-arid climate and the depth of the unsaturated zone, under natural conditions, the direct infiltration of rainfall over the plain was not able to reach the Plio-Quaternary aquifer in significant water volumes. Even now, we were unable to find any traces of a possible return of irrigation water to the plain groundwater (a more detailed study based on 15N content is in progress). If it exists at all, this phenomenon is probably slight.

Natural recharge of the Kairouan aquifer was indirect and resulted from infiltration of Merguellil floods. Very exceptional events, such as the one in 1969, extended over the whole plain and induced remarkable rises in the water table (Besbes et al., 1978). Other floods concerned only a limited width and a variable length of the river bed, depending on the strength of the flood, and groundwater recharge occurred discontinuously in the most pervious parts of the bed. Figure 4 shows the 8 m rise in the piezometer M7 in 1969 and much smaller rises in 1973 and 1974. This natural process still occurs when reservoir water is released, which is very rare and amounted to only 13×10^6 m^3 in the last 17 years.

The construction of the El Haouareb Dam stopped the natural recharge process and the Plio-Quaternary aquifer is now essentially fed by groundwater flow from the upstream catchment through the El Haouareb karst sill. The creation of an artificial hydraulic boundary limit (the reservoir) at a much higher elevation than the previous river elevation led to a new geographical pattern of recharge where infiltration is limited to the area close to the dam, over its whole aquifer width, but with no extent downstream. Head changes in the reservoir are transferred through the karst and progressively disappear into the plain aquifer. In the two years following completion of the dam, the water table showed a continuous rise, up to 7 m close to the dam which could still be identified at a distance of 6 km downstream. In piezometer M7, this impact was of 4 m, i.e. half of the 1969 flood; in piezometer M14, 27 km downstream from the dam, the impact of the construction of the dam was no longer visible.

Decreases in the plain water table may result from the natural return to equilibrium (after exceptional events such as that of 1969), drawdown induced by pumping, or even a long-term change caused by the new recharge process (in place and flow). The last two causes cannot easily be differentiated because they interfere in the same direction: a wet year brings more water to the reservoir and requires less irrigation water for the same crop. Piezometers located farthest from the El Haouareb Dam are obviously less sensitive to hydrological events happening in, or close to, the reservoir, and their temporal change is more easily linked solely with the exploitation of the aquifer. The comparison of present levels with much older observations made by Stépanoff (1935) showed an identical depth of the water table in the 1930s and in the 1970s. The depletion of the plain aquifer caused by the development of irrigation first became visible in the 1980s.

Considering the first ten years after completion of the dam, Kingumbi et al. (2004) proposed a mean annual budget comprising 14×10^6 m^3 of surface water infiltrating under the dam with 5×10^6 m^3 of groundwater from the Aïn el Beidha aquifer.

According to these authors, this mixture flows directly into the plain aquifer (9×10^6 m^3) or goes out through karstic springs (10×10^6 m^3), of which most again infiltrates and joins the groundwater flow recharging the plain aquifer. Our own calculation of infiltration under the dam resulted in an average of 11×10^6 m^3 for the first ten years, and 9.5×10^6 m^3 for the whole period 1989–2005. The discrepancy between the previous and our estimate is linked with the uncertainty in calculations, especially evaporation uptake, as well as the link between the level of the lake and recharge intensity.

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2.2 Climate induced changes of land-use and their impacts on evolution of the EU Groundwater Directive

2.3 | Interactions of surface and ground waters

abstract id: **129**

topic: **2**
Groundwater and dependent ecosystems

2.3
Interactions of surface and ground waters

title: **Hydrodynamic interaction between surface water and groundwater in volcanic aquifer system of Lake Ciseupan, Cimahi, West Java, Indonesia**

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keywords: groundwater-surface water interaction, volcanic aquifer system of Lake Ciseupan, Cimahi, West Java, Indonesia

INTRODUCTION

The Lake Ciseupan was a sand mining area which excavate sands and stones, that has been started from 1980 to 1990. The remains of the activities are dug holes turned in to man-made lake, with undulating depth and 300 meters in diameter. Such holes are surrounded by hills with a height between 690 to 720 meters above sea level (m a.s.l.) (Figure 1).

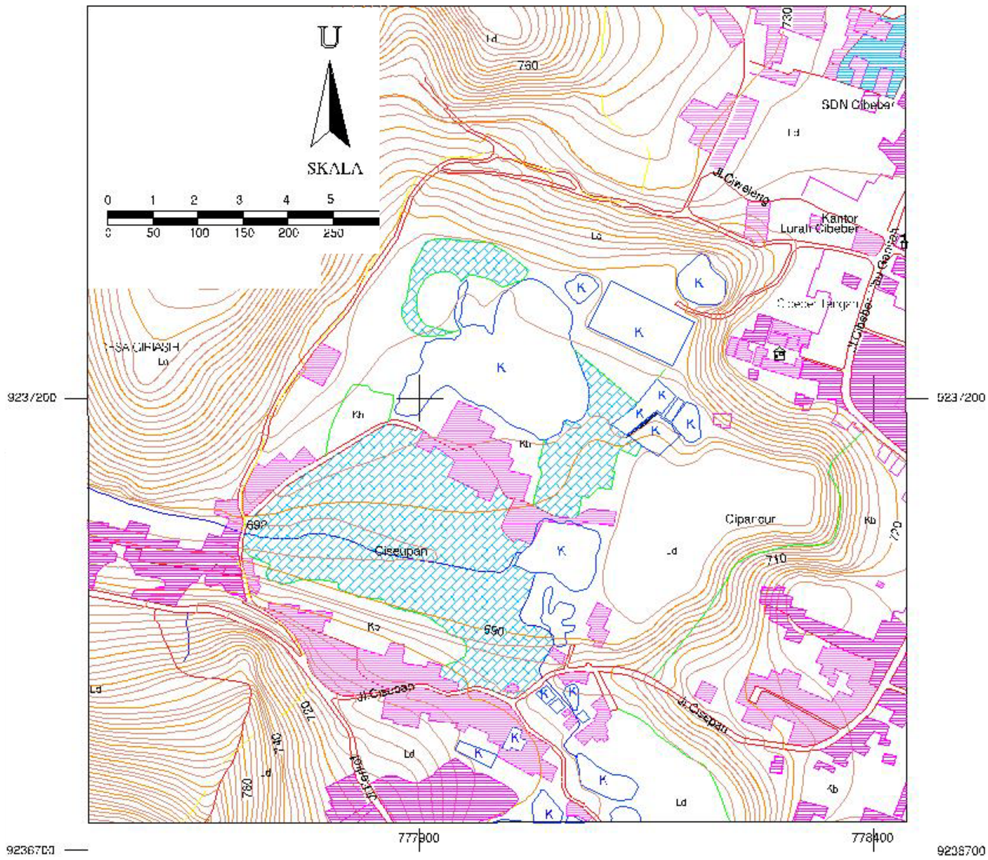

Figure 1. The location of Ciseupan Lake, Cimahi, West Java, Indonesia.

The lake water is utilized by the surrounding residential and industries. The volcanic aquifer consists of tuff and volcanic sand as part of Cibeureum formation, underlain by impermeable breccias, and bordered by intrusion at the southern part (Table 1 and Figure 2). Volcanic deposits are proven to have high productivity, than older sedimentary rocks. The volcanic aquifers are composed of combination between porous and fractured systems.

Table 1. Stratigraphical unit and aquifer productivity of the study area.

	Age	Lithological unit			Litologi utama	Satuan hidrogeologi	Produktivitas akifer (IWACO, 1991)
		Silitonga (1973)		Kusumadinata and Hartono (1981)			
	Holocene	Lake deposit (Ql)		Kosambi Fm.	Clay and sand	Shallow aquifer	Intermediate
Quartenary	Pleistocene	Sandy Tuff (Qyd)	Yoi-ung vol-can-ics	Cibeureum Fm.	Sandy Tuff	Mid aquifer	High
		Pumice-Tuff (Qyt)			Tufaceous sand		
		Old volcanic deposit (Qob)		Cikapundung Fm.	Breccias, lahar, lava	Deep aquifer	
		Andesite (a), Basalt (b)			Andesite and basalt	Bed rock	None
Tertiary	Pliocene	Tufaceous Breccia, Lava Sandstone, Conglomerate (Pb)			Breccias		Low
	Miocene	Old sedimentary rock (Cilanang Fm.)			Marl		None

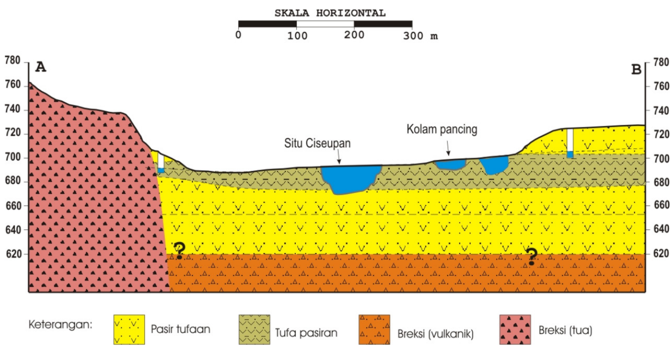

Figure 2. Aquifer section of the study area.

METHODS

A finite difference modelling with Visual ModFlow was used to identify the hydrodynamic interaction between surface water and groundwater around the lake. It was built based on surface geological observation, geophysical and hydrochemical measurements (Figure 3).

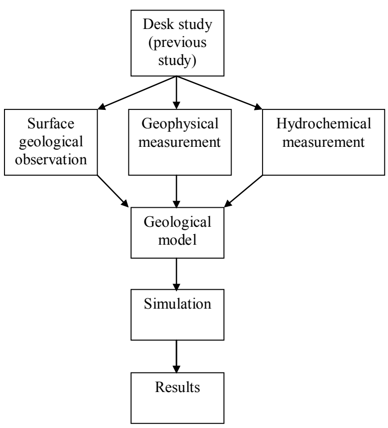

Figure 3. Aquifer section of the study area.

The total area modelled is 810,000 m^2, 900 m × 900 m.

RESULTS

The result shows that the groundwater flows westward with radial pattern and 0.05 hydraulic gradient (Figure 4 and 5).

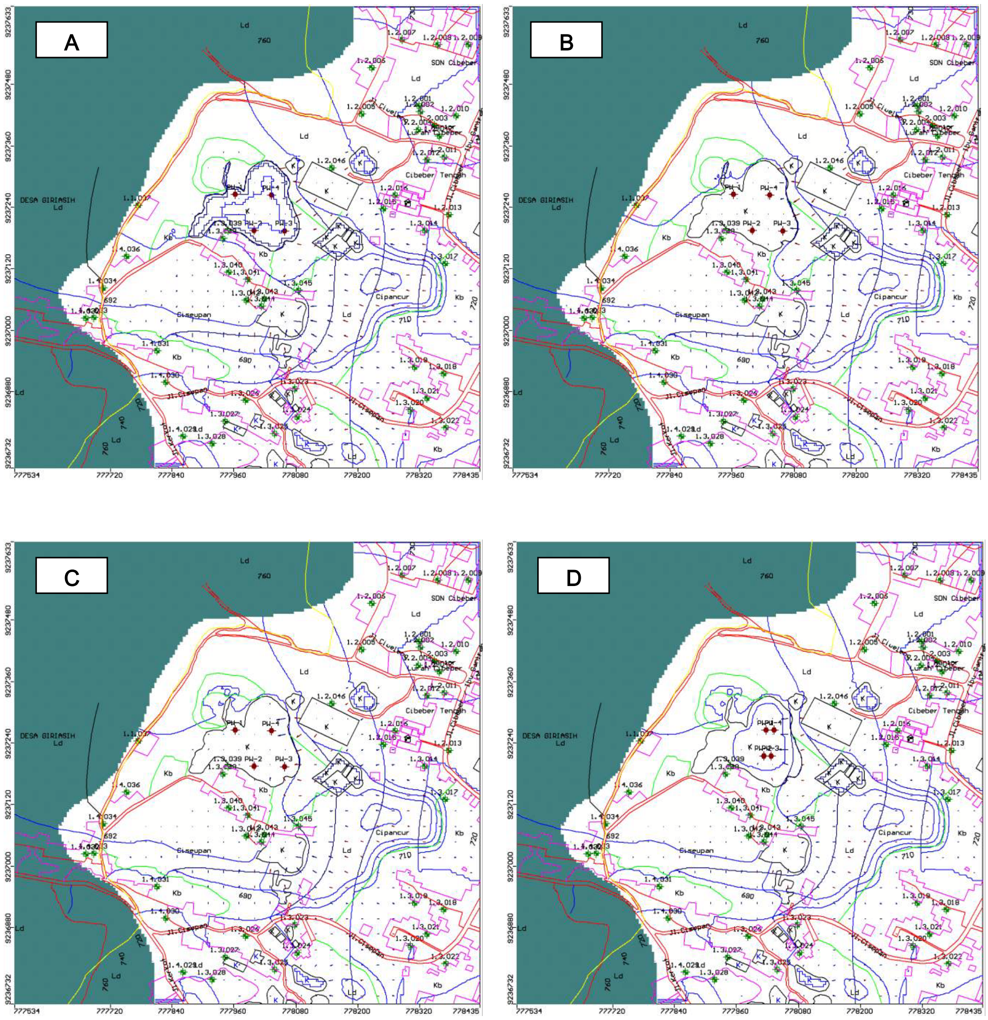

Figure 4. Scenarios of groundwater modeling.

Based on the modelling and hydrochemical analysis, showing bicarbonate dominations and small quantities of ammonium, there are similarity between lake water and groundwater. The truncated volcanic aquifer by the previous excavation have exposed the groundwater to fill in all the abandoned openings and have diverted the groundwater flow. Therefore the exploitation of the lake water will convincingly affect the groundwater level at the surrounding areas, as reflected by cone depressions at the settlement area, southern part of the lake. Scenarios of lake water and groundwater level depletion modelling show that when the lake water drop by 1.3 m, which is equivalent with lake water pumping of 21,000 m^3/day, will cause the depletion of groundwater level by 1 m at the nearest well 10 m from the lake.

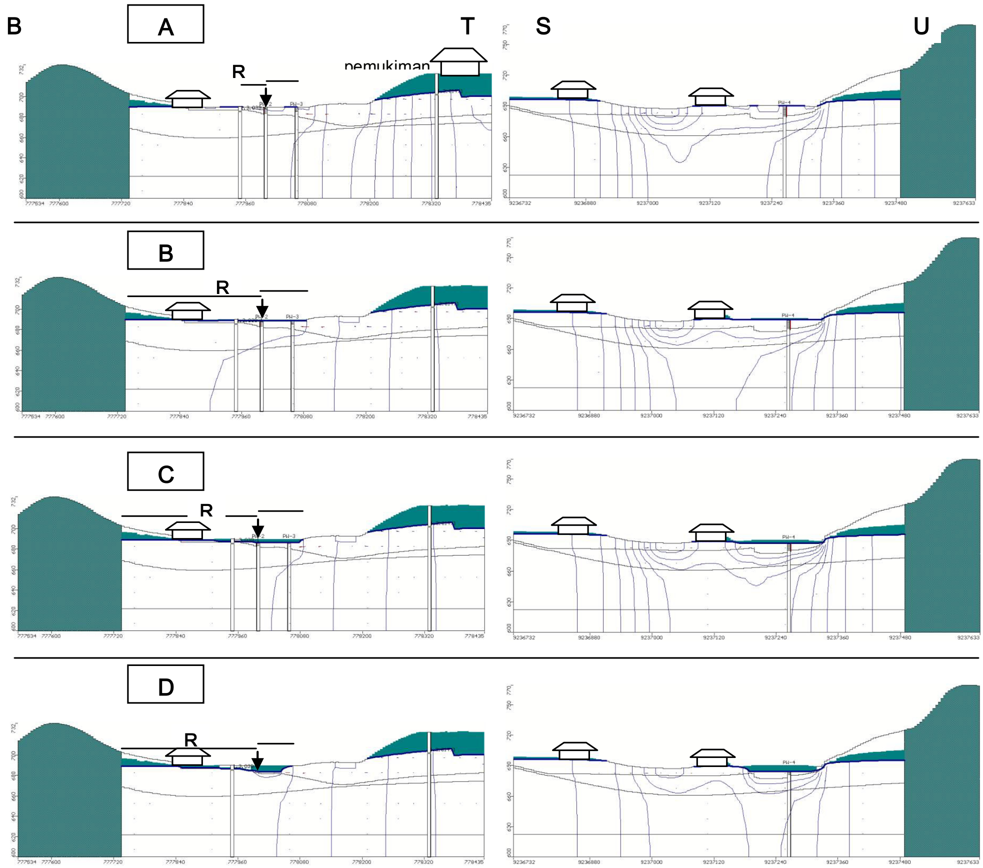

Figure 5. Scenarios of groundwater modeling cont.

The conceptualization of hydrogeological model at the man-made lake area reveals a complex interaction between lake and groundwater systems, with also considering the layers of volcanic rocks. This research with various scenarios also shows that groundwater flow around a depressional form can be in divergent pattern rather than always in convergent. This condition is controlled by the slow dip of volcanic layers.

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abstract id: **153**

topic: **2**
Groundwater and dependent ecosystems

2.3
Interactions of surface and ground waters

title: **Impact of climate change and variability on groundwater-surface water interaction for unconfined aquifers in cold snow dominated regions**

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keywords: Finland, unconfined esker aquifer, climate change, surface water-groundwater interaction

We are providing a methodology to estimate surface water–groundwater interaction in snow-dominated regions. The methodology was tested on an unconfined esker aquifer in northern Finland. Three models were linked together to estimate the temporal and spatial variations in the groundwater-surface water interaction. The physically based hydrological model CoupModel (Jansson, Karlberg, 2004) was used to estimate changes in the groundwater recharge in the present and under future anticipated climate conditions. Because in cold snow dominated, regions water infiltrates through frozen soil, too (Stähli et al., 1996; Sutinen et al., 2007), the recharge model must also provide for water flow through frozen soil and be able to simulate the temporal variation of the depth of frozen soil, snow cover, snowmelt discharge, evaporation, and thickness of the vadose zone, all of which affect the variation in groundwater recharge. In snow dominated regions, the maximum groundwater level in spring is dependent on the spring melt period. The onset of snowmelt and groundwater recharge may be important to estimate the timing of the maximum groundwater levels during and after the snowmelt period. The recharge rate was simulated with and without the influence of soil frost, and the variation of recharge was then compared with observed monthly groundwater levels. In determining the impact of climate change on groundwater recharge, we ran the model only with the influence of soil frost.

The watershed model WSFS (Vehviläinen, 2007) was used to estimate changes in the surface water levels under present and future anticipated climate conditions. In Finland, surface water intrusion typically occurs during and after the spring melt period. In summer, fall, and winter, the groundwater level is usually higher than the surface water level, and the groundwater discharges to the surface water. This intimate connection means that variation in the surface water level is important for assessing the groundwater discharge and focused recharge rates.

The results of the simulated surface water level and groundwater recharge were linked to the Groundwater Modeling System (GMS) version 6.5 (Brigham Young University, 2005), and the three-dimensional groundwater flow model MODFLOW was used to predict the effect of four climate change scenarios for Finland (periods 1971–2000, 2010–2039, 2040–2069, 2070–2099) on groundwater levels and groundwater–surface water interactions.

The groundwater flow model was run with an average pumping rate of 750 m^3/d to study the combined impacts of climate variability and groundwater pumping on the groundwater–surface water interaction. The intrusion of surface water into the aquifer was studied by comparing the surface water level with the groundwater level in the cell of the pumping well. Surface water intrusion was assumed when the water level in lake Pudasjärvi was higher than that in the cell of the pumping well. Monthly nonpumping and pumping scenarios, and one-year-long hot/dry (year 1988) and cold/wet (year 1981) scenarios were simulated by perturbing the regional temperature and precipitation data according to the projected climate scenarios. A constant pumping rate of 750 m^3/d was assumed in the simulations. The frequency of the surface water inflow to the aquifer was also plotted. The probability of surface water intrusion occurring was estimated by assessing the probability of surface water flow into the cell of the pumping well

The winter surface water level maximum is predicted to decrease and shift to earlier in the year due to increase in snowmelt and rainfall in winter. A rise in winter groundwater level, and a shift in the timing of the groundwater maximum to earlier in the year are expected to follow the increase in winter recharge. Flow reversal will increase more in cold/wet years than in hot/dry years because the surface water level will more often rise above the groundwater level in cold/wet years.

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abstract id: **154**

topic: **2**
Groundwater and dependent ecosystems

2.3
Interactions of surface and ground waters

title: **A groundwater flow model for understanding aquifer-river interactions in Mancha Oriental System (SE Spain)**

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keywords: numerical modelling, MODFLOW, aquifer/river interactions, groundwater abstractions

INTRODUCTION

The Mancha Oriental System (MOS) (7,260 km^2), is one of the largest aquifer within Spain. MOS is located in the SE of Spain is completely confined within the physical Jucar river basin (Fig. 1). Since the 80's, the exploitation of groundwater resource has become a key driver for the socio-economic development of region. Irrigation agriculture area currently exceeds (1,000 km^2), and groundwater abstraction runs at rate of more than 400 Mm^3/yr (Estrela, 2004), from which 98% is used for irrigation. This figure contrasts with the available groundwater resources estimated in the Jucar Hydrological Plan, which is 320 Mm^3. The quantitative analysis made by Jucar river basin Authority for the MOS clearly indicates that environmental objectives are not currently satisfied and that there is a risk of not reaching good status by 2015 as specified in the Water Framework Directive WFD. The implementation of the WFD requires the application of numerical modelling that can answer questions concerning the complex interactions of surface and ground waters.

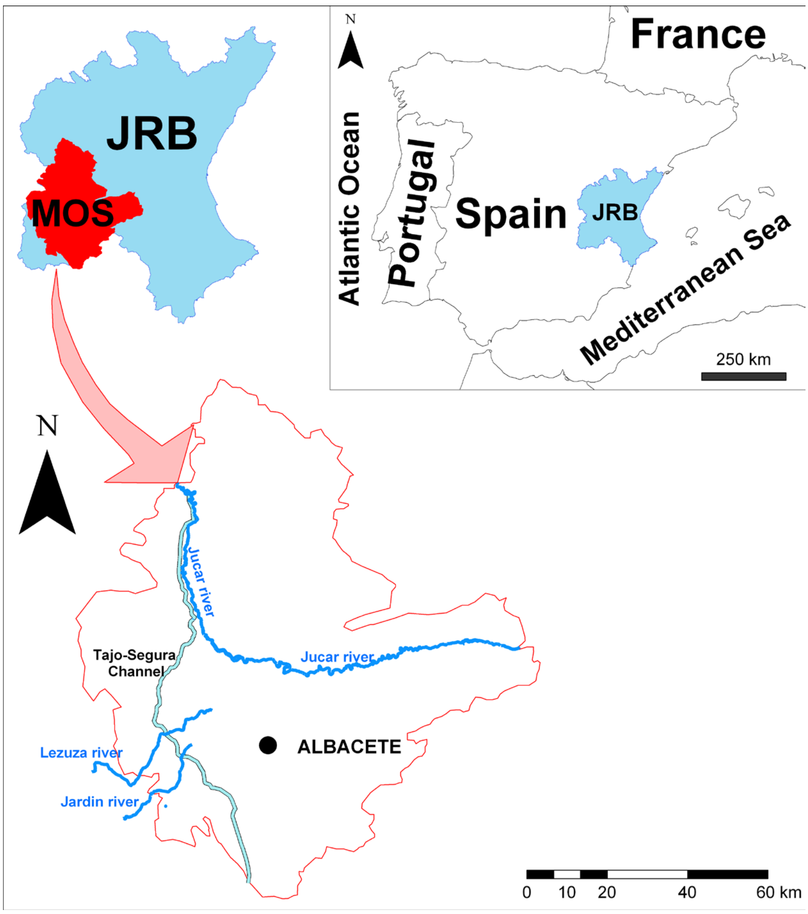

Figure 1. Location of Mancha Oriental System (MOS). Jucar River Basin (JRB).

Aquifer-river interactions can be drawn from different methodologies, however the assessment, quantification and spatial prediction of river-aquifer interactions is usually provided with numerical models that can represent the overall complexity of regional hydrogeological systems (Sophocleous 2002). In this work presents the development of a three-dimensional large-scale numerical groundwater flow model by MODFLOW.

MODEL DEVELOPMENT

The area of study was divided horizontally in three dimensions into square cells of 1 km, lined up in a northerly direction with 126 columns and 131 rows for a total of 16,506 cells per layer. The 3D geometry of the lithostratigraphic layers has also been incorporated, generating a model of six layers with three aquifer units and three semipermeable units. The temporal discretization was defined for a period of 23 years (1982 to 2005), with stress periods taken on a monthly scale. The boundary conditions were defined by making model limits coincide with the physical limits of the system. The Jucar River was represented as a boundary condition with specific potential in terms of limits within the area of study. To hydraulically characterize the hydrogeologic units in the MOS we reviewed data in (Sanz et al. 2009). Recharge values from rainwater infiltration in the MOS which were obtained from JRB water authorities (CHJ). To determine groundwater abstraction for irrigation, we used a multitemporal and multispectral analysis of Landndsat 5-TM and Landsat 7-ETM+ satellite images. Estimating groundwater pumping for urban and industrial uses has been performed by relating the volume of water used in supplying areas in the MOS with population data (see for further details Sanz et al., in press).

Calibration was performed in two phases: steady and transient state. In the steady state, the permeability and storage coefficient were modified to minimize differences between groundwater levels observed and simulated. This calibration yielded initial conditions for simulations in the transient state. Calibration was considered finished and satisfactory when the simulated and observed tendencies of groundwater evolution distributed spatially throughout the aquifer coincided, and when the differential discharges simulated in various reaches of the Jucar River were similar to the discharge values recorded (Fig. 2).

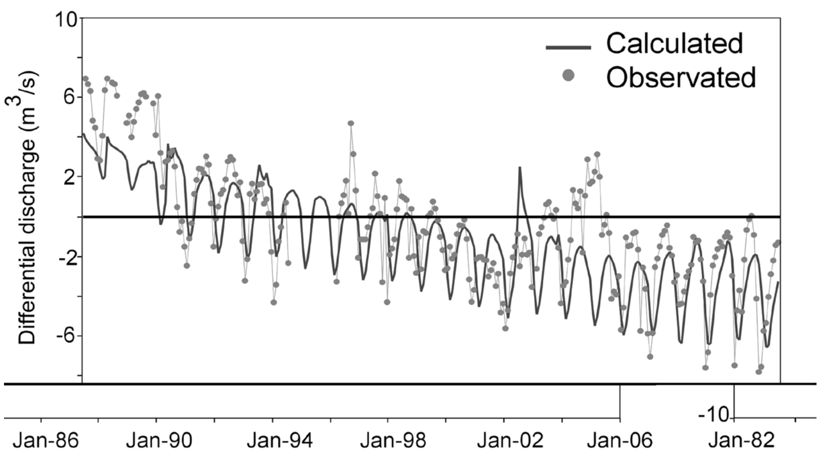

Figure 2. Monthly differential discharge values obtained from gauging stations in middle reach of the Jucar river.

MODEL RESULTS

MOS groundwater flow model was calibrated successfully and it has allowed details on the hydrogeological system and establish both in space and in time the qualitative and quantitative relationship between the river and the aquifer system, with respect to the pumping of groundwater (see Sanz et al., in press). Model results show that although groundwater extractions increase progressively from the '80s, the loss of groundwater storage tends to decrease. This behaviour is related to the system's response to effects from pumping-induced river-aquifer relations. The river-aquifer disconnection point may be affected and drain less aquifer discharge than before pumping initiated. When a river passes from a losing river to gaining there is a disconnection and the disconnection point begins to move downstream (Fig. 3). MOS model groundwater has become a useful tool that allows assessment, quantification and spatial prediction of river-aquifer interactions under influence of groundwater abstractions in MOS.

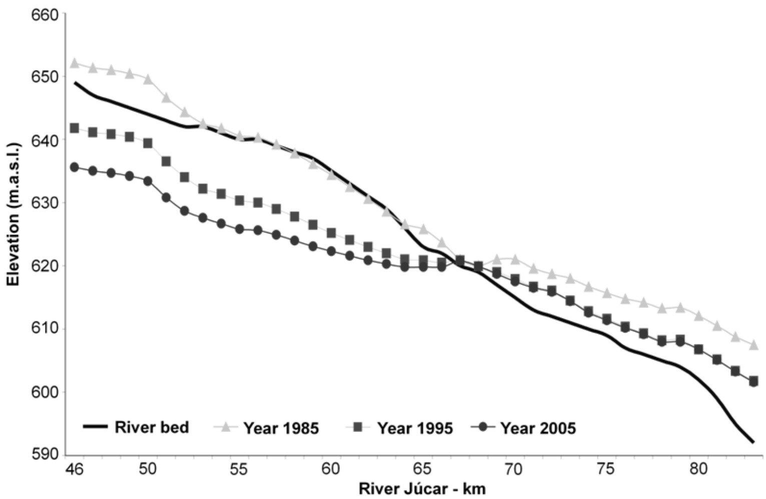

Figure 3. Simulated groundwater table below the river bed 1985, 1995, and 2005 from middle stretch of the Jucar river.

ACKNOWLEDGEMENTS

This study was funded by research projects financed by CGL2008-06394-C02-02/BTE of the Spanish Government. Special thanks go to water authorities (CHJ) and Stakeholders (JCRMO) in Mancha Oriental System for providing the different information.

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abstract id: **156**

topic: **2**
Groundwater and dependent ecosystems

2.3
Interactions of surface and ground waters

title: **In situ detection of thermal drawn springs in the Danube riverbed using helium and radon isotopes**

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keywords: drawn spring, helium, radon, river water, GSI

The western part of the capital of Hungary is a large karstic mountain region where many thermal springs break to the surface. Many of them arise in the bed of the Danube River, under the water surface. Knowledge of the locations of these springs and of the dependence of their recharge rates on the river water level is of major interest for the local thermal water resource management.

We intend to use in-situ measurements of dissolved ^{222}Rn and helium ($^{3}He/^{4}He$ ratios) to study the related groundwater/surface water interaction (GSI) processes. The concentrations of both gases in the thermal waters probably exceed that of the river water by at least one or two orders of magnitude, making them particularly suitable GSI tracers. As it has been already mentioned we are planning to present a field survey during which we detected drawn springs in the Danube River bed using in-situ measurements of helium and radon dissolved in the water as well as other suitable noble gases and physical and chemical water parameters (conductivity, temperature, etc.).

We will show how sampling of these tracers has been preformed. In the winter of 2010, when the river water level is low and the water is cold we are planning to carry out a field measurement. The sampling will be done in the following way: the water at the bottom of the river bed is pumped into the membrane inlet system of a portable quadrupole mass spectrometer (QMS). The dissolved gases are penetrating through the silicon membrane and entering the ion source of the QMS, enabling us to in situ analyse their concentrations. For the radon measurement, the water is flowing into a vessel that is equipped with a long silicon tube of wall thickness of 0.4 mm. Both ends of the silicon tube are attached to a radon detector device making a closed circuit for the gases in the tube and the radon detector. The pump in the radon detector makes the entire gas to circulate. Between the river water and the gas in the silicon tube a gas exchange occurs until equilibrium is reached. The response time of this sampling technique is about a few minutes. Additionally, noble gas samples in copper tubes will also be taken so that more precise helium measurements are performed.

IAH 2010
Krakow

abstract id: **165**

topic: **2**
Groundwater and dependent ecosystems

2.3
Interactions of surface and ground waters

title: **Quantification of bank filtration in restored and channelized sections of a losing stream reach using time series of natural tracers determined by point and distributed sensors**

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keywords: groundwater — surface water interactions, river restoration, time series evaluation, temperature method, electrical conductivity

INTRODUCTION

Hyporheic exchange has been identified as important for the ecological status of rivers and the quality of groundwater. In the hyporheic zone transformations of nutrients (Triska et al., 1993) and pollutants occur. For the assessment of groundwater quality in the vicinity of losing rivers, it is of particular importance to know the quantity of exchange fluxes between river and groundwater. Especially in Switzerland where 40% of the drinking water originates from pumping wells close to regulated rivers (BUWAL, 2004), travel times and mixing ratios of the pumped groundwater, which is a mixture of freshly infiltrated river water and old alluvial groundwater, are crucial parameters. In recent years many river restoration projects have been conducted at Swiss rivers connected to gravel aquifers. To increase habitat diversity common changes in riverbed morphology are e.g. widening of the riverbed or small meanders. The modified riverbed morphology may increase the variability and potentially the magnitude of hyporheic exchange processes, and may also affect the associated alluvial aquifer system. In terms of ecological habitat diversity an enhanced interaction between river and groundwater is an intended amendment of the system, but in the vicinity of riparian pumping wells river restoration measures are critical. Groundwater management in such contexts requires special methods for quantifying the exchange of water and solute mass between surface and subsurface water bodies. In this paper, we present a method for quantification of time-variable riverbed seepage rates by means of high-resolution profiles of distributed temperature data. Moreover, travel-time distributions of observation wells and a pumping well in a restored and channelized river section of River Thur in North-East Switzerland are determined through the use of nonparametric deconvolution technique (Cirpka et al., 2007) of EC time series.

TEST SITE

We study bank filtration at a test site in northeast Switzerland at an adjoining channelized and restored section of the peri-alpine losing River Thur, which is part of the RECORD Project (Assessment and Modeling of Coupled Ecological and Hydrological Dynamics in the Restored Corridor of a River (Restored Corridor Dynamics)). Due to its alpine to peri-alpine catchment (1750 km^2) and the absence of a lake or artificial reservoir discharge of River Thur exhibits strong fluctuations (low discharge: 3 m^3/s; mean discharge: 20–50 m^3/s; peaks up to 1000 m^3/s; Federal Office for the Environment, http://www.bafu.admin.ch/publikationen/01005). In the central Thur valley (altitude ~ 400 m a.s.l.), the river was channelized in the 1890s as a flood-protection measure. In response to large flooding events, restoration projects were realized since 1993, with the aim to improve flood protection and the ecological status of the river and the riparian zone. At our test site, the riverbed consists of gravel and river water is infiltrating through out the whole year into groundwater. The productive aquifer is about 5 - 6 m thick and consists of Pleistocene glacio-fluvial sandy gravels with an avarage hydraulic conductivity of 3.4×10^{-3}m/s.

METHODS

A wide range of methods exist to estimate water flux between surface water and groundwater. The exchange processes between both water bodies vary both in time and space (Woessner, 2000). Therefore, a spatial distribution and high temporal resolution of measurements is necessary to understand the exchange dynamics in a river corridor. Due to advances in sensor technique and data loggers, time-series analysis of natural tracers like temperature and EC has been shown to be useful in obtaining seepage rates and travel times of young groundwater in losing streams (Cirpka et al., 2007; Vogt et al., 2010).

Fiber-optic high-resolution streambed temperature profiling

The vertical and lateral temperature distribution in a riverbed is a function of boundary conditions, heat conduction and advection (Anderson, 2005). Therefore, streambed temperature profiles have been used to identify losing and gaining reaches of rivers (Constantz, 2008) and to quantify seepage rates (Keery et al., 2007). Time series obtained at several depths contain information on both effective advection and conduction in the sediment. To obtain high-resolution temperature profiles of the streambed over time we use DTS, which is based on the temperature dependence of Raman scattering. Light from a laser pulse is scattered along an optical fiber of up to several km length, which is the sensor of the DTS system. By sampling the back-scattered light with high temporal resolution, the temperature along the fiber can be measured with high accuracy (0.1 K) and spatial resolution (1 m) for 10 min measurement intervals. We wrapped an optical fiber around a 2 m long piezometer tube and measured the temperature distribution along the fiber (Figure 1). Due to the wrapping, we obtained a vertical resolution of approximately 5 mm. We analyzed the temperature time series by means of dynamic harmonic regression as presented by Keery et al. (2007), who calculated the amplitude and phase angle of diurnal temperature oscillations as continuous, auto-correlated time variables. From the travel time, which is a converted phase angle, and amplitude attenuation of the diurnal time signal, we estimated the apparent velocity and diffusivity of temperature propagation for each 5 mm depth interval, which then can be used to quantify time variable infiltration rates (Vogt et al., 2010).

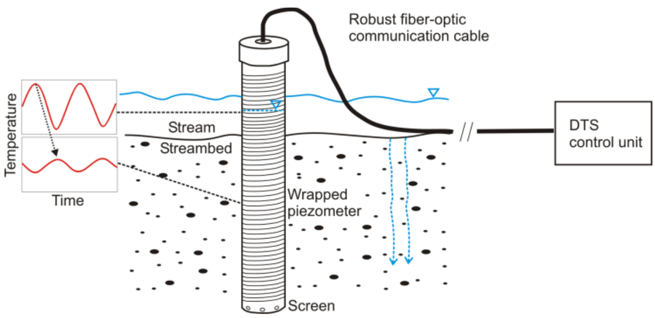

Figure 1. Schematic sketch of the fiber-optic high-resolution vertical temperature profiler.

Time-series analysis of electrical conductivity

The river and selected observation wells at the channelized and restored river section were equipped with sensors with an integrated data logger for continuous measurements of hydraulic head, water temperature, and EC of water (DL/N 70, STS AG, Switzerland; error of single measurement: ±0.1% for head, ±0.25 K for temperature, and ±2 % for EC, according to manufacturer's manual). The measuring interval was set to 15 min. In the groundwater observation wells, the sensors were installed about 0.5–1.0 m below mean groundwater table. As the temperature signal is retarded compared to solute transport, we use EC data.

The River Thur shows strong fluctuations of EC. Diurnal, event related, and seasonal signals exist. During river bank filtration these signals are transported into the aquifer. The diurnal oscillations only propagate to wells close to the river. We analyze the diurnal EC oscillations by means of Dynamic Harmonic Regression as described above for temperature time series resulting in time variable travel times.

For travel times in the range of days to weeks we use non-parametric deconvolution. For a detailed description of nonparametric deconvolution of EC time series we refer to Cirpka et al. (2007). Due to dispersion and mixing, the EC signal is more and more damped with increasing travel time. Therefore, pumping wells or observation wells further away form the river show a strongly attenuated EC signal without diurnal oscillations. But characteristic event related EC fluctuations are still present and can be analyzed. In non-parametric deconvolution, we calculate a continuous transfer function which we interpret as travel time distribution between the river and the observation well. The river signal is the input and the groundwater signal the output signal. In contrast to parametric deconvolution, the transfer function in non-parametric deconvolution is free to adjust to the data. Hence, it is possible to detect multiple peaks. In order to achieve reasonable estimates, we use a geostatistical smoothness criterion and Lagrange multipliers to implement non-negativity.

RESULTS AND DISCUSSION

Streambed seepage rates

The high resolution of the fiber-optic vertical temperature profiler gives a detailed view of the diurnal variation of riverbed temperature over depth and time. The determination of time shift and amplitude attenuation for each depth interval was effective using dynamic harmonic regression. We estimate apparent seepage rates from the effective temperature velocities using literature values for thermal properties. Over the entire observation period shallow depths exhibit stronger apparent fluxes ($3.0 – 4.0 \times 10^{-5}$ m/s) than depths below 0.6 m ($1.5 – 2.5 \times 10^{-5}$ m/s). The estimated apparent seepage fluxes vary also over time (Figure 2).

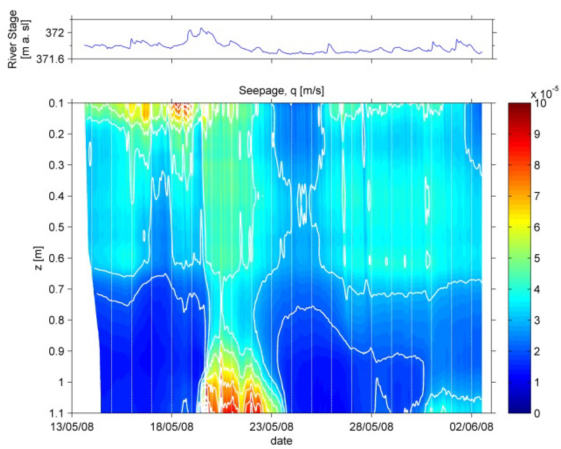

Figure 2. Estimated apparent seepage fluxes compared to the river stage. A: River stage of gauging station. B: Calculated vertical seepage fluxes. Contourlines: isolines of 1×10^{-5} m/s.

During falling river stage after a small event the highest infiltration occurred. The small temperature amplitudes during this time at a depth below 0.9 m may have distorted the estimate of seepage rates. While the temporal variation can easily be attributed to changing hydrological conditions, namely the difference between the river stage and the hydraulic head in groundwater at depth, the vertical variation is more complex. Vertical variability of hydraulic conductivity alone cannot explain vertical variation of the apparent vertical seepage flux, because we used a 1-D uniform expression for heat transport (Vogt et al., 2010). Thus, a variation of the vertical flux must be balanced by variations of horizontal flux components. Our findings represent only local exchange, but demonstrate that the presented method works. In future studies we thus plan to install a grid of fiber-optic temperature profilers to obtain a multi-dimensional image of the vertical and lateral seepage processes on a larger scale.

Travel times of young groundwater

Data evaluation and an automatic temperature compensation of the EC data guarantee that the fluctuations of EC do not reflect instrument instability or temperature effects, but changes in solute ion concentrations. The diurnal oscillations occur perennially under low discharge conditions. Like for the streambed temperature data, the determination of time shift (Figure 3) and amplitude attenuation of the diurnal EC oscillations was effective using dynamic harmonic regression and the time shift results show a temporal variability.

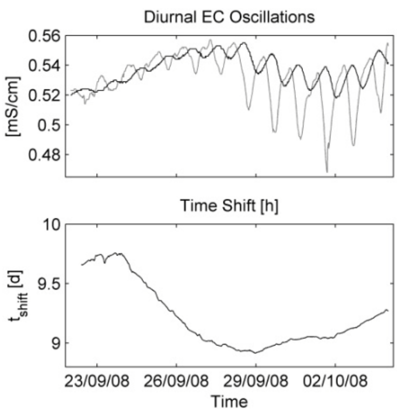

Figure 3. Diurnal oscillations of EC over a time period of approximately two weeks and the calculated time shift of the diurnal EC fluctuations. Gray line: river; black lines: observation well close to the river.

The event-related changes of EC are associated with a variation of discharge of the River Thur (Figure 4A). During peak flow, EC shows distinct minima. Figure 4B shows the travel time distribution for a pumping well in the channelized river section determined by non-parametric deconvolution of the EC time series. The secondary peak may possibly be explained by the existence of several flow paths from the river to the well with distinct travel times. We observed the shortest travel times in the restored river section, where observation wells are situated close to the river. In the channelized river section the travel times of the observation wells with the same distance of 5 – 20 m to the river are about three times longer. We attribute this fact to the differences in riverbed morphology, type of bank, and elevation of the overbanks. In particular, banks with gravel bars without steep slopes offer the river the possibility to create various flow paths with increasing water level due to a bigger area of infiltration.

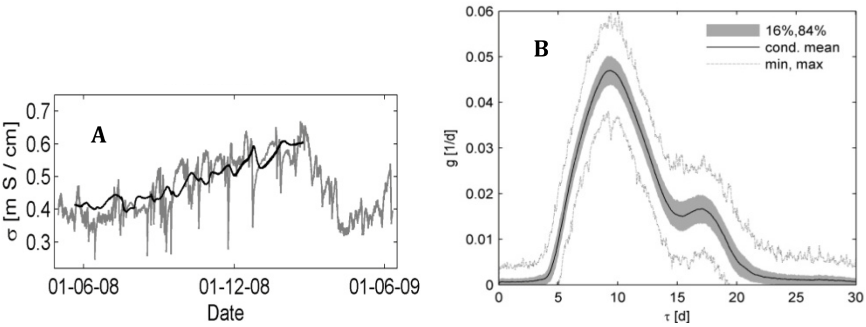

Figure 4. Data and result for a pumping well in the channelized river section. A: Time series of electrical conductivity. B: Travel-time distribution after non-parametric deconvolution.

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abstract id: **212**

topic: **2**
Groundwater and dependent ecosystems

2.3
Interactions of surface and ground waters

title: **Impacts of river-bed gas on the hydraulic and thermal dynamics of the hyporheic zone**

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keywords: gas, hyporheic zone, hydraulics, thermal dynamics, river-aquifer interaction

Highly variable redox conditions within river bed sediments can lead to the production of gas via a range of microbial processes. The water quality and ecological importance of such processes have become well known. However, the potential feedbacks of biogenic gas production on the hydraulic and thermal dynamics of the hyporheic zone (HZ) has not been widely recognized. In the context of the HZ, gas is most likely to be present as a non-wetting phase in a water-wet porous media and, unless present in large quantities, is likely to be predominantly immobile within the hyporheic zone. It is hypothesized that the presence of immobile gas within the river bed may lead to increased specific storage, decreased hydraulic conductivity and porosity, and increased thermal diffusivity. Conceptual descriptions for the presence of the immobile gas include both the trapped gas saturation and gassy sediment models described in the petroleum and soil science literature.

Using observational data from a short reach of the urban River Tame, UK, and a range of numerical and analytical models we have tested a series of hypotheses in order to quantify some of these effects for the fieldsite. Gas is present within the river bed in quantities up to around 14% by volume, and to at least 0.8 m depth below river bed. Given the indications from hydrochemical data taken from in-bed arrays of multilevel piezometers, it is thought that this gas is predominantly produced by microbial denitrification and, to a lesser extent, methanogenesis. Freeze cores from the site indicate that the carbon source for this microbial activity may be organic rich layers of sediment which have been observed to depths of several tens of cm below the river bed. Analysis and modelling of intensive hydraulic and temperature monitoring collected from the river channel and river-bed have enabled the following summary conclusions to be made for the study site:

- Gas accumulation may lead to an increased proportion of discharge of groundwater from the river banks (relative to river bed) during low flow periods in the river. During storm events the presence of 10% gas by volume in the upper part of the river bed increases the modelled capacity for flow reversal within the centre of the channel by more than 30% compared to water saturated conditions. Furthermore, the same model simulations suggest that in the presence of such volumes of trapped gas, due to the reduced effective porosity, the possible depth of such reverse flows may increase by more than a factor of 2. Figure 1 shows the difference the presence of 10% gas by volume makes to differential heads at 30 cm depth in the centre of the river bed.
- Observed diurnal temperature variations within the gaseous river bed at 0.1 and 0.5 m depth are approximately 1.5 to 6 times larger, respectively, than those predicted for saturated sediments (Figure 2). On an annual basis fluctuations are enhanced by around 4 to 20% compared to literature values for saturated sediments.

The results of the study have important implications for the hydraulic and thermal functioning of the HZ. Hydraulically, the changes in the depth and timing of mixing between groundwater and surface waters of different character will impact the biological functioning of the hyporheic zone on a range of temporal and spatial scales. Thermally, as a fundamental biological variable, such differences in the temperature regime of the river bed due to the presence of gas may be particularly significant for microbial processes and hyporheic ecology. Also, the presence of gas may alter the bulk thermal properties to such a degree that the use of heat tracer techniques becomes subject to a much greater degree of uncertainty. Quantifying the significance of these changes for chemical attenuation and hyporheic zone biology is beyond the scope of this paper.

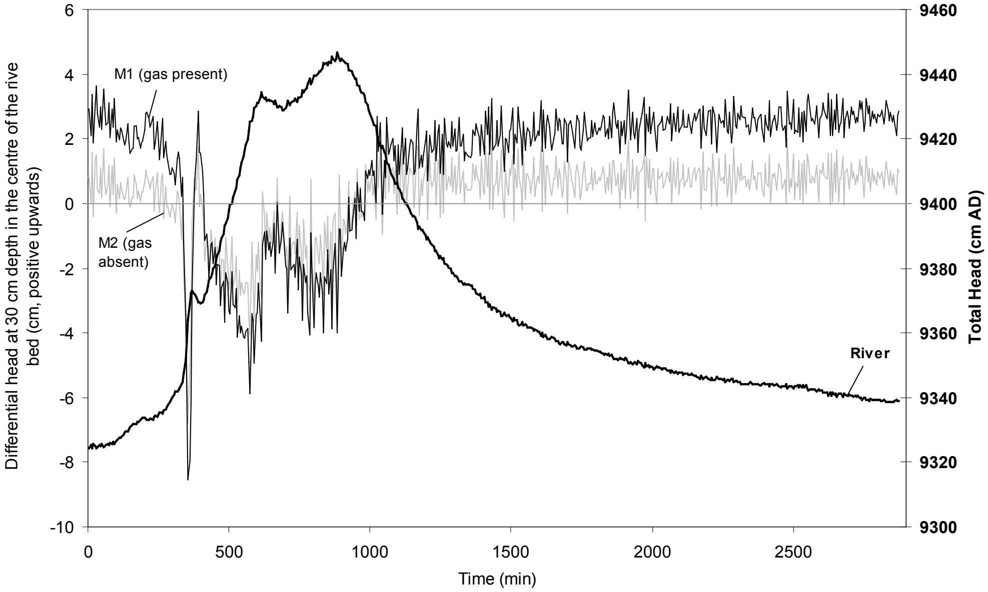
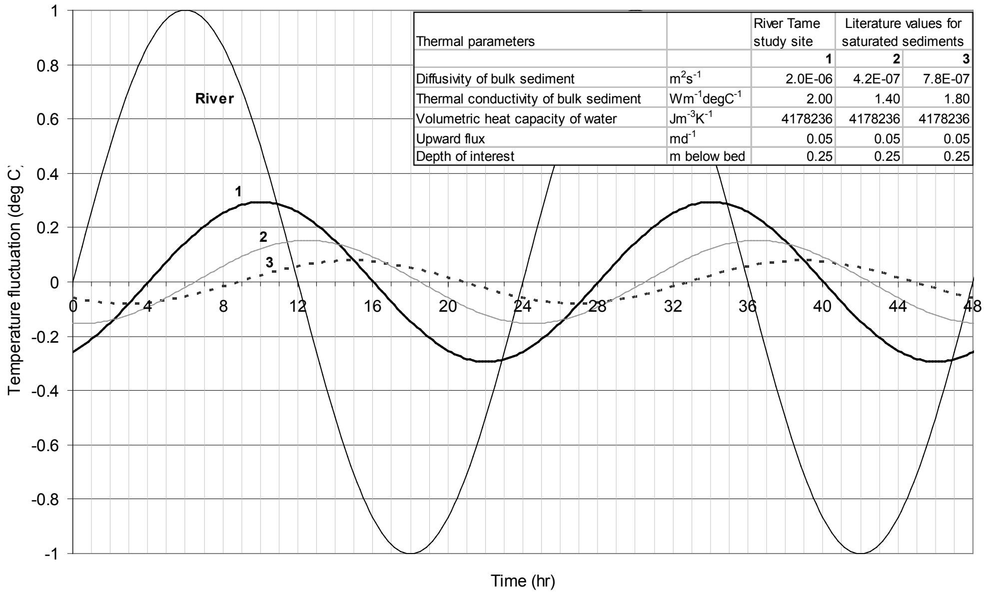


Figure 1. Comparison of modelled river bed differential head relative to head at the base of the river for simulations M1 (gas present) and M2 (gas absent), shown alongside observed river stage.



Thermal parameters		River Tame study site	Literature values for saturated sediments	
		1	2	3
Diffusivity of bulk sediment	m^2s^{-1}	2.0E-06	4.2E-07	7.8E-07
Thermal conductivity of bulk sediment	$Wm^{-1}degC^{-1}$	2.00	1.40	1.80
Volumetric heat capacity of water	$Jm^{-3}K^{-1}$	4178236	4178236	4178236
Upward flux	md^{-1}	0.05	0.05	0.05
Depth of interest	m below bed	0.25	0.25	0.25

Figure 2. Modelled diurnal river bed temperature fluctuations using a range of thermal parameters at 0.25 m depth below the riverbed.

Furthermore, the models used to test the possible changes in hydraulic behaviour due to the presence of gas have been kept highly simplified. In reality, a complex distribution of gas is likely to result in heterogeneity at a range of scales. However the data are not available to support a more complex approach at this stage and further data collection is needed.

abstract id: **230**

topic: **2**
Groundwater and dependent ecosystems

2.3
Interactions of surface and ground waters

title: **Groundwater-lake interaction in a saline wetland area, Duna-Tisza Interfluve, Hungary**

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keywords: groundwater-lake interaction, salinization, wetland

The preservation of wetland areas is an imperative question nowadays. The understanding of the interaction between groundwater and the wetland systems are essential for their appropriate management in the changing climatic circumstances. The subject of the present study is an ephemeral saline lake, the Lake Kelemenszék which is surrounded by a saline wetland area. The area is part of the Kiskunság National Park and it is under protection because of its unique flora and fauna. The preservation of the natural conditions for sustaining the ecological diversity, the knowledge of the hydrogeological conditions of the area is crutial.

The lake is situated in the lowland area of the Hungarian Great Plain, Pannonian Basin, in a special hydraulic position. In the area two groundwater flow systems interact: a deep overpressured, uprising saline water system, originating from the Pre Neogene basement and a fresh water regime driven by the topography i.e. water table differences. In the study area these groundwater flow systems discharge based on regional hydraulic, hydrostratigraphic and seismic investigations (Mádl-Szőnyi and Tóth, 2009). According to these results it was supposed that the ascending deep saline water can contribute to the water budget of the lake and formation of the salinizaton phenomena around it. The qualitative and quantitative influence of groundwater on the Kelemenszék wetland area was evaluated based on detailed hydraulic, hydrological and chemical investigations. The hydraulic and chemical data arise from regular sampling of chanels, lake water and shallow groundwater wells, settled around the lake. Near the lake shore a meteorological station was established, for precipitation and evaporation measurements. Based on these data the water budget was set up for the lake. According to the water level data, the seasonal and spatial variation of the interaction between groundwater and the lake could be observed.

Although regionally the lake situated in a discharge area, but in local scale throughflow conditions could be observed during a year period. The artifical hydraulic effect of channels operating from the 1970's in the eastern and western side of the lake can be responsible for this throughflow situation. It was pointed out that the vertical hydraulic gradient that is responsible for inflow or outflow of groundwater to or from the lake varies seasonally. According to the water budget calculation, the amount of the groundwater recharge and discharge to the lake is negligible, the water budget of the lake is governed mainly by the evaporation and the precipitation. Nevertheless the contribution of the deep saline groundwater in the lake water chemistry and the surrounding salinization is relevant.

The results of the study indicate, that the interaction between the groundwater and the lake is controlled not only by hydrologic conditions but also by the flow regimes. The deep ascending saline water quantitatively is not decisive in the water budget but qualitatively it is significant and modulate the chemical character of the lake and responsible for the surface salinization around it.

ACKNOWLEDGEMENTS
The authors are pleased to acknowledge the advices and support of Prof József Tóth. We would like to thank for the help of undergraduate students in the course of field measurements and of the processing of evaporation data (Sándor Jákfalvi, Attila Vaczula, Tamás Burián). The research was financially supported by the Hungarian Science Foundation (OTKA) No. T047159 of J. Mádl-Szőnyi.

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abstract id: **253**

topic: **2**
Groundwater and dependent ecosystems

2.3
Interactions of surface and ground waters

title: **The influence of surface waters (ponds and drainage ditches) on the salinization of a coastal aquifer in the south-eastern Po plain (Italy)**

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keywords: salinization, coastal aquifer, hyporeic zone, lowland, Po plain

The south-eastern Po plain consists of a subsiding coastal lowland, where the phreatic aquifer has been extensively contaminated by seawater (Antonellini et al., 2008; Giambastiani et al., 2007).

Prolonged dry seasons, natural and men-induced subsidence, dunes and beaches erosion have been indicated as the basic salinization causes by most of the authors.

This study has the objective of investigating the role of surface water-groundwater interactions on the phreatic aquifer contamination by salt water.

In 2008, we performed a preliminary surface water and top groundwater monitoring and we have identified ponds and drainage ditches as an additional factor contributing to the salinization process of the area (Marconi et al., 2009). In the early stage of the project the distribution of the chemical-physical parameters and of some minor elements (e.g. arsenic and iron) confirmed that a seepage of deep groundwater was taking place in the surface water bodies, which are located in the main depressions of the area.

We are now testing the hypothesis that the presence of surface water bodies enhances the salinization of the phreatic aquifer through a double seasonal mechanism. During the dry seasons, the surface water bodies are almost dried up and the seepage of deep salty groundwater is allowed by the lowering of the groundwater head falling below sea level. At the same time evaporation of the surface water in the Summer induces the precipitation of salt solid phases at the bottom of ponds and ditches. During the fall, the rainwater, which recharges the surface water bodies is contaminated by the salts deposited at the bottom and in the hyporeic zone of ditches and ponds during the Summer. The infliltration water, therefore, is already brackish before reaching the aquifer. The low hydraulic gradients and the scarcity of rainfall that characterize the study area, do not allow the salt minerals flushing during the rainy seasons.

In order to have a better understanding of this phenomenon, we planned a detailed survey focusing on surface water-groundwater interactions, which is still ongoing. Temperature, electrical conductivity, redox potential, pH, and dissolved oxygen of the surface water bodies are measured each month in selected monitoring stations located in the proximity of fully screened observation wells, which are totally penetrating the phreatic aquifer. The chemical and physical parameters of the groundwater are measured at the top and at the bottom of the aquifer (5 m thick on average) by means of a multilevel sampler. In addition, we obtained seasonal electrical conductivity and temperature cross sections of the main ponds.

In the Summer 2009 we also collected a number of vertical chloride concentration profiles, which were performed in the subsoil below the bottom of ditches and ponds and in the aquifer close to the surface water bodies. This survey was made by means of a T-EC probe that measures the electrical conductivity of the whole saturated system (composed by sediments and groundwater) with a spacing of 0.1 m. Chloride concentration in the groundwater was deduced through the analyses of detailed lithological descriptions collected at each T-EC probe measurements point.

Our first results show that in the observation wells located close to ditches and ponds, the salinity of the top aquifer groundwater is higher than that measured at the bottom of the aquifer; this is in contrast with what is commonly observed in coastal aquifers. Chloride concentrations gradients in the hyporeic zones of the surface water bodies also decrease with depth in both seasons (Figure 1).

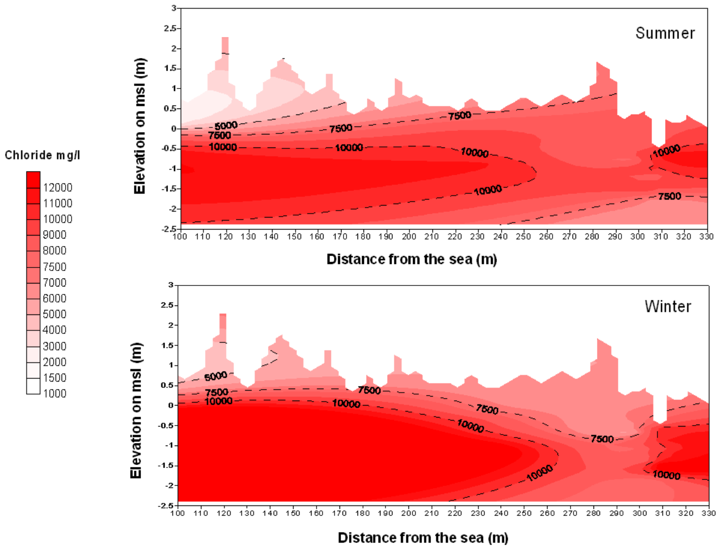

Figure 1. Seasonal chorides distribution in a 2D profile across the study area. The lowest topography correspond to a drainage ditch, where saline water is upconing.

The salinity of the surface water bodies increases with depth in the case of very shallow ponds, where the strong evaporation rates induce a stratification of the water column during the summer and the precipitation of salts (Fig. 2). On the contrary, salinity pattern does not show any correlation with water depth in the case of deeper surface water bodies, which do turn into hypersaline solutions (Fig. 3).

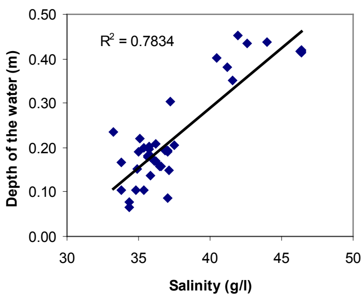

Figure 2. Positive correlation between salinity and water depth in very shallow and hypersaline ponds.

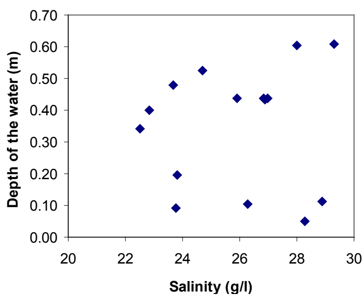

Figure 3. Salinity and water depth show no correlation in brackish-saline shallow ponds.

These observations indicate that the occurrence of stagnant surface water bodies in semi-arid climate conditions may enhance the salinization of coastal phreatic aquifers prone to seawater intrusion.

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abstract id: **270**

topic: **2**
Groundwater and dependent ecosystems

2.3
Interactions of surface and ground waters

title: **Three dimensional modelling of a long term bank-side borehole pumping experiment for better understanding of river-aquifer interactions**

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keywords: river-aquifer interaction, bank-side extraction test, 3D modelling, hyporheic zone, biochemical processes

MOTIVATION

The biogeochemical processes in the hyporheic zone may naturally attenuate the concentration of some pollutants. Nevertheless, the different factors controlling these processes, especially the influence of hydrodynamic conditions on biodegradation, are not fully understood, and therefore cannot be artificially controlled. An experiment has been implemented to better understand the hydrodynamic conditions that can affect the biogeochemical processes in the hyporheic zone and, potentially, provide the basis for new tools to improve the natural potential of attenuation by artificial means. This paper examines the performance of this test and the lessons that can be drawn from its implementation.

AN INNOVATIVE EXPERIMENTAL DESIGN

The experiment used long-term extraction from a bank-side well installed adjacent to the River Tame, Birmingham, UK, to modify the hydrodynamic conditions locally within the hyporheic zone of a well geologically and topographically characterised reach. Both short-term and long-term extraction induce a decrease in the vertical components of flows from groundwater to surface water (Figure 1) increasing their residence time within this interface as well as, potentially, increasing the river / groundwater mixing depths. The resulting temporal evolution of hydrodynamic and chemical conditions was monitored using a network of riverbed minipiezometers and multilevel samplers (Figure 1). The key objective was to observe the impact of the changing hydraulic conditions on the processes involved in surface water/groundwater mixing and the conditions causing changes in biodegradation.

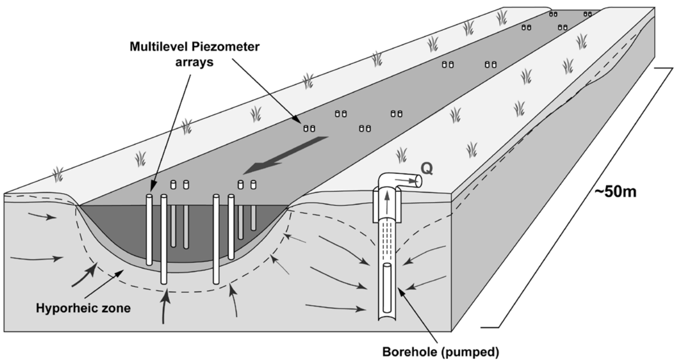

Figure 1. Schematic view of the experimental design.

RESULTS AND INTERPRETATION THROUGH A 3D HYDROGEOLOGICAL MODEL

A 3D hydrogeological model was built to run with the MODFLOW code. This allowed to test the sensitivity of some key parameters.

Calibration of general parameters

Step pumping tests in January 2008 allowed the general calibration of the hydrodynamic parameters. The hydraulic conductivity (K) of the Permo-Triassic sandstone was found around 2.3×10^{-5} m/s, and the storage coefficient (S) around 2×10^{-5}. However, the cells corresponding to the borehole had to be set with higher values for these parameters ($K=10^{-2}$m/s, $S=3\times10^{-3}$), due to the gravel pack. The Figure 2 shows the best fit (reference model) found with a pumping rate of 103 l/mn, and two sensivity tests decreasing respectively K in the sandstone and S in the borehole by a factor 2/3. The first test leads to a final head value in the borehole 2.5 m below the observed one. The second test leads to a faster decrease of heads in the borehole at the beginning of the pumping.

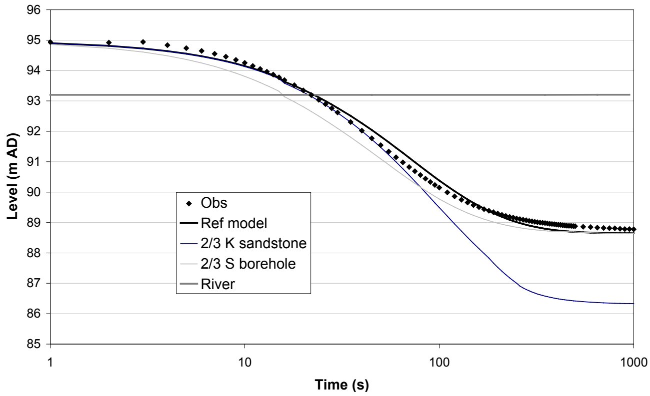

Figure 2. Heads in the borehole during a short pumping test of 103 l/mn (January 2008); observations compared to three simulation results: a reference model and two others, decreasing respectively the value of the sandstone hydraulic conductivity and the storage coefficient in the borehole cells.

Impact of pumping in the hyporheic zone

A two hour pumping test in June 2008 allowed to quantify the impact of the pumping on the hyporheic zone heads. A head decrease between 2 and 3 cm within the hyporheic zone could be related to the impact of the pumping (Figure 3). This is relatively low compared to the natural variations of the river, in the same range of values at this low flow period, but potentially increasing of one to two meters during flood events.

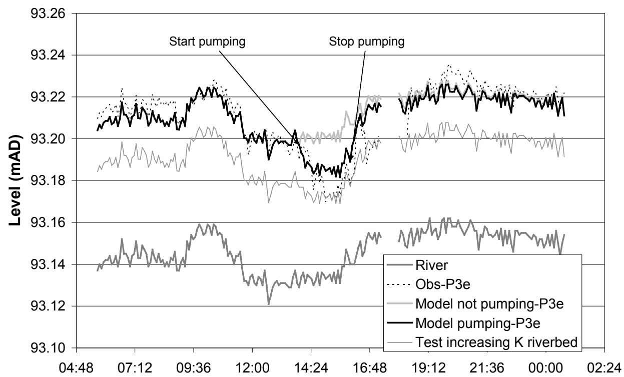

Figure 3. Impact of a 2h pumping test within the hyporheic zone (June 2008). Observation heads compared to one model without pumping and one under pumping conditions. Sensitivity of a K increase in the riverbed by a factor 10.

On Figure 3, one can also note that an increase of the hydraulic conductivity in the riverbed by a factor 10 leads to lower heads within the hyporheic zone: reduction of 2 cm all across the modelled period.

CONCLUSION

Both the field measurements and the 3D hydrogeological model results show a coupled influence of the river levels and of the extraction test on the hydraulic heads within the hyporheic zone. A pumping rate around 80 l/mn induces a decrease in the average vertical flow discharging from the hyporheic zone to the river of about 15% across the monitored section. A novel aspect of the results is that the intensity of the on-site monitoring installations has enabled the spatial and temporal patterns of change in hydraulic gradients, both across and along the river reach, to be directly measured. The results show that this pattern is highly heterogeneous spatially, depending on the hydraulic conductivity distribution, on the riverbed morphology, and on the relative position to the pumping. During the pumping experiment, the hydrochemical data collected indicate that the dynamics of the river flows provide significant temporal variability to the exchange flows in the river bed on timescales from hours to months. Full account of these had to be included in the model in order to explain the observations. The results also show that anthropogenic modification of this stretch of urbanised river (e.g. riverbed, made ground, bridge/sewer crossings) is significant in altering both the spatial and temporal pattern of discharge to the river by affecting the permeability and storage properties of the river bed and banks. This has important implications for river restoration approaches within the urban environment.

abstract id: **285**

topic: **2**
Groundwater and dependent ecosystems

2.3
Interactions of surface and ground waters

title: **Uncertainty of vertical streambed seepage rates under realistic field conditions using diel temperature fluctuations**

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keywords: groundwater, surface water, connectivity, heat modelling, temperature

INTRODUCTION

Groundwater and surface water are connected and form one single resource. Sustainable water management requires knowledge of direction and magnitude of flow between streams and aquifers. The use of heat as a tracer promises to be an alternative to traditional methods, such as seepage meters, successive stream gauging and hydrometric methods. Flow through streambeds has been shown to vary greatly on a temporal and spatial scale (e.g. Schmidt et al. 2007; Keery et al. 2007; Essaid et al. 2008). Analytical solutions to the 1D conductive convective heat flow equation have been developed to estimate streambed fluxes (Stallmann 1965; Silliman et al. 1995; Hatch et al. 2006; Keery et al. 2007). In particular, the method devised by Hatch et al. (2006) is based on the analysis of the thermal response to the diurnal temperature signature recorded at two depths in the streambed. The direction and magnitude of vertical flow velocity distinctly impacts on thermal response at depth, causing variable amplitude damping and shift of phase (Hatch et al. 2006). Testing of this method with field data provided interesting unresolved artefacts in the flow results. These are large fluctuations of flow that could not be ascribed to hydraulic changes, and large deviations between velocities derived by either analysing the amplitude ratio or the phase shift (Rau et al. 2010).

Theoretically, deviations in flow velocities between measurement locations can be caused by natural variability in physical parameters introducing non-uniqueness into the analysis. It has been noted that the thermal conductivity of the streambed is generally well constrained and is not a function of grain size unlike the hydraulic conductivity (Blasch et al. 2007). This suggests a possible advantage of quantifying flow using heat as tracer compared to traditional Darcy type investigations. However, the heat method still requires estimates of a number of streambed properties before results can be calculated. Investigation of how parameter uncertainty impacts on calculated flows is required to estimate the overall uncertainty of the heat method. This paper quantifies the uncertainty in the calculated velocity using the method by Hatch et al. (2006) related to the widest range of physical parameters reported in the literature. Furthermore, numerical simulations confirm that the reduction in dimensionality (1D) is an important limitation to the method.

METHODOLOGY

The basic equations that relate amplitude ratio (AR) and phase shift (PS) of two vertical temperature time series to vertical water velocity are derived from an analytical solution to the conductive convective heat transport equation with sinusoidal boundary condition (Hatch et al. 2007):

$$AR = \frac{A_2}{A_1} = \exp\left(\frac{\Delta z}{2 \cdot \kappa_e} \cdot \left(\upsilon - \sqrt{\frac{\alpha + \upsilon^2}{2}}\right)\right) \text{ and } PS = t(P_2) - t(P_1) = \frac{P \cdot \Delta z}{4 \cdot \pi \cdot \kappa_e} \cdot \left(\sqrt{\frac{\alpha - \upsilon^2}{2}}\right)$$

with $\alpha = \sqrt{\upsilon^4 + \left(\frac{8 \cdot \pi \cdot \kappa_e}{P_i}\right)^2}$, $\kappa_e = \frac{\lambda_f^n \cdot \lambda_s^{(1-n)}}{\rho \cdot c}$, $\rho \cdot c = n \cdot \rho_f \cdot c_f + (1-n) \cdot \rho_s \cdot c_s$

and $\upsilon = v_f \cdot \frac{\rho_f \cdot c_f}{\rho \cdot c}$

Parameters are: AR and PS are amplitude ratio and phase shift between two temperature time series; κ_e is effective thermal diffusivity; κ_f and κ_s are thermal conductivity of water and solid; κ_e is the effective thermal diffusivity; n is porosity; v_f is the vertical water velocity; ρ_f and c_f are density and heat capacity of the water, and ρ_s and c_s are density and heat capacity of the solids; and ρ and c are density and heat capacity of the saturated sediment-fluid system; Δz is the vertical spacing between temperature measurement points. The physical properties of water are accurately known.

Analytical and numerical simulations were performed in order to clarify the impact of streambed physical parameter uncertainty and the field condition of horizontal flow on this 1D vertical method. The study focuses on two major aspects, the impact of: 1) natural variability in streambed parameters (solid thermal conductivity, solid heat capacity, solid density, porosity and dispersivity), and 2) directional flow and directional heat propagation which can be caused by thermal dispersivity.

For 1) a Monte Carlo analysis was performed: a min/max range for values derived from literature (e.g. Schön 1996; Schärli & Rybach 2001; Maqsood 2004; Markle et al. 2006; Markle & Schincariol 2007; Chen 2008; Smits 2010) was defined for each thermal parameter. The ranges are: solid thermal conductivity: $1 < \lambda_s < 4.5$ W/mK; solid heat capacity: $650 < c_s < 1{,}550$ J/kgK; solid density: $2{,}500 < \rho_s < 3{,}200$ kg/m^3; porosity: $0.1 < n < 0.5$. The mechanism of thermal dispersion was discarded from the uncertainty investigation because it is not well understood and statistical details are not available. This limits the uncertainty results to systems where conduction is dominant over convection, as is best described by the dimensionless particle related thermal Peclet number (Koch and Brady 1984; Anderson 2005)

$$Pe = \frac{\rho_f \cdot c_f}{\lambda_f} v_f d_p$$

The investigation is based on the following assumptions: a) the investigated streambed parameters are in general normally distributed, b) parameters are independent from each other, c) ranges as found in literature represent approx. 95% of values found in the field, which corresponds to the area between $\mu \pm 2\sigma$ under the normal distribution. Although field site specific samples of above thermal parameters exhibit normality (e.g. Markle et al. 2006), a general statistical distribution of streambed thermal parameters is unknown and therefore the statistical normal distribution is forced.

The above parameter ranges were used to create a large number of random values according to the assumptions. For a measurement spacing of 0.15m, amplitude ratios (AR) and phase shifts (PS) dependent on velocities between -10 m/d (downward flow) and +10 m/d (upward flow) were synthesised using the computed statistical variability for each individual parameter fixing all others to the respective mean values. Furthermore, the computations were repeated allowing for variability in all parameters. The velocity from the synthesised AR and PS values were then re-interpreted using parameter mean values as would be done for temperature field data with unknown streambed properties. The deviation from the real velocity value was calculated, and upper/lower probability of non-exceedence (90%) was computed for the velocity deviations. These calculated confidence limits can be plotted against the original velocity in order to reveal the impact of individual and combined statistical parameter uncertainty on the AR and PS estimates over the entire range of vertical flow velocities.

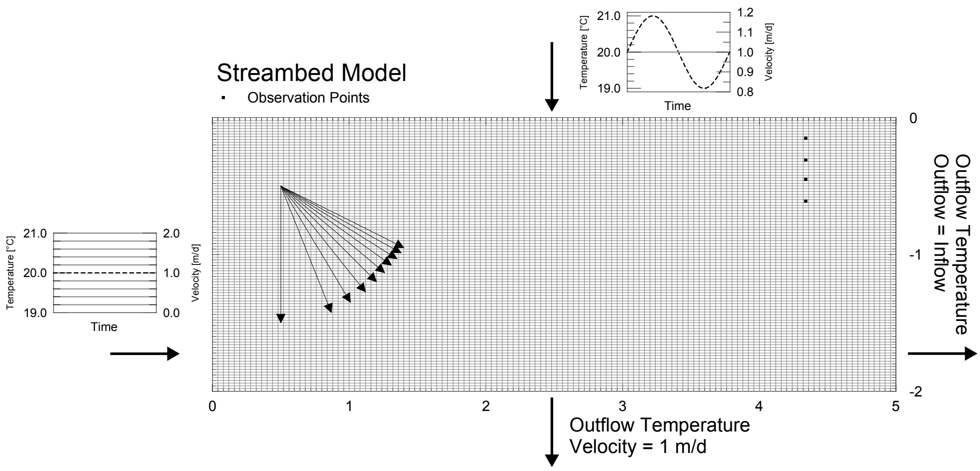

Figure 1. Setup of the numerical heat transport model used to investigate the effect of horizontal flow components on the results of the 1D analytical method.

For 2, a 2D vertical slice of a streambed was set up (Fig. 1) in the numerical code VS2DH (Healy 1996). Temperature boundary conditions were: diel sinusoidal temperature change at the top and constant temperature at both sides as well as the bottom. Flow boundary conditions were: a constant downward flow component and ten simulations of increasingly higher horizontal flow (expressed as ratio of horizontal to vertical velocity V_h/V_z between 0 and 2). Five observation points at depths of 0.15, 0.3, 0.45 and 0.6 m recorded temperature time series. For each model run, the thermal dispersivity was restricted to 10% of the largest spacing. The last temperature peak of the top boundary condition in combination with each depth response was taken to calculate the vertical velocity using amplitude ratio and phase shift according to the method by Hatch et al. (2006).

RESULTS & DISCUSSION

The results of the Monte Carlo analysis using the above analytical models illustrate that the AR and PS estimates exhibit different statistical distributions, with the AR results being skewed as a result of the non-linear model (Fig. 2).

Generally, the downward velocity estimates are less affected by parameter variability than upwards flow. The major impact by variation in thermal properties is on the AR results and caused by the thermal conductivity in particular for upwards flow. Uncertainty in streambed solid density is the parameter of least impact (Fig. 2).

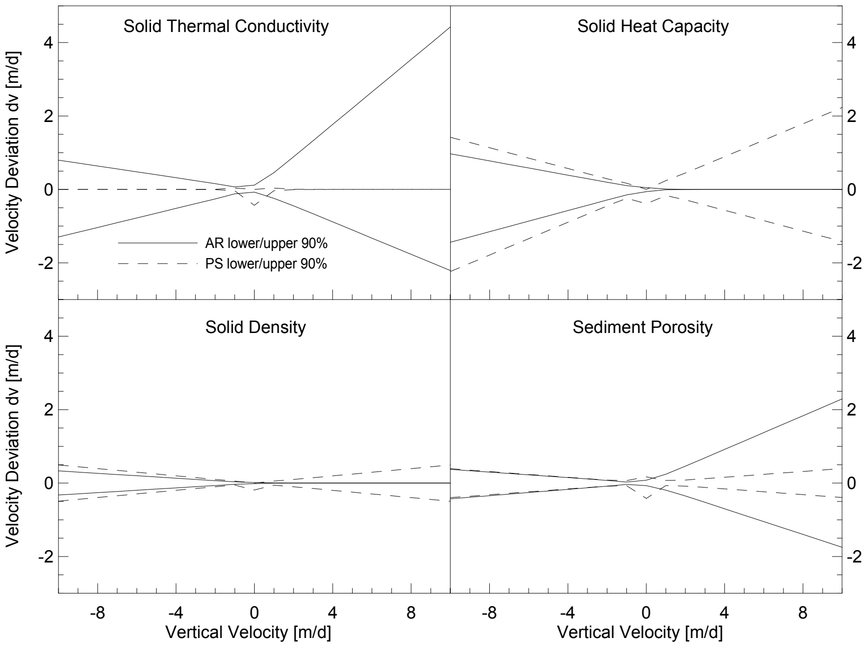

Figure 2. Lower and upper 90% non-exceedence limits for velocity deviations, a result of combined streambed thermal parameter variation, as function of vertical flow velocity.

For downward flow, solid density and porosity have the least effect on the results, whilst thermal conductivity and heat capacity distort results much more severely. Overall, there is a 90% probability that estimates are within 25% of the real vertical flow rate when mean literature thermal streambed parameter values are used (Fig. 3). The PS solution should be avoided at small or zero velocities because of its divergent nature (Hatch et al. 2007).

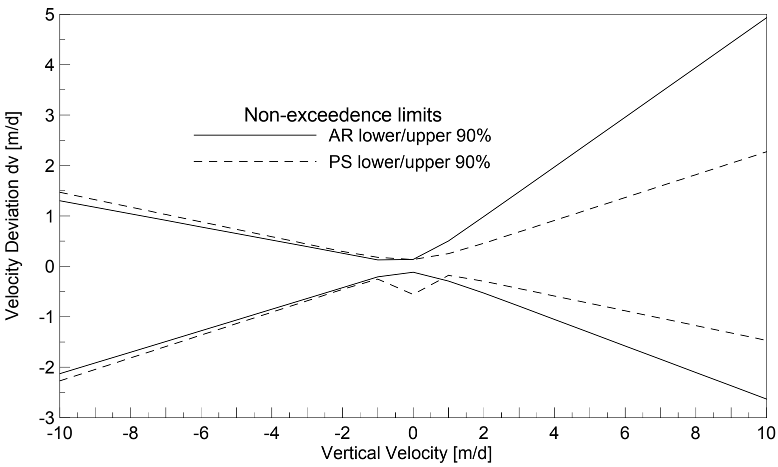

Figure 3. Lower and upper 90% non-exceedence limits for velocity deviations, a result of combined streambed thermal parameter variation, as function of vertical flow velocity.

In hydrogeology, hydrodynamic thermal dispersivity is mathematically described in terms identically to solute dispersivity, an approach that is disputed (Anderson 2005). Theoretical and experimental investigations on the issue of thermal dispersion in general porous media have been comprehensively reviewed (Kaviany 1995). Even though there is a lack of experimental data for thermal transport under slow flow rates, theoretical investigations suggest that the effective thermal conductivity term is much less dependent on the fluid velocity when conduction is dominant, meaning thermal Peclet numbers $Pe_t < 1$. It appears that the hydrodynamic thermal dispersivity has no or little impact in this case so that uncertainty results are limited to conduction dominant conditions. Theoretically, this is given for velocities that are slower than 10 m/d when the mean grain size of the streambed does not exceed 1.2 mm. However, more research is needed especially for different grain size distributions as found in streambeds.

Numerical modelling under 2D flow conditions revealed that thermal dispersivity can introduce deviation between the AR and PS results when horizontal flow is present in the streambed (Fig. 4).

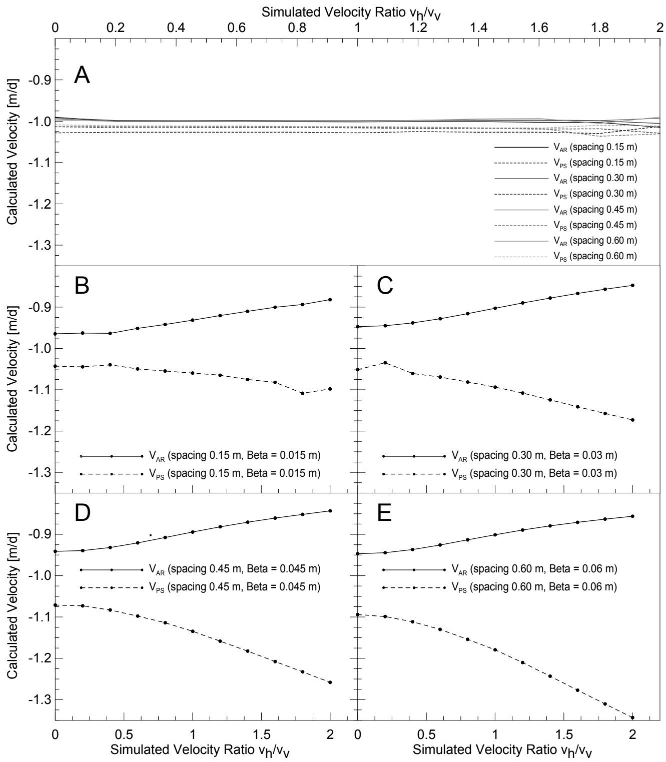

Figure 4. Numerical modelling results showing the potential impact on the AR and PS velocity estimates of thermal dispersivity in simulations with a horizontal flow component.

The directional impact of thermal transport can significantly alter the phase derived velocity results depending on the magnitude of horizontal flow (Lautz 2010), and on the measurement spacing. In comparison, the amplitude derived results vary less when the direction of flow changes from vertical, and they do not show much dependence on the measurement spacing.

CONCLUSION

The outcome of this investigation highlights that caution must be applied when analytical methods are used to interpret diel temperature field measurements with the method devised by Hatch et al. (2006). Lacking knowledge of sediment thermal properties prior to velocity calculation can cause results with a 90% likeliness that velocity estimates can deviate by up to approx. 25% for systems with downward flow. However, this potential error can be decreased if the thermal properties are either directly measured or estimated e.g. from streambed mineral content. Unfortunately, these results are limited to conduction dominant conditions, because the mechanism of hydrodynamic thermal dispersivity is not well understood.

The numerical analysis suggests that deviations between amplitude and phase derived velocities can be caused by horizontal flow when there is significant thermal dispersivity. Systematic deviations between the AR and PS velocities can thus be used as an indication that significant horizontal flow may be present in the streambed. If that is the case vertical flow is generally overestimated. Nevertheless, this paper shows that analysis of diel temperature signatures can improve the understanding of streambed water exchange even when the streambed thermal parameters are estimated from literature values.

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abstract id: **291**

topic: **2**
Groundwater and dependent ecosystems

2.3
Interactions of surface and ground waters

title: **Surface water-groundwater interaction in the fractured sandstone aquifer impacted by mining-induced subsidence: 1. Hydrology and Hydrogeology**

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keywords: surface water-groundwater interaction, longwall mining, fractured aquifer, streamflow reduction

ABSTRACT

Mining-induced subsidence under surface waterways enhances surface water-groundwater interaction due to the enlargement of existing fractures, development of new fractures and the separation of bedding planes. Fracturing of streambeds and rockbars causes surface flow to divert to subsurface routes. The surface water-groundwater interaction in an undermined stream in the Southern Coalfield of New South Wales (NSW), Australia, has been assessed by analysing hydrological data including flow measurements upstream and downstream of the longwall panels. The data suggests leakage of surface water to the subsurface through fractured streambeds and rockbars. Mining-induced fracturing across the catchment is likely to have caused increased rainfall infiltration, reduced runoff, and reduced baseflow discharge, resulting in streamflow reduction and possibly loss, particularly during low flow conditions affecting the catchment's water balance. During medium and high flow conditions, the streamflow loss is relatively small in comparison to the total volume of flow in the stream, as the capacity of the subsurface system limits the volume of water that can enter subsurface routes. Streamflow reduction in mining-impacted catchments is likely to be an effect of the spatial distribution and density of fracture networks, changes in porosity and permeability of the subsurface rock mass, changes in groundwater storage capacity, modification to baseflow discharge and alteration of the hydraulic gradient near streams.

INTRODUCTION

The importance of water resource protection and the maintenance of stream function has increased following the observed surface water-groundwater connectivity in areas where mining-induced subsidence has led to declines in baseflow discharge to streams. There have been various studies undertaken above active longwall mines, providing some insight into mining-induced subsidence on the temporary or permanent impact on streamflow, however, relatively little is known about flow losses as a result of longwall mining. Some of the published papers which cover this aspect of impacts of mining on surface water flow were investigated in the Appalachian Coalfield, USA (Dixon, Rauch, 1990; Tieman et al., 1987), Utah Coalfield, USA (Slaughter et al., 1995); East Midlands, England (Shepley et al., 2008); and Southern Coalfield, Australia (Jankowski, 2007, 2009; Jankowski et al., 2008).

SURFACE WATER-GROUNDWATER INTERACTION

The stream-aquifer system can be classified based on the predominant local groundwater flow component for:

- underflow-component with groundwater flow longitudinal to a stream;
- baseflow-component with groundwater flow lateral to or from a stream;

or a combination of both.

The above three groundwater flow types are postulated in the Waratah Rivulet catchment, Southern Coalfield, NSW, Australia, impacted by longwall mining, through the development of new fractures, enlargement of existing fractures, separation of bedding planes and the modification of stream topography (Jankowski, 2007, 2009). The conceptual lateral and longitudinal flow model of surface water-groundwater interaction in a mining-impacted area was described by Jankowski (2007). The inflow of surface water into the subsurface mainly occurs along vertically outcropping fractures, joints, and veins that provide dominant pathways for surface water to infiltrate an aquifer. Depending on the opening, length, and position of fractures, the surface water-groundwater interaction can be permanent or temporary. Streamflow may be permanent or temporary based on the following scenarios:

Permanent flow occurs when the:

- stream is connected-gaining and there are baseflow contributions from an aquifer in the local groundwater flow system;
- size and distribution of the surface fracture network is small, limiting surface water infiltration;
- capacity of the subsurface system to store water is lower than the streamflow infiltration rate.

Temporary flow occurs when the:

- baseflow contribution is small and unreliable;
- size and distribution of the surface fracture network is large, allowing increased surface water infiltration;
- capacity of the subsurface system to store water is higher than the streamflow infiltration rate.

The location of surface water inflow depends on the interconnectivity of vertical fractures and horizontal bedding planes. Some fractures and bedding planes are well connected and others are not, which can result in complex flow patterns, with flow in part of the stream and a lack of flow in another part, particularly during low flow conditions. Several recharge-discharge zones can be present along a streambed, causing surface water to recharge the subsurface and reappear downstream as surface flow. Cracks in rockbars further complicate the system. Vertical flow can extend to substantial depths depending on the fracture network and whether there is low permeability material present, such as claystone or shale. Horizontal inflow of surface water depends on the extension of bedding planes and their opening. Some large opened bedding planes can be used as preferential pathways for groundwater flow (Jankowski, 2007).

In the Southern Coalfield, for example, observed maximum subsidence may be up to 2.2 m and observed maximum upsidence in the Waratah Rivulet may be up to 197 mm. Mining–induced subsidence causes topographic and structural modifications to streambeds and the drainage basin, generally bounded by the angle of draw (subsidence to 20 mm). Fracturing of streambeds (Fig. 1) and rockbars (Fig. 2) causes surface water to divert to subsurface routes and interact with groundwater. In the Southern Coalfield, surface water typically flows vertically through fractures and horizontally through bedding planes. Recharge to the shallow sandstone aquifer also occurs through joints, veins and large cavities, with baseflow discharge occurring through fractures (flow is often under artesian pressure) and bedding planes.

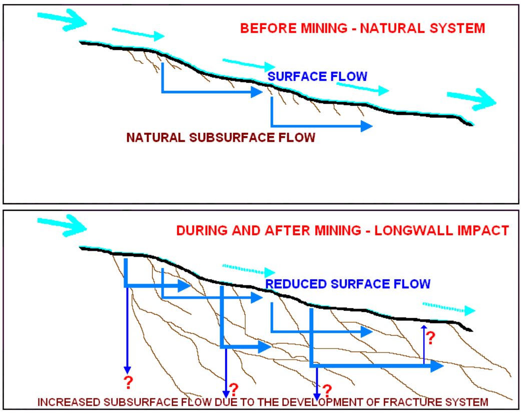

Figure 1. Diversion of surface flow into the subsurface due to fracturing of streambeds — natural versus impacted systems.

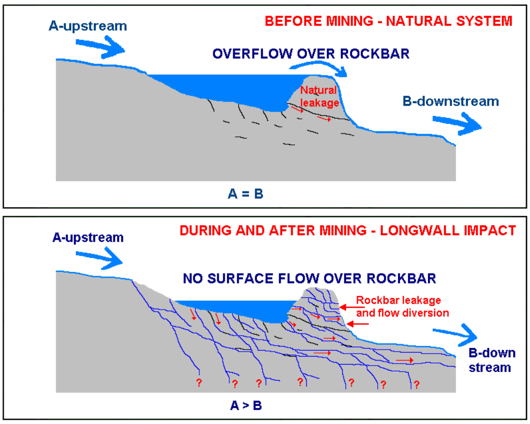

Figure 2. Diversion of surface flow into the subsurface due to fracturing of rockbars — natural versus impacted systems.

STREAMFLOW REDUCTION/LOSS

A lack of detailed baseline hydrological monitoring data is the main obstacle to adequately assessing the impact of mining on catchment hydrology, however a range of methods have been used to assess streamflow. Figure 3 shows the streamflow data from the main stream in the Waratah Rivulet catchment impacted by longwall mining. Although there is no pre-mining data, one method used for assessing the streamflow data is based on subtracting the upstream streamflow from downstream streamflow, which has been used by others, such as Tieman et al. (1987).

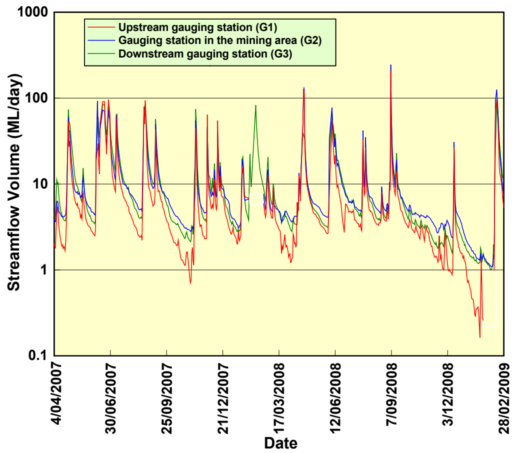

Figure 3. Comparison of streamflow upstream (G1), in the mining area (G2) and downstream of the mining area (G3).

As shown in Figure 3, the upstream gauging station (G1), which is located on the upstream edge of the mining affected area and is likely to represent close to natural flow conditions, has lower flow during dry periods compared to the other gauging stations (G2 is located on the downstream edge of the mining area and G3 is located downstream of the mining area). This lower flow is expected, as the catchment area increases downstream and there is likely to be increased volume contribution to G2 and G3 from additional runoff, flow from tributary creeks and baseflow discharge. During periods of prolonged dry weather, the reduction in surface flow becomes visually evident as streamflow is diverted into the subsurface and there are sections of the stream which are dry.

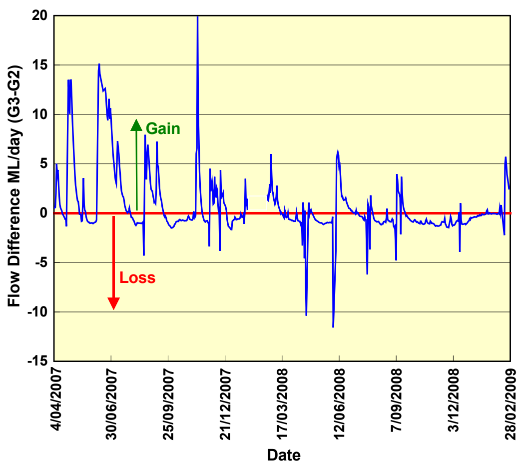

Figure 4. Flow difference between downstream (G3) and mining area (G2) gauging stations.

When the flow data from G1 is subtracted from the flow data from G2, it appears that typically the low flows at G2 are higher than the low flows at G1. Increasing flow downstream is due to incremental contributions from the catchment and baseflow discharge to some or the entire stream length between these two gauging stations. When the flow data from G2 is subtracted from the flow data from G3, the volume of water at the downstream location is lower than the volume of water at the upstream location (Fig. 4). The sharp losses shown in Figure 4 typically occur just before large rainfall events and may represent a lag in travel time.

A number of representative low flow days have been selected from the record and normalised per unit of area for each drainage basin in Figure 5. This figure indicates that the flow on these days is greater at G2 than G3. As these low flows are expected to be dominated by baseflow discharge, baseflow discharge was calculated for each drainage basin bound by the gauging station, by subtracting flow upstream from flow downstream and dividing by the drainage basin area. For G1, baseflow was calculated by dividing the flow at G1 by the drainage basin area bound by G1.

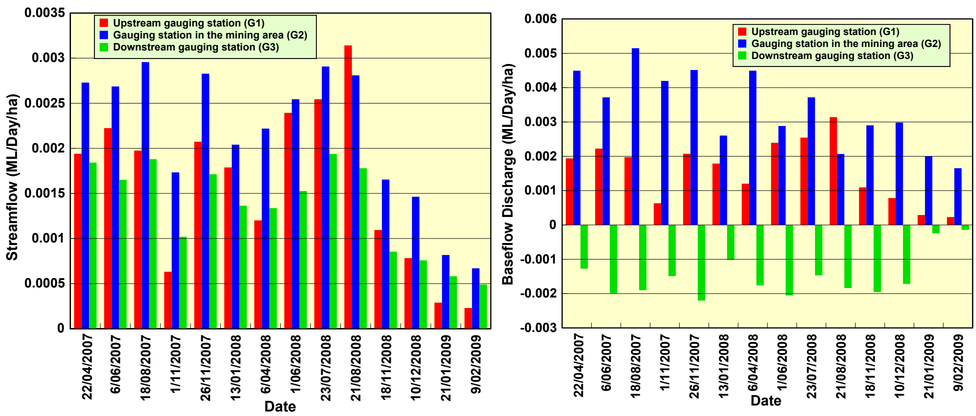

Figure 5. Normalised streamflows during low flows (baseflow discharges) at each gauging station (left) and normalised baseflow discharges at each gauging station (right).

As shown in Figure 5, G1 and G2 have positive baseflow discharge and baseflow increases downstream, except on 21 August 2008, which may be due to rock movements associated with subsidence and the rapid recharge of the shallow aquifer. However G3 is showing negative baseflow during all representative low flows presented in Figure 5, indicating that baseflow may not have discharged between G2 and G3 or streamflow loss is higher than baseflow discharge.

CONCLUSIONS

The following conclusions can be made concerning the impact of longwall mining-induced subsidence on the hydrological flow regimes in the Southern Coalfield catchment discussed in this paper:

- The streamflow changes described in this paper suggests that longwall mining-induced subsidence has enhanced the surface water-groundwater interaction, both laterally and longitudinally;
- A vertical and horizontal extension and enlargement of fractures and bedding planes resulting from the longwall mining activity could explain the loss of flow due to a more inten-

sified surface water-groundwater interaction, and to a greater depth, than would have occurred prior to mining;

- The flow system is both connected-gaining and disconnected–losing over various segments of the main stream;Streamflow losses due to mining dominate during very low to low flow conditions, whereas streamflow losses during medium to high flows are masked by the large volume of streamflow;Surface flow which has been redirected to the subsurface may reappear further downstream or be permanently lost from the drainage basin.

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abstract id: **292**

topic: **2**
Groundwater and dependent ecosystems

2.3
Interactions of surface and ground waters

title: **Surface water-groundwater interaction in the fractured sandstone aquifer impacted by mining-induced subsidence: 2. Hydrogeochemistry**

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keywords: surface water-groundwater interaction, longwall mining, fractured aquifer, hydrogeochemical processes, water quality

ABSTRACT

Hydrochemical data from the Waratah Rivulet a small stream in the Southern Coalfield, New South Wales (NSW), Australia, shows significant changes in water chemistry and quality along the rivulet. These changes are as a result of impact of mining induced-subsidence on water resources. The higher salinity and concentrations of major ions and metals are related to water-rock interaction, which causes the dissolution of carbonates, reductive dissolution of oxides and hydroxides, and oxidation of metal-sulphur minerals. The chemical composition of surface water changes from Na-Ca-Cl-HCO_3 type upstream to Ca-Na-HCO_3-Cl type downstream of the mining area. The discharge of groundwater rich in iron and manganese to the rivulet causes the development of thick mats of iron/manganese-oxides/hydroxides together with large quantities of iron oxidising bacteria during laminar flow conditions at low stages. Deterioration of water quality occurs through elevated concentration of metals and increased salinity, and aesthetic changes of the stream through precipitation of red/brown iron-oxides and hydroxides. The occurrence of metal precipitates and iron-oxidising bacteria is particularly evident where groundwater discharges through streambed cracking to surface water. Hydrogeochemical modelling shows that all surface water samples upstream, in mining area and downstream are undersaturated with respect to all cation and metal carbonate minerals and that all water samples are supersaturated with respect to iron and manganese oxides and hydroxides causing precipitation of these minerals as yellowish/orange-to-reddish/brownish precipitates.

INTRODUCTION

Longwall mining may have a significant impact on surface and groundwater quality as a consequence of mining-induced subsidence and additional fracturing and development of cracks in streambeds and rockbars. Surface water flowing through a river channel in a pristine environment is exposed to atmospheric oxygen and chemical reactions are relatively slow as rock materials and minerals are in a metastable equilibrium with flowing water. Rapid changes in chemical composition occur since fresh rock in well developed network of fractures, joints and bedding planes that previously have had no contact with water, is exposed to infiltrating surface water, groundwater and mixture of both. Rates of chemical reactions rapidly increase, mobilising large amounts of cations, anions and metals from the rock mass into the aquatic system. The concentration of these elements depends on the availability of soluble minerals present in the rock mass and the initial chemical composition of infiltrating surface water into subsurface routes. This causes deterioration of water quality through the elevated content of metals, mostly iron and manganese as well as aluminium, zinc, cobalt and nickel, increased salinity, and oxygen depletion, causing aesthetic changes in the river channel through precipitation of orange-reddish-brownish iron-oxides/hydroxides and formation of red and green algal blooms (Bullock, Bell, 1997; Jankowski, 2007; Jankowski, et al., 2008).

ENVIRONMENTAL SETTING

The Waratah Rivulet catchment is located approximately 45 km southwest of Sydney (Fig. 1). The elevation varies from around 360 m a.s.l. in the headwaters to 170 m a.s.l. where the rivulet enters Woronora Lake, one of several Sydney's drinking water supply system storages. The catchment is located in the southern part of the Sydney Basin. The geology of this area comprises a gently deformed sequence of Triassic sandstone that forms the upper sequence of the Sydney Basin sediments.

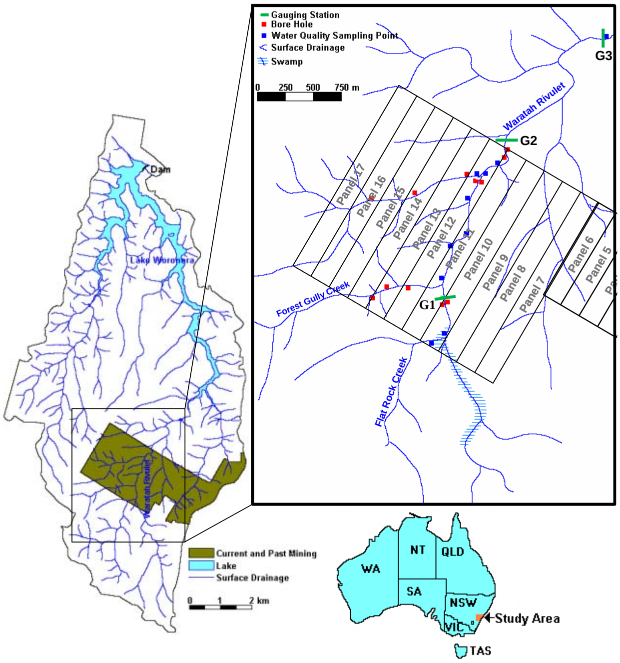

Figure 1. Location of the Waratah Rivulet catchment (left) and location of sampling points and longwall panels (right).

The mining occurs in the upper coal seam unit of the Permian Illawarra Coal Measures known as the Bulli Seam, which has a thickness of 3.2–3.6 m across the catchment area, and which underlies the Narrabeen Group. The main surface waterway in the catchment is the Waratah Rivulet, which flows north and discharges into the Woronora Lake. The longwall panels are located directly underneath the catchment and orientated in a southwest–northeast direction, 450–500 m below the ground surface (Fig. 1). Seventeen of the currently approved nineteen-longwall panels have been mined at the date of this paper.

RESULTS

Surface water sampling locations for water chemistry determination were set-up along the rivulet and are representative of areas upstream of the present mining, in the impacted part of the rivulet, and downstream of mining (Fig. 1). A reference point located in a tributary creek represents a pristine water quality environment. Groundwater quality samples were collected from recently drilled shallow bore holes along the rivulet and along two main tributary creeks. These locations cover pristine and impacted areas (Fig. 1). Water quality upstream of the longwall panels is quite similar to water flowing in creeks and rivers from pristine sandstone bedrock environments and to limited water quality data collected prior to mining (Fig. 2). Chemical data shows that concentrations of major and minor elements are much higher in groundwater than in surface water. The higher concentrations are related to presence of well developed and interconnected fracture networks in the mining-induced subsidence area and exposure of more rock strata to water-rock interaction, which causes dissolution of carbonates, reductive dissolution of oxides/hydroxides, and oxidation of metal-sulphur minerals. These processes mobilise Ca, HCO_3, Fe, Mn, Ba, Sr, S (SO_4) and other trace metals from the rock mass.

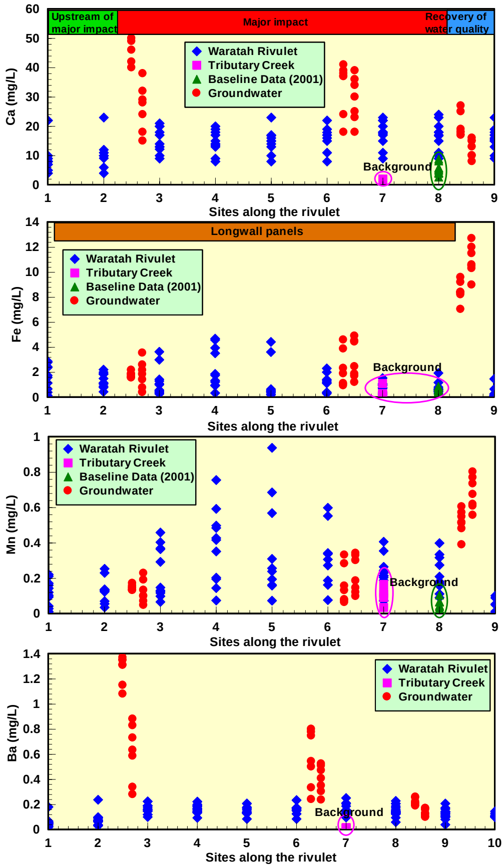

Figure 2. Variation of Ca, Fe, Mn and Ba concentrations along the Waratah Rivulet.

Deterioration of water quality occurs through elevated content of metals, increased salinity, and aesthetic changes of the creek channel through precipitation of yellowish/orange and reddish/brownish iron oxides/hydroxides. The occurrence of metal precipitates and iron-oxidising bacteria is particularly evident where groundwater discharges to surface water through streambed cracking. The pH and HCO_3 increase due to dissolution reactions involving carbonate minerals such as calcite, siderite, rhodochrosite, strontianite and barite, which are the most abundant carbonates in the sandstone aquifer matrix. The presence of metal carbonates in the rock mass cause Fe, Mn, Sr and Ba to mobilise, significantly increasing concentrations of these elements downstream, where subsurface flow re-emerges at the ground surface. The highest rates of chemical reactions occur during and after rainfall events, when acidic rainwater with a pH of 3–6 and surface run-off infiltrate the subsurface system and mobilise metals from carbonate minerals.

Infiltrating fresh, acidic of low concentration rainwater rapidly changes its chemical composition in contact with rock matrix. Concentrations of Fe and Mn initially rise in surface flow as groundwater discharges from the subsurface. This causes the development of thick mats of iron/manganese-oxides/hydroxides together with large quantities of iron oxidising bacteria during laminar flow conditions at low stages. The bacteria grow thick mats of iron/manganese-oxides/hydroxides, which reduces the interstitial habitat, clogs the stream, reduces available food, and causes the development of toxicity through decreased oxygen content. Loss of native plants and animals occurs directly through iron toxicity or indirectly via smothering. However a few hundred metres downstream dissolved metal concentrations decrease as Fe and Mn are removed from aquatic system and precipitate as oxides and hydroxides, causing orange/red to brownish stains in the creek channel. These stains on the streambed and thick mats of iron/manganese-oxides/hydroxides floating on surface water are present until the next rainfall event which dissolves precipitates by slightly acidic runoff. This process re-mobilises iron and manganese oxides and hydroxides, eroding them from the streambed and dissolving them from floating mats and returning these metals again to the aquatic system causing further contamination downstream, mostly in the Woronora storage.

Chloride ion in surface water along the rivulet as well as in groundwater has very uniform concentration. Input of Cl into aquatic system occurs through rainfall input containing this ion and originating from marine aerosols as groundwater chloride concentration is low due to freshwater depositional environment of sandstone and long term flushing of shallow subsurface by rainfall. Ion/chloride ratios have been calculated to assess changes of reactive ion concentrations versus conservative chloride ion (Fig. 3).

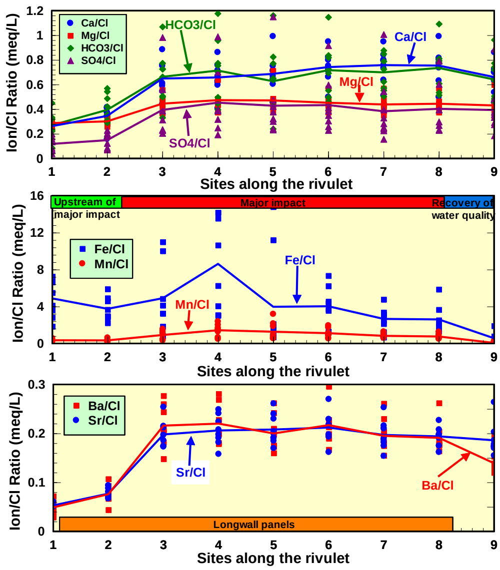

Figure 3. Ion/chloride ratio along the Waratah Rivulet (continuous lines represent average values for each ratio)

Data shows significant increase of Ca and HCO_3 relative to Cl indicating dissolution reaction of calcite, lesser increase of Mg from dissolution of traces of dolomite and weathering of aluminosilicates containing Mg. Oxidation of traces of pyrite/marcasite supply some SO_4 to aquatic system. High increase relative to concentration as well as to Cl occurs for Ba and Sr along the impacted part of the rivulet. The PHREEQC — v. 2.11 computer program (Parkhurst, Appelo, 1999) was used to model the speciation and saturation indices of surface waters. Hydrogeochemical modelling has shown that surface water is undersaturated with respect to carbonate minerals (Fig. 4). These minerals are dissolved from the rock mass and the addition of Ca, Mg, Sr, Zn, Mn, Ba, Fe and HCO_3 into the aquatic system occurs, significantly increasing the concentration of these elements in groundwater and surface water. All sulphate minerals are undersaturated; except barite which is in equilibrium in aquatic system. All iron oxide/hydroxide (Fig. 4) and manganese-oxide/hydroxide-minerals are strongly supersaturated, including magnetite, hematite, maghemite, goethite, lepidocrocite and ferrihydrite, hence precipitation of these minerals quickly remove iron from the aquatic system.

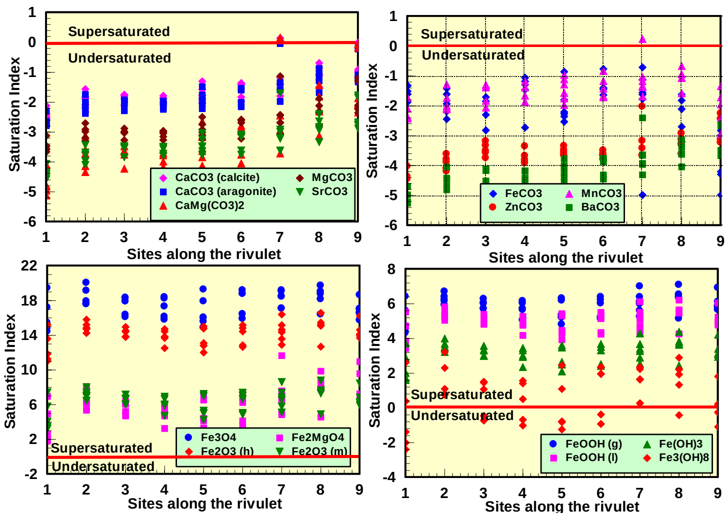

Figure 4. Saturation indices with respect to carbonates and iron oxides/hydroxides along the Waratah Rivulet.

Interaction between surface water and groundwater can be interpreted on the basis of baseflow discharge data and hydrograph separation studies. The chemical composition of groundwater and surface water is used as a tool to show this interaction, as well as demonstrating the impact of groundwater chemistry on surface water quality. Mixing between re-emerging groundwater with flowing surface water changes the concentration of Fe and Mn in surface water. As groundwater contains higher concentrations of Fe and Mn due to mobilisation from the rock mass during water-rock interactions, mixing of this groundwater with surface water causes higher concentrations than is present upstream of the mining area. These same processes are related to elevated concentrations of Sr and Ba in surface water after mixing with groundwater. Both Sr and Ba are present in very low concentrations in the natural surface water system; input from groundwater can provide insight about discharge locations and presence of fractures.

CONCLUSIONS

Mining-induced subsidence alters the hydrological system of surface water and groundwater and intensifies surface water and groundwater connectivity. Increased water-rock interaction on the newly exposed rock in fractures, joints, veins, fracture zones and bedding planes mobilises chemical elements from the rock mass. This in turn increases the salinity of surface water, brings more metals into the surface waterways, and results in the deterioration of water quality. An understanding of the rates of chemical reactions and mobilisation of metals through dissolution, weathering, and redox processes should be established to assess water quality in mining impacted catchments.

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abstract id: **313**

topic: **2**
Groundwater and dependent ecosystems

2.3
Interactions of surface and ground waters

title: **Deuterium and O-18 data to estimate the relative contribution of summer and winter season precipitation to surface water pools; A Case study from Hamersley Basin, Western Australia**

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keywords: groundwater, stable isotopes, below water table mining, groundwater surface water interaction, precipitation

INTRODUCTION

The Hamersley Basin of Western Australia contains the world's single biggest deposit of iron ore. Below water table (BWT) deposits often require substantial dewatering and drive the need to understand the source, flow and interconnections between the regional water table, the orebody and nearby groundwater dependent ecosystems. Conventional hydrogeological investigations allow measurements of water levels and hydraulic properties of aquifers and estimation of water balance through water table monitoring and pumping testing. However in some areas, drilling for installation of monitoring bores is not possible due to rugged terrain or indigenous cultural values and it is here that the chemical and isotopic tracers are useful as a non-evasive low cost method to supplement conventional hydrogeological investigations (Cook, Herczeg, 1999).

The Cl concentration in Stuart Pool (an environmentally sensitive water body near a proposed BWT mining area) is almost constant throughout the year ranging from 19 mg/l in August 2008 to 25 mg/l in April 2009. The δ^2H values on the other hand, change from enriched values of 5.1‰ in August 2008 to highly depleted values of –78‰ in April 2009 and more enriched values of –5.1‰ in August 2009. δ^2H of ore body groundwater is approximately 70‰ depleted compared to that measured in Stuart Pool in August 2008 and 2009 (Fig. 1a). Therefore groundwater seepage is not the processes that results in the variation in δ^2H values in Stuart Pool. Evaporation will result in enrichment of both heavy isotopes and Cl concentration. The only plausible explanation for the constant Cl and large difference in deuterium concentration is that the water in Stuart Pool is derived entirely from the mixing of dry and wet season rainfall with no significant evaporative effect.

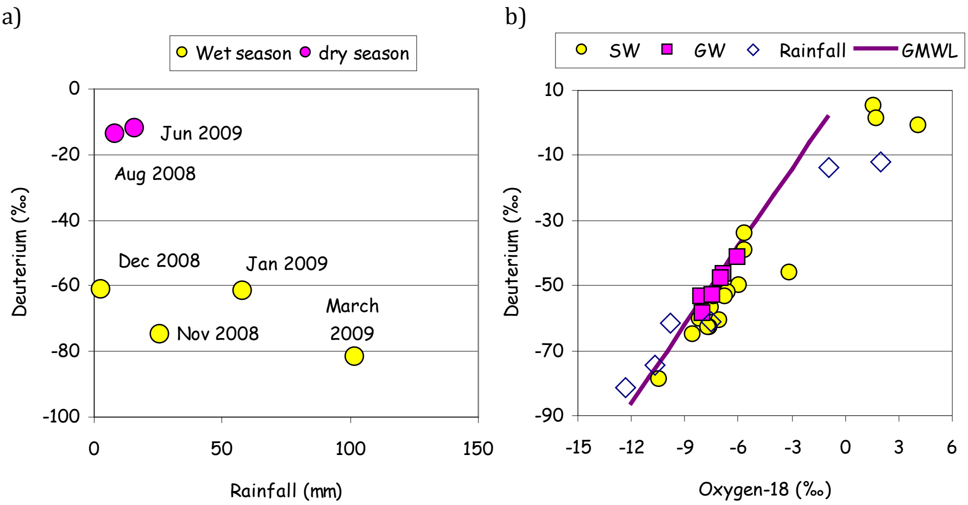

Figure 1. a) Deuterium concentrations versus amount of rainfall in the study area; b) Stable isotope concentrations in groundwater, surface water and rainfall. GMWL is plotted for comparison.

This hypothesis is corroborated by the results of stable isotope analysis of precipitation in the area showing that the isotopic signature of wet season rainfall (δ^2H~–60‰) is significantly depleted compared to dry season rainfall (δ^2H~–10‰). The summer wet season vapour flux is derived largely from the tropical Indian Ocean whereas; in winter the dry season vapour flux is originated from lower latitudes that are characterised by enriched stable isotopes (Yurtsever, Gat, 1981; Rozanski et al., 1993); and the mixture of lower latitude and tropical band moisture sources may explain the comparably enriched stable isotope signatures observed within seasonal precipitation.

The distinct isotopic signature of summer and winter rainfall in the area is reflected in the isotopic signature of surface water and groundwater. The isotopic signature of permanent surface water of Stuart Pool and groundwater in the region shows that while the surface water pool can provide a reasonably good proxy for the event based precipitation; the isotopic signature of groundwater reflects the long term mean of wet season rainfall (Fig. 1b) as larger rainfall, and by inference greater recharge, are associated with the more depleted wet season stable isotope signature. Ultimately, the correct application of stable isotope and chemical tracers may prove invaluable in identifying the level of groundwater dependence in surface pools and for understanding the potential impacts of dewatering for below watertable mining within the Hamersley Basin.

ACKOWLEDGMENTS

We thank Dr Grzegorz Skrzypek from West Australian Biogeochemistry Centre (John de Later Centre), The University of Western Australia for measurements of $\delta^{2}H$ and $\delta^{18}O$.

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abstract id: **320**

topic: **2**
Groundwater and dependent ecosystems

2.3
Interactions of surface and ground waters

title: **Investigation of surface water-groundwater interactions and temporal variability of streambed hydraulic conductivity using streambed temperature data**

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keywords: heat as a tracer, surface water, groundwater, connectivity

INTRODUCTION

Water resource management is increasingly moving towards a conjunctive approach for surface water and groundwater. For this to be successful the possible interactions between surface water and groundwater needs to be understood and quantified. However, quantifying this interaction is notoriously difficult. Often groundwater management decisions are based on numerical models of a groundwater aquifer system where the connection to surface water is poorly conceptualised. This has implications for the usefulness of such models as predictive tools. For example, the impact of groundwater abstraction on the river-aquifer exchange will not be properly quantified if the model does not capture this process appropriately. In part, this difficulty has arisen due to a scarcity of field based studies into river-aquifer interactions. In this context, a study of the interaction between a major river and underlying aquifer in a semi-arid region, the Maules Creek Catchment located in north-western New South Wales, Australia, was carried out (Figure 1).

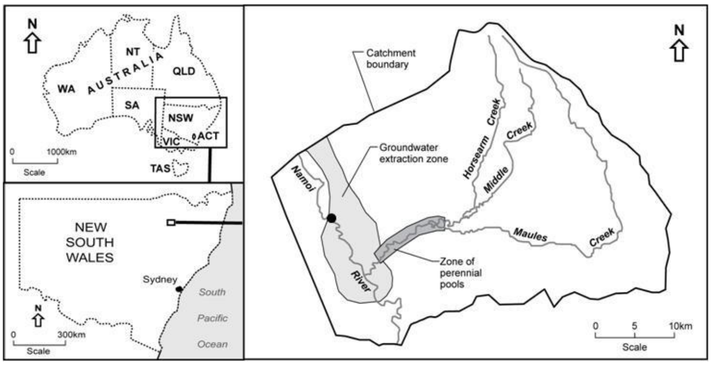

Figure 1. Maules Creek Catchment with location of the study area shown as a black marker (Source: McCallum et al., 2009).

METHODOLOGY

A thermal approach using arrays with temperature loggers was employed to investigate the river-aquifer interaction. Four arrays, each consisting of three loggers mounted in a PVC pipe, were installed vertically into the riverbed, with loggers located at 0, 15 and 30 cm depth. The arrays were deployed in a single pool within the Namoi River (Figure 2). The loggers were set to record every 15 mins (from November 2007 to April 2008). In addition, pressure transducers were installed to log the river stage and groundwater level in a nearby borehole (approximately 40 m from river) every 15 mins.

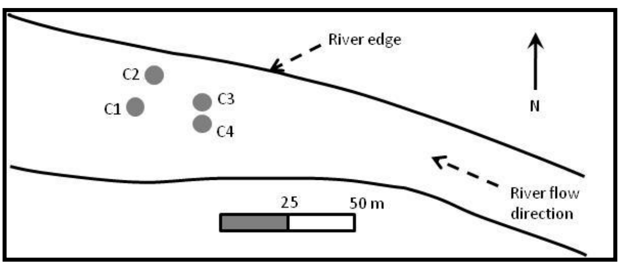

Figure 2. Location of temperature probes within the Namoi River.

Streambed water fluxes were calculated on the basis of the 1D convection-conduction heat transport differential equation for fully saturated conditions:

$$\frac{\partial T}{\partial t} = \kappa_e \frac{\partial^2 T}{\partial z^2} - \frac{n v_f \rho_f c_f}{\rho c} \frac{\partial T}{\partial z}$$

where T is temperature, which varies with time (t) and depth (z); κ_e is effective thermal diffusivity; n is porosity; v_f is vertical fluid velocity; ρ_f and c_f are density and heat capacity of the fluid; and ρ and c are density and heat capacity of the saturated sediment-fluid system.

Hatch et al. (2006) presents a solution to this equation in which two values of vertical flux can be independently calculated by comparing the diurnal amplitude damping and phase shift of temperature time series at different depths. The recorded temperature time series were filtered to isolate the diurnal variations. The amplitude ratio and phase shift for the upper and lower loggers were then computed and used to derive river-aquifer fluxes. For more details as well as thermal parameters used see also Rau et al. (2010).

RESULTS AND DISCUSSION

The river stage data shows that during the period of investigation there were four main flow events (Figure 2a, solid line). Two were large (~ 3–4 m stage increase) events caused by rainfall periods each of which were preceded by a smaller (~1 m stage increase) event caused by dam releases up river. The groundwater levels responded in a damped fashion to each of the flow events (Figure 2a, dashed line). Also evident in the groundwater levels were rapid events of drawdown (~1 m) caused by near-by groundwater abstraction. The difference between the river stage and groundwater level is the driving force for river-aquifer interactions (Figure 2b).

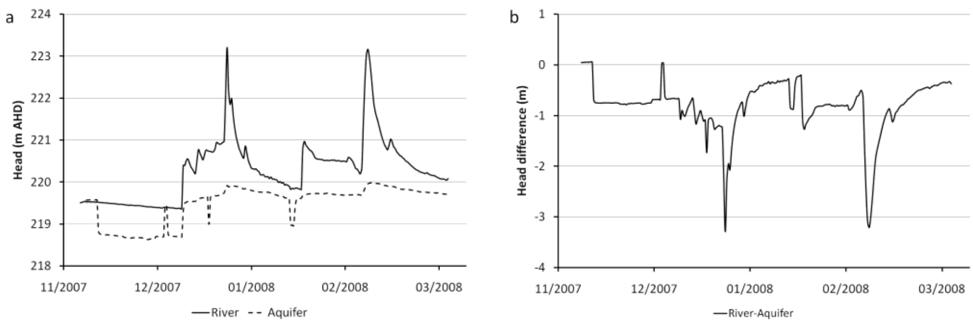

Figure 2. a) Head time series in river and aquifer; b). River-aquifer head difference (negative value indicates potentially losing conditions).

The measured temperature time series show strong diurnal heat patterns as well as longer-term heat trends and noise (Figure 3a) while the filtered time series more clearly reveals a damping of amplitude and shift of phase with depth at each location (Figure 3b).

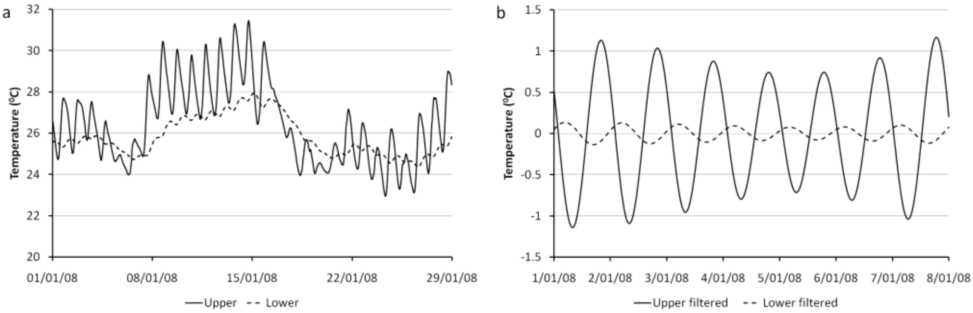

Figure 3. a) A portion of unprocessed temperature data from temperature array C1. The solid line is the surface water temperature at the streambed and the dashed line is at 30 cm into the streambed; b) Example of 7 days of filtered temperature data from the same sensors in array C1.

Interestingly, the fluxes derived from the phase shifts were consistently greater than those calculated from the amplitude ratios. This is possibly due to violation of the 1D flow assumption inherent in the analysis (Rau et al., 2010). Regardless of this discrepancy, both sets of results showed the same overall patterns. Results discussed below are those derived from using the amplitude ratio, which have been found more robust (Lautz, 2010).

At all locations the computed long-term river-aquifer fluxes were approximately 0.1 m/day downwards, indicating losing river conditions, which is consistent with the negative gradient in Fig. 2b. There was little apparent spatial variability in flux rates between arrays (Table 1). This was somewhat surprising as it was anticipated that the heterogeneity of the streambed would have led to strong spatial trends. This result, however, gives confidence in the possibility of up-scaling these point measurement to larger spatial scales.

Table 1 Statistics of flux results (m/day).

	C1	C2	C3	C4
Mean	–0.107	–0.101	–0.144	–0.095
Median	–0.087	–0.084	–0.138	–0.084
Variance	0.003	0.002	0.001	0.001
Std deviation	0.055	0.046	0.032	0.031
Minimum	–0.295	–0.245	–0.245	–0.190
Maximum	0.280	0.201	0.027	–0.036

The time series of calculated velocities revealed a number of interesting features (Fig. 4a). First, for short periods of time, following the initial high river stage related to a flow event, an up-wards flux was observed. The cause of this is presently unknown but could possibly reflect a return of bank-storage to the river. Second, the pattern of the temperature-derived flux follows a similar pattern to the river-aquifer head difference (compare Fig. 4a with Fig. 2b). The correlation coefficient between these two variables during the flood events varies from 0.77 to 0.98. This indicates that there is a clear relationship between river stage and river loss. Third, the fluxes were constant for long periods but changed temporarily during flood events as indicated by the change in slope of the cumulated river-aquifer fluxes in Fig. 4b.

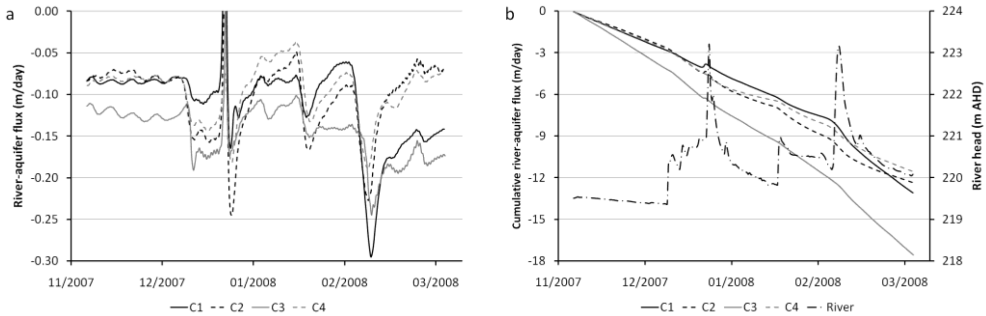

Figure 4. a) River-aquifer flux calculated from the temperature data. A negative flux indicates losing conditions; b) The river-aquifer fluxes as in a. but cumulated over time.

It is hypothesised that these field observations can be interpreted using a simple conceptual model of how the riverbed hydraulic conductivity changes over time (Figure 5).

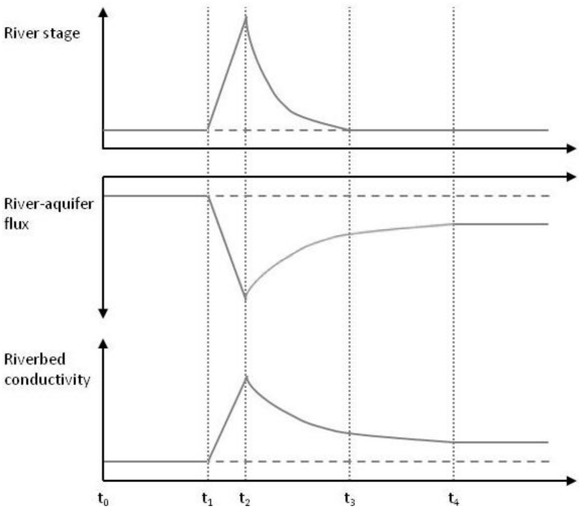

Figure 5. Conceptual understanding of riverbed conductivity changes through time and relationship to river stage and river-aquifer flux.

Between t_0 and t_1 the system is in a steady state. From t_1 to t_2 a flood increases the river stage. Corresponding to this increase in an increase in river-aquifer flux (more negative since the river is already losing) according to Darcy's law. Importantly, also corresponding to this increase in river stage is an increase in riverbed conductivity due to scouring of lower permeability material in the riverbed by the flow event. As the river stage declines between t_2 and t_3 the river-aquifer flux decreases, again according to Darcy's law. However, at t_3 where the river stage is back at the level at t_1 the exchange flux is still larger than at t_1. This is due to the increased riverbed conductivity. Between t_3 and t_4 the river-aquifer flux slowly reduces, although the river stage remains constant, as the riverbed conductivity declines due to deposition and colmation of the riverbed. At t_4 a new steady state is reached. The observed change in riverbed conductivity and consequently in the exchange flux related to flood events is an important finding since most numerical models simulating stream aquifer exchanges assumes the streambed hydraulic conductivity is constant over time. The data presented here suggest that it is important not only to understand the spatial variability of the hydraulic conductivity but that the temporal variability must be assessed as well.

CONCLUSIONS

This study demonstrates how surface water groundwater interactions can be understood and quantified using thermal investigations. Further work is still required to make the interpretation more robust, especially unravelling the discrepancy between results derived using amplitude damping and phase shift of temperature time series. Nevertheless, the method can be used to better constrain the river-aquifer interaction in groundwater models, in particular riverbed changes through time.

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IAH 2010
Krakow

abstract id: **407**

topic: **2**
Groundwater and dependent ecosystems

2.3
Interactions of surface and ground waters

title: **Springs in Drawa National Park and its border area, NW Poland**

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keywords: springs, groundwater geochemistry, Drawa National Park

Drawa National Park (DNP) is one of the newest and biggest national parks in Poland. It was set up in 1990 (as 16th from 23th national parks) on 114,41 km^2 (8th in the big-wise). Border area of DNP amounts 409 km^2. It is only one national park in Poland which belongs to the three voivodeship (Zachodniopomorskie, Lubuskie, Wielkopolskie). The landscape of the area was shaped during the last stage of the Vistulian glaciation. About 80% area are forests and 8% are surface waters. The Park boasts of 25 lakes, very diversified as regards the ecological character. The main river s are Drawa (with average flow 15 m^3/s and and its left-bank tributary Płociczna (3 m^3/s). The Park owes them distinguishing shape like "V" letter. The Drawa has a character of the mountain river due to rapidity of its current.

Some of the unique elements of the Drawa National Park water system are outflows of underground water: springs, leakages, and exudations, as well as the well-head peatbogs formed by those outflows. The sandy plain Równina Drawska, where the Park is located, is amiable to the infiltration of rain water into the ground. Provided with the right geological make-up of the land, these waters then low out from the beneath where the land tends to be lower, especially by the edges of river valleys. Hydrogeological conditions of Drawa National Park and border area are relatively poor recognized. Especially it concerns chemistry of groundwaters. The best way to recognized it is carrying researches of springs (there are not many wells in this area). The second aim of investigation is making photographical documentation, list and map of all springs and its precisely describing. Thanks results of researches will be possibility identifying of chemical background of this area in a wide range of elements. It will give rise to better protection of groundwaters in Drawa National Park and other compounds of nature.

During investigations in the DNP (since 2007) over 50 springs were found, 119 groundwater samples were taken and 170 field measurements were taken. Field investigation consists of measurements: temperature, pH, conductivity and redox potential of groundwater. After that chemical composition in laboratory was examined using volumetric methods and ICP spectrometer. It were measured as follows: main ions Cl^-, HCO_3^-, SO_4^{2-}, NO_3^-, Na^+, K^+, Ca^{2+}, Mg^{2+} and F^-, PO_4^{3-}, SiO_2 and cations Fe, Mn, Al, Sr, Ba, Ti, V, Cr, Co, Ni, Cu, Zn, As.

The current results of investigations shows that springs of Drawa National Park are very diversified in many respects. For example outflow efficiency changes in a wide range from 0.1 l/s to a few liters per second. Some springs are very close to each other and makes so-called well-heads. The most abundant well-heads are located in the lower part of Rynna Miradzka. Some of the springs have hydrological windows, through which water flows out and gathers into streams that together form a brook. Its efficiency reaches (in some periods in the year) about 120 litres per second. Sometimes springs situated very close each other differs in hydrogeochemical conditions and chemical composition. Temperature of groundwater changes from 3,7 to 19,3°C (mean is 9,0°C), pH changes from 6,00 to 8,28 (mean is 7,34), conductivity changes from 135 to 786 μS/cm (mean is 426 μS/cm). The most usual springs hydrogeochemical type is HCO_3–Ca (about 60% of samples) and HCO_3–SO_4–Ca (about 30 of samples).

ACKNOWLEDGEMENTS

Researches are supported by the polish Ministry of Science and Higher Education grant and ends in October 2010.

IAH 2010
Krakow

abstract id: **429**

topic: **2**
Groundwater and dependent ecosystems

2.3
Interactions of surface and ground waters

title: **Hydrology of a groundwater dependent Esker lake**

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keywords: esker, water balance, groundwater, lake, ecosystems

INTRODUCTION

In Finland, the main source of groundwater is from esker deposits from the last ice age. Small lakes are typically found in eskers. These lakes are formed in the last glacial stage where ice melted and a hollow depression was left. These lakes usually lay in the groundwater sand deposit with no specific outlet or inlet. Also the catchment for surface water is often small. Lakes at Rokua esker have been suffering from large water level changes and a permanent decline of water level has raised considerable concerns as the area is also used for recreational and tourism. A potential threat for the lakes and the groundwater is the drainage of peatlands which normally are found in the discharge zone of the aquifer. As the lake catchments are potentially small without inlets and outlets also the natural variation in water levels could be high. The aim of this study was to understand in more detail the hydrology of the groundwater deposit and the lake systems so potential causes for lake level variations could be determined.

MATERIALS AND METHODS

A small lake within the esker Rokua was studied in detail. Direct seepage measurements were carried out using the approach by USGS with some modifications (Rosenberry, LaBaugh, 2008). The seepage was measured at regular intervals around the lake. Climate data was observed and groundwater levels and water levels registered with pressure probes. Long term data on climate and hydrology was also used for comparison.

The dynamics in the lake water level changes were modeled with a water balance approach in Matlab. The model included estimation for seepage and the groundwater-lake interaction.

RESULTS

The preliminary results from 2009 show that the direct seepage measurements show large variation in seepage along the shoreline with a clear area of water input and a clear area of water output. The water balance model clearly shows that the water level changes depend on climatic variations (precipitation and evapotranspiration). Also seepage from the lake is a significant component in the water balance.

ACKNOWLEDGEMENTS

The project was financed by the EAKR project ROKUA, Maa- ja vesitekniikan tuki r.y. and the 7th framework project GENESIS (226536).

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abstract id: **430**

topic: **2**
Groundwater and dependent ecosystems

2.3
Interactions of surface and ground waters

title: **Threats to a coastal aquifer in northern Albania**

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keywords: coastal, intrusion, heavy metals, recharge, isotopes

ABSTRACT

The Mati plain aquifers in Northern Albania serves as water source for two larger towns and the local habitation. An inventory of threats to the sustainability of the aquifers has been done. Brackish water in the outer portion of the aquifers turns out to be old and the salinity seems to come from diffusion from intercalated clay. Artesian conditions indicate that the current pumping rate is safe. Heavy metals from upstream mines and smelters is adsorbed onto sediments under a stable pH, mirroring the carbonate bedrock in the catchment. What is a serious threat is the sand and gravel extraction in an alluvial cone where the Mati river enters into the plain. This is an important recharge area and the digging lowers the head versus the sea level, may clog the sediments and cause spills of hydrocarbons from machinery used.

BACKGROUND

Coastal aquifers are globally under threat due to several facts. A large fraction of the global population lives in coastal areas leading to a high demand for water supply. The coastal plains, often situated on river deltas, offer good agricultural lands with irrigated agriculture. This is especially the case in S and SE Asia (Ericson et al., 2006). Sea water intrusion has been experienced in many coastal aquifers (Ballykrya & Ravi, 1998; Shammas & Jacks, 2007). The threat of sea water intrusion is often difficult to foresee as recharge rates are not known and recharge mechanisms are complex (Shammas, 2008). Countermeasures in addition to decreased water extraction have been tested and found useful in several cases (Ballykrya & Ravi, 1998; Shammas, 2008). Other threats are land subsidence (Phien-wej et al., 2006) and climate change with a rising sea level (Ericson et al., 2006). The coastal aquifers are often large and have a complex past history with sea water transgression and regression mirrored in the groundwater chemistry (Jacks et al., 2009). Thus any brackish water occurrence does not necessarily mean sea water intrusion. The redox conditions in delta plains globally has caused widespread mobilisation of arsenic even from sediments having background contents of arsenic (Bhattacharya et al., 1997).

Albania is not poor in water resources. The southern part of the country is blessed with many large karstic springs. Several of the rivers are polluted which may indirectly pollute the groundwater (Cullaj et al., 2005). This investigation deals with a major aquifer in Quaternary sediments in the northwestern part of Albania. The aquifer serves as water supply to two towns, Durres to the south and Lezha to the north. The current water extraction rate is about 1.5 m^3/s in two major well fields. The investigation was initiated due to concern about the future water quality of these well fields. The groundwater in the outer portion of the Mati river aquifer is brackish with chloride levels up to 2 000 mg/l. In the catchment there are many sites polluted by copper and chromium mining and smelting. About 10 M tons of copper containing waste is present in the catchment. A source for chromium and nickel is the large Burrel chromium smelter (Shiza et al., 2005). Another obvious threat is gravel extraction in the alluvial cone in the river Mati at its entry into the plain.

The aim of this investigation has been to elucidate and assess the threats to the Mati river plain aquifer, including the origin of brackish groundwater, possible pollution risk from upstream sites and other threats.

SITE AND METHODS

The Mati river has a catchment area of 2441 km^2 and the mean annual discharge is 103 m^3/s. The rainfall in the catchment is between 1000 and 1500 mm. The river forms a plain in northern Albania which is about 20 km broad from the foothills to the sea side and about 30 km long in north-south direction. It consists of three main aquifers of Quaternary age sandwiched between clay layers. Topmost there is a clay layer with about 20 m thickness. Where the river Mati enters into the plain, there is an extensive alluvial cone of sand and gravel contacting all the three aquifers (Fig. 1). In the plain there are two large well fields supplying Durres and Lezha towns.

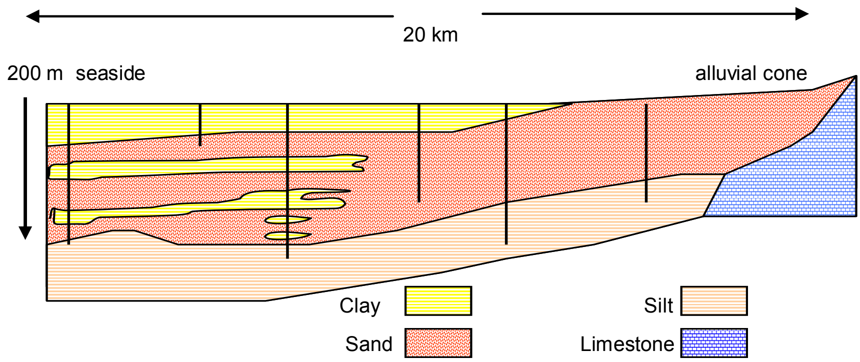

Figure 1. Cross section through the Mati Plain aquifers.

The sampling was done on five occasions in March and August 2008 and in January and in December 2009, covering all the seasons. Water was sampled from pumps and from the overflow of artesian wells. pH and temperature were measured on the sites and the water was passed through 0.20 μm filters. On the last two occassions sulphate was sampled for sulphur isotope analysis along a section from the alluvial cone of Mati river to the seashore in direction ENE to WSW to distinguish between sulphate of sea water origin and that of sulphide oxidation origin from the mine polluted sites in the catchment.

Six samples were taken for ^{14}C and ^{13}C analysis. The carbonate was precipitated from about 5 litres of water and the pH was raised by the addition of a sodium hydroxide pellet. The clear supernatant was decanted after the precipitate had settled.

A number of samples were taken for stable isotope analysis of ^{18}O and D in dense polyethylene bottles. The anions were analysed by ion chromatography and cations and trace metals by ICP-OES.

RESULTS

There exist two types of groundwater in the aquifers, a Ca-Mg-HCO_3 type in the eastern and central part of the aquifers and a Na-Ca-Cl type in the near shore areas. The majority of the brackish groundwater wells in the clay covered western portion of the plain were artesian with a pressure head of up to about 1 m.

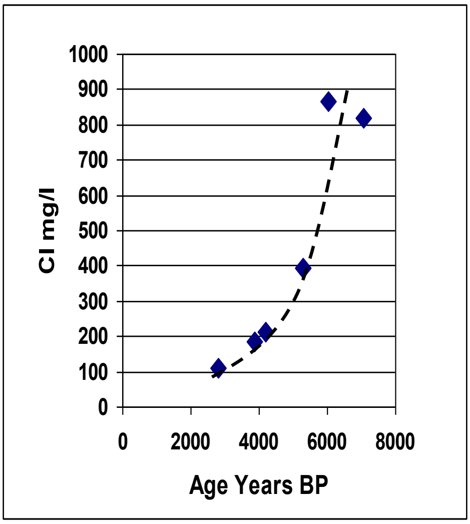

Figure 2. Chloride versus 14C ages.

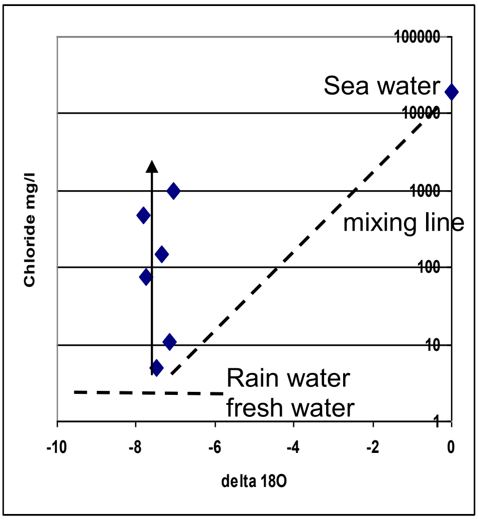

Figure 3. Chloride versus δ 18O.

The dating of six samples with elevated chloride content gave a range of 2 800 to 7 000 years of age BP. The ages were related to the chloride content (Fig. 2).

The ^{18}O analyses revealed a narrow range of values between -7 to -8‰ (Fig. 3) and no relation to the chloride concentrations. The river water is an isotopic blend of rainwater from low altitudes to levels around 2000 m. Rainwater $\delta^{18}O$ in the region (Vreca et al., 2006) show values for that range of altitudes of 5 to 10‰. The seasonal variations of $\delta^{18}O$ and range in values depending on altitude is in the river narrowed down by the mixing of groundwater of different flowpaths and the Ulez and Lake Shkopet reservoirs upstream.

Copper, chromium and nickel concentrations are elevated in sediment samples taken from the alluvial cone (Table 1). The concentration of arsenic is lower than found in other investigations in Albania (Lazo et al., 200). In groundwater, no case of excess concentrations of heavy metals has been found. Two samples showed slightly above permissible levels of arsenic with 11 respectively 16 μg/l as compared to the WHO limit of 10 μg/l.

Table 1. Cu, Ni, Zn and As contents in sediments in river Mati and reference values (Taylor, 1964; Plant et al., 2004).

Sample	Cu mg/kg	Cr mg/kg	Ni mg/kg	Zn mg/kg	As mg/kg
Sand < 2 mm	372	328	369	209	11
Organic matter	289	235	364	193	10
Crustal average	55	100	75	70	1-10

The $\delta^{34}S$ samples taken gave values for the fresh water samples in the range of 4-6‰ and values of 21-23‰ for the brackish groundwaters (Table 2).

Table 2. Sulphur isotope data for samples with different chloride concentration.

Sample	$\delta^{34}S$‰	Cl- mg/l	Note
A3:1	+11.6	4.3	Municipal well N:o 1 at river side
A3:2	++4.5	12	Private well 1 km from eiver
A3:3	+7.3	23.7	Village well
A3:4	+4.8	3.4	Durrres pumping station
A3:5	+5.3	15.8	Well 3 km from sea side
A3:6	+23.1	418.9	Close to sea side
A3:7	+21.8	186.3	1 km from sea side
A4:1	+3.6	6.5	Municipal well N:o 2 at river side
A4:2	+24.4	700	Artesian well 2 km from sea
A4:3	+23.0	550	Artesian well 1 km from sea
A4:5	+3.6	12	Well in eastern part of plain
A4:M	+1.6		Copper ore from mining site

DISCUSSION AND CONCLUSIONS

The plain is covered by a 20 m thick clay layer making the aquifers below confined. The clay must have been deposited below water. The sea water level in the Mediterranean has not been appreciably higher than present for the last 120 ky BP (kilo-year before present) (Lambeck & Parcell, 2005). However, while most of the eastern coast of the Adriatic sea has been subject to subsidence, north in Slovenia and Croatia (Antonioli et al., 2007) and in south in Greece (Palyvos et al., 2008) the Albanian coast has with some exceptions (Aliaj et al., 2001) been subject to uplift (Mathers et al., 1999). Mathers et al. (1999) have observed beach ridges on Landsat images close to the foothills in the Mati river plain which is verified by Foache (2006). The age of these beach ridges should be of late Holocene age or from the last 10 ky BP and of the same age as the Flandrian transgression in western Europe. Thus the brackish groundwater dated at 2 to 7 ky BP could be a remnant from the period when the plain was under sea level. The presence of the $Na\text{-}HCO_3$ type of groundwater indicates the aquifers are under a late stage of fresh water flushing. Possibly the age interval of the groundwater may be related to a period of wetter climate that appeared after 7 ky BP (Rolph et al., 2004).

A crucial issue is the hydraulic connection between the alluvial cone and the two pumping stations in the plain where 0,8 m^3/s respectively 0,4 m^3/s are extracted. The sulphate concentrations are elevated in the river or about 20 mg/l and most of it originating from sulphide oxidation from copper mines and smelters upstream. As the $\delta^{34}S$ ($^{34}S/^{32}S$ ratio) is close to 0‰ in sulphides and clearly differs from that in sea water ($\delta^{34}S$ = 21‰) or in sea spray ($\delta^{34}S \sim$ 15-17‰) it was considered possible the assess the fraction of water in the pumping stations coming from the river and the alluvial cone and from the seaside to the west by stable sulphur isotopes. The values for the fresh groundwater samples indicate a mixture of rainwater sulphate and sulphate from sulphide oxidation. The pumping stations thus appear to be completely fed by river water as per the sulphate isotope results.

The heavy metals leached from the copper mines and the smelters upstream have made an imprint in the sediments leaving elevated copper, chromium and nickel concentrations but due to the stable and high pH, mirroring the limestone-dolomite in the catchment this does not comprise a problem for the groundwater quality. In addition to carbonate rocks the copper ores are hosted in ophiolitic structures built up by mafic and ultramafic rocks (Economou-Eliopoulos et al., 2008) also providing good buffering towards acidification by sulphide oxidation. However, the most polluted sites should be identified and remediated.

The most immediate threat to the recharge is the gravel extraction in the alluvial cone at the entrance of the river Mati into the plain. This will decrease the head of the groundwater at the recharge area which today is situated about 10 to 20 m above the sea level. The risk for clogging of the sediments exists as well and finally the risk of oils spills from the bulldozers and digging machines. The soil erosion in Albania is considerably high (Grazhdani & Shrunka, 2007). This is another threat to the recharge as the suspended load is very high in October and November. However, the soil erosion is lesser in Mati river catchment then elsewhere in Albania and the reservoirs mentioned above act as sinks for the suspended sediments. As is evident from the sulphur isotope results the groundwater extracted in the well fields is more or less completely derived from the river recharge.

ACKNOWLEDGEMENTS

We are thankful to colleagues at the Albanian Geological Survey, notably the Director Prof. Dr Adil Neziraj and Dr Arben Pambuku. We are also thankful for the support from Swedish Environmental Agency.

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abstract id: **446**

topic: **2**
Groundwater and dependent ecosystems

2.3
Interactions of surface and ground waters

title: **Groundwater-surface water interaction: insights from a lowland Chalk site in the UK**

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keywords: groundwater-surface water interaction, chalk, UK

An understanding of the processes controlling groundwater-surface water interaction is essential for the effective management of water resources and for the protection of sensitive ecosystems. The Chalk is an important European aquifer and occurs in a number of countries around the southern North Sea. In the United Kingdom the Chalk aquifer forms the country's most important groundwater resource and in south-east England many streams and rivers are substantially supported by groundwater flow from the aquifer. It is important therefore to understand the mechanisms of groundwater-surface water interaction in Chalk-fed watercourses.

For several years the British Geological Survey has undertaken a study of groundwater-surface water interaction at a valley-bottom site situated on the Chalk aquifer on the River Lambourn in Berkshire (Allen et al., 2010). At this site the river flows over fluvial gravels underlain by Chalk and investigations of the hydraulic system have involved boreholes, riparian and river bed piezometers and have employed a combination of hydrophysical and hydrochemical techniques. The investigations have shown that the pattern of interaction between groundwater and surface water at the site is complex.

A 3-D geological model of the site was constructed, based on a combination of surface geology and borehole logging data. This model provided a framework for the ensuing conceptual hydrogeological model, which utilised physical hydraulic and hydrochemical data.

Potentiometric data from piezometers, boreholes and a stilling well indicated that the direction of groundwater flow in the Chalk at the site follows the regional trend; however Chalk groundwater apparently flows under the river with little interaction with it, and probably discharges to the river further downstream.

Hydraulic heads in the mainly gravel alluvium underlying and bordering the river indicate the presence of a complex groundwater flow system. There seems to be little hydraulic connection between the gravels and the underlying Chalk over most, though not all, of the site, while the gravels appear to be broadly in hydraulic contact with the river. The alluvial groundwaters show components of flow both parallel, and transverse, to the river, with general indications of upward flow below the river bed. The relationship between bankside gravel groundwaters and the river is complex, with both influent and effluent behaviour seen.

At the study site, three reservoirs of water with potentially different hydrochemical quality exist; the Chalk, the gravel alluvium and the river. The general chemistry of these three reservoirs is similar, because all three are effectively sourced from groundwater. However local variations in certain chemical species in the gravels have enabled the movement of alluvial groundwaters to be traced across much of the site, showing flow components both parallel to, and under, the river. This has enabled the physically based conceptual hydrogeological model of the site to be substantially refined.

The conceptual model of the site has suggested that, while the gravel aquifer has a significant influence on local surface water-groundwater interaction it has limited importance as a route for down-catchment water flow compared with the discharge of the stream.

More recently, in conjunction with the Centre for Ecology and Hydrology, the studies have been extended downstream, to include wetland areas adjacent to the river. In addition to extending the hydrological monitoring array used at the initial site, these studies involve approaches such as temperature surveys and monitoring the effects of anthropogenic changes in river level on the groundwater system, in order to further investigate the nature of the flow systems at the enlarged site.

In conclusion, the investigations at the study site so far have indicated a complex pattern of interaction between groundwaters and surface waters. This has implications both for the way such systems are studied and for the implementation of regulations such as the European Water Framework Directive. BGS© NERC 2010.

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abstract id: **451**

topic: **2**
Groundwater and dependent ecosystems

2.3
Interactions of surface and ground waters

title: **Hydropower regulation impact on river-groundwater interaction and the riparian zone – a geochemical approach**

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keywords: geochemistry, pristine, Northern Sweden, Kalix River, Luleå River

INTRODUCTION

Hydropower regulation of rivers was for a long time considered to be an environmentally friendly source of energy (e.g. Renöfält et al., 2009). However, damming of rivers has later been recognized as one of the most dramatic anthropogenic impacts on the natural environment (Petts, 1984). Today about two-thirds of the fresh water flowing to the oceans is obstructed by about 40,000 large and more than 900,000 smaller dams (Petts, 1984; McCully, 1996). The zone beneath and close to the river, where most of the exchange with the groundwater takes place, is sometimes called the hyporheic zone (Boulton et al. 1998; Hyporheic network, 2009) and sometimes the riparian zone (e.g. Swanson et al. 1982). The two concepts overlap but they have different focuses; the riparian zone focus is on the river and its environment, while the focus for the hyporheic zone is on the interaction between the river water and the groundwater. From here on only the concept riparian zone is used here.

The conditions in the riparian zones differ from the conditions in the river itself and in the adjacent aquifers. Riparian zones in natural rivers are diverse, dynamic, and multi featured ecosystems that participate in the regulation and maintenance of landscape biodiversity (Dynesius, Nilsson, 1994). The extent of these zones varies with stream order, season, morphology and characteristics of the river (e.g. Curie et al., 2009). Water flow into and out of this zone is largely influenced by advective exchange between the river and the groundwater controlled by vertical and lateral channel morphology, the pressure heads of the river water and the groundwater, as well as by the hydraulic conductivity of the river bed sediments and adjacent aquifer (Wörman et al., 2002; Cardenas, Wilson, 2007). These zones provide retention of water and nutrients, physical filtration as well as cycling of nutrients and organic matter with dissolved oxygen and NO_3 reduction (Claret, Boulton, 2008).

For northern pristine rivers the normal situation is that spring snowmelt produces a distinct flow peak and that the rivers normally are gaining water from the groundwater even if shorter stretches of the river might be loosing (e.g. Johansson et al., 2001). However, in regulated rivers, stored water released during summer results in smoothing of the spring peak and a combination of low groundwater levels and high river water stages, and long river reaches will then lose water to surrounding aquifers. If also short time regulation is applied frequent river water level fluctuations cause alternating fluxes in and out of the riparian zone disturbing the natural flow (Silliman, Booth, 1992) and geochemical patterns.

The overall aim of this study is to increase the knowledge regarding effects of river regulation on riparian zone geochemistry by:

a) analysing previous measurements of river water geochemistry with respect to river-groundwater exchange for the regulated Luleå River and the pristine Kalix River,
b) measuring a one-year cycle of riparian groundwater and river water quality for the same rivers.

This paper is focused on aim a) and initial findings from the measurements presented.

MATERIAL AND METHODS

A comparison between the geochemistry of two northern Swedish rivers, the heavily regulated Luleå River (2000–2001) and the pristine Kalix River (1991–1992) with otherwise similar features (geological settings and climatic conditions) has already been conducted, but not fully analysed. The Luleå River comprises 15 reservoirs where 72% of the annual river runoff can be stored (Dynesius, Nilsson, 1994) and has been regulated for almost a century. The Kalix River, the last major unregulated river in Europe, was used as a reference even if the flux in this river is slightly lower. The sampling methodology was similar in the two studies, thus permitting comparison. The only difference was in the filtered phase sampling, with filter pore sizes of 0.22 µm and 0.45 µm for the Luleå River and the Kalix River, respectively.

Monitoring of effects of river water geochemistry on riparian zone processes has started for both rivers in spring 2010. Sampling sites in the rivers were chosen approximately 100 km upstream of the river mouth (Fig. 1).

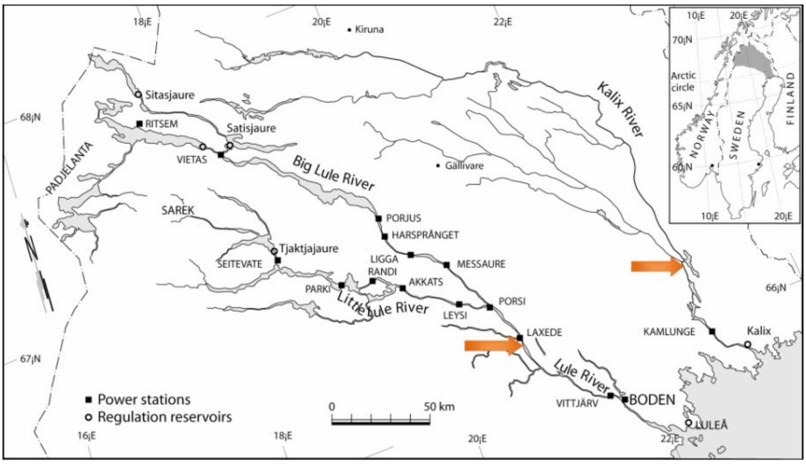

Figure 1. River catchments and location of monitoring stations for previous (Boden and Kamlunge) and present (shown with arrows) studies (modified after Drugge, 2003).

Monitoring at the two sites was made in the river and in two groundwater wells located orthogonal to the rivers, equipped with data loggers recording water levels, temperature, pH, specific conductivity, dissolved oxygen (DO) and oxidation-reduction potential (ORP) (Fig. 2). The well nearby the river is located close to the shore while the other tube is about 20m away. Water quality measurements both in the rivers and in groundwater wells were preformed using the in-situ Hydrolab MS5 Multiprobe. Water samples filtered through 0.45 µm filter were taken weekly or bi-weekly for metal and nutrient analyses. Analyses for Ca, Mg, Na, K and S in the dissolved fraction were determined using inductively coupled plasma atomic emission spectroscopy (ICP-AES), while ICP mass spectrometry (ICP-MS) was used for the other elements. Ion chromatography was utilized to obtain Cl, NO_3, NH_4 and PO_4 anion concentrations. Hydraulic conductivities at the sites will be determined from soil samples.

River groundwater interaction along the reaches in the sampling areas will also be studied using field seepage meters (Rosenberry, 2008).

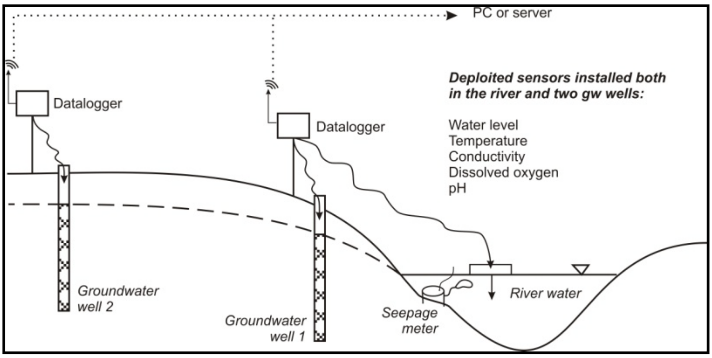

Figure 2. Schematic illustration of groundwater and river water measuring equipment.

RESULTS AND DISCUSSION

The previous study by Drugge (2003) showed, as expected, that water storage in reservoirs influenced the seasonal water discharge (truncated and postponed spring peaks, increased base flow). For the pristine river the highest conductivities were found for the lowest discharges (Fig. 3a) indicating a large content of groundwater in the river water during low flow conditions (base flow) while for the regulated Luleå River it was hard to find any obvious explanation for the conductivity discharge relationship (Fig. 3b). This suggests that the geochemistry of the regulated Luleå River is strongly influenced by the mixing of river water and groundwater in the riparian zone.

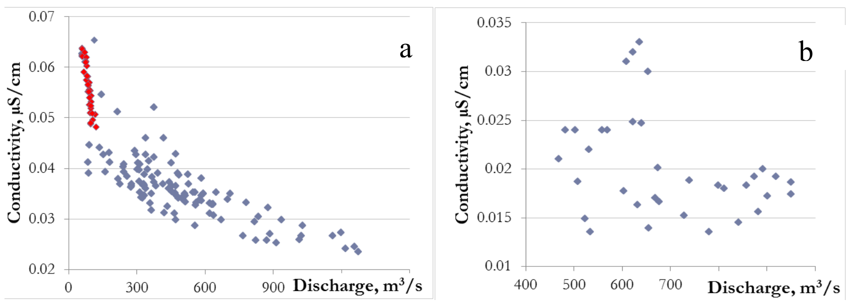

Figure 3. Discharge versus conductivity in the Kalix and Luleå Rivers (Drugge, 2003).

If similar geological and hydrological settings in both rivers can be assumed, the observed reduction in the transport of Ca, Fe, Mn, Na, S, and Si (Fig. 4) can be attributed to sedimentation in the reservoirs, and the smaller variations in element concentrations in the regulated Luleå River, to the reduced seasonal discharge variations in the regulated river (Drugge, 2003).

Judging from the observed differences in river water quality between the regulated and the natural river (Figure 3 and 4) the groundwater quality of the riparian zone in the regulated river has also been affected (Drugge, 2003).

The first results from the 2010 sampling campaign showed increasing specific conductivity with distance from the river for the Kalix River and a slightly reduced riparian zone in comparison with the river water and the reference well 2 (Figure 5).

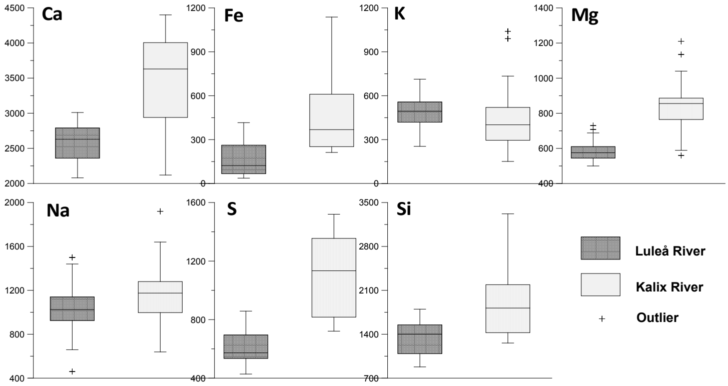

Figure 4. Dissolved element concentrations (μg/l) in river water for Luleå and Kalix Rivers measured in Boden and Kamlunge (modified after Drugge, 2003).

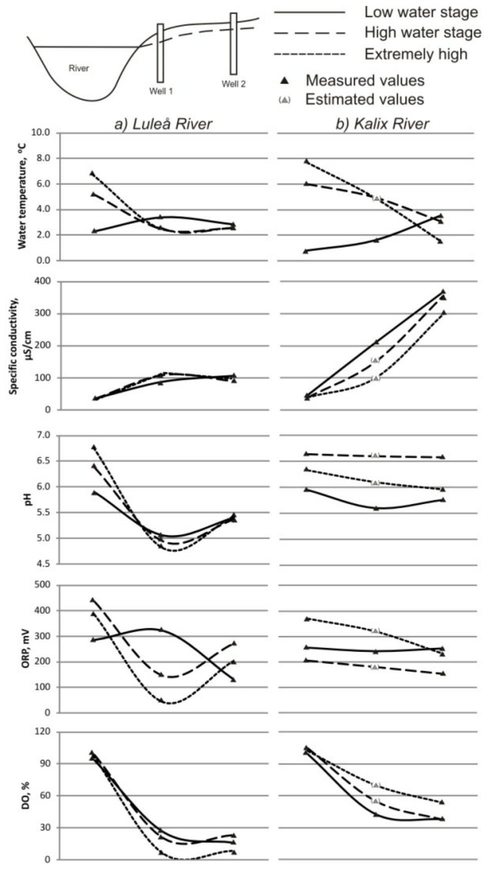

Figure 5. Geochemical profiles (water temperature, specific conductivity, pH, ORP and DO) of the Luleå and Kalix Rivers including their riparian zones, for low, high and very high water stages. Note: For the Kalix River only low water stages were measured in Well 1, so the high and extremely high values in this well were estimated.

This corresponds with the results obtained by Bourg and Bertin (1993). The reduced zone in the Kalix River shows decreased pH values, slightly lower redox potential, as well as dissolved oxygen concentration.

Although the general pattern in the Luleå River was rather similar, some important differences were found. Considerably lower pH (4.8–5.0) and conductivity values were registered in the riparian zone and it showed different pH patterns along the profile as well. In the Luleå River conductivity in Well 2 was three times higher than in the river, while in the Kalix River the groundwater conductivity in Well 2 was 10 times higher. This suggests continuous mixing of the Luleå River water with riparian waters due to river water level fluctuations. In the vicinity of the Kalix River decreased conductivity in both wells during high water stages testifies turning of the reach at spring flood into a loosing one. ORP and temperature patterns in the riparian zone are affected by short term regulation in the Luleå River as well.

The riparian zone plays a key role in river water DOC balance, since it is a major source of DOC in boreal rivers together with water from adjacent mires (Drugge, 2003). In the Kalix River, DOC originates mainly from the riparian zone during winter base flow conditions, and is extensively flushed out during the spring flood. In contrast, the Luleå River doesn't show any pronounced annual variations in DOC concentrations. We assume changes in geochemistry of adjacent areas and alteration of riparian processes under regulated conditions. A new monitoring program in the riparian zone will increase our understanding of these modifications. We expect DOC concentrations to be naturally lowered in the riparian zone due to its bacterial degradation and oxidation by easily available O_2, NO_3 and other electron acceptors.

CONCLUSIONS

Hydropower regulation appears to affect the geochemistry of the riparian environment. A better understanding of processes occurring within the riparian zone will be possible with results from the ongoing sampling campaign and from further research. Major questions to be answered are the geochemical fate of redox elements in riparian zone, their correspondence with fluctuating water stages and major differences with pristine conditions.

ACKNOWLEDGEMENTS

This research is part of the pan-European project GENESIS and the authors of this paper would also like to express their gratitude to The Kempe Foundation, who provided financing for the measuring equipment.

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abstract id: **458**

topic: **2**
Groundwater and dependent ecosystems

2.3
Interactions of surface and ground waters

title: **The piston model of groundwater recharge**

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keywords: infiltration, piston model, vadose zone

ABSTRACT

An extension of the Green-Ampt model for the case of infiltration with varying water contents above the wetting front has been presented in this paper. Both increase and decrease of soil water contents caused by changes in supply of water at the surface were considered. The presented model uses a balance approach and in this way evades the problem of soil moisture hysteresis. The theoretical considerations are illustrated by two examples. One of them enables comparison of results obtained using the piston model with a numerical solution of the diffusion equation which takes the hysteresis into account. The second example shows typical solution cases.

INTRODUCTION

Interaction between surface and ground water has usually been modeled using a discrete model of flow in aeration zone. If even the applied model is one-dimensional (vertical cylinder) it is seriously complicated because of the spatial distribution of parameters. A large number of detailed data on infiltrating stream is however needed by the model. In case when we are interested in general groundwater movement rather than in infiltration itself it becomes uneconomical to use the full model. In this case a model which would supply only a couple of most important data but which would be simpler in use, is much more needed. It has however be able to describe a fully unsteady process. The above conditions are met by the piston model of infiltration.

ASSUMPTIONS FOR THE PISTON MODEL

Varying intensity of rainfall may cause increase or decrease of soil water content behind the wetting front. This process could be expressed by a simplified piston model with only a few variables describing the moisture content. A relative stable moisture profile connected with a wetting front that moves without shape changes – like a piston, is adopted in the model. Only two variables are necessary for description of a single front motion – the position of a front z_f and water content behind the front θ_z. In an unsteady model several wetting fronts may appear and each one is characterized by a pair of variables (z_i, θ_i). Before a head of each wetting front water content θ_{i+1} corresponds to the previous wetting front of z_{i+1} position. Just before the lowest water front there is only the initial water content θ_o . Water content above each water front remains stable while a front position changes continuously. Moisture changes may occur behind the highest front only, hence a successive wetting front is described by *j* index.

To simulate changes of water content the classical Green-Ampt model for a sharp front is applied together with the piston model of unsaturated infiltration and the Morel-Seytoux model of moisture redistribution.

Front velocity

While fronts are balanced one can determine velocity of their movements and then their present positions. This contributes to a general spatial picture of a soil water content distribution (Figure 1). Regardless of the kind of a motion front velocity v_f is calculated from the following water balance:

$$v_f = \frac{v_{i,j} - k(\theta_{i+1})}{\theta_{i,j} - \theta_{i+1}} \tag{1}$$

In result of redistribution water content behind the first front θ1j may decrease. In case of its disappearance its function and features are overtaken by the preceding front. This means in particular that since then the corresponding water content may change again.

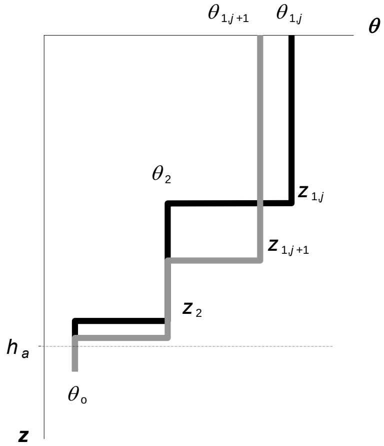

Figure 1. Water budget for two wetting fronts.

Velocity of infiltration v_{ij} for the first front is determined on the basis of pluviometric data and only after the surface is sunk it is limited to the soil infiltration capacity. For the following fronts this velocity is equal to unsaturated hydraulic conductivity behind a wetting front $v_{ij} = k_i$, which is constant for constant water content after a wetting front. It can be derived from equation (1) that velocities of all wetting fronts are different and they allow to calculate positions of fronts after Δt time interval:

$$z_{i,j+1} = z_{i,j} + v_f \; \Delta t = z_i^{\,j} + \frac{v_{i,j} - k(\theta_{i+1})}{\theta_{i,j} - \theta_{i+1}} \Delta t \qquad (2)$$

Infiltration after increase of rainfall intensity

During intensive rainfalls water almost entirely drives air out of soil and maximal moisture content θ_n is reached. On the other hand velocity of infiltration cannot exceed soil infiltration capacity (Green, Ampt, 1911):

$$v_g = k_n \left(1 + \frac{h_g + h_k}{z_{i,j}} \right) \qquad (3)$$

All the rainfall surplus $v_{r\,j}$ above this value remains on the land surface and makes surface run-off. Rainfall capacity smaller than soil infiltration capacity entirely infiltrates. Until recharge drops below hydraulic conductivity $v_{r\,j} \geq k_n$ the full soil saturation is kept while supply velocity changes together with rainfall intensity $v_z = \min(v_{r,j}, v_g) = v_{1j}$ as well as a wetting front velocity v_f.

In case water supply $v_{r\,j}$ does not make soil fully saturated, for a constant moisture (piston model) a hydraulic gradient is equal to 1 behind a wetting front. Hence soil unsaturated conductivity k reaches the value of infiltration velocity and this enables to calculate moisture content after a wetting front (Bouwer, 1976):

$$\theta_{1,j} \Leftarrow k(\theta_{1,j}) = v_{r,j} \tag{4}$$

With the previous partial saturation of the upper soil layer each increase of water supply $v_{r\,j}$ generates appearance of a new wetting front of moisture $\theta_{1j}(v_r)$ calculated from equation (4). However these fronts move with different velocities v_f.

Infiltration after decrease of rainfall intensity

When precipitation exceeds soil infiltration capacity (eq. 3) the decrease of water supply intensity has no direct and considerable impact on infiltration. Small changes of infiltration velocity may be caused by changes of water depth h_g on a ground surface. Only after supply intensity drops below soil infiltration capacity (but for $v_r > k_n$) velocity of infiltration changes together with water supply velocity ($v_{1j} = v_r$) and a wetting front velocity changes respectively. In these both cases moisture after a wetting front remains maximal ($\theta_{1j} = \theta_n$).

For rainfall intensity lower than soil infiltration capacity ($v_r < k_n$) the decrease of water supply v_r causes negative budget of a surface layer up to the nearest wetting front since its velocity does not change at first (Morel-Seytoux, 1984). Front transition that can be then calculated results in decrease of moisture after a wetting front (Figure 1) as well as front velocity but these changes are slow. So, equation (1) can be still approximately used and a front position $z_{1,j+1}$ is calculated on the basis of the value of previous moisture $\theta_{1,j}$ (Charbeneau, 2000):

$$z_{i,j+1} = z_i^{\,j} + \frac{k(\theta_{1,j}) - k(\theta_2)}{\theta_{1,j} - \theta_2}\Delta t \tag{5}$$

At the end of time step Δt humidity is equal to:

$$\theta_{1,j+1} = (v_{1,j} - k_2)\frac{\Delta t}{z_{1,j+1}} + (\theta_{1,j} - \theta_2)\frac{z_{1,j}}{z_{1,j+1}} + \theta_2 \tag{6}$$

In result of humidity decrease velocity of a wetting front gradually drops down until the balance is reached again or a new wetting front appears.

Propagation of a wetting front

Despite of a water supply regime, fronts move down and are exposed to wetting process. It is possible that in a given soil column several fronts exist simultaneously which is caused by changes of water supply intensity. Each higher front is more humid and in consequence it moves with higher velocity. As an exception velocities of fronts may equalize or even an earlier front may move faster. However, most often the difference between velocities leads to superposition of fronts (Książyński, 2007).

Creation of a new front. Each increase of water supply in condition of partial saturation leads to appearance of a new front. This front (no 1) has the initial position $z_{1j}=0$ and it is described by the water content behind a front θ_{1j} calculated from equation (4). Further changes of these parameters undergo principles presented above and they depend on varying conditions of water supply. Numbers of other fronts are then increased by 1 but their water content is stable since then.

Superposition of fronts. If two consecutive increases of water supply take place and in consequence moisture changes from θ_{i+1} to θ_i and then to θ_{i-1}, the mentioned difference in velocities of fronts makes the first front reach the second one ($z_{i-1} \rightarrow z_i$) in a given time period. Humidity equalizes at the θ_{i-1} level and because of increase of soil infiltration capacity ($\theta_{ij+1} > \theta_i$) the front velocity drops down. As to ensure balance conditions the calculated positions of fronts z_i and z_{i+1}($<z_i$) should be substituted by positions z_i' ($z_{i+1} < z_i' < z_i$):

$$z'_{i,j+1} = z_{i+1,j+1} + \left(z_{i,j+1} - z_{i+1,j+1}\right)\frac{\theta_i - \theta_{i+1}}{\theta_i - \theta_{i+2}} \tag{7}$$

It can be noticed that the wetting front i+1 disappears and the numbering of others will be decreased by 1. This enables to use this vacant number in further calculations and keep continuity of numbering.

Spread of a front. It may also happen that the first front dissolves and its water content becomes equal to water content of the previous one. Such situation is signaled when moisture θ_{1j} calculated from (eq 6) is smaller than θ_2. This means that the water content of fronts reached the same level and the first front joined up the second one which since then may have negative balance and may diminish its moisture. Since the first front disappeared the numbering of others will be decreased by 1. Moisture θ_{1j+1} is calculated according to following formula:

$$\theta_{1,j+1} = \left(v_{1,j} - k_2\right)\frac{\Delta t}{z_{1,j+1}} + \left(\theta_{1,j} - \theta_2\right)\frac{z_{1,j}}{z_{1,j+1}} + \left(\theta_2 - \theta_3\right)\frac{z_{2,j}}{z_{1,j+1}} + \theta_3 \tag{8}$$

Numbering of fronts on the right side of the equation corresponds to numbering before the fronts are joined.

Changes in groundwater supply

Groundwater recharge is connected to accretion of a wetting front on the upper edge of a capillary fringe $z = h_a$.. Such approach enables to avoid complex calculations of time- and depth-dependant velocity of infiltration. Amount of water reaching an aquifer is then equal to water amount in this part of a moisture profile which passed into a capillary fringe in a given time interval.

Intensity of groundwater recharge. For the calculation of recharge a balance of wetting fronts volume, which at that time step migrated below the border line has been used. After the calculation of every time step the location of fronts is reverted to the border $z_{ij} = h_a$, and so the volume absorbed by groundwater in the next step can be easily specified as:

$$h'_{V,j+1} = \sum\left(z_{i,j} - h_a\right)\left(\theta_i - \theta_{i+1}\right) \tag{9}$$

and positive sum components are included. Basing that, the average supply rate of groundwater can be calculated as:

$$w_{j+1} = \frac{h_{V,j+1}}{\Delta t} = \frac{1}{\Delta t}\sum\left(z_{i,j} - h_a\right)\left(\theta_i - \theta_{i+1}\right) \tag{10}$$

Infiltration velocity through vadose zone. It is easier to assess infiltration velocity at a depth below the surface. If the first (the highest) wetting front did not reach yet a level for which the velocity is calculated, this one corresponds directly to conductivity value $k(\theta_i)$ for the local moisture content but just above the first front moisture changes decide about the velocity. When local moisture θ_{1j} does not vary, infiltration velocity is equal to the the surface supply v_z. In the case of moisture redistribution infiltration velocity increases linearly from the surface to the first wetting front, according to the formula:

$$v = \left(1 - \frac{z}{z_f}\right) v_z + k(\theta_d) \frac{z}{z_f} \tag{11}$$

Exemplary calculation

To illustrate typical phenomena occurring during unsteady infiltration the velocity changes course at different depths were calculated for a specially selected rainfall distribution. The intensity of precipitation in the first hour was 7.2 mm; in the second hour it increased to 14.4, and in the third dropped down to 3.6 mm. Another event occurred after 2 hours break and gave within one hours again 7.2 mm of water, after which rain stopped. The process run in the sandy soil of conductivity for full saturation k_o = 10.8 mm/h, that corresponds to the moisture θ_n=30%, capillary height h_k= 12 cm, initial moisture θ_o= 0.5% and conductivity characteristics described by Irmay-Avierjanov formula (Averjanov, 1950) (power exponent m_k=3.5, residual moisture content θ_r =0).

Figure 2 presents redistribution of moisture content, computed with the help of the piston model.

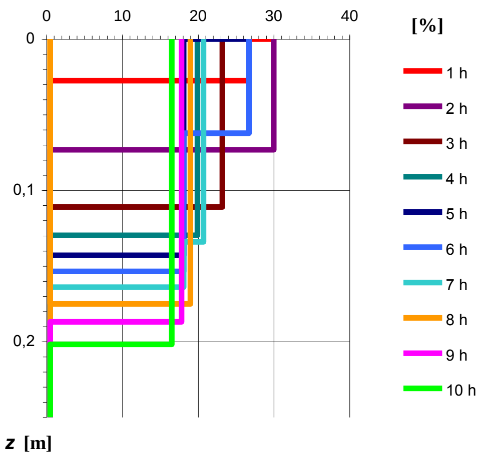

Figure 2. Simulation of moisture distribution during unsteady infiltration according to the piston model.

After two hours a new front appeared resulting from the increase in rainfall intensity which absorbed already the old one and only one fully developed front of water content θ=30% remained. To the fifth hour the moisture redistribution supplemented by too low or zero surface recharge is visible. But in the sixth and seventh hour of the process two wetting fronts occur simultaneously — lower with moisture frozen by the next front at level of 18.1% and the higher with full saturation, above which moisture redistribution takes place. The fronts undergo superposition near the end of eighth hour and further redistribution runs already inside one front zone.

Particular plots in Figure 3 present infiltration process on different depths beneath the surface of the soil computed in 15min. intervals. A wetting front achieves the depth of 3 cm after ca 10 min. from its appearance, which means more than 1 hour's delay. Variety of moisture content causes fluctuation of recharge and disappearance of precipitation only is followed by gradual regression. On the depth of 10 cm infiltration appears after more than three hours, evident flattening of hydrogram is observed. On the depth of 20 cm only one wetting front occurs, gradually declining in the soil.

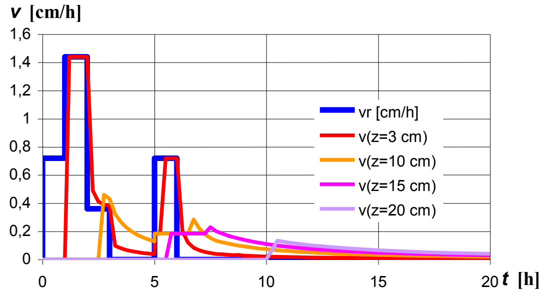

Figure 3. Process of unsteady infiltration according to piston model.

In Figure 4 process of infiltration obtained from the grid model simulation is presented for comparison.

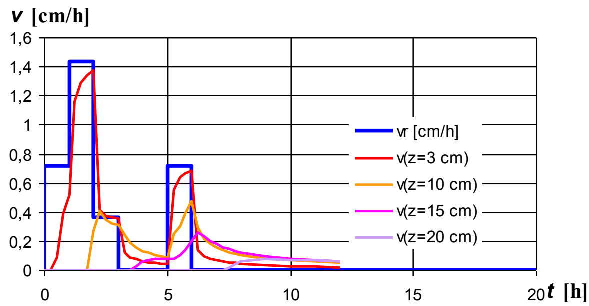

Figure 4. Process of unsteady infiltration according to the discrete model.

CONCLUSIONS

The presented model is a useful tool enabling to determine in an easy way time-dependant groundwater recharge for many soil profiles (Figure 2). Good model results make the model recommendable for simulation of groundwater supply.

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abstract id: **469**

topic: **2**
Groundwater and dependent ecosystems

2.3
Interactions of surface and ground waters

title: **Managing groundwater resources linked to perennial and non perennial streams: Santa Coloma River Basin, Girona, Spain**

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keywords: aquifer-river interaction, Santa Coloma River, verifying conceptual, numerical flow modelling

SUMMARY

Hydrological relationships between surface and groundwater are crucial in alluvial aquifers, both for management purposes and with the aim of accomplishing the objectives of the Water Framework Directive. This paper presents a numerical flow model that considers a river-connected alluvial aquifer in Catalonia, NE Spain. The model mass-balance shows the dual gaining/losing character of the Santa Coloma River and the relevance of the drains in a wetland area, which account for a significant percentage of groundwater withdrawn from the alluvial aquifer. The model also points out the role of "extraction" associated with phreatophytic plants in reducing surface flow rates, especially during summer and droughts. A good understanding and quantification of the river-alluvial relationship helps to determine the best actions in order to promote conjunctive use (groundwater-surface water) whilst preserving fluvial ecosystems.

INTRODUCTION

The Water Framework Directive (WFD, Directive 2000/60/CE) is essentially an environmental norm, which seeks the good ecological status for all European waters. Among the distinct groundwater bodies, managers are especially concerned with alluvial aquifers because of their relationship with stream hydrology and ecology. Given the objective of reaching the good ecological status for surface streams, hydrogeologists claim that assessing the hydrological stream-aquifer mass-balance should be a must.

In order to accomplish with some of the requirements of the WFD, the Catalan Agency of Water (the Agency), as a regional authority responsible for water management and planning, has drawn up the Environmental Flows Plan in the Inner Catalan basins (PSCM, 2006). This plan establishes the necessary environmental flows to fulfill a good development of fluvial ecosystems and imposes restrictions on water users. In this context, the Santa Coloma River (SCR) poses a challenge to PSCM's implementation due to the difficulty to guarantee ecological flows in the latest dry periods.

According to the importance of groundwater in river-connected systems, the Agency has carried out several studies in SCR alluvial aquifer in order to reverse the current trends and to meet environmental goals as well. Probably, the main step consists of estimating the system water budget, including the details of stream-aquifer fluxes. This is far more necessary in dry seasons when the availability of water resources is lower and water demand higher, and it exists a lack of external water supplies.

A third factor to be considered is the need to ascertain the most appropriate conceptual model of the stream-aquifer system. Issues such as a difficult geological context, the lack of information on hydrogeological flows, the historic construction of draining channels, the uncertainty about some pumping rates, and the inherent complexity of stream-aquifer interactions explain some of the discrepancies found in the preliminary studies performed up to now.

All these reasons explain the decision taken by the Agency, in collaboration with other institutions, to build-up a reliable conceptual model of the SCR aquifer that has been translated to a numerical model capable of quantifying groundwater flows between the stream and the aquifer. Our final goal is to identify the factors, and their magnitude, that control such processes as a mean to improve water management in these locations within the WFD goals of environmental preservation and sustainability.

GEOLOGY AND HIDROLOGIC CONTEXT

The SCR hydrographic basin (270 km²) is located in the Guilleries range, within the Selva basin (Catalonia, NE Spain) in a range-and-basin setting formed during the Neogene period (Fig. 1). In particular, the SCR main course follows a main tectonic line, i.e. the regional fault zone in the geological contact between the Guilleries range and the Selva basin.

The Selva basin aquifer systems presents a sedimentary infilling that took place during its tectonic evolution. Sedimentary materials (mainly sand and silt layers) may reach a thickness of more than 200 m in this area, and behave as a multilayer aquifer with intergranular porosity. Along its course, the SCR shows a quaternary alluvial belt with an average width of 1.3 km and a depth of 15-20 m. In its lower part, the SCR joints the Sils channel, which collects the eastern drainage network of the basin. Due to its tectonic setting and geomorphological evolution, the Sils channel sedimentary formations are about 5-m thick and develop in flat areas that have permitted the recent recovery of part of the original wetlands. The Guilleries range is mainly constituted by igneous rocks, with a weathered horizon at the surface. Its porosity is due to fractures except in its most weathered parts.

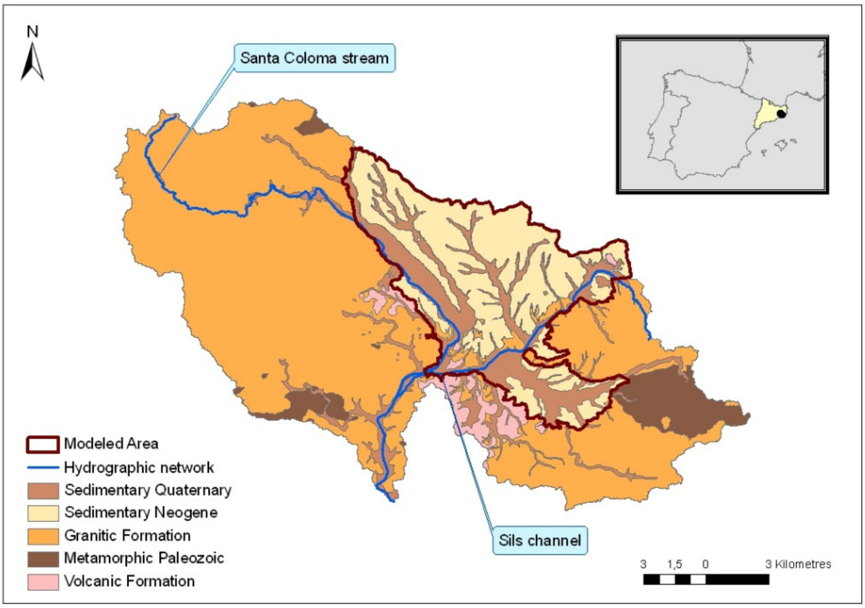

Figure 1. Aquifers of the Santa Coloma river basin and modeled area.

The hydrogeological behavior of this system is complex and characterized by both local flow systems, whose recharge areas are on the hills within the Selva Basin itself, and regional flow systems, which are recharged in the nearby ranges in the NW (Guilleries, Transversal mountains) and discharge through the main fault zones (Folch, 2010; Menció, 2006). A previous study pointed out the fault zone (Folch, Mas-Pla, 2008) influences on the recharge of the sedimentary infilling in this area.

The SCR is an affluent of Tordera River. The fixed measuring gauge is just at the end of the basin, before their confluence. The average flow is 1.26 m³/s during the period comprised between January 2003 and May 2009 (Fig. 2). Surface discharge varies much seasonally, and often is well below the defined environmental flow (0.243 m^3/s) in summer. The lack of minimum flows was particularly serious during the last drought (spring of 2007 until summer 2008), when measured mean discharge was under 0.304 m^3/s and 0.365 m^3/s in autumn and winter, respectively (PSCM, 2006).

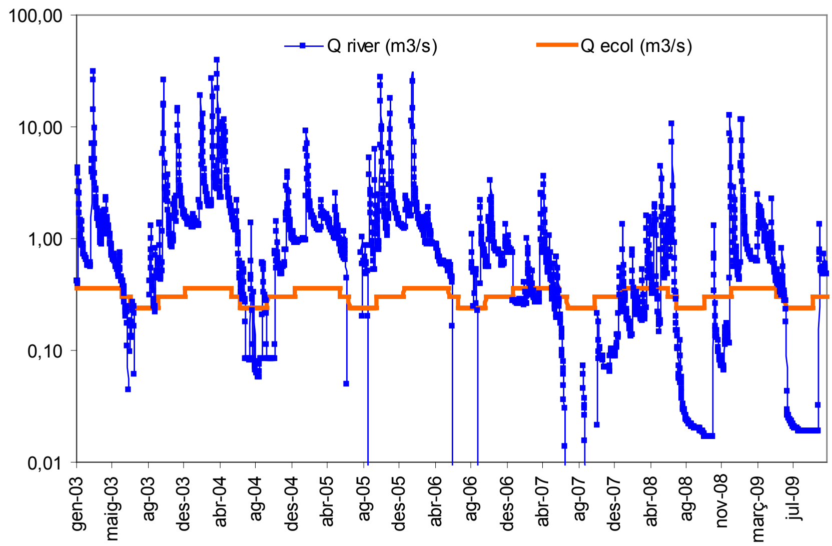

Figure 2. Measured SCR flows (Q river) and calculated environmental flows (Q ecol), in m^3/s.

Apart from the two perennial streams called SCR and Sils channel, there are also non-perennial streams that contribute to the surface drainage.

METHODOLOGY

The conceptual model has been based on existing geological and hydrogeological information derived from previous work, including 12 hydraulic head data surveys starting on 2002. Additionally, two new field surveys were conducted in the framework of this project to increase and update potentiometric data of the alluvial and upper (< 30 m deep) neogene formations. Hydraulic head data loggers were used to estimate transmissivity parameters. As hydrological data, the difference between monthly rainfall and evapotranspiration rates (calculated from land-use and crop distribution) was estimated.

In order to investigate flow relationships between the uppermost hydrogeological units (up to 30 m depth) and the stream-connected alluvial, as well as assessing the water mass balance, a groundwater flow numerical model was developed using the Visual Modflow 4.3 platform (Schlumberger Water Services).

Quantifying groundwater abstraction is usually a hard task. In this model, pumping from the superficial aquifers has been estimated at 4.00 hm^3/yr: 1.30 hm^3/yr for urban water supply; 2.30 hm^3/yr for agricultural demand, which was obtained by means of specific coefficients for the distinct crop types in the area; 0.06 hm^3/yr for cattle-rising water demand, and 0.34 hm^3/yr

for industrial demand. Also, evapotranspiration due to phreatophytes was considered in the model, and included as negative recharge (-1.21 hm^3/yr). Finally, returns from waste water treatment plants (3.50 hm^3/yr) were included as injection wells at the nearest cells of the drainage network.

Distinct types of boundary conditions were implemented in the model, as follows: 1) prescribed head at the lower reach of the alluvial formation; 2) prescribed flow to cells located in the upper reaches of the alluvial formations representing groundwater flow from the upper part of the basin; 3) general head boundary (GHB) at part of the southwest boundary, coinciding with the tectonic contact with the igneous rocks of the Guilleries range, in which a head representing an average value within the mountain area is prescribed[7], together with a conductance parameter that can be approximated using hydraulic conductivity data from the igneous rocks. This GHB condition intends to account for fluxes coming from the weathered granite as well as the contribution of the fault zone to the nearby alluvial formation; 4), a no-flow boundary has been defined upon the neogene materials in the northern hydrographic limit of the SCR basin that acts as a water divide with the surrounding basins, and also on those limits whose hydraulic conductivity is very low; 5) the Modflow "River" boundary condition was applied to the SCR main stream; 6) the so-called "Drain" boundary condition was assigned to the Sils channel, to non-perennial streams as well as to all the main drains in the wetland area. Final conductance values at the base of the river and drains were refined through calibration.

A steady-state simulation was conducted to set-up the initial conditions, as compared to field data. The transient simulation covers a 6.5 years period, from January 2003 to May 2009.

RESULTS

Results from different simulations are consistent with the observed head distribution and give acceptable water balance error (<0.003 %). Simulations also point out the relevance of rainfall recharge, which is especially evident during the dry years of 2006 and 2007. It is significant that the output flow from the aquifer layers (including alluvial and neogene formations up to 30 m deep) is linked to groundwater discharge to perennial (3.27 hm^3/yr) and non-perennial (14.92 hm^3/yr) streams, and only with a minor proportion to pumping wells (3.35 hm^3/yr). Nevertheless, wells have strong impacts on environmental flows in summer or droughts, which is of upmost relevance to meet the WFD goals (Tab. 1). Besides, considering phreatophytic evapotranspiration (-1.21 hm^3/yr) has an effect on groundwater-to-river discharge (0.1 hm^3/yr), yet it also reduces surface water flows by 0.9 hm^3/yr (0.3 hm^3/yr in the SCR and 0.6 hm^3/yr in drains), and also groundwater withdrawal by 0.1 hm^3/yr from aquifer storage. The influence of phreatophytes, which mostly transpire in summer, causes a 1.0 hm^3/yr reduction in surface water flow just in this period (i.e. almost 0.130 m^3/s, which is a 54% of the proposed environmental flow, 0.243 m^3/s).

Table 1. Mass-balance results for the transient simulation, in hm³/yr.

	2003	2004	2005	2006	2007	2008	2009*	Mean
Recharge In	24.21	20.85	16.32	9.31	2.87	11.36	5.89	14.15
GHB In	0.96	0.97	0.96	0.96	0.96	0.97	0.40	0.96
River leakage In	2.21	2.01	2.26	2.32	2.67	2.63	0.91	2.35
Drains In	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wells In	5.64	5.73	4.62	3.94	3.33	4.60	3.45	4.64
Constant Head In	0.44	0.42	0.44	0.44	0.46	0.45	0.18	0.44
Total Input	***33.5***	***30.0***	***24.6***	***17.0***	***10.3***	***20.0***	***10.8***	***22.6***
Recharge Out (**)	1.24	1.06	1.25	1.25	1.25	1.23	0.25	1.21
GHB Out	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
River leakage Out	3.90	4.78	3.38	3.32	2.04	2.19	1.44	3.27
Drains Out	15.84	19.14	15.48	15.66	11.64	11.78	6.79	14.92
Wells Out	3.54	2.98	3.20	3.63	3.68	3.07	0.68	3.35
Constant Head Out	1.11	1.14	1.11	1.11	1.07	1.09	0.46	1.10
Total Output	***25.6***	***29.1***	***24.4***	***25.0***	***19.7***	***19.4***	***9.6***	***23.9***
Storage Variation	***7.8***	***0.9***	***0.2***	***-8.0***	***-9.4***	***0.7***	***1.2***	***-1.3***

*.- 2009: data up to May,ç

**.- Estimated evapotranspirtaion by phreatophyte vegetation.

Calibrated conductance value is of 500 m²/day for the SCR main stream. A sensitivity analysis for this parameter is shown in Fig. 3 for a wide range of conductance values.

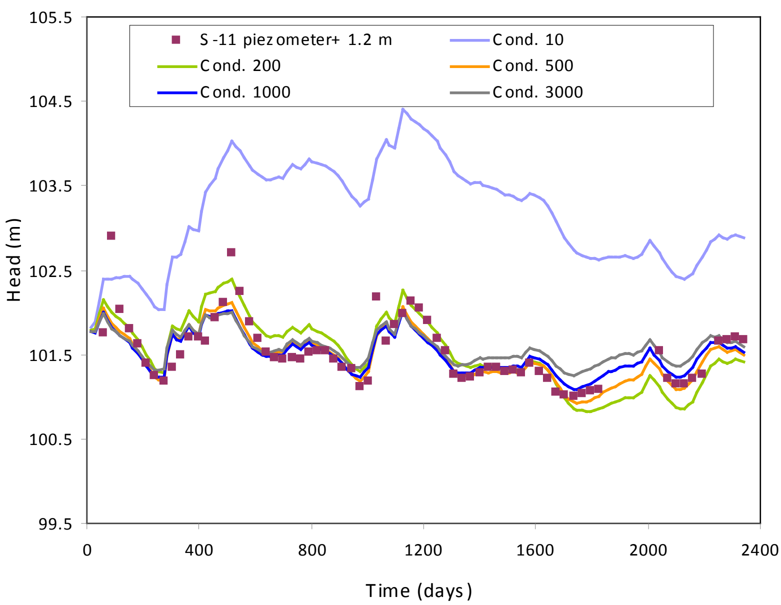

Figure 3. Evolution of piezometer S-11 (after topographic levelling in m) with different values of river conductance during the transient simulation.

The drain's conductance values vary between 5 and 80 m^2/day for the smaller and bigger drains, respectively. Drains are responsible for a 67% of the total rainfall recharge. This result suggests that both, underlying quaternary alluvial formations and neogene sedimentary layers, may contribute to the loss of groundwater resources as surface discharge.

It is also significant that, according to our conceptual model, some reaches act as "loosing stream" or "gaining stream" along the SCR. This suggests a complex behavior of the stream-aquifer relationship that needs to be locally considered. Nevertheless, drains always act as output flow boundaries which indicate an effective drainage in the flat wetland zones.

Finally, the model quantifies at 0.96 hm^3/yr the contribution of lateral and/or deep flows that are necessary to fit the observed groundwater heads and stream discharge flows. This is roughly a 3% of the total inputs to the system, but a significant percentage (74%) of the urban groundwater withdrawal which it mainly takes place in the alluvial aquifer close to this tectonic contact.

CONCLUSIONS

The numerical model shows the response of the surface (< 30m-deep) aquifers of the Santa Coloma river basin under the hydrological pressures given by groundwater withdrawal and phreatophyte plant crops. In particular, quantitative estimations of the model indicate the dual "gaining"/"loosing" character of the main stream course (SCR) and emphasize the role of drains; both river and drains account for most of the groundwater outputs. The models specifies the local effects on stream discharge, specifically in those reaches where a "loosing" stream-aquifer relationship will require detailed management strategies to minimize the impact on surface discharge. The extraction due to phreatophytes concentrates in summer, causing a 1.0 hm^3 reduction in surface water flows, i.e. more than 50% of the environmental flow. This evidences that integrated (surface-ground water) management actions should be undertaken to maintain ecological flows in the SCR basin. Moreover, urban water supply may be guaranteed, even during droughts, although further measures are needed to attain a good ecological status of the surface drainage network.

ACKNOWLEDGEMENTS

This project has been funded by the Catalan Agency of Water (codes CTN0802571 and CTN0802572). It also benefited from field data acquired within the framework of Spanish Government CICYT research Project CGL2008-06373-C03-03/BTE.

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IAH 2010 Krakow

abstract id: **483**

topic: **2**
Groundwater and dependent ecosystems

2.3
Interactions of surface and ground waters

title: **A model of long-term catchment-scale nitrate transport**

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keywords: nitrate, Water Framework Directive, groundwater solute transport, water quality, modelling

This paper presents a model of catchment-scale nitrate transport applied to a small agricultural watershed (Alton Pancras: <10 km^2) in the river Piddle catchment, Dorset UK. Historical land use and land management data are used in conjunction with estimates of typical nitrate inputs from atmospheric deposition, livestock, ploughing of permanent grassland, and the uptake due to crop growth, to estimate the net annual loading of nitrate to the catchment between 1930 and 2007. This uses a monte-carlo framework to represent uncertainty in both the size and timing associated with each input component. The estimated net-catchment nitrate-loading is then related to observed annual average nitrate concentrations at the catchment outfall (1981 to 2004) using a simple advection-dispersion analogue requiring four parameters: an initial baseline river concentration (c_b); a factor to relate each unit change in load to a change in concentration (α); a time delay (t_a) between the change in loading and the stream concentration response – the mean catchment travel time (MTT); and, a parameter to account for dispersion (P_e). A further monte-carlo analysis is used to find an optimal parameter fit.

A simple graphical translation of the median catchment nitrate loading estimate and annual average river concentration data suggests a MTT (t_a) of 37 years. The mean absolute error (MAE) reached a minimum at P_e=1418, and beyond this the MAE rises to a stable plateau of 0.26 mg/l. Estimates of α and c_b converge with increasing P_e. For this particular catchment the value of P_e suggests catchment-scale dispersion may be ignored, thus allowing model simplification such that catchment nitrate loading and stream response are related by a simple linear model.

We use the model to explore three aspects of nitrate transport in the study catchment: (1) identification of the key travel time from catchment parameters; (2) the prognosis for nitrate concentrations between 2007 and 2044; and (3) the effect of alternative loading scenarios for present and future stream concentrations.

It is shown that the mean travel time of 37 years may be strongly linked to the estimated median unsaturated zone depth of around 37 m, given previous estimates of solute transport through the Chalk unsaturated zone of about 1 m per year. The 37-year lag time between input and response enables prediction of stream concentration response up to 2044 with present data, which shows that concentrations will continue to rise until around 2020, before slowly declining. Alternative catchment nitrate loading scenarios were considered, assuming fertiliser inputs between 1930 and 2007 were cut by 25, 50, 75 and 100%, respectively. This shows two point of interest: fertiliser inputs are only partially responsible for the stream concentration rises between 1970 and the present, but the future peak in around 2017 will be almost 50% attributable to fertiliser inputs. It is noted that rises in stream nitrate concentration observed to date result from a combination of grassland ploughing, increasing animal inputs and fertiliser application, rather than solely from the latter.

Hence, policies that rely solely on fertiliser management address only around a third of the total inputs. The results demonstrate that, in groundwater-dominated catchments, MTTs are of the order of several decades, even in the smallest of watersheds. Therefore diffuse pollution strategies implemented now will not have a measurable impact on the river, in this case, for almost 40 years. Further, in this particular catchment, stream nitrate concentrations will continue to rise due to past land use and management, peaking just before 2020.

abstract id: **537**

topic: **2**
Groundwater and dependent ecosystems

2.3
Interactions of surface and ground waters

title: **Estimation of ratio of water taken by shelterbelts to total evapotranspiration**

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keywords: ecohydrology, evapotranspiration

Capitalizing on ecological knowledge that ecosystems perform various functions like altering intensity of water balance components, influencing on water chemistr***y***, modifying microclimatic conditions, sustaining biodiversity and so on, the concept of ecosystem services was developed. Using the classification of ecosystem services distinguished by the world Millennium Ecosystem Assessment (MEA 2005), the following groups of services have been distinguished:

- Basic services, pre-conditioning the existence of ecosystems through the distribution of energy streams into the production of plant biomass, evapotranspiration, warming up air and soil, permanent turnover of the matter and water in particular, and the course of soil-forming processes;
- Productive services, which condition the production of food of plant origin, wood, fibres, herbs and animal production;
- Regulatory services, which stimulate natural self-purification processes of soil, water, air, modify climate, restrict erosion, flatten flood waves, maintain biological diversity, etc.;
- Cultural (social) services, which favour economic, tourism, landscape aesthetics, education, natural inheritance, etc.

A few of the most important for human well-being are regulatory services connected with water cycling in agricultural landscape and provisioning services ensuring indispensable clean water supplies. Long term studies carried out by Institute for Agricultural and Forest Environment proved that one of the best tool for counteract negative effects of intensive agriculture is increasing of landscape structure mainly by introducing nets of shelterbelt which very effectively control and limit spreading of non-point pollution, especially chemical compounds of fertilizers and means of plant protection. Efficiency of reduction of chemical compound concentration in ground water depends on quantity of water taken by shelterbelts from saturated zone of soil. Not all transpired water used for Evapotranspiration is taken from ground water; partly is taken from unsaturated zone. The special model for estimation the ratio of water taken from saturated zone to total water used for evapotranspiration was elaborated by authors (Fig. 1.).

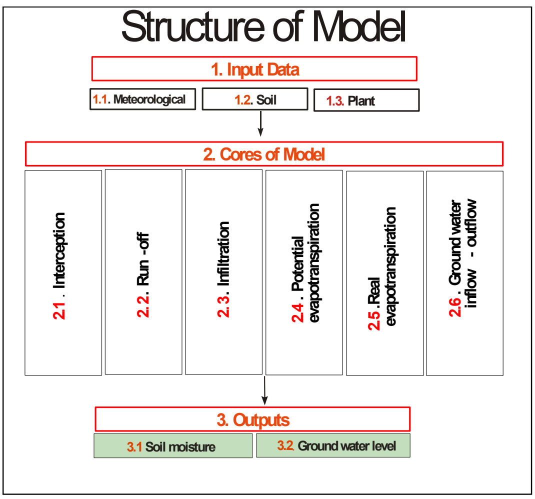

Figure 1.

The field experiment for estimation of all mathematical function need for applying the model was carried out during three years. Whole catchment can be covered by regular grid net or can be divided into quasi-homogeneous units. In the last case, land-use is the main criterion of this division. Moisture condition of the habitat is an additional criterion. Each of the plots is differentiated into levels that are homogeneous as regards soil. Regular grid net is better when rather small area is analysed. Dealing with regular grid net in very mosaic landscape composed of small fields is unusable. The model is designed to estimate:

1. Real evapotranspiration of different ecosystems on the basis of calculation of all components of developed water balance; any vertical and horizontal water fluxes
2. Proportion of water uptaken by plants from saturated zone to total water uptaken by plants.

Time resolution is one day for calculation.

The results of the experiment showed that the shelterbelt ewapotranspiration during growth period was by 40% higher then evapotranspiration of adjoining agroecosystems and the ratio of uptaken by plants from saturated zone to total water uptaken by plants is function of real evapotranspiration of shelterbelt and depth of ground water level (Fig. 2).

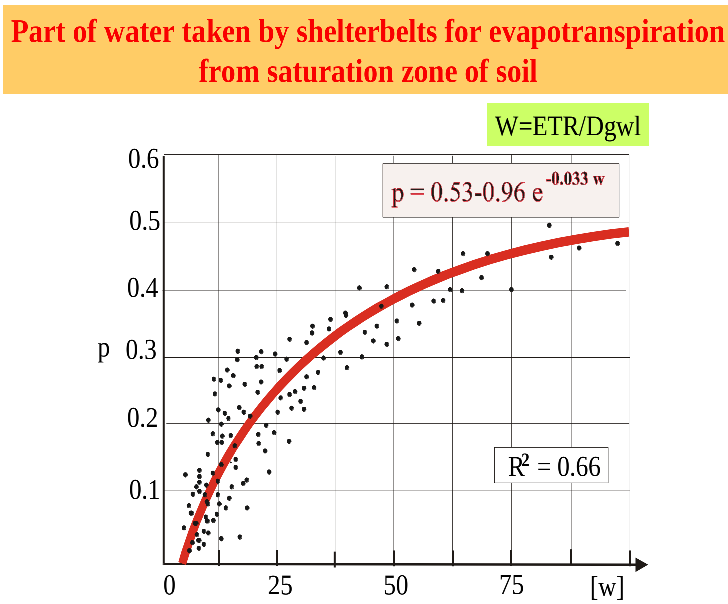

Figure 2.

Share of ground water in evapotranspiration related to weather conditions and depth of ground water level. Maximal value of this ratio reach about 50% in warm weather and shallow ground water level, while in cold weather and deep ground water level this ratio is about 30% (Fig. 3).

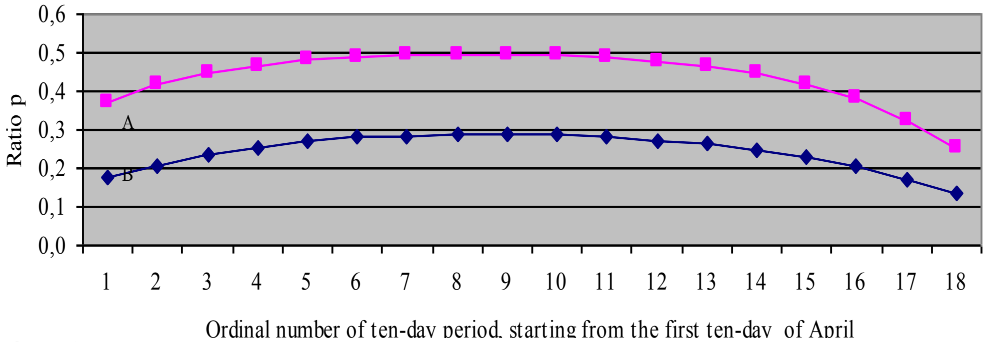
0,6
0,5
0,4
0,3
0,2
0,1
0,0
Ratio p
A
B
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Ordinal number of ten-day period, starting from the first ten-day of April

Figure 3.

abstract id: **538**

topic: **2**
Groundwater and dependent ecosystems

2.3
Interactions of surface and ground waters

title: **Ecohydrology as a key for application of systems solution for stormwater management and city strategic planning**

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keywords: ecohydrology, stormwater management

Water in the urban space has been considered up to now mostly from the perspective of water supply, sewage purification and storm water management, with increasing awareness of the necessity of freshwater ecosystems conservation. The environmental cost of this rapid urbanization includes degradation of natural resources and compacted, highly impermeable development in the city.

Most of the urban streams were channelized, converted into a combined sewerage and stormwater system in the early years of the Twentieth Century, contributing to accelerated water outflow. Such investments permanently changed the environmental conditions, reduced catchment capacity for water retention and deteriorated water resources, living environment and quality of life.

According to the Ecohydrology concept, sustainable development of water resources is dependent on the ability to control processes of water and nutrient circulation, and the energy flow at the basin scale (Zalewski et al., 2002).

Ecohydrology principles provide a new framework for urban water management where the use of ecosystem properties as an integrating management tool should serve to reduce hydro peaking, improve storm water quality and retention, and convert excess nutrients, pollutants and even sludge in to biomass/bioenergy.

New environmentally friendly approaches in the Urban Water Management include a complementary component to the success strategy – the amplification of opportunities for enhancement of the absorbing capacity of ecosystems against intensified impact.

High quality of environment and ecosystem services are important for assuring high quality of life and human health as one of the top priorities for the sustainable city development. Therefore, there is a need for a new paradigm of holistic city management. Cities needs to be considered as ecological systems, where fundamental processes such as water circulation, matter and energy flow are extremely condense (Zalewski and Wagner 2005).

Understanding flow paths of these components can help to regulate them and enhance the effectiveness of the Integrated Urban Water Management (IUWM).

The city location, catchments morphology, compacted, highly impermeable historical development and streams chanalization reduces water retentiveness in the landscape and hydrological capacity of streams. This particularly evidences during storm events, through increased peak flows in the streams and sewage treatment systems.

The efficiency of the environmental resources use in highly impacted urban systems can be increased by understanding interrelations between hydrological and biological processes subjected directly to laws of thermodynamics.

The paper presents results of research related to demonstration activities in Lodz [SWITCH Project GOCE 018530]., focused on the application of ecohydrological approach to restoration of the municipal river for stormwater management by:

- harmonization of the existing hydro-technical infrastructure with ecosystems in urban catchments;
- enhancement of the absorbing capacity of the reservoir in the Sokolowka River cascade to reduce pollution and eutrophication by adaptation of the bottom structure by using phy-

totechnology to re-allocate nutrients into the unavailable pool for water quality improvement;

- increase of water retentiveness and improvement of quality of life by adaptation Blue-Green Network concept a framework for the sustainable development of the city based on its specific hydrological situation and character of water resources.

Storm-water related issues are being tested on the Sokolowka river(average flow: 0,17 m^3/s, catchment area on the City: 39,1 km, crossing the northern part of the city and representing a typical urban storm water receiver. The main channel was regulated by concrete slabs, to straighten the course and deepen the bed for purpose of runoff detention. The river's natural flow gradually disappeared, being nowadays supplied mostly by around 50 storm water outlets. Nevertheless, the middle section of the river valley located in the outskirts of the city, has maintained semi natural character with patches of meadows, wetlands and forests made this section appropriate as a pilot area for analyses best ecohydrological river rehabilitation options.

Hydrological, physical, chemical and biological parameters monitoring of the Sokolowka river, including installation of the online flow monitoring stations, which allows for analysis of the water budget and development of mathematical model for the stormwater management especially around residential area. These results, together with the results of large-scale field experiments, allowed for designing a Sedimentary Biofiltration System for efficient stormwater purification at stormwater outflows. Its constructions enhances allocation of nutrients into un unavailable pool and prevents flushing of pollutants into the river during high flows. Appropriate shaping of its hydrodynamic and plant structure shall positively influence the growth of sedimentation and reduction of biogenes in the outflow water.

The overarching goal of all the research activities is to develop a system solution which addresses the complexity of water and water-related issues in Lodz, and help to accomplish sustainable development of the city, based on water resources and Ecohydrology as a its fundamental component.

abstract id: **543**

topic: **2**
Groundwater and dependent ecosystems

2.3
Interactions of surface and ground waters

title: **Ecohydrological system solutions to enhance ecosystem services: the Pilica River demonstration project**

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keywords: ecohydrology, ecosystem

The application of ecohydrology principles as part of Integrated Water Resources Management (IWRM) has the potential to enhance the resilience of a catchment to anthropogenic impacts. Linking this approach with an understanding of water users and social and economic conditions in a given region, provides a foundation for the development of system solutions. Improving the quality of the environment, and the ecosystem services provided, can be a driver of new employment opportunities that contribute to both the overall economy of a region and sustainability.

A methodology for ecohydrology implementation for Integrated Water Resources Management includes the following four steps: a) monitoring of threats, b) assessment of cause-effect relationships, c) development of ecohydrological methods, and d) development of system solutions (Zalewski, 2002)

Identification of threats is usually driven by stakeholder concerns and the existing and potential environmental problems they perceive. Quantification of threats requires **monitoring** of the appearance, intensity, seasonal and/or spatial dynamics of a threat, as well as the risk or costs to society (and stakeholders).

Monitoring programmes provide a basis for the identification and quantification of the **cause-effect relationships** that determine the dynamics of the threat, as well as its drivers. This step requires a close look at hydrology-biota relationships, and recognition of the impact of other abiotic and biotic drivers. Understanding cause-effect relationships can help to recognise the hierarchy of factors controlling the threat, and thresholds for the switch between the abiotic and biotic regulation, following the assumption that the abiotic ones are the primary force of ecosystem dynamics while biotic regulation may become dominant at optimal abiotic conditions (first principle of ecohydrology). Based on these results, the thresholds for the resilience (or resistance) of individual ecosystems to stress can be determined, which is necessary for enhancing their absorbing capacity (second principle).

The hierarchy of factors controlling the dynamics of a threat can be used to identify the key processes that can be controlled using **ecohydrological tools and methods** that employ dual regulation between hydrology and biota in the individual elements (e.g., for wetlands, pre-reservoirs, ecotones, floodplains, constructed systems) to improve or rehabilitate water resources in a catchment. The methods use intrinsic properties of these ecosystems such as the pulsing character of water, energy and matter flows through floodplains, high productivity of ecotone zones, enhanced sedimentation and siltation in the upper reaches of reservoirs, hydrodynamic effects on phytoplankton composition, and others. Existing hydrological infrastructure, such as dams, levees, and irrigation systems, can actually provide an advantage in lowering the costs of potential adjustments of hydrological parameters (e.g. water level regulation, water retention time, and hydroperiod at a floodplain). Dual regulation may be also employed by using new soft-constructions such as vegetated embankments for hydrodynamic control, and the reconstruction of floodplain banks for water retention control and others.

These individual methods can be synergistically linked as part of the described earlier **system solutions** contributing to the enhancement of the overall resilience of a catchment (third principle of ecohydrology), enhancing a catchments ability to provide ecosystem services (Krauze, Wagner, 2008) and improving ecological security of societies and sustainability. At this stage, the system solution should also be tested and modified accordingly, following the concepts of the adaptive management.

This approach was formulated and tested within a UNESCO-IHP and UNEP-IETC Demonstration Project on the Pilica River in Poland. The key management issue addressed has been the ecological and health hazards resulting from eutrophication of the river-reservoir system and toxic cyanobacterial blooms which also impact on recreational uses of the area.

2.4 Water in extreme conditions (arid and polar regions)

abstract id: **130**

topic: **2**
Groundwater and dependent ecosystems

2.4
Water in extreme conditions (arid and polar regions)

title: **Cryopegs of the Yakutian diamond-bearing province (Russia)**

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keywords: cryopegs, permafrost, hydrogeochemistry, isotopes

INTRODUCTION

Cryopegs (intrapermafrost and subpermafrost negative-temperature chloride saline waters and brines) as a major component of cryolithosphere circulate in the cooled sedimentary rock and kimberlite pipes, forming aquifers regionally distributed. The interaction between the frozen rock and cryopegs, the ability of negative-temperature waters to move through permafrost diluting ice inclusions in rocks, as well as the considerable decrease in temperature during the cryopeg's migration has caused deep cooling in the geological section (Pinneker et al., 1989).

The origin of cryopegs is one of great scientific interest and now it is widely discussed among world scientists. This study helps in understanding of cryopegs formation and accordingly will be useful in diamond exploration and drainage brines disposal.

GEOLOGY AND GEOCRYOLOGY

The Yakutian diamond-bearing province with a total area of 840,000 km^2 is located in the northern part of the Siberian platform (Fig. 1). Within the boundaries the geological section consists of sedimentary rocks underlain by an Archaean crystalline basement.

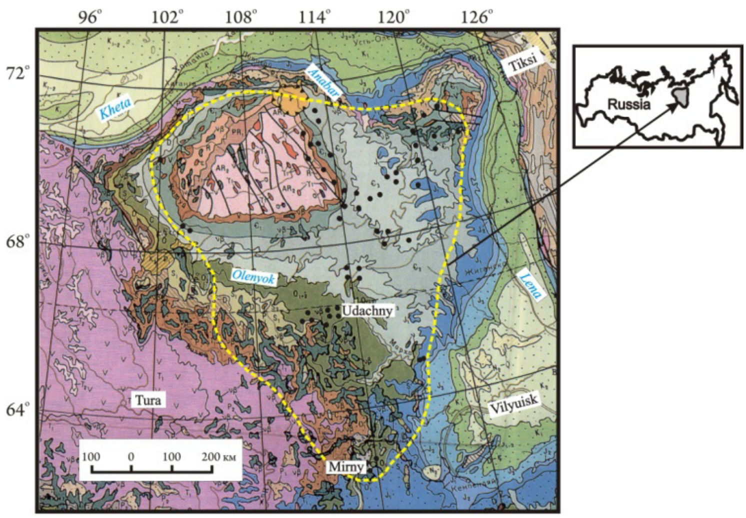

Figure 1. Location of the Yakutian diamond-bearing province. The black circles show the position of kimberlite pipes.

The thickness of the sedimentary cover varies from 2 to 3 km. Although the sedimentary rocks in the Yakutian province range in age from Proterozoic (Vendian) to Jurassic, they are dominated by Cambrian sediments. In the central part of province the Vendian rocks are mainly dolomites interlayered with marls and sandstones. The Cambrian sediments consist of dolomites and limestones interlayered by argillites, clayey limestones and gritstones.

The southern part of province has another stratigraphy. The basement is covered by Vendian-Early Cambrian sediments that are made up primarily of dolomites interlayered with argillites, anhydrites, limestones and gritstones. The Cambrian sediments overlay and consist of dolomites and limestones interbedded with marls, argillites, anhydrites and rock salts (halite). The thin layers of Jurassic sandstones and clays are exposed at the surface. In the province there are numerous Middle Paleozoic kimberlite pipes and Late Paleozoic-Early Mesozoic trappean intrusions that are confined to tectonic fault zones in the area.

Yakutian diamond-bearing province is unique in view of the extreme cooling of the geological section and is characterized by continuous permafrost, low mean annual rock temperatures (–2.9…–8.8°C on the north and –1.2…–4.0 on the south), high rock thermal conductivity (2.2–5.2 W/(m·°K) and lowest (0.008–0.027 W/m^2) intensity of heat flow (Balobaev, 1991; Duchkov, Balobaev, 2001). These characteristics have caused the formation of the anomaly thermal field and low thermal gradients. In the central part of province the position of zero isotherm varies from 720 up to 1450 m. On the south it fixes at the depths of 340–820 m. According to updated data concerning the geocryological section of the province, the cryolithozone represents the interlayering of ice-rich permafrost, dry permafrost and cooled rocks. The cooled rocks are saturated with the cryopegs (Fig. 2).

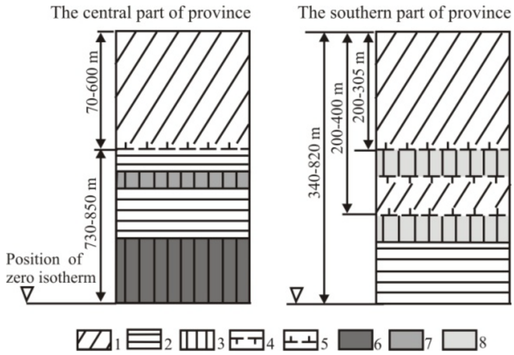

Figure 2. The generalized permafrost structure and cryopegs position in the Yakutian diamond-bearing province. 1 – ice-rich permafrost; 2 – "dry" permafrost; 3 – basal cryopegs; 4 – permafrost table; 5 – permafrost base; 6 – Cl Mg-Ca cryopegs (group A samples); 7 – Cl Mg-Ca or Ca-Mg or Ca-Na cryopegs (group C samples); 8 – Cl Na cryopegs (group B samples).

HYDROGEOLOGY AND HYDROGEOCHEMISTRY

The water samples (more than 500) collected from exploration boreholes were analyzed for chemical composition. The chemical compositions were determined by ICP-MS/ICP-AES and Ion Chromatography (IC) for cations and anions, respectively. High concentration samples were diluted 20 times before they were analyzed. The detection limits for Ca, Na, K, Mg, Li and Sr of the ICP-MS/ICP-AES method are 100, 200, 10, 100, 0.1 and 0.1 µg/L, respectively. The detection limits for Br, Cl and SO_4 of the IC method are 100, 200 and 100 µg/L, respectively.

The Yakutian diamond-bearing province is characterized by few different types of cryopegs. Two hydrochemical zones can be distinguished in the vertical section of the central part of province. The groundwaters of the Upper Cambrian aquifer within the sedimentary strata and Middle Paleozoic kimberlite aquifer are contained in the first zone. The zone is represented by saline waters and diluted brines. The chemical composition of groundwaters is only chloride. The cations balance is Ca>Mg>Na>K or Mg>Ca>Na>K or Na>Ca>Mg>K. TDS values vary from 31 to 252 g/L. Groundwater samples collected from the depths of 110–650 m, and the thickness of the first zone is limited, not more than 20 m. Cryopeg's temperatures vary from –4.0 to –3.0°C.

The second zone contains concentrated brines of the Middle Cambrian aquifer within the sedimentary strata and Middle Paleozoic kimberlite aquifer. Groundwaters pumped from depths 600 to 1450 m. TDS values range from 224 to 404 g/L and increase depending on the groundwater occurrence. Ninety eight percent of the anion balance is represented by chloride. The mean concentrations of cations (%) are: Ca — 50–70, Na — 15–30, Mg — 15–25, K — 3–5. Cryopeg's temperatures vary from –2.6 to –1.0°C.

On the south of the Yakutian diamond-bearing province cryopegs occur at the depths of 200–400 m. The groundwaters are represented by saline waters and brines. Their occurrence corresponds to the Early-Middle Cambrian supersalt-bearing aquifer and Middle Paleozoic kimberlite aquifer. The chemical composition of groundwaters is also chloride and predominantly sodium. The cations balance is Na≫Ca>Mg>K. TDS values range between 28 g/L and 165 g/L. The peculiarity of groundwaters is high content of H_2S, up to 90–120 mg/L. Cryopeg's temperatures vary from –2.5 to –0.5°C.

STABLE ISOTOPE SIGNATURES

The ^{18}O, ^{2}H, ^{37}Cl and ^{81}Br stable isotopes were analyzed by Isotope Ratio Mass Spectrometry (IRMS) in University of Waterloo (Canada). The analytical precisions for the ^{18}O, ^{2}H, ^{37}Cl and ^{81}Br isotopes are 0.2‰, 1.0‰, 0.1‰ and 0.1‰, respectively.

The δ^{2}H and δ^{18}O results range between –171‰ and –61.7‰; and –21.4‰ and –2 ‰, respectively. The pattern obtained from the δ^{2}H and δ^{18}O values is similar to that previously reported by Pinneker et al. (1987). The δ^{37}Cl values range between –0.40‰ and +1.3‰. This range is within the known variation for Cl stable isotopes of formation waters (Kaufmann et al., 1993; Eastoe et al., 2001; Frape et al., 2004). The δ^{81}Br values have a wide variation and range between –0.80‰ and +2.31‰. This variation is larger than the previously reported range (0.00‰ to +1.80‰) for Br stable isotopes for natural samples (Eggenkamp, Coleman, 2000; Shouakar-Stash et al., 2005).The different cryopegs groups are not distinguished from each other based solely on their chemical composition; they are also distinguishable based on isotopic characteristics.

Group A: the δ^{2}H and δ^{18}O values of the cryopegs samples range between –70.5‰ and –61.7‰; and between –5.52‰ and –2.0‰, respectively (Fig. 3). The δ^{37}Cl (Fig. 4) and δ^{81}Br values range between –0.4‰ and –0.2‰; and between –0.13‰ and +0.24‰, respectively.

Group B: the δ^{2}H and δ^{18}O values of the cryopegs samples range between –171‰ and –113.2‰; and between –21.4‰ and –9.57‰, respectively. The δ^{37}Cl value of one sample is +1.54.

Group C: the δ^{2}H and δ^{18}O values of this cryopegs samples range between –139.6‰ and –95.9‰; and between –16.45‰ and –10.2‰, respectively. The δ^{37}Cl and δ^{81}Br values range between –0.4‰ and +1.3‰; and between –0.8‰ and +2.31‰, respectively.

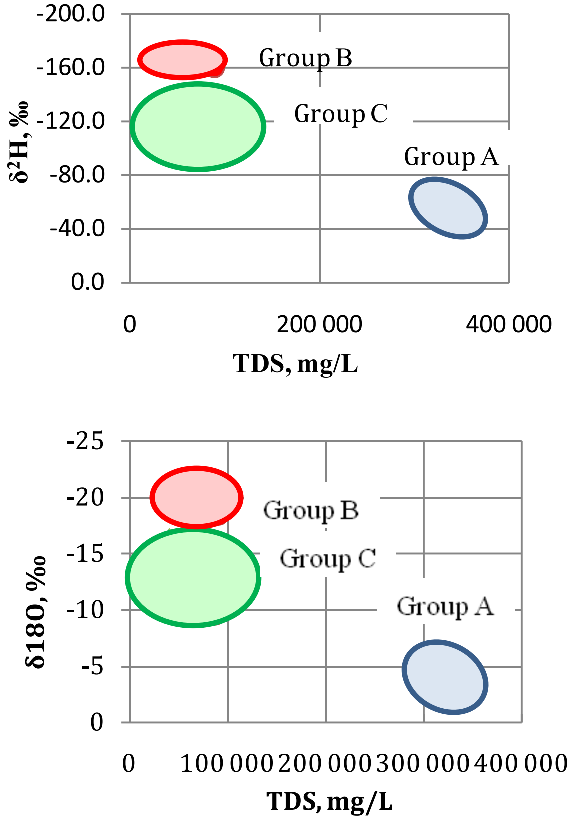

Figure 3. Stable isotopic composition (δ^2H and $\delta^{18}O$) of cryopegs of the Yakutian diamond-bearing province. The cryopegs are distinguished on three groups: Group A (Cl Mg-Ca), Group B (Cl Na), Group C (Cl Ca-Mg or Mg-Ca or Ca-Na).

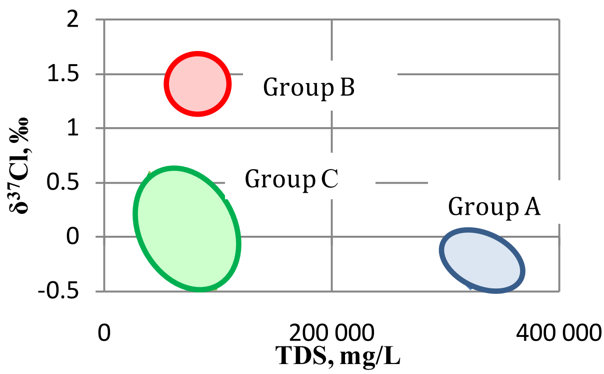

Figure 4. Plot of the $\delta^{37}Cl$ versus TDS for the cryopegs.

CONCLUSIONS

The cryopegs of the Yakutian diamond-bearing province classified into three different groups based on their chemical composition and isotopic features (H, O, Cl and Br stable isotopes).

Group A includes Cl Mg–Ca brines. They pumped from depths 600 to 1450 m and are characterized by TDS 224–404 g/L. Cryopeg's temperatures vary from –2.6 to –1.0°C. The O, H and Cl stable isotope signatures of these cryopegs are the most enriched in comparison to the other groups. It is postulated that they are residual brines of evaporated paleoseawaters (Shouakar-Stash et al., 2007).

Group B samples are Cl Na. They occur at shallower depths (200–400 m) and their TDS values range between 28 g/L and 165 g/L. Cryopeg's temperatures vary from –2.5 to –0.5°C. The waters are the most depleted in O, H and Cl stable isotopes of all samples and their signatures are very different from group *A* signatures. Data obtained for group *B* indicate that these groundwaters are derived from halite dissolution, most likely as a result of recharge in a colder climate, possibly Pleistocene derived water.

Group C consists of Cl Ca–Mg or Mg–Ca or Ca-Na type waters. Groundwater samples collected from the depths of 110–650 m and their salinity vary from 31 to 252 g/L. Cryopeg's temperatures vary from –4.0 to –3.0°C. The isotopic data are disposed between isotopic values of group *A* and group *B***.** Data interpretation could not lead to a definite brine source. However, the available data suggest that these waters were modified greatly via a number of scenarios; geochemical evolutionary processes such as permafrost freezing, mixing, leaching of salt and water–rock interaction could have all affected their chemistries and isotopes.

ACKNOWLEDGEMENTS

The authors wish to acknowledge to the Russian Fund for Basic Research (Project 08-05-00086).

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abstract id: **186**

topic: **2**
Groundwater and dependent ecosystems

2.4
Water in extreme conditions (arid and polar regions)

title: **Well field design for abstraction of high volume saline groundwater from Thumbli Aquifer, Barmer Basin, Rajasthan, India**

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keywords: aquifer geometry, salinity, Arid region, grain size

ABSTRACT

A huge volume of saline water exists in deep aquifers in the desert region of Rajasthan. However, these saline water resources are not in general economic use due to the relatively high cost of abstraction, processing and disposal of used water. Therefore, the stress on the limited supply of fresh groundwater remains high and the fresh water aquifer is not being replenished to the extent that it is being utilised. Consequently, the scarcity of the fresh water resources is a limiting factor in the economic development of the region. This paper deals with an example of the effective utilization of saline water resources for industrial use in the Barmer Basin of Rajasthan without creating an environmental impact and without generating any conflicts with the local stakeholders (community, farmers, public drinking water supplier).

The study made use of subsurface data associated with oil field exploration and production to locate a deep confined aquifer, define its geometry, hydraulic parameters, salinity and locate highly transmissive zones to sustain a continuous water supply to the oil field with minimal environmental impact. Based on the study, an 800m thick aquifer zone located 350mBGL consisting of well sorted, medium to fine grained sand and having a uniformity coefficient of 2.81 and hydraulic conductivity in range of 20 m/day–25 m/day has been identified. The salinity varies with depth from 5,500 mg/L at the top of the aquifer to ~10,000 mg/L at the bottom of the aquifer. The aquifer water is corrosive due to high chloride content (2200–2900mg/L), presence of Sulfur Reducing Bacteria (SRB, 1–10 mg/L), free carbon dioxide (220 mg/L) and oxygen (80 ppb).

The schematic study of oil field data, its integration with the hydrological properties of the aquifer, coupled with the drilling of test wells, long duration aquifer testing and detailed chemical analysis of the aquifer water has helped to understand the deep aquifer in a better way compared to the hydro-geological information originally available for this aquifer. Numerical flow and solute transport simulation has further helped to optimise the pumping rate and interwell spacing criteria. It has been found that it is possible to get the required volume of water with three high capacity water wells spaced 100 apart by tapping only 100 m of the upper portion of the aquifer; with screens of 10¾ inch diameter continuous slot wire wrapped 0.45 mm slot aperture. It was found that 316L metallurgy for well casing, screen and tubing was appropriate to meet the corrosion threat due to the highly corrosive nature of the aquifer water. The high uniformity co-efficient of the aquifer material has helped in deciding the natural development of a filter pack across the screen part of the well instead of using artificial gravel pack. Formation damage due to drilling fluid has been minimized by using potassium carbonate polymer mud system. All the three wells were tested at a pumping rate of up to 10,000m^3/day and well efficiencies were in the range of 75–80%.

Efficient saline water well field development has been achieved due to integration of oil field data, aquifer testing and numerical modeling. The integrated approach has helped to minimise the risk related to availability of resources, impact on the environment and conflict with the stakeholders. Efficient design of both the saline water delivery system and the wells further reduced the drilling and operational cost. This study provides opportunity to demonstrate judicious utilisation of the oil field data in defining the deep groundwater aquifer.

INTRODUCTION

Significant oil discoveries have been made in the Barmer sedimentary basin (Compton, 2009) located in the Thar Desert of Rajasthan (Figure 1). Several of these fields contain waxy crude with APIs of 16-22° and a pour point of around 60°C (Tandon et al., 2008). Development of such fields requires large volumes of water, typically 25,000 m^3/day, for pressure support. Finding such huge volumes of water in an arid desert region was a considerable challenge. Fresh water is available in the vicinity of the oil fields but its utilization for industrial purposes would jeopardize long term availability of water supplies to rural and urban populations of the desert. A detailed hydro-geological investigation was thus carried out to locate saline water aquifers that historically have no practical use for domestic or irrigation purposes. These aquifers should be sustainable for the life of the oil field developments where the water can be abstracted at high rates with minimum construction and operating costs.

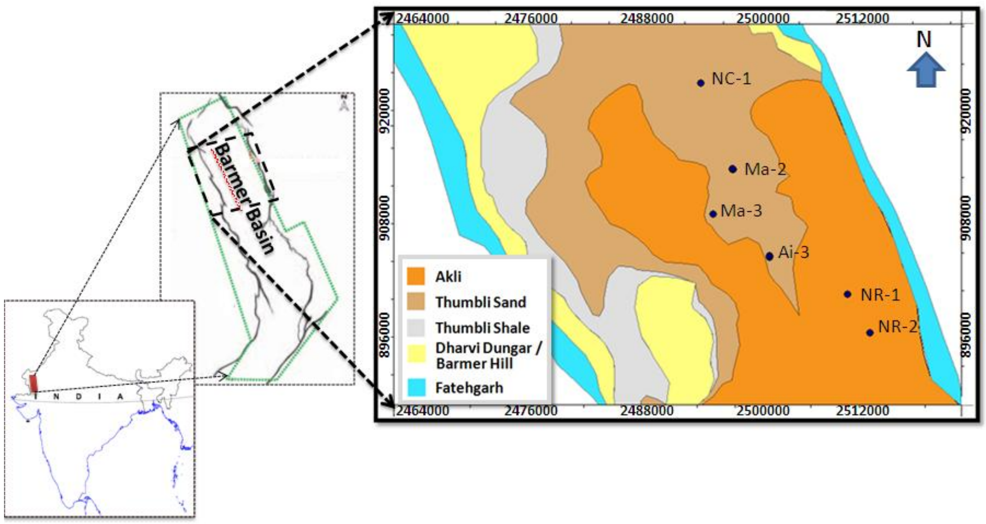

Figure 1. Geological setting of the Thumbli aquifer with respect to Barmer Basin and rift system.

METHODOLOGY

Initially, mapping of the stratigraphic layers in the Barmer Basin was carried out using available oil field seismic data, petrophysical analysis of the oil field log data and Modular Dynamic Formation Tester (MDT) data analysis. Once a potential saline aquifer distal to the fresh water aquifer was identified in the stratigraphic section, drilling of water production and observation wells at various key spatial locations was undertaken to conduct the aquifer tests and derive the field hydraulic parameters of the aquifer. This was followed by grain size and water quality analysis. The results of long duration Constant Rate Tests (CRT) were analysed to develop an understanding of the aquifer flow behavior. Step Drawdown Tests (SDT) were conducted to understand the well and aquifer losses in the pumping well associated with adopted drilling method and well design. Based on the integration of these types of data the aquifer was characterised and a numerical 3D flow and solute transport model was developed. Simulations were carried out with various geometric layouts of production wells with the objective of analysing drawdown interference for each producing well and its possible impact on the distant fresh water lens within the aquifer. Finally, locations of production wells, their optimal number and distribution throughout the aquifer and completion design were optimised.

AQUIFER PHYSICAL PROPERTIES AND CHEMICAL CHARACTERISTICS

The Barmer Basin is part of a failed rift basin contiguous with the Cambay Basin to the south, and defined in the west and east by extensional faults (Compton, 2009). The basin was tilted and inverted after the Miocene in response to the collision of India with the Asian Plate, such that much of the stratigraphy is exposed along the northern margin of the basin with regional dips inclined to the south. The stratigraphy of the basin (Table 1) comprises a syn-rift Fatehgarh reservoir overlain by a regional seal and source rock, the Barmer Hill Formation, which consists predominantly of bituminous shales and silica-rich diatomaceous sediments. The overlying Dharvi Dungar, Thumbli and Akli formations are shale-rich units with minor sands of fluvio-deltaic depositional origin, many of which were derived from the northeasterly or northwesterly basin margins. Regional studies of the basin indicate that the main fluvial channels had a major axial component along the rift basin.

Table 1. Lithological sequence of the Barmer Basin.

Formation	Unit	Thickness	Lithology
Akli Formation & younger		0–>1000 m	Shales and lignites; sands in Miocene.
Thumbli Formation	Thumbli Sand	0–1000 m	Sand and semi-consolidated sandstones with interbedded clay, shale and lignite.
Thumbli Formation	Thumbli Shale	0–500 m	Shale, locally carbonaceous, rare sands.
Dharvi Dungar Formation	—	200–1200 m	Shales, locally carbonaceous, rare sands
Barmer Hill Formation	—	100–1,000 m	Shales and diatomaceous siltstones
Fatehgarh Formation	—	50–400m	Sandstones and shales

The Thumbli Formation is a major fluvial plain sequence with the Thumbli Sand Member representing a major channelised river deposit, sourced from the north eastern faulted flank in the northern part of the basin. The Thumbli aquifer is subaerially exposed in the north of the basin where it recharges but is overlain and confined by the shales of the Akli Formation to the south. The thickness of the Thumbli aquifer ranges between 0 m and 950 m. In the northern area of the basin it typically has high porosity and permeability. The unconfined portion of aquifer contains fresher groundwater at the water level but the water rapidly becomes saline with depth and reaches a maximum salinity of some 10,000 mg/L. The confined portion of aquifer water (overlain by Akli Formation) is saline (>3000 mg/L) and reaches maximum of 10,000 mg/L at depth. A summary of the physical properties of the Thumbli Sand Member aquifer is given in Table 2.

Table 2. Physical properties of the Thumbli aquifer.

Feature	Representative value
Boundaries	West and North – No flow (Thumbli Shale and Dharvi Dungar shale). East – No flow (fault truncated). South – No flow (gradational to finer textured lithologies).
Underlying aquiclude	Thumbli Shale and Dharvi Dungar Formation.
Overlying aquitard	Akli Formation
Saturated thickness	Saturated net sand yields a range in thickness of 0 m to 740 m.
Effective Porosity	Approximately 31% in the northeast of the aquifer, declining to around 10–20% towards the south-western boundary.
Storage coefficient	Storage coefficient 5.1 × 10^{-4}
Hydraulic conductivity	Khanji ka Tala (Ai-3) K_h = 13.5 m/day Madpura Barawal (NR1) K_h = 11.5 m/day
Recharge	An average long term value for recharge of 0.6 mm/year
Groundwater quality	5,000 – 10,000 mg/l TDS in confined zones

WELL LAYOUT AND WELL DESIGN

Based on the initial estimates from well logs, core cuttings, grain size estimation, pressure and permeability data obtained from oil wells, a total of 24 water production wells spread over 25 km^2 and set 1km apart were planned in the confined portion of the aquifer (below 350 m BGL) with each having installed capacity of 1,000m^3/day (Fig. 8). Grain size analysis (Fig. 2) indicates that the D_{50} of the aquifer material of the upper 100–150m zone is 0.45mm and uniformity coefficient (D_{40}/D_{90}) is 2.8 which formed the basis to natural filter pack around the screen.

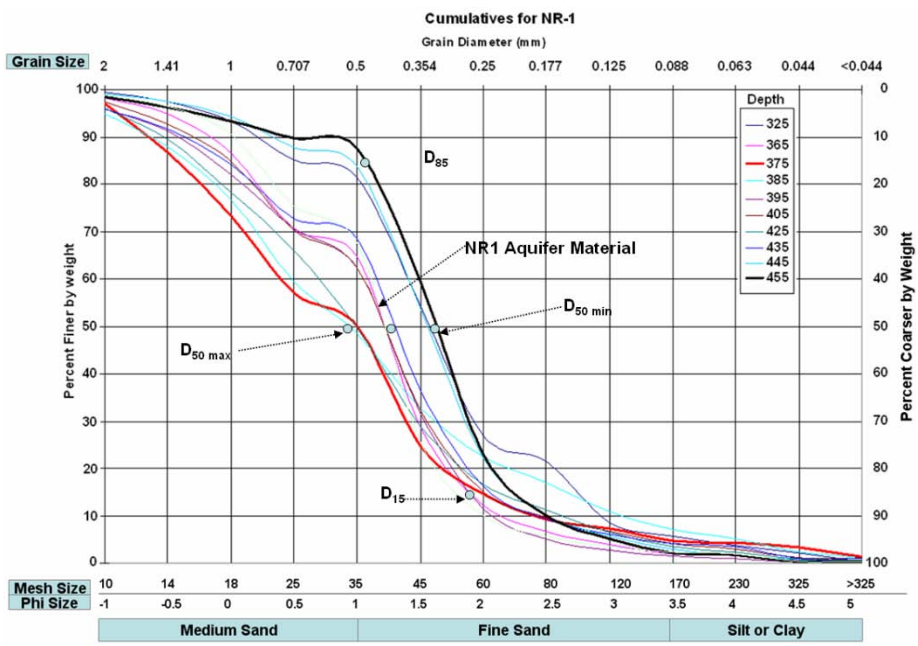

Figure 2. Results of grain size analysis of the aquifer in the NR-1 area.

A test well (Fig. 3) and 3 observation wells were drilled and CRT (Fig. 5) and SDT were carried to ascertain the hydraulic conductivity, storage coefficient and boundary effects in the proposed field.

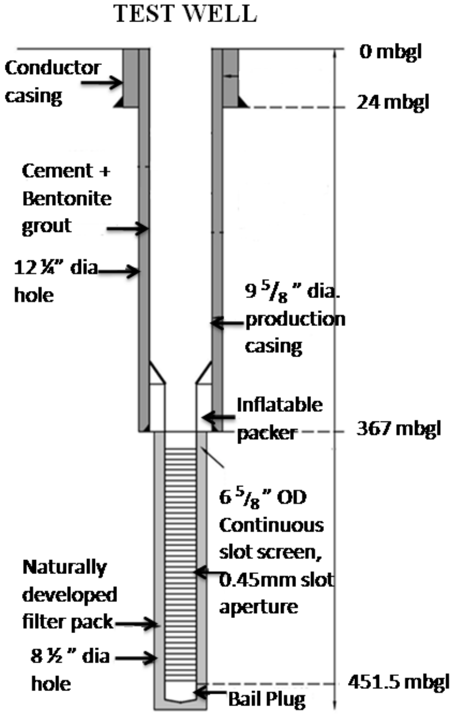

Figure 3. Schematic of the Test well drilled for aquifer testing in the saline part of the aquifer to produce 2400 m³/day.

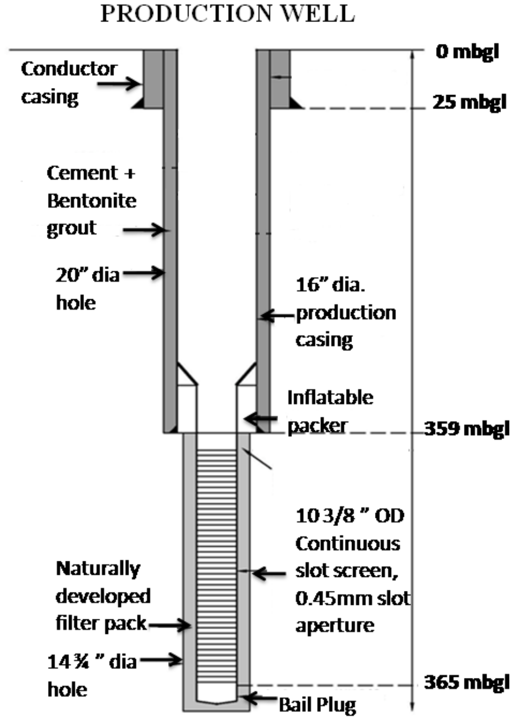

Figure 4. Schematic of the production well drilled in the saline part of the aquifer to produce 10000 m³/day.

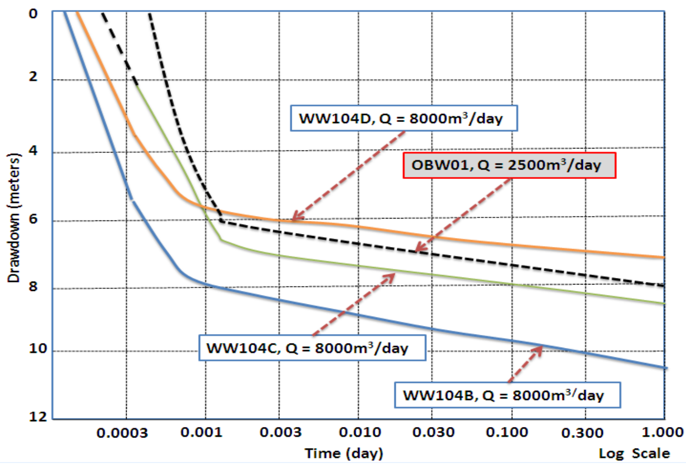

Figure 5. Drawdown curves of Production well WW104-B, C and D each pumping at rate of 8000 m³/day and OBW01 (Test well) pumping ≅ 2500 m³/day.

The test well was drilled with a pre-hydrated bentonite (PHB) mud system (Bentonite, Caustic Soda, Barite and Lignosulphate). The long duration CRT showed the aquifer hydraulic conductivity was 10 m/day in the area. Based on the hydraulic properties of the aquifer (Fig. 6 and 7), a numerical groundwater flow and solute transport model was set up.

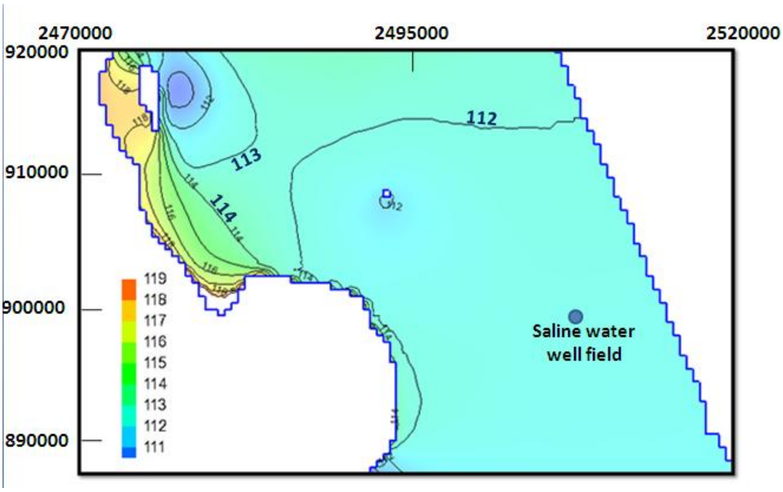

Figure 6. Hydraulic Head within the aquifer.

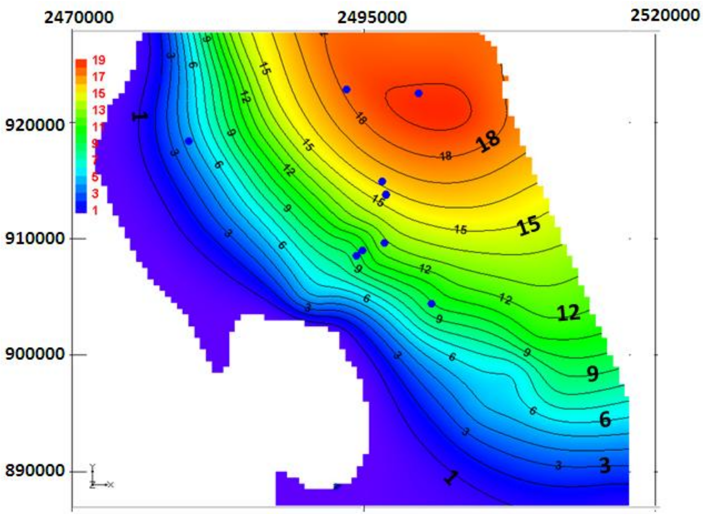

Figure 7. Hydraulic conductivity within the aquifer.

Various scenarios were examined using the ground water model. Simulations were carried out with different well layouts to understand the flow (Fig. 8) and solute behaviour of the aquifer. Drawdown and interference between pumping wells with different well numbers and geometries was also analysed. Modeling and analytical calculations suggest that the required yield could be achieved with three wells (Fig. 8) spaced at a distance of 100 m. Each well could deliver 10,000m^3/day.

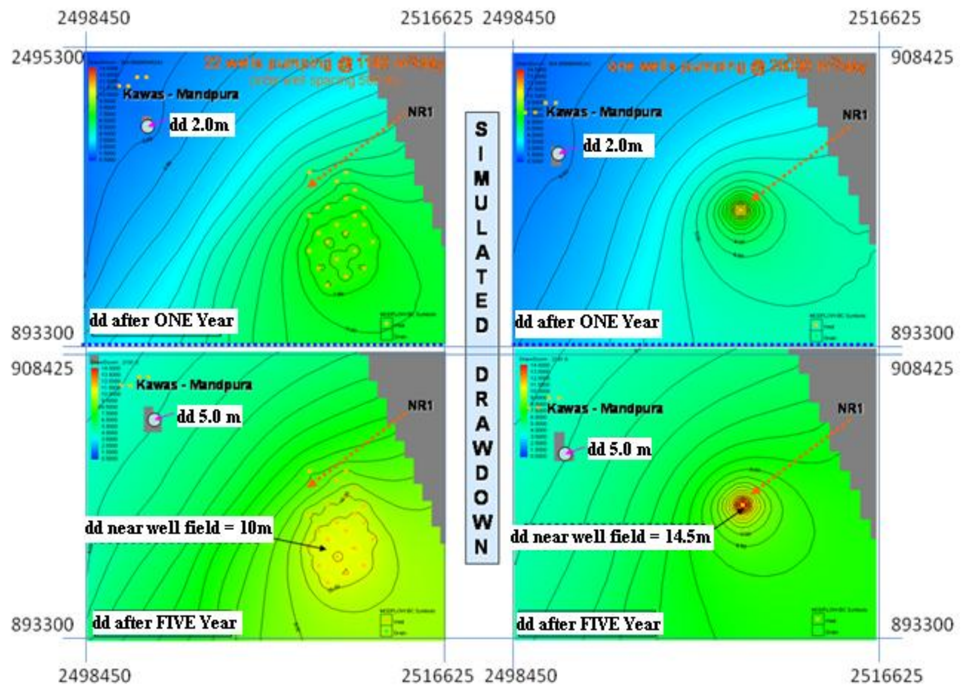

Figure 8. Simulated drawdown in aquifer with two different well layout (five wells and 24 wells) using MODFLOW 2000 (USGS) computer code.

The required volumes of water can thus be attained with the use of three high capacity water wells (Fig. 4) by tapping only 100m of the upper portion of the aquifer spaced 100m apart with and completed with 10^3/$_4$ inch diameter continuous slot wire wrapped screens with 0.45mm slot aperture. It was also found that 316L metallurgy for well casing, screen and tubing was appropriate to meet the corrosion threat due to the corrosive nature of aquifer water (Table 3).

Table 3. Aquifer water quality corrosion related parameters.

Parameters	**Range**
Total Dissolved Solid	5000–5500 mg/L
Chloride	2200–2900 mg/L
Carbon Dioxide	220–300 mg/L
Sulfur Reducing Bacterial	1–10 count per litre
Oxygen	80ppb
Corrosivity	up to 28 mils (~0.7mm) per year

Formation damage has been minimized by using K_2SO_4 (a water-based mud system including $CaCO_3$, K_2SO_4, and KOH) with a mud weight 9.4–10ppg for drilling the sand lithologies. The improved design (Fig. 4) and mud system has helped to get the required volume of water with three high capacity wells located 100m apart instead of drilling 24 wells spread over 25 km^2. The new design has helped to achieve well efficiency up to 80% at pumping rate of 10,000m^3/day (Fig. 5).

CONCLUSION

This study demonstrates the use the oil field data to locate a deep confined aquifer (in this case the Thumbli aquifer), and define the geometry, hydraulic parameters, and salinity of the aquifer, as well as target the high transmissibility zones. Detailed technical evaluations using this extensive database indicated that huge volumes of saline groundwater resources are available within the Thumbli aquifer and that these can be accessed for abstraction without impacting the associated shallow freshwater lens. Numerical flow and transport simulations confirm that there is no risk related to availability of the resources and environmental impact on other usable groundwater resources.

The numerical model has been used in optimizing the well count and distribution for water abstraction. Only three high capacity wells, spaced at a distance of 100m with a screen of 10 $^3/_4$ inch diameter continuous slot wire wrapped 0.45 mm slot aperture are required to produce 25,000 m^3/day saline groundwater by tapping the 100 m upper portion of aquifer. This integrated data acquisition, modeling and analysis approach has reduced drilling and operational costs significantly.

ACKNOWLEDGEMENTS

This paper has been written using information available from various sources to the authors although the synthesis is the responsibility of the authors alone. Authors are thankful to Central Ground Water Board (Govt. of India), Public Health Engineering Department (Govt of Rajasthan) and Ground Water Department (Govt. of Rajasthan) for sharing data and technical inputs. Authors also like to thank Nigel Bank, (Bank Geosciences, UK) and Water Management Consultant (Schlumberger Water Services, UK) for their technical contribution in mapping of Thumbli aquifer. The authors express their thanks to Cairn India Limited and their Joint Venture partner Oil and Natural Gas Corporation of India for the opportunity to write and present this paper.

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abstract id: **249**

topic: **2**
Groundwater and dependent ecosystems

2.4
Water in extreme conditions (arid and polar regions)

title: **Estimation groundwater recharge in arid, data scarce regions; an approach as applied in the Hawashyia basins and Ghazal sub-basin (Gulf of Suez, Egypt)**

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keywords: groundwater recharge estimation, arid region, flood marks, hydrogeology

INTRODUCTION

Estimating groundwater recharge in arid regions is an extremely important but difficult matter, one reason for the latter being definitely the scarcity of data in arid regions. This is also true for the East Egyptian desert where along the Red Sea coast line groundwater is used for irrigation purposes in agricultural reclamation.

This paper summarizes an approach that was applied in the area of the East Egyptian desert for the estimation of runoff and ultimately groundwater recharge, despite the described scarcity of data. It is based on a rainfall–runoff relation that itself was developed on the basis of geomorphologic and hydrogeologic catchment data and uses flood marks in the catchments for the calibration of the hydrograph. For this purpose, two models, "Gerinne (=channel model)" and "Stormwater Management and Design Aid (SMADA6)" were coupled. The method was so far applied in two basins, the El Hawashia basin and the Ghazala sub-basin.

HYDROGEOLOGICAL CHARACTERISTICS

The El Hawashia basin can be divided into three geomorphological entities, (1) the mountainous area composed essentially of Pre-Cambrian basement rock, a maximum altitude of 1019 m and steep slopes, (2) the hilly area and (3) the piedmont plain with a shallow slope. Geologically, the El Hawashyia basin is located in the West Bakr sedimentary basin that is primarily used for petroleum abstraction. It has a total catchment area of 976 km^2, consists of basement rock (51.2% surface outcrops), cretaceous rock (24%) and quaternary deposits. Two aquifers, one Post-Miocene and one Miocene aquifer are present in the area. The Post-Miocene deposits, which are composed of gravels and sands are represented by large thicknesses in the El Hawashyia basin ranging from 100 m in the west to 450 m in the east, i.e. at the Wadi outlet to the Red Sea. From the available, scanty data, it is known that the water table actually reflects the topography and that the aquifer is unconfined. From geoelectrical investigations it is known that the thickness of the alluvial in the main channel of El Hawashyia ranges from 80 m to 200 m. The groundwater level lies as deep as 120 m below surface towards the inner catchment and close to 20 m below surface towards the Gulf of Suez. It is assumed that rains in the upper catchment tend to result in flood hydrographs in the El Hawashyia Wadi, which recharge the Post-Miocene aquifer if the flood reaches the lower parts of the catchment, i.e. the piedmont plain with its the less slopy main channel and in succession the active alluvial fan of the catchment.

The Ghazala sub-basin contributes with 155 km^2 to the El Hawashiya basin and lacks the presence of cretaceous rocks. Basement rock contributes to 81% of the surface are of the sub-basin.

RESULTS

Using the model "Gerinne", it was calculated from the flood marks at the edges of the main channels in the catchments, that a total rainfall of 25 mm must have fallen for the observed events at Ghazala sub-basin and 18 mm in the Hawashyia basin. This corresponds to a discharge of 635 m^3/s at El Hawashyia basin and 290 m^3/at Gazala sub-catchment at their outlet towards the quaternary plain. These rainfall amounts have a return period of 20 years and a probability of 5% as compared to the Hurghada climate station. For El Hawashyia basin the corresponding discharge volume that is transferred to the delta corresponds to 10.2×10^6 m^3. The infiltration corresponds in total to 4.7 mm, i.e. 26% of the rainfall. In Ghazala sub-basin, a total runoff volume of 3.16×10^6 m^3 is calculated to reach the delta while 3.2 mm (13%) of the rainfall infiltrate. The difference in the infiltration percentage between El Hawashyia and Ghazal sub-basin can be matched to the difference in Geology in the two catchments, with the Ghazala sub-basin consisting with 84% of a much higher proportion of basement rocks. For an estimation of groundwater recharge, the evaporation loss should be considered which accounts on daily mean to approximately 10.4 mm/day. From archival data and from oral information from inhabitants, the time of concentration in El Hawashyia basin ranges from 12–20 hours. This matches with the calculated times of concentration of 15 hours for El Hawashyia basin and 10 hours for Ghazala sub-basin. For the studied flood events the modelling resulted in calculated evaporation losses of about 3.3 mm and 2.1 mm, i.e. with percentages of 18% of total rainfall and 8% for El Hawashyia basin and Ghazala sub-basin, respectively.

IAH 2010
Krakow

abstract id: **370**

topic: **2**
Groundwater and dependent ecosystems

2.4
Water in extreme conditions (arid and polar regions)

title: **The hydrogeology of the glaciated catchment in the arctic environment**

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keywords: polar catchment, water balance, groundwater

INTRODUCTION

The hydrological investigation at high latitudes in the Arctic has received significant attention over the last years. Particular stress is put on the recognition of water balance calculation within catchments (i.e. the identification of water circulation components within catchment). The complexity of this type of investigation connected with specific Arctic conditions should be taken into consideration (Killingveit et al., 2003). These conditions are related mainly with the irregular functioning of polar meteorological stations (most of them operates only during polar summer) and their irregular spatial locations (most of them are located near the sea-coast). This caused that the investigation of same water balance components is computed approximately or estimated indirectly (Hagen, Lafauconnier, 1995; Marciniak et al., 2007).

Groundwater systems in the high Arctic regions (especially deep aquifers) probably belong to the least studied groundwater systems in the world (Haldorsen, Heim, 1999). As Killingveit et al. (2003) summarize also shallow groundwater occurring in the seasonally refreezing active layer is the most unique recognized component of water balance.

The aim of the present study is the recognition of groundwater in the active layer of the region of Ebbaelva catchment located in central Spitsbergen. The specific targets are:

- The investigation of the conditions of groundwater occurrence in the shallow seasonally refreezing active layer of glaciated catchment;
- The field estimation of the hydrogeological parameters (thickness of the active layer, hydraulic conductivity, groundwater level fluctuations);
- The calculation of the Ebba River recharge components (special emphasis was put on the calculation of the recharge of Ebba River caused by groundwater flow).

THE STUDY AREA

The study area is located in the northern part of Billefjorden (central part of Spitsbergen, Figure 1). The period of time that the air temperature is above 0°C (the period of active groundwater and surface water flow) normally starts in June and lasts until the end of August or mid-September.

The Ebba Riber originates mainly from the Ebba Glacier and the Bertram Glacier. The Ebba is a polythermal glacier and has been in recession over the last hundred years (Rachlewicz et. al., 2007). From the north and south, the valley is surrounded by mountain edges. The streams recharged periodically by snow melt (during the summer season) flow down from mountains edges to the Ebba River. The boundary of the catchment was assigned using morphological criteria (Figure 1). The boundary on the glaciated area of the catchment is uncertain. The catchment area is about 70 km^2, about 51 km^2 of this area is covered by glaciers.

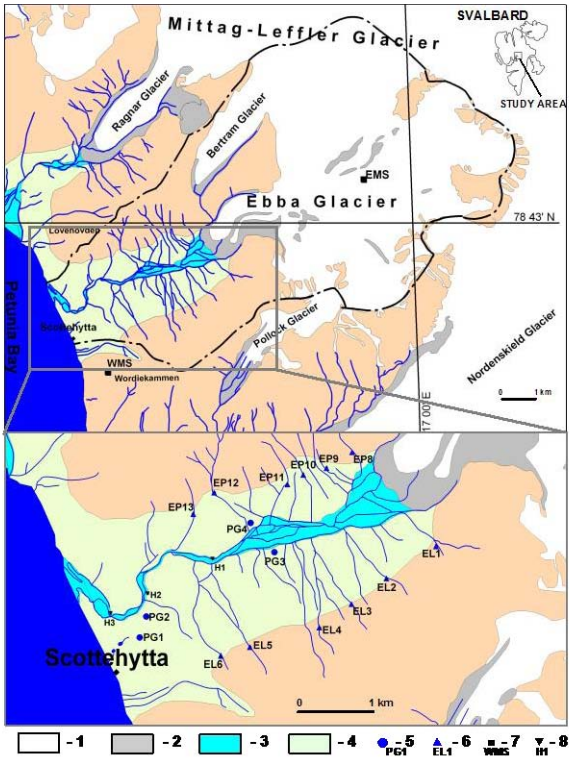

Figure 1. The location scheme (after: Dragon, Marciniak, 2010, modified). 1 — glaciated area; 2 — moraines; 3 — wetland area; 4 — valleys area; 5 — location of the piezometers groups; 6 — location of the surface water sampling points; 7 — location of the meteorological stations (WMS — Wordie Meteorological Station; EMS — Ebba Meteorological Station); 8 — location of the Hydrometric Stations (H1, H2 and H3).

Dislocations along the Billefjiorden Fault zone dominate the bedrock geology of the region (Dallmann et al., 2004). The mountain massif in the part of the region close to the glacier (the eastern part) is composed mainly of metamorphic rocks (amphibolites, gneisses and achiest). The central part of the region is dominated by gypsum, dolomite and anhydrite. Sandstone, limestone and dolomite dominate in the area near the seaside. The Ebba Valley is covered mainly by slope deposits which are composed of rocks originating from the surrounding mountains ridges (Dallmann et al., 2004).

The slope deposition covering the valley area thaws seasonally and forms a shallow active layer, which enables the flow of groundwater (Shur et al., 2005). Based on field investigation with the support of the hydrochemical data (Dragon, Marciniak, 2010) the conceptual model of water circulation within catchment was formulated (Figure 2). When the temperature rises above 0°C the flow of water starts and the thickness of the active layer increases. Streams that flow from the mountain ridges recharge the groundwater occur within the active layer. These streams, in some cases, in the upper portions of the slopes disappear and formulate subsurface flows. In other cases the overland flow is created. At the end of the melting season, when the temperature drops below 0°C the active layer freezes up and water stays locked to the next season (Dragon, Marciniak, 2010).

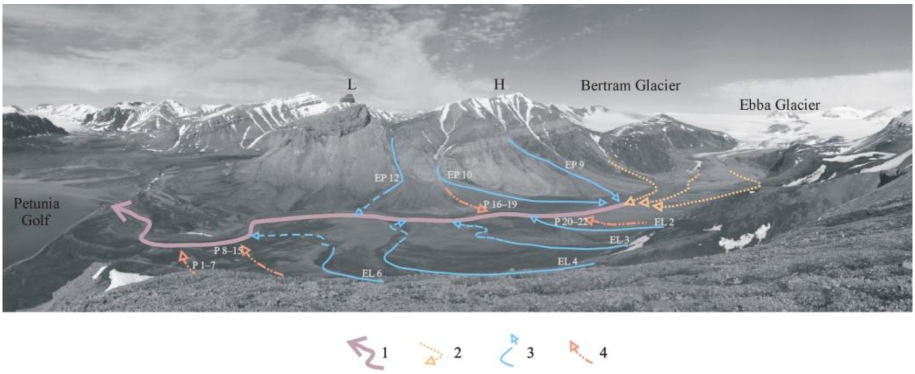

Figure 2. Conceptual model of water circulation within Ebba River catchment (after Dragon, Marciniak, 2010, modified). Explanations: 1 — Ebba River (Q_{Ebba}); 2 — recharge from glaciers (Q_{gl}); 3 — recharge from Ebba tributaries (not all streams are visible on the picture) and overland flow (Q_{su}); 4 — recharge from groundwater (Q_{gw}). The arrows are marked at places of piezometers installations).

MATERIALS AND METHODS

The runoff of the Ebba River was measured at three hydrometric stations during the summer of 2008. The first hydrometric station (H1) was located at a place where the river flow is changes from dispersed overland flow to clear channel flow (Figure 1) while the third hydrometric station (H3) was located close to the river estuary. The hydrometric station H2 was located at the middle part of the river channel. The measurements were performed with the use of an electromagnetic hydrometric meter (SEBA-Hydrometrie type). Open channel flow measurements were performed every five days (11 measurement series).

Four groups of piezometers were installed within the investigated catchment in the summer of 2007. These piezometers were made of PVC pipes with a diameter of 40 mm. Piezometers were installed using hand drilling equipment during the period when the active layer was at its maximum thickness. In the regions of coarse rock occurrence, piezometers were made by digging a pit, but the lower part of each piezometer (the part where the screen is installed) was always drilled to retain the original hydrogeological conditions. The piezometers depth varied between 0.5 and 1.0 m. Each of the piezometers was equipped with a 5 cm long PVC screen (installed at the bottom part of the active layer) and a gravel pack to prevent siltation. In all piezometers, measurements of water level and temperature were taken at three-day intervals in the period between 20 July and 4 September 2008.

The background data of meteorological conditions were derived from three meteorological stations located in the vicinity of Petunia Bay, called Scotte, Ebba (EMS) and Werdie (WMS) (Figure 1). The following parameters were measured (with automatic recording) at these stations: precipitation, wind speed and direction, air humidity, air pressure and temperature.

RESULTS

The most significant water components that recharge the Ebba River are (Figure 2):

$$Q_{Ebba} = Q_{gl} + Q_{su} + Q_{gw} \quad (1)$$

where:

- Q_{gl} — recharge from the Bertram and Ebba glaciers,
- Q_{su} — recharge from the Ebba tributaries (streams originated from mountains ridges) and overland flow,
- Q_{gw} — recharge from groundwater.

It was assumed that the recharge from direct precipitation can be dissembled because during the whole summer period the precipitation intensity was very small (Dragon, Marciniak, 2010).

The clear differentiation of the runoff is visible between H1 and H3 hydrometric stations (Fig. 3A). It is connected with the influence of recharge components other than water from glaciers.

The groundwater runoff was calculated using Darcy's law:

$$Q_{gw} = kbmJ \tag{2}$$

where:

- Q_{gw} — groundwater runoff,
- k — hydraulic conductivity,
- b — the width of the recharge (calculated for each groups of piezometers),
- m — thickness of the active layer,
- J — hydraulic gradient.

The estimation of the hydraulic conductivity (k) of the active layer was assessed in the field using the PARAMEX method (Marciniak, 1999). The thickness of the active layer (m) was calculated as the height of the groundwater level above the permafrost. The hydraulic gradient (J) was calculated using measurement of the groundwater level in each groups of piezometers.

First, the specific discharge for each group of piezometers was calculated and then the total groundwater runoff for the whole valley area was assessed (Table 1).

Table 1. The sample calculation of groundwater flow performed for data measured in the field 09 July 2008.

2008-07-09	*J*	*m*	*k*	*q*	*q*	*q average*	*L Ebba*	Q_{gw}
	[—]	m	m/h	m³/h/m	m³/s/m	m³/s/m	m	m³/s
Group 1	0.060	0.4	2.22	0.053	0.0000148	0.0000185	4765	0.18
Group 2	0.056	0.5	1.43	0.040	0.0000105			
Group 3	0.051	0.4	1.72	0.035	0.0000094			
Group 4	0.089	0.4	4.00	0.142	0.0000391			

Explanations (all parameters was estimated using data from measurement performed during one day):

- J — hydraulic gradient,
- m — thickness of the active layer,
- k — hydraulic conductivity (average for each groups of piezometers),
- q — specific discharge,

- *q average* — specific discharge (average for each groups of piezometers),
- *L Ebba* — the length of Ebba River (the width of the recharge from groundwater),
- Q_{gw} — total groundwater runoff.

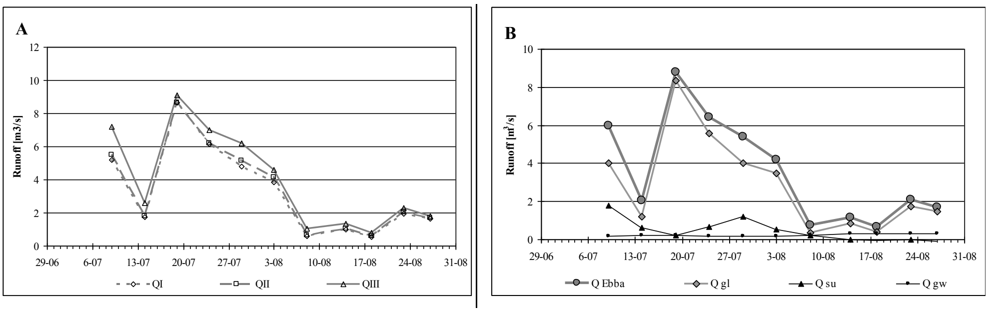

Figure 3. The runoff of the Ebba River during summer season of 2008 (A) and the total runoff of Ebba River and components of Ebba River recharge (B). QI, QII and QIII were measured at H1, H2 and H3 hydrometric stations (respectively), the rest of explanation in text.

It was assumed that the difference in total runoff between hydrometric stations H1 and H3 (Figure 3A) was connected with recharge from the Ebba tributaries (streams originating from mountains ridges) and overland flow as well as with groundwater recharge:

$$Q_{III} - Q_{I} = Q_{su} + Q_{gw} \quad (3)$$

from where:

$$Q_{su} = Q_{III} - Q_{I} - Q_{gw} \quad (4)$$

where:

- Q_{III} — total runoff at the H3 hydrometric station,
- Q_{I} — total runoff at the H1 hydrometric station.

The total runoff of Ebba River (Q_I and Q_{III}) was known from field investigation and the groundwater runoff (Q_{gw}) was calculated. In this case, using equation (4) the calculation of surface runoff — Q_{su} (calculated as a sum of streams tributaries recharging the Ebba River and overland flow) was possible (Table 2).

The recharge of the Ebba River from glaciers (Q_{gl}) was calculated using formula:

$$Q_{gl} = Q_{Ebba} - Q_{su} - Q_{gw} \quad (5)$$

The calculation of the total runoff of the Ebba River is presented on Table 2 and Figure 3B. The calculation confirms that the main component of the Ebba River recharge is the flow of water from glaciers. The amount of this water was calculated as 80.11 percent of total runoff. The recharge of the river by surface flow was estimated as 13.02 percent. The negative value at the end of melting season is connected with the error of estimation. The recharge of the river by groundwater flow was estimated as 6.87% of the total runoff. What is interesting the value of this parameter increase systematically during the melting season (Table 2). It is related with the increase of the active layer thickness during summer season. This factor has the biggest importance at the end of the summer when the melting of the glaciers decline but groundwater flow in the active layer is still present.

Table 2. The average total runoff of Ebba River and components of Ebba River recharge during summer melting season of 2008 (explanations in text).

Date	Q_{Ebba}	Q_{gl}	Q_{su}	Q_{gw}
	m^3/s	m^3/s	m^3/s	m^3/s
2008-07-09	5.96	4.00	1.78	0.18
2008-07-14	2.06	1.21	0.63	0.22
2008-07-19	8.80	8.35	0.23	0.22
2008-07-24	6.45	5.60	0.66	0.19
2008-07-29	5.39	4.02	1.19	0.18
2008-08-03	4.20	3.47	0.53	0.19
2008-08-08	0.76	0.34	0.21	0.21
2008-08-14	1.14	0.83	–0.01	0.32
2008-08-18	0.65	0.38	–0.05	0.32
2008-08-23	2.09	1.75	0.02	0.33
2008-08-27	1.70	1.45	–0.08	0.33
Maximum	8.80	8.35	1.78	0.33
Minimum	0.65	0.38	–0.08	0.18
Average	3.56	2.85	0.46	0.24
Percent	100.00%	80.11%	13.02%	6.87%

CONCLUSIONS

The investigation of groundwater occurrence in the Ebba River catchment located in central Spitsbergen (Petuniabukta region) was documented during ablation season of 2007. It was documented that groundwater occurs there seasonally in the summer melting season when the melting of active layer take place and enable flow of groundwater. These water at the end of summer season froze up and stay locked to the next melting season.

Using data performed from four groups of piezometers measurement the hydrogeological parameters that characterize this shallow water system (thickness of the active layer, hydraulic conductivity, groundwater level fluctuations) were investigated. Then using Darcy's low the amount of water that recharge Ebba River was calculated. This calculation enabled more precise estimation of other component of Ebba River recharge (surface and overland water inflow, recharge from glaciers).

It was calculated that the main component of Ebba River recharge is flow of water from glaciers (80.11 percent of total runoff). The amount of water originated from the inflow of Ebba River tributaries and overland flow is 13.02 percent of total river runoff. The amount of groundwater that recharge Ebba River is 6.87% of the total runoff.

The calculation of groundwater flow has the most unique character. This component of recharge in Arctic environment is usually estimated approximately, assessed using conceptual models (Killingveit et al., 2003) or even omitted in water balance calculations (Hagen, Lafauconnier, 1995). The direct field investigation of groundwater flow allows the other recharge components to be estimated more precisely. What is the most important — the field investigation of groundwater occurrence eliminates the speculations about the possibility of groundwater flow within active layer.

ACKNOWLEDGMENTS

We would like to thank the members of the Adam Mickiewicz University Polar Expedition to Svalbard for their support. We would also like to thank mgr Lukasz Chudziak for his help in the measurement of the Ebba River runoff. The financial support of the Ministry of Science and Higher Education (grant 3505/2007) rendered this work possible. Everyone's support is gratefully acknowledged.

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abstract id: **428**

topic: **2**
Groundwater and dependent ecosystems

2.4
Water in extreme conditions (arid and polar regions)

title: **Characteristics of chemical weathering in a periglacial catchment of the Obruchev Glacier (Polar Urals, Russia)**

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keywords: chemical weathering, Polar Urals, Obruchev Glacier, periglacial basin

INTRODUCTION

Modern hydrochemical research in polar and alpine regions tends to be focused primarily on glaciated basins (Collins, 1979; Tranter et al., 1996; Hodson et al., 2000; Brown, 2002). The hydrochemical properties of periglacial basins, however, have not received as much attention (Caine, 1992; Darmody et al., 2000; Beylich et al., 2004).

Hydrochemical investigations were carried out in the periglacial basin of Obruchev Glacier (Polar Urals, Russia) in order to provide main features of chemical weathering occurring during the ablation season. Additionally, mineral composition of rocks and deposits was taken into account.

STUDY AREA

The Obruchev Glacier Basin (OGB, Fig. 1) is 12.83 km^2 in area (glacier covers about 2%). The study area is characterized by changes in elevation up to 900 m. The depth of snow cover varies from 0.5 m in open areas to 50 m in cirques (Tushinkiy, 1963).

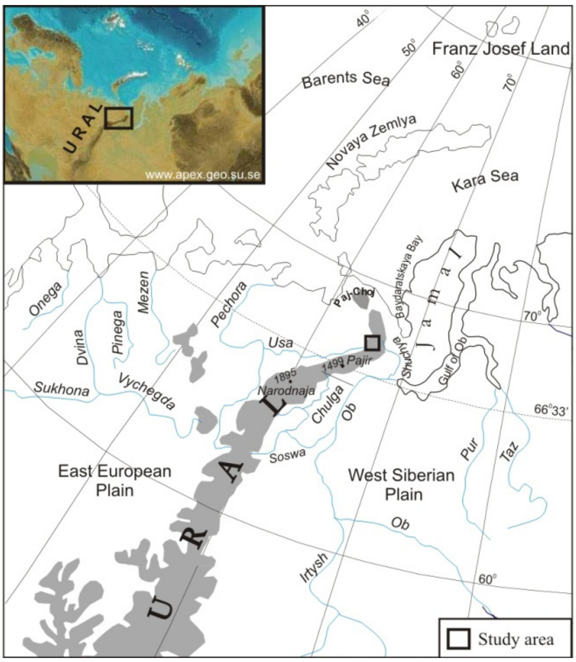

Figure 1. Study area.

From point of view of geology, OGB is located in a Mid-Ural zone formed primarily of paleozoic metamorphic rocks (phyllite, chlorite schist, sericite schist and rarely gneiss). Mineral composition comprises primary of silicate minerals such as micas (mainly muscovite) as well as small amounts of paragonite, quartz, chlorite and feldspars (mainly plagioclases).

METHODS

Specific conductivity and temperature of water were obtained by ELMETRON conductometer CC-315 (conductivity sensor CFT-201, k=0.1/cm). Before investigations, conductivity sensor was calibrated by the Hamilton conductivity standard (147 μS/cm). During field work, water samples were filtered using membrane nylon filters (Whatman 0.45 μm) and Sartorius filtration kit. The filtered water samples were kept in a dark place at temperatures below 4°C. Collected water samples were analyzed by the ion chromatograph ICS-2000 DIONEX (detection limits are shown in Tab. 1) at the Hydrochemical Laboratory of the Institute of Geography and Spatial Management at the Jagiellonian University in Kraków (Poland).

Table 1. Detection limits of the ion chromatograph DIONEX ICS-2000 RFIC.

Ion	Detection limit [ppb]
Ca^{2+}	5.0
Mg^{2+}	5.0
Na^{+}	10.0
K^{+}	5.0
NH_4^{+}	5.0
Li^{+}	5.0
HCO_3^{-}	25.0
SO_4^{-}	10.0
Cl^{-}	2.5
NO_3^{-}	2.5
NO_2^{-}	2.5
PO_4^{3-}	10.0
F^{-}	1.0
Br^{-}	5.0

Assuming very low ion concentration, charge balance error was rather low (on average 5.7%; Tab. 2). Additionally, relationship between conductivity measured in the laboratory and in the field were significant and positive (r=0.96; Fig. 2). The research was performed during the ablation season (summer) during the following two periods: 1) with snow cover – July 11, 2008 to Aug. 2, 2008), and 2) without snow cover – Aug. 2, 2007 to Aug. 20, 2007).

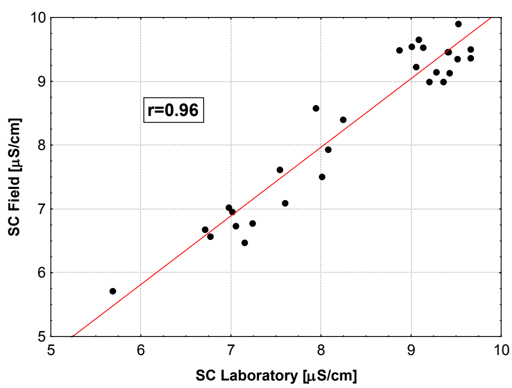

Figure 2. Comparison of Specific Conductivity (SC) measured in the laboratory and in the field.

RESULTS AND CONCLUSIONS

According to Polish standard for acceptable charge balance error (PN-89/C-04638/02), very low TDS allows to interpret water analyzes, even if charge balance error is slightly higher than 10%. Moreover, significant and positive correlation coefficient between conductivity measured in the laboratory and in the field also enables to use these hydrochemical data to describe main features of chemical weathering in OGB.

The total dissolved solids (TDS) in the surface waters of the investigated basin is very low (4.48–7.92 mg dm^{-3}). It is most of all due to harsh local climate conditions. resistant geologic structure (mainly chlorite-sericite schist and phyllite) as well as small extent of geochemically active moraines from Last Glacial Maximum (LGM). These factors contribute to the low rate of chemical weathering in the study area. The concentration of dissolved solids in the waters of the investigated basin can be as much as several times lower than that in periglacial basins located on the Scandinavian Peninsula (Beylich et al., 2004; Darmody et al., 2000) and in the Rocky Mountains (Caine, 1992).

Calcium (1.27 mg dm^{-3}, on average) and HCO_3^- (3.32 mg dm^{-3}, on average) dominated the chemical composition of water samples. Moderate concentrations of the following ions were detected: SO_4^{2-} (0.74 mg dm^{-3}, on average). Na^+ (0.51 mg dm^{-3}, on average), NO_3^- (0.34 mg dm^{-3}, on average), Cl^- (0.32 mg dm^{-3}, on average); (Tab. 2).

Table 2. Descriptive statistics of chemical composition of surface water (N=34) from the Obruchev Glacier Basin; Av – average, Min – minimal, Max – maximum, Sd – standard deviation, Cv – coefficient of variation.

	Av	Min	Max	Sd	Cv
	[mg/L]				[%]
Ca^{2+}	1.27	0.92	1.61	0.130	10
Mg^{2+}	0.072	0.054	0.084	0.0073	10
Na^+	0.51	0.36	0.73	0.068	13
K^+	0.073	0.044	0.24	0.035	48
NH_4^+	0.0156	0.0038	0.047	0.010	63
HCO_3^-	3.32	2.02	4.17	0.59	18
SO_4^{2-}	0.74	0.57	0.83	0.052	7
Cl^-	0.33	0.25	0.68	0.082	25
NO_3^-	0.35	0.25	0.46	0.057	16
TDS	6.68	4.48	7.92	0.79	12
Charge balance error	5.7	-0.50	12.4	3.0	52

Lower amounts of the remaining ions were detected and their concentration order was as follows: $K^+ > Mg^{2+} > NH_4^+ > F^- > NO_2^-$. According to indices of chemical weathering (Hounslow 1995), it appears that several different factors are determining elevated Ca^{2+} concentrations. It may be trace amounts of calcium plagioclase in rocks and deposits, aeolian delivery of dust particles from carbonate-dominated basins located to the south (e.g. Pajpudyna River catchment) or an ion exchange process.

Moreover, results obtained indicate that a larger dissolved solids yield was transported during the period with snow cover (106 kg/km^2 day, on average), than at the same time of the year but without snow cover (13 kg/km^2 day, on average) indicating that melting snow is an important factor impacting the yield of dissolved solids in surface waters.

ACKNOWLEDGEMENT

Authors would like to thank Barbara Jaszczyńska and Łukasz Jelonkiewicz (Institute of Geography and Spatial Management. Jagiellonian University) for hydrochemical analysis of water samples; Anna Łatkiewicz (Institute of Geological Sciences. Jagiellonian University) for determining mineral content of rocks and deposits by XRD.

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2.5 | Wetland hydrology

abstract id: **247**

topic: **2**
Groundwater and dependent ecosystems

2.5
Wetland hydrology

title: **Groundwater modelling and wetland flow system analysis of Czerwone Bagno, Biebrza Valley, Poland**

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Groundwater modelling is a widely used tool for identification of flow paths in wetlands, where the soil, vegetation and groundwater flow processes are strongly connected (Wassen, 1990). Spatial distribution of seepage and dynamics of the phreatic groundwater table are the most important parameters that influence main function of those ecosystems (Van Loon et al., 2009). However, the detailed spatial variation of phreatic organogenic aquifer is often neglected in wetland groundwater modelling due to lack of data and complexity of the soil profile. Comprehensive wetland groundwater models should therefore consider spatially distributed physical complexity of surficial layers. Validation of such models should involve dynamic criterions such as inundation time and seasonal variability of unsaturated zone thickness (Chormanski et al., 2009).

Main goal of this study was to examine spatial distribution of groundwater discharge within the Middle Biebrza Basin. Biebrza Valley (Poland) becomes one of the largest coherent wetlands on European Lowlands. To analyze groundwater flow pathways that determine ecohydrological continuum of wetlands, a regional steady-state groundwater flow model based on the MODFLOW code (McDonald, Harbaugh, 1988) was setup. Developed model covers the area of 182,5 km^2 and consists of four layers, which include fluvio-glacial sands as a main regional aquifer and Holocene sediments (peat, moorsh and gyttia) (Falkowski, Złotoszewska-Niedziałek, 2008; Pajnowska, 1996). Physical parameters of organic soils as well as its spatial distribution was based on field research. To quantify groundwater discharge patterns the DRAIN PACKAGE was applied to the whole model domain (Batelaan, De Smedt, 2004). Calibration of presented model included data of groundwater level measured in 33 shallow piezometers located in various wetland habitats. In result of trial-and-error calibration as well as the PEST inverse modelling calibration (Doherty, 1994), root mean squared error of presented model was reduced to 0,3 m. EC and pH measurements were taken into account in the groundwater discharge conditions examination. Spatial analysis of groundwater seepage was compared to actual wetland habitat distribution within the Middle Biebrza Basin. Groundwater catchment mapping indicated areas of rivers and canal's draining impact, which can cause wetlands degradation in future.

ACKNOWLEDGEMENTS

Presented research was funded by EEA Grant (PL-0082) "Biodiversity protection of Red Bog (Czerwone Bagno) — relic of raised bogs in central Europe" led by Department of Hydraulic Engineering and Environmental Restoration, Warsaw University of Life Sciences. The first author was benefitted from a scholarship of the Flemish Government.

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abstract id: **306**

topic: **2**
Groundwater and dependent ecosystems

2.5
Wetland hydrology

title: **Determination of water pollution at Sultansazligi wetland Kayseri — Turkey**

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keywords: pollution, water chemistry, groundwater, Sultansazligi Wetland, Develi Closed Basin

INTRODUCTION

Develi Closed Basin is the sub-basin of Kızılırmak Basin in the border of Kayseri city in Turkey. Area of Develi Closed Basin (research area) is 3197 km^2. Sultansazligi Wetland is placed in Develi Closed Basin and it is one of the seven important wetlands of Turkey and the second important bird habitat of Turkey. Sultansazligi Wetland is also known as one of the most important wetlands of the Eastern Europe and the Middle East. There are Yay Lake, Col Lake, North and South marshland areas in Sultansazligi Wetland Region. This wetland area is a conservation area protected by International Ramsar Agreement. Sultansazligi Wetland has water scarcity and pollution problems. There is only one waste water treatment plant at Develi Closed Basin which is not operating sufficiently. So water pollution is also an important problem for Develi Closed Basin. This study describes surface and groundwater pollution at Develi Closed Basin and gives some recommendations in order to prevent the water pollution.

METHODOLOGY

This study describes surface and groundwater pollution at Develi Closed Basin and gives some recommendations in order to prevent the water pollution. Water samples from surface water, 22 deep wells and 16 springs, had been collected in 3 years (between 2003-2005) and chemical analysis of these water samples had been made by the 12th Regional Directorate of State of Hydraulic Works. Ilipinar Spring and two wells at Calbalma zone have high boron concentration and there is ammonium and nitrite pollution at the wells, located at Yesilhisar District. Surface water samples which had been collected from Camiz and Cöl Lake at Sultansazligi; have high EC values because drainage water feeds Sultansazligi Wetland. Surface water and groundwater contamination has been investigated in the content of this study. Figure 1 shows the location of the project area. Figure 2 shows electrical conductivity (EC) and total dissolved solid (TDS) values of groundwater samples which had been taken from Develi Closed Basin.

CONCLUSION

It is determined that there is ammonium and nitrate pollution at groundwater around Yesilhisar District. Also EC of these groundwater samples are very high. There is only one waste water treatment plant in the basin so industrial and domestic waste water pollute the surface water and groundwater at Develi Closed Basin. Drainage water feeds Sultansazligi and drainage water cause contamination at this wetland. Also the wastewater disposal pollute Sultansazligi Wetland. EC, nitrate, ortho-phosphate and ammonium concentrations are increased and dissolved oxygen concentrations are decreased from 1982 to 1998, 2000 and 2003 because of water pollution at Sultansazligi Wetland.

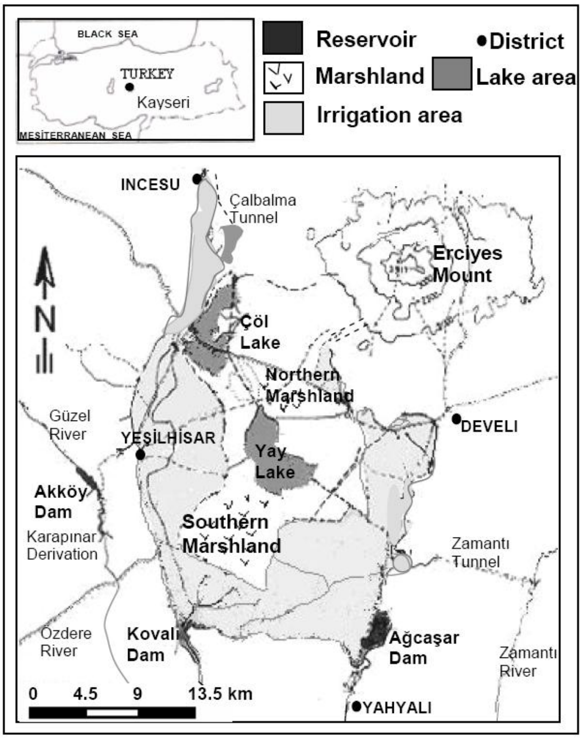

Figure 1. Location of Develi Closed Basin.

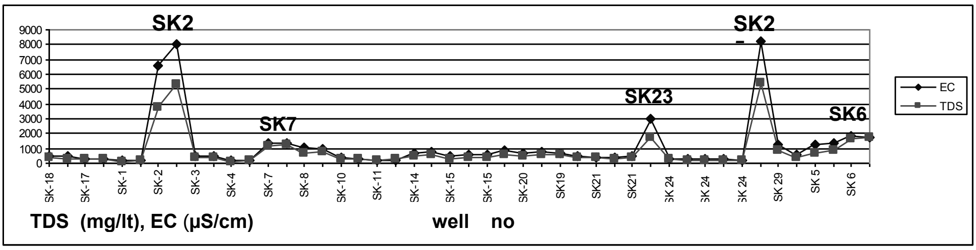

Figure 2. TDS and EC values of groundwater samples.

REFERENCE

Ünsal N., Gürer I., Yildiz F.E., 2006: *Hydrochemical Evaluation of Sultansazlığı Wetland and Develi Closed Basin.* V.GAP Mühendislik Kongresi, Şanlıurfa, 26-28 April 2006, TURKEY.

abstract id: **389**

topic: **2**
Groundwater and dependent ecosystems

2.5
Wetland hydrology

title: **Equivalent density flow model of the Fuente de Piedra Lagoon hydrogeological system (Spain)**

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keywords: variable density, brines, equivalent density, Fuente de Piedra lagoon

The Fuente de Piedra lagoon (Malaga, Spain), has a high ecological value, being an important nesting site for flamingos in the Mediterranean basin, is nature reserve and is included in the Ramsar Convention. The lagoon has a closed basin and a complex hydrogeological system due to the extreme variability between the densities of the shallow aquifer freshwater, brackish water and deep and shallow brines present in the basin and the lagoon. The basin is located in the external zones of the Betic Cordillera, in the so-called Chaotic Subbetic Complex (CSC), made up of sedimentary series Subbetic source, whose age is between the Trias and lower Miocene. It presents a very complex and deformed internal structure, transformed in a chaotic brecciated mass set (Fig. 1a) without internal coherence.

a)

b)

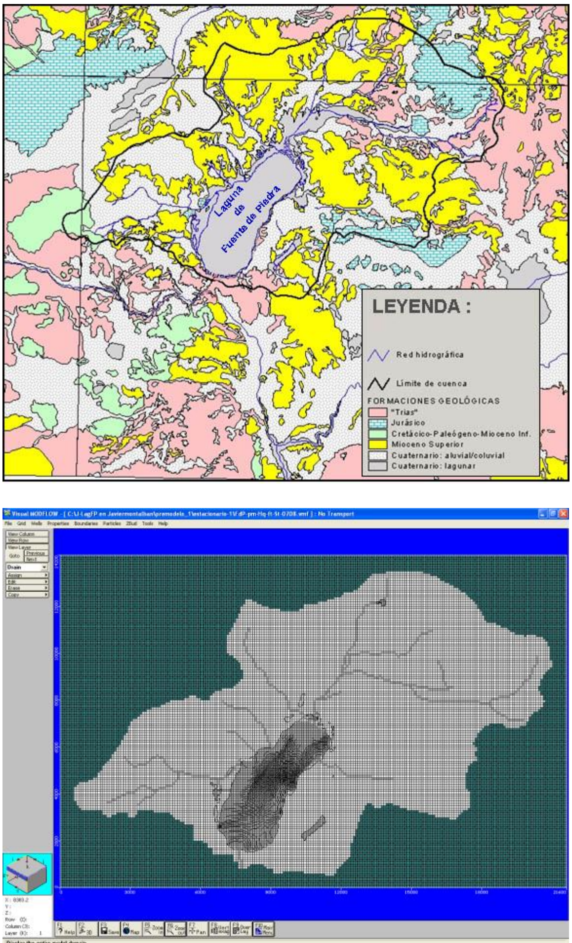

Figure 1. a) Geology of Fuente de Piedra lagoon; b) Levels associated with the condition of drain to the bed of the lagoon.

The hydrological conceptual model (Fig. 2) is made up of three sets of flows that are stratified by their density: 1. A surface flow system consisting of materials from the upper Miocene, Quaternary sediments and blocks of Jurassic limestones and dolomites. Its area coincides with the closed basin surface. 2. An intermediate flow system that would circulate through the low permeability materials from the marly-gypsum matrix and in CSC blocks of limestones and dolomites. Although its exact extent is unknown, he can be considered coincident with the superficial system, without making an obvious error of conceptualization. 3. A deep karst system that would develop into massive accumulations of evaporites and gypsum in CSC. Its extent is regional. These systems discharge into the lagoon of Fuente de Piedra.

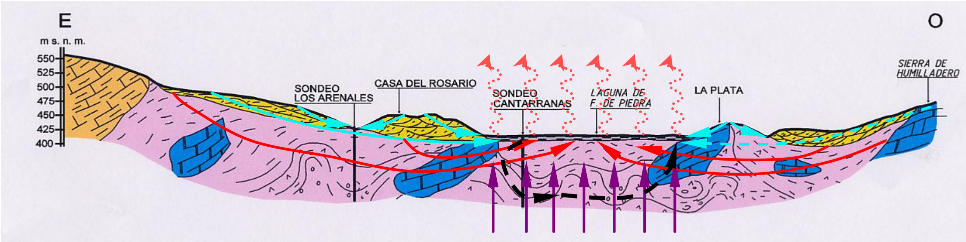

Figure 2. Conceptual model. Genesis brine: process evaporative + evolution hydrogeochemistry + factor lithology.

This paper presents an equivalent density flow pre-modeling of this hydrogeological system, which represents in steady regime the average situation of the hydrological year 2007/08 and the transitional regime of that hydrologic year. It has been implemented in the widely used code MODFLOW. The main objective is to analyze some numerical aspects for the further development of a variable density model of the system. A secondary objective is the study of the "performance" of the equivalent levels boundary conditions associated with the: the preset level, H_{eq}, which represents the piezometric charge of deep and karstified brine levels, and the condition of drain, $C_h (H_{eq} - h)$ (Fig. 1b), assigned to the bed of the lagoon where is the shallow brine.

ACKNOWLEDGEMENTS

We would like to thank Manuel Redón, director of the R.N. Fuente de Piedra lagoon and Paul Carrión professor from the Escuela Superior Politécnica del Litoral – Ecuador.

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abstract id: **437**

topic: **2**
Groundwater and dependent ecosystems

2.5
Wetland hydrology

title: **Range determining factors and tendencies of groundwater level changes in wetland areas**

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keywords: renaturalization, wetland areas, groundwater level

ABSTRACT

The marsh zone areas include about 2 440 km^2 in Kampinoski National Park, which amount nearly 30% of park and its buffer's surface. The specific characteristic of KNP marsh zones is presence of shallow groundwater; mean depth to groundwater table is formed from 0.16 do 2.30 m. Range and tendencies of groundwater level changes in marsh zones are related to the influence of geogenic and anthropogenic factors. Among geogenic factors, the most important sense have distribution and seasonality of precipitation, which determine the value of infiltration recharge, evapotranspiration and watercourse drainage of shallow groundwater system. The basis of the researches on defining the role of factors determining range and tendencies of groundwater level changes in KNP, has been regular monitoring observations conducted in the park since 1999. The results of correlation indicate on high diversification of relation: atmospheric precipitation — depth to groundwater level. Determination of trend on the different significance levels provides detaching areas where relation between groundwater levels and precipitation is so high that influence of other environmental factors indicating on depth to groundwater table could be skipped and areas where the relation is so low, which indicates on influence of various factors. Groundwater level in marsh areas are characterized by large dynamic of changes. Since 1999, the beginning of the observations, downward trend of groundwater table has been observed, after 2003 the character of trend has been conversed. Another decreasing trend has started in 2007 and with assumption of previous tendencies, its inversion will occur after 2011 (after extremely dry year). Geostatistical analysis of spatial difference of mean year amplitude of depth to groundwater level enabled the assessment of surface water influence on groundwater level changes. The areas of highest value of amplitudes are localized in southern part of northern marsh belt and central part of southern marsh belt.

Anthropogenic factors such as: water withdrawal and improper draining system, have not changed in recent years, so their influence can be called as "steady" and acceptably to eliminate in case of elaborating of programs of wetland areas renaturalisation.

INTRODUCTION

The research concerning of the range and tendencies of groundwater level changes to the effort of forecasting the direction of changes were conducted in marsh zones localized in Kampinoski National Park.

For the purpose of Ramsar Convention wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed 6 metres. Preservation of existing wetland ecosystems and renaturalisation of chosen degraded areas are important elements of ecological improvement strategies, biodiversity protection and water resources formation. In The Water Framework Directive (WFD) (2000) wetland and marsh areas are not defined in any way, although are marked throughout pointing its function (article I WFD) and environmental purposes (article IV WFD). Requirements of Directive presented in Annex V, point 2.1.1. and 2.1.2 define good quantitative status of water as if the level of groundwater is not subject to anthropogenic alterations such as would result in any significant damage to terrestrial ecosystems which depend directly on the groundwater body.

Within the KNP, the wetland areas are situated in so called marsh hydrozones (Krogulec, 2004), the regions with similar hydrodynamic and environmental features, which cover an area of about 142 sq. km. Range and tendencies of groundwater level changes in marsh hydrozones are connected to influence of anthropogenic and geogenic factors. Among geogenic factors, the most important sense have distribution and seasonality of precipitation, which determine the value of infiltration recharge, evapotranspiration and watercourse drainage of shallow groundwater system. Anthropogenic factors such as: water withdrawal and improper draining system, have not been changing in recent years.

CHARACTERISTIC OF HYDROGEOLOGICAL AND ENVIRONMENTAL CONDITIONS IN MARSH HYDROZONES

The vide range of previous hydrogeological recognition in KNP, has let to allocated 6 hydrozones in the park (Krogulec, 2004). Spatial configuration of hydrozones refers to a typical for the KNP and its buffer zone, belt configuration of the relief surface. In the vicinity of KNP following hydrozones were distinguished (Fig. 1):

- The Vistula River flood plain terrace
- 2 marsh zones (northern and southern),
- 2 dune and eolian zones (northern and southern),
- accumulative-erosive Warsaw-Blonie terrace called Blonski level (with part of the upland).

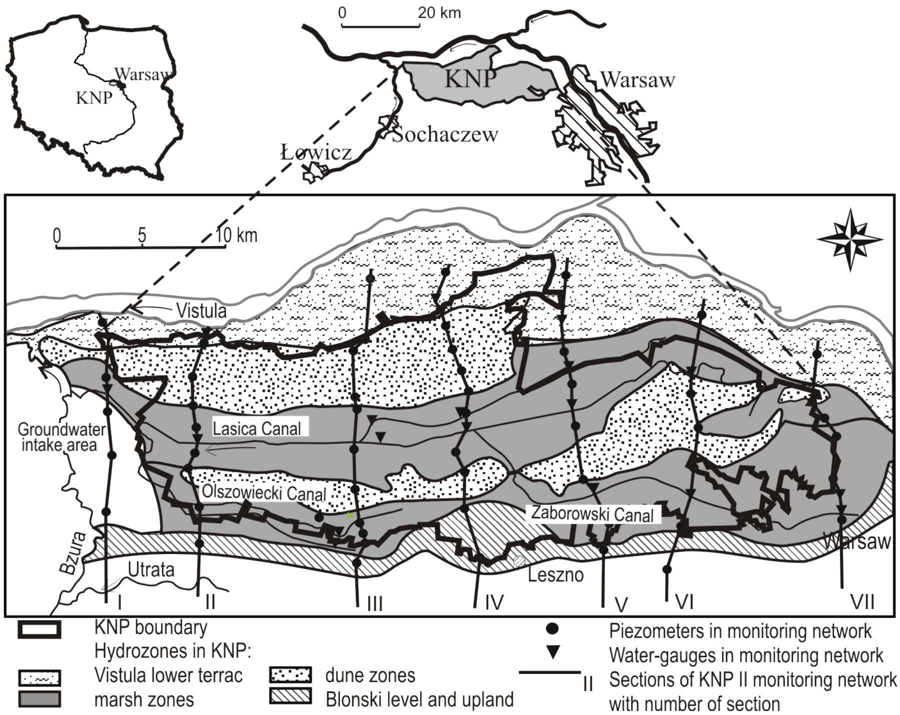

Figure 1. Location map of the Kampinoski National Park (KNP) with type of hydrozones.

On account of specificity of recharge and drainage, distinguished hydrozones are partially related to the division of Lasica catchment proposed by Somorowska (2003), who allocated 2 hydrological different regime zones:

- wet, flat, low-laying zone with shallow groundwater, where groundwater table lays to 1.5 m below ground level,
- dry zone of rather diverse morphology with groundwater table located deeper, less than 5 m below ground level.

In KNP, wetlands are ecosystems, which genesis is associated with water related communities in such an extend that decides on the presence in it hydrophilic vegetation and accumulation of hydrogenic soils. The wetland areas, in which water occurs at a depth to 0.5 m with possibly, a short spring occurrence on the surface, cover approximately 110 sq. km. The moist areas where the water is up to 1 m below ground level cover about 30 sq. km. The marsh zones cover an area of about 2 440 sq. km (Fig. 1).

In a generalized lithological profile, typical for whole Vistula valley, 4 granulometric different beds were distinguished in the region of KPN. Fine-grained sand mixed with silt-grained sand builds an unsaturated zone and the upper part of the aquifer. Below, there is a layer of small thickness consisted of medium-grained sand. Lower in the profile a clear dichotomy of the aquifer can be marked. In the upper part there are 2 complexes of coarse-grained sediments, sand with gravel, gravel and pebbles and fine-grained sand, silt, sometimes sandy clay at the bottom. The geological building of southern and northern hydrozones is similar. The unsaturated zone in terms of lithological composition mostly corresponds with the saturated zone. Under the 0.4 m thick layer of soil, characteristic for wetlands, there are mostly sandy silts or fine-grained sand covering varying and locally medium-grained sand. Underneath, the aquifer is dual likewise in the whole KNP region.

Lithologic differentiation within the aquifer is well illustrated by hydrogeological parameters of individual complexes. The upper part of the aquifer (up to 17.5 m below ground level is characterized by the value of permeability coefficient in the range from 30 to 71 m/d. In the bottom part of the aquifer, the value of permeability coefficient is significantly lower and takes values less than 30 m/d.

Within the marsh hydrozones 3 types of vegetation communities represented by the various phytosociological units were allocated. The largest area is covered by dry and fresh communities, which cover 53.2% all northern zone communities and 37.9% of southern zone. Most of all natural ecosystems are related to this community but also introduced by man. The group of natural ecosystems is composed of forestry and shrub areas as well as meadows, swards and wastelands. Artificial ecosystem, is associated with the planting such as woodlands and shrublands. This unit is often recorded on the desiccated parts of the river valleys, the potential habitats of hornbeam forests on dry ground and in the driest parts of the riverine communities. An important environmental factor is the level of groundwater, which should be occured at 0.4 m below ground level Periodic floodings are rare but in dry seasons, the groundwater table may occur below 1.5 m below ground level (Szewczyk, Domańska, unreported). Other distinguished units occupy small areas, and their location is mosaic.

The moist communication is less differentiate and consist of 2 ecosystems – meadows and forest. It covers 22.0% of northern hydrozone and 13.5% southern hydrozone. The meadows play an important role in retention of surface water thus preventing the mineralization of organic soils (Szewczyk, Domańska, unreported). An important part of this community, especially in the northern hydrozone are ash-alder riverine forests. This kind of forests stabilize the water balance and are one of the elements deciding of natural water retention (Wigry, 2010).

The third distinguished type, most associated with water, is comprised with marsh communities. It covers 24.8% of northern hydrozone and 48.6% southern hydrozone. Vegetation of this type is created by highsedge rushes and current alders. Marsh communities is characterized by visible clumpy structure. For most of the year, in depressions between the clumps, water should be maintained on the surface.

In the area of marsh zones 8 type of soil were evolved. Scope and structure of different types of soils is complex, multifactorial (Konecka-Betley, 1999) and mosaic.

RANGE OF MONITORING RESEARCHES

Geostatistical analysis of monitoring data in the range of groundwater level, based on hydrodynamic datum, allows for presentation of the conclusions in a scope of characteristic of groundwater level fluctuations. The results are an output to forecast of the groundwater level changes. Water system monitoring is based on manual (regular) and automatic (continuous) observations of groundwater level, which has been conducted since 1999 in 56 piezometres located in whole KNP area and its buffer zone. Manual measurements, which are the base of analysis of range and tendency of groundwater level changes, include therefore 11 years or 160 hundred measurements. In the marsh hydrozones: northern and southern, there are located accordingly: 11 and 9 groundwater monitoring points (Fig. 2). Statistical analysis in marsh areas includes 57 hundred of measurements led regularly in fortnightly intervals. This range of measures and research points location allows for: indicating and characteristic of constant and seasonal tendencies, identifying abnormal values and spatial characteristic of groundwater level changes. The major aim of an interpretation of the results of geostatistical analysis, based on monitoring observations, is to define factors influencing on range and tendencies of groundwater state changes.

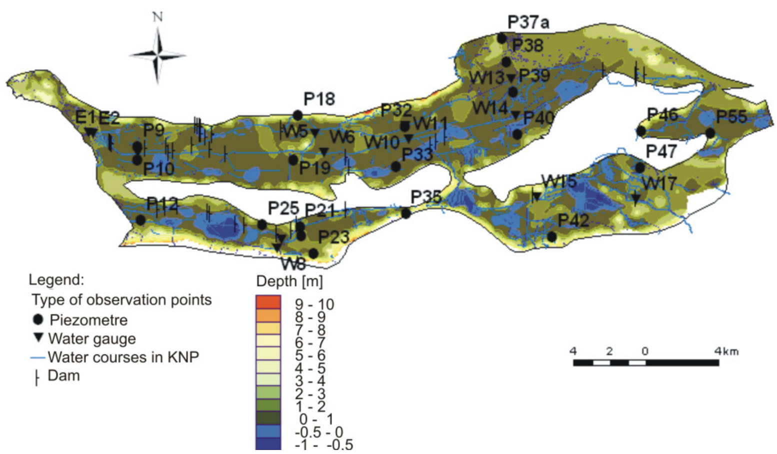

Figure 2. Groundwater depth in the marsh zone areas with number of monitoring point.

CHARACTERISTIC OF GROUNDWATER LEVEL FLUCTUATIONS IN MARSH HYDROZONES

Specification and characteristic of groundwater level fluctuations was conducted in marsh hydrozones in KNP area. In the first stage of statistical analysis of monitoring data, assessment of groundwater level tendency of changes was done by designing trend lines. The conducted analysis of observations from 10-year period by drawing trend line in the form y=ax+b (Krogulec et al., 2009) does not allow for firm defining of change tendency direction. Under this circumstances there is no conclusions pointing at permanent marsh zones desiccatin. More reliable matching is obtained by trend line with third degree polynomial equation (tab.1).

Table 1. Summary of the groundwater level observations in piezometres of marsh hydrozones with the trend lines of changes.

Hydrozone	No. of piezometre	Groundwater depth [m]			Amplitude [m]	Average amplitude [m]	Equation of trend line
		year mean	year max	year min			
Northern marsh zone	P9	0.85	1.45	0.13	1.32	0.86	$y = 9E{-}08x^3 - 5E{-}05x^2 + 0.0059x + 0.7368$
	P10	0.62	1.11	-0.19	1.30	0.70	$y = 1E{-}07x^3 - 5E{-}05x^2 + 0.0062x + 0.5034$
	P18	0.91	1.52	0.30	1.22	0.76	$y = 1E{-}07x^3 - 5E{-}05x^2 + 0.0083x + 0.6153$
	P19	1.37	2.14	0.34	1.80	1.11	$y = -7E{-}08x^3 + 2E{-}05x^2 + 0.0006x + 1.1859$
	P32	0.85	1.35	0.27	1.08	0.68	$y = 1E{-}07x^3 - 6E{-}05x^2 + 0.0058x + 0.8334$
	P33	1.30	2.03	0.59	1.44	1.06	$y = 1E{-}07x^3 - 7E{-}05x^2 + 0.0094x + 0.9801$
	P37A	1.18	1.62	0.57	1.05	0.73	$y = 3E{-}07x^3 - 0.0001x^2 + 0.0156x + 0.6651$
	P38	1.15	1.76	0.10	1.66	0.93	$y = 3E{-}07x^3 - 0.0001x^2 + 0.0184x + 0.5453$
	P39	0.61	1.26	0.04	1.22	0.91	$y = 2E{-}07x^3 - 7E{-}05x^2 + 0.0081x + 0.3966$
	P40	1.47	2.16	0.87	1.29	1.05	$y = 2E{-}07x^3 - 7E{-}05x^2 + 0.0091x + 1.2162$
	P46	1.00	1.60	0.25	1.35	0.91	$y = 1E{-}07x^3 - 6E{-}05x^2 + 0.0085x + 0.661$
	P55	0.70	1.46	0.32	1.14	0.84	$y = 9E{-}09x^3 - 1E{-}05x^2 + 0.0029x + 0.5637$
Southern marsh zone	P12	0.51	1.15	-0.23	1.38	0.82	$y = 8E{-}08x^3 - 3E{-}05x^2 + 0.0032x + 0.485$
	P21	0.16	0.98	-0.48	1.46	0.90	$y = 4E{-}08x^3 - 3E{-}05x^2 + 0.0049x + 0.047$
	P22	0.68	1.60	-0.16	1.76	1.02	$y = -4E{-}08x^3 - 8E{-}07x^2 + 0.0032x + 0.4842$
	P23	1.35	2.41	0.55	1.86	0.89	$y = 2E{-}07x^3 - 0.0001x^2 + 0.0142x + 1.1185$
	P25	1.67	2.25	1.10	1.15	0.88	$y = 9E{-}08x^3 - 5E{-}05x^2 + 0.0076x + 1.406$
	P35	2.30	3.16	1.54	1.62	1.23	$y = 2E{-}07x^3 - 8E{-}05x^2 + 0.0119x + 1.8312$
	P42	0.95	1.86	0.25	1.61	1.15	$y = -9E{-}09x^3 - 3E{-}06x^2 + 0.0022x + 0.784$
	P47	1.95	2.63	1.09	1.54	1.18	$y = 2E{-}07x^3 - 9E{-}05x^2 + 0.012x + 1.5817$

Series of groundwater level observations in piezometres in analysed hydrozones, represented by statistically significant trend lines, indicate on three characteristic periods of groundwater level changes. Trend line, similar in shape to cosinusoide, has two maxima — in 1999 and 2007 (Fig. 3). These years are beginning of the sequences of dry years and the end of wet ones. Since 1999, the beginning of the observations, the downward trend of groundwater table had been noticed. After 2003 the character of the trend had been observed. Following decreasing trend has started in 2007 and with assuming previous tendency, its reversal will occur after 2011 (after extremely dry year).

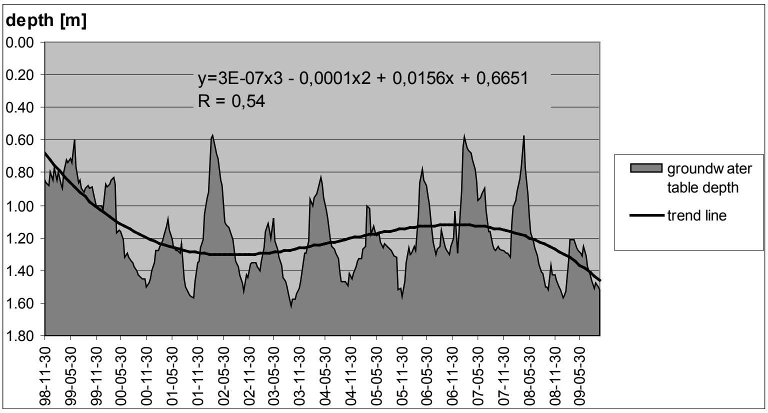

Figure 3. Trend of groundwater level changes on the instance of the observations in P37A piezometre.

Changeability of the trend lines and their degree of matching for series of the observations from particular piezometres are conditioned by many environmental factors (value of correlation index of trend lines with groundwater levels in a range from 0.16 to 0.57). Environment of groundwater in marsh areas is defined by large dynamic of table level. Amplitudes of changes during the year reach magnitude around 2 m in northern belt and above 3 m in southern (Fig. 4). In northern marsh belt annual, high table level in spring season, holds averagely on the level 0.05 – 0.2 m below ground level, the lowest occurs in autumn season and reaches depth around 2 m, with mean year around 1 m below ground level for years 1999–2009. Southern belt is an area, where annual floodings averagely reach a height around 0.30 m and in extremely cases almost 0.50 m. In autumn period low level of groundwater table occurs on the depth of 3 m. Average depth, similarly as in northern belt, occurs on the level of 1 m (for years 1999–2009 this value is 1.19 m).

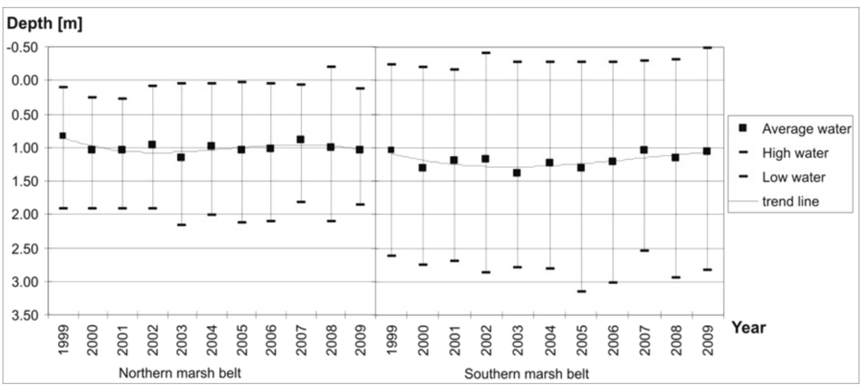

Figure 4. Range of changeability of groundwater level in marsh belts.

Groundwater level changes were also analyzed by comparing difference between following measurements in particular piezometres (regularly measurements in fortnightly intervals). Average change of table level is 0.086 m/2weeks in northern belt and 0.096 m/2weeks in southern. In particular piezometres this changeability forms between 0.057 m/2weeks and 0.122 m/2weeks (Fig. 5). In the area of northern marsh belt spatial distribution of table level is significantly higher than for the changes occurring in the southern marsh belt area. Described changes indicate on differential retention ability of unsaturated and saturated zone in both belts.

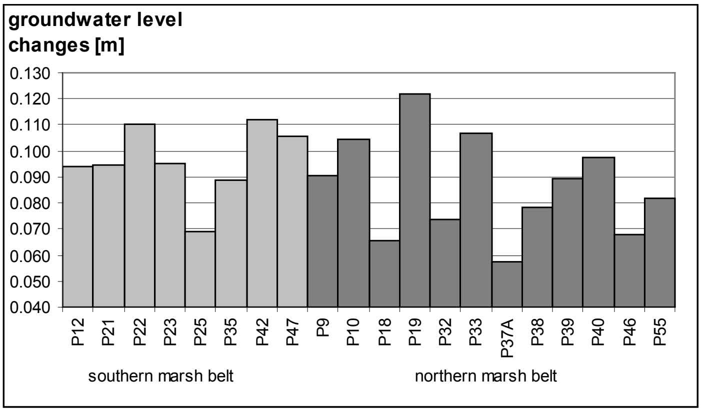

Figure 5. Average changes of groundwater level in fortnightly intervals in piezometres of marsh hydrozones.

FACTORS DETERMINING CHANGES OF GROUNDWATER LEVEL IN MARSH HYDROZONES

The most important factor determining depth to groundwater table in the marsh hydrozone areas is an infiltration recharge. Value of groundwater recharge was a subject of detailed researches (Krogulec, 2004; in print). Conducted researches had a character of quantity regional assessment (Tab. 2). Adapted methodology of an assessment of infiltration recharge value involves data and parameters mostly averaged for whole, delineated area or significantly generalized area, which does not give the basis for analysis of changeability of infiltration recharge value. Differentiated infiltration recharge values, defined by application of varied methods, are related to adopted, different input data and technique of calculations (tab.2). Separated analyses concerning on the influence of evapotranspiration for groundwater level changes were not conducted, assuming that mentioned process limits infiltration recharge value.

Table 2. Infiltration [mm/year] – summary of different calculation method.

Hydrozone	Method of estimation	Infiltration 1951-2000	Infiltration 1998-2002
Vistula flood plains	Empirical method	133-166	118-147
	Water Table Fluctuation	-	73
	Numerical method	-	56–95
Swamp areas	Empirical method	133	118
	Water Table Fluctuation	-	73-100
	Numerical method	-	10-44
KNP area	Meteorological method	121	107
	Empirical method	161	143
	Water Table Fluctuation		143
	Hydrograph separation method	81	50-102
	Numerical method		48-94

An infiltration recharge quantity is mostly connected with precipitation value. On the basis of the data from rainfall stations located in the KNP area and its buffer zone, average precipitation during the period 1986-2009 is 614 mm. According to Kaczorowska's classification (1962), sequences of wet, ordinary and dry years were designated (Tab. 3).

Table 3. Classification of hydrological year type according to precipitation value.

Hydrological year type	Percent of average precipitation from years 1986-2009	Hydrological year in period 1999-2009
Extremely dry	<50	-
Very dry	51 - 74	-
Dry	75 - 89	2000, 2003, 2005
Ordinary	90 – 110	2001, 2002, 2004, 2008, 2009
Wet	111 - 125	2001, 2006, 2007
Very wet	126 - 149	-
Extremely wet	>150	-

Periods of sequences of dry and wet years (Tab. 3) correspond with maxima of trend lines allocated for particular observations in piezometres. The most significant years were: 2003 (dry), when annual precipitation was 84% of the average precipitation and 2007 (wet), when annual sum was 118% of average from years 1986-2009.

Correlation of groundwater level with precipitation was conducted for each piezometre in marsh hydrozones. The results indicate on notably differentiation of dependence: precipitation – groundwater table depth, which illustrates various values of determination coefficient (Tab. 4).

Table 4. Strength of groundwater depth correlation with precipitation value and their significance.

Hydrozone	No. of piezometre	Determination coefficient R^2	Level of significance		
			0.05	0.1	0.2
Northern marsh belt	P9	0.36	YES	YES	YES
	P10	0.28	NO	YES	YES
	P18	0.25	NO	NO	YES
	P19	0.01	NO	NO	NO
	P32	0.43	YES	YES	YES
	P33	0.21	NO	NO	YES
	P37A	0.08	NO	NO	NO
	P38	0.11	NO	NO	NO
	P39	0.29	NO	YES	YES
	P40	0.41	YES	YES	YES
	P46	0.01	NO	NO	NO
	P55	0.34	NO	YES	YES
Southern marsh belt	P12	0.13	NO	NO	NO
	P21	0.41	YES	YES	YES
	P22	0.22	NO	NO	YES
	P23	0.45	YES	YES	YES
	P25	0.38	YES	YES	YES
	P35	0.17	NO	NO	NO
	P42	0.18	NO	NO	YES
	P47	0.13	NO	NO	NO

Strength of correlation apparents in significance of trend line. Three levels of significance such as: 0.05, 0.1 and 0.2 were chosen to analysis. Determination of the trend significance at the particular levels results in choosing the piezometres, in which relation between groundwater level and precipitation is so important, that other environmental factors influencing on groundwater level could be ignored (piezometres P9, P32, P40 and P21, P23, P25) and group, where this dependence is very low and influence of other factors needs special consideration (P37A, P38, P46 and P12, P35).

An attempt to correlate the groundwater table fluctuations in marsh hydrozones with vegetation communities and types of soils (Szewczyk, Domańska, unreported) were also done. Statistical Chi-squared tests were conducted in order to check wheather there is a dependence between groundwater table level and concrete vegetation or soil type occurring in the neighborhood of piezometres. In the first stage of the analysis all piezometres belonged to marsh hydrozones were included. Minimal and maximal groundwater depth values, amplitude and mean amplitude of groundwater table level were compared to vegetation and soil types. A null hypothesis about independence of the characteristic on the level of significance set to 0.05 was assumed. In all calculations value of test statistic was lower than critical value, which was a basis to accept placed hypothesis about independence. In the second stage groundwater monitoring points, in which groundwater table depth highly depends on precipitation value, were excluded from analysis, having left only points, where this relation is inconsistent or absent. Hypothesis about independence of characteristics was assumed again. All analyzed cases reaffirmed existing hypothesis.

Next research stage was a geostatistical analysis of spatial changeability of mean year groundwater amplitude values, which was done on the basis of the results of groundwater level correlation with surface water level (Krogulec et al., 2009). Spatial arrangement was calculated by ordinary kriging method. The best semivariogram marching was achieved with expotential model with parallely situated anisotropy axis and 7 minimal neighbors to include. Mean standard error was calculated at 0.17. The watercourse dams, stopping river outflow are also presented in the result map. In the areas, where there are no dams on the watercourses, mean amplitudes reach over 1 m (max. 1.23 m). In case of presence numerous objects restraining surface water outflow, amplitude values are in range from 0.48 to 0.68 m. Areas characterized by highest values of amplitudes are located in the southern part of northern marsh belt and in the central part of the southern marsh belt (Fig. 6).

Analysis of location particular observation points is the most proper to explain groundwater level changes in piezometres, where the influence of precipitations is unnoticeable (Fig. 2, Fig.6). Piezometre P12 is situated in the area with the highest dam density, which could directly affects on the range of registered groundwater changes. Piezometres P37A and P38 are located in the neighbor of the Vistula river flood plain terrace, where possibility of river influence on groundwater level fluctuations is high. Piezometres: P35 and P46 are located on the verge of the dune and the marsh hydrozones. In the piezometre P19 groundwater level changes are related to neighbor of the Lasica river and the object retraining surface water flow occurred there.

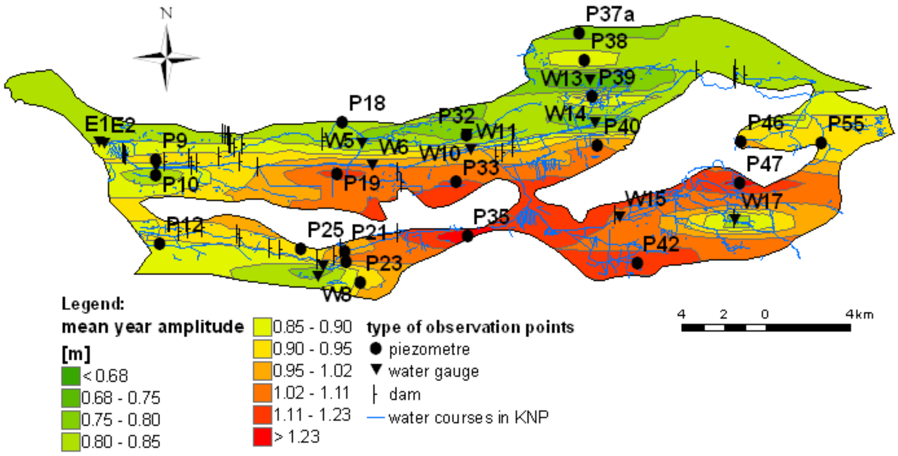

Figure 6. Map of arrangement of mean annual amplitude of groundwater and surface water in marsh areas.

FINAL CONCLUSIONS

Kampinoski National Park is situated in hydrogeological valley unit, typical for Polish Lowland. Protected wetland areas located in the Park were the subject of detailed environmental researches. Planned marsh renaturalization requires diagnosis of the present state and assessment of the tendency and range of water relation changes in this area. Researches were conducted basing on manual groundwater level observations, which have been led in 20 monitoring points located in marsh hydrozones (over 5700 measurements) since 1999 as well as the data elaborated within Project (map of existing vegetation communities and types of soils).

Statistically significant trend lines described by third degree polynomial indicate on typical periods of groundwater level changes. Downward groundwater table trend corresponds with beginning of dry years sequences while increasing trend with beginning of wet years sequences.

The obtained information indicates on directly relation between groundwater level and precipitation value in infiltration recharge function. Detailed correlation of groundwater level with precipitation values in the particular monitoring points reveals that described relation is inconclusive for all monitoring points. Defining of trend significance permits to allocate the regions, where dependence on precipitation is noticeable and the other environmental factors influencing on the groundwater level depth, could be skipped and the group, where this dependence is very low. Statistical Chi-squared test excluded existence of relation between groundwater level and delineated within Project vegetation communities and types of soils. High generalization of vegetation and soil data, in regard of largeness of analyzed area, could not be a basis for description of local environmental conditions and their influence on groundwater table fluctuations in monitoring point.

Geostatistical arrangement of the amplitudes of groundwater depth and in the water courses draining marsh belts, allowed for extracting the areas precisely connected to surface water fluctuations and depended on existing dams. Additionally, analysis of the location explained influence of other factors on water conditions registered in the rest of measure points.

ACKNOWLEDGEMENTS

The study was undertaken as part of a research Development of the method for reconstruction of primary hydrological conditions in Kampinos National Park in order to restrain nature degradation and improve biodiversity status — is implemented within framework of EEA Grants and the own means of Faculty of Geology.

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abstract id: **513**

topic: **2**
Groundwater and dependent ecosystems

2.5
Wetland hydrology

title: **Eco-hydrological monitoring of wetlands in a semi-arid region using remote sensing, GIS, GPS and various data sets: a case study of Konya closed basin, Turkey**

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keywords: wetland monitoring, ETa, NDVI, SEBS, Konya, Turkey

INTRODUCTION

Wetlands are considered the most biologically diverse, fertile, productive, regulatory and informative ecosystems on earth. Desertification of wetland is a common problem mainly driven by scarcity of water due to global warming, depletion of groundwater aquifer, man made construction of extensive drainage canal networks, and reservoirs on rivers feeding wetlands, etc (Komuscu, 2000; Ünal, Sargın et al. 2009). The study was conducted for the wetlands around the lake Tuz in Konya closed basin, in Turkey. The lake Tuz is undergoing desertification, has lost its 60 % water over the past 18 years (Özkaymak, 2009). Konya closed basin has witnessed a decline in groundwater level in the past 3 decades. The wetlands ecosystem, surrounding the lake Tuz, has rainfall and ground water recharge as hydrological inflow where as evapotranspiration as hydrological outflow. The eco-hydrological monitoring of the wetlands gives a clear picture of its dynamics in relation with the surrounding environment. The objective of this study was to monitor eco-hydrological variables by quantifying Actual Evapotranspiration (ET_a) and Normalized Deviation Vegetation Index (NDVI) as hydrological and ecological variables in the wetlands. Estimation of ET_a and NDVI spatio-temporally utilizing earth observation data, field data using remote sensing, Geographic Information System (GIS), Global Positioning System (GPS) and time series analysis were done. For the quantification of ET_a spatio-temporally, the MODerate-resolution Imaging Spectroradiometer (MODIS) data was used for the year 2000, 2004 and 2008. Image pre-processing and Surface Energy Balance System (SEBS) processing were carried out to calculate the energy fluxes and ET_a. Time series of ET_a spatial distribution have been made for different 12 habitat types in the wetland.

STUDY AREA

The wetland, near Lake Tuz, is located between 38°11' - 39°18'N latitudes and 32°15' - 34°15'E longitudes in the Konya closed basin to the south from Ankara in the heart of Turkey. The wetland is of an irregular shape having total area of 7651 km^2. It is situated at an elevation of 905 m above mean sea level (Gökmen, 2009).

RESEARCH METHODS

To study ecological dynamics of spatio-temporally for different habitat types in the wetlands, NDVI, MODIS-derived vegetation index, was used for the year 2000 to 2008. The ecological index, NDVI was also derived from SEBS processing of MODIS data for the year 2000, 2004 and 2008. The ET_a and NDVI was inter and intra related with other meteorological variables to have better understanding of dynamics of the wetlands ecosystem.

RESULT AND DISCUSSION

This section discusses results of the study in quantifying hydrological flux and ecological variables spatio-temporally and finding the inter-relationship among these variables in the wetlands in semi-arid closed basin by utilizing earth observation, GIS, meteorological and field observation data.

Figure 1 is graphically plot of annual mean NDVI and annual rainfall from year 2000 to 2008. The mean NDVI represents mean of NDVI of D6.1, E1.2 and E6.2 habitat types in the wetlands.

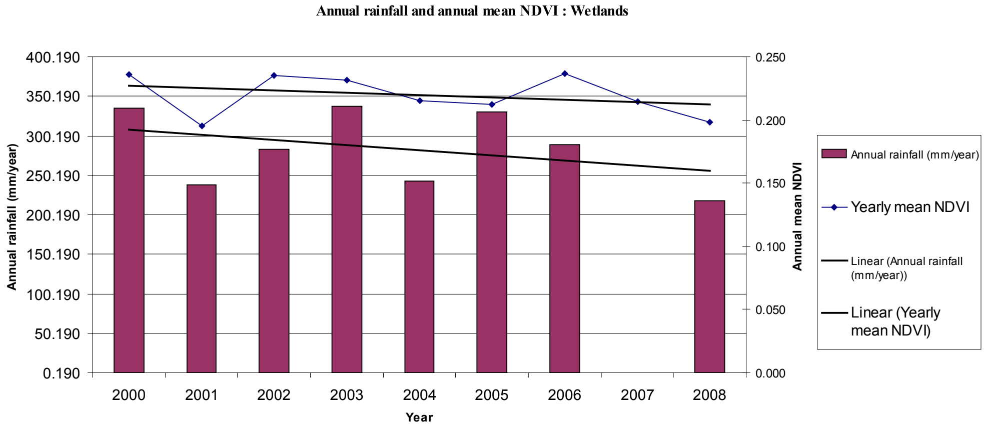

Figure 1. Annual mean NDVI and annual rainfall in the wetlands.

The overall results of the study were that the ET_a and NDVI for various habitat types have declining trend over the year 2000 to 2008. The annual mean rainfall and class A pan evaporation in the study area also had declining trend during overall study period. These demonstrate that the wetlands of Konya closed basin in the semi – arid region are in the process of desertification.

ACKNOWLEDGEMENTS

I express my heartiest appreciation to Dr Zoltan Vekerdy, MSc. Ir. Gabriel Norberto Parodi for the support and guidance extended to me during this research period; Mr. Mustafa Gökmen for preprocessed MODIS NDVI 16 days composite data availability and field visit arrangements; and Mr. Obioma Nze K.E. for valuable discussion at Water resources department, Faculty of Geo-Information Science and Earth Observation (ITC), Universiteit Twente, Enschede, The Netherlands.

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2.6 | Groundwater in eco-hydrology

abstract id: **114**

topic: **2**
Groundwater and dependent ecosystems

2.6
Groundwater in eco-hydrology

title: **Natural and anthropogenic factors that participate in the formation of the water environment and its biotic elements in the karst area of Cracow-Czestochowa upland, Poland**

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keywords: groundwaters, karst, region, water, ecosystems

The necessity for groundwater protection is considered in the European Union in the context of its influence on the state of surface water and connected directly with terrestrial and aquatic ecosystems as well in the context of its significance for the drinking water supply of the human population. An estimation of surface water quality includes among others the recognition of its biological elements of quality: plankton, macrophytes, phytobenthos and benthic invertebrates (Directive No 2000/60/EC, 2000).

The authors have carried out their investigations at the karst carbonate massif of the Cracow-Czestochowa Upland (the CCU) since the 90s of the XX century. The CCU is located within the Silesian–Cracow monocline formed during the Alpine diastrophic cycle. This is the area of an upland karst not fully developed and diversified in its inner structure. The Upper Jurrasic aquifer, which is a Major Ground Water Basin (MGWB No 326), was delimited in this area. Water-bearing carbonate formations are represented by limestones of diversified facies, underlain by marly deposits of Oxford age. The Upper Jurassic carbonates form an extensive generally unconfined aquifer of fractured-karstic-porous type. The carbonate series are strongly cracked and fractured. Wells draining water from the Upper Jurassic aquifer characterize with a large range of yields from 0.4 to 567 m^3/h and drawdowns from 0.11 to 26 m. The specific discharges of wells range from 0.1 to 416 $m^3/h \cdot 1m$. Among 153 wells predominate discharge values from 0.1 to 5 m^3/h (35% of statistical population). Hydraulic conductivity of the rock complex determined by the well tests ranges from $1.3 \cdot 10^{-7}$ m/s to $6.19 \cdot 10^{-3}$ m/s, while the mean value is $1.14 \cdot 10^{-4}$ m/s. Diversification of aquifer water storage capacity is measured by a spring discharge. The spring discharges vary from 0.5 to 187 l/s. Springs of high discharges are mostly ascending karstic springs located along fault zones. Single springs of high discharge occur mainly at the Częstochowa Upland. Their yields amount usually 40–187 l/s, only the yield of the spring group Julianka, located at the catchment of Wiercica river exceeds 400 l/s. Index of springs multiyear variability changes from 2 to 10. The hydrological system of the Upper Jurassic aquifer at the elevated Upland area usually reacts to preceding precipitation with a delay and "inertia". It is, at the same time, an internally diversified system. In the Rudawa catchment area (southern part of the CCU) the water residence time in the aquifer measured as a result of the spring recession curve analysis, ranges from 31–68 days concidering small yield springs (<1 l/s), 52–290 days in the case of up to 10 l/s springs, and 103–340 days for up to 20 l/s springs (Różkowski, 2006). Observations of Wiercica catchment basin pressure fields showed that its reaction time to spring snow melting or continuous rains varies from 3 to 6 months. The recharge of the aquifer takes place at the entire area, directly at the outcrops, or indirectly through the permeable Quaternary sediments. Predominate diffusive recharge. A clear relationship between precipitation intensity and groundwater run-off was determined. Long-term observations conducted in the Upper Jurassic drainage basins revealed considerable diversification of the groundwater run-off modulus during both: low and high-water periods, reaching values from 2.9 to 7.3 $dm^3/s \cdot km^2$ at the Wiercica drainage basin, 2.8–6.0 $dm^3/s \cdot km^2$ at the Prądnik drainage basin and 2.5–6.4 $dm^3/s \cdot km^2$ at the Czarna Przemsza drainage basin**.** The waters of the Upper Jurassic aquifer form in the system of shallow circulation, in the carbonate rock environment. They are typical HCO_3–Ca type, two–ion waters. The calculated saturation indices (SI) for carbonate minerals oscillate around the values indicating a saturation state. Sampled waters are low mineralized (200–450 mg/L), slightly alkaline (pH<8.3) and of moderate hardness (170–300 mg $CaCO_3$/L), with mean concentrations of biogenic elements in springs: 5–25 mg NO_3/L, <0.01–0.15 mg PO_4/L (Różkowski, 2006, 2009).

The Upper Jurassic aquifer is closely connected with surface waters and its biocenoses. In a mineral composition of springs bottom deposits dominate calcite and quartz originating from the overburden strata erosion and accompanying in the minority clayey minerals, dolomite, iron compounds and locally among others metallurgical wastes. The organic matter content (measured at fine sediments only) was low in the majority of studied springs, especially in northern part of the Upland (Galas, 2005).

In the land use of the CCU area predominate farming. In particular catchment areas arable land have 55–80% share, forests — till 20%, while orchards, meadows and pastures have minor meaning. Urban-industrial agglomerations are situated on margins of the CCU area. Local pollutions are connected with farming (mainly with water-supply-and-sewage-disposal management), aerial sources – with air pollution and use of fertilizers and pesticides. Due to protection of the natural environment and groundwater resources, most of the area of the CCU is protected by law (Ojców National Park, Landscape Parks, Nature 2000 area).

The presented investigations refers to hydrogeoecological studies. Investigations have dealt with the water environment regime and also with the presence of invertebrates in it (Humphreys, 2009). These habitats connected directly with groundwater outflow are treated in the Habitat Directive of the European Union as very valuable and they have the rank of European cultural heritage.

In the area of the CCU there are several hundred springs. They are not only the local groundwater drainage points but they also set composite ecosysytems depending on hydrologic conditions (Springer, Stevens, 2009).

Up to now the entire invertebrate fauna have been studied in about 30 springs only whereas single taxonomic groups such as water mites (Biesiadka et al., 1990) and caddisflies (Czachorowski, 1990) have been investigated in numerous objects. Studied springs differed by discharge values, type of bottom sediments (fine or coarse grains), amount of organic matter accumulated on the bottom and concentrations of nutrients in water. Moreover several studied springs were encased what changes some abiotic parameters e.g. temperature, organic matter content in the sediments (Galas, 2005) and in consequence – had influence on the composition of benthic fauna communities and their densities.

The durability and stability of habitat conditions in springs results in the occurrence of a specific fauna. In the area of the CCU the species living exclusively in the springs (named crenobionts) are represented by a few species of water mites (Hydracarina) (Biesiadka, Kowalik, 1999) and small crustaceans (Ostracoda) (Matolicz et al., 2006). Strictly crenobiontic species are not found in other invertebrates groups, but crenophilic taxons are common in various groups. Sometimes even taxonomic name of genera shows their connections with the springs e.g. *Krenopelopia, Krenosmittia* or *Crunoecia*. Typical mountain species living in cold waters with small temperature fluctuations (named oligostenothermic species) are the most important group of spring fauna in the area of CCU. Among them there are some relict species, e.g. flatworm *Crenobia alpina* and snail *Bythinella austriaca*. The populations of these species living in the CCU area are isolated from mountain populations probably since the end of the last glacial epoch, but genetic studies are necessary for the confirmation of their actual separation. Numerous specimens of *Bythinella austriaca* are present in almost all the studied springs (Dumnicka et al., 2007) but *Crenobia alpina* is known from a few localities only. This species inhabits springs located along the middle course of Sąspówka stream, moreover it was found recently in one spring situated in Pilica–Piaski village (Tyc, 2004). It seems that other population, known from Źródło Zygmunta spring disappeared in 80. totally (Skalska, Skalski, 1992). Larvae of a few insect species such as *Diura bicaudata* (stonefly, Plecoptera) and *Drusus trifidus*, *D. annulatus* and *Plectrocnemia conspersa* (caddis-fly Trichoptera) were also found exclusively in the springs and a short sector of headwater streams (hypocrenal) characterizing by low temperature. Several beetles (Coleoptera) live permanently (as larvae, pupae and imago forms) in such waters. In the CCU area they are represented by species from the genera *Agabus*, *Hydraena* and *Elmis*. The highest densities of these species were stated in the spring niches and they decreased along the stream very quickly. Only in Sąspówka stream the above mentioned species and others which prefer low temperature but can survive its fluctuations, inhabited long stream sectors due to the presence of numerous near-channel or channel springs. It seems that the populations of oligostenothermic insects living in remote springs are not so strictly isolated as populations of flatworms or snails because adult forms of insects can actively migrate.

The most common species in karst running waters in the CCU area is *Gammarus fossarum* (Crustacea), which was found in all the studied springs. In some of them this detritivorous species forms about one half of the benthic community (Dumnicka et al., 2007).

Interesting group of species, which may possibly be found in the springs, are stygobionts (the name originated from the underground Styx river known from Greek mythology). In the area of CCU the presence of a few such species was confirmed (Dumnicka, 2005, 2009). Crustacean *Niphargus tatrensis* vastly distributed in underground waters of Poland, in karst and non-karst areas (Skalski, 1981), was found in a small number of springs situated along Prądnik and Sąspówka streams and in Źródło Zygmunta spring (Dumnicka, 2005). Moreover two species of stygobiontic oligochaetes were present in the studied water bodies: *Trichodrilus cernosvitovi* in the southern part of CCU (Dumnicka, 2005) and *Gianius aquedulcis* in the northern part, exclusively in springs situated along Warta river in Mstów village (Dumnicka, 2009). Stygophilous species were more common and they had representatives in more invertebrate groups such as ostracods, hydracarins and oligochaetes. In Poland among insects larvae, widespread in surface aquatic environments, stygobiontic as well as stygophilous forms are absent.

Many semi-aquatic species were also present in the studied springs, what is typical for small water bodies. Among them the most numerous were oligochaetes (Dumnicka, 2006) and larvae of flies (Diptera) (Dumnicka et al., 2007).

Beside remarkable groups of fauna shortly presented above, there are many eurybiontic species living in the springs. They belong to various taxonomic groups and their percentage share in the whole benthic fauna usually increased in encased or polluted springs, where typical inhabitants of such water bodies disappeared.

The majority of springs situated on CCU area, above all in its southern part, are small, that is why the diversity of benthic fauna in particular spring is not high. Existing faunistic and ecological studies on the springs located in the CCU indicate that they are highly diverse what resulted in a high number of species found in this area.

The composition of fauna living in springs is influenced by hydrogeological conditions such as spring discharge, spring variability index, chemical composition of waters, physical–chemical properties (temperature, water reaction — pH, oxidability, redox potential — Eh), hydrostatic pressure, their surroundings, what decides about the input of biogens and allochtonic organic matter into the spring and by disturbances, especially in the form of anthropopression. Springs are situated mainly in the areas covered with forests and protected by law. Even the localisation on protected areas does not assure the preservation of natural biocenoses in such springs, what could be observed in Źródło Zygmunta spring where the invertebrate fauna almost disappeared (Dumnicka et al., 2007) due to the strong penetration by tourists.

About 50% of springs preserve their natural character. The most important threat for springs and their biocenoses set stream regulation works and direct intervention in zone of spring niche (among others spring tapping-seizing, municipal waste dumping, tourism, road traffic). Up to now the information about diversity of fauna and the composition of spring-living communities is only fragmentary. Moreover, there are no complex studies on fauna which take into account the presence and conditions of populations of crenobiontic and oligo-stenothermic species in individual springs. That is why the more strictly protection is necessary and multidisciplinary studies are needed. The study, done together with the recognition of regional management and pollution sources, will allow the influence of natural and antropogenic factors on water environment and its biotic elements within the karstic area of the CCU to be estimated. They will also show the current trends of this environment is development. In addition to the study aspect the investigations also have practical and methodological aims. For the purpose of providing the effective protection of karst water and its ecological environment in the area of the CCU, the further development of research procedures typical for the karstic areas is necessary.

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abstract id: **182**

topic: **2**
Groundwater and dependent ecosystems

2.6
Groundwater in eco-hydrology

title: **Patchiness of soil and wetland salinization due to hydrodynamic interplay between gravity-driven and overpressured groundwater flow regimes, Duna-Tisza interfluves, Hungary**

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keywords: groundwater, gravity-flow, over-pressure, salinization, Hungary

The Duna-Tisza Interfluve in Hungary has an agricultural economy but is plagued by severe problems of soil and wetland salinization. The study's objective was to determine the source of the salts and the controls and mechanism of their distribution.

Based on regional hydrostratigraphic, hydraulic and hydrogeochemical evaluation, two groundwater flow-domains were identified: a gravity-driven meteoric "fresh" water domain and an over-pressured deeper domain of saline water. Gravitational flow-systems are perched hydraulically upon the rising salt waters. A schematic pattern of groundwater flow was proposed for the Interfluve region, the "Duna-Tisza Interfluve Hydrogeological Type Section" (Fig. 1) (Mádl-Szőnyi and Tóth, 2009). (Ca,Mg)-$(HCO_3)_2$-type meteoric fresh water infiltrates in the ridge region of the Interfluve and is hydraulically perched on the rising saline waters of the overpressured regime. The salts are found to originate partly from the NaCl-type water of 10000–38000 mg·L^{-1} TDS of the basement and deep-basin sediments. This water rises into a zone of the higher Neogene sediments where the $NaHCO_3$-type waters (TDS: 450–2500 mg·L^{-1}) are the second source of the salts. These waters mix and the Cl^-, originated from the basement can be used as a natural tracer of deep waters at near surface depths.

Salinity distribution at the surface is explained by the tectonically driven cross-formational rise of deep saline waters channeled in and mixed with fresh waters by near-surface sediments and gravity flow-systems.

The hydrodynamic interaction between these fresh and saline deep waters seems adequately to explain the pattern of soil and wetland salinization as well as the contrasting chemistry between the wetlands of the low-lying Danube Valley and the elevated Ridge Region.

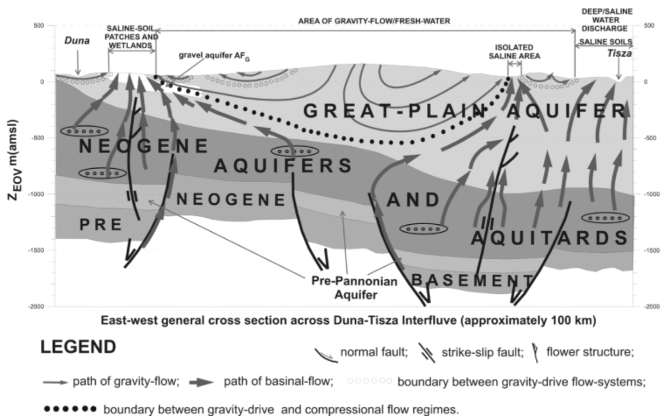

Figure 1. The Duna-Tisza Interfluve Hydrogeological Type Section.

ACKNOWLEDGEMENTS

The authors are pleased to acknowledge the assistance and contributions received from the following agencies and individuals for data and logistical support: the Kiskunság National Park (A. Iványosi-Szabó); the Institutes for Soil Science and Agricultural Chemistry, and Ecology and Botany (Zs. Bakacsi, Zs. Molnár) of the Hungarian Academy of Sciences. Gy. Pogácsás, Associate Professor, Eötvös Loránd Science University (ELTE). L. Máté; K. Nyúl; Sz. Simon; R. Varga, F. Zsemle, B. Czauner former students of ELTE, kindly contributed results from their graduate theses. The research was supported by the Hungarian OTKA grant No. T 047159 to J. Szőnyi-Mádl, and the Canadian Natural Sciences and Engineering Research Council's „Discovery grant" No. A-8504 to J. Tóth.

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abstract id: **202**

topic: **2**
Groundwater and dependent ecosystems

2.6
Groundwater in eco-hydrology

title: **From individual cells to aquifers: Modelling the groundwater ecosystem**

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keywords: individual-based model, groundwater ecosystem, contamination degradation, natural attenuation, physiology

INTRODUCTION

Groundwater is increasingly threatened by contamination. We know that micro scale heterogeneities influence the bioavailability (both in terms of contaminant concentration and biotic population density) and hence the decay rates of contaminants. In the WATERBUGMODEL project, a contaminant degradation model for the groundwater ecosystem is developed that accounts for the biological functions and processes of a complex community. With this model it will be possible to evaluate the importance of such heterogeneities and the various functionalities of microorganisms and higher organisms in natural attenuation and bioremediation.

APPROACH

Increasingly, microbial aspects and possibilities in contaminant degradation are acknowledged, but we still lack the in-depth insight in biological degradation processes. Field monitoring will always remain of limited explanatory power. Models with high spatial resolution can provide theoretical insights into the groundwater ecosystem that cannot be obtained from field sampling.

Protozoan predation stimulates microbial productivity (Mattison, Harayama, 2001). The same might be true for higher organisms and viruses in groundwater. To implement such biological components in current schemes of groundwater management, there is an urgent need for models taking into account the (i) patchy distribution of resources and microbial and faunal growth and (ii) the interactions in the groundwater food web in computational models of the groundwater aquifer ecosystem.

In conclusion, the major objectives of the scientific program of the WATERBUGMODEL project are:

- to explore the importance of spatial heterogeneity of organisms and pore structure on microbial degradation, as well as the prediction of feedback mechanisms,
- to evaluate the impact of protozoan and faunal grazing on microbial degradation, and thus
- to guide experimentation to verify the efficiency of management measures.

These goals are achieved by coupling the existing individual-based model platform iDynoMiCs to the GeoSysBRNS simulator (Centler et al., 2010), a model and solver for aquifer-scale groundwater-relevant processes and parameters. A hierarchical approach will be used to scale up the results from the grain surface scale to the aquifer field scale through the use of different geometries at process relevant scales for microbial degradation. In first steps the heterogeneous biological functions will be evaluated in simplified geometries.

ACKNOWLEDGEMENTS

This project is supported through an EU FP7 Marie Curie IE Fellowship to SIS.

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abstract id: **210**

topic: **2**
Groundwater and dependent ecosystems

2.6
Groundwater in eco-hydrology

title: **Assessment of the groundwater ecosystem**

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keywords: groundwater, community, ecosystem, microbial, threshold

INTRODUCTION

The role of organisms in the groundwater ecosystem for the global turnover of materials and energy is not known. Estimations that 6–40% of the bacterial biomass of the earth is living subterranean (Griebler, Lüders, 2008), show that the biomass of this ecosystem has great importance. The groundwater ecosystem plays a role in the global carbon and nitrogen cycles and has importance for the quality of drinking water resources and surface water.

The groundwater ecosystem is characterized by geological, geochemical and hydrological conditions as abiotical factors. Under the given circumstances a typical biocoenosis is built, which is fundamentally different from those in surface waters. Due to the darkness in the groundwater biotop there are no primary production by photosynthesis. Nutrients are not produced on site but yielded from outside. The area groundwater is largely anaerobic.

The quality of groundwater in Germany are assessed only by chemical criteria, at which toxicological aspects for humans stood in front as standards (Geringfügigkeitsschwellenwerte — no deterioration clause). A groundwater damage occurred when these human toxicological standards were exceeded. In surface waters the quality is detected since a long time by indicator organisms. This time research projects deal with the transfer of this system to groundwater and to find some indicator organisms in groundwater. The EC groundwater directive (2006/118/EC) demands "Research should be conducted to provide better criteria for ensuring groundwater ecosystem quality".

INDICATOR ORGANISMS IN GROUNDWATER

Due to the anaerobic conditions in the groundwater biotop the diversitiy of microorganisms is much higher than the diversity of invertebrates. Invertebrates needs oxygen for their life and are not able to exist in anaerobic deeper groundwater. Investigations to detect indicator organisms like crustaceans or nematods in groundwater for an assessment of biocoenosis can only be used in groundwater areas under aerobic conditions. The research of this groundwater invertebrates are just beginning so this time neither an sufficient amount of species nor the knowledge of their pretension to habitats and environmental conditions are present. There is a lack of bioindicators for groundwater habitats.

Another problem is the sampling technique. The conditions in the well water are different from the environment. So it is necessary to use a sampling technique that collects organisms of the representative groundwater area. This is much easier for microorganisms than for invertebrates, because one can use a radial pump with high through flow according to the DIN/ISO. This makes possible one sampling of groundwater for chemical and micro- and molecularbiological investigations. The results of the KORA project show that emissions out of landfills into the groundwater have an influence of the ecosystem. The DGGE-fingerprints of bacteria in groundwater influenced by landfill emissions differ, dependent from the concentrations of the emissions, significantly from those of the not influenced ones (Struppe, 2006). So an assessment of the groundwater ecosystem has to refer to main and can only refer to microorganisms.

METHODS

In this investigation the groundwater microbiocoenosis in the area of nine German landfills are characterised by DGGE-Fingerprints and DNA-Microarrays. The DGGE-Fingerprints were done as described by Kilb (1999) and Eschweiler (1999). Parallel the emissions from the landfills into the groundwater are determined.

The sample was taken according to the DIN 38 402 T13 with a Grundfos MP1-pump when the in situ parameters show constant values and the volume of the well tube was exchanged three times. Relative high through flow (10–12-L/min.) provides that sessile microorganisms will be teared from aquifer material and registered. The groundwater sample then were anaerobically filtered and the DNA was extracted, cleaned amplified by PCR and then separated by denaturing gel electroohoresis (DGGE). The DGGE-Fingerprints were compared by Sørensen-indices and Cluster analysis. The resulting dendrograms show the similarity between wells at one landfill. For more information an additional quantification of the bacteria was done using fluorescent dyes.

There is a definition of groundwater damage by Kerndorff et al. (2006), which we used too for influence definition (Fig. 2). To define not influenced groundwater, the background concentrations have to be detected. This is done by adding the 84.1%-percentiles of the groundwater main ions (Na, K, Ca, Mg, Fe, Mn, HCO_3, NO_3, NH_4, Cl, SO_4, TOC) of numerous groundwater (Schleyer, Kerndoff, 1992). The sum is 760 mg/L. So groundwater with concentrations of groundwater main ions <800 mg/L are defined as not influenced (neutral wells).

RESULTS

The results show that the landfills cause groundwater damages or at least an increase compared to the upstream. Normally the concentrations downstream are higher at the border of the landfills and were decreasing with distance. A dendrogram of the Sørensen-indices of a landfill shows that the microbiocoenosis of two wells is separated from the others (Fig. 1).

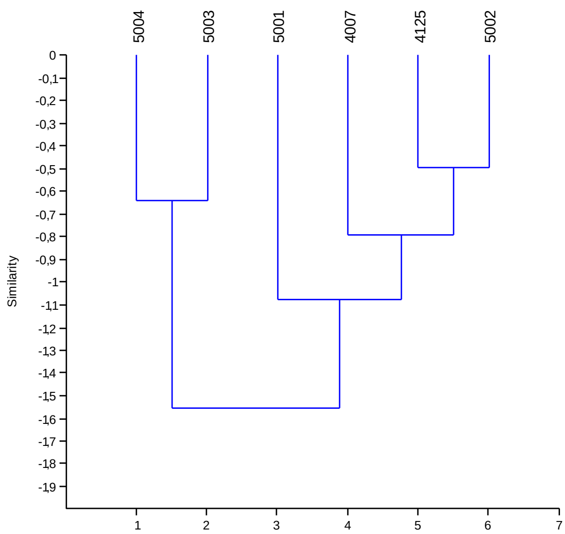

Figure 1. Clusterdendrogram of Sørensen-Indices from wells of a landfill.

One well (5003) is added to the neutral well (5004) the others are separated from the neutral well. The concentrations of the main ions in the separated wells ranged from 1100 mg/L up to more than 2500 mg/L. The well 5003 has a concentration of maximal 600 mg/L and the neutral well 390 mg/L. At all landfills it can be shown that downstream wells with concentrations of main ions below 900 mg/L in clusterdendrograms of the DGGE-Fingerprints are added to the neutral wells. If the concentrations of main ions are higher than 1200 mg/L the changes in the groundwater microbiocoenosis compared to those of the neutral wells are so significant that the wells are separated in clusterdendrograms (Tab. 1).

Table 1. Addition and separation of wells in clusteranalysis of Sørensen-Indices.

Landfill	Wells added to the neutral well	Groundwater main ions [mg/L]	Wells separated from the neutral well	Groundwater main ions [mg/L]
1	5003	599	4007, 5001, 4125, 5002	1088–2839
2	none	—	4653, 4654, 4010*, 4024*, 4042*	942–960 (533–940)*
3	4010, 4024, 4042	533–940	4003, 4011, 5008, 5009	1089–1788
4	4019, 5006	969–1015	4002, 4012, 5007, 4001	998–4368
5	none	—	DE16, DE II, DE VI, DE VIII	1303–1673
6	none	—	GWM 8, GWM 9, GWM 12	1733–5400
7	none	—	W08/029, W08/032	1634–5189
8	MA2a, MA16	260–1174	GWM 18	3652
9	P5/01, P4/01	787–808	none	

* wells are added at landfill 3 to the neutral well.

Wells with concentrations between 900 and 1200 mg/L are sometimes separated from neutral and sometimes added to the neutral well. So this is similar to the groundwater damage definition by Kerndorff et al. (2006) (Fig. 2).

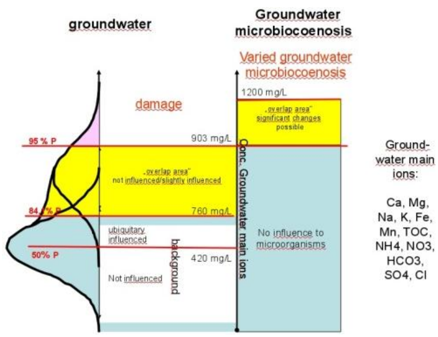

Figure 2. Thresholds for assessment of groundwater and groundwater ecosystem damages.

It is possible to define a threshold of non-toxic emissions, which causes significant differences in the groundwater ecosystem. Of special interest is that the threshold of 900 mg/L is the same for a groundwater damage and for not influenced groundwater microbiocoenosis. These changes in assembles of groundwater microorganisms can cause in two effects. First there are toxic effects of other components in the emissions, which lead to a decrease of bacterial diversity and amount. Second there are adaptations of the bacterial settlement to the emissions, which lead to an increase of bacterial amounts, caused by better nutrition situation downstream of landfills.

Quantifications of bacteria at the investigated landfills show that both effects can be observed. At one landfill the amount of bacteria near the landfill is lower than some 50 meters away, although the concentration of the main ions is higher. This is caused by pesticide containing emissions (Fig 3). At the other landfills the amount of the bacteria show an increase downstream, which is decreasing with distance and concentration of the main ions and nutrients.

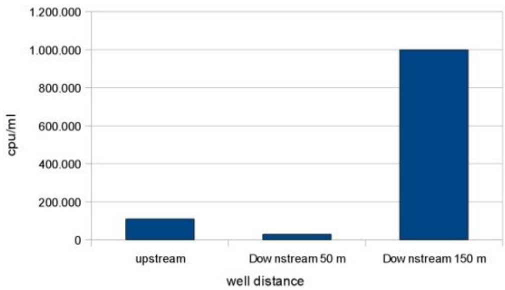

Figure 3. Amount of bacteria in groundwater of a landfill.

SUMMARY AND CONCLUSIONS

A significant change of groundwater biocoenosis caused by non toxic landfill emissions is possible. Above a threshold of 1200 mg/L main ions in groundwater the assemblage of microorganisms changes. This is an adaptation to the nutrient offer and coupled with an increase of the amount of bacteria in groundwater. This adaptation and increase is leading to natural attenuation effects. If the change is caused by toxic emissions the abundance of the bacteria decreases. This is of great importance for the assessment of groundwater biocoenosis. A change in groundwater micorbiocoenosis together with a decrease of the amount of microorganisms is considered as a damage. On the other hand an adaptation leading to natural attenuation is a "positive damage" in microbiocoenosis which reduce the geochemical damage. This is a difference to the assessment of surface water. The DGGE fingerprints allows only the comparison between influenced and not influenced groundwater microbicoenoses. The fingerprints give no information about the species behind the bands in the gel but they detect species, so local differences are emphasized to much. Desiderable are an evidence about the biodiversity in groundwater habitats. This will be possible by using DNA-microarrays which can differentiate groups of microorganisms with respect to their dependence on metabolism. The outlined investigation could be improved by using DNA-microarrays and is a field proved standard for the description of the groundwater ecosystem quality.

ACKNOWLEDGEMENT

The authors wish to thank the BMBF for funding KORA TV 4.1 (FKZ.:0330501) and for funding the following project PRONABAC (FKZ: 033 R040 A).

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abstract id: **459**

topic: **2**
Groundwater and dependent ecosystems

2.6
Groundwater in eco-hydrology

title: **Proposed classification scheme for groundwater-dependent ecosystems in mountainous regions**

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keywords: groundwater-dependent ecosystems, mountains, hydroecology, stable isotopes, Switzerland

INTRODUCTION

It is increasingly recognized that groundwater-dependent ecosystems (GDEs) are of special interest from an ecological (high natural value) and socio-economical (many supplies of services and functions) perspective (e.g. Groundwater Directive of the European Parliament, 2000/60/EC). Groundwater connects the biocenosis in the aquifer itself and supplies water, nutrients and energy to surface waters and terrestrial ecosystems (Eamus and Froend, 2006). New strategies for the ecological characterization of groundwater bodies and the protection of its biodiversity are currently developed (Hahn, 2009). In particular, specific ecologic (e.g. endemism) and climatic features of mountainous areas (*e.g.* glaciers, snow) have to be taken into account (Viviroli, Weingartner, 2004; Cantonati et al., 2006). In order to evaluate the ecological role of groundwater resource in alpine areas, we are developing two axes of research:

1) Establishment of a typology for GDEs summarizing the different types of interactions between groundwater and vegetation;
2) Eco-hydro-geological field studies in Switzerland, focusing on the groundwater-plants relationships, with a particular interest on the degree of dependency of different species on the groundwater resource.

GDE'S TYPOLOGY IN MOUNTAINOUS AREAS

The GDEs typology takes into account the spatio-temporal variability of flow (hydroperiod, source and movement, quality of the groundwater) and expressions (in caves, in rivers through hyporheic zones, in marshes, etc…). Additionally, the species and communities that depend on groundwater have to be known.

Some drivers, i.e. the factors which influence nutritive and physical role of groundwater need to be characterized at the appropriate scale: roles of groundwater are dependent on (Figure 1):

- Regional scale characteristics, mainly type of climate,
- Aquifer scale characteristics from geometrical ones (Geographical and geological settings) to hydrological ones,
- Emergence scale characteristics (types and geometry of outlets, microclimate, relationship with surface and meteoric waters, type of biocoenosis and its metabolism and strategies of development).

The groundwater occurrence constrains numerous factors that control existence and biodiversity of GDEs. Several ecological attributes related to hydrogeological system functioning that can be important for GDEs:

- Hydrologic regimes: quantity, timing, location and duration of water delivery,
- Water chemistry: groundwater integrates initial chemical conditions of the recharge water and then the geologic materials composition through which the water circulates. Groundwater can also be punctually or continuously influenced by dissolved species in relation with the land occupation and management,
- Specific temperature conditions: One of the specificity of groundwater is that temperature is maintained stable along the year. Temperature exerts a direct control of all metabolic processes,

- Biocoenosis feedbacks on its biotope, including the hydrogeological processes, such as infiltration, evapotranspiration, and chemical feature of discharging water.

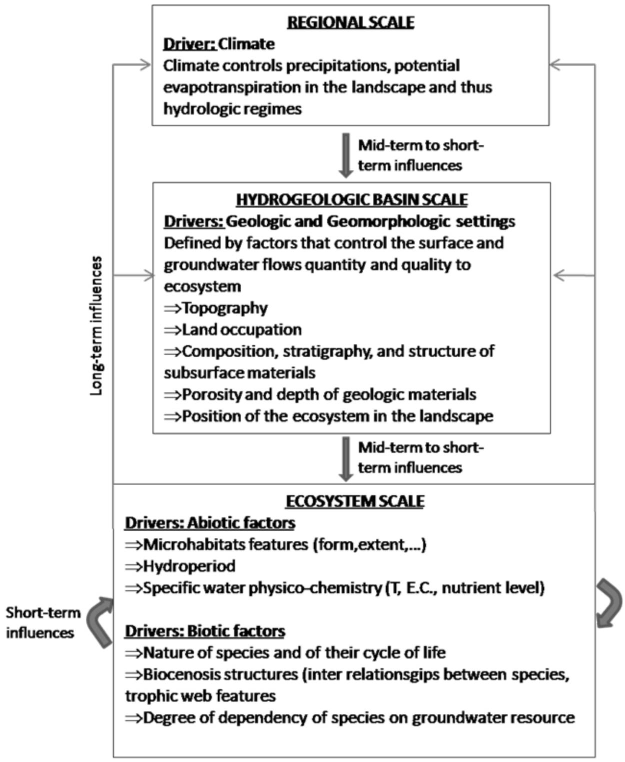

Figure 1. Conceptual scheme of drivers and variability relevant with aquifers functioning and ecological consequences on the GDEs.

By following the water cycle from recharge to surface waters depending on groundwater discharge, the main GDEs identified in mountainous areas are: ecosystems linked with springs, lentic ecosystems (lakes, wetlands), lotic ecosystems (streams fed by springs, rivers) and associated phreatophytic or terrestrial ecosystems (riparian zones, alluvial plains). In order to propose a complete scheme of eco-hydrogeological functioning at the ecosystem scale, a case study site representative of specific conditions in mountainous areas has been selected.

ECO-HYDRO-GEOLOGICAL FIELD STUDY

The second axis of the study consists of an eco-hydrogeological study of the Bois de Finges site (Figure 2) which is a 6 km long alluvial zone in the upper Rhone valley, near Sierre (Wallis, Switzerland). From a hydrological point of view, the Rhone has a glacio-nival regime type in this area. Between low-flow and high flow periods, groundwater levels strongly vary (about 8 m) near the main river-aquifer interaction zone in the most upgradient part of the site. In contrast, the downstream part of Pfyn is characterized by a low groundwater level fluctuation of about 1 or 2 m.

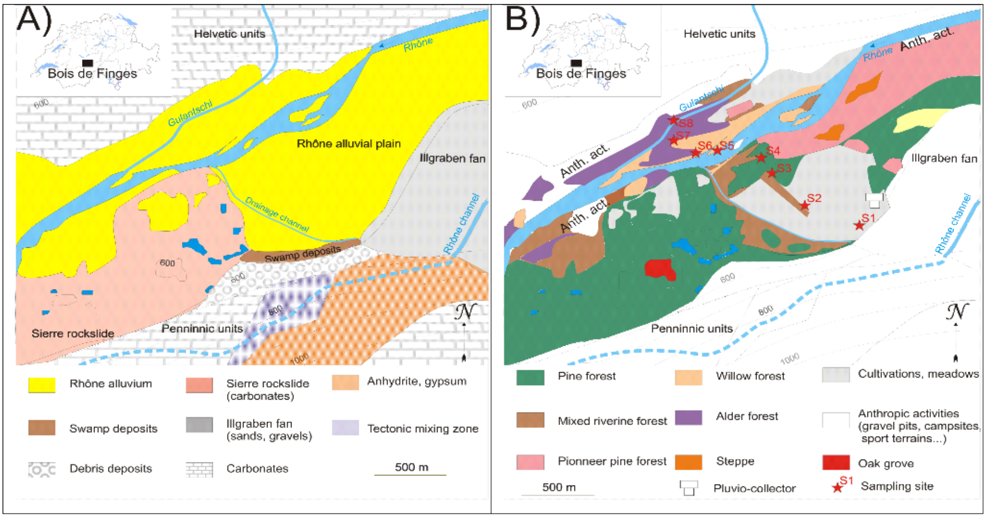

Figure 2. Hydrogeological (A) and ecological (B) settings of the Bois de Finges site. Sampling sites used for this studyare also located on (B).

From an ecological point of view, the riverine fringe at Pfyn presents a broadly recognized natural value but faces many threats due to human activities (derivation channel located upstream, gravel pits). Phytocoenosis vary from dry environments associations (*Pinus sylvestris, Stipa sp.*) upstream to active floodplain associations (*Alnus incana, Salix sp.*) downstream. Between these two end-members, a transition mixed forest occurs. The hydrological continuum described above could, at least partially, explain the ecological continuum between dry ecosystems resulting from the strongly variable water availability and more typical groundwater-dependent ecosystems.

To evaluate the groundwater-phytocoenosis relationships, isotopic characterizations ($\delta^{18}O$, $\delta^{2}H$) of each water compartment (precipitations, groundwater, river, soil, plants) along a transect through the alluvial valley (Figure 2B), coupled with the evaluation of the water balance is planned. This approach makes it possible to characterize pathways of water supplying plants and to assess ecological use of groundwater under diverse hydrological conditions.

Preliminary results shown on Figure 3 indicate a moderate variability of groundwater signatures_(-14.0 ‰ < $\delta^{18}O$ <-12.4 ‰; -108 ‰ <$\delta^{2}H$<-101 ‰) In contrast, soil and plant water signatures vary on both temporal and space scales.

Concerning the atmospheric compartment, rainfall events occurred between 16 and 22 April 2010 (H= 1.5 mm; $\delta^{18}O$=-6.1 ‰; $\delta^{2}H$=- 52 ‰) provided enriched water in the first centimeters of the soils. Mean soil compartment $\delta^{18}O$ signatures (obtained from 10, 30, 50 cm depths signatures weighted by their water volume content) is quite homogenous on the 22 April 2010 for the sampled sites (S2, S4, S6) and $\delta^{18}O$ ranges from -14.2 to -15.4 ‰. One week later (28 April 2010), the $\delta^{18}O$ signatures in the same soils range from -12.2 to -16.7 ‰. Except for one individual ($\delta^{18}O$ = -9.4 on S7), *Salix* (-11.9 ‰ < $\delta^{18}O$ <-14.0 ‰); seems to uptake water mainly from the groundwater source, whereas others (*Alnus, Populus*) show different patterns. Water used by these plants is enriched on 22/04/2010 (-7.9 ‰ < $\delta^{18}O$ <-12.9 ‰), what could be related with the rainfall events during the past week, and less enriched (-11.8 ‰ < $\delta^{18}O$ <-13.1 ‰) on 28/04/2010. This would be consistent with the fact that *Alnus* and *Populus* are facultative wetlands plants (Reed, 1988); therefore, a strategy of adaptation as a function of water availability would be possible.

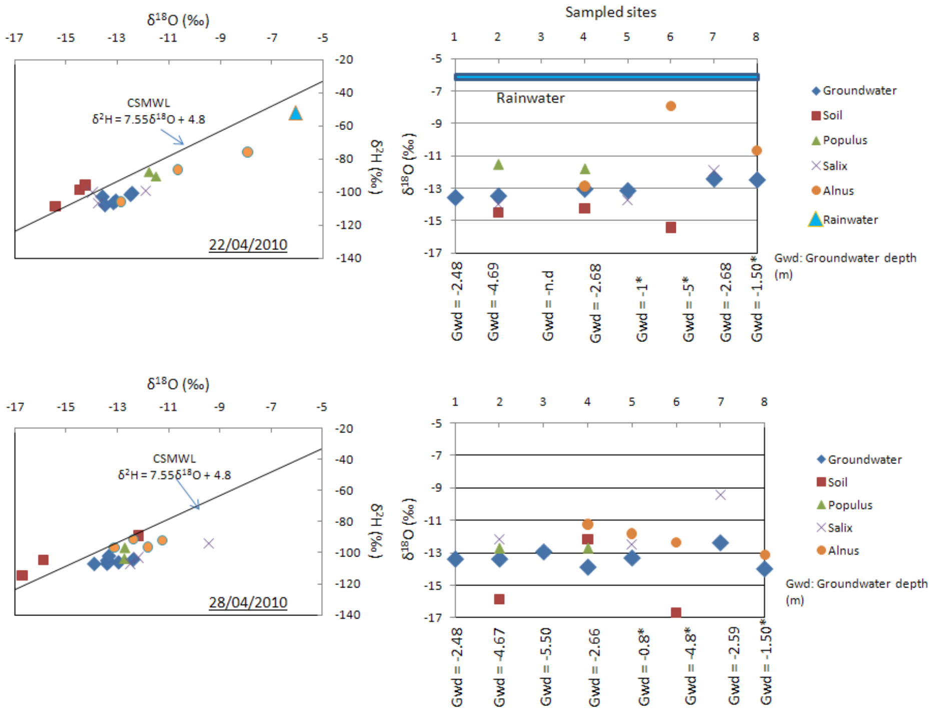

Figure 3. $\delta^{18}O$ and $\delta^{2}H$ signatures of the different compartments of the water cycle at Bois de Finges (22 and 28 /04/2010). CSMWL is Central Switzerland Meteoric Water Line (Kullin, Schmassmann, 1991). Groundwater depth values are the distance between ground and water table. Values with asterisk are estimations.

These first observations must be considered with care: groundwater and soil water values were similar in some place. In this case the interpretation of water uptake by plants is not evident. Furthermore, mixing between 2 different sources of water is possible (e.g. rainwater and deep soil water). In this case, some plant water isotopic signatures need to be evaluated on longer period. Therefore, a number of environmental factors not yet characterized in this study could be necessary to explain the water use patterns for the site. Soil hydrodynamic properties (e.g. water percolation rates) in alluvial settings (Li et al., 2007) need to be taken into account. Moreover, the influence of groundwater depth needs to be investigated. The observed differences between individuals must be clarified in order to understand if individual ecology or adaptations to phytocoenosis structure, e.g. competition in water uses (Snyder and Williams, 2000), could explain the isotopic signatures variability.

CONCLUSION

This work will help to improve the understanding of GDEs functioning in mountainous areas. It will also provide the basis to evaluate how GDEs might be affected by anthropogenic pressures (water abstraction, land use changes) and climate change at the hydrogeologic basin scale. In order to clarify these points at the ecosystem scale, intensive field campaign, analyses of soils structure and monitoring of hydrological variations of the Pfyn alluvial aquifer are currently done.

AKNOWLEDGEMENTS

This study is supported by the GENESIS project (7th Framework Project of the European Union) that aims to understand how changes in land-use and climate affect Groundwater Dependent Ecosystems (GDEs).

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abstract id: **464**

topic: **2**
Groundwater and dependent ecosystems

2.6
Groundwater in eco-hydrology

title: **Groundwater as an ecological supporting condition in raised bogs and the implications for restoration; an example from Clara Bog, Ireland**

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keywords: raised bog, restoration, subsidence, GWTDE

INTRODUCTION

The protection of wetland habitats that are sustained by regional groundwater flows is a basic tenet of the EU Water Framework Directive (WFD). Such systems are considered to be 'groundwater dependent terrestrial ecosystems' (GWDTEs) and understanding their 'environmental supporting conditions', which are primarily represented by their dependency on the prevailing hydrological regime, is essential for the conservation of wetlands.

Natural peatlands such as bogs are essentially wetlands that are, first and foremost, hydrological systems and their ecological functioning is primarily dependent upon the dynamics of the hydrological flows. However, raised bogs are generally considered to be isolated hydrological systems, separated from regional groundwater flows. Groundwater as a 'supporting' ecological condition is usually confined to the perimeter of a raised bog, where peat and underlying clay thin towards the margin, allowing regional groundwater and peat water to converge and mix, thereby giving rise to characteristic nutrient rich *lagg* zone vegetation. However, the relationship between groundwater and the raised bog body itself is complex and current research on Clara Bog, Ireland, suggests that groundwater provides some form of "support function" to the bog and that it should, in reality, be considered a GWTDE under the WFD.

SUBSIDENCE OF CLARA BOG

Clara Bog, located in midland Ireland, is one of Western Europe's largest and most important raised bogs, primarily because there are still considerable areas of active *Sphagnum* and peat growth. It also retains examples of soak systems, which have disappeared almost completely from raised bogs in Ireland, and are characterised by assemblages of rheotrophic and minerotrophic vegetation in an otherwise ombrotrophic environment. Though a Scientific Area of Conservation (SAC), Clara Bog has been extensively damaged in the past and it is estimated that the bog, as it exists now, covers less than half of the extent it once did in its pristine state. The bog may be considered to be two bogs, Clara Bog West and Clara Bog East, as a road, the Clara to Rahan 'bog road', bisects the wetland into two separate bog entities (Fig. 1). Marginal drainage associated with the bog road has resulted in the bog subsiding by up to 6m in the last 200 years (Bell, 1991), thereby permanently altering its hydrological dynamics.

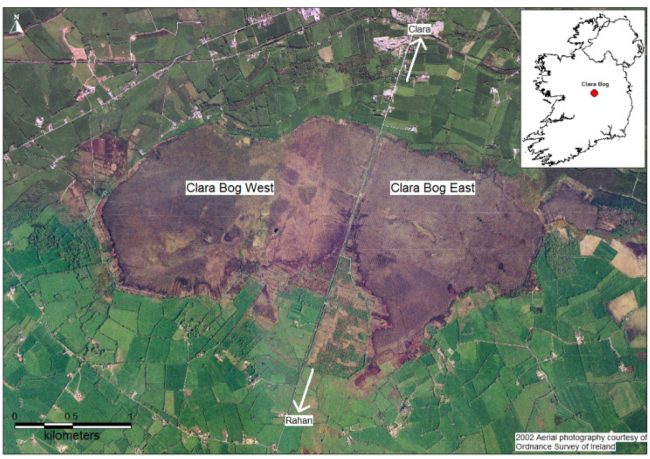

Figure 1. Location of Clara Bog.

In the recent past, the southern margins of Clara Bog West have been cut for turf. The removal of peat on the bog margin results in the development of 'face banks', which removes the natural lagg zone and results in vertical peat profiles marking an abrupt, and artificial, border to the main bog body. Coincident with such peat-cutting activities, is the development of marginal drains, which deepen as cutting extends into the bog. It is now known that Clara Bog West has subsided significantly since the early 1990's due to marginal drainage (Ten Heggler et al., 2004), thereby altering the surface level gradients on the bog which in turn alters the local flow paths that maintain sensitive rheotrophic ecotopes, such as the soak systems. The acrotelm capacity will therefore also be affected as its maintenance depends on shallow slope gradients (gradient must not exceed 0.3 m/100 m; Daly et al., 1994).

The southern sections of Clara Bog West have subsided locally by over 1 metre since 1991. Indeed, subsidence has now propagated as far as 600 m into the high bog (Ten Heggler et al., 2004; Regan, 2010). Coincident with this subsidence has been the development of bog pools and lakes due to differential rates of peat settlement. While drainage on the high bog (i.e. internal drainage) will affect the upper layers of the peat profile, drainage in cut-away sections by the high bog will reduce the piezometric head at the base of the peat profile and in the subsoil deposits underlying the peat (Ten Heggler et al., 2004). As a consequence, peat consolidation will concentrate in the deeper layers of the peat profile. Compaction of the peat implies an increase of the volume fraction of organic matter and a decrease of the vertical hydraulic conductivity, which in turn means an increase of the hydraulic resistance of the peat (Ten Heggler et al., 2004). Recent research (Regan, 2010) now indicates that subsidence is not solely due to simple consolidation of the peat body, but that external drainage has created a hydraulic connection between the high bog and regional groundwater flow, resulting in increased vertical flow movements. However, this "connection" is a localised phenomenon.

HYDROGEOLOGICAL FRAMEWORK OF CLARA BOG WEST

Clara Bog formed within a glacial basin and is bounded by an east-west trending esker on its northern side and is surrounded by an undulating topography consisting of glacial till on its eastern, western and southern sides. The predominant geological succession underlying the bog consists of (1) Carboniferous Limestone bedrock to (2) glacial till deposits of varying permeability to (3) low permeability lacustrine clay sediment, which is overlain by shelly marl in the central areas of the glacial basin. The lacustrine clay effectively acts as an aquitard, or "hydraulic barrier", by isolating the bog from regional groundwater flows in the subsoil (glacial till) aquifer and thus preventing downward leakage of water from peat to the till aquifer.

In section 2 the physical changes that have occurred on Clara Bog West, due to subsidence, since the early 1990's were briefly discussed. However, the surface level elevation of Clara Bog East has remained relatively static during the same time period implying it has not subsided. Significantly, Clara Bog East is almost wholly underlain by lacustrine clay, whereas Clara Bog West is not. The subsoil geology underlying the high bog of Clara Bog West is illustrated in Figure 2 and it can be observed that much of the western section of the high bog is underlain by glacial till. This subsoil aquifer protrudes through the lacustrine clay beneath the high bog at localised connections and, significantly, directly underlies the peat substrate in an area between the two most important ecological features of Clara Bog West, namely the Western Soak and Shanely's Lough.

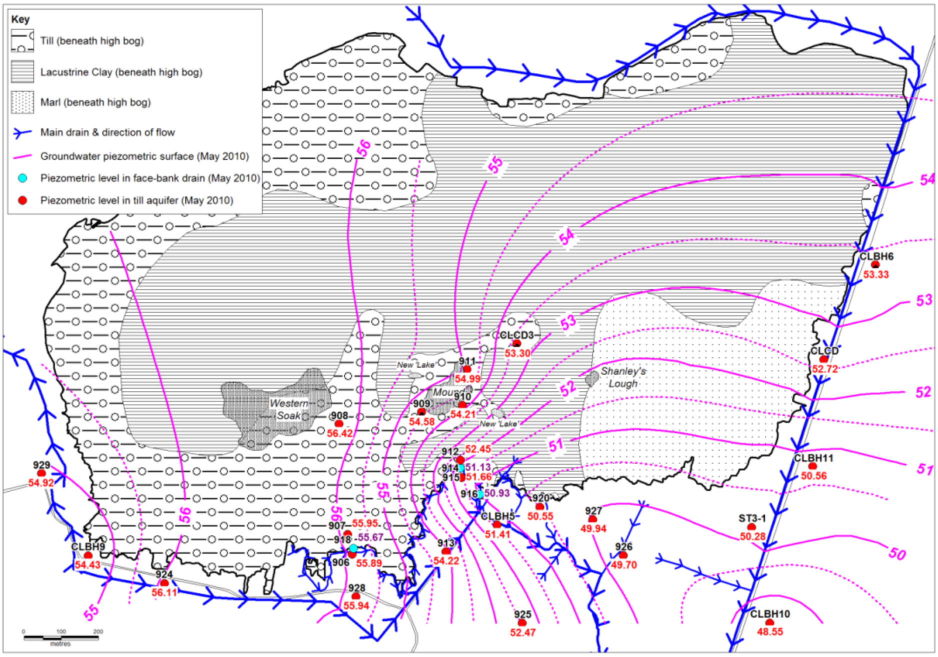

Figure 2. Clara Bog West: underlying subsoil geology, marginal drainage pattern and May 2010 piezometric contours in the mineral subsoil (till).

EFFECTS OF MARGINAL DRAINAGE

Groundwater discharge

In the mid 1990's, turf cutting on the southern margins of Clara Bog West accelerated to the extent that face-bank drains cut in so far as the underlying mineral subsoil (till). Agricultural drains in the southern regions of Clara Bog West were also deepened into the till deposits, some of which are connected to the face-bank drains bordering the high bog. To investigate the linkage between the marginal drainage and the groundwater levels beneath, and surrounding, the high bog, a number of piezometers were installed (Regan, 2010) in the glacial till aquifer. The piezometric surface of the groundwater table in the glacial till aquifer is illustrated on Figure 2. Hydraulic gradients are steep in the central area of the bog, where the glacial till underlies the peat, and groundwater flows in a south easterly direction from the Western Mound, which is a topographical high on the high bog, to the face-bank drains. A groundwater divide, broadly trending in a north-south direction, exists where the Western Soak occurs on the bog. The hydraulic gradient steepens considerably east of the Western Mound, and it has been found that where the hydraulic gradient is steep, the elevation at the base of the face-bank drains is below or coincident with the regional groundwater level (Regan, 2010). Elevated electrical conductivities (> 200 µS/cm) also occur in the face-bank drains where peat directly overlies till and the piezometric level is above that of the face-bank drain level (Figure 3). As such, where lacustrine clay is absent, the face-bank drains are a zone for groundwater discharge.

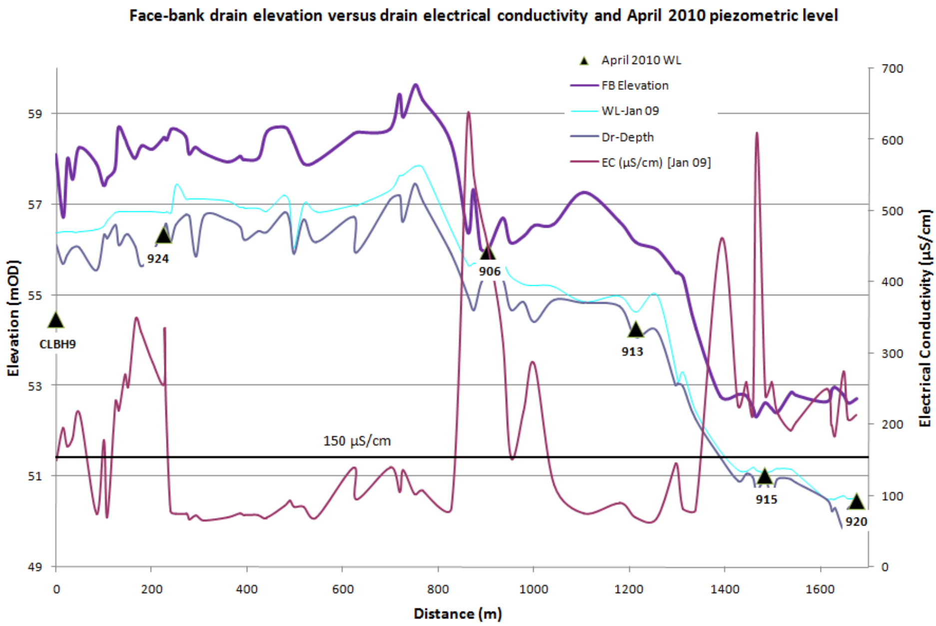

Figure 3. Face-bank drain elevation, April 2010 groundwater level, January 2009 drain water level and drain electrical conductivity values on southern margin of Clara Bog West.

Drop in regional groundwater table

There is evidence that marginal drainage has lowered the regional groundwater table at the margins of Clara Bog West, which has extended into the centre of the bog, coincident with the observed bog subsidence and bog pool/ lake development. A hydrograph from borehole CLBH5 (see location in Figure2), which is located on the southern margin of Clara Bog West, comparing the water level in the subsoil aquifer over similar time intervals in the years 1991/1992, 1996/1997 and 2009/2010 is presented in Figure 4.

It is clear from Figure 4 that the groundwater table has dropped significantly at CLBH5. Significantly, CLBH5 is located adjacent to an agricultural drain deepened into the till subsoil, which is the same till body which, in local areas, directly underlies the high bog, and within 60 to 160 m of the face-bank drains. The water level has decreased between c. 0.4 and 1.0 m from 1991/1992 to 2009/2010. Similar analysis of subsoil piezometric levels from boreholes surrounding Clara Bog West reveals little change in water level (Regan, 2010) over the same time period, implying that the lowering of the regional groundwater table is a localised phenomenon. However, a drop in regional groundwater level, between c. 0.3 and 0.5 m, has also been recorded at subsoil installation CLCD3 (Figure 3), which is located near the centre of the bog and where the lacustrine clay unit is absent (Regan, 2010).

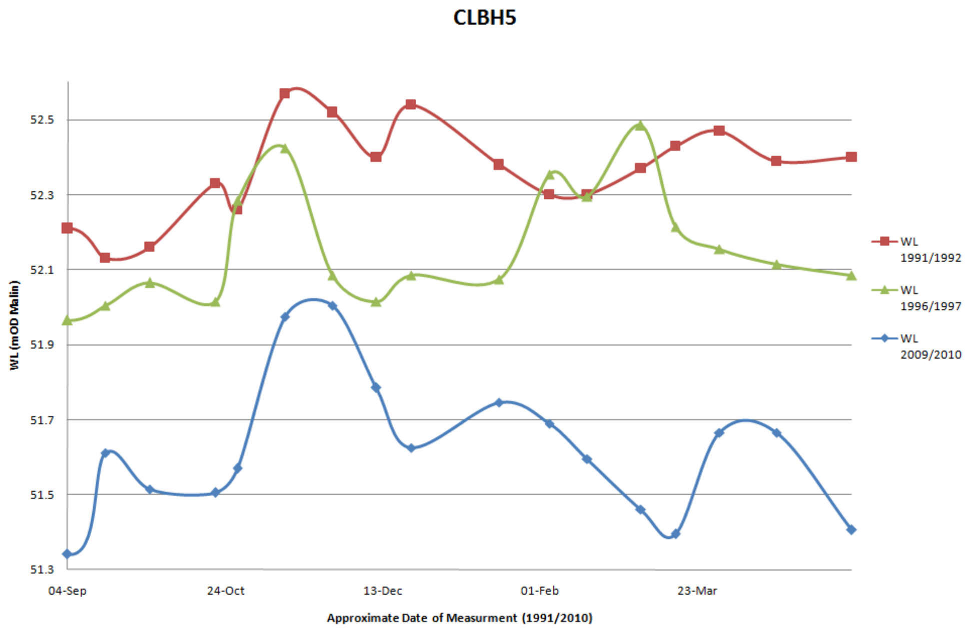

Figure 4. CLBH5 hydrograph of mineral subsoil water levels from 1991/1992, 1996/1997 and 2009/2010. Note: all levels are referenced to the same datum to avoid levelling inaccuracies.

SUMMARY

Traditionally, raised bogs are considered to be isolated hydrological systems, separated from regional groundwater flows. However, research at Clara Bog has indicated a greater dependency of raised bogs on groundwater, especially in the absence of lacustrine clay. In the recent past, subsidence of the bog has coincided with a local drop in the regional groundwater table, induced by marginal drainage of the aquifer underlying the main bog body. Evidence now suggests that if regional groundwater is affected, there is a corresponding impact on the raised bog peat vertical drainage. The hydrogeological monitoring and analysis of Clara Bog West to date indicates that water losses from the main bog body are not simply a result of lateral seepage of water through the peat profile at the bogs margins but are also a result of vertical water losses in the peat profile in the main bog body. As such, though groundwater is not directly supporting ecology on the high bog, the hydrostatic pressure of groundwater is crucial in maintaining a high water table in the bog. Where lacustrine clay is absent, and the bog is hydraulically linked to regional groundwater, marginal drainage adjacent to the bog (face-bank drains), and outside the bog (agricultural drains), creates pathways for vertical water movement, thereby reduces the hydraulic gradient and resulting in drainage of moisture from peat in the high bog. Restoration measures to arrest subsidence of the high bog are therefore dictated by understanding, and quantifying, these drainage pathways.

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abstract id: **484**

topic: **2**
Groundwater and dependent ecosystems

2.6
Groundwater in eco-hydrology

title: **Impacts of litter on soil physical and chemical properties and its karst effect in epikarst dynamic system in China**

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keywords: epikarst dynamic system, litter, soil physical and chemical properties, epikarst spring, karst effect

In forest ecosystems, the effects of litter on soil properties are far from being fully understood. We conducted a study in 60a mature forest (S1), 20a earlier arbor forest (S2) and 10a shrub (S3) in Nongla epikarst dynamic system, Guangxi, China. Litter and soil physical and chemical properties was conducted to understand the effects of litter on soil properties. Our data showed that: The reserves of litters in S1, S2 and S3 were 18.4 t/hm^2, 16.85 t/hm^2, 1.84 t/hm^2,the total amounts of nutrient elements (N, P, K, Ca, Mg, Si, Al, Fe, Zn, Cu, Na, Mn) returning to soil from the litters were: S1 (4.657 t/hm^2) > S2 (4.068 t/hm^2) > S3 (0.193 t/hm^2), respectively. The reserves of litters in S1 were ten times than that in S3. The effective retaining content of litter layer in S1 were 11 times than that in S3, which enhanced the eco-hydrological function of forest soil. When the soil depth became large, soil properties influenced by litters become weaken gradually. Properties in deep soil was decided by parent rock, which content were stable, however, properties in top soil was controlled by litters. Nutrient in top soil, such as contents of organic matter (OM), available N, P, K, available Mn and Zn were controlled by litter's reserves, decomposition rate and component. Element's available state was inversely proportional to soil Ph usually. Litters can speed up the formation and evolvement of limestone soil in karst area. The preserve of litter layer prolonged the time of interaction of water/rock, at the same time, it can provide more contents of organic matter and CO_2 to karst ecosystem, and then accelerate its running.

2.7 Integrated groundwater management with dependent ecosystems

IAH 2010
Krakow

abstract id: **151**

topic: **2**
Groundwater and dependent ecosystems

2.7
Integrated groundwater management with dependent ecosystems

title: **BEST: a tool to determine groundwater pumping effects on eco-systems under the Water Framework Directive**

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keywords: groundwater, pumping, dependent ecosystems, effects analysis, management

A critical problem under the Water Framework Directive and associated rules is determining effects from groundwater recovery on terrestrial and aquatic ecosystems. In order for the Directive to be implemented comprehensively it is necessary to have methods that are easy and quick to apply while still being scientifically sound.

Analytical methods, such as are used in well test analysis, could be used to address these problems; however, there are many assumptions behind these methods and they are rarely satisfied. Furthermore, cumulative affects from multiple groundwater users should be addressed and the methods become clumsy when applied to large number of wells and the affected terrestrial and aquatic habitats.

The application of numerical groundwater models is another alternative, but these are specialist tools and require a special skill set to be effectively used. Furthermore, they are computationally intensive if to be used in an administrative environment.

We have developed a web-based application that permits accessing the computational accuracy and flexibility of the numerical groundwater models while keeping the user interface relatively simple (Figure 1).

Figure 1. Map based dialog used to select the wells that are to be analyzed as well as showing the potential ecosystems that can be affected, multiple wells can be selected for analysis.

In order to do this we take advantage of the linear systems view of groundwater systems often used in optimization approaches to solving groundwater management issues. We calculate the response matrix for all wells in the county and use all other wells as well as terrestrial and aquatic biotopes as observation points. This response matrix provides the key to determining the effects from arbitrary pumping rates at a set of wells on the ecosystems in question (Figure 2). The response matrix needs to be tested for linearity.

A key in the methodology for developing the response matrix is to determine time-constants for seasonal abstractions. Irrigation abstractions from groundwater operate at high rates for only a few months each year. This means that the effect from these abstractions is a combination of a long-term average effect plus a seasonal contribution each year. A similar effect could be produced by some industrial groundwater users such as potato flour factories.

Key issues in implementation of the methodology will be presented. These include:

- The merging of existing groundwater models where there is model overlap,
- The development of pseudo-analytical numerical groundwater models for areas without existing numerical models, and

- The determination of cumulative effects from groundwater pumping on large fluvial systems.

The interface to applying the response matrix to determine effects is based on a web-service application (Figure 1), so all the data lies on a central server. This is important for data security, as well as facilitates the updating of information on ecosystems, hydrogeology and wells. While not implemented here, a web-service application opens the possibility for public distribution of say the resulting effects on ecosystems and other data/results that could be useful in public consultation on how to manage natural resources and ecosystems.

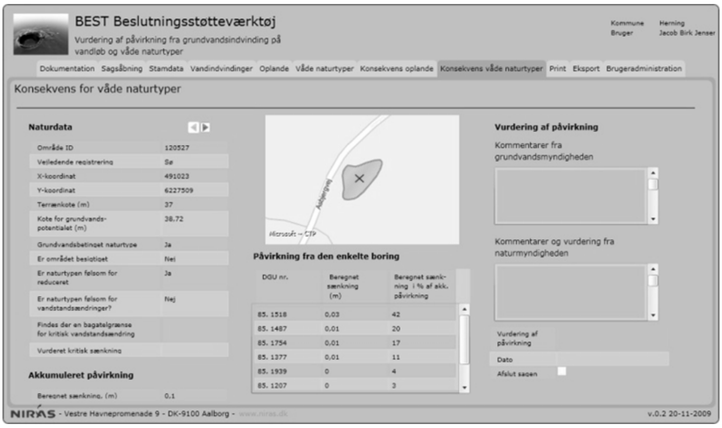

Figure 2. Dialog that presents the effects on each terrestrial ecosystem, note that each wells contribution to the effect is presented.

RESPONSE MATRIX

The foundation of the method is the response matrix. This is developed under the assumption that the groundwater system at hand behaves as a linear system. Given the boundary conditions applied in the numerical model for the simulations used to develop the response matrix this is a reasonable assumption. The boundary conditions used are drains and rivers; as well as constant head and no-flow boundaries. In development of the response matrix all pumping is injection to increase solution stability when the model needs to be run several thousand times for a water district.

The model is run for each well with a set injection rate and the effect on head is observed at all cells and flow effects are recorded at boundary condition cells. We disregard any effects less than respective user defined limits for head change and flow change.

The response matrix is stored on a database server so that every 100×100 m model cell that is for any injection is geocoded, and linked to the well(s) that affect water levels. Boundary conditions that are affected are managed in a slightly different manner, as it is necessary in the context of the WFD to see cumulative effects within a basin. So, in addition to geocoding the location along a river or in a wetland that is affected; it is also necessary to have these locations geographically linked to the catchment they lie in. Additionally it is necessary to have system for the interconnection of catchments so that one can see which extractors affect flows at some arbitrary point along a river system.

ABSTRACTION EFFECTS ANALYSIS

The work flow for determining the effects from an abstraction starts on a screen such as seen in Figure 1. The user selects which well they wish to determine effects for; this initiates a series of geodatabase server queries that result in identifying all the habitats and water bodies that are affected by the abstraction. Furthermore, all other abstractions that affect these areas, habitats or bodies are identified. This is an advantage of geoindexing effect features.

In order to determine the seasonal affects from irrigation abstractions or other seasonal groundwater uses; the groundwater model used to determine the response matrix is run as a transient model, where effects are recorded at a series of times across a year. The final time step is run as a steady-state time step (stress period) in order to show the long term effects from the abstraction in question.

The user verifies that the abstraction rate at the well to be evaluated is correct, if not the rate is adjusted. The user now can see the effects on water levels and flows. The user is also presented with the target status and sensitivity for each water body, and practical information such as when or if the body has been surveyed and the results of such a survey. The user can also see how much of the effect on each water body is from the well being evaluated versus the total effect. The may choose to see each wells absolute or relative contribution to the effects.

The method is rapid enough that the user can, in cases where the affect is unacceptable, use the tool to determine an acceptable abstraction rate. In principle one could apply optimization methods to reallocate abstraction permits.

EVALUATION DISSIMINATION

The results from the evaluation for an abstraction are stored on the database server, so that other system users have the information available. The results of the evaluation are also stored in PDF files, one for effects on terrestrial habitats and one for effects on surface water bodies. The report on terrestrial habitats also includes drawdown effects. Given the rules applied for the administration of groundwater abstraction in Denmark, we have not developed a report on the effects on other groundwater users.

CONCLUSIONS

We have presented a novel method for determining effects from groundwater abstraction in context of the WFD and Habitat Directive. This method is implemented as a web-based application that permits accessing the computational accuracy and flexibility of the numerical groundwater models while keeping the user interface relatively simple.

A key to the successful implementation of the method is the application of geoindexing and georeferencing at the database level so that the interrelated causes and effects from abstractions for habitats and water bodies can be quickly accessed.

IAH 2010 Krakow

abstract id: **169**

topic: **2**
Groundwater and dependent ecosystems

2.7
Integrated groundwater management with dependent ecosystems

title: **Investigation of diffuse groundwater chemical impacts on groundwater-dependent terrestrial ecosystems in England and Wales: Implications for WFD significant damage assessments**

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keywords: groundwater, nitrates, wetlands, significant damage, WFD

INTRODUCTION

Procedures for risk screening and assessment of significant damage to groundwater-dependent terrestrial ecosystems (GWDTEs) for EU Water Framework Directive (WFD) implementation have been developed by the Environment Agency for England and Wales (Hulme et al., 2007; Brooks et al., 2009; Whiteman et al., 2009; Whiteman et al., in press).

FIELD INVESTIGATIONS

Field investigations have been undertaken at a small number of wetlands to test the procedures, and to improve our ability to detect significant damage and help us to prevent further deterioration in groundwater status. This paper reports the results of these investigations, which focus on diffuse groundwater chemical impacts, and their implications for significant damage assessments, research needs and policy implementation through groundwater status assessments in the second cycle of WFD river basin planning.

Investigations have been based on a source-pathway-receptor approach, quantifying these linkages at each site. Multiple sources and pathways of nitrates have been demonstrated by a combination of techniques, including high resolution logging of multilevel piezometers, combined with hydrochemical and nitrogen isotope sampling, geophysical and hydro-ecological surveys and ecological mapping. At each stage of the investigation, the eco-hydrological conceptual model has been reviewed and updated by a multidisciplinary team of ecologists and hydrogeologists.

It has also been important to consider the timing of impacts and lag time in the ecological response, as some GWDTEs may still be responding to historic chemical pressures rather than current pressures.

DISCUSSION & CONCLUSIONS

The results suggest that desk-based risk screening procedures are inadequate on their own to confidently predict the likelihood of significant damage. A combination of risk screening methods and targeted site-based data analysis will be required to ensure good status of WFD groundwater bodies in future river basin cycles. Site specific chemical data are required, along with knowledge of hydrological and chemical thresholds to trigger detailed assessment of significant damage. Existing groundwater monitoring networks do not provide this site-specific data.

The implications of the investigations for WFD Programmes of Measures, groundwater quality sustainability and effective management of the GWDTEs will be discussed in the paper.

ACKNOWLEDGEMENTS

The Authors wish to acknowledge the contribution of the national statutory conservation organisations Natural England and the Countryside Council for Wales towards the work described in this paper.

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abstract id: **337**

topic: **2**
Groundwater and dependent ecosystems

2.7
Integrated groundwater management with dependent ecosystems

title: **The ecology of a groundwater fed wetland in relation to the surrounding gravel aquifer: micro-hydrological and micro-meteorological controls on survival of an indicator specie of the whorl snail Vertigo geyeri**

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keywords: eco-hydrology, hydro-ecology, GWDTE, bioindicators, wetlands

Vertigo geyeri is a rare, tiny species of mollusc, living only in calcareous, spring fed wetlands. It is considered to be a threatened specie within the territory of EU; therefore it is protected under Annex II of the EU Habitat Directive (92/43/EEC). The snail is very small and reaches 2 mm height only; therefore it has very limited movement capacity. Subsequently, in order to survive, the snail requires very specific micro-habitat conditions, which although recognized as to be "damp and humid" were largely unknown until now. This study was initiated to provide more information on the detailed micro-hydrogeological and micro-meteorological requirements for this microscopic species in order to manage their future existence within their habitats of spring-fed wetlands, which are often threaten by human activities, such as groundwater abstractions, drainage schemes, groundwater pollution, etc.

The hydrology of the of the snail's preferred habitat was studied at a site in Ireland, at Pollardstown Fen, during an extensive research project carried out in connection with dewatering of the major gravel aquifer in Ireland. The reason for the dewatering was construction of a major road in a cutting below the water table in the local sand and gravel aquifer. There was a serious concern that dewatering operations might lead to a decline in water levels and hence a reduction in spring flows to the fen, with consequent impacts on the fen ecology, including the sensitive V. geyeri snail.

This paper addresses the snail's micro-habitat, which was studied at a total of four sites around the fen margin, and then describes the relationship between the fen micro-habitat, micro-hydrology and the regional hydrogeology. The ecology of the fen and its relationship with the surrounding aquifer was studied in detail between 2002 and 2005.

The results show that high relative humidity (above 80%) and close proximity to a phreatic water surface (approximately 0.1 m below ground surface) are the most important factors for maintaining populations of the snail. A study of the groundwater inflows to the fen, involving measurements of vertical and lateral hydraulic gradients, coupled with an evaluation of soil thermodynamics and meteorological observations, suggested that the hydrological regime of the fen is sensitive to both the groundwater inflow rate and the transpiration process of the wetland vegetation. Local topography and geomorphology are important considerations when deciding on the extent of potential snail conservation areas, as the long-term viability of conservation sites is likely to be greater in areas with gentle slopes that allow seepages to emerge at lower levels, if such seepages are reduced or lost at higher elevations.

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abstract id: **454**

topic: **2**
Groundwater and dependent ecosystems

2.7
Integrated groundwater management with dependent ecosystems

title: **Impacts and threats on groundwater systems at a European scale — the GENESIS Project**

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keywords: groundwater systems, land use impacts, Groundwater Directive, GENESIS test sites

ABSTRACT

Groundwater resources are facing increasing pressure from consumptive uses (irrigation, water supply, industry) and contamination by diffuse loading (e.g. agriculture) and point sources (e.g. industry). This causes major threats and risks to valuable groundwater resources and on groundwater dependent ecosystems. The impacts of land-use changes and climate changes on groundwater resources are difficult to separate as they partly result in similar changes in the ecosystems affected. Moreover, the effects are highly interwoven and complex.

Within the EU seventh framework program the integrated GENESIS project was approved. It is the basic concept of GENESIS to base research on different relevant aquifer sites in various European countries to test scientific issues and find advanced solutions to the important problems. The most relevant and actual impacts on groundwater recharge, groundwater dependent ecosystems and substances leaching into aquifers will be revealed. Their mathematical implementation into models will then be pursued and likely scenarios of future aquifer use calculated. Thus, a basis for the revision of the Groundwater Directive and better management of groundwater resources is being developed.

INTRODUCTION

During the seventh framework program of the EU an integrated project on assessing climate change and land-use impacts on groundwater systems (acronym: GENESIS) has been initiated in 2009. The project consortium consists of 26 partners from 17 different European countries. It is the basic idea of the project to improve scientific insight and to create new concepts and tools for the revision of the Groundwater Directive (GWD) and better management of groundwater resources.

Typical aquifers in the European Union differ widely with respect to their geologic background, climate conditions, size and land as well as water use. In order to review the present situation and measures on European scale, 16 test cases have been evaluated including Po aquifer (Italy), Rokua-Hailuoto Esker (Finland), Mancha Oriental aquifer (Spain), Czestochowa aquifer (Poland), Koycegiz-Dalyan coastal catchment and lagoon (Turkey), Transfleuron site (Switzerland), Lule river (Sweden), Feucherolles site (France), Sumava region (Czech Republic), Vosvozis river basin (Greece), Grue site (Norway), De Kroome Rijn (Netherlands), Bogucice aquifer (Poland), Murtal aquifer (Austria), Zagreb aquifer system (Croatia) and the Bitterfeld site (Germany). The locations of the sites are shown in Figure 1. The corresponding hydrogeological regimes range from lagoon systems, fractured rock, sand and gravel aquifers and karst systems to peatlands and eskers.

Based on the analysis of the case studies the most relevant and actual impacts and threats on (i) groundwater dynamics, recharge and water balance of groundwater systems, (ii) substances leaching to groundwater aquifers due to different land-uses and (iii) groundwater dependent ecosystems interacting with surface water shall be revealed. These results will be input for further research on processes in groundwater systems and their mathematical implementation in models. Additionally, likely scenarios of future aquifer use can be inferred from the test sites considering all relevant stakeholders, which will lead to the development of economical and social viable measures for sustainable groundwater use and protection.

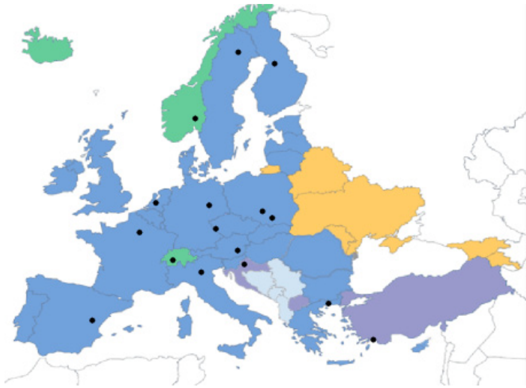

Figure 1. Locations of the test sites examined within the GENESIS project

Moreover, possible gaps with respect to the Water Framework Directive (WFD) and the GWD are discussed. Finally, a general overview of modeling approaches used and their purposes with a specific focus on model requirements and data availability and needs is put together.

IMPACTS AND THREATS ON GROUNDWATER DYNAMICS, RECHARGE AND WATER BALANCE OF GROUNDWATER SYSTEMS

First analyses show that three major reasons can be identified that significantly influence groundwater recharge and the water balance of groundwater systems. The most obvious cause of all is overexploitation, typically related to the use of groundwater for agricultural irrigation. At one test site the observed drawdown between the starting of the pumping period in May and the end in September reaches 20 m. Furthermore, infiltration from a connected river and a lake into the subsurface are induced (which was not the case before), diminishing an important source of water for the wetland system. Another threat is the intrusion of seawater into the wetland area. At the Spanish site a maximum decline of 100 m of groundwater levels has been reached in 30 years of exploitation. As a consequence, the streamflow of an interacting river becomes depleted leading to direct effects for groundwater dependent ecosystems.

The next group linked to disturbance of natural subsurface conditions summarizes more general kinds of land use like gravel mining activities, increased sealing of ground surfaces due to urbanisation and industrialization and artificial groundwater recharge (washing sites, drinking water purpose). An important component within this group is the regulation of rivers that interact with groundwater which may lead to riverbed erosion (potentially changing a feeding into a gaining river), the reduction of areal recharge from flooding due to embankments and the prevention of any water exchange due to the colmation of water reservoirs that were built for hydro power generation. Drainage ditches significantly influences groundwater systems in Finland and the Netherlands.

Finally, climate change and with it the modification (or reduction) of seasonal water availability will potentially influence groundwater systems in the future, especially in mountain regions. In the Swiss karst aquifer some pumping wells were abandoned after the dry summer of 2003, because their yield became insufficient. In addition, during the dry autumn of 2009, the spring discharge (and hence the river discharge) was too low for hydroelectrical production and likely had also some detrimental affect on the river ecosystem.

IMPACTS AND THREATS OF SUBSTANCES LEACHING TO GROUNDWATER AQUIFERS DUE TO DIFFERENT LAND-USES

A common threat to groundwater quality is linked to the non-point source pollution of nitrate leaching from the soil through the unsaturated zone into the groundwater body. The nitrate mass often derives from disproportionate use (i.e. amount and timing of application) of fertilizers in agriculture. This situation is present in many of the test sites, as for example in Spain, where nitrate contents of 125 mg/l have been observed, in Greece, where nitrates in some boreholes were detected in much higher concentrations compared to the EU limits, or also in Austria.

Cold climates represent a special condition in this context since findings of several pesticides from grain and potato production demonstrate that slowly degradation of pesticides can contribute to the deterioration of groundwater resources. Due to the rapid infiltration into the subsurface after the frozen soil has thawed the use of pesticides on such areas might represent an additional threat to the groundwater quality.

Moreover, groundwater pollution may be linked to an entire mixture of emission sources comprising leaky sewage systems, municipal landfills, illegal waste depositories (containing all kind of chemical wastes like sludge or ashes), non-authorized gravel pits and also industrial plants, that partly discharge waste water in uncontrolled manner. High concentrations of pollutants like nitrates, atrazine, heavy metals and chlorinated hydrocarbons in groundwater confirm the influence of these sources. Furthermore, in situ transformation (e.g. reductive dechlorination) of these substances can be observed.

Leaching of substances into groundwater is not only related to excessive pollution but can also be favoured by hydrogeologic conditions. The Swiss Karst aquifer (due to its general hydraulic characteristics) has only limited buffer capacity and the Polish site barely shows any soil cover.

IMPACTS AND THREATS ON GROUNDWATER DEPENDENT ECOSYSTEMS INTERACTING WITH SURFACE WATER

Most often threats to groundwater dependant ecosystems may have a quantitative background, are related to a water quality issue or are a combination of both. Due to surface streams or shallow groundwater that may contain significant concentrations of nutrients the risk of eutrophication of connected ecosystems exists in such different environments as coastal lagoon systems (e.g. nutrients coming from waste water discharge) and shallow weathered bedrock aquifers (e.g. nutrients coming as leachate from agricultural fertilizer). At the latter site (Czech Republic) the situation is even worsened because of acid athmospheric depositions influencing the natural pH and the seepage of mine waters containing a variety of heavy metals. These elements have a direct toxic or inhibit effect on the fluvial biota as the riverbed sediments are incrusted by iron and manganese oxides to a depth of about 10–15 cm.

Equilibrium shifts in freshwater bodies as a result of nutrient loading have been reported at the Dutch test site. Water bodies once characterised by clear water, macrophytes and predator fish have been replaced by turbid water systems dominated by algae and freshwater bream. In strongly regulated rivers (e.g. for power production) the discharge patterns are completely changed. Thus, riparian zone processes are also altered leading to retention of chemical elements that induce the production of diatom in stored water (Swedish test site).

The application of tracers has proven a powerful tool in exploring the dynamics and time scales of groundwater exchange and in assisting to build good conceptual models, which are the basis for corresponding numerical modeling efforts. At the Polish site, impacts of long-term changes of water balance (including the delineation of climate change impact) and anthropogenic pollution on the ecosystem functioning have been studied by these methods.

POSSIBLE GAPS WITHIN THE WFD AND GWD

With respect to the Water Framework Directive and the Groundwater Directive possible gaps have been identified as unconsidered processes, non-existing tools for particular conditions (e.g. spreading patterns of pesticides in areas with winter climate), missing thresholds and the negligence of uncertainty bounds as well as implementation deficits (e.g. incomplete definitions of protection zones).

Climate change is not directly covered in the WFD or the GWD. However, the changed water availability could lead to an imbalance between water availability and water use, violating Art. 4 of the WFD, which imposes to ensure equilibrium between withdrawal and renewal of water. Definition of threshold values and environmental indices should also consider the needs of wetland ecosystems and provide means to account for uncertainties since otherwise difficulties in assessing environmental and resource costs might occur.

For some of the test site countries national River Basin Management Plans (RBMP) already exist, for others they will be published in the near future. In general, these plans are based on large river catchment areas and discuss the quantitative and qualitative status of the water systems. Within the RBMPs also the most important threats to groundwater are presented and corresponding measures are suggested to preserve or improve aquifer conditions. However, the proposed measures sometimes are of basic nature and their quantitative impact is difficult to assess. If feasible the suggestions will be adapted to the specific conditions present at the test sites and evaluated within the groundwater systems management scenarios.

CURRENT MODELING APPROACHES

The investigated test sites strongly vary regarding the already existing use of modelling approaches. At some sites a lot of modelling experience already exists in diverse aspects of saturated groundwater flow, thus future aims comprise extension, further refinement or improved characterization of particular processes (e.g. surface water–groundwater interaction). Moreover, bridging the gap from the plot to the regional scale in the field of combined modelling of unsaturated water movement and substances (e.g. nitrate) fate and transformation is pursued by several groups applying different codes that are validated against field experiments.

The coupling of yet individual models is also applied in the framework of linking climate models to integrated hydrologic models (e.g. SWAT). At the Spanish site the development of a socio-hydro-economic modelling framework goes even further since it allows selecting sustainable cost-efficient measures and management strategies to achieve a good quantitative and chemical groundwater status in an uncertain environment. In this model chain agronomic simulation is linked to numerical representation of groundwater flow and pollutant transpsort and optimization algorithms. In order to limit computational time also stochastic methods are used that offer a wide range of specific implementations. For the Dutch test site a discrete number of realizations for extreme events is defined within an integrated hydrological model and the results are evaluated in terms of frequency distributions.

For the sites with no present numerical model applications, clear visions exist about initial model uses including verification of conceptual models, improvement of process understanding and providing the basis to predict the impact of various land management practices on groundwater conditions. Additionally, the modelling of in situ biochemical attenuation processes is of strong interest to compute the evolution of plumes at large uncontrolled landfills. It that case collection of further field data is often needed to infer corresponding degradation parameters.

ACKNOWLEDEGEMENTS

This work is for the most part funded by the European Commission under contract number 226536.

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River Basin Management Plans:
http://ec.europa.eu/environment/water/participation/map_mc/map.htm

abstract id: **486**

topic: **2**
Groundwater and dependent ecosystems

2.7
Integrated groundwater management with dependent ecosystems

title: **Modeling stream-groundwater interactions for different water extraction scenarios: the Almádena-Odeáxere case study**

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keywords: numerical groundwater flow models, groundwater-surface water interactions, groundwater dependent ecosystems

INTRODUCTION

The Almádena-Odeáxere aquifer system (hereafter known as AO) extends over a 63.5 km^2 area, across the Lagos and Vila do Bispo municipalities (Almeida et al., 2000) in the southern region of Portugal, Algarve. Up until the end of the 20th century it was the main source of public water supply for these municipalities, and records show that it was the main source of supply for the city of Lagos as far back as the 15th century. In 1999 a multi-municipal water supply system entirely dependent on surface water provided by large reservoirs was implemented, leading to the abandonment of the AO (and other aquifer systems in the region) as sources of water supply. However, the extreme drought of 2004–2005 brought to light the serious limitations of this single-source strategy when several reservoirs reached their exploitation limit and could not satisfy water demand.

It is likely that in the near future, a water management approach that integrates the use of surface and groundwater in order to guarantee public water supply will be put into practice (Martins, 2007). However, in order to do so in a responsible manner, it is necessary to understand the implications of extracting water from these aquifer systems. In the particular case of the AO, it is known that there are several surface water bodies which are hydraulically connected to the aquifer system, the most significant of which are two wetlands linked to the aquifer's natural discharge areas (Almeida et al., 2000).

CONCEPTUAL FLOW MODEL AND NUMERIC FLOW MODEL

The AO has an area of 63.5 km^2 and stretches from Odeáxere (East) to Almádena (West). The aquifer system is a free to confined karstic system, which develops in carbonate Lias-Dogger outcrops and stretches in a NE-SW direction. The dominant lithologies are limestone, dolomite limestone and dolomite rock with thicknesses between 750 m and 60 m, and which present, in certain places, a well developed karst (Reis, 1993; Almeida et al., 2000). The average precipitation occurring in the area of the AO is 650 mm/year and there is an average recharge of 40.3% of the precipitation (Vieira, Monteiro, 2003), which corresponds to an average annual recharge of 16.6×10^6 m^3/year.

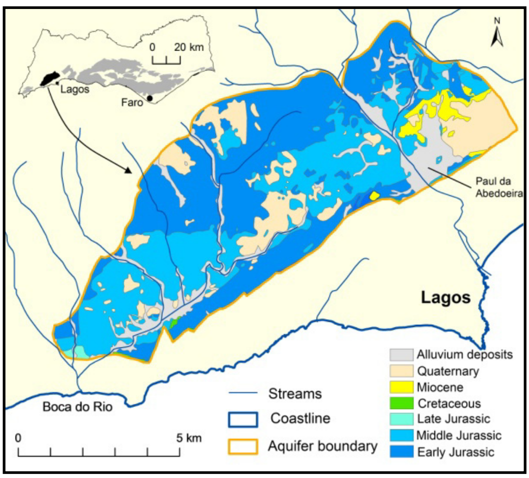

Figure 1. Geographic location and geology of the Almádena-Odeáxere aquifer system.

Regional groundwater flow occurs predominantly from the NE to SW. There are two main sources of recharge: indirect infiltration from streams flowing across the system and direct infiltration from rainfall over the entire system (Reis, 1993). The main natural discharge areas are located (1) along the final reach of the Bensafrim stream, which feeds into the wetland of the Paul da Abedoeira and (2) a second diffuse discharge area at the SW point of the system which feeds a second wetland area (Almeida et al., 2000).

The physical principals that are the basis of the simulation of the aquifer systems hydraulic behavior can be expressed by the following equation (1):

$$S_s \frac{\partial h}{\partial t} + div\left(-[K] grad h\right) = Q \tag{1}$$

In which T [L^2 T^{-1}] is transmissivity, *h* is the hydraulic head [L], Q is the volumetric flux per volume unit [L^3 T^{-1} L^{-3}]. Representing sources and/or sinks and *S* is the storage coefficient [-]. In steady state conditions the variables are time-independent, and in this case equation (1) can be reduced to equation (2):

$$div\left(-[T]\, grad\, h\right) + Q = 0 \tag{2}$$

The total simulated budget will be equal to zero, because a medium permanent state of the aquifer is represented, i.e., recharge and discharge have the same value at the flow domain global scale.

The direct solution of equation (2) was implemented using a standard finite element model based on the Galerkin method of weighted residuals. The model has a mesh based on the AOs geometry, with 7494 nodes and 14533 triangular finite elements for which the defined conceptual flow model was translated. The use of finite element models is currently a standard approach for solving problems in hydrogeology and is described in textbooks such as Huyakorn and Pinder (1983), Kinzelback (1986), Wang and Anderson (1982) and Bear and Verrujit (1987).

Over the last two decades, hydraulic parameters were obtained for AO via pumping tests in boreholes (Reis, 1993; Almeida et al., 2000); however these methods cannot provide sufficient data to carry out a realistic representation of regional aquifers (Martins, Monteiro, 2008). In order to overcome these limitations, simulations were performed, using a synthetic bi-dimensional numerical representation of the AO, in which *T* was estimated by inverse modeling. These results allowed a very important improvement on the reliability of the simulation of the regional flow pattern, in particular a better characterization of the spatial distribution of hydraulic head. The calibration of *T* undertaken by Martins (2007) was performed by inverse modeling using the Gauss-Marquardt-Levenberg method, implemented in the nonlinear parameter estimation software PEST (Doherty, 2002). This calibration approach has already been thoroughly described and implemented by authors such as Carrera et al. (2005) and Poeter and Hill (1997).

EXTRACTION SCENARIO SIMULATIONS

Data on the volume of water extracted per month from the eight main public water supply boreholes during the last decade was obtained. The data showed, as can be seen in Figure2, a steady increase in the number of boreholes as well as in the total extracted volume during the last few years prior to the implementation of the multi-municipal water supply system, in particular the year 1999 and the subsequent dip as of the year 2000. Extracted volume rose on average 3.08E+05 m^3/year between 1989 and 1999.

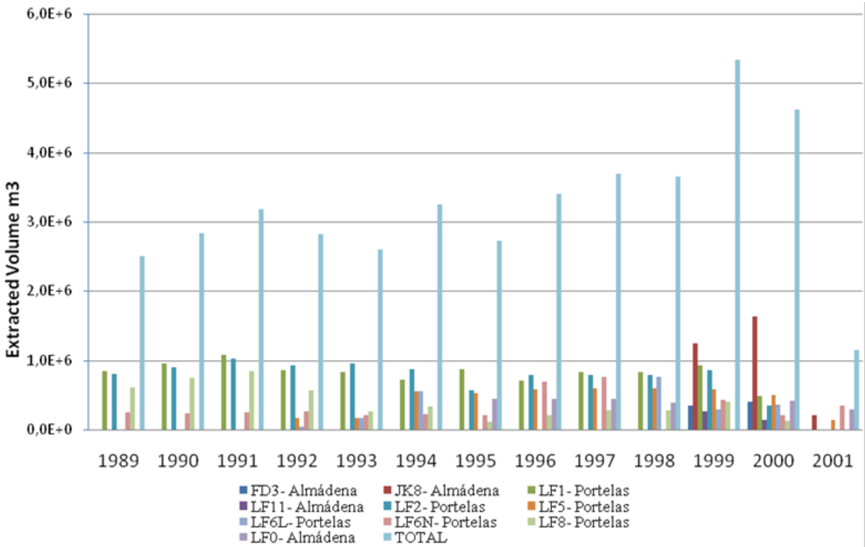

Figure 2. Yearly extracted volume from the main public water supply boreholes on the AO.

Simulations were performed for various extraction scenarios. Initially a simulation was run under natural conditions, with no artificial water extraction, the results of which represent the aquifer systems current state. Subsequently, several more scenarios were considered (1) in which the average pumping rates for the year 1999 (the year with the highest registered extraction) were applied and, (2) pumping rates were raised by 50%, 100% and 150% of the average pumping rates in 1999 (which correspond to potential rises in pumping rates for 10, 20 and 30 years).

ANALYSIS OF RESULTS

Groundwater Flow Patterns

Figure3 shows the simulated regional flow pattern under natural conditions, and with average pumping rates registered during the year 1999. The results of these simulations helped to validate the functionality of the model as the values of hydraulic head of the pumping scenario mode closely resemble the values measured during the year of 1999 than those of the no pumping scenario.

The effect of pumping for public water supply is easily visible, in particular around the area of Portelas, however the model suggests that discharge does not cease under these conditions. This refutes reports of the Paul de Abedoeira wetlands drying up during periods of intense pumping. On the other hand, this steady state model does not take into consideration the large seasonal variability of rainfall and water demand characteristic of this region. Considering that most pumping is concentrated during the dry months, it is possible that discharge could cease during these periods and recover during the rainy season.

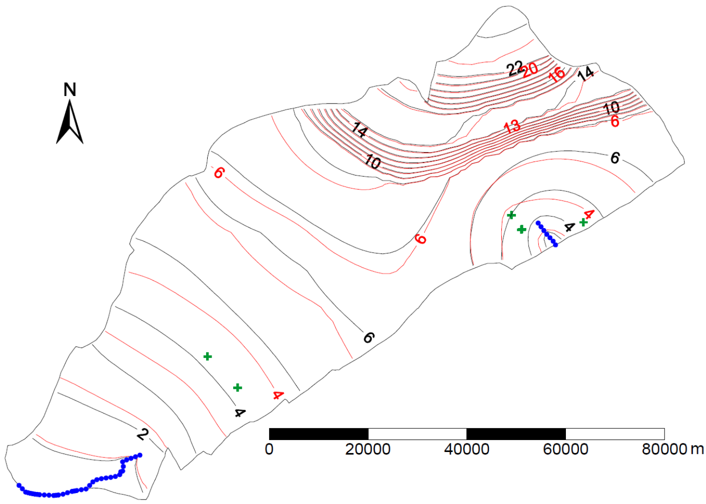

Figure 3. Simulated groundwater flow patterns: no extraction scenario (black lines), average pumping rates for 1999 (red lines). Main boreholes for public water supply (green crosses); main discharge areas (blue lines).

Three hypothetical scenarios were simulated in which the pumping rates were raised by 50%, 100% and 150%, which correspond to periods of 10 years considering the average yearly rise in water demand observed between 1989 and 1999, in order to estimate the impacts of extraction for public water supply. As was to be expected, there was a significant drop in values of hydraulic head around the discharge area at Portelas with the raising of the pumping rates, and although natural discharge at this area is significantly reduced it does not cease completely until pumping rates are higher than 200% of average rates in 1999. As can be seen in Figure4, for 250% of the pumping rate the reduction in hydraulic head is significant, causing the discharge to cease at Portelas. On the other hand, although there is a decrease in discharge, the south-western natural discharge area is not significantly affected by the rise in pumping rates.

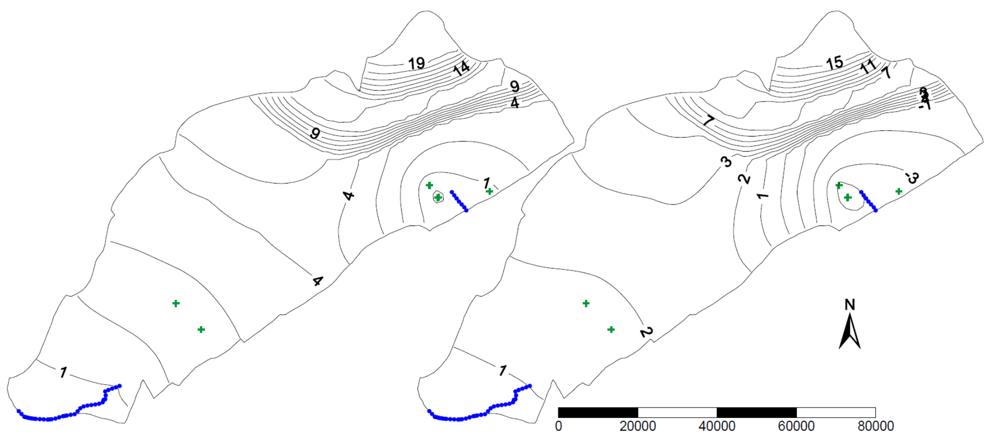

Figure 4. Simulated groundwater flow patterns: 200% (left) and 250% (right) of average pumping rates during 1999.

FINAL REMARKS

It was found that water extraction from the main existing public water supply boreholes could affect the surface water bodies hydraulically connected to the AO by reducing the amount of groundwater flow from the aquifer to the streams. However, to properly quantify the effects of this reduction on groundwater discharge, a more detailed study of the importance of the groundwater component to the streams flow is needed.

It also demonstrated that should the extraction rates rise to 250% of average values during 1999, discharge at Portelas would effectively cease allowing for current values of average recharge. Future research should be carried out to better determine where and how much water can safely be extracted for public water supply, as well as to determine the importance of the groundwater component for the surface water bodies to which the AO is hydraulically connected. Considering the high seasonal variability of the region, this research should involve the development of transient variations of the AO model, in order to consider the variation of recharge and withdrawals over time.

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abstract id: **505**

topic: **2**
Groundwater and dependent ecosystems

2.7
Integrated groundwater management with dependent ecosystems

title: **Hydro-ecological guidelines for wet dune slacks**

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keywords: wet dune slacks, eco-hydrology, groundwater

INTRODUCTION

The spatial mosaic and successional development of coastal dune systems include humid slacks with water levels that fluctuate seasonally with varying amplitudes. They have distinctive biodiversity and high conservation importance, representing European habitat features 2190 and 2170 in Annex I of the European Union Habitats Directive. This legislation requires competent authorities to assess all plans and projects that could affect the nature conservation objectives of European sites (SACs and SPAs), in order to maintain their ecological integrity. Dune slacks are particularly susceptible to the effects of water abstraction, changes in local land use, nutrient pollution, and sea-level rise.

NEW GUIDELINES FOR DUNE SLACKS

The Environment Agency, as a competent authority, is responsible for reviewing all it's existing authorisations, consents, licences and permissions in England and Wales, which includes water abstraction licences. Natural England, the Countryside Council for Wales and the Environment Agency have collaborated to address the requirement for scientifically robust information (the "Wetland Framework") in order to establish eco-hydrological guidelines for dune slack management. We examined information available in site-specific reports, as well as unpublished eco-hydrological and hydrochemical data for English and Welsh dune systems. We have established a model for hydrological functioning of humid slacks (Davy et al., 2006), and made detailed appraisals of and recommendations for British dune slack community types corresponding to Annex I (NVC types SD13–SD17). Finally, we highlight the many deficiencies in the data and make recommendations for further work.

ACKNOWLEDGEMENTS

The Authors wish to acknowledge the contribution of the national statutory conservation organisations Natural England and the Countryside Council for Wales towards the work described in this paper.

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3 | Aquifer management

3.1 | Regional groundwater systems

abstract id: **120**

topic: **3**
Aquifer management

3.1
Regional groundwater systems

title: **Past recharge conditions in the Guarani Aquifer System**

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keywords: Guarani aquifer system, environmental isotopes, recharge

Analysis of groundwater isotopic ratios are routinely used in hydrogeology to complement the hydrogeochemical and hydrodynamic data, and can supply important information about patterns of flow, age and origin of groundwater, occurrence of mixtures, and environmental conditions during the recharge of these waters. The purpose of this article is to analyse the spatial distribution of groundwaters isotopic ratios (δ^2H and δ^{18}O) in the western portion of Guarani Aquifer System (GAS), and how these isotopic variations are associated with present and past climatic conditions in the recharge zones.

GAS is the most important hydrostratigraphic unit in the southern portion of South America where it covers about 1,090,000 Km^2. GAS comprised a package of Mesozoic sedimentary continental clastic rocks which occurs in the Parana Sedimentary Basin (LEBAC, 2008). In its western part the groundwater flow pattern is characterized by the existence of two regional recharge areas in the north, and a potentiometric divide in the south, which trends approximately NS. Groundwater flow is radial from the regional recharge areas towards the center of Paraná Sedimentary Basin and towards the western outcrop areas (Gastmans et al., 2009).

Rain shows wide dispersion in isotopic ratios (δ^{18}O varying from –15.8 to +5.2‰ SMOW and δ^2H varying from –111.4 to +47‰ SMOW), with a clear differentiation between rainy summer season (November to April) and drier winter season (May to October). Summer rains show, throughout the sampled period, –5.74 ± 3.35‰ SMOW for average δ^{18}O and –34.43 ±24.32‰ SMOW for δ^2H. The δ^{18}O for GAS groundwater vary from –9.1 to –4.8‰ SMOW and the δ^2H vary from –58.4 to –21.7‰ SMOW (Fig. 1).

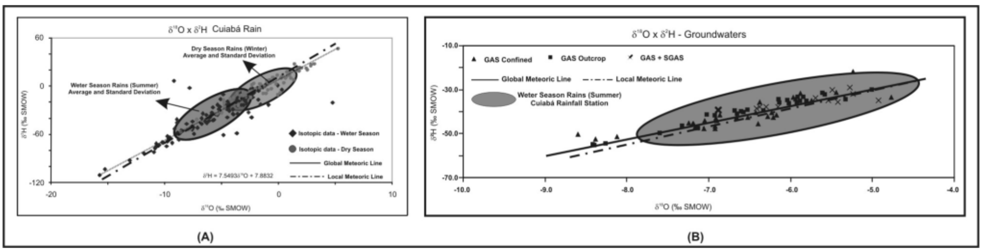

Figure 1. (A) δ^{18}O versus δ^2H cross plot of rain water. (B) δ^{18}O versus δ^2H cross plot for GAS groundwaters.

The spatial distribution of groundwater δ^{18}O indicates values comparable to the present day rain in the outcrop and regional GAS recharge zones, located in the north of the area, and most depleted δ^{18}O groundwaters are in the confined zone (Fig. 2).

This isotopic distribution reflects directly paleoclimatic evolution in the southern portion of South American continent through the Pleistocene, when climates were colder and more humid in lower latitude zones. Under these climatic conditions, the rain waters are more depleted in δ^{18}O and δ^2H than the present day. These ratios are similar to those observed in the central portion of the study area (–8.2‰ SMOW δ^{18}O and –45‰ SMOW δ^2H). Groundwaters more enriched in δ^{18}O are observed close from recharge areas; this fact reflects the increase in average temperature during the Holocene. Based on these ages for the recharge, groundwater flow velocities were calculated, and the values reach tens meters per year, similar to those observed by Silva (1983) in the east border of the aquifer. These velocities are important for the groundwater resource management, because the renewal of GAS groundwater, mainly in the confined portion, is very slow, occurring in longer time intervals than normally are used in management plans.

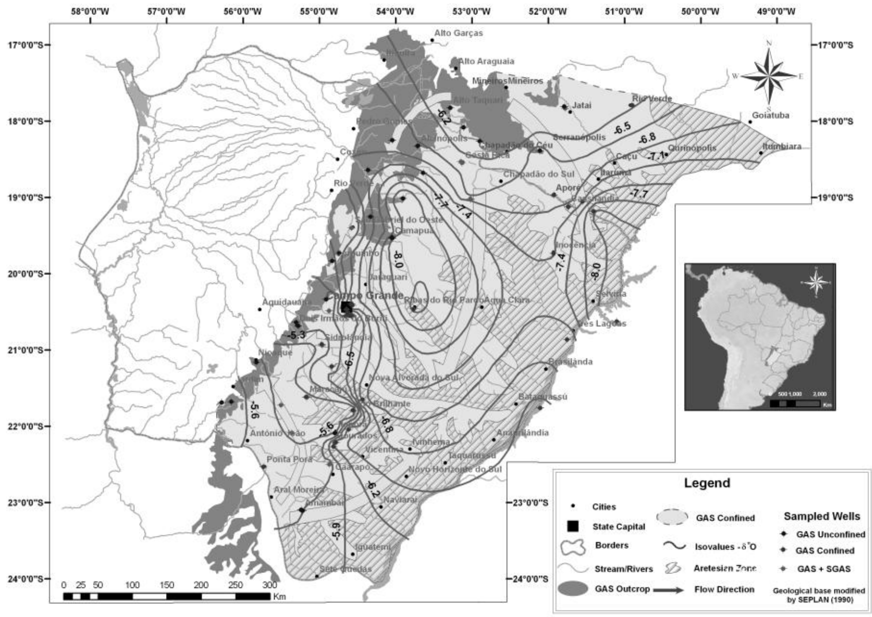

Figure 2. Map of $\delta^{18}O$ GAS groundwater spatial distribution in the western portion of the Guarani Aquifer System.

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abstract id: **127**

topic: **3**
Aquifer management

3.1
Regional groundwater systems

title: **Creating of regional hydrogeological model for the south-east of Lithuania**

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keywords: groundwater, regional modelling

INTRODUCTION

To fulfil the European Commission water directives (98/83EC, 2000/60EC), Lithuania has prepared the program (2007–2025) focused on improving management of its rich groundwater resources and on supplying the country with drinking water of high quality. The program includes the task to evaluate groundwater resources by processing accumulated hydrogeological data by methods of mathematical modelling. For the first time, the regional hydrogeological model (HM) has been developed for the Quaternary groundwater system located in the South-East of Lithuania (Figure1). This groundwater body covers one third of the country. The rectangular HM area has the size 290km×210km= 60900 km^2. Local river basins comprise the active HM area of highly irregular shape (Figure2). The model area, exterior to the active one, does not take part in simulation.

Figure 1. Model location.

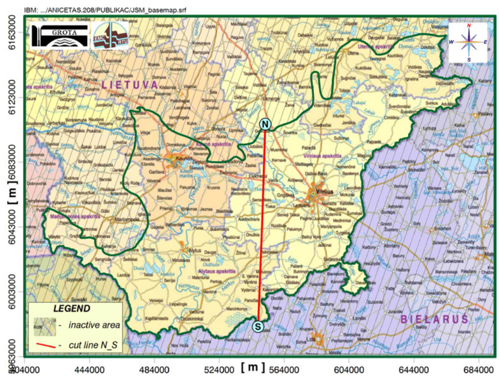

Figure 2. Model area (290km×210km, *h*=0.5km).

The Quaternary groundwater system to be modelled is highly irregular (Figure 3). To account for its complexity, HM contains 11 layers (planes). The finite difference 3D scheme is applied with the plane approximation step *h*=500 metres. Therefore, the HM grid plane contains 481×421=244601 nodes and the HM 3D grid includes 2690611 nodes. The Groundwater Vistas (GV) system (Environmental Simulations Inc., 2007) was used for creating of steady state HM that simulated the mean annual hydrogeological conditions.

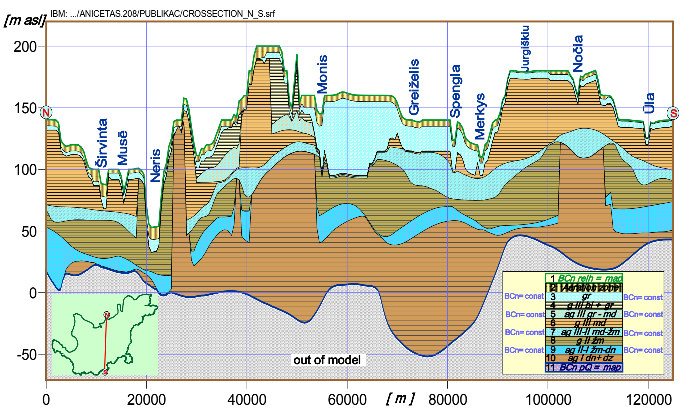

Figure 3. Geological cross section NS.

To create HM, two new methods were applied: 1) by using the ground surface elevation map, as the boundary condition, the feasible infiltration distribution was obtained; 2) in the "start on" version of HM, the uniform flat layers were applied to substitute the real geometry of HM. The real geometry can be accounted for later, by using grid calculations which transform permeability maps of calibrated HM containing flat layers. This extended thesis is based on information given in the publication (Spalvins et al., 2009).

BASIC MATHEMATICS OF HM

To consider the process of the HM creating, its basic matrix mathematics is presented by the following algebraic equation system:

$$A\varphi = \beta - G\psi, \quad A = A_{xy} + A_z \qquad (1)$$

where φ is the solution vector (heads) at nodes of HM grid; A – the symmetric sparse matrix of the geological environment presented by the xy-layer system containing horizontal (A_{xy} - transmissivity) and vertical (A_z – vertical hydraulic conductivity) elements of the grid; ψ - the boundary head vector, which includes ψ_{top}, ψ_{bot} and ψ_{bound} - subvectors on the HM top, bottom and borderlines, accordingly; G – the diagonal matrix (part of A) which elements links the nodes where φ must be found with the ones where ψ is given; β - the boundary flow vector.

By using the 3D finite difference approximation, the xyz grid of HM is built using ($h\times h\times m$) - sized blocks (h is the block plane size; m is the variable thickness of a layer).

The elements a_{xy}, a_z of A_{xy} A_z (or g_{xy}, g_z of G) are computed by using the following formulas:

$$a_{xy}=km, \qquad a_{zy}=(h^2k)/m, \qquad m_i=z_{i-1}-z_i>0, \qquad i=1,2, \quad s, \qquad (2)$$

where z_{i-1}, z_i are the elevations of the top and bottom surfaces of the i-th geological layer; z_0 represents the ground surface elevation map $\psi_{top} = \psi_{rel}$ with the hydrographical network included; k, m are, accordingly, elements of digital m, k-maps of the computed layer thickness and permeability; s – the number of layers.

The set of z-maps describes full geometry of HM. It is built incrementally: $z_0 \rightarrow z_1 \rightarrow \ldots \rightarrow z_s$ by keeping the thickness of the i-th layer $m_i>0$. If in some areas $m_i=0$, then the i-th layer is discontinuous. To prevent "division by zero", in the a_z calculation of (2), $m_i=0$ must be replaced by $\varepsilon>0$ (for example, $\varepsilon = 0.02$ metres). In GV, only the z-maps serve as the geometrical ones (no m-maps accepted).

Two tasks of the HM creating are the most difficult ones: obtaining the distribution for the infiltration flow β_{inf} on the HM top; building the z-map set.

For reported HM, these tasks were considerably eased, as follows:

- by using the ψ_{rel} –map, a feasible infiltration flow was obtained, as a part of the solved system (1);
- no real z-maps were applied, until the HM calibration was finished.

When ψ_{rel} is used, the flow $\beta_{aer} = \beta_{inf}$ passes through the aeration zone:

$$\beta_{aer} = G_{aer}(\psi_{rel} - \varphi_Q) \quad (3)$$

where φ_Q is the computed head (subvector of φ) for the first Q aquifer; G_{aer} submatrix of G contains the vertical ties g_{aer} of the aeration zone connecting ψ_{rel} with φ_Q. The expression (3) reflects the response of HM, if the ψ-condition is applied. As a rule, even the first run of HM provides good results for β_{aer} that can be easy calibrated.

For calibrated HM, its real geometry can be accounted for by applying the following grid data transformation for k_{xy}, k_z-maps:

$$k_{zy}=(km_c)/m, \qquad k_z=(k_z/m)_c m \quad (4)$$

where $(km)_c$, $(k_z/m)_c$ - the calibrated transmissivity and vertical leakance values, accordingly; m – the real thickness of a layer. The transformation (4) does not change flows and heads of calibrated HM.

DESCRIPTION OF HM

Boundary conditions of the ψ -type were applied on the top and bottom HM planes (1st and 11th), on the borderline of the active HM area (planes 3, 5, 7, 9 of aquifers). The ψ_{rel}-map carried by the plane 1 regulates the infiltration flow which distribution is highly irregular. The plane 2 represents the aeration zone as a formal aquitard with a variable permeability. Its distribution was obtained during HM calibration. The plane 3 simulates the first unconfined Quaternary aquifer. The next three aquifers (planes 5, 7, 9) are the confined ones. The planes 4, 6, 8, 10 simulate aquitards that control vertical groundwater flows passing between aquifers. The hydrographical network was implemented in the plane 3 and in the plane 1 as a part of the ψ_{rel}-map. The HM bottom plane 11 carries the ψ_{pQ} -map that represents the pre-Quaternary piezometric heads.

To run the GV program, it is necessary to feed into it the following maps and data files: the surface elevation digital maps of layers (z-maps), the permeability maps (k-maps), the boundary conditions for the planes 1 and 11 (ψ-maps), the ψ_{bound} data for the active area borderline (planes 3, 5, 7, 9), the groundwater withdrawal data β_w for well fields.

To gain time for building the z-maps, and not to postpone creating of HM, the uniform flat layer system was used instead of the real one. Because all layers of this simplified HM version have the thickness m_c=1.0, the transmissivity km-maps were used instead of the k-maps for creating elements of the matrix A_{xy}. For aquifers, the km-maps of good quality were available. For aquitards, the A_{xy} elements were insignificant, because of their small permeability values ($10^{-2}>k_0>10^{-5}$) m/day.

Unfortunately, no data were available of the aquitard permeability k_z for A_z elements. As the first try, the k$_z$-maps were used where $k_z=k/m$ (m – an expected thickness of a layer). In areas where m=0, large values $k_z=10^5$ m/day were applied, to connect tightly the neighboring layers.

CALIBRATION OF HM

Finding and correcting errors occurring in the ψ and β-maps of boundary conditions were the first tasks to be done, because no calibration could eliminate this type of faults. Searching for the right k_z-maps of aquitards were the main object of HM calibration.

Two kinds of calibration targets were applied: the observed heads; the mean subsurface runoff rate of river basins. In Tables 1 and 2, the calibration results for both groups of targets are presented. As the calibration targets for heads, 823 monitoring wells were used. Satisfactory match was achieved between observed and modeled heads. The standard deviation was within the range (2.49-3.08) metres; the relative deviation obtained as "standard deviation/observed range" did not exceed 1.8%.

Table 1. Target statistics for calibrated heads.

Nr. of layer	Number of targets	Residual mean [m]	Standard deviation [m]	Observed range in heads [m]	Relative deviation [%]
3	357	-0.11	2.53	210.2	1.2
5	104	-0.41	3.08	190.5	1.6
7	189	-0.19	2.91	192.5	1.5
9	173	-0.46	2.49	138.8	1.8
Total	**823**				

Not all available head targets were used, because of the following reasons:

- hence the HM grid was not detailed enough (h=500 m), in areas where the φ-distribution was steep, it could not reproduce the monitored heads correctly;
- in the vicinity of well fields, the head observations of previous years could not reproduce the modeled ones, because nowadays the water withdrawal rates had dropped considerably;
- considerable influence of the seasonal head changes, especially, for the first aquifer (plane 3).

Table 2. Subsurface runoff rate for river basins.

River basin	Area of river basin in model [km^2]	Expected subsurface runoff rate [l/s km^2]	Modelled subsurface runoff rate [l/s km^2]	Relative error [%]
Neris	3529	3.80	4.03	6.0
Merkys	2860	5.16	5.18	0.6
Zeimena	2693	4.45	4.39	1.4
Nemunas	6054	3.37	3.30	1.9
Sesupe	1676	1.34	1.41	4.7
Sventoji	1186	2.82	2.46	13.5

It follows from Table 2 that HM satisfactory reproduces the mean subsurface runoff rates for the six river basins. The maximal relative errors 31.6% and 13.5% are for the Neris and Sventoji basins, respectively.

CONCLUSIONS

The regional hydrogeological model has been built for the South-East of Lithuania. It simulates the Quaternary groundwater body that represents the main source of drinking water for this part of country.

The model was created by applying an innovative methodology that enabled to shorten the time for building of this complex model.

The model is open for possible improvements and it also serves as a base for creating local models of well fields, and for the areas where sanitation measures of contaminated places should be evaluated.

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abstract id: **135**

topic: **3**
Aquifer management

3.1
Regional groundwater systems

title: **Geogenic and mining factors controlling the groundwater conditions of the Cracow Sandstone Series (CSS)**

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keywords: Upper Silesian Coal Basin, Cracow Sandstone Series, hydrogeological conditions

GEOLOGICAL CONDITIONS AND MINING ACTIVITY

The Cracow Sandstone Series (CSS) forms the upper lithostratigraphic series of the coal-bearing Carboniferous formation (Westphalian B, C, D) in the Upper Silesian Coal Basin (USCB). The CSS is composed mainly of coarse-grained clastic rocks (sandstones and conglomerates), interbedded with siltstone and claystone deposits accompanying coal seams. The share of coarse-grained sediments exceeds 75% of a series profile (Kotas, 1985).

The Cracow Sandstone Series occurs in the central and eastern parts of the Upper Silesian Coal Basin (USCB) (Fig. 1). It covers the area of about 1500 km^2. The total thickness of the formation is variable, ranging from tens to 1140 m. The roof of a series lies on the depth changing from +320 to –720 m below sea level.

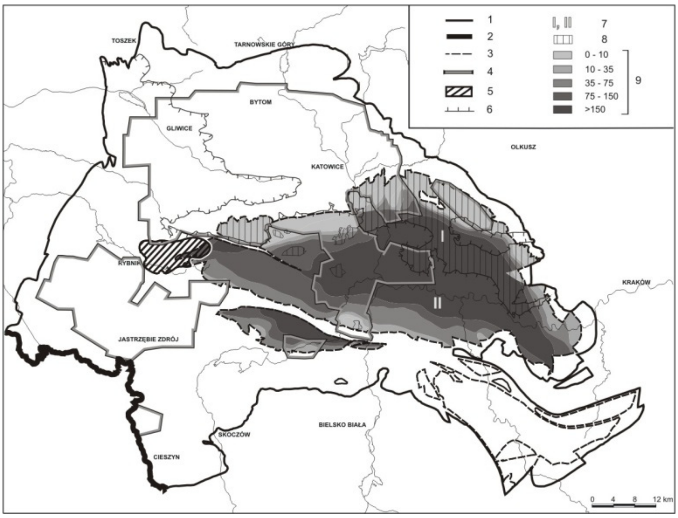

Figure 1. Hydrochemical map of the Cracow Sandstones Series (CSS). Explanations: 1 — Extension of the productive Carboniferous formation in the Polish part of the USCB; 2 — State border; 3 — Extension of the CSS; 4 — Extension of the coal mine mining areas; 5 — Salt deposit in the Miocene formation; 6 — Extension of the isolating series of the Miocene formation; 7 — Hydrogeological subregions; 8 — Recharge areas of the CSS aquifer; 9 — Mineralization (TDS) and hydrochemical types of groundwater in the sole part of the CSS: 0–10 (g/dm^3); multi-ion types; 10–35 (g/dm^3), multi–ion types; 35–75 (g/dm^3), Cl–Na type; 75–150 (g/dm^3); Cl–Na, Cl–Na–Ca types; >150 (g/dm^3), Cl–Na, Cl–Na–Ca types.

An area of the CSS extent characterizes block tectonics. The north–eastern part of the CSS area lies in range of the Paleozoic block where the overlying formations are of the Mesozoic and Quaternary age. The southern and central parts are within the reach of the Carpathian Fordeep, where sediments are covered with the clayey formation of Miocene. Exploitation of coal deposits on industrial scale of production has started since the turn of the XVIII and XIX century. At the beginning exploitation concentrated exclusively at the outcrops. With the development of mining techniques and exhaustion of coal seams close to the surface, begun an underground exploitation, below the groundwater level. The depth of mining works varies from 190 to about 650 m. Due to the great number of mineable coal seams in the sequence, exploitation is carried out simultaneously at several depth levels. Localization of mining areas within the CSS extent is shown on Fig. 1.

Mines exploiting coal seams within the CSS characterize with total inflows in range from a few to 52.8 m^3/min. Maximal individual inflow to the mines results from proximity of present and buried river valleys in the NE part of the USCB. A tendency of water inflow decreasing to specific mining levels with increasing depth was observed (Wilk, ed., 2003). The total inflow amount depends on morphological and geogenic factors as well as time and technique of exploitation and an area of underground workings (Rogoż, Posyłek, 2000; Wilk, ed., 2003). Since 1989 a process of mining industry restructuring has began. Some of mining works were closed and flooded, the others only partly.

HYDROGEOLOGICAL ENVIRONMENT OF THE CRACOW SANDSTONE SERIES

The geological structure of the CSS is diversified. The Paleozoic block structure in the NE part of the USCB is treated as the main recharge area of the CSS hydraulic systems due to its hypsometric position and occurrence of permeable Mesozoic and Quaternary overburden. Syncline structures in the southern part of the Carboniferous basin, under impermeable Miocene cover, constitute the hydrogeological complex with defined flow routes and discharge areas. It is an area where high piezometric pressures are formed.

Taking into account the hydraulic structures of the CSS, two hydrogeological subregions of different hydrogeological conditions have been distinguished: the north-eastern (I) and the south-western (II) (Fig. 1). Their boundaries are delineated by the extent of the isolating series of Miocene formation.

In a hydrogeological profile of the CSS hydrogeological complex prevail water-bearing sandstones and conglomerates of thickness attaining up to 24 m. Claystones and siltstones are reduced to a thin 0.05–6.2 m isolating intercalations. Results of field and laboratory research of the CSS sandstones and conglomerates hydrogeological properites examined in an interval up to 1200 m were recently presented in the paper of Różkowski and Witkowski (2004).

Conducted studies revealed high variability of hydraulic conductivity from 5.0×10^{-8} m/s to 3.3×10^{-4} m/s. Laboratory investigations of sandstones permeability showed its falling tendency with increasing depth (Fig. 2). Effective porosity of coarse-grained clastic rocks reduces adequately to depth from 31.7 to 4.6%, while specific yield — from 10.0 to 1.6%.

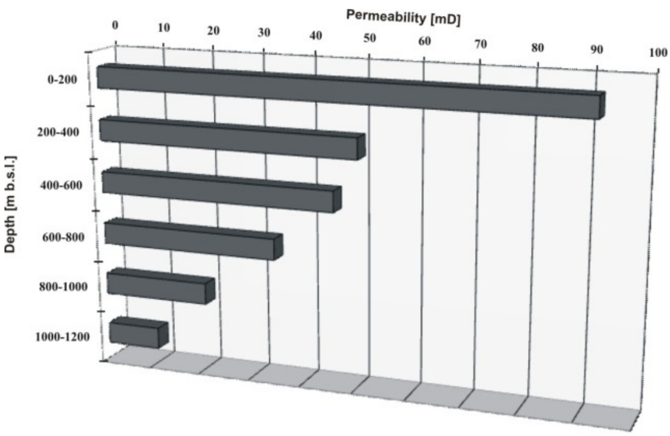

Figure 2. Variation of permeability of CSS water-bearing strata with depth in a division to 200 m intervals.

Results of field and especially laboratory research enabled a determination of general, natural model and mechanisms of hydrogeological rock properties variability in a geological Carboniferous profile. They are related to only a few primary factors. Among them are: 1) structural and textural diversity of sandstones as well as variability of mineralogical composition and cementing material; 2) diversity of spatial shapes and sizes of pores as well as their specific surface and volume; 3) increase of majority hydrogeological parameter values with grain diameter size; 4) diagenesis degree of rock mass.

Observed elevated values of hydrogeological parameters in the roof series of the CSS should be linked first of all with intensified activity of mechanical and chemical weathering processes at the outcrop areas. As a result of the mining activity increases the transmissivity of rock massif as well as a storage capacity and permeability. Decrease of hydrogeological parameters of sandstones with depth is connected with progressing processes of deposits lithification. Water storage capacity of sandstones represented by specific discharge of wells varies with depth from 10.25 $m^3/h/1mS$ at the depth of about 60 m to 0.004 $m^3/h/1mS$ at the depth of 850 m.

According to Toth's theory (1995) it can be assumed, that in the extent of the whole Upper Silesian Carboniferous sedimentary basin, within which the CSS structure is located, groundwaters under the conditions of gravitational flow pattern, are in mutual hydraulic connection, independently from the depth of rock mass deposition and permeability. As a consequence of water percolation forms a regional flow system of a great extent, in range of which transitional and local flow systems exist (Różkowski, 2003).

Natural hydrogeological environment of the CSS has been transformed at the areas of mining activity influence (Rogoż, Posyłek, 2000; Różkowski, 2003; Wilk, ed., 2003). Mining exploitation leads to surface subsidence over exploited beds what causes breakings down, fracturing and rock mass relaxation implicating increase of transmissivity and formation of hydraulic connections between water-bearing horizons on a large scale. Dewatering of mine galleries causes rock mass drainage and simultaneous drop of groundwater level in the CSS structure. Hydraulic gradients, directions and velocity of groundwaters flow are altered. At present, at the time of mining industry restructuring, some of the mines are partially or completely closed. Cessation of mine workings dewatering causes gradual self-flooding of extracting levels and partial filling of depression cone by underground recharge as well as infiltration of atmospheric precipitation. Progressive reconstruction of pressure field in the CSS complex and change of mine waters chemical composition takes place. This process is slow and long-lasting.

CHEMICAL COMPOSITION AND GENESIS OF GROUNDWATERS

Total water mineralization within the CSS formation expressed as TDS varies between 0.12 and 179.15 g/dm^3. There is observed a general trend of water total mineralization increase with depth as well as a change of ion mutual relations (Fig. 3). Analysis of hydrochemical investigations has shown an occurrence within the CSS hydrostructure of vertical, regional zonality, typical for sedimentary basins (Różkowski, 2003). On the base of chemical composition and hydrochemical indices of groundwaters, were distinguished three hydrochemical zones in a vertical profile of the CSS, which are in correlation with the hydrodynamic zones (Różkowski, 2004). In a relation to geological structure, hydrodynamic conditions and intensity of mining exploitation, vertical extent of hydrochemical zones differs in both subregions and even within their boundaries as well as varies in time.

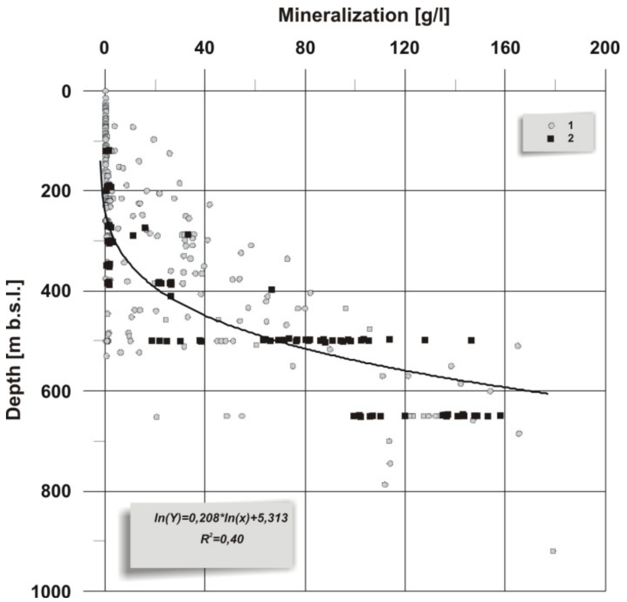

Figure 3. Increase of groundwater mineralization with depth in CSS hydrogeological complex. Explanations: 1 — waters sampled from bore-holes; 2 — waters sampled from mine galleries.

The results of isotope investigations confirmed occurrence of mentioned three hydrochemical zones in a hydrogeological profile of the CSS (A. Różkowski, 2003). Zone of infiltration waters is characterized by isotope values: $\delta^{18}O$ -11.7 to -9.0 per mille and δD -80 to 67.9 per mille. Waters of this zone with mineralization from 0.5 to 3.6 g/dm^3 occur in the first subregion at the depth interval from the roof of the series to 410 m. In a gaseous composition of water dominate atmospheric gases. Zone of mixed waters with a mineralization from a dozen or so to 62.7 g/dm^3 characterize isotope values ranging from $\delta^{18}O$ -8.2 to -8.8 per mille and δD -67 to -61 per mille. Nitrogen is dominant in a gaseous composition of the upper part of their occurrence, while methane – at the lower one. Such results reveal presence of both oxidizing and reduction zones in hydrochemical profile. Relict waters occurring at the depth under 650 m have isotope values: $\delta^{18}O$ -6.30 to -3.80 and δD -49.0 to -36 per mille, while their mineralization varies from 79.9 to 149.8 g/dm^3. Brines with TDS values exceeding 35 g/dm^3 belong to hydrochemical types Cl-Na and Cl-Na-Ca. They occur only in a reduction zone. In a gaseous composition dominates methane, originating from coal seams.

Conducted investigations proved a presence of regional hydrochemical zoning characterized by changes of total mineralization and chemical composition of waters along their flow routes (Fig. 1). The studies revealed a general tendency of water mineralization increase with depth, independently from the age of water-bearing sediments, as well as a change of water ion composition in conformity with sequence: $HCO_3 \rightarrow SO_4 \rightarrow Cl$. The basic importance for hydrochemical zonation forming in the CSS aquifer have thickness and permeability of overburden strata, total thickness of the Carboniferous complex and a degree of sediment diagenesis, as well as activity of coal mining.

Analysis of spatial distribution of mineralization zones has shown an occurrence of waters with mineralization from 0.3 to 10.0 g/dm^3 within the first hydrochemical subregion and locally in the second one, in recharge zones of the CSS complex. Multi-ion waters predominate, with a supremacy of HCO_3 and SO_4 ions. In a zone of waters with TDS from 5 to 10 g/dm^3, in an ionic water composition dominate chlorides and seldom sulfates. In the second hydrogeological subregion, in the intermediate and stagnant zones, water mineralization increases along the flow routes. At first highly mineralized waters are present, replaced afterwards by brines of Cl–Na and Cl–Na–Ca types.

Mining activity is a fundamental factor forming present hydrodynamic field of the CSS (Różkowski, Różkowski, 2003). Physical and chemical processes influencing the chemistry of mine waters proceed in a dynamic system, changeable in time and space. The basic influence on modification of physical and chemical composition of mine waters have following factors: 1) deepening infiltration of waters from overlying strata, 2) mixing of waters from connected by mine exploitation aquifers, 3) water interaction with geochemically altered rock matrix, 4) ascension of brines through the dislocation zones. Desalinization of mine waters in time is in general a main result of the intensive drainage (Fig. 3). This process is especially intensive at the areas of the Carboniferous aquifer recharge.

Mine waters sampled in the mine workings within the CSS rock mass are diversified in their chemical composition, total mineralization and genesis. Isotopic investigations of natural mine waters have shown a variation in obtained values in limits: $\delta^{18}O$ –11.18 to –3.80 per mille and δD –80 to –36.0 per mille. These data revealed that sampled mine waters belong to the group of contemporary infiltration waters, but also mixed and relict ones (Różkowski, 2003). The investigations carried out in the mines situated in the extent of hydrochemical region of the first subregion, have shown occurrence of multi-ion infiltration waters with mineralization of a few grams to the depth usually of about 400 m. Multi-ion and chloride waters with higher mineralization occur in a zone of mixed water, up to the depth of about 500 m. Underneath brines typical for stagnant zone are present. In the second hydrochemical region mine waters are characterized by variable chemical composition and depth of their occurrence. Mentioned conditions result from the degree of the CSS sediments isolation and the range and time of mining exploitation. Zone of infiltration and mixed waters was investigated to the depth of 300–400 m. Underneath 400 m brines occur as a rule. Process of partial or complete liquidation of mine workings by self-flooding, influences a change of chemical composition and physical properties of mine waters. Physical and chemical processes in abandoned mine workings have special meaning. They proceed dynamically in the variable arrangement of hydrodynamic field. Pumped waters chemical composition is strictly connected with exploitation technology, mine workings liquidation technique and especially with variations of groundwater level in abandoned workings. Hydrochemical processes in a rock mass under the mining drainage are connected mainly with oxidation of metal sulfides, especially of pyrite and marcasite. In a result of this processes increases the concentration of sulfates, selected metals, among them total iron, water hardness, suspension level, while simultaneously decreases the pH of water. In favorable hydrogeochemical environment, oxidation of sulfide minerals in mine workings can lead locally to formation of acid waters with pH 2.5–4.5.

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abstract id: **148**

topic: **3**
Aquifer management

3.1
Regional groundwater systems

title: **The quantitative evaluation of the catchment available groundwater resources – the case study**

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keywords: catchment, a big lysimeter, constant volume transformation, available groundwater resources

INTRODUCTION

In Poland there are officially two categories of the groundwater resources: the available resources determined for a given area and exploitation resources assessed for a given well or a group of wells.

The objective of the presented case study was to determine the amount and spatial distribution of the available groundwater resources in the Cenozoic productive aquifers in the catchment of the Łeba river in Poland. The resources distribution was calculated using the author's method incorporated into the modeling process. In this method the assessment of the renewability of the modeled groundwater flow system was the first step in the resources evaluation process.

CHARACTERISTICS OF THE INVESTIGATED CATCHMENT

The investigated catchment of the 97 km long Łeba river is located in northern Poland. The catchment area is 1800 km^2. The hydrogeological investigations and groundwater flow modeling covered larger area of 2420 km^2 (Fig. 1) (Kwaterkiewicz et al., 2001).

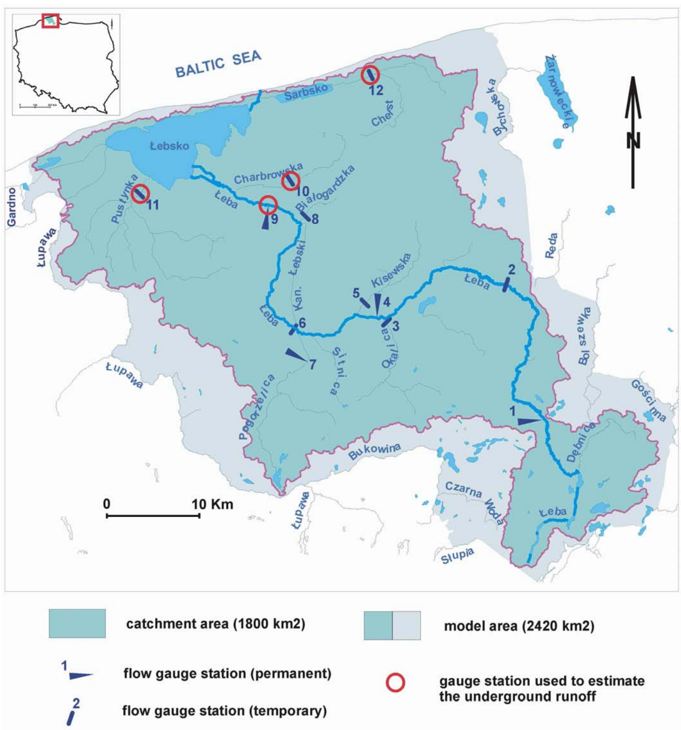

Figure 1. The Łeba river catchment.

The catchment groundwater flow system is recharged by the infiltration from the precipitating water. The mean annual precipitation varies from 644 mm in the central part of the sea coast to 823 mm in the nearby glacial upland (Kuroś, 1999). Higher precipitation was recorded in the elevated upland areas while lower values were measured in the wide Łeba river valley which originated as the marginal structure during the last deglaciation.

The groundwater resources investigations within the Łeba catchment were focused on the Cenozoic geological system (Kwaterkiewicz et al., 2001). This system comprises the paleogene, neogene and quarternary sediments. The paleogene is represented mainly by silts and clays. The neogene series also include the dominant low permeability series like silts and clays however with the presence of the permeable sand layers (Morawski, 1990). The thickness of the quarternary system is highly diversified in this catchment ranging from 0 m in one locality in the northern part to more than 250 m in the south (Morawski, 1990). The geological sketch of the catchment surface is shown in Fig. 2.

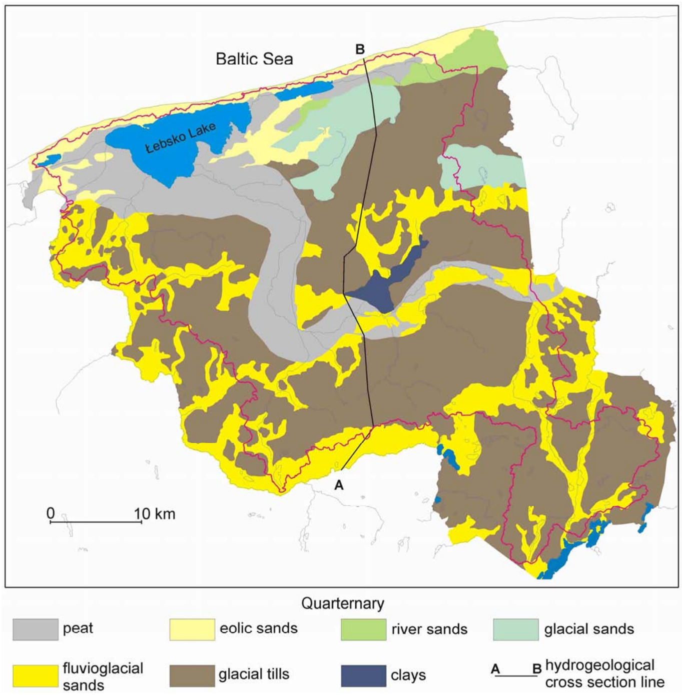

Figure 2. The geological sketch of the surface sediments (on the base of the Geological Map of Poland 1: 200 000).

This area underwent several quarternary glaciations but the sediments of the three youngest ones were identified. The glacial tills of the last glaciation (vistulian) are dominant on the surface of the upland part of the catchment. Also significantly large upland areas are covered with the vistulian fluvioglacial and glacial sands.

The hydrogeological drillings made in the Łeba river marginal valley revealed the presence of the 40–60 m thick highly permeable sand and gravel series of the fluvioglacial origin. According to the geological investigations these series were deposited in relatively short time in one sedimentation cycle during the recession of the vistulian glaciation (Morawski, 1990).

The insight into the structure of the catchment Cenozoic system is presented in the hydrogeological cross section (Fig. 3) which also shows the location of the main productive aquifers which were assigned the status of the mathematical model layers.

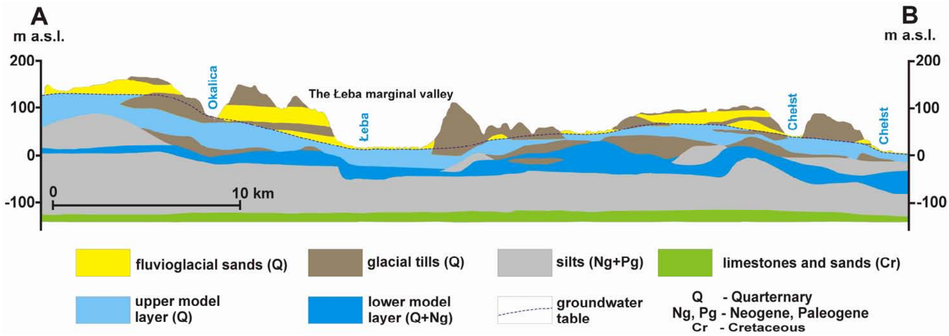

Figure 3. The hydrogeological cross section (Kwaterkiewicz et al., 2001).

RENEWABILITY OF THE MODELED GROUNDWATER FLOW SYSTEM

The applied approach to the renewability assessment assumes that the catchment subsurface system operates like a big lysimeter (BL) (Fig. 4) the outflow from which is measurable as the underground runoff Q_U to the river system. As the groundwater lateral flow Q_L across catchments boundaries can often be assumed as much less than Q_U the BL approximation can be applied in many cases. With this approximation the underground runoff Q_U is practically the same as the catchment recharge Q_{RCH} less the field evaporation Q_{EV} taking place in the river flood terraces mainly in the Łeba marginal valley and in the coastal lowland.

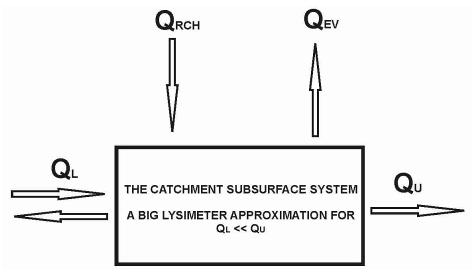

Figure 4. The concept of the catchment subsurface system as a big lysimeter; Q_U — underground runoff to the river system, Q_L — groundwater lateral flow across the catchment boundary (in or out), Q_{RCH} — recharge, Q_{EV} — field evaporation.

The construction of the steady-state model was preceded by the estimation of the flow through the model domain using the BL approximation and river flow records from the investigated catchment and from the neighboring catchments. The underground runoff Q_U from the model domain was estimated as 9.48 m^3/s and this is assumed equal to the net recharge $Q'_{RCH} = Q_{RCH} - Q_{EV}$ called the recharge down the text and represents the renewability or flow through the domain. For the catchment itself the recharge was assessed as $Q_{RCH}^{CATCH} = 6.0\ m^3/s = 21\ 600\ m^3/h$. Dividing this by the catchment area we get the mean areal recharge $q_{RCH}^{CATCH} = 106$ mm/year.

QUANTITATIVE EVALUATION OF THE CATCHMENT AVAILABLE GROUNDWATER RESOURCES

The catchment available groundwater resources Q_{AVAIL} must be viewed as a certain fraction of the catchment estimated recharge Q_{RCH}^{CATCH} according to the formula:

$$Q_{AVAIL} = C \cdot Q_{RCH}^{CATCH};\ 0 \leq C \leq 1 \qquad (1)$$

From the conceptual point of view the groundwater available resources can be defined as the withdrawal by virtual wells distributed in the regular model mesh over the catchment area (Szymanko, 1980). Adapting this concept the amount of the available groundwater resources and their distribution over the catchment area were calculated using the author's constant volume transformation algorithm (CVT). The presented results are for the upper model layer.

The model based optimization process allowed to estimate the maximal allowable value of C in the formula (1) and calculate the resources distribution in the presented upper model layer for the defined weight functions (Fig. 5).

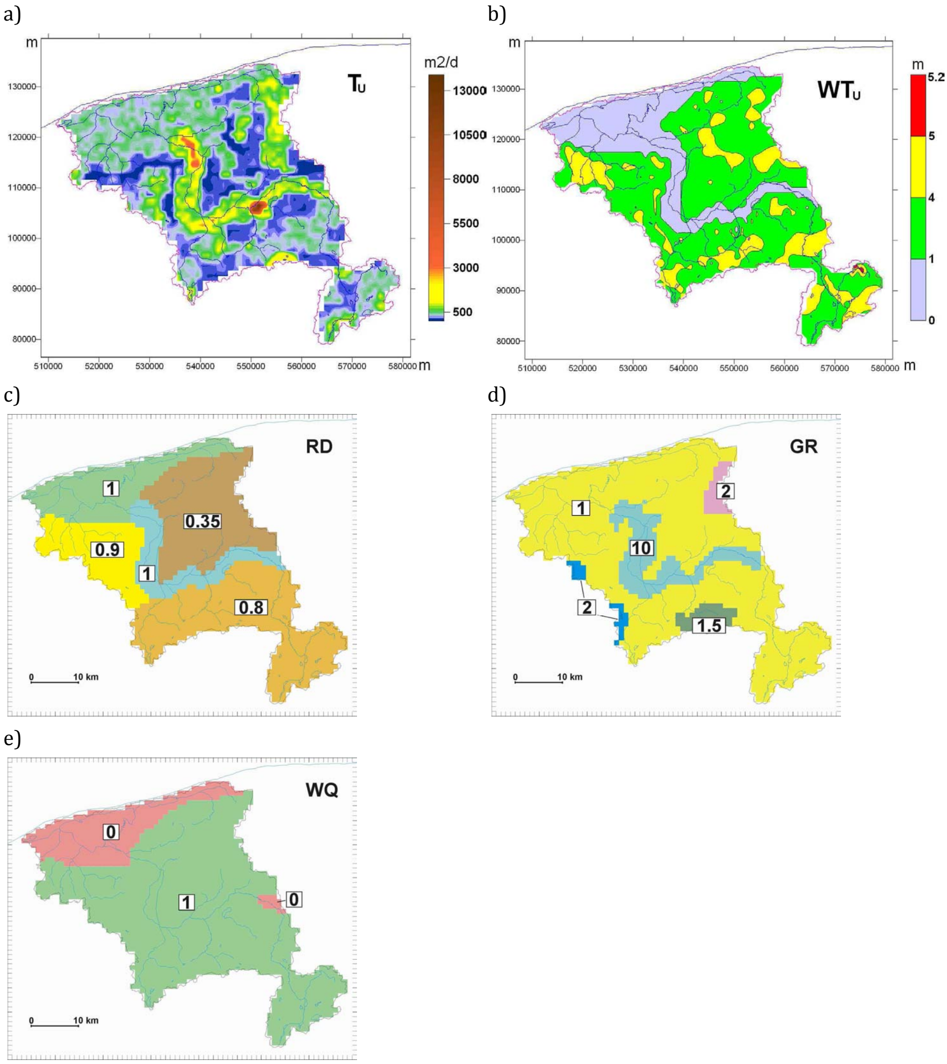

Figure 5. The definitions of the weight functions used to calculate the distribution of the available groundwater resources with the final weight values for RD and GR.

These weight functions were the distributions of:

- the calibrated upper layer hydraulic transmissivity T_U (Fig. 5a),
- the upper layer maximal allowable regional water table drawdown WT_U (Fig. 5b),
- the flow system recharge and discharge zones RD (Fig. 5c),
- the areas of the main groundwater reservoirs GR (Fig. 5d),
- the areas of good, bad and potentially bad groundwater quality WQ (Fig. 5e).

The CVT formula used to calculate the distribution of the available groundwater resources in the upper model layer in case of the applied square model mesh is as follows:

$$Q^{U}_{AVAIL}(i,j) = \frac{T_U(i,j)\cdot WT_U(i,j)\cdot RD(i,j)\cdot GR(i,j)\cdot WQ(i,j)}{\langle T_U(\,)\cdot WT_U(\,)\cdot RD(\,)\cdot GR(\,)\cdot WQ(\,)\rangle}\cdot P_U\cdot A\cdot C\cdot q^{CATCH}_{RCH} \quad (2)$$

where:

- Q^{U}_{AVAIL} (i,j) — rate of the virtual well in the upper layer model node (i,j) [m^3/h],
- T_U(i,j), WT_U(i,j), RD(i.j), GR(i,j), WQ(i,j) – weights in the node (i,j),
- P_U — fraction of the resources allocated to the upper layer ($P_U = 0.85$),
- A — area of the model cell (in the presented case A = 1000 m × 1000 m),
- q^{CATCH}_{RCH} — fraction of the catchment recharge defining the amount of the available resources,
- q^{CATCH}_{RCH} — catchment mean areal recharge ($q^{CATCH}_{RCH} = 1.21\times10^{-5}$ m/h = 106 mm/year),
- $\langle T_U(\,)\cdot WT_U(\,)\cdot RD(\,)\cdot GR(\,)\cdot WQ(\,)\rangle$ — mean product value over the catchment area.

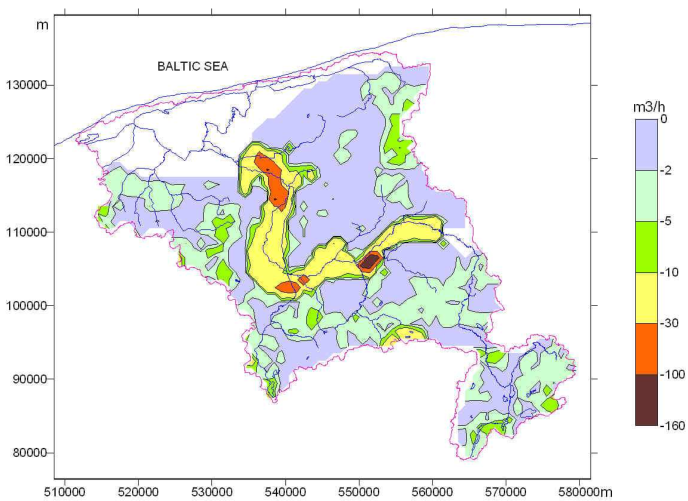

Figure 6. The calculated according to the formula (2) distribution of the upper layer available groundwater resources $Q^{U}_{AVAIL} = 7383.6$ m^3/h for $C = C_{MAX} = 0.4$.

The resulting distribution of the upper layer available groundwater resources Q^{U}_{AVAIL}=7383.6 m^3/h is shown in Fig. 6. In white catchment areas these resources equal zero due to the bad or potentially bad groundwater quality (red colour in Fig. 5e).

The total amount of the resources evaluated in the model based optimization process for both layers is 8686.6 m^3/h (Tab. 1). This is 40% of the catchment assessed recharge Q_{RCH}^{CATCH}, so the C maximal allowable value in the formula (1) and (2) was determined as $C = C_{MAX} = 0.4$. The optimization variables were: the C coefficient, the RD weights (Fig. 5c) and GR weights (Fig. 5d). There were two optimization objectives: the simulated leakage to the rivers not less than the river base flow and less than 15% increase of the lateral inflow across the catchment boundary both as the effect of the modeled resources withdrawal.

Table 1. The available groundwater resources and existing withdrawal.

Model layer	The available resources (m^3/h)	The existing withdrawal (m^3/h)
upper	7383.6	568.3
lower	1303.0	453.2
both layers	8686.6	1021.5

CONCLUSIONS

- The presented method directly connects the available groundwater resources to the renewability of the investigated flow system and its hydrogeological characteristics.
- The prior awareness of the quantity of the flow through the model domain is the elementary precondition for the reliable model assessment of the groundwater resources. This implies that practically only river catchments can be the subject of the successful regional groundwater modeling aimed at the proper quantitative evaluation of the groundwater resources.

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abstract id: **191**

topic: **3**
Aquifer management

3.1
Regional groundwater systems

title: **Regional groundwater flow system analysis in Kanto Plain, Japan with thermal and geochemical data**

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keywords: regional groundwater flow system, groundwater modeling, thermal data, geochemical data, Kanto Plain

INTRODUCTION

Recently much attention has been paid on deep groundwater behavior predictable water resources or as promising stable environment for geological sequestration of carbon dioxide and high level radioactive waste (HLW). A lot of techniques have been developed to evaluate deep groundwater behavior. However, deep groundwater evaluation is capital intensive and limited in situ data could be obtained. Groundwater modeling technique is an effective tool for providing supplementary information. Especially, geological sequestration requires careful evaluation with long term changing environmental conditions. Groundwater modeling technique has much advantage for such evaluations. This paper briefly presents newly developed groundwater modeling approach to evaluate deep groundwater characteristics (Yoshizwa et al., 2008).

STUDY AREA

Kanto plain is selected as the study area on the research because the area contains one of the largest groundwater basin in Japan and the largest number of existing in-situ data could be obtained in the area. Study area is shown in the Figure 1.

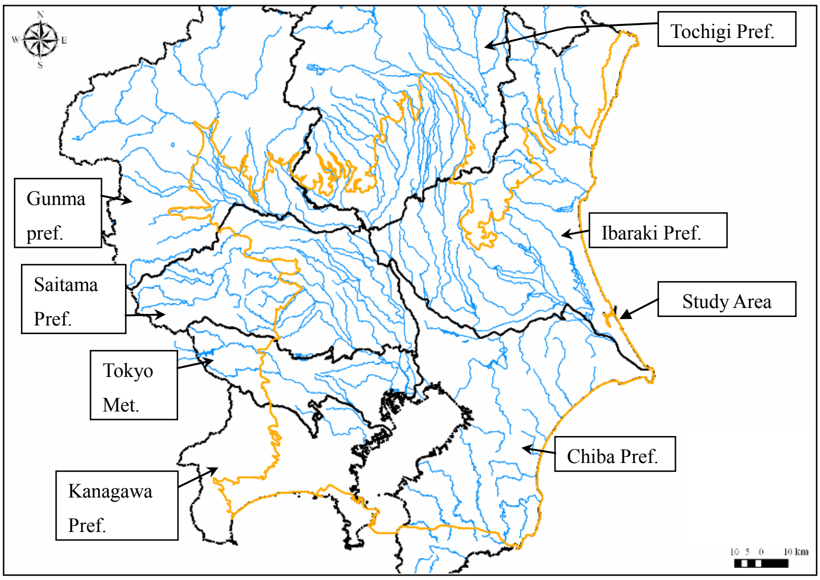

Figure1. Study Area.

DATA COLLECTION AND ANALYSIS

Existing data such as existing drilling data, groundwater level monitoring data, borehole temperature logging data and water quality data are collected in the area. Data collected are complied to establish groundwater model. Groundwater level data could be obtained for only shallow aquifer zone and could not be utilized for the modeling analysis. Therefore, the remaining data, borehole temperature logging data and water quality data is selected to utilize modeling analysis.

Collected borehole temperature data is utilized to extrapolate subsurface temperature distribution. Study area is vertically classified into four major geological formations. Subsurface temperature for the geological formation is obtained from extrapolated data. Figure 2 shows example of subsurface temperature distribution for surface of geological formation.

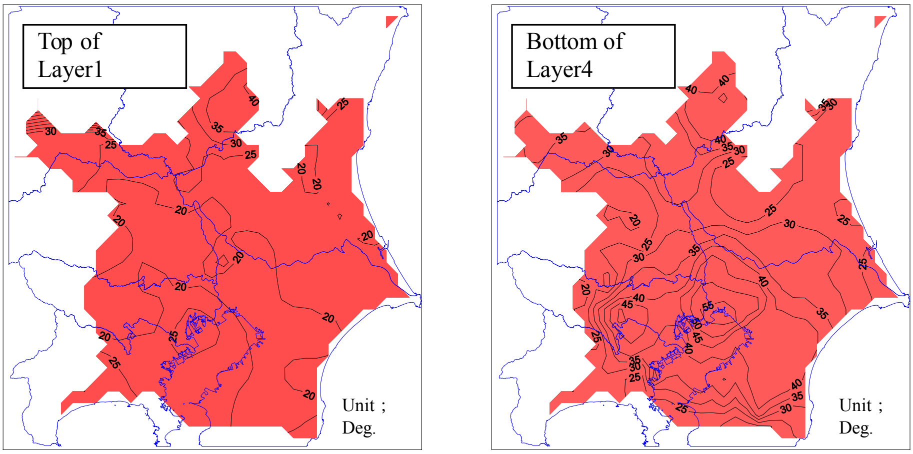

Figure2. Extrapolated temperature distribution.

NUMERICAL MODELING ANALYSIS

3D saturated-unsaturated, variable-density ground-water flow with solute or energy transport model SUTRA is used for the analysis. At the first step, borehole temperature logging data is utilized as the parameter of groundwater flow size from shallow aquifer to deep one. To simulate underground temperature distribution with the SUTRA, hydrogeological settings are used to estimate from the analysis. Figure 3 shows created mesh of numerical model. Extrapolated subsurface temperature distribution is used for calibration target of the simulation.

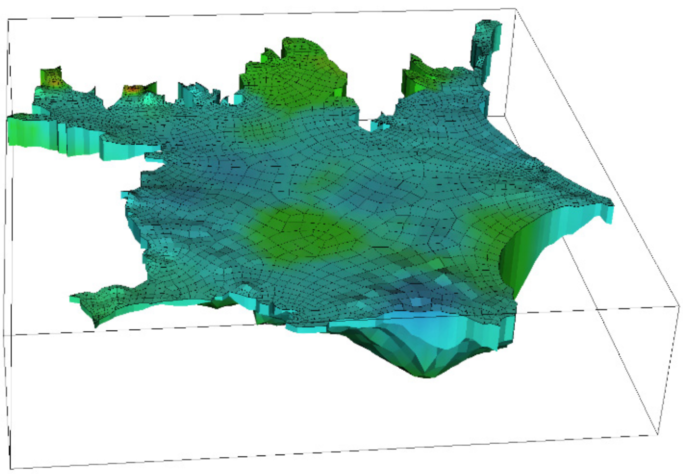

Figure3. Created mesh of numerical model.

In the second step, chloride ion concentration data is utilized for the analysis. To simulate underground chloride concentration distribution with the SUTRA, hydrogeological settings are used to estimate from the analysis.

RESULTS

Hydrogeological settings from shallow to deep aquifer could be estimated and groundwater flow velocity could be evaluated from the analysis. Evaluated groundwater potential distribution provides local scaled to regional scaled groundwater flow system.

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abstract id: **205**

topic: **3**
Aquifer management

3.1
Regional groundwater systems

title: **Using spatial profile of recharge potential for the definition of primary recharge area on Chou-Shui Alluvial Fan**

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keywords: primary recharge area, distributing factor, Chou-Shui Alluvial Fan, recharge potential

The surface hydrology in Taiwan varies immensely in the time and space domains. The impact of global climate change may cause the situation to become severe. Using only surface reservoirs cannot provide a reliable water supply because rainfall influences reservoir water supplies. Thus, groundwater resources become more vital. The protection and sustainable management of groundwater resources are imperative issues to consider. For groundwater protection and management, defining the high recharge areas of a groundwater basin is essential, making it possible to monitor and manage human activities. To define a high recharge area is a challenging issue because of complicated surface and geological conditions. Nevertheless, to avoid confusion and facilitate communication with the public, the methodology for determining a high recharge area must be simple and easy to demonstrate.

In response to previous discussions, this study proposes a methodology by combining a factor scoring method and a geographic information system (GIS) to define the high recharging areas of a groundwater basin systematically. The factor scoring method computes the recharge-potential score for a basin. The GIS system facilitates the spatial analysis of selected factors and demonstrates the results. Thus, recharge-potential scores form the basis for defining a high recharge area. The summation of the weighted factors score yields the recharge-potential scores. The factors are selected based on influence on groundwater recharging. Seven factors were selected for computing the recharge potential of the Chou-Shui Alluvial Fan including land use, surface soil, river density, average annual rainfall, correlation between rainfall and groundwater storage, variation of storage for unit aquifer area and hydraulic conductivity.

The computation of recharge-potential scores consists of two major steps. Each factor score is computed from its original data format. The data format for each factor in its original state is di erent and is collected from a groundwater database, remote sensing data, and GIS coverage. All factor scores range from 0 to 100 and a high score implies a high recharge potential. The scores are spatially distributed and represented as cell-based coverage with 1 km2 cells size. The original data format for "land use" and "surface soil" is GIS coverage with polygons and features. For these two factors, a factor score was assigned to each feature based on its influence on groundwater recharging. The cell-based coverage of the two scores was obtained by applying GIS spatial analysis techniques of regrouping and overlaying. The other factors' original format is points distributed in space with a continuous data value. These factors require an interpolation scheme to interpolate the point-wise data into cell-based coverage. The scores were assigned based on its influence on groundwater recharging.

Second, the recharge-potential (RP) scores were computed by summing the weighted seven factor scores. Therefore, the factor weighting must be defined before computing the RP scores. The causal analysis among the factors suggested by Shaban (2006) was implemented to determine the factor weighting. The causal analysis defined the mutual interaction among the factors and a causal network for the seven factors was developed. The factor weighting was computed based on the causal network. To demonstrate the feasibility for a practical application of this method, the propose method was applied to determine the high recharge areas of the Chou-Shui Alluvial Fan, one of the most important basins in Taiwan. A groundwater recharge-potential score coverage was obtained and the score revealed that the RP score decreases from the proximal area to the distal area. Therefore, based on this study, the primary high recharge area for Chou-Shui Alluvial Fan is located at the proximal area. This result was compared with previous field investigations and shows good agreement, indicating the proposed methodology is applicable to a complicated high recharge area definition problem.

abstract id: **219**

topic: **3**
Aquifer management

3.1
Regional groundwater systems

title: **Groundwater recharge in the fractured massif of Gardunha mountain (Central Portugal)**

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keywords: groundwater resources, Gardunha mountain, recharge, fractured rocks

Serra da Gardunha (central Portugal) belongs to a great mountain system, the Iberian Massif. In highland areas such as the Serra da Gardunha formed by predominantly low permeability igneous and metamorphic rocks, the bedrock itself may be a potential source of groundwater.

Detailed hydrogeological studies have been carried out in the Serra da Gardunha in order to estimate the natural recharge rate of crystalline bedrock.

Part of the rainfall in the region rapidly flows downhill towards the drainage areas of the principal rivers and streams. The rest infiltrates in the bedrock moving mainly through secondary openings, such as joints, fractures and faults. Traditionally, horizontal wells and springs are used to abstract these groundwater resources.

The methods used to estimate groundwater recharge include the analysis of daily data of spring base flow and its comparison with data provided by the chloride mass balance method. Chemical data from rainfall and groundwater were also collected.

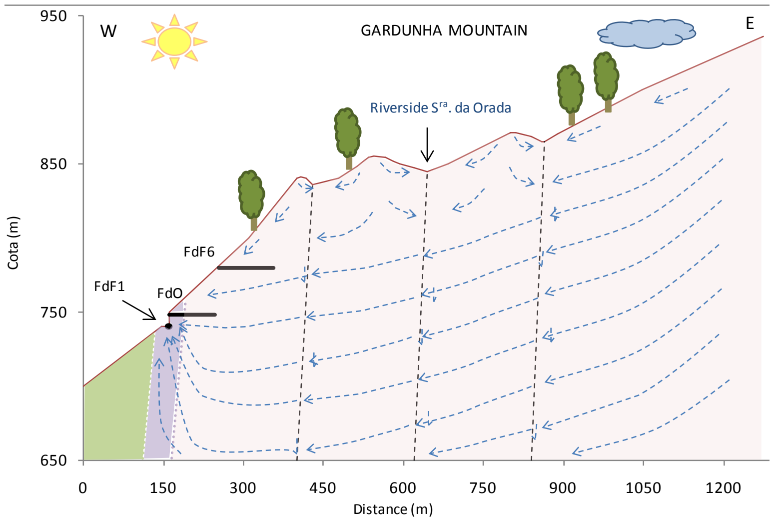

Figure 1. Schematic cross-section of the region in study.

The results contributed for the development of the hydrogeological conceptual model of the region (Fig. 1) and show that about 15% of the rainfall recharges shallow groundwater resources. This recharge values may not be of significance at regional level, but certainly constitute an important local source of water for drinking supply.

ACKNOWLEDGMENTS

Eric Mendes would like to thank the Portuguese Foundation for Science and Technology and also Beira Vicente Lda. for funding the PhD grant (SFRH/BDE/33328/2008). All the authors would like to thank to CVRM-Centro de GeoSistemas for the facilities conceded.

IAH 2010
Krakow

abstract id: **228**

topic: **3**
Aquifer management

3.1
Regional groundwater systems

title: **Hydrogeological characterisation of the heterogeneity of aquitards from a multilayered system**

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keywords: aquitard, borehole logging, multilayered system, hydrogeological model

INTRODUCTION

In sedimentary basins, the vertical organization of geological deposits leads to the existence of interbedded aquifers and aquitards. This alternation of hydrogeological units forms a complex multilayered aquifer system. The aquitards, also called leaky confining layers are low permeability units generally composed of clay materials. They can have very high storage capacities but they cannot transmit water at rates fast enough to supply wells. Nevertheless, they can transmit water slowly from one aquifer to another leading to quality issues. This exchange is generally known as "leakage". This phenomenon can become very important for long-term transient systems and is generally considered as a significant component of the total inter-aquifer recharge. Then, it is necessary to assess these vertical fluxes as accurately as possible and integrate them in general groundwater flows in order to tackle the management of groundwater resources.

There is increasing evidence that flow through many aquitards is much more complex (Remenda 2001) than can be accounted for by simple one-dimensional vertical flow model (Eaton, 2007). This could be explained by multiple sedimentary layers of differing properties found in stratified rock sequences.

In order to quantify as accurately as possible the fluxes flowing through aquitards, the characterization of their architecture and their hydraulic properties remains a major objective.

BOREHOLE LOGGING CONTRIBUTION TO SPATIAL CHARACTERIZATION

Composed by sedimentary deposits that correspond to several transgressive-regressive episodes extending from Jurassic period (-210 ma) to the end of the Miocene (-5 Ma), the north part of the Aquitain sedimentary Basin shows a complex structure both vertically and horizontally. Therefore, this basin is a multilayered aquifer system (Figure 1) within which 6 main aquifers (one unconfined aquifer and five confined aquifers) are more or less connected and are separated by low-permeability units more or less continuous.

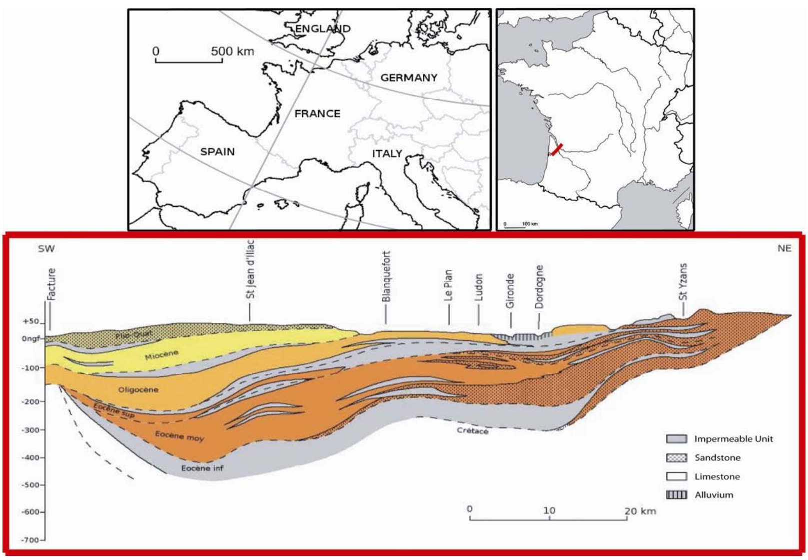

Figure 1. Schematic hydrogeological cross-section of the North of Aquitain Basin (Moussié, 1972).

Currently, groundwater resources are broadly exploited for different uses (freshwater supply, geothermal energy, thermal water, agricultural and industrial domains…). The amount of water available from such system is an essential issue for the long-term management of freshwater supply. The anthropogenic influence manifests through important withdrawals concentrated on the three shallowest confined aquifers (Eocene, Oligocene and Miocene aquifers).

Two recent hydrogeological models developed in this area incorporate the confining layers. Even if they both identify the presence of vertical flows through the aquitards, they cannot correctly reproduce the functioning of the groundwater system and the level state of the water reserves. The lack of knowledge about aquitard structures and associated hydrodynamic measurements leads to those uncertainties. The use of direct or indirect measures to redefine the vertical organisation of the multilayered system and the horizontal heterogeneity of the aquitards appears to be a priority.

We present here borehole data that allow to re-examine the geological nature of the aquitards and their heterogeneities to increase the hydrogeological description of the multilayered aquifer system prior to its numerical implementation.

The measurements are based on the use of geophysical borehole loggings such as Gamma-ray, normal-resistivities and flowmeters which, used as a complement to geological data, allow to redefine facies boundaries with depth and to assess the heterogeneity of the aquitards.

A 110 wells database was constructed to organize information on well completion, geological data and geophysical loggings in the study area using Kingdom software (Fig. 2).

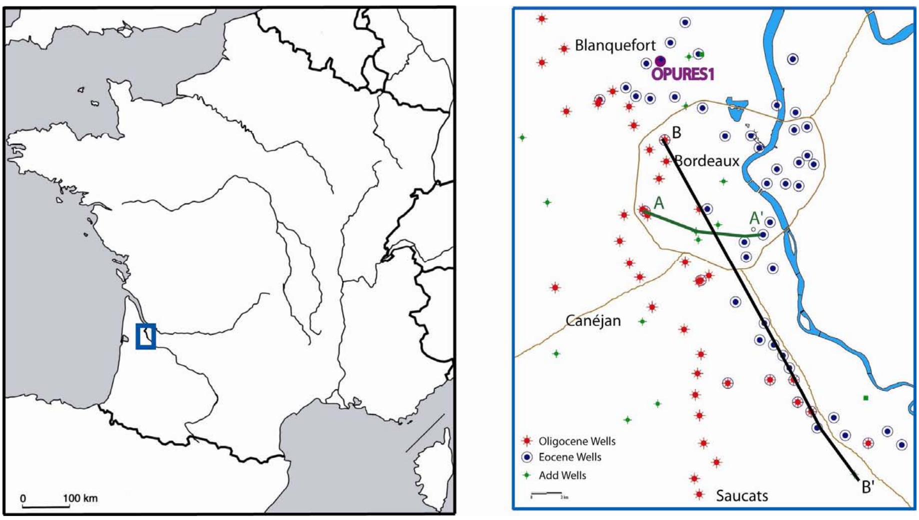

Figure 2. Map of the study area with boreholes and cross sections A-A’ and B-B’ locations.

Indeed, Gamma-ray logs allow to measure the total natural radioactivity of the formations crossed by a well. This measurement is essentially used to distinguish high radioactive shale beds, corresponding to aquitards in our case, from less radioactive sandstone and limestone. As for Normal-resistivity, it enables us to locate the main conducting and non-conducting formations (aquitards and aquifers). Flowmeter logs data were used to constrain more the reinterpretation by locating the permeable zones of aquifer’s limits.

Before correlating all these geophysical loggings, Gamma-ray data were formatted for import. Indeed, the gamma-ray logs have been performed by different companies since the two last decades. Because of the use of different probes, scaled gamma-ray logs were produced from raw gamma-ray data to eliminate calibration gaps due to various probes. Gamma-ray data were scaled using the formula (Miller, 2000):

$$SCGR = \frac{(GR - Min)}{(Max - Min)} \times 100$$

Where *SCGR* is the percent of scaled gamma radiation, *GR* is the original gamma-ray value, *Max* is the base-line value for maximum radiation and *Min* is the base-line value for minimum gamma radiation.

The well-to-well correlations were constrained using the original geologic description to reduce the factors affecting the individual gamma-ray response such as logging speed, hole conditions effect (tubing, casing, cement, diameter…) (Serra, 2004).

HIGH RESOLUTION AQUITARD ASSESSMENT

In addition, a borehole called OPURES1 (Fig. 2 and 3) was drilled and completed for the first time in the region directly in an aquitard to observe on the long-term the evolution of the hydraulic gradient and perform in situ measurements to assess hydraulic parameters at different levels. It concerns the Oligocene/Upper Eocene Aquitard which is about 50 m thick.

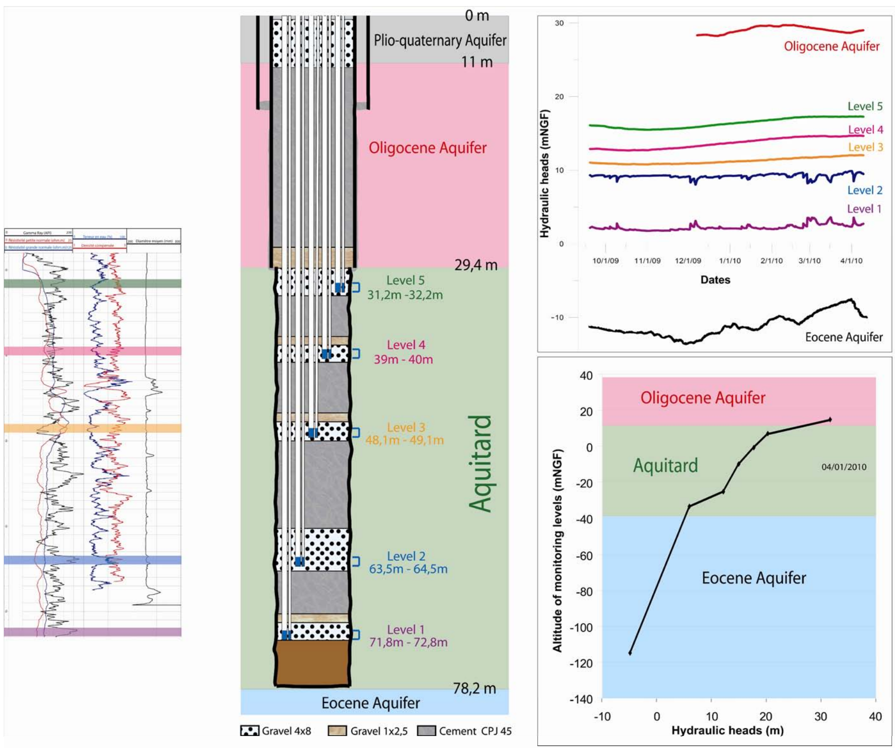

Figure 3. Completion of OPURES1 borehole and results.

It underlies the oligocene aquifer and confines the upper eocene and medium eocene aquifers. The latter is heavily pumped by a borehole which is 1km from our experimental site.

The borehole was drilled using both rock coring and air-rotary methods, logged using downhole geophysics, and instrumented as multi-level wells. Thus, 5 levels were selected for pressure monitoring inside the aquitards (Fig. 3).

Normal-resistivities and Gamma-ray logs as well as cores measurements confirm the heterogeneity of the aquitard. This is notably revealed by the presence of a silty clay layer. On a small scale, cores measurements showed some fractures and different indurated levels of generally small thicknesses. *In situ* hydrodynamic properties measurements are planned to account for this heterogeneity.

A non-linear hydraulic gradient is observed within the aquitard. This is likely due to contrasts of permeabilities. Actually, the hydraulic heads are not totally balanced. The aquifer exploitation can generate hydraulic disturbance which interferes in the balance.

DISCUSSION AND CONCLUSION

The use of borehole geophysical loggings shed new light on the geology of the Aquitain sedimentary basin in the region of Bordeaux (Fig. 4).

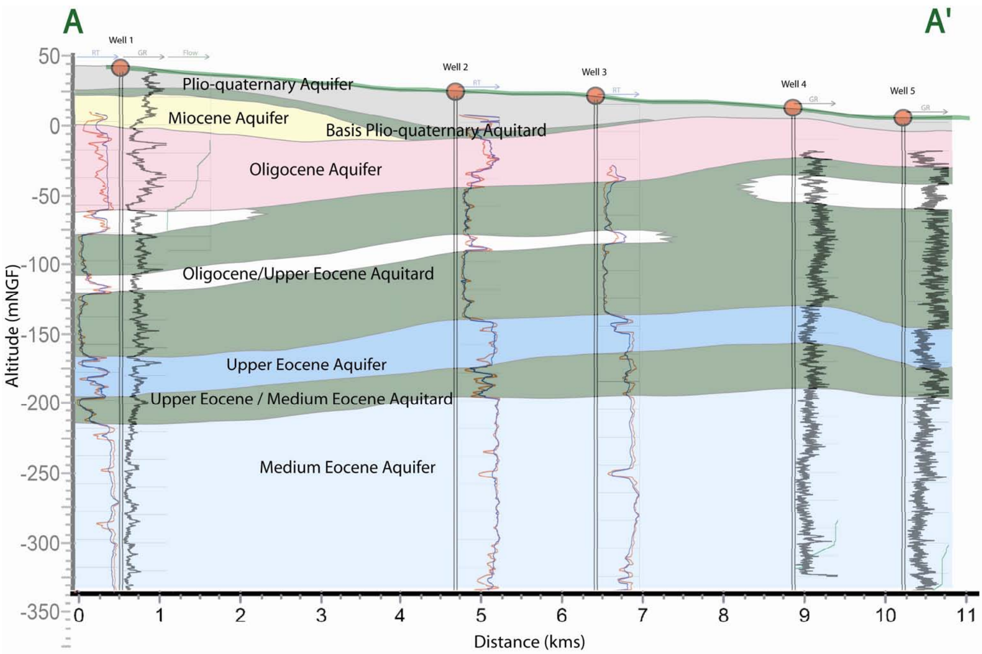

Figure 4. Example of interpretation from well logging data: RT= Normal-resistivity; GR= Gamma-Ray. Location of the cross section is indicated by the A-A' trace in Fig. 2.

By comparing two cross sections (Fig. 5), we can observe the contribution of borehole geophysical loggings to the reconstruction of the geology and an accurate 3D model.

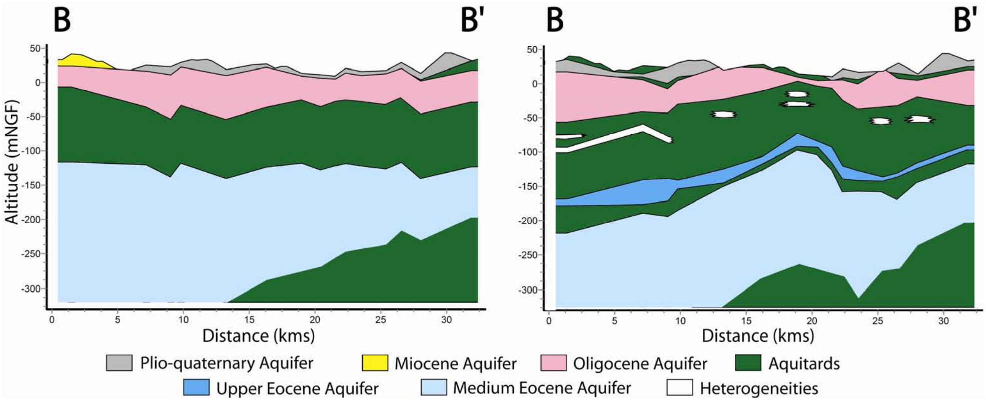

Figure 5. Comparison of two cross sections. One based on geological data, the other one constrained by the use of borehole geological loggings. Location of the cross section is indicated by the B-B' trace in Figure 2.

The comparison reveals the presence or not of clayey layers which were not integrated in the generally accepted geological model. The first one is situated under unconfined aquifer. This aquitard will limit the recharge of underlying aquifers and will protect them from pollution. We also noticed that a new aquifer body (Upper Eocene) appeared on the borehole geophysical loggings. The medium Eocene is thus divided into two aquifers (Upper Eocene and Medium Eocene) separated by an aquitard. The Upper Eocene is currently not used for the freshwater supply. Next, in some areas, the thin aquitard which separate the Miocene and the Oligocene does not exist leading to the possibility of hydraulic continuity. Finally, heterogeneities within the aquitards were pointed out. These heterogeneities correspond to limestone and sandstone with more or less clay. They form lenses of limited extension at different levels within the aquitard.

Finally, this reinterpretation allowed to assess the geological nature of rocks composing the aquitards in order to provide relative information on permeability values related to each facies.

The integration of geological and hydrogeological properties of aquitards in the numerical models allows to quantify the impact of local heterogeneity on groundwater flows. The results yield to the update of the regional model which will allow to assess an accurate description of leaky fluxes from the aquitards in the scope of enhancing freshwater exploitation.

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abstract id: **272**

topic: **3**
Aquifer management

3.1
Regional groundwater systems

title: **Spatial distribution of potential aquifer recharge from precipitation for the period of 1951–1980 over Slovakia**

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In this study, the evaluation of effective precipitation by means of geostatistical analysis of meteorological stations over the territory of Slovakia for the period 1951–1980 is presented. The effective precipitation is the essential part of any hydrogeological study involving estimation of recharging groundwater amounts. Since the effective precipitation is primarily defined by temperature and precipitation, both varying strongly with local geomorphology, a very careful approach in spatialization of data drawn from sparse meteorological stations must be taken. For this purpose a detrended kriging is recommended as a favourable method and its usefulness is proven on the territory of Slovakia in this study, where the method of residual kriging with removed global trend was used to estimate mean monthly and annual air temperatures and precipitation totals. To identify global trends in the two fundamental climatologic variables — temperature and precipitation, a stepwise regression was applied to detect their trends in the geographic position as well as in the local geomorphology (Adam et al., 2006). Two positional and three geomorphological parameters were judged to be governing the global variation in these variables. Verification of the results proved that the method is well capable of reproducing observations.

For the sake of mean potential evapotranspiration evaluation, the Thornthwaite's method (1948, 1955) with monthly calculation steps was used. The results gained were subsequently entered into the calculation of actual (real) monthly evapotranspiration, where the response of precipitation totals and potential evapotranspiration to the change in soil water content was examined, which determines the real quantity of water evaporated from the surface. The outcome is the map of spatial distribution of potential aquifer recharge by effective precipitation, calculated by subtracting actual (real) evapotranspiration from precipitation totals. For the whole Slovak territory, the average value of effective precipitation on the 1951–1980 period is of 176.5 mm (5.60 l s^{-1} km^{-2}). The mean precipitation for the same period was 721.9 mm and mean actual evapotranspiration 545.5 mm (mean potential evapotranspiration according to Thornthwaite's method was 638.3 mm). Average annual volume of precipitation over Slovakia (49,030 km^2) is then 35.395 km^3, and a ratio of unevaporated water ca 24.4% (8,653 km^3). When looking at the calculated data in regional details, we can realize that the most of the water wealth of Slovakia is created in only several parts of the regions located in the north and center of the country itself. In the mountains, spatial averages of effective precipitation exceed 500 mm or even 700 mm. On the contrary, 60–70 mm of the average effective rainfall can be found in the lowlands — see Fig. 1.

Because only a part of the data from existing meteorological stations was available at the time of this study, a future work on including remaining stations and thus increasing the precision of effective rainfall distribution is necessary. In this study, monthly average air temperature data from 98 climatic stations and monthly average precipitation totals from 211 stations were used. The representative period for the results presented is 1951–1980. Nowadays, in the monitoring network of the Slovak Hydrometeorological Institute there are 105 climatic stations and 680 precipitation stations, what means an increased potential for better solutions in the future. Nevertheless, an altitudinal distribution of these stations still does not cover higher altitudes, where majority of effective precipitation takes place.

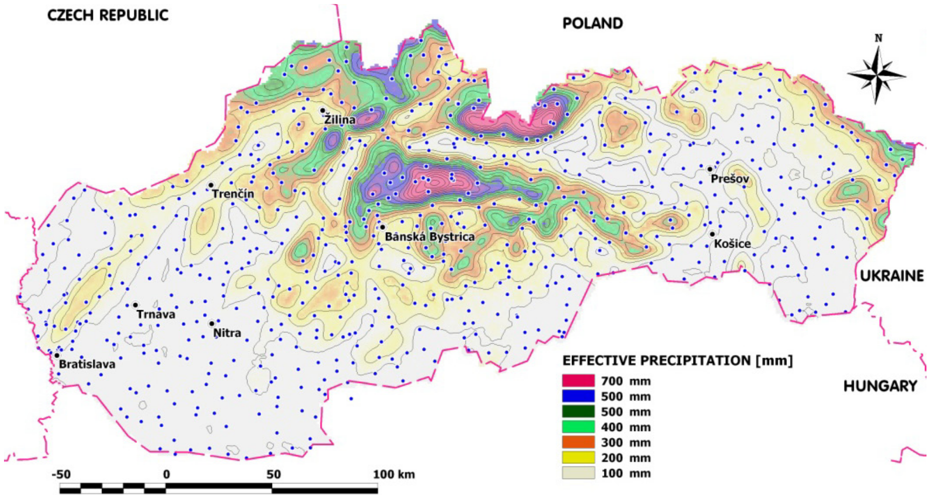

Figure 1. Map of mean effective precipitation (in mm) over Slovakia during the period 1951–1980. Contours base interval is 50 mm. Precipitation stations are shown as dots.

The practical consequence of assessing the mean effective precipitation for individual regions is appealing not only with respect to groundwater recharge, but also in solving quality problems. In this respect, the climatic pollution attenuation potential, e.g. diminishing of contamination by simple dilution, is of particular interest. The partitioning of the effective precipitation into surface- and groundwater runoff depends on hydraulic properties of rocks and local morphological characteristics, especially the slope, and should be under the scope of further investigations.

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abstract id: **284**

topic: **3**
Aquifer management

3.1
Regional groundwater systems

title: **Developing of an aquifer management strategy for the rapidly expanding City of Lusaka, Zambia**

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keywords: aquifer management, groundwater potential, groundwater pollution, remote sensing analysis, vulnerability assessment

INTRODUCTION

Lusaka, the capital of Zambia with an estimated population of about 1.3 million in 2005, is experiencing a rapid population growth of about 3.7 percent per annum. The population density has increased from about 700 in 1969 to over 3,000 persons per sq. km in 2000 (LCC, 2008). Water is supplied by a Commercial Utility, the Lusaka Water and Sewerage Company (LWSC). According to the National Water and Sanitation Council (NWASCO, 2009), the water supply coverage (ratio of urban population with access to safe and reliable water) served by the LWSC is 68%. Total water production in 2008/2009 reached almost 260,000 m^3/d while actual daily water demand (including private and commercial abstractions) is estimated at 340,000 m^3/d. Currently, the LWSC pumps 125,000 to 140,000 m^3/d from the local groundwater systems whereas the remaining water is sourced through a pipeline system from the Kafue river situated about 40 km south of the City. The LWSC was advised to increase the water supply capacity to cope with the estimated water demand of 640,000 m^3/d by the year 2030 (KRI Int. Corp. et al., 2008).

The very productive, karstic aquifers are characterised by shallow water tables and a lack of protective cover, and therefore considered very vulnerable to pollution. The majority of Lusaka's population lives in formal and informal urban areas where the most people are using on-site sanitation facilities. One of the major factors influencing water quality therefore is the provision of safe sanitation. According to NWASCO the sanitation coverage (ratio of population with access to adequate sanitation) is only 17%. A lack of city planning and its implementation, especially in terms of new industrial and commercial areas, puts the resource further at risk. Poor drainage, inappropriate handling of industrial effluents and uncontrolled dumping of industrial and domestic waste together with unplanned developments have significantly contributed to the problem of groundwater contamination. These and many other concerns have created a huge challenge for effective groundwater resource management in Lusaka. Despite of its importance, the use of groundwater is currently not regulated. Groundwater management regulations are incorporated in the proposed Water Resources Management Bill which is yet to be enacted.

PHYSIOGRAPHY AND HYDROGEOLOGY OF THE STUDY AREA

The project area covers an area of approximately 3,000 square kilometres and extends over the City of Lusaka and adjacent areas including parts of the Mwembeshi and Chongwe Catchments. The tropical continental highland climate is characterised by a cool and hot dry season lasting from May to October and a wet season between November and April. 80% of the total annual rainfall (average of 860 mm) occurs from December to March, usually with a peak during January (average of 220 mm).

Regionally, the Lusaka rocks are part of the Zambezi Belt that, by definition, is separated by the Mwembeshi Shear Zone (MSZ), from the Lufilian Belt to the north (Porada, Berhorst, 2000). The Lusaka area is covered by strongly folded overthrusted metasedimentary rocks of Katanga (Neoproterozoic) age which have been intruded by granitic and basic bodies (Hanson et al., 1994, Johnson et al., 2007). Owing to the intense tectonical deformation of the Katanga sequence, the stratigraphic succession and its regional correlation are still not fully clarified. Based on the stratigraphical succession proposed by Simpson et al. (1963) the metasedimentary cover can be divided into three formations: the Chunga Formation comprising schist and quartzites, the Cheta Formation including schist and carbonates and the Lusaka Dolomite Formation (Figure 1).

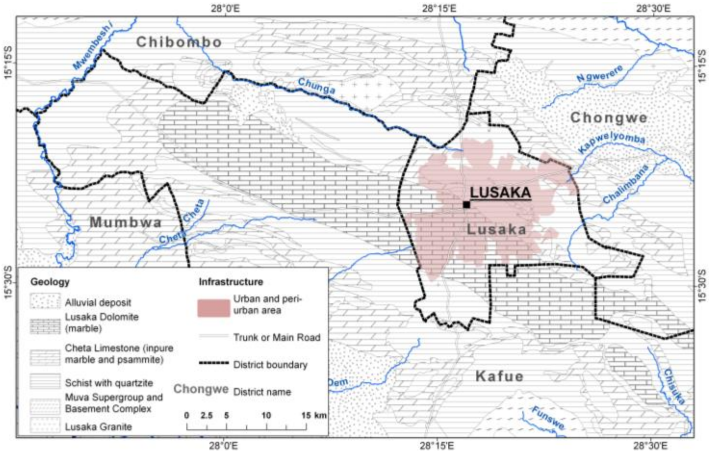

Figure 1. Geology of the study area.

The carbonate rocks cover an area of 1,600 km^2 and are known to form a terrain undergoing recent and active karstification. On the surface, an epikarstic zone has developed with an average depth of 5 m extending to a maximum depth of 25 m below the surface. The main aquifer is hosted by the marbles of the Lusaka Dolomite Formation forming an elongated about 65 kilometres long and 20 m wide plateau with its axis striking in WNW–ESE direction. Subordinate aquifers occur in the crystalline limestone and dolomite of the Cheta Formation located to the north, west and south of the Lusaka Dolomite aquifer. Minor aquifers are developed in the schists, psammites and quartzites of the Cheta and Chunga Formations and within alluvial deposits.

PRELIMINARY FINDINGS OF THE INVESTIGATION PROGRAM

First investigations carried out during the preparatory phase of the study included the development of a groundwater information system including a Geographic Information System (GIS), the establishment of a groundwater, spring and surface water monitoring network, remote sensing studies and water quality sampling campaigns. The database stores information on water points including hand dug wells, boreholes, springs and groundwater exploration drill sites comprising information of all major hydrogeological investigations carried out since the mid-1970s (Bäumle, Kang'omba, 2009).

Satellite imagery was used to identify land use distribution, directions of maximum principal stress and the main trends and types of faults (Hahne, 2010). The current land use and surface cover distribution was determined by an automated supervised classification with the method "maximum likelihood" of 80% using a Landsat ETM scene with acquisition date May 13, 2002 as the main information source. To obtain a more recent picture, the obtained major classes were then manually adjusted in a GIS on basis of four SPOT scenes with acquisition dates July 11, 2008 (western part), August 13, 2007 (north east) and July 14, 2007 (south east). Major land use and surface cover classes included water, settlement, various types of shallow or bare soil, agriculture and forest. From 2002 to recent the most striking change is a loss of forest and scrubland in favour of commercial- small scale agriculture, as well as for the production of charcoal. Also development areas grew rapidly, especially in the south of Lusaka.

Three main trends of faults could be derived from satellite imagery (Figure 2):

- A strike direction NW–SE (± 120°), parallel to the main structural trend,
- A further NW–SE direction (140°),
- A probably conjugate NE–SW direction (035°, 045°).

To a minor extent also a NE-SW trend (080°) parallel to the MSZ direction is present.

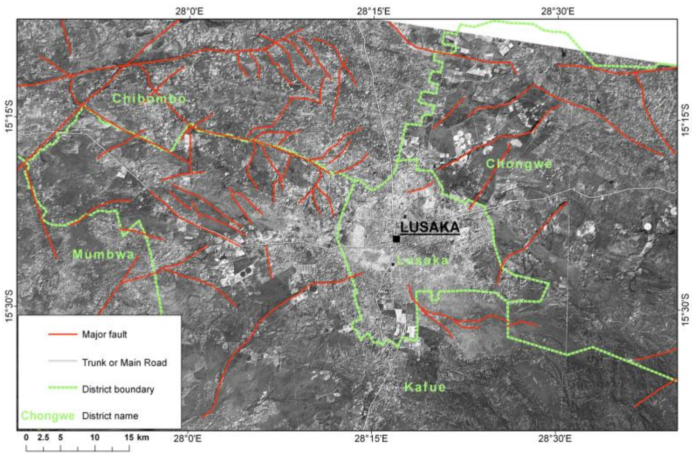

Figure 2. Examples for major faults derived from satellite images projected into Landsat ETM band 5.

Water quality sampling comprised inorganic constituents and heavy metals as well as microbiological indicators. Sampling points included perennial and seasonal springs as well as water supply wells operated by the LWSC and private wells. The water from springs and water supply wells in the limestones and dolomites corresponds to the Ca-Mg-HCO_3 type as was expected. In terms of water hardness, the water is generally hard (>250 mg/l $CaCO_3$) to very hard (>375 mg/l $CaCO_3$). Groundwater hosted by schist can be distinguished from the carbonate springs by overall lower TDS, slightly lower pH, lower HCO_3:SiO_2 ratios as well as much lower hardness and alkalinity (i.e. buffering capacity). The results could be used to identify the chemical water composition of areas that are unaffected by human pollution sources. These waters were characterised by an electrical conductivity (EC) of less than 800 µS/cm and concentrations in sodium, chloride, nitrate and sulphate below 10 mg/L. Higher levels in these parameters could consequently suggest the presence of urban pollution sources. Groundwater pollution from human activities was apparent in higher levels of EC reaching 1450 µS/cm, sodium contents up to 138 mg/l, chloride levels up to 123 mg/l, and sulphate concentrations up to 172 mg/l. Whilst these values still comply with the Zambian Drinking Water Standard (ZDWS), nitrate levels frequently exceeded the recommended standard of 10 mg/l NO_3–N. High values in EC as an indicator for anthropogenic pollution were confirmed during a recent sampling campaign in April/May 2010 (Figure 3). Especially in the unserviced areas in the southwest of the City as well as in the industrial area in the west-northwest EC values reach up to 1200 µS/cm and 2900 µS/cm respectively. Concentrations of heavy metals and iron were low throughout the study area. This could be due to the low solubility of iron and the heavy metals such as cadmium, lead and zinc at the prevailing high pH and the abundance of bicarbonate ions. The study proved that microbiological (including faecal) contamination and pollution is widespread throughout the City area confirming descriptions of numerous previous publications.

OUTLOOK

The successful development of the aquifer management strategy for Lusaka will depend on a thorough assessment of the groundwater potential, the current pollution status and potential risks, and the vulnerability of the Lusaka groundwater systems. Its successful implementation will largely rely on the institutional framework and capacities.

As large parts of the groundwater recharge areas have already been urbanised existing development can hardly be reversed. Of major importance to an improved protection of groundwater will hence be the development of suitable management concepts that take the specific situation in and around Lusaka into account.

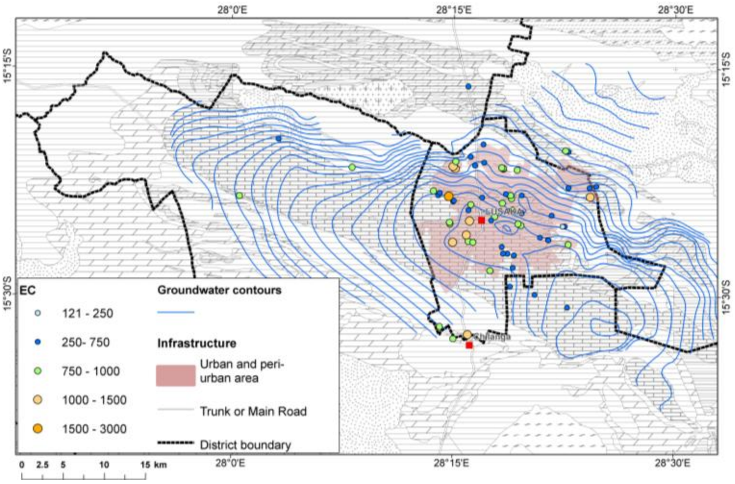

Figure 3. Distribution of electrical conductivity (in μS/cm) found in the Lusaka area during April and May 2010.

ACKNOWLEDGMENT

The authors express their gratitude to the Governments of the Republic of Zambia and the Federal Republic of Germany who financially support this program in the framework of bilateral technical cooperation agreements.

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IAH 2010
Krakow

abstract id: **319**

topic: **3**
Aquifer management

3.1
Regional groundwater systems

title: **Hydrochemical evidences of hydraulic connection between crystallinic and carbonate aquifers (the Tatra Mts., East-Central Europe)**

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keywords: springs, groundwater, Tatra Mts.

INTRODUCTION

The hydrogeology of fissured crystalline and karst rocks complexes remains one of the most difficult and not much developed areas of hydrogeology, both theoretically and practically.

Ground water circulation in the Tatra Mts. has been investigated mainly by J. Chowaniec (2009), T. Dąbrowski and J. Głazek (1968), D. Małecka (2003), K. Różański and M. Duliński (1988) and A. Zuber et al. (2008). They stated hydraulic connection between the aquifer in the High Tatra Mts. built of Paleozoic igneous rocks (granite) and the karst aquifer in the lower parts of the Tatra Mts. built mainly of the Mesozoic limestones, dolomites, quartzites and shales. Mesozoic formations are drained by vaucluse springs with high yield and very low mineralization which proves their crystalline rocks origin (Oleksynowa, Komornicki, 1996).

In spite of wide knowledge in hydrogeology of the biggest vaucluse springs in the Tatra Mts. (Małecka 1996, 1997; Małecka et al., 1998) there is no well recognized recharge of springs with considerable small yields. Hence, the aim of the research is investigation of recharging small springs, which are not common in this area. The project was designed to identify water circulation paths and water supply mechanism in the Olczyski Creek catchment in the Tatra Mts. — a highest range of the Carpathians in southern Poland. The paper presents preliminary results obtained by hydrochemical investigations.

AREA OF INVESTIGATION

The Olczyski Creek catchment is located in the northern part of the Polish Tatra Mts. (7.94 km^2). Mountain peaks surrounding the valley rise from 1200 to 1531 m a.s.l (Figure 1).

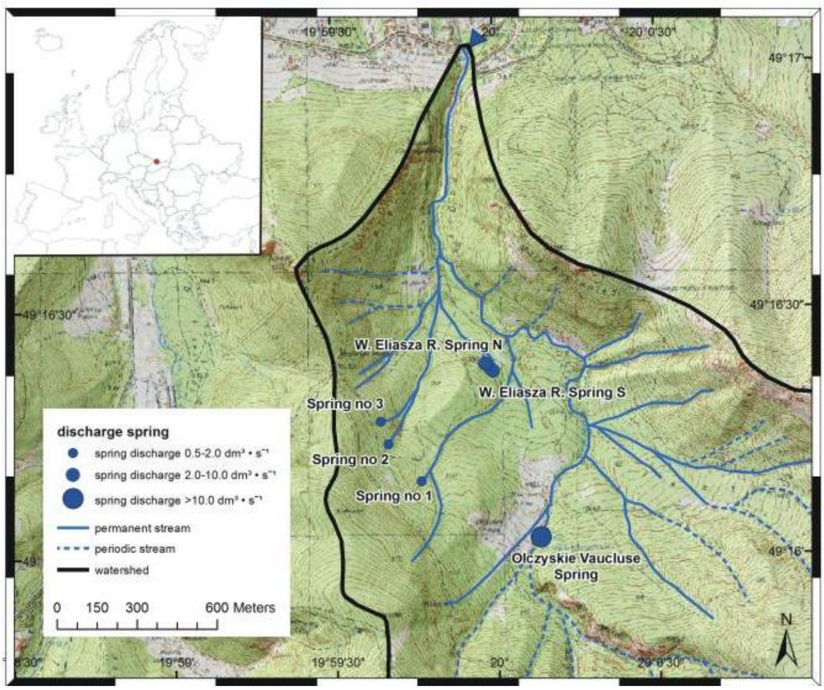

Figure 1. Location of the study area.

The geology of the catchment is dominated by nappe structures and the SW-NE tectonic thrusts. Most of the catchment lies within the temperate cool belt (to 1150 m a.s.l.) where amount of annual precipitation reaches 1200 mm and mean annual air temperatures amounts 4–6°C (the lower subalpine forest zone). The highest parts of peaks surrounding the valley lay in the cool climatic belt where amount of annual precipitation reaches 1500 mm and mean annual air temperature amounts 2–4°C (the upper subalpine forest zone).

Spring density in the investigated catchment is equal 4 per km^2, however spatial distribution of springs is differentiated: most of them occur in the middle part of the catchment. Small springs belonging to VI-VIII Meinzer's classes of discharge prevail in the area.

Special attention was paid to the vaucluse Olczyskie Spring representing III Meinzer's class and W. Eliasz springs representing V Meinzer's class (W. Eliasz Spring South and W. Eliasz Spring North; Fig. 2). Their names are related to Walery Eliasz Radzikowski – the famous Polish painter which visited the valley in the XIX c. Three small springs representing V and VI Meinzer's classes were taken into consideration additionally (No 1, 2 and 3; Table 1).

Table 1. Elevation and types of investigated springs in the Olczyska Creek catchment.

Spring	Altitude [m a.s.l.]	Type of outflow, geology	Yield [$dm^3 \cdot s^{-1}$]	Type of spring (after Meinzer)
Olczyskie	1065	crevasses, dolomites	233	III
W. Eljasz South	1000	crevasses, quartzitic sandstones	7.11	V
W. Eljasz North	998	crevasses, quartzitic sandstones, spongolites	4.22	V
Spring no. 1(61)*	1030	seepage spring, quartzites, loamy shales	0.46	VI
Spring no. 2 (64)*	1080	debris, loamy shales, quartzites – trace	1.39	V
Spring no. 3 (65)*	1030	debris, loamy shales, quartzites – trace	0.22	VI

*numbering is according to Oleksynowa, Komornicki (1989).

a)

b)

Figure 2. Water outflowing from the South W. Eliasz (a) and North W. Eliasz (b) Springs (Photo. S. Wójcik).

FIELD OBSERVATIONS AND METHODS

Water samples from six selected springs and from the Olczyski Creek were collected once a month in 2009 during the weather conditions representing annual seasonality. The time interval between measurements varied between 2.5 and 5.5 weeks (Table 2). Chemical analyses were done in the laboratory at the Institute of Geography and Spatial Management, Jagiellonian

Univeristy using ion chromatography (DIONEX ICS-2000). Water temperature, electrical conductivity and pH were carried out in the terrain (Elmetron CX-401). The spring discharges were measured using volumetric method (except the vaucluse spring). Simultaneously, the water level in the Olczyski Creek were observed (Figure 1).

Table 2. Dates and weather conditions during a fieldworks and during a week before field works in the Olczyski Creek catchment.

Date	Mean air temperature during a week before field works *	The daily total precipitation in the week preceding the field studies*	Weather conditions during fieldworks
	°C	mm	
January 12, 2009	-9.6	3.3	Sunny, snow cover
February 9, 2009	1.7	2.0	Snow cover
March 9, 2009	1.4	23.9	Snow cover
April 20, 2009	8.7	1.0	Cloudiness, patches of snow
May 12, 2009	10.1	16.0	Rainfall
June 17, 2009	13.3	30.7	Sunny weather
July 2, 2009	16.2	70.6	Sunny
August 4, 2009	18.2	0.0	Little rainfall
September 7, 2009	13.1	28.7	Cloudiness
October 11, 2009	10.7	17.0	Rainfall
November 10, 2009	1.6	14.7	Rainfall
December 16, 2009	-4.6	10.4	Cloudiness , snow cover

*data from the Zakopane meteorological station; http://www.ncdc.noaa.gov/oa/wdc/index.php.

PRELIMINARY RESULTS AND DISCUSSION

The Olczyskie Spring and the W. Eliasz South and North springs joint discharge is considerable higher than the discharges of the rests of springs (Table 3). The mean values of the spring discharges in 2009 amounted from 0.22 to 233 $dm^3 \cdot s^{-1}$. The Olczyskie Spring are the main source of water in the Olczyski Creek (Oleksynowa, Komornicki 1989).

Table 3. Properties of investigated springs in the Olczyska Stream catchment in 2009.

Spring	SEC [$\mu S \cdot cm^{-1}$]	Mean water temperature [°C]	pH
Olczyskie	131.43	4.5	8.24
W. Eliasz South	173.72	5.3	8.09
W. Eliasz North	173.43	5.2	8.08
Spring no 1	205.79	6.1	7.99
Spring no 2	216.11	5.5	8.17
Spring no 3	261.29	5.1	8.26

The observed springs are characterized by snow-rain regime: maximum discharge in most of them occur in April and second one — in November (Figure 3a). The high water level in the Olczyski Creek has been prolonged to July, what is suitable for streams supplied by water from snow cover melting gradually from the lower to highest parts of the Tatra Mts. during spring and early summer months (Figure 3b). It represents typical mountain rivers flow regime described by I. Dynowska (1971), A. Dobija (1981) and W. Chełmicki et al. (1998–1999).

a) b)

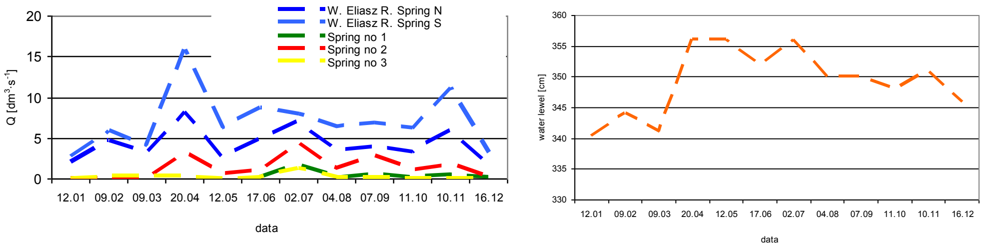

Figure 3. Discharges of springs (a) and water level in the Olczyski Creek (b) in 2009.

The mean annual water temperature of investigated springs is amounted from 4.5 to 6.1°C (Table 3). The mean water temperature of the Olczyski Creek amounts 4.6°C and approximates the Olczyskie Spring. The most differentiated temperature during the year represents the smallest springs — no 1 , 2 and 3 and the Olczyski Creek (Figure 4). Water temperature variability of the W. Eliasz R. Springs and Olczyskie Spring is considerable lower.

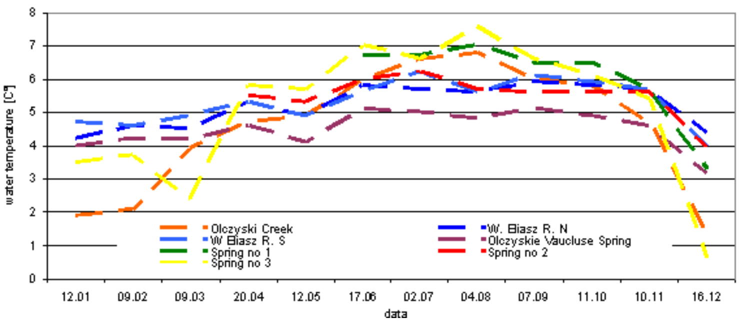

Figure 4. Water temperature of springs and the Olczyski Creek in 2009

Springs water alkalinity during investigations period (7.99–8.26 pH) can be easily explained by the dominance of calcium ion due to presence carbonate rocks in the catchment. The SEC of small springs (no 1, 2, 3) is considerably higher (205.79–261.29 μS·cm^{-1}) than the Olczyskie and W. Eliasz springs (131.43–173.72 μS·cm^{-1}) (Table 3).

The chemical composition of stream and springs water represents bicarbonatic-calcian-magnesian type except the spring no 2 which represents bicarbonatic-calcian type. The share of ions Ca^{2+}, HCO^{-}_{3} and SO^{-}_{4} is differentiated and two groups of springs may be identified: 1st group with high concentration of Ca^{2+} and HCO^{-}_{3} (springs no 1, 2, 3) and 2nd group with lower concentration of Ca^{2+} and HCO^{-}_{3} (Olczyski Creek, Olczyskie and W. Eliasz springs) (Table 4).

Table 4. Mean ion contents in the water in the Olczyski Creek catchment in 2009.

Object	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{2-}	Cl^{-}	NO_3^{-}	Hydrochemical type of water, number of type (after Shtsukariev and Priklonski)
	mval·dm^{-3} mg·dm^{-3}								
Olczyski Creek	0.97 19.55	0.59 6.97	0.04 0.87	0.01 0.31	1.41 86.69	0.16 7.83	0.01 0.44	0.03 1.95	HCO_3–Ca^{2+}–Mg^{2+} (18)
W. Eliasz R. Spring South	1.33 26.54	0.57 7.06	0.04 0.87	0.01 0.46	1.80 109.77	0.17 8.31	0.02 0.59	0.03 1.67	HCO_3–Ca^{2+}–Mg^{2+} (18)
W. Eliasz R. Spring North	1.34 26.74	0.57 7.01	0.04 0.82	0.01 0.42	1.81 110.74	0.16 8.04	0.01 0.54	0.03 1.68	HCO_3–Ca^{2+}–Mg^{2+} (18)
Olczyskie Spring	0.83 16.83	0.56 6.95	0.03 0.78	0.01 0.34	1.26 77.49	0.14 7.03	0.01 0.42	0.03 2.03	HCO_3–Ca^{2+}–Mg^{2+} (18)
Spring no. 1	1.57 31.55	0.72 8.70	0.03 0.78	0.01 0.50	2.06 125.79	0.22 1064	0.02 0.72	0.03 1.69	HCO_3–Ca^{2+}–Mg^{2+} (18)
Spring no. 2	1.99 39.84	0.43 5.25	0.03 0.76	0.01 0.44	2.05 125.06	0.34 16.28	0.02 0.77	0.04 2.55	HCO_3–Ca^{2+}(9)
Spring no. 3	2.16 43.29	0.77 9.32	0.03 0.71	0.02 0.60	2.37 144.81	0.47 22.50	0.03 1.05	0.09 5.51	HCO_3–Ca^{2+}–Mg^{2+} (18)

CONCLUSIONS

On the base of hydrological research conducted in 2009 in the Olczyski Creek catchment one may state, that springs water differs in the degree of mineralization, chemical composition, pH and several other parameters. It proves the existing a complicated hydrogeological system favoured by variuos geology and existing tectonic thrusts and faults.

The properties of the vaucluse Olczyskie Spring confirm that the most important alimentation area is located beyond the topographic catchment what was discovered by T. Dąbrowski and J. Głazek and investigated by D. Małecka and W. Humnicki (1989).

The present study proved a complicated hydrological system, featuring three connected subsystems: granitic fissured, carbonate karst and quartzites fissured ones. Karst subsystem plays the role of semi-drain that collects water infiltrating from granitic rock formation occured in the High Tatra Mts.

Hydrochemical properties of small springs (no 1, 2, 3) show that these springs drain mainly the local groundwater aquifers: the carbonate karst complex one and — in minority — another one — quartzitic sandstones with alternating loamy shales, which are visible around the outflow.

The properties of the W. Eliasz springs are considerable different and they are more related to the vaucluse Olczyskie Spring, which may indicate partially the same alimentation area (High Tatra Mts.) and bigger share of water coming from local basin aquifer. It may be assumed, that relatively small discharge of the W. Eliasz springs is limited by system of narrow fissures in quartzitic sandstones.

It may be also probable another scenario: the W. Eliasz springs drain local aquifers within the topography catchment — ie. quartzitic sedimentary fissured rocks and — in minority — carbonate karst complex. For complete explanation of groundwater circulation in the Olczyski Creek catchment, the authors recommend further and additional investigations involving tracers methods.

ACKNOWLEDGEMENTS

We would like to acknowledge the help and guidance of Ewa Lubera and Joanna Plenzler in field works in the Tatra Mts.

The Project was supported by the Ministry of Science and Higher Education (Grant N305 081 32/2824 — *Factors determining spatial variability and dynamics of water chemical composition in the Tatra National Park*).

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abstract id: **356**

topic: **3**
Aquifer management

3.1
Regional groundwater systems

title: **Recent trends in groundwater levels in shallow hydrological system in the Czech Republic**

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keywords: groundwater levels, trend, shallow boreholes

A very complex geology of the Czech Republic led to defining many hydrogeological zones. The area of the country is currently divided into 152 zones in three layers — 111 zones in the main layer, 38 in the top layer (comprising zones in the Quartenary sediment) and 3 zones in the layer of basal Cretaceous aquifer (Olmer et al., 2006). Groundwater patterns of the most of the zones in the main layer and of all zones in the top layer are evaluated regularly based on data from shallow boreholes, measuring first unconfined aquifer (with depth mainly to 15 m). The evaluation of groundwater levels for individual years is processed usually as a comparison to the monthly cumulative-frequency curve (1971–2000). However, it does not provide comprehensive information about the long-term system development necessary for water policy and groundwater resources assessment.

We assumed that the trend analysis provides important information about changes in groundwater levels in a hydrological zone. Regarding the nature of investigated data, it is difficult to test the groundwater levels directly with simple methods such as linear regression. The seasonality of shallow groundwater systems with a typical cycle of spring maximum and autumn minimum and serial dependences in the time series complicates the resolution of trends in groundwater levels. A representative subset of 380 wells (from the total amount of 992 wells currently under observation) was tested. The selection was based on the amount and quality of available data; only time series with less than 5% missing data in the period of 1971–2009 were processed. We tested monthly medians in order to minimize the influence of outliers caused by measurement errors. Using the linear interpolation method gaps were filled. We used a seasonal decomposition of the time series to seasonal and residual components and tested the trend in residuals of monthly medians. Time series were separated into components of seasonal fluctuation and residuals based on the formula (1).

$$y = \alpha + \beta \sin(2\pi t) + \gamma \cos(2\pi t) + \varepsilon \qquad (1)$$

where t represents time, scaled so that the complete annual cycle is of length 1.0, α, β, γ are parameters of the model and ε is the residuum (Crawley, 2002). We also tested the significance of the model parameters (1) before we evaluated trends in residuals.

Standard F-test was used to test the significance of upward or downward trends in residuals ($p < 0.05$).

The results showed that 36% of shallow boreholes have been significantly decreasing, while the long-term increase of groundwater level occurred by 25% of tested wells. Regarding the spatial distribution of objects revealing significant change, we cannot draw any general conclusions describing the situation in the Czech Republic (Figure 1). However, the results from monitoring objects provided important information for further, more detailed evaluation of individual hydrogeological zones. The information about trends is valuable especially for zones of top layer (Quaternary sediments) and zones covering Proterozoic and Palaeozoic Crystalline rocks where the shallow boreholes provide together with spring yield the only information about the groundwater condition (Figure 2).

In conclusion the applied decomposition method provides a simple tool that allows operating larger datasets, however it is worth noting that the function (formula 1) for separation of seasonality may not always capture completely the nature of groundwater cycle.

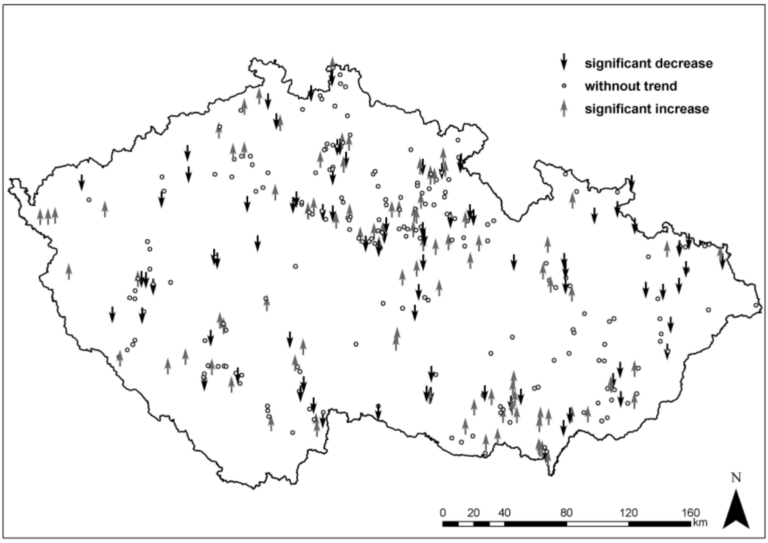

Figure 1. Trends in groundwater levels in the Czech Republic between 1971 and 2009.

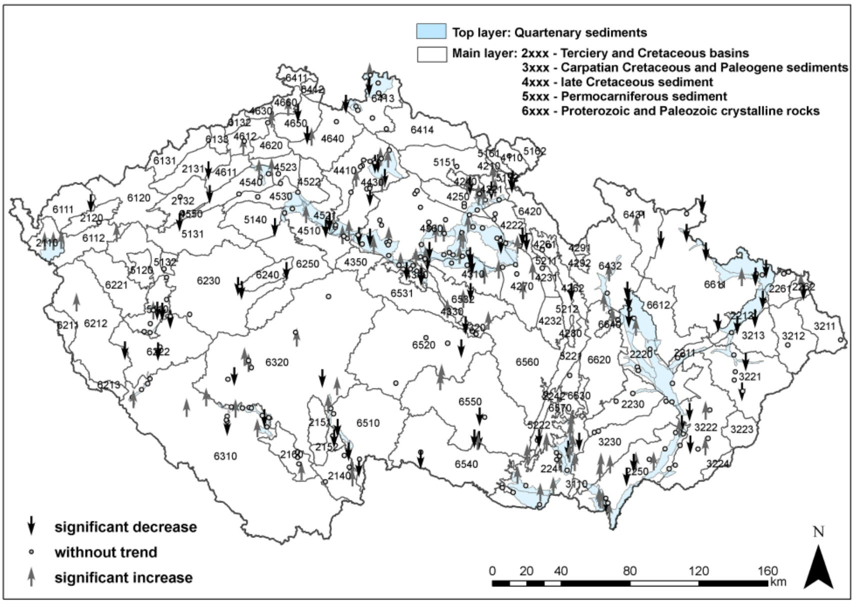

Figure 2. Trends in groundwater levels in the Czech Republic between 1971 and 2009 in hydrological zones.

ACKNOWLEDGEMENT

The research was supported by a grant of the Czech Ministry of Environment (VaV SP/2e1/153/07).

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abstract id: **357**

topic: **3**
Aquifer management

3.1
Regional groundwater systems

title: **Hydrogeological mapping of managed aquifer recharge in the lower Yom River Basin, Thailand**

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keywords: managed aquifer recharge, hydrogeological mapping, Yom River Basin

ABSTRACT

The study area is located in the Lower Yom River Basin embracing an area of about 970 km^2 in the lower part of northern Thailand. Large volumes of shallow groundwater used for rice production has caused groundwater levels to drastically decline to below the normal threshold for viable pumping (8 meters below the ground surface) in some areas. A detailed understanding of the subsurface processes is necessary to underpin the implementation of supply-side interventions such as Managed Aquifer Recharge. The objective of this paper is to characterize the hydrogeological parameters and groundwater flow systems through detailed field investigations. These investigations include field surveys of the hydrology, land use, geological and hydrogeological information at a scale of 1:50,000. A census of all the existing water wells in the area was conducted. This was supplemented by the construction of 40 new piezometers between March to December, 2009. Detailed hydrogeological investigations such as pumping tests of 150 selected wells were conducted. The investigations reveal the presence of two major aquifer layers; a shallow aquifer (5 to 20 m deep) consisting of sand, silt and clay of the Yom floodplain deposits and the deeper aquifer (15 to 60 m deep) consisting of gravel, sand, silt, and clay of an alluvial fan deposits of the Ping-Yom River Basin. The shallow and deeper aquifers are separated by a thin clay layer with an average thickness of one to five meters. Most of the farmer wells (2,400 wells) in the study area pump water from the shallow aquifer with a total annual abstraction of approximately 1,170 million m^3. The transmissivity values of the upper aquifer range from 300-7,000 m^2/day and the thickness varies from five to ten meters. The regional groundwater flows from the west to east, whereas the local flow systems actively flows from north to south and in some areas from south to north. Several geological and hydrogeological parameters were determined from the new hydrogeological map such as the thickness of the top clay layer, the thickness of the aquifer, hydrochemistry, recharge areas, etc. These parameters are important for locating the most prospective zones for establishing managed aquifer recharge schemes. Moreover, based on these findings, detailed water balance as well as surface water and groundwater interaction mechanisms are being simulated through the use of numerical modeling.

INTRODUCTION

In the Lower Northern Region of Thailand, groundwater-based irrigation of rice paddy is a dominant land use for the largely agrarian economy in the region. In the Phitsanuloke area alone, over one million rai of rice is grown, often year-round. As a result of the rapid groundwater development that has occurred in recent decades, groundwater levels have fallen dramatically, and put into question the long-term sustainability of current levels of rice production. The region would benefit greatly from detailed studies of the physical resource as well as the demonstration of technically and economically viable methods to restore the groundwater balance. One such area has been selected for these sorts of investigations.

The study area is located in the Lower Yom River Basin with the topographic elevations vary from 54 to 34 m above mean sea level. The area covers an area of about 970 km^2 in the lower part of the northern Thailand. Large amounts of shallow groundwater usage for rice growing has caused groundwater levels to decline below the normal threshold for viable pumping (8 m below the ground surface, DGR, 2009) in some areas. The objective of this paper is to characterize the hydrogeological parameters and groundwater flow systems by detailed field investigations. The Lower Yom River Basin consists of 13 subwatersheds and has a tropical monsoon climate with an annual average temperature about 28°C and annual rainfall of about 1,083 mm. The Yom River is the main river which flows from north to the south. The stream flows at Bang Rakham, (Y16) and Sam Ngam (Y.17) districts ranges from 3-550 m^3/s and 5–400 m^3/s, respectively (Figure 1).

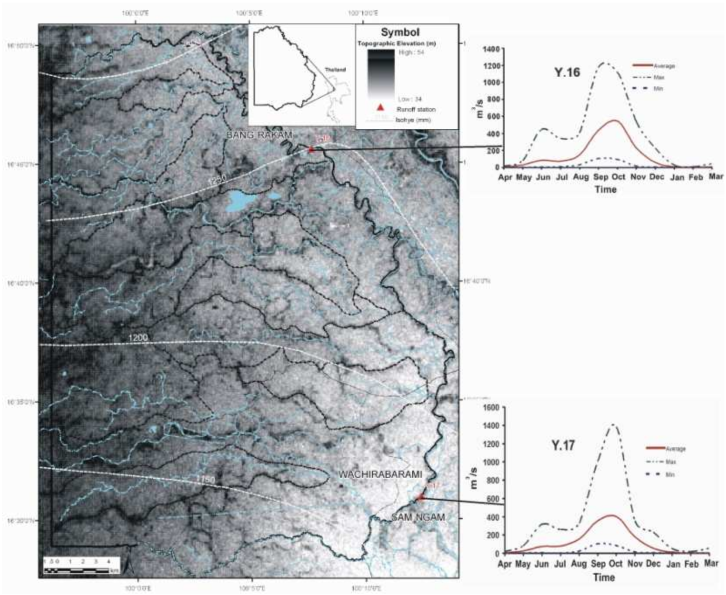

Figure 1. Subwatersheds, isohyets and hydrograph in the study area.

The turbidity of surface water in this area ranges from 40–190 NTU. Paddy field occupies more than 70% of the area. The Lower Yom River Basin is underlain by alluvial fan, floodplain deposits, and channel and natural levee deposits. Alluvial fan deposits are comprised of gravel, sand, and clay. Floodplain deposits consist mainly of clay. Channel and Natural levee deposits are comprised of sand and clay.

METHODOLOGY

The procedure employed commenced with compiling all related information from the existing Quaternary geological map of the Department of Mineral Resources (DMR, 2009) and geological map of the scales of 1: 250,000 (DMR, 1967) and groundwater maps (DMR, 1987 and 1996). Field investigations included water well census and drilling of 120 wells with the depths ranging from 20 to 100 m, landuse mapping, geomorphological mapping, pumping tests of the farmer shallow wells of about 100 wells and database formulation and interpretation by applying ArcGIS 9.3. Groundwater level measurements and groundwater sampling from 80 selected existing water wells were conducted during March to December 2009. Hydrochemistry of groundwater and regional groundwater flow patterns were interpreted and delineated.

RESULTS

The Lower Northern Region Basin is underlain by thick sequences of unconsolidated sediments in the central part and igneous and sedimentary rocks in the north and northeastern areas (DMR, 1983, Figure 2).

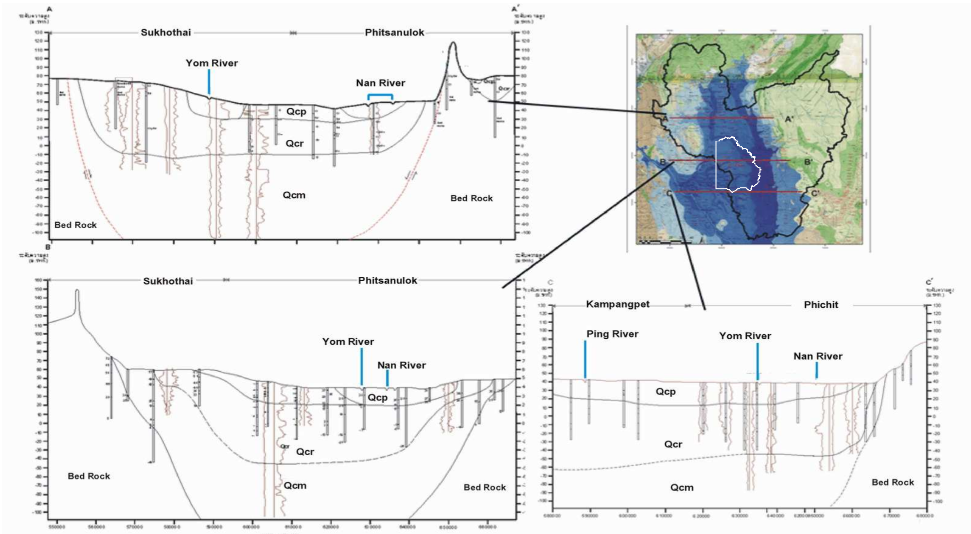

Figure 2. Hydrogeological map of the Lower Northern Region Basin.

The unconsolidated sequence consists of (1) Recent flood plain deposits (Qfd) or Chao Phraya Aquifer (Qcp); consisting of sand and gravel interbeded with clay; with an average thickness of about 30-35 m and well yields ranging from 15-25 m^3/hr. (2) Low terrace deposits (Qlt) or Chiang Rai Aquifer (Qcr) consisting of clay, silt, interbeded with sand and gravel (10-60 m thick) and well yields ranging from 15-20 m^3/hr., (3) High terrace deposits (Qht) or Chiang Mai Aquifer (Qcm) consisting of gravel, sand, and rock fragment with well yields ranging from 30-50 m^3/hr. The consolidated rocks are mainly limestone; interbeded with shale and sandstone with well yields ranging from 2-5 m^3/hr and metamorphic and Igneous rocks with well yields ranging from 1-5 m^3/hr.

The Lower Yom River Basin is underlain by thick sequences of unconsolidated sediments deposited in the block-faulted basin. The objective of this study is to identify the most suitable zones for managed aquifer recharge by using ponding methods of recharge, and therefore, the shallow sequences of unconsolidated sediments are the target areas for mapping. The shallow aquifers consist of an Alluvial fan deposit unit (Qfa), Flood plain deposit unit (Qff), and Channel and Natural levee deposit unit (Qfc) (Fig. 3). The Alluvial fan deposit unit consists of medium-coarse sand interbedded with gravel and clay layers with the thickness ranging from 5 to 60 meters. The Flood plain deposit unit consists of clay and silt with the varying thickness of 2 to 7 meters spreading throughout the study area. The Channel and Natural levee deposit unit consists of very fine-medium sand, fine sand and silt with the varying thickness of 2-5 m. The major aquifer is the Alluvial fan deposit unit that has relatively high transmissivity of 300-7,000 m^2/day.

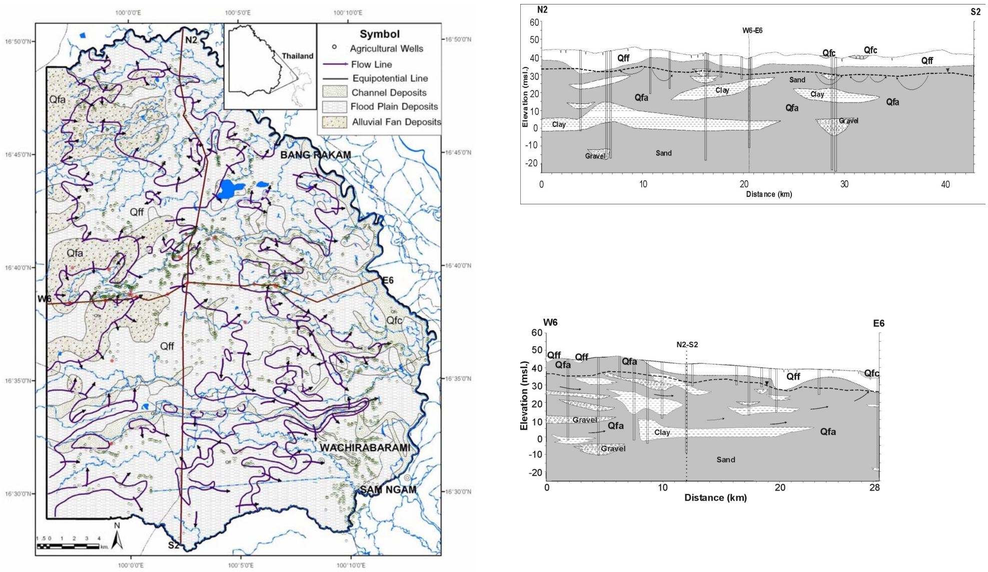

Figure 3. Hydrogeological map and hydrogeological cross sections.

Census data revealed that most of the farmer wells (2,400 wells as shown in Figure 4) in the study area are being pumped from the shallow aquifer with a total annual abstraction of approximately 1,170 million m^3. The highest densities of farmer wells (up to 10 wells/km^2) are located in central part of the study area.

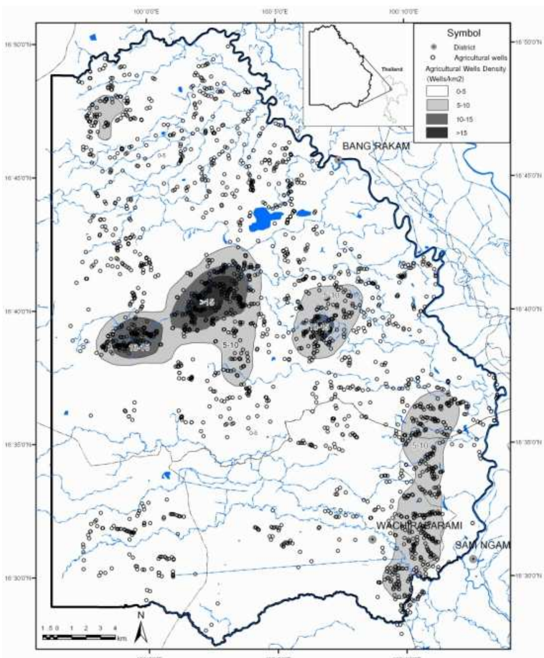

Figure 4. Water well density drilled by the farmers.

The groundwater level survey conducted in May 2009 showed the water level varies from 7-10 meters below the ground surface. Regional groundwater is mainly flows from the west to the east. The local shallow groundwater (6-20 m deep) flows in various directions. The minor steams flow is from west to east and discharge to the Yom River in the eastern region. The main local groundwater flows to the existing streams, such as Huai Lan Ba. The local recharge areas are located in relatively higher topography, especially in the west and south to north portion of the area. Figure 5 shows the thickness of the clay layer overlying the first layer of sand and gravel aquifer. The thin clay layer is identified in the west and locally in the central region. There are several sand pits and gravel excavations located in the central west. Sixty water samples collected from farmer wells were collected in June 2009. The averaged Total Dissolved Solids (TDS) content is relatively low (300 to 500 mg/l). Hydrochemical facies are classified based on Piper's Diagram as shown in Figure 6. There are 12 water types, namely, Ca-Na-HCO_3, Ca-Na-HCO_3-SO_4, Na-Ca-HCO_3, Na-Ca-HCO_3-Cl, Na-Ca-HCO_3-SO_4, Na-HCO_3, Na-HCO_3-SO_4, Na-HCO_3-SO_4-Cl, Na-Mg-Ca-HCO_3, Na-Mg-HCO_3-SO_4, Na-Mg-SO_4-Cl, Na-SO_4-HCO_3 type. Water of Ca-Na-HCO_3-SO_4 water type is one of the dominant type and found in the west and east regions. Water type Ca-Na-HCO_3 is locally found in the western recharge areas. Whereas Na-HCO_3 water type is mainly found in the central area.

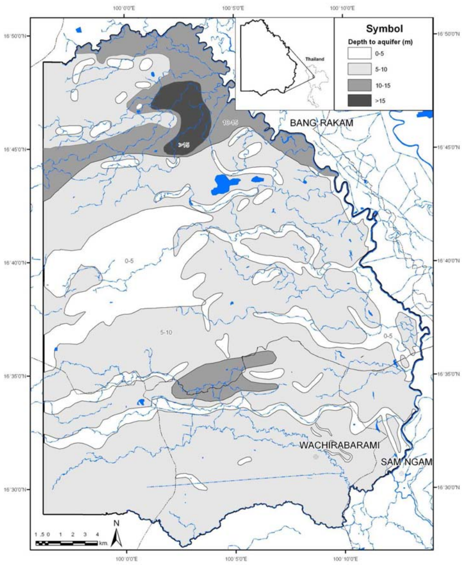

Figure 5. Depth to aquifer map.

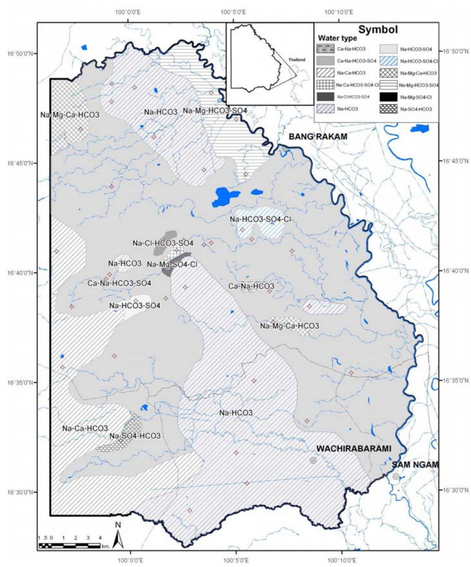

Figure 6. Hydrochemical facies map.

CONCLUSIONS AND RECOMMENDATIONS

The main shallow aquifer in the Lower Yom River Basin is the alluvial fan deposit. The data for the managed aquifer recharge (MAR) using ponding system is being complied and analyzed by several techniques. The data on regional water balance of the area will be analyzed by numerical modeling. In addition, several types of MAR techniques such as trenching, aquifer storage recovery (ASR), roof recharge, check dam recharge and others are being classified in accordance with the suitable potential areas.

ACKNOWLEDGEMENTS

We would like to thank the Department of Groundwater Resources, Ministry of Natural Resources and Environment for providing financial support to the project.

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abstract id: **396**

topic: **3**
Aquifer management

3.1
Regional groundwater systems

title: **Groundwater chemistry in the area of the Ryjak Catchment (Magurski National Park, SE Poland)**

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keywords: springs, groundwater, hydrochemistry, Magurski National Park

INTRODUCTION

Water chemistry in the Carpathian Mountains has been the subject of research since the 19th century. In the early years, researchers were mostly set on the discovery of mineral water aquifers. Although a great deal of groundwater research has been conducted in the Carpathians — especially in the last twenty years — still little is known about the groundwater chemistry of the eastern part of the Western Carpathians. The purpose of this paper is to present the spatial distribution of water outflows and their hydrochemical properties in the Ryjak catchment area, located in the southern part of Magurski National Park (SE Poland).

STUDY AREA

The research study was conducted in July and August of 2006, during a period of low precipitation (10 mm in July and 40 mm in August) in the catchment of Ryjak (45 km^2). It is situated, for the most part, within Magurski National Park, however, the upper part of the catchment consists of rural areas located in the park's outer fringe zone. Average elevation across the study area does not exceed 600 m. Its bedrock consists of Magura Nappe-type Carpathian flysch such as fine-grained sandstone and shale.

METHODS

Springs of interest were mapped and their discharge as well as basic physical and chemical properties (temperature, pH, SEC_{25}) measured *in situ*. The concentration of selected ions was analyzed using a Dionex ICS-2000 ion chromatography system. The following ions were analyzed: Ca^{2+}, Mg^{2+}, Na^+, K^+, NH_4^+, Li^+, HCO_3^-, SO_4^{2-}, Cl^-, NO_3^-, NO_2^-, PO_4^{3-}, F^-, Br^-. Aqueous Fe samples were acidified and analyzed using a Merck SQ 118 photometer. A cooled $CO_{2(aq)}$ sample was titrated within four hours of sample collection.

RESULTS

The total ion content of groundwater outflows was determined to be within 70–650 $mg·dm^{-3}$. The chemical composition varied spatially, especially in the case of Na^+, K^+, SO_4^{2-}, and Cl^-. The carbon dioxide level detected in the springs of interest approached 80 $mg·dm^{-3}$, which created favorable conditions for the precipitation of travertine as well as ferrous species. Most of the tested outflows (60%) were of a simple HCO_3–Ca type or an HCO_3–SO_4–Ca type (33%) based on the Szczukariew-Priklonski classification system. However, three outflows were discovered to have an atypical for this particular catchment, but already well known in the Carpathian Mountains (Rajchel 2002), type of water labeled HCO_3–Ca–Mg and HCO_3–Ca–Na (Fig. 1). The greatest degree of diversity in water chemistry was detected in springs located at the point of contact between variegated Eocene shale and shale with sandstone inserts in the northern part of the catchment. However, springs with the highest overall ion content were found in Oligocene sandstone, close to Dąb Mountain. The maximum discharge of the tested springs was found to be 1 $dm^3·s^{-1}$, however, most of the springs produced much smaller rates of discharge.

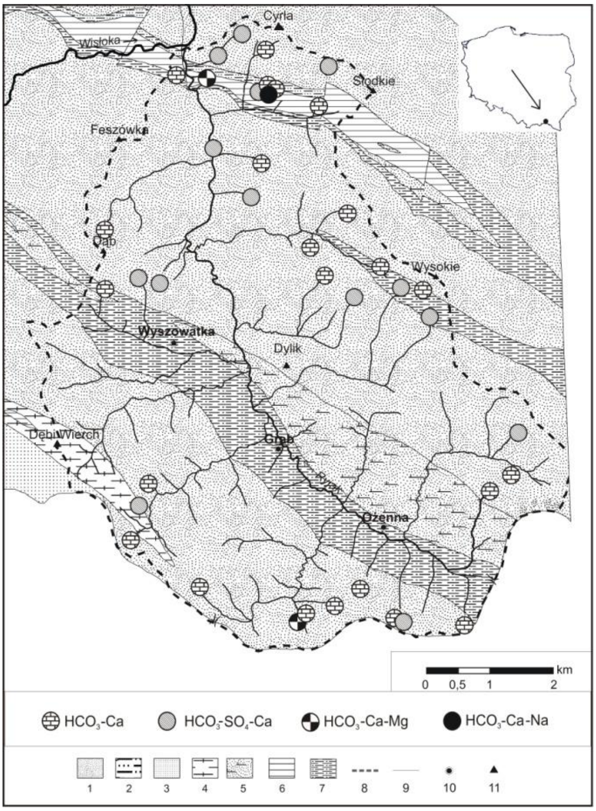

Figure 1. Hydrochemical classes of springs, based on on Szczukariew-Priklonski classification, in Ryjak catchment on geological map (self-processing based on A. Slaczka 1968): 1 — Oligocen thick-layered sandstone and shale (Magura beds); 2 — Eocene shale with sandstone insert (Magura beds); 3 — Eocene thick-layered sandstones (Magura beds); 4 — Eocene shale and thin-layered sandstones (Hieroglyphic and Magura beds); 5 — Eocene shale and thin-layered sandstones (Hieroglyphic and Beloweza beds); 6 — Eocene variegated shale; 7 — Eocene shale with sandstone-insert and shale with thin-layered sandstone (Magura and Hieroglyphic beds); 8 — Watershed; 9 — Streams; 10 — Villages; 11 — Main peaks.

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abstract id: **418**

topic: **3**
Aquifer management

3.1
Regional groundwater systems

title: **The volcanic aquifer system of the Middle Awash basin (Main Ethiopian Rift, Ethiopia)**

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keywords: Middle Awash, 2D tomography, volcanic aquifers, Main Ethiopian Rift

The Middle Awash basin is located in the active volcano-tectonic centre of the East African Rift valley (Fig. 1) and includes complex hydrogeological systems. At regional scale, groundwater flow converges towards the rift floor constrained by mountain blocks bounding the rift floor in both side. On the other hand, the nature and distribution of aquifers are locally controlled by geological structures that affected the rocks.

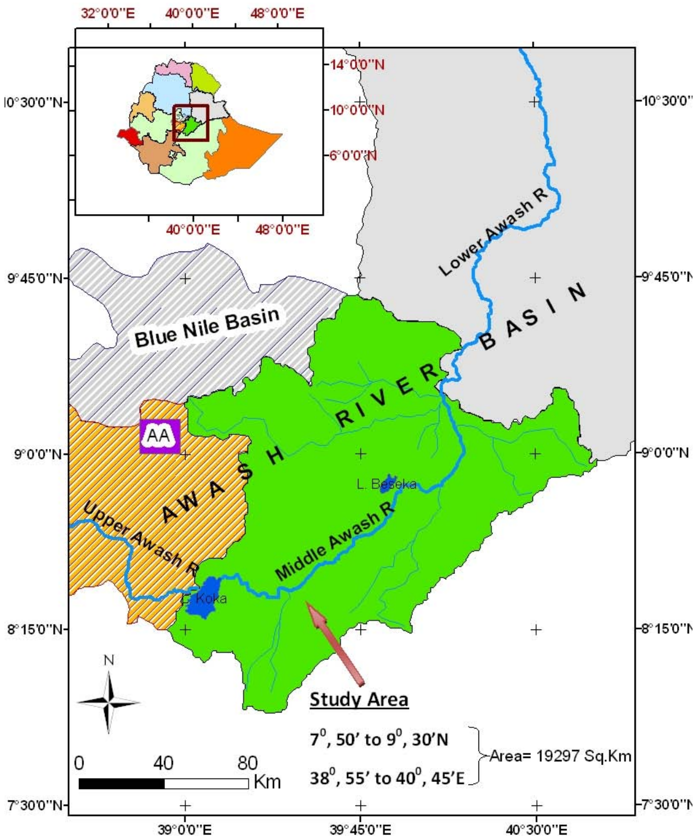

Figure 1. Location map of the Middle Awash Basin.

Integrated approach including hydrochemistry, environmental isotopes and geophysics was applied to analyze the hydrogeological systems of the basin. The combined results from various hydrogeological datasets show two distinct aquifer systems linked to geology and landforms. The calc-alkali rocks like basalts, ignimbrites, and trachybasalts form aquifers in the mountain regions. Ground waters in this region have generally acceptable natural water quality unaffected by volcanotectonics and geothermal activities. Laterally the aquifers are intercepted by slice of massive landscapes which cause lateral confinement forming a discontinuous and compartmentalized flow system. In this region, both deep and shallow flow systems have identical water chemistry of Ca–Na–HCO_3 type with TDS < 400mg/l and contain modern water. On the other hand, the alkali vesicular rocks like scoria, pumice, tuff and volcanoclastic form rift floor aquifers. Hydrochemically, the waters are Na–HCO_3 with TDS > 800 mg/l and groundwater quality is largely affected by geothermal activities.

The effect of geological structures on groundwater flow system in the study basin is substantial. The geoelectric sections along selected transects show layer with similar resistivity exhibit large displacement indicating the disruption of aquifer systems by subsurface faults. Result from 2D tomography show that faults, fissures and fractures brought two separate aquifers into contact as well as form connectivity between irrigation water and groundwater at Wonji basin. On the other hand, faults form breaching the continuity of an aquifer and disconnection between adjoining aquifers and create preferential flow paths. This is particularly common in rift floor where volcanic rocks hosting the faults retain large apertures enabling the preferential flow paths as dictated by groundwater chemistry and water isotopes.

abstract id: **432**

topic: **3**
Aquifer management

3.1
Regional groundwater systems

title: **Regional groundwater management in Ontario, Canada**

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ABSTRACT

The Oak Ridges Moraine (ORM) Groundwater Management Program presents a unique case in Ontario where, since 2000, a partnership of the municipalities of York, Peel, Durham, and Toronto (YPDT) and the nine Conservation Authorities (watershed management bodies) with jurisdiction on the Oak Ridges Moraine (collectively known as the Conservation Authorities Moraine Coalition (CAMC), recognized a deficiency in coordinated groundwater management, and partnered for the purposes of establishing a groundwater management program across a broad geographical extent of south-central Ontario. Supporting the initiative to various extents are Provincial Ministries (Ministry of Northern Affairs and Development (Ontario Geological Survey), Ministry of Natural Resources, and the Ministry of the Environment) as well as the Federal Government (Geological Survey of Canada (NRCAN)). The program, known as the YPDT-CAMC Groundwater Management Program, has the Oak Ridges Moraine as a common physiographical element of interest to all partner agencies.

The Oak Ridges Moraine stretches some 160 km across southern Ontario from the vicinity of Trenton in the east to the Niagara Escarpment in the west (Figure 1).

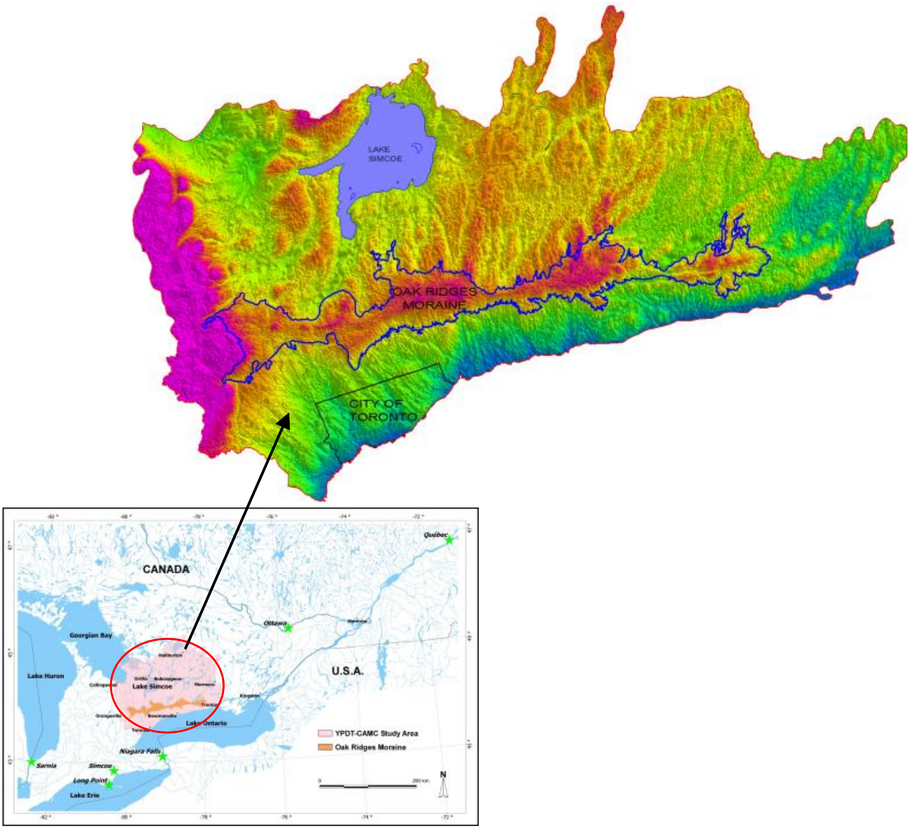

Figure 1. Location and DEM of the Oak Ridges Moraine, Toronto, Canada.

The moraine serves as the height of land separating southward flowing drainage towards Lake Ontario from northward flowing drainage into Lake Simcoe and other northern Kawartha

Lakes. The moraine is recognized as a regional groundwater recharge area, providing a source of groundwater to numerous aquifers and to the streams having headwaters on the flanks of the moraine.

From a groundwater perspective, the Moraine has long been the focus of significant attention by municipalities, conservation authorities and the Provincial Government, as well as by the public owing to:

- the recognition of the moraine as a naturalized area where hydrologic processes are seen as an important part of Ontario's natural heritage;
- the extensive use of groundwater in the area for municipal and other uses;
- pressing development encroaching onto the moraine from the rapidly growing communities surrounding Toronto that has the effect of reducing groundwater recharge and degrading groundwater quality; and
- the numerous groundwater dependant, cold water streams emerging from the moraine flanks.

The culmination of this attention led finally to the passage of the Oak Ridges Moraine Conservation Act and the accompanying Oak Ridges Moraine Conservation Plan, both of which were released by the province in late 2001. These legislative pieces not only significantly curtailed development on the Oak Ridges Moraine, but were significant in the context of Ontario water legislation as a result of requirements to use modeling to develop water budgets for watersheds originating on the moraine and for the first time in Ontario put in place Provincial land use restrictions in wellhead protection areas.

Since 2001 the central focus of the YPDT-CAMC groundwater management program (Holysh et al., 2003) has been on the understanding of flow systems (both groundwater and surface water systems) originating on the Oak Ridges Moraine, for the purposes of making effective water management decisions. The study has produced three key products: 1) a comprehensive water-related database; 2) a detailed geological model (Kassenaar et al., 2003); and 3) a calibrated numerical groundwater flow model (Wexler et al., 2003). Each of these products is now being used by the partner agencies for numerous practical applications. The products continue to be refined to meet the growing needs of the partnership.

COMPREHENSIVE DATABASE

In initiating the project, and from experience with previous studies within the Province, it was apparent that data, and in particular ready access to data, was a limiting factor restraining advancements in water resource management. In Ontario, as in many jurisdictions in North America, data, and in particular water and environmental data, have been neglected. Historically, water-related studies have been required for a wide variety of land development projects by government agencies at Provincial, Regional and local levels, and each study generally has a data acquisition component. Although hydrogeological data are constantly being collected in Southern Ontario, and at a considerable cost, the information has never been assembled into a comprehensive, centralized database that can be used for future reference. Rather, data is collected by consultants, reported through various studies, and then simply lost in archived paper reports within the various agencies. In a similar fashion, individuals at many partner agencies have, as part of their on-going daily duties, collected water related data that now resides in files stored on one or two computers unknown and unavailable to others in the organization.

One of the first YPDT-CAMC projects set out to assemble a comprehensive digital database that would not only support groundwater flow model construction, but also form the foundation for long term groundwater management. A key element of the database construction approach was to bridge both agency and disciplinary boundaries by compiling an integrated, comprehensive database covering geology, groundwater, surface water and climate related information across a wide regional area. This broad scope recognizes that water management cannot stop at municipal boundaries and that a broad range of data sources need to be tapped in order to establish the foundation for credible groundwater decision making and effective long term resource management.

Processes have been established with the partner agencies to transfer new information to the database as it is acquired. For example, data logger files of water levels from monitoring wells are being added to the database on an ongoing basis. With the growth of the database, access to the data has become more complicated and front-end interactive database tools have been developed to facilitate queries and general access to the database. Database synchronization between partner agencies and the central database is a critical component of the database management work and has proven to be challenging.

CONCEPTUAL UNDERSTANDING AND DETAILED GEOLOGICAL MODEL

The second major product from the YPDT-CAMC program has been the construction of digital geological layering at a regional scale to represent subsurface geological and hydrogeological units. The Geological Survey of Canada (GSC) undertook a multi-year investigation of the Oak Ridges Moraine through the 1990's and highlighted the need for an understanding of the regional Quaternary sedimentology in groundwater investigations (e.g. Russell et al., 2001). As a result of their lead, a considerable effort was expended in building upon the GSC's work to construct a digital geological model that would directly integrate into groundwater flow modeling.

The glacial sediments laid down across south-central Ontario constitute the primary aquifers in the area and an understanding of their morphology is critical to understanding groundwater flow patterns on a number of scales. The glacial sediments are complex in nature, transitioning from aquifer to aquitard material over short distances. Understanding the depositional setting at a regional scale assists in developing an understanding of changes encountered at a local scale. As an example, knowing that sediments are associated with deltaic deposition with feeder channels coming from the northeast, provides a model for considerable variation in grain size (and therefore hydraulic conductivity) in moving from east to west, while at the same time providing a model for continuity of grain size in a north-south direction associated with channelization.

Typically, groundwater studies carried out within the Oak Ridges Moraine area characterize subsurface aquifers as either “upper”, “middle” or “lower” without any reference to a broader understanding of the geological package. Of course the “upper” aquifer from one study might be several tens of metres higher or lower than the “upper” aquifer from an adjacent study. The absence of a rigorous regional framework into which local studies can be set, provides an opportunity for those undertaking local studies to be casual and inconsistent in their geological interpretations and therefore these studies fail to advance the overall understanding of the subsurface geology. It has been recognized in Ontario that geological information from water well records (generally mud rotary drilling with little sampling) can be of poor quality, which makes interpretations difficult to begin with. Despite this, however, observations of a rapid transition in grain size or sediment type lead to the immediate conclusion that the well records are "suspect", without any due consideration of the regional depositional setting in which the sediments were laid down. A goal of the groundwater management program is to provide a regional geological context into which local studies can be more effectively interpreted, thereby advancing the overall understanding of the geological setting.

A key aspect of the interpretation process was a focus on understanding the depositional setting and the geological processes of the Quaternary deposits. In addition to simply kriging hard geological data from well records to construct geological surfaces, an emphasis was placed on incorporating "expert knowledge" into the kriging process, in the form of digitized interpretation lines. This ensured continuity of valley systems, and allowed for layer pinch-outs to be effectively represented (Kassenaar et al., 2003). The selected approach was to resist from automating the geologic interpretation. The incorporation of geological knowledge and/or interpretation, allowed for considerable refinement of the original contoured surfaces. The 3D lines constrained the gridding process, and ensured that the resulting surfaces honoured both the well picks and the geologically inferred valleys and channels. Figure 2 shows the application of this approach with respect to the bedrock surface.

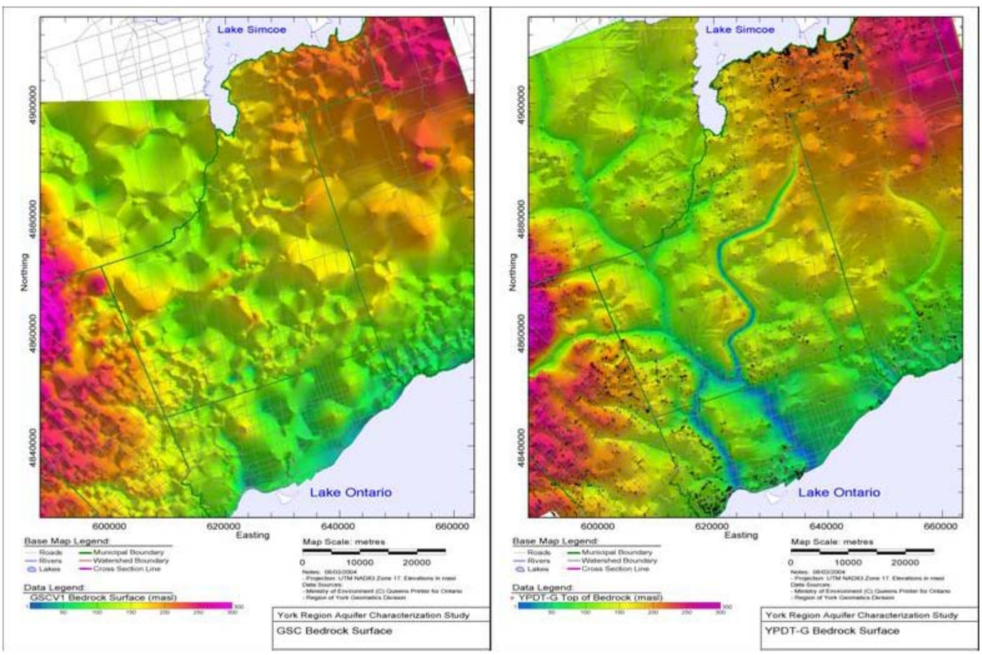

Figure 2. Comparison of unconstrained (left) and constrained (right) bedrock surface.

Figure 2a (left side) shows the bedrock surface constructed for an area extending north and west of the City of Toronto using only hard well picks. Figure 2b (right side), on the other hand, shows the same bedrock surface after a sub-aerial fluvial erosional system was interpreted to have eroded the bedrock surface. Although Figure 2a strongly hints at a topographical low on the bedrock surface extending northwestwards from Toronto (near the Lake Ontario label on the figure), it is only in Figure 2b that the river system is fully developed through the use of the 3D polylines. When incorporated into the numerical flow model this fully developed Laurentian River bedrock system allows groundwater flow systems to develop in deeper aquifers that partially infill the bedrock valley. The exact location of the channel thalweg and the slopes of the channel walls, even though they are based on the available hard data, could be subject to question due to the lack of hard data in particular areas. It is the intent of the project to update and improve the surfaces as new data is made available.

NUMERICAL GROUNDWATER MODELING

A third focus of the program was to use the database and geological layering as key inputs to develop a numerical groundwater flow model across the area to assist in water management decision making. Initially the program called for modeling at two scales; i) a "regional" scale whereby the entire ORM area would be modeled; and ii) a "local" scale, centred on Toronto and York Region, and stretching between Lake Ontario and Lake Simcoe. Although challenging in terms of optimizing computer capabilities, the successful development of the five layer regional model, consisting of some 3.3 million 240 m × 240 m cells, showed that some computer modelers were capable of developing the type of regional groundwater management models that the project was seeking.

Until recently, regional groundwater assessment studies were rarely undertaken in southern Ontario. Traditionally, of the agencies comprising the partnership, municipalities have focused on local groundwater supply investigations surrounding well fields, while conservation authorities have focused on surface water management for flood control purposes, generally paying little attention to low flows and groundwater discharge into the surface water system. In the 1960s and 1970s, the Ministry of the Environment undertook some excellent work in terms of integrating groundwater and surface water understanding however, structural changes within the Provincial Government put an untimely end to the good work that was progressing. It is only recently that water managers are starting to again recognize the need for groundwater flow models to focus on stream/aquifer interaction, and this was a key focus of the YPDT-CAMC modeling. The strong linkage between groundwater and surface water systems in southern Ontario, as evidenced by the strong influence of streams on groundwater levels and flow directions, demands that both resources be managed in an integrated manner.

The "local" scale model was particularly tailored to better evaluate groundwater – surface water interactions. The 8 layer model consists of 7.1 million 100 m × 100 m cells. The cell size was selected to better represent: i) stream-aquifer interaction since each small tributary would be separated by several model cells; and ii) drawdowns around the municipal wells. To assist in better representing the surface water system in the groundwater model several unique tasks were undertaken in the YPDT-CAMC modeling:

- Incorporation of the numerous smaller stream reaches, including the headwater tributaries that emerge on the flanks of the moraine, rather than just the larger-order streams that discharge south into Lake Ontario and north into Lake Simcoe. These numerous small tributaries represent a significant "wetted area" of contact between the groundwater and surface water system. Because headwater streams only partly penetrate the water table, they tend to be extremely sensitive to small changes in the groundwater system, such as those caused by changes in land use. A water table decline, for example, as a result of increased pumping or a decrease in recharge due to urban development, can shift the "start-of-flow" location in these streams by tens of metres, thus decreasing the habitat potential for many of the moraine's freshwater organisms. With over 25,000 Strahler Class 1 stream reaches in the study area, it is clear that the cumulative impact on small streams can be significant.

- Small, upper-reach tributaries were simulated as MODFLOW "drains", only allowing for one way movement of groundwater from the ground into the drains, while larger tributaries were simulated as MODFLOW "rivers" and could lose water back to the aquifers.
- Stream-aquifer geometry was also considered a critical factor controlling GW/SW interaction. The controlling stream level, or stage, was estimated from a high resolution 10 m Digital Elevation Model that had been hydrologically corrected.
- Hundreds of cross sections were "cut" under the rivers to evaluate the stream-aquifer geometry. Stream conductance and interaction parameters were adjusted based on the insight provided by these cross sections.
- The 100 m uniform cell size allowed local groundwater flow systems to develop between the streams and results in a more realistic representation of the interaction between the groundwater and surface water system.
- To effectively calibrate the groundwater model, both static groundwater levels and estimates of groundwater discharge (obtained from streamflow hydrographs) were set as targets for the model to match.

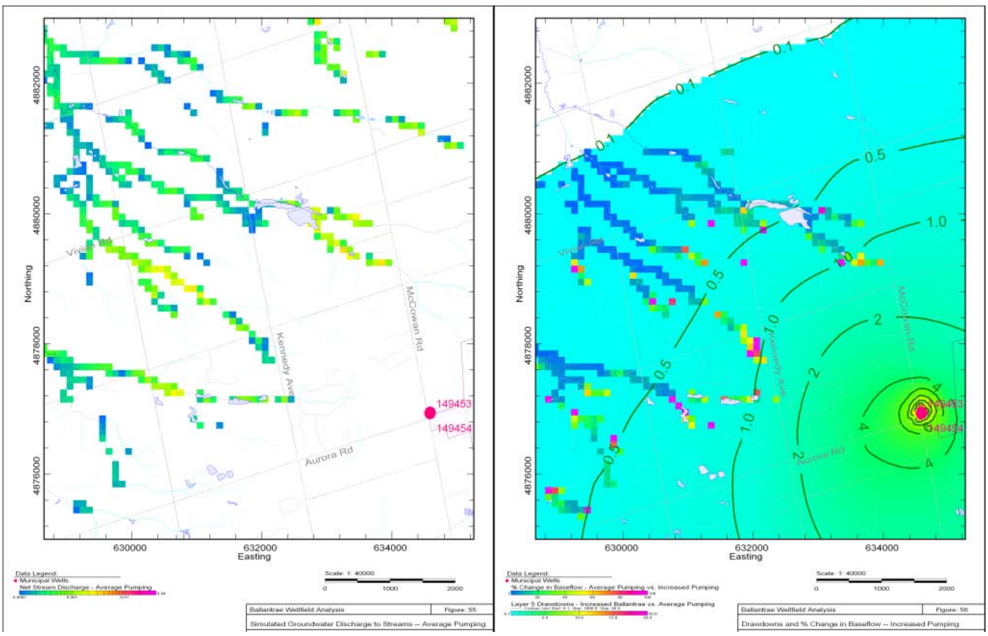

Figure 3. (Left) Stream baseflow, (right) Percent change in baseflow due to pumping.

Once calibrated, the model indicated that most groundwater discharges to streams rather than to the large lakes (Kassenaar and Wexler, 2006). Thus, an increase in groundwater withdrawals or a decrease in recharge will result in an eventual decrease in baseflow (once local aquifer storage is depleted). Figure 3 (left) shows the predicted discharge (color coded) to each of the 100 m cells along headwater tributaries within a portion of the model area under baseline conditions. Simulated discharge to streams under different land use and pumping conditions can be compared on a cell-by-cell basis to produce maps of predicted per-cent change and predicted absolute change in streamflow. Figure 3 (right) shows the predicted percent change in the flux to the streams after increasing pumping at a nearby municipal well. Only by incorporating all streams into the model and calibrating to observed baseflows is this level of stream impact evaluation possible. Conservation Authorities, armed with this information, can target specific tributaries or reaches of streams for further investigation, monitoring, and sensitivity analysis to assist in determining the significance of the predicted changes.

SUMMARY

The study provides an example of how local government agencies can combine limited resources to foster strong ties and achieve a sound technical understanding of the groundwater resource across a significant geographical area.

abstract id: **435**

topic: **3**
Aquifer management

3.1
Regional groundwater systems

title: **A methodology for determining sustainable groundwater exploitation in aquifer systems based on a simulation-optimisation approach using a multi-criteria analysis tool**

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keywords: sustainable, groundwater exploitation, simulation-optimisation approach, MCA, Flanders

Is has become evident in recent years that management and future planning of aquifer exploitation should be based on the concept of "sustainable development" as more and more groundwater systems are being depleted by overdrafting. Even for aquifers that are not (yet) threatened today, there is a risk that socio-economic development and climate change will ultimately lead to decreasing groundwater storage and increasing problems with water supply capabilities. In that context, the question how much can be pumped in a sustainable way is probably most crucial. The first description of "safe yield" is nearly a century old (Lee, 1915) and the concept has evolved over the years into "sustainable yield" (Alley and Leake, 2004), but all these definitions were diffuse, only descriptive and non-quatitative. The Brundtland Report (United Nations, 1987) defined "sustainable" as a "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Sometimes it was stated that groundwater withdrawal must not exceed the "capacity" of the aquifer system (Custodio, 2002). Many articles and books about sustainability of groundwater resources restrict themselves to listing all negative impacts of overdrafting, but do not provide a quantitative method for calculating how much can be pumped from a specific aquifer in a specific hydrogeological setting. Simple estimations were based on global water balance or water budget considerations but this has lead to much confusion. It was often thought that sustainable yield was related to the recharge of aquifers. Instead, sustainable groundwater development is determined by capture of natural discharge. Basing groundwater development sustainability on natural recharge (i.e. safe yield) is a myth and irrelevant (Bredehoeft, 1997 and 2002). Although the Brundtland definition of sustainability was vague, it cleverly captured two fundamental issues: the problem of environmental degradation that so commonly accompanies economic growth, and yet the need for such growth to alleviate poverty. The core of mainstream sustainability thinking has become the idea of three dimensions, environmental, social and economic sustainability (UCN, 2006). Therefore, a methodology for quantifying sustainable groundwater exploitation, should include the possibility to account for both hydrogeological, ecological and socio-economical impacts. This can be accomplished by using a multi-criteria analysis (MCA).

A methodology is being developed for determining sustainable groundwater exploitation rates in the groundwater bodies of Flanders (Belgium). The method extends the simulation-optimisation approach (combination of a groundwater flow model with a general optimiser) with a MCA tool to define an object function that is related to both hydrogeological, ecological and socio-economic aspects, including maximising exploitation rates. As ecological impacts have typically a strong spatial dependency (e.g. the occurrences of local habitats), a distributed groundwater model is used. This also allows for a compartimentalisation of pumping rates into different regions. A general optimisation program is used to minimise the object function and as a result quota for each subregion are obtained. To decrease calculation times, the concept of unit response functions (URF) is used to replace simulation runs with the regional models with faster URF grid manipulations. Some preliminary results obtained with this approach will be presented.

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abstract id: **447**

topic: **3**
Aquifer management

3.1
Regional groundwater systems

title: **The groundwater age and diluted in water helium distribution in the Lithuanian aquifers**

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keywords: groundwater, radiocarbon age, tectonic fracture, helium

INTRODUCTION

The interpretation of groundwater residence time in the artesian basins by radiocarbon data is complicated and apparent. The decrease of radiocarbon activities during time is conditioned not only by radioactive decay but also by geochemical processes in groundwater carbonate system, which regulated the carbon-14 activity of dissolved inorganic carbon in groundwater. Progress in regional studies of the delta carbon-14 values of the aquifers in Lithuania has been made by Banys et al. (1979), Juodkazis et al. (1995), Mažeika and Petrošius (1996), Mokrik and Mažeika (2002), Mokrik (2003), where the initial values of carbon-14 data were quoted via dilution factor (q) initiated as 0.75-0.85, which reflected a statistical index of carbonate dilution in the aquifer. In the some cases dilution factor was calculated using stable isotope carbon-13 data (Mokrik (2003), Mokrik et al. (2009).

The carbon isotopes composition of saturated zone should be a result of many factors – fractionation of dissolved carbon dioxide in the unsaturated "open" system condition, involve of the "dead" carbon during weathering and dissolution of carbonaceous minerals, fall from solution of re-precipitated carbon and other constituents, mixing of different age waters through leakage, decay of radioactive carbon-14 in flow system. These processes direct regulate the carbon-14 activities and complicate assessment of groundwater ages. The corrected age of groundwater was determined from the well-known decay equation (Clark and Fritz 1997):

$$t = -8267 \cdot \ln \frac{a^{14}C_{DIC}}{q \cdot a_0{}^{14}C} \qquad (1)$$

where: t – is the age of groundwater; q – the dilution factor; $a_0{}^{14}C$ - the initial carbon-14 activity of water at the time of recharge; $a^{14}C_{DIC}$ - the measured groundwater activity of carbon-14.

This paper is resulted from encompasses the isotope-geochemical aspects of different correction methods used to estimate ages of groundwater in Lithuania. The isotopical-hydrogeochemical data in this study mainly are made in the Radiocarbon Laboratory of the Geological Institute of Lithuania.

AGE OF GROUNDWATER

The main problem to find an appropriate correction model of groundwater age is requirement to determine initial carbon-14 content and to draw the geochemical reactions through additional representative parameters as such as delta carbon-13 and tritium along the pathways from the recharge to discharge area. One of the simple modus to eliminating bombs related carbon-14 activities in DIC is to plot the tritium and carbon-14 values of samples on the diagram. The initial carbon-14 activities for different aquifers can be find from this versus plot, where the distribution curves hits the detection limit boundary of tritium. Whereas many samples has high tritium content, water in these wells water contains a large content of modern groundwater (<50 years old). The groundwater with the tritium –bearing water had so named "future" radiocarbon age uncertainty. Thus, the apparent radiocarbon age of groundwater will be adjusted. Below of the tritium detection boundary the groundwater carbon-14 activities should be exclude bomb outcomes in the infiltration recharge water. Tritium qualitative-quantitative age estimation in Lithuania based on the more 200 tritium bearing water samples shows, that groundwater with tritium activity below 2.5 TU have the lying depth interval 14-

125 meters and are recharged earlier as 450 years and is submodern (Mažeika and Petrošius 1996). To estimate of the initial carbon-14 activities of groundwater in the Lithuanian aquifer systems we are pick the tritium detection limit value equal to 2.5 TU (Figure 1). As shown in Figure 1, the initial carbon-14 activity for Devonian aquifers can be accepted as 50 pmC corresponding to the carbon-14 activities average except the Middle and Lower Frasnian aquifers, where the average activity is much lower – 10 pmC, because by evidence of large karst system with gypsiferous layers.

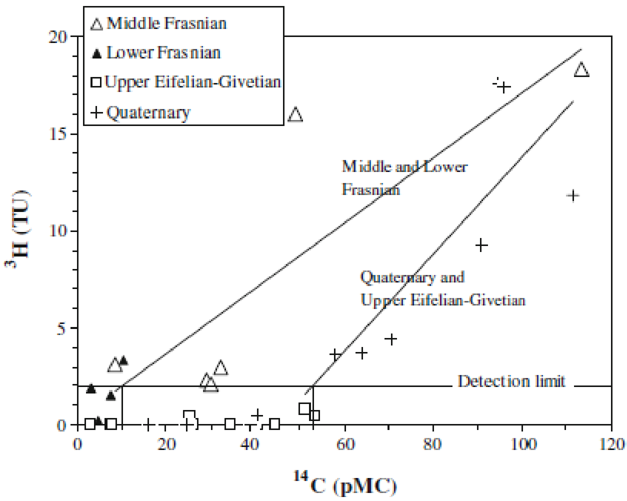

Figure 1. Relationship between 14C and tritium of studied groundwater (based on Mokrik et al. 2009).

The simple combined model regarding to delta carbon-13 and carbon-14 activities was earlier found and well-known:

$$a_0{}^{14}C = a^{14}C_{soil}\,\frac{\partial^{13}C_{DIC}}{\partial^{13}C_{soil}} \quad (2)$$

Neglecting geochemical reactions, the age equation (1) is then modified:

$$t = 8267 \cdot \ln a^{14}C_{soil}\,\frac{\partial^{13}C_{DIC}}{\partial^{13}C_{soil}\,a^{14}C_{DIC}} \quad (3)$$

Assume that carbon-14 activity value of soil is around 100% and delta carbon-13 value respectively -25‰, the formula (3) is:

$$t = 8267 \cdot \ln \frac{-4\partial^{13}C_{DIC}}{a^{14}C_{DIC}} \quad (4)$$

Ferronsky et al. (1984) were recommended for a "close" aquifer system conditions use in equation (4) instead value -4 number of -5.7, because has recipient accordingly the carbon-14 activity value of recharge water 85 pmC and the delta carbon-13 value -14.9‰ respectively.

A groundwater corrected carbon-14 residence times in Lithuanian aquifers was calculated by the carbon mixing (Pearson and Hanshaw 1970; Mook 1976; Wigley 1976), matrix exchange (Fontes and Garnier. 1979, 1981), also according to Ferronsky et al. (1984) and equation (4) models (Figure 2).

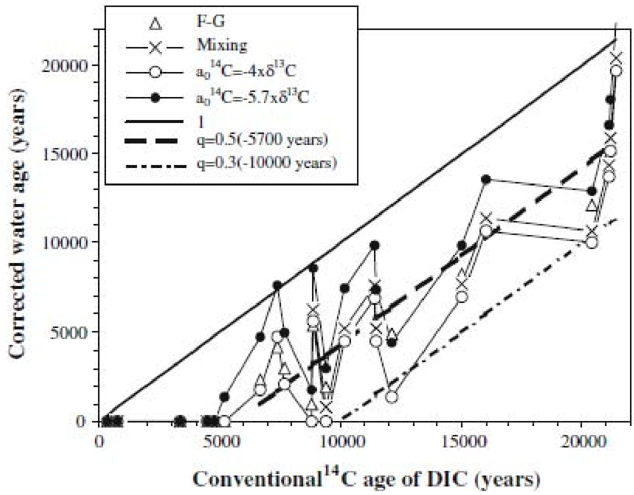

Figure 2. Comparison between age of 14C correction models for studied groundwater (based on Mokrik et al. 2009).

Good congruence were found between the delta carbon-13 mixing and Fontes-Garnier matrix exchange models whish correlated signally with tritium data to determine initial carbon-14 activities for groundwater or with the dilution factor equal to 0.4. Worthy of note, that easy for calculating formula (4) can give same a good confirmation to respect of geochemical models and indicates as viable method for correct dating. The delta carbon-13 values in the groundwater changes from -20.2 to 2.3‰ reflecting dissolution step of carbonates during regional movement of water along lateral downgradient and into depth. Thereof, these trend objectives are related with the rates of infiltrating, and groundwater ions activities in aqueous solution during water-rocks interaction.

For all analyzed groundwater samples the adjusted carbon-14 ages distribution by depth is demonstrated on *Figure 3*. Age versus depth diagram shows that the modern recharge water is spread for the Quaternary and Lower Frasnian aquifers from the several tens to 90 meters, for Middle Frasnian – from several to 24 meters and for the Upper Eifelian-Givetian aquifer 90-185 meters correspondingly. Along the downgradient flow path in the diapason of 40-250 meters the groundwater age increased progressively up to 20000÷25000 years BP, except many samples of the Middle Frasnian aquifer, where the old age of water considered with water-bearing rocks dedolomization adding much dead DIC near the surface. On the areas of groundwater upgradient flow the ages distribution along the depth have a reverse character, because by vertical leakage through tectonic lineaments and river valleys towards surface. Old ages in the rivers valleys and in vicinities of hydraulically permeable tectonic fractures has confirmed by geogenic helium anomalies locations (Mokrik 2003; Mokrik et al 2002).

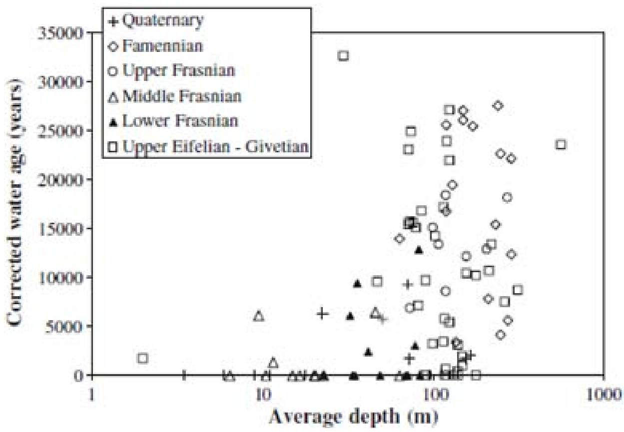

Figure 3. Groundwater corrected age distribution by average depth (based on Mokrik et al., 2009).

Most fresh groundwater of Ca-HCO_3 and Ca-Mg-HCO_3 facies resulted from the modern recharge water at highlands where aquifers is covered by Quaternary cover. The same type of groundwater occurred within the Quaternary aquifers. Thus, the aquifers groundwater chemical composition here is formed through downward percolation from the above lying Quaternary deposits, owing to short residence time that is substantially equal to modern. The radiocarbon age of Quaternary aquifer system and shallow aquifers groundwater at highlands of Lithuania is close to recent or essentially several hundred years old and consist about 30-50 pmC of modern meteoric carbon-14 activities.

The sodium bicarbonate groundwater facies of the aquifers forms at the intermediate depth (65-270 meters). In the Na-HCO_3 groundwater facies a high concentration of Na^+ might result from cation exchange with sodium rich clay minerals on the surface of interbedded clay layers occurrence within the aquifers. The time required for Na-HCO_3 facies formation ranges from 1681 to 10234 years BP. This groundwater facies for the Upper Eifelian-Givetian aquifer are transitional from the Ca-HCO_3 and Ca-Mg-HCO_3 types of facies to the chlorides type groundwater facies. The corrected radiocarbon age of sodium bicarbonate groundwater varies in range of 13905÷27436 years BP. The oldest water spread on the coast of Baltic Sea vicinities which are related by upward leakage of oldest groundwater through the discharge zones from the underlying deeper aquifer. The groundwater hydrochemical facies are outgoing from the carbon dioxide dilution in water and dissolution of carbonate minerals in the aquifers deposits. Most influence of carbon dioxide pressures ($10^{-1.2}$÷10^{-2} atm) are found in the Quaternary aquifer, which has equilibrated or supersaturated with calcite and dolomite. In the pre-Quaternary aquifers the carbon dioxide content derived from the Quaternary deposits decreases and the final CO_2 pressure come lower – 10^{-2}÷10^{-3} atm and is accompanied with increase of pH values and by positioning of the water samples on the dolomite stability field. These features were realized during correction of groundwater radiocarbon age modeling.

Deeper groundwater age of the Na-Cl facies is estimated only on the western part of the Lithuanian coast from the depth of 565 meters in the Upper Eifelian-Givetian aquifer, where the carbon-14 activity was 2.91 pmC, and corrected age form 23510 years BP.

The presence of the total helium in groundwater is a clear indication of a parent radioactive source in the crystalline basement and of intensive diffusion as through fractured zones in the basement and sedimentary bedrocks towards the shallow groundwater aquifers. The dissolved helium concentration in the groundwater was measured using the INGEM-1 equipment. Increased contents of it occur along faults near the Rapakivi granite massifs. The helium dissolved in the groundwater was found to vary considerably from $5 \cdot 10^{-5} \div 100 \cdot 10^{-5}$ ml/l in the low helium generating blocks to $100 \cdot 10^{-5} \div 60000 \cdot 10^{-5}$ ml/l along deep-seated faults. The maximum helium values are found in the groundwater samples taken from and near the basement. High values of helium, up to $50000 \cdot 10^{-5}$ ml/l, occur also in the groundwater of oil fields, because solubility of helium increases several times in oils. The dissolved in groundwater helium values decrease upwards from the basement surface. This suggests that Rapakivi massifs are important producers of helium in groundwater, and that faults penetrating from the basement are the active carriers of helium up to surface.

CONCLUSIONS

The investigation of isotopic geochemistry shows that obtained results can rarely be approached as true groundwater age. The decrease of radiocarbon activities during time is conditioned not only by radioactive decay but also by geochemical processes in groundwater carbonate system, which regulated the carbon-14 activity of dissolved inorganic carbon in groundwater. Geochemical models, which include carbon-13 data in their calculations, were used for the evaluation of these processes and for corrections of groundwater radiocarbon dating. Tritium data were also used for the motivation of this analysis. Obtained results show that initial activity of radiocarbon in groundwater of Lithuanian aquifer systems decreases approximately in half because of geochemical processes. In the active karstic matrixes the reservoir correction can reach up to 29 ky, where the groundwater age of aquifer system is approximately equal to modern or submodern. In the vicinities of hydrogeologically active tectonic fractures zones the groundwater radiocarbon age and dissolved helium values are maximally high. The high values of dissolved in groundwater helium content confirm leakages through the tectonic lineaments.

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abstract id: **467**

topic: **3**
Aquifer management

3.1
Regional groundwater systems

title: **Clarke contents of chemical elements in the groundwaters of the supergene zone**

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keywords: groundwater, supergene zone

For the first time, the average (clarke) contents of more than 50 chemical elements in ground waters of supergene zone were calculated by the author in 1978. During the last 30 years, new data on a great number of chemical elements were obtained by more modern methods. All this provided a basis for the calculation of more precise clarkes of chemical elements in waters. In the same way as previously, the calculation was based on the principle of latitudinal zonality of shallow ground waters. Altogether, more than 34 thousand ground water samples from 66 regions of the world were used.

According to the obtained average data, ground waters of permafrost provinces are the freshest in the world. It is natural, because permafrost rocks considerably prevent infiltration of atmospheric precipitate into not deep horizons of the supergene zone. This defines short ways of ground waters movement and, therefore, short duration of their interaction with rocks. However, groundwaters of this province have moderate acidity and extraordinary high contents of dissolved organic matter, in the composition of which fulvic acids and NH_4^+ prevail. The widespread opinion on the abundance of silica-rich waters in northern latitudes failed to be supported by concrete data, as SiO_2 contents turned out to be the lowest here.

Very fresh waters are formed in the environment of tropical and subtropical regions with the maximum intensity of water exchange. This province is characterized by the most acid water composition, high annual average temperatures, and predominance of the underground run-off over the surface run-off. The highest silica content is an important feature of waters of this province. This supports the idea that the most typical silica-saturated waters are formed not in cold northern regions, as it is thought, but in hot tropical areas.

As to the degree of mineralization, the region of mountain massifs is the next in the list. It is characterized by a very extensive water exchange and the formation of fresh waters. These waters have relatively high alkalinity related to an insufficient neutralizing effect of organic matter. Unlike all other provinces, underground waters of mountain regions contain the lowest quantifies of dissolved (C_{org}) and mineralized (CO_2) organic matter.

Ground waters of moderate climate regions are the most mineralized. They are developed on platforms, shields, and rarely in ancient fold belts. A relatively low level of water exchange leads to the formation of underground waters, which have a total mineralization of 354 mg/1 and are close to neutral waters. An increase of total salt content in waters in comparison with that of other provinces takes place mainly at the expense of hydrocarbonates of the main cations, i.e., cations obtained from the sum of mineralization products of organic matter and products of rock weathering.

The average composition of leaching ground waters can be presented by Kurlov's formula:

$$M_{0.24}\frac{HCO_3 80.7 Cl 9.4 SO_4 8.8 NO_3 1.0 F 0.3}{Ca 46.4 Mg 31.5 Na 20.3 K 1.7} pH 6.75 \qquad (1)$$

i.e., these waters are moderately fresh, low-acidic, and of the hydrocarbonate calcium-magnesium composition.

Unlike leaching waters, the ground waters of continental salinization, judging by their average composition, are saline, low-alkaline, chloride-sulfate-hydrocarbonate sodium in composition and are characterized by Kurlov's formula:

$$M_{1.36}\frac{Cl37.3SO_4 32.5HCO_3 29.3NO_3 0.5F0.4}{Na56.7Ca21.7Mg19.3K2.3}pH7.50 \quad (2)$$

The average chemical composition of underground waters of the supergene zone is expressed by Kurlov's formula:

$$M_{0.47}\frac{HCO_3 48.9Cl26.7SO_4 23.4NO_3 0.6F0.3}{Na44.9Ca29.9Mg23.2K2.0}pH6.9 \quad (3)$$

i.e., these waters are moderately fresh, practically neutral, of a hydrocarbonate-chloride and sodium-calcium composition.

Each hydrogeological province is clearly distinguished by specific geochemical features of ground waters. This is confirmed by calculations of Student's criterion. It turns out that each hydrogeological province is clearly characterized by its own geochemical nature, i.e., *by its specific individuality governed by zonal factors, among which water exchange plays the most important role*.

The geochemical individuality of waters of each province is so great that it is not being lost even under the action of seasonal factors. A great number of facts suggest that seasonal variations of water compositions and water movement from to discharge areas result in limited changes in their compositions and not much affect the geochemical individuality of waters of each province.

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abstract id: **468**

topic: **3**
Aquifer management

3.1
Regional groundwater systems

title: **Formation and evolution of hydromineral systems in Mongol-Baikalian region and prospect assessment of the resources use**

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keywords: regional hydrogeology, Mongol-Baikalian region

The Mongol-Baikalian region is considerred as a vast area (in total it makes more than 500 000 square kilometers) including Baikal Rift zone, the neotectonic lifting in Trans-Baikal area and Mongolia as well as the hilly plain of the Onon-Kerulensk interfluve. As a hydrographical object, the area belongs to the following basins: to Lake Baikal, which is a unique reservoir on our planet, and to Amur River (in its upper flow) up to the confluence of Shilka River and Argun' River.

An author's conception of the region integrity as a major hydrogeological system of the first order within the terrestrial branch of the Pacific volcanogenic belt is suggested in the poster presentation. The main peculiarity of the system is the fact that rift lakes (Lake Baikal, Khubsugul Lake, Gusinoe Lake, Kotokel Lake, etc.) on its area contain fresh and ultra-fresh waters practically with the same chemical composition and mineralization along the water column – from surface up to the bottom. The lakes are characterized by an active water exchange in the water body, what is confirmed by isotope hydrochemistry data and by hydrochemical calculations. This is the uniqueness of the Mongol-Baikalian region. The big lakes of the other rift systems (Europe, Asia, Africa, America) have a near-bottom system of complicate water exchange, where formation of the gas and chemical content occurs due to the system interaction "water-bottom", and where pollution processes take place and they except possibility of using lake waters as drinking water.

According to the long-term studies of the mineral water regime and hydro-geological mapping with the use of new original methods and aero-cosmic information, fracture tectonics and isotope data , also with participation of the poster authors and Mongolian colleagues "The Map of mineral waters in Mongolia" (1:2 500 000) was worked out and published.

As a basis of the map are taken new theoretical developments and a new mapping technology. The classification criteria were worked out by the authors.

The map contains the following information:

- The map legend includes a new classification of mineral water on physical and chemical characteristics, chemical, gas and isotope compound and temperature. For the first time, balneological classification with indications for treatment of different deceases with the use of mineral ground waters and mineral lake waters is given.
- The map has a hydrological zoning of the territory of Mongolia with indication of the hydromineral provinces and regions with different formation conditions and spacial distribution of different types of hydromineral resources (balneal ground waters, industrial and thermo-energetic waters, mineral lake and therapeutic mud).
- Information given for different water points is explained in the legend, so the map can be used without annotation.
- Hydrogeological formations ground water systems of the area with data on hydrogeodynamic and hydrogeochemical characteristics for ground water as well as hydrogeochemical peculiarities of aqueous solution, brine, and bottom sediments for mineral lakes are given.
- For the first time the map is supplied with the theme of spa climatic zoning and information on spa object construction in Mongolia.

- New mineral water types revealed by authors are shown on the map, among them Khingan type of carbonaceous thermal waters unknown before.
- Elements and salts which are deficit mineral raw material on their concentration –"liquid ore" (Li, Sr, B, Bromine, I, K) are displayed on the map.
- For the first time aquiferous fractures are indicated with the use if isotope information (H^2, Rn, He, $^3He/^4He$), timed to unloading site mineral waters of crust (on H^2 and He) and amphicyte ($^3He/^4He$) genesis.
- For recreation and tourism purposes a new version of the map in the scale of 1:5 000 000 was separately published.

The map can be used for further development planning of spa constructions, survey of the new mineral water deposits, hydro-mineral raw materials as well as for students and young scientists as a tutorial aid including hydro-geological tasks and translations from English into Russian.

The main task of the report determining its theoretical importance, novelty and corresponding to its title was formulated as "Basic theoretical justification of unique for Mongolian-Baikal region system for studies and rational use of hydromineral resources aimed to their integrated quantitative assessment for economically profitable and ecologically safe use in the economics". The possibility of fulfillment of such program for a short, 2-years period (2008-2009) is based on a perennial scientific potential of the project executors and on the professional experience of joint research done by Russian and Mongolian specialists resulted in making and publishing of a unique "Map of Mongolian Mineral Waters" with the scale 1:2 500 000 (2003). The authors of this map recognized both in these countries and worldwide are the participants of this project. In Russia, maps of mineral waters of Baikalian part of the region were also done, but for a while they are not published. At present, the authors are creating a common map for the whole Baikal-Mongolian Region for publishing. This is justified by the fact that before, scientific and methodological analysis of maps done for Mongolia and Russia separately showed their unconformity in the boundary zone of these countries and give no possibility for basic scientific generalizations and for assessment of the possibility of use of hydromineral resources in the common Russian-Mongolian system. Hydrological mapping using permanent integrated survey of the whole region is not justified due to complex character of expeditions in mountain areas with difficult access and to absence of permissions from boundary authorities, only boundary line remained, and the line of State boundary between Mongolia with Russia and China crosses united water bearing system without reflecting natural and geological-hydrological boundaries of united water-bearing systems of mountain-folded structures in the regions of recent and modern volcanism. It is especially complex at expedition activities which cannot be fulfilled for a short period of time. Therefore for the mapping, we developed a new technology of hydrogeological survey of the structures of recent and modern volcanism by large areas of mineral waters discharge. Such a technology is developed taking into account modern achievements of worldwide sciences, by special parameters it is pioneer one. For their studies we selected the most important water units, characteristic representatives of different types of hydromineral resources (medical, industrial and thermal energy waters). These units are partially presented on the maps made before, but they are yet poorly studied or known only due to information from local population. For studies and mapping, we selected such units in 2008, and while studying we revealed and proved that they are yields of different types of hydromineral resources perspective for practical use at joint exploitation which is quite real nowadays due to progress in cooperation between our countries. Such yields investigated in detail in 2007-2008 are: 1) unique in the region.

- From seismic and tectonical point of view, Mongolian-Baikal region is very active with rather complex composition of extension (Baikal Rift) and compression zones (Khangay and Khentey-Dauria neotectonic lifts). Formation and evolution of nitrogen hydrothermal systems in these zones are connected genetically with the source of the heat income. In Baikal Rift this is a regional heat field in which fissure-vein hydrothermal systems of deep circulation are formed. These are mainly siliceous nitrogen waters in the anion composition of which sulphate dominates (Goryachinsk type of hydrotherms). At neotectonic lifts, the source of the heat income is connected with mantle plumes. By its chemical and gas composition, acrototherms of Khentey ara analogous to thermal waters of Khangay arc lift related to the area of Cenozoic tectonic-magmatic activation. These are also siliceous nitrogen waters, however, in difference with therms of Baikal Rift, the sulfate-ion in them is not major. Therefore the anionic composition can serve as a criterion for outlining of boundaries of arc lifts of Khangay – Khentey and Baikal Rift. Within Mongolian-Baikal region (at the flanks of Baikal Rift) there are hydrothermal systems connected with the areas of development of marine volcanism and having local heat sources. Here exceptionally subthermal and thermal carbon dioxide and carbon dioxide – nitrogen mineral waters are developed, they are connected with mofette stage of volcanic activity. On the base of some sources, health resorts are functioning, the pouring of mineral waters is organized, but their resources are used not completely.
- Lake systems including highly-mineralized surface waters, silt brines, as well as rocks forming lakes bed and their basins slopes are very peculiar. At present, main attention is paid to the perspectives of extraction of important microelements (bromine, lithium, iodine, boron, etc.) from lacustrine systems. Recent studies carried out by the authors on the territory of Mongolian-Baikal region showed that the brine from some lakes (Borzinskoye, Khara-Torum, Tsagan-Nor, etc.) contains enough important microelements for organization of their industrial extraction. We have to notice that besides halogenesis process connected with salts concentration during evaporation under the conditions of arid climate, there is some lakes microelements income from deep supply sources.
- Let us notice for conclusion that in 2007-2009, our investigations were supported by international grant. The program “Russia-Mongolia” is continued at present, it will be finished in 2011 with final report and of draft of the map of hydromineral resources of Mongolian-Baikal region with the scale 1:2 500 000 ready for publication.
- The activities within the grant are investment character with additional financing both from Russian and from Mongolian party, it allowed to drill search and trial holes with depth up to 120 m in productive zones of neotectonic faults at the most important for studies and consecutive use thermal waters, maximal forecast temperature of which (by siliceous geothermometer) at the depth of vapor hydrotherms formation (ca. 3-4 km) is ca. 150°C.

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abstract id: **515**

topic: **3**
Aquifer management

3.1
Regional groundwater systems

title: **Hydrogeological aspects of Quaternary sediments in Poland**

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Quaternary evolution of Poland started 2.5 million years ago and comprised of two stages; Prepleistocene — time before glaciations, and Pleistocene glaciations time including Holocene epoch. The river's system with eroded deep valleys existed in Prepleistocene, but the outflow from rivers was oriented towards the Black Sea, White Sea and North Sea. Marine sediments in the vicinity of present Baltic Sea area are said to emerge in the Eemmian Interglacial. The rivers on polish territory have started to orientate towards to the North (Prebaltic) from that time. Deep erosions were repeated at early stages of glaciations followed by gravel and sand fill. These process created buried valleys' up to 200 m deep, which are now abundant Quaternary aquifers. The biggest groundwater aquifers in Poland are in places of interference of these structures and fluvioglacial sands developed as sandurs. These aquifers are separated by glacial till and silt strata. The most abounding aquifers are delimitated and protected (Żurek et al., 1994; Skrzypczyk, 2000). The interglacial sediments are connected to loamy and silty sand often mixed with organic matter and peat accumulated in lakes, swamps and valleys. The average thickness of fresh water layer is ca. 200 m (Kleczkowski (ed.),1987; Paczyński, Płochniewski, 1996). The salt waters and brines of synsedimentary and infiltration origin and Cl-Na type occur beneath the fresh groundwater on the lowlands (Dowgiałło et al., 1974; Różański, Zuber, 2000).

The multiaquifer system' are common in the area of Polish Lowlands (Paczyński (ed.), 1993, 1995). Transmissivity of these water bearing strata often exceeds 200 m^2/hr. Tremendous groundwater resources and their position close to the ground surface allow for their utilization as water supplies in Poland 2,1 km^3 annually, which means are 51% that of total amount of exploited waters on water intakes comes from the Quaternary aquifers (Herbich, 2005). The recharge areas of these aquifer lie in the highlands whereas the wide river valleys are discharge areas. The mean resident time of groundwater in the Quaternary aquifers in Poland is estimated to be 50 yrs, whereas residence time of water in the sluggish circulation systems in deeper strata, exceeds 1000 yrs.

The Quaternary aquifers are vulnerable to municipal and agricultural pollution (Żurek et al., 1994). Along the Baltic coast lowlands the geogenic pollution as sea water intrusion or brines ascension is observed especially in the vicinity of big water intakes (Burzyński et al., 1999). Trends in water table lowering is noted in the central part of Polish lowlands, possibly due to the climate variability.

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abstract id: **529**

topic: **3**
Aquifer management

3.1
Regional groundwater systems

title: **Research on the Karst Hydro-geological structure in Jinping Hydropower Project Area**

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keywords: karst groundwater,, Jinping hydropower station,, Karst water storage structure

INTRODUCTION AND PREVIOUS WORK

Located at Jinping mountain, between Qinghai-Tibet Plateau and the Sichuan Basin, Jinping Hydropower Station is one of the biggest ones in China. The projection area of the station is around by the Big Bend of Yalongjiang river in western Sichuan province, where the Landscape is very complex with big and high mountains, deep gorges. And the karst landscapes are also well developed, with big karst springs, peak cluster and peak forest. The deep rivers and rich precipitation in the projection area cause a large hydraulic gradient as well as abundant potential Hydropower resources.

The aim of the Hydropower Project is to straighten Yalongjiang river at the the Big Bend by tunneling 6 tunnels (with up to 18 km for each) from the West side of Jinping mountain to the Eeast side of Jinping mountain, in order to access to the more than 300m water level drop's hydraulic power for Generate electricity. Preliminary investigation shows a relatively complex geological structure, with many different kinds of closed folds, faults, and the limestone and marble of middle Triassic distributed alternately with sandstone and slate of upper Triassic. The project area, a typical karst mountain canyon area, also shows a significant regional or lithological difference in karst Development. There are three big karst springs in the project area: Mofanggou spring, Lao Zhuangzi spring, and Sangushui spring. Some scientists and scholars put a proposal of dividing the Lithostratigraphic units into three grades of karst development formations based on their geological survey and karst groundwater investigation and mapping: The strong (T_2b), medium (T_2Z) and weak (T_2y) ones (East China Investigation and design Institute under CHECC, 1992). Five hydro-geological divisions are also put forward. They also agreed that, the Mofanggou spring and Lao Zhuangzi spring are two separate hydrogeologic units, and a real karst groundwater divide exists between Mofanggou spring and Lao Zhuangzi spring (Zhigang, Ning, 1993). Finally they gave a suggestion to tunnel at the groundwater divide of the two major karst groundwater systems: from a place in Western Yalongjiang riverbed, near Jingfeng bridge, at a height of 1600 m above sea level, West side of Jinping mountain, to Dashuigou, a place in Eastern Yalongjiang riverbed, at a height of 1300 m above sea level, East side of Jinping mountain. The suggestion was accepted by the Hydropower station policy-making department.

PROBLEMS

The tunneling began from 1993, and with the progress of different kinds of tunnels, more and more tunnel water inrushing revealed, which shows the suppose above was incorrect. Up to end of 2009, about more than dozens of large scale of tunnel inrush events appeared during the excavation of the long geological exploration tunnels (at 1993), the auxiliary tunnels (from 2003 to 2009) and the diversion tunnel (since 2008). Large scale of caves or concentrated zones of karst water flow are also encountered. Up to 2009, the total flow of inrushing ground water is nearly 10 m^3/s, which caused the completely drying of Mofanggou spring and seasonal drying of Laozhuangzi spring. The groundwater levels in the project area dropped rapidly from about 2170 m above sea level to about 1600 m above sea level, which cause a seriously damage to the ecological environment.

NEW THINKING ABOUT THE KARST HYDRO-GEOLOGICAL STRUCTURE

In order to solved the problems appeared above in the process of tunneling, a new detailed karst hydro-geological investigation and relative research work, such as hydro-geochemistry research, geological mapping, long-term's karst hydrological monitoring, cave exploration, etc., are carried out. The following new understanding was put forward based on the comprehensive analysis on data from the works above and long-term's hydrological monitoring for the inrushing grounwater, as well as the Experimental data of more than 6 times of large-scale karst groundwater tracing from 1993 to 2010 (Zulu et al., 2010).

(1) No underground divided exists between Mofanggou spring area and Lao Zhuangzi spring area. on the contrary, the karst grounwater is gathered in the "geological structure low" from places around, to form a unified "Jinping Karst water storage structure" between the two big karst spring areas. The tunnels designed are just pass through the center of "Jinping Karst water storage structure", which lead to a serious damage to the original hydro-geological structure (that is "Jinping karst groundwater storage structure"), and thus a large scale of groundwater inrushing appeared while tunneling, and finally the tunnel become the new karst groundwater discharge center with the rapid drop of groundwater level. The completely drying of Mofanggou spring and seasonal drying of Laozhuangzi spring is just the direct result of the human behavior.

(2) A new proposal is put out according to the property of regional litho-stratigraphic units, gushing water position, outflow revealed and karst development, that the litho-stratigraphic units should be divided into three grades of karst development formation groups: The strong (T_2b, T_2y^5, T_2y^6), medium (T_2z, T_2y^1, T_2y^2, T_2y^3) and weak (T_2y^4) ones, with the relative aquifer media type of karst conduits, karst fissures with limited conduits, and isolated karst fissures separately. The last one (T_2y^4), together with the sandstone and slate (T3), consists the border of Jinping Karst water storage structure.

(3) Jinping Karst water storage structure has a unified groundwater level: about 2130~2170 m above sea level during wet period, and less than 1580m above sea level in the dry season, then a forecast of up to 15.0 m^3/s of potential total flow of inrushing groundwater was given when tunneling at an altitude of more than 1600 m above sea level based on the present tunnel inrushing hydrological data.

(4) The main geological section of tunnel groundwater inrushing is located between the boundary of T_2y/T_2b and the boundary of T_2y^5/T_2y^4 in the east wing of Jinping syncline.

(5) Affected by the low regional erosion base level in the East, the situation that, the groundwater level in the East is much lower than that in the West, lead to a general trend of groundwater flow from the West to the East, and a leakage recharge exist at the boundary of the two hydro-geological division: from the hydro-geological division (T_2b) to the hydro-geological division ($T_2y^5 \backslash T_2y^6$). The inrushing water points at present concentrated mainly in the T_2y marble in the east wing of Jinping syncline.

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3.2 | Transboundary aquifers

abstract id: **173**

topic: **3**
Aquifer management

3.2
Transboundary aquifers

title: **Investigations of the aquifer characteristics of the dolomite formation on the Northern Calcareous Alps in Germany and Austria**

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keywords: dolomite-formation, groundwater age, Northern Calcareous Alps, hydrochemistry, water supply

INTRODUCTION

At the northern edge of the Northern Calcareous Alps there are sectural problems in providing a stable and efficient drinking water supply. The existing waterworks extract from karst springs, delivering waters with extremely short residence times or from wells in porous groundwater bodies which, because of the intensive land use in the catchment areas includes a risk of significant pollutant levels.

Both methods of providing drinking water supply can only be used by defining extensive protection areas in which many restrictions are applied to land usage.

An alternative way of obtaining drinking water in the Northern Calcareous Alps region was investigated to ascertain the suitability of the widespread but rarely used Hauptdolomit (HD) feature. The typical HD-aquifer was described by Kassebaum, Zankl (2004) and Kassebaum (2006) as a medium of double porosity. The larger fractures representing fracture porosity are responsible for discharge. The micro fractures determine the matrix permeability which is responsible for filtering and retention capacity. In the context of these investigations the questions of the hydrochemical properties and the mean residence time of the waters in HD aquifer have not yet been answered satisfactory.

Within the region between Reit im Winkl and Waidhofen/Ybbs 12 groundwater withdrawals (springs and wells) were found suitable for use for the characterization of this special aquifer. Figure 1 shows the larger study area and the single measurement points.

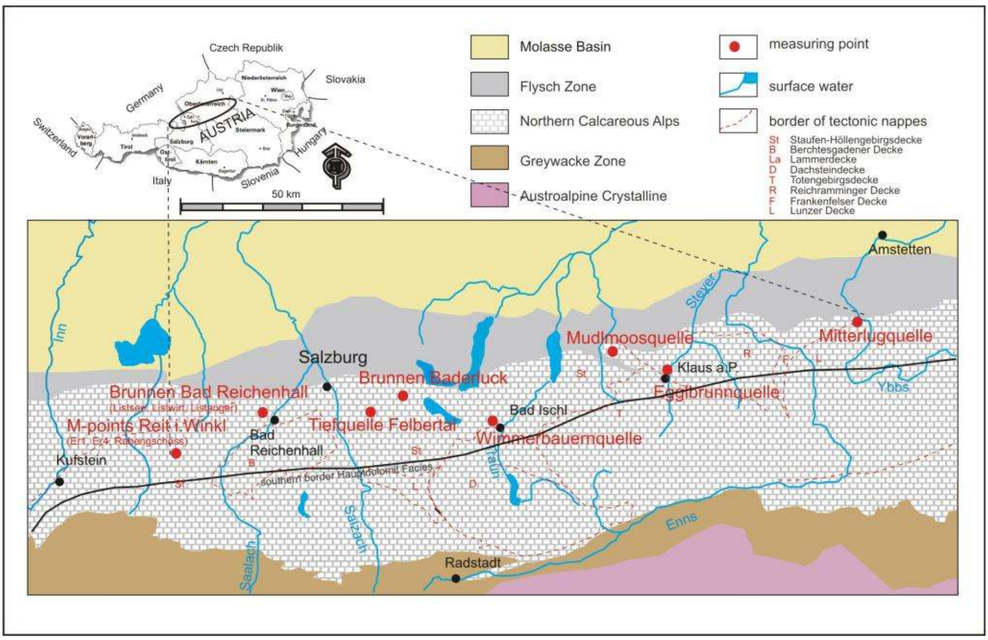


Figure 1. Overview of the study area (simplified after Beck-Mannagetta and Matura 1980, Geol. Karte von Österreich 1:1.500.000, supplemented after Tollmann 1976)

METHODS

Initially the orographical catchment areas of the chosen springs and wells were mapped geologically and hydro geologically in order to check the basic requirement to work in HD-dominated catchment areas. Further aims of mapping were to collect hydrogeological objects like seepages, swallow holes, further springs and signs of karstification. Field parameters like conductivity, water temperature and amounts of discharge were measured in samples from springs and surface waters.

Structural data were collected to explore the characteristics of the network of fissures in the catchment areas as this affects infiltration, flow velocity in the aquifer, variability of discharge. These are very important factors in deciding on the suitability of a spring for water supply and the hydrological broadening of the catchment area.

Parameters like temperature and conductivity were measured in the field. In addition laboratory analysis focused on the parameters calcium, magnesium, sodium, potassium, sulphate, chloride and hydrogen carbonate ion concentrations as these are the most important ions to be considered in the formations of the Northern Calcareous Alps.

The evaluation of the saturation indices for dolomite and calcite in combination with the calcium-magnesium ratio was used to distinguish between HD-waters, limestone-dominated waters and waters influenced by low mineralized run off of precipitation.

Stable isotopes were used to determine the mean elevation of the catchment areas. In addition Tritium was used to estimate the mean residence time and the age distribution of the investigated waters. To improve the result of isotope investigations micro pollutants like CFC and SF_6 were used.

RESULTS

The main results of the field survey are listed in table 1. The field survey in some of the studied areas in the range of Stauffen-Höllengebirgs nappe showed springs with their origins in steeply dipping macro fractures striking more or less in E–W or in N–S-direction. The more eastern situated springs are results of NW–SE (Egglbrunn) and N-S (Mitterlug)-striking fractures, whereas the main joint set in the catchment area of Mitterlugquelle is NW–SE and NE–SW-directed. Besides these bigger scale fractures, small-scale brittle structures play an important role in the dynamic behavior of the aquifer. As characteristic omnidirectional micro fractures in the HD-unit are regarded as responsible for infiltration and for retention capacity, these small scale structures were of special interest of the field survey. As table 1 shows the presence of micro fissure structures on the surface strongly differs in the study areas.

Table 1. Basic data of field survey in some of the studied areas. Whereas measuring points within Stauffen-Höllengebirgs nappe are based on N or E-striking fractures, the more eastern situated catchment areas are dominated by NW- or NE-striking structures. In every study area micro fissures are not developed laminary, further springs surface run offs etc. are rare in every area.

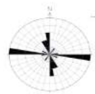
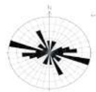
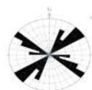
study area	geological formations besides HD	direction of main joint sets	direction of the spring relevant fracture	presence of micro fissures	spring situation in the catchment area	distinctions
Tiefquelle Felbertal	moraine		steep ENE striking fracture, open width decimeter	seperate mircofractured areas, HD for the most part massy	widespread diffuse discharge, only few small springs	scale deposits in the range of diffuse discharge
Brunnen Baderluck	limestones (Dachsteinkalk, Oberalmer Schichten) moraine		unknown	seperate mircofractured areas, HD for the most part massy	very rare diffuse run off, no further springs in the whole mapped area	black bituminous layers, distinctive banking
Wimmerbauernquelle	no extreneous units		steep N-striking joint sets	very few sperate microfractured areas, HD for the most part massy	no further springs, little creeks E nad W of the spring border the catchment area	relatively low conductivities and high temperatures, very steady discharge
Mudlmoosquelle	limestones (Plattenkalk) talus material		NNE-striking fracture under debris	no microfractured areas	many small springs, obviously near surface water	
Egglbrunnquelle	limestones (Riffkalke)		WNW-striking fractures	widespread strongly microfractured parts in the cachtment area, massy HD in the proximity of the spring	two other small springs lateral to eggelbrunn, no further springs	
Mitterlugquelle	no extreneous units		N-striking morphological structure, direction not found in exposures	microfissures widespread in the cathment area, HD-detritus	no further springs but some diffuse run offs	spring not bound to the main joint set in the catchment area

Table 2. Classification of springs and wells by different approaches. The measuring points in Reit im Winkl, Wimmerbauernquelle and Mitterlugquelle are identified as dolomitic waters, whereas all other points show a significant influence of limestones. Brunnen Listwirt Bad Reichenhall and Brunnen Baderluck show the influence of gypsum.

Measuring point	Water type	Ca-Mg-ratio	Classfication by sulphate concentration	Classification by hydrochemical modelling
	(>20%)	(<=1,2)	sulphate > 10 mg/l	
Reit i. Winkl, ER1	Ca-Mg-HCO_3	Dolomitewater	free of sulphate	mature dolomite water
Reit i. Winkl, ER4	Ca-Mg-HCO_3	Dolomitewater	free of sulphate	mature dolomite water
Reit i. Winkl, Rabengschöss	Ca-Mg-HCO_3	Dolomitewater	free of sulphate	mature dolomite water
Bad Reichenhall, Listanger	Ca-Mg-HCO_3	mixed water	sulphate	mature mixed water
Bad Reichenhall, Listsee	Ca-Mg-HCO_3	mixed water	sulphate	mature mixed water
Bad Reichenhall, Listwirt	Ca-Mg-HCO_3-SO_4	mixed water	sulphate	mature mixed water
Tiefquelle Felbertal	Ca-Mg-HCO_3	mixed water	free of sulphate	undersaturated mixed water
Brunnen Baderluck	Ca-Mg-HCO_3-SO_4	mixed water	sulphate	undersaturated mixed water
Wimmerbauernquelle	Ca-Mg-HCO_3	Dolomitewater	free of sulphate	mature dolomite water
Mudlmoosquelle	Ca-Mg-HCO_3	mixed water	sulphate	undersaturated mixed water
Egglbrunnquelle	Ca-Mg-HCO_3	mixed water	free of sulphate	undersaturated mixed water
Mitterlugquelle	Ca-Mg-HCO_3	Dolomitewater	free of sulphate	mature dolomite water

Table 3. Basic results of groundwater dating considering geological and hydrochemical results of the study. The highest amount of young water (>10% younger than one year) and the lowest amount of old water (<1% older than 50 years) are found in those springs delivering unsaturated water. There is no significant difference in age distribution between dolomite and mixed water. Both mature water types show amounts of very young water (1 to 10% younger than one year) and of very old water (1 to 12% older than 50 years) except Wimmerbauernquelle which exhibits more than 75% old waters.

Measuring point	Geological units	Classfication by hydro-chemical modelling	Best fitting discharge modell	Calculated mean residence modell	Components young-er than one year	Components older than 50 years
				years	%	%
Reit i.Winkl Rabengschóss	Hauptdolomit	mature dolomite water	EM	10.5	9.1	0.9
B ad Reichenhall, Listanger	Hauptdolomit + Wettersteinkalk	mature mixed water	EPM(75%)	EM 11,PM15,5	6.5	5
Bad Reichenhall, Listsee	Hauptdolomit + Wettersteinkalk	mature mixed water	EPM(50%)	EM24, PM17,5	2	6.2
Bad Reichenhall, Listwirt	Hauptdolomit + Wettersteinkalk	mature mixed water	EPM(75%)	EM27, PM16	5.4	11.8
Tiefąuelle Felbertal	Hauptdolomit	undersaturated mixed water	EM	9	11.5	0.4
Brunnen Baderluck	Hauptdolomit	undersaturated mixed water	EM	7,5-10	13.5	0.1
Wimmerbauernquelle	Hauptdolomit	mature dolomite water	EPM(30%)	EM30, PM>100	1	75.7
Mudlmoosąuelle	Hauptdolomit, Dachsteinkalk, Platten-kalk	undersaturated mixed water	EPM(90%)	EM8,5, PM6	10	0.1
Egglbrunnquelle	Hauptdolomit, Kossen-er Schichten	undersaturated mixed water	EM	9-10	10	0.4
Mitterlugąuelle	Hauptdolomit	mature dolomite water	EM	10-14,5	9.5	5.7

EM = exponential modeli, PM = pistonflow modeli, EPM(75%)= combined modeli, 75% exponential component

To evaluate the influence of the mapped geological features on the aquifer behavior it must be seen in context of the discharge dynamics of the studied springs. Although the frequency of measurements and the observed time ranges differ strongly, the measured discharge variations can be used to characterize each aquifer. The measured values are shown in figure 2.

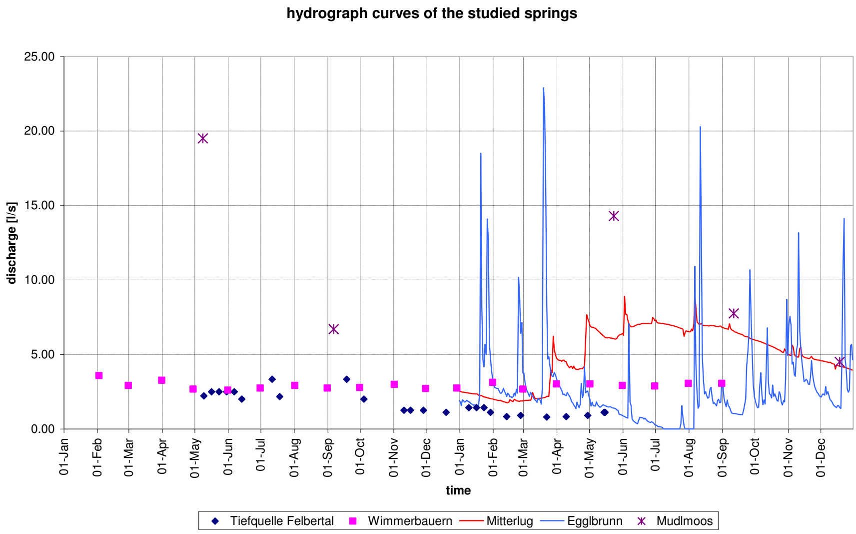


Figure 2. Discharge variations of some of the studied springs. Steady discharge in Wimmerbauernquelle, Tiefquelle Felbertal and Mitterlugquelle is significantly different from strong variations in discharge in Mudlmoosquelle and Egglbrunnquelle.

Comparing the discharge variations seen in the results of the field survey it is evident that the presence of karstified limestone in the catchment area significantly influences to flow behaviour of a spring. This is also the case if the main aquifer is dominated by little karstfied HD.

The relation between Ca–Mg-ratio and the saturation index of dolomite is shown in figure 3. Here three groups of water types can be defined: dolomite waters in equilibrium with the phases calcite and dolomite, saturated mixed waters and unsaturated mixed waters.

The different approaches to classify the investigated aquifers on the base of their hydrochemical settings are shown in table 2.

The table shows that pure dolomite waters are Ca-Mg-HCO_3-water type, free of sulphate (and other extraneous parameters) and saturated in dolomite.

To determine the mean residence times tritium concentrations were measured in the period of 2005 and 2006. Some older samples were available for the measurement points in Bad Reichenhall (Brunnen Listsee, Listanger and Listwirt) and for Mitterlugquelle. In combination with CFC and SF_6-data measured in Mitterlugquelle, Egglbrunnquelle and Brunnen Baderluck, the mean residence times of the waters were calculated by using the software MULTIS by Richter and Szymczak (1992). Regarding the hydrogeological situation and the hydrochemical classification of the measuring points the best fit between output function and measured values was calculated.

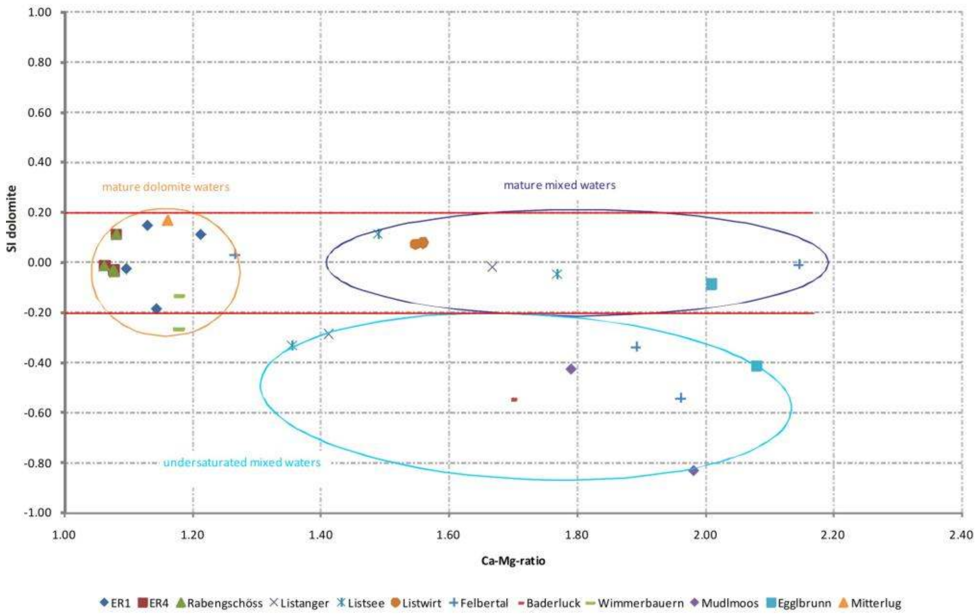
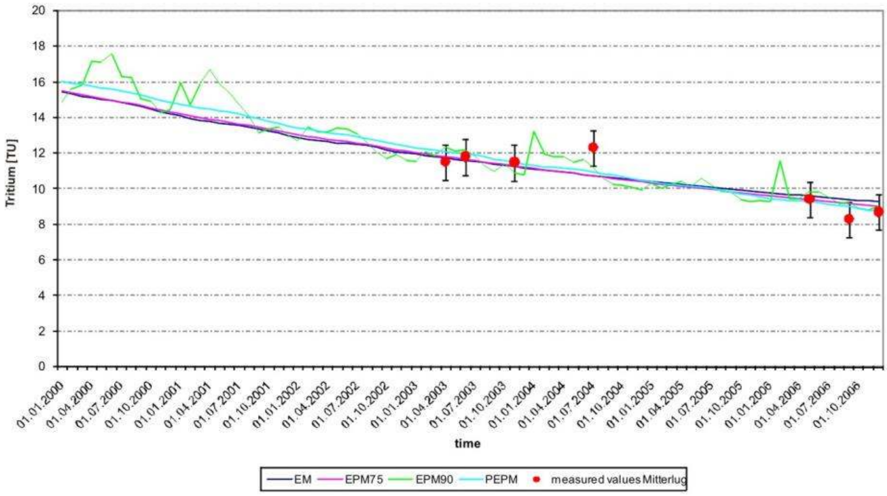


Figure 3. Ca-Mg ratio versus SI Dolomite. Three groups of waters can be defined considering Ca-Mg-ratio and saturation indices of dolomite. Mature dolomite waters show a Ca-Mg-ratio < 1.2 and are saturated in the dolomite phase. The influence of limestone in the range of the aquifer leads to a widespread group of mature mixed waters or unsaturated waters.

Generally the exponential model represents the situation in a dolomite aquifer as micro fracturing allows a perfect mixing in every part of the aquifer. Karstification in limestone dominated units as well as the lack of micro fractures in the dolomite-dominated sections lead to a partial conduit flow and a mixed discharge model with a more or less important participation of piston flow components.

For some of the measuring points the dating via tritium was verified by measuring the concentrations of CFC (Mitterlugquelle) or SF_6 (Tiefbrunnen Baderluck and Egglbrunnquelle). By means of the example Mitterlugquelle the approach is shown in figure 4.



Mean residence times after different calculation approaches [years]

tracer	Tritium		CFC11	
flow model	EM	PM	EM	PM
EM	10		14.5	
EPM75	16.5	65	5	29.5
EPM90	10	23	13.5	22
PEPM	14 (65%)	14	12 (99%)	12

EM exponential modell EMP75 exponential pistonflow modell (75% EM-portion)

EMP90 exponential pistonflow modell (90%EM-portion)

PEPM exponential pistonflow model (50% EM-Portion) combinated with a fixed pistonflow portion

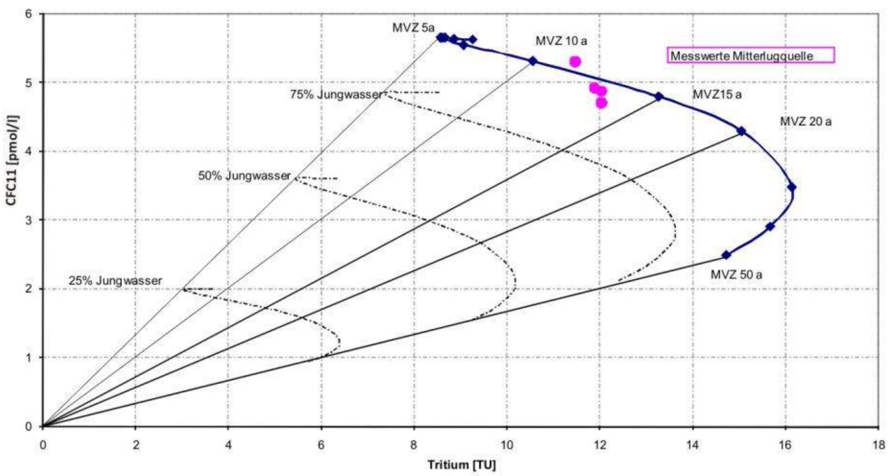


Figure 4. Groundwater dating by means of tritium and CFC-data measured in Mitterlugquelle. Top diagram shows the very few differences between the different output function. It is not possible to identify the current function only by comparing with the measured values. For finding the best fitting output function a second tracer (CFC11) was used. As shown in the figures middle part the best accordance is found in using the exponential flow model. The combination of tritium and CFC11 is shown in bottom diagram, according to BAUER et al. (2002).

CONCLUSIONS

Hydrogeological mapping in the different study areas showed that the expected typical micro fractured weathering structures are not developed consistently over the HD-dominated catchment areas. Of more importance is the presence of limestone units in the orographic catchment areas. Obviously karstified limestone units overlying the HD-formation impact the tendency for internal karstification of the HD-aquifer. In those cases HD-aquifer acts like a karst aquifer and looses the advantages of a typical double porosity medium considering the suitability for water supply.

The comparison of the hydrochemical composition of the samples generally supports the above statement as the classification by hydrochemical modelling leads to the three groups mature dolomite waters, mature mixed waters and unsaturated mixed waters. Conductivity obviously is not a significant parameter to identify HD-dominated waters.

Groundwater dating had the aim to find out if there are significant differences in age distribution between pure dolomite waters and limestone influenced aquifers. The assumption that pure dolomite aquifers show significantly longer mean residence times without any contingents of very young waters was associated with the advantage of smaller protection areas and fewer restrictions within these areas. It was shown that there is no significant difference in age distribution between pure dolomite waters and mature mixed waters. As the mean residence times differ between 10 and about 30 years the contingent of young components (< 1 year) varies between 2 and 9.5% while the contingent of old components (> 50 years) are in the range of 0.9 to 6.2% independent of the classification of the catchment area.

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IAH 2010
Krakow

abstract id: **201**

topic: **3**
Aquifer management

3.2
Transboundary aquifers

title: **Hydrogeological study of a Hungarian-Ukrainian transboundary aquifer**

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keywords: transboundary aquifer, groundwater management, regional scale groundwater modeling

In the framework of an EEA Norway grants project involving industrial and scientific partners, complex hydrogeological investigation and groundwater modeling of a regional transboundary aquifer between Hungary and Ukraine were carried out in 2009. This challenging cooperation work was completed by an EU country (Hungary) and a non-EU country (Ukraine). This pilot project demonstrated how the EU Water Framework Directive can be applied for a regional scale transboundary aquifer between Hungary and Ukraine. The transboundary aquifers play significant role in Hungary because the country land is mainly located in a deep and closed basin called Carpathian. 40 from the total 185 groundwater bodies are classified as transboundary in Hungary. The authors of this work were lucky to participate in an earlier NATO Science for Peace Project (Lenart et al., 2003), which investigated a transboundary aquifer between Hungary and Romania some years ago. The experience gained in that project (Dassargues et al., 2004) was utilized by the researchers to conduct the present complex hydrogeological study in a well-organized and efficient way.

In order to achieve the sustainable water management of the investigated internationally shared aquifer (Lenart et al., 2003), the main tasks of the present international project were: a) development of a common hydrogeological data-base; b) additional field measurements; c) interpretation of the geology for a common conceptual hydrogeological approach; d) creating the conceptual flow model of the investigated transboundary aquifer; e) regional scale groundwater modeling; f) model simulation of different scenarios for groundwater management purposes; g) review of the main results obtained from the transboundary approach in the view of the European Water Framework Directive. As one of the main output, a common regional groundwater flow numerical model has been built and calibrated on historical measured field data. It is already and will be in the future very useful for a possible joint management of groundwater resources between Hungary and Ukraine. The derived results allow a better evaluation of groundwater resources and a sustainable management of these resources.

The targeted aquifer, which extends on both sides of the Ukrainian-Hungarian border on 550 km^2 area (see Fig. 1.), supplies drinking water to a population of about 100000 inhabitants in Ukraine and in Hungary.

Figure 1. The area of the investigated transboundary aquifer between Hungary and Ukraine.

The project focused on improving the previous understanding of the groundwater conditions including flow and pollutant transport across many scales, using data acquisition techniques and computer simulation models. On the basis of analysis of the available data (Gogu et al., 2001), new campaigns of field measurements were carried out focusing on the following aspects: piezometric levels or hydraulic heads; pumping tests for hydrodynamic parameters. The priority was given to measurements in areas with low density of observation wells, in order to prepare ideally all the needed data allowing a reliable groundwater modeling.

One of the most important steps in the mathematical modeling was the choice of the conceptual model of the aquifer. By keeping the essential features of the system, a reasonable compromise between the complexity of the multi-layered aquifer and the available reliable data concerning the actual structure and hydrogeological parameters was proposed. The Hungarian and Ukrainian experts agreed on a conceptual model consisting of three Pleistocene aquifer layers. The groundwater flow simulations were carried out with the Processing MOFFLOW Pro program package. As a first step, a steady-state flow model reflecting average conditions were created and calibrated. The calibration results and the simulated heads (see Figure 2.) confirmed the reliability of the conceptual model and the accuracy of the flow model (Szucs et al., 2006).

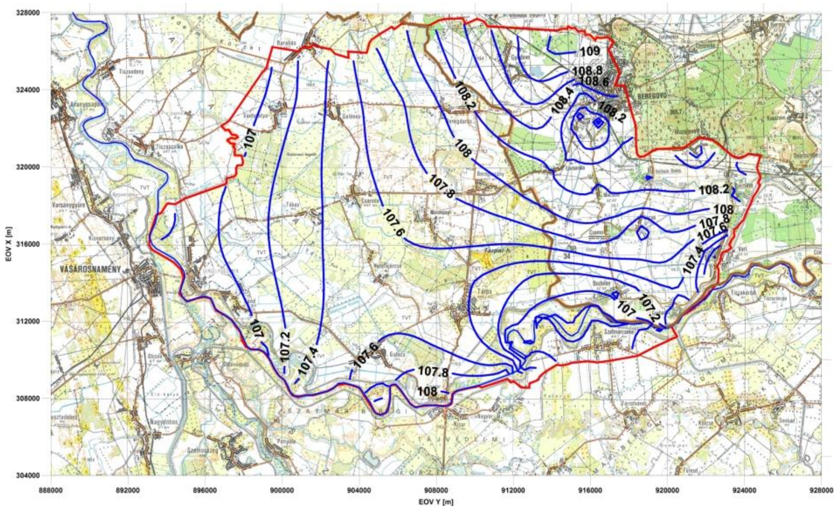

Figure 2. The calibrated hydraulic head map for the transboundary aquifer in case of the steady-state regional groundwater model.

The thickness of the Pleistocene transboundary aquifer is increasing from the Ukraine to Hungary (see Figure 3.). The total thickness of the targeted aquifer can exceed 130 m. A MODFLOW grid system was generated to simulate the hydrodynamic behavior of the groundwater flow systems. Then the boundary conditions were determined for the modeling activity using mainly natural geological and rivers conditions (see Figure 4.). The calibration results of the regional scale flow model were satisfactory. The RMSE value was 0.32 meter. As a next step, different future production scenarios were investigated. The expected future Ukrainian groundwater production increase is much more significant than the Hungarian one. As a result, groundwater level depressions are expected larger on Ukrainian side.

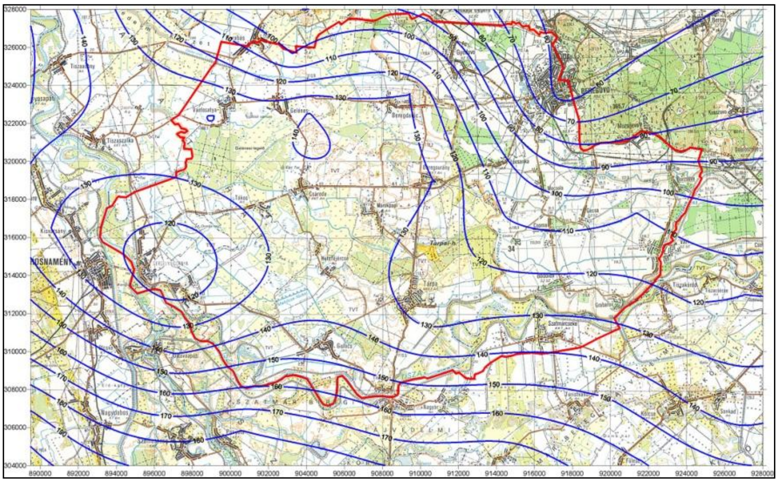

Figure 3. The thickness of the investigated Pleistocene aquifer between Hungary and Ukraine.

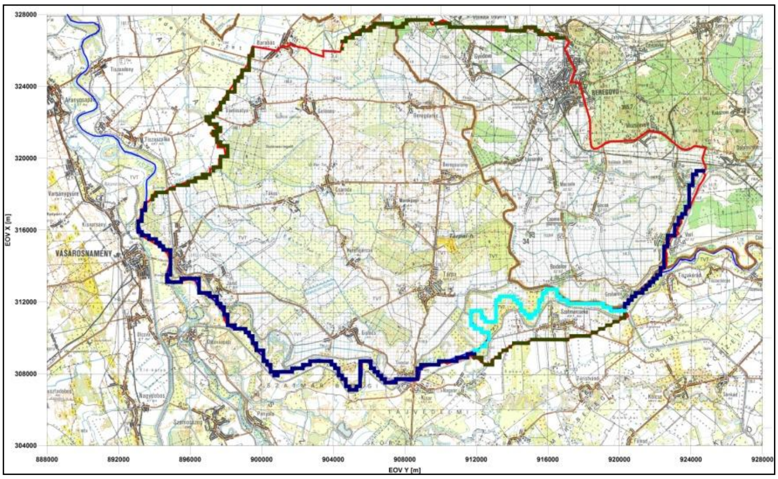

Figure 4. The grid system and the boundary conditions in the MODFLOW based flow model.

Figure 5. demonstrates that in some places the simulated shallow groundwater level decrease can exceed significantly the 0.5 meter. That means that harmful effects can occur in those areas if the given production scenario is realized. In order to avoid the harmful consequences, some future common measures between Hungary and Ukraine should be introduced.

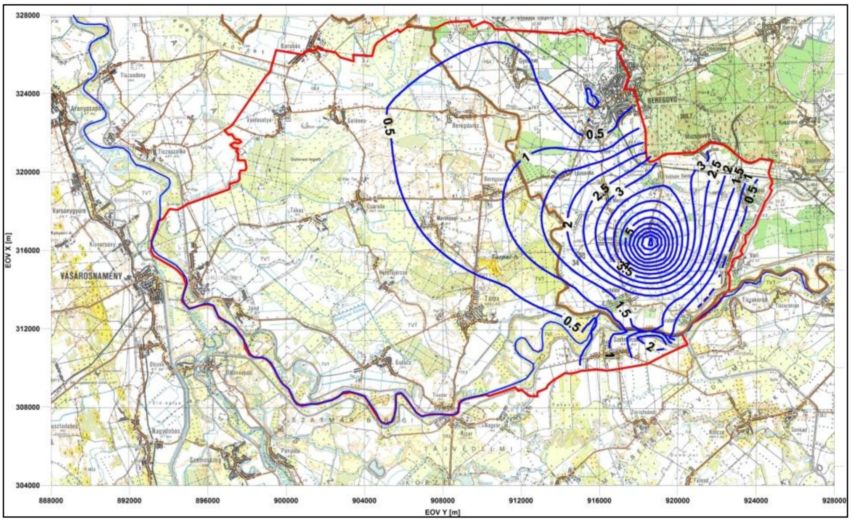

Figure 5. The expected shallow groundwater level decrease in case of a future production scenario.

The collaboration between the Hungarian and Ukrainian experts was outstanding. Some of the obtained results have already been involved into the water management policy of this transboundary region. The monitoring activity (see Figure 6.), the data exchange, and modeling activity will be continued in the future to get more detailed knowledge of the targeted internationally shared aquifer.

Figure 6. Field measurement will be continued in the future in the framework of the common monitoring activity.

ACKNOWLEDGMENTS

The collaborating Hungarian and Ukrainian partners gratefully acknowledge the EEA Norway grants for the support of this research. Special thanks to the end-users and field experts who provided a lot of help in order to finalize the project.

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abstract id: **235**

topic: **3**
Aquifer management

3.2
Transboundary aquifers

title: **Transboundary water resources management between Tunisia, Algeria and Libya Aquifer NWSAS**

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The North Western Sahara Aquifer System (NWSAS), shared by Algeria, Libya and Tunisia contains considerable water reserves, which are nevertheless lowly renewable and not fully exploitable. During the last thirty years, the exploitation of NWSAS waters by drilling increased from 0.6 to 2.5 billion m^3/an. Because of the non-concerted withdrawal multiplication, the resources is now confronting many risks such as water salinity, artesianism reduction, natural discharge depletion, piezometric level fall, or interferences between countries, thus seriously threatening the sustainability of socio-economic development in the entire zone.

In the face of such risks, a cooperation process between the three countries sharing the NWSAS water resources is crucial. This is the spirit of the NWSAS project facilitated and implemented by the Sahara and Sahel Observatory (OSS) in collaboration between the three countries. The joint work has focused its program on the scientific stakes in the first place, enabling a significant knowledge improvement of the aquifer system, based on information exchange and a joint definition of working hypotheses among the three countries. The simulations by the mathematical model built within such framework have highlighted the most vulnerable areas in the medium and long terms. They have also enabled identifying new withdrawal zones that could increase the current exploitation while ensuring risk control through a reinforced consultation among the three countries.

To this effect, the scientific cooperation is gradually leading to the establishment of a formal institutional framework for the management of shared water resources among the three countries, i.e. the consultation mechanism.

This paper presents the main obtained results from the implementation of the different components of the project: Hydrogeological data collection, analysis, and synthesis; elaboration of a common database and an information system; development and exploitation of the NWSAS mathematical model and the regional sub-models; establishment of a consultation mechanism for the basin joint management, socio-economic study; and environmental study.

abstract id: **304**

topic: **3**
Aquifer management

3.2
Transboundary aquifers

title: **Trans-boundary Groundwater Resources Management in the Azerbaijan Republic: looking for new ways for solving old problems**

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keywords: groundwater, transboundary rivers, hydrogeology, anthropogenic impact, sustainable development

Of the available annual average fresh water quantity of 367 billion m^3 in Azerbaijan, roughly 70% are the waters of transboundary rivers of Kura (Turkey and Georgia), Araz (Turkey, Armenia and Iran), Ganykh (Georgia), Saumur (Russia), and Astarachai (Iran). Most of fresh groundwater reserves are also in transboundary aquifers.

In the territories of Turkey and Iran environmental conditions of Kura and Araz Rivers are relatively better. The Kura River in the Georgian Varsiya-Akhalkalaki region and Araz River beginning from Gumru region of Armenia to Azerbaijan territory are polluted. Wastewaters in Armenia and 36–40% of Georgia are discharged in the Kura and Araz Rivers. There is no self-purification process in the rivers here. In connection with that physically, chemically and biologically altered and unsafe waters enter into Azerbaijan territory.

In the current situation, the groundwater play an important role in all fields of endeavor providing Azerbaijan Republic with sustainable development, because it is well known that the level of natural protection of the groundwater in the artesian basins is high. Though, the groundwater's contamination by surface waters from Armenia and Georgia in their hydraulic interaction areas is already registered.

Within the geologic-structural features of the Republic of Azerbajan, several groundwater basins (aquifers) were recognized: the Greater Caucasus basin, the Kura basin, and the Lesser Caucasus basin. Within these basins, sixteen sub-regions (corresponding to field survey of fresh groundwater) are identified based on the nature of the hydrogeological setting and the geologic-geomorphologic structure. From the 16 identified fields (aquifers) of fresh groundwater resources, seven of them are Transboundary Aquifer Resources — Nakhchivan (with Armenia, Iran, Turkey), Lesser Caucasian, Jebrail, Mil-Garabakh, Mugan-Salyan (with Iran), Alazan-Agrichai (with Georgia), and Gusar-Divichi (with Russia). Practically about 90% of the fresh groundwater of the Republic falls in the category of transboundary basins and potentially it can produce over 12 million cubic meters (m^3) per day. If we take into consideration that Gyanja-Gazakh (with Armenia), Mountain-Talysh, Lyankaran (with Iran), Ajinour-Jeiranchol (with Georgia) aquifers (fields) of fresh groundwater resources are Transboundary Aquifer Resources for Azerbaijan (i.e., despite the fact that the whole groundwater basin is situated within the Republic, the recharge areas are in other countries), one can readily surmise that 11 out of 16 groundwater basins are in need of individual consideration and assessment. The largest transboundary aquifers with fresh waters are Gyanja-Gazakh, Mil-Garabakh, Alazan-Agrachai and Gusar-Divichi. More than 80% of the existing reserves of fresh groundwater in Azerbaijan are confined to these basins.

Complex analyses of hydrogeological, geological and hydrological data using hydrodynamic, hydrochemical, probabilistic, statistical and water balance methods allow the creation of a conceptual model of the groundwater flow system, schematization of aquifer boundaries, estimation of basic hydrogeological parameters, and show strong interaction between the groundwater and surface waters. The obtained results provide a basis for creation of interactive mathematical models of groundwater movement for use in management and sustainable development. At the same time, to assess of the limits of anthropogenic impacts on the groundwater and the development of predict methods for the definition of possible detrimental impacts on the groundwater and other parts of the environment.

At a first glance it may seem that the problem associated with transboundary water resources is relatively new for Azerbaijan. This is because it is been only 18 years since Azerbaijan has gained independence. Although most of water basins that are transboundary now used to be within the State boundaries during the USSR era, there still existed transboundary water resources issues. This notion that these issues have appeared since the break up of the USSR is basically inaccurate point of view. There existed in the USSR internal boundaries between "autonomous" republics. Even then due to sever contamination of some water resources and the lack of plans for regional use of water resources of Kura and Araz rivers, their inflows from Georgia and Armenia was a great concern for Azerbaijan. With the disintegration of the former USSR and the emergence of the newly independent Commonwealth of Independent States (CIS) countries the issue of the shared water resources within the South Caucasus has attracted the attention of officials at many levels of the new governments as well as former neighboring countries of USSR. Off course, the practical and just solution of this problem requires a multidisciplinary approach that encompasses various expertise and disciplines such as scientific research, legal, socio-economic, institutional, ecological, international relations, etc.

Analysis of situation associated with the use and protection of transboundary water basins of Azerbaijan Republic (where in our view there are major issues to be resolved) can be of great interest and helpful to all parties concerned.

abstract id: **443**

topic: **3**
Aquifer management

3.2
Transboundary aquifers

title: **Sustainable use and protection of groundwater resources — transboundary water management — Belarus, Poland, Ukraine**

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keywords: transboundary river basins, groundwater management

Water is of profound importance for biodiversity and the protection of water resources prerequisite for environmental sustainability. The water protection is also a crucial aspect of human life and is, therefore, prime policy objective of the European Union. According to Frame Water Directive water is not a commercial product like any other but, rather, a heritage which must be protected, defended and treated as such. Water is also an element that takes little notice of political and administrative borders. The history of interest in issues of water management on transbondary scale is relatively new phenomena rise during the last few decades. These issues include globalization, the development of civil society and increased competition between economy sectors for limited natural resources. Water management in a transnational context is much more complex and multifaced than water management within one nation state. Transboundary waters are interwoven with landscape, with societies and culture, and with political systems. Water management in Poland is based on European Union policy. The concept of multi-level governance implies that there is a multilevel network of interactions between wide range of actors, such as state and sub-state, public and private, national, transnational and supernational, NGO's and others.

Integrated water management becomes a particularly complex challenge when two or more countries share a river and its drainage basin. The same situation we encounter on the territory of Bug river basin where tree riparian countries Belarus, Poland and Ukraine manage water system. The major challenge of the management of transboundary waters is that the waters must be manage in the contest of anarchy where is no single government to take control. In every riparian country there are different quality and quantity methods of research. In the past transnational groundwater research between Poland and its neighbors could not be freely carried on because of specific geopolitical condition in the period precedent political transformation in the region of Central Europe as well as establishing a partner relationship with eastern neighbors out of European Union structure. Up till now there is lack of international agreements between riparian countries regulating all the issues related to transboundary water management in the region.

Till now there have been some international projects aimed to cover that issue. Although most of the projects mainly manly emphasize the surface water management with little care of groundwater. Groundwater resources will be of increasing significance for the domestic economy in the future because surface waters - the main water source used by humans over ages - become progressively more contaminated. From the early 80ies in XX century the usage of groundwater in Poland is more or less stable (1 500 000 m^3/d). But because of rapid decrease observed in applying of surface waters nowadays almost 70% of man used water became form groundwater resources.

In 2006 the new Science for Peace and Security NATO Pilot Study project “Sustainable Use and protection of Groundwater Resources - Transboundary Water Management” has been launch. This project focuses on development of international cooperation on implementation of water quality assessment and water quality monitoring and assessment as important issues in relation to sustainable land management. It is also a scientific platform for expert form Belarus, Poland and Ukraine as well as from other countries to exchange ideas about water management with special emphasis to groundwater and its protection. The project initiates trilateral cooperation on monitoring, contamination migration and water management issues. The project consists following activities: an inventory information concerning water management and water-quality issues, current practices for monitoring and assessment, improvement of monitoring and assessment activities (information needs, strategy of monitoring surface water and groundwater as well as final recommendation). Abandonment of study of contamination migration and monitoring of groundwater can degrade the water dependent ecosystems as well as can cause a future problems with drinking water supply.

Nowadays when clean water is becoming increasingly valuable it is vital to develop methods of protecting groundwater resources and modelling the flow in the aspect of potential contamination of drinking water supply. Groundwater research is especially important in case of terrorism threats or military conflicts.

The main objectives of the project are:

- Exchange of ideas of water management at transnational aquifers;
- Building bridges for international cooperation for scientists;
- Presentation of the local groundwater systems monitoring in the transboundary area;
- Assessment of groundwater monitoring tests carried out in Belarus, Lithuania, Poland and Ukraine;
- Exchange of technical experience in the field of groundwater chemical analyses;
- Test different field methods of groundwater probation;
- Establish the best practice in groundwater research by creating common procedures;
- Identification of united method for transboundary groundwater monitoring;
- Create new projects ideas and support their implementation.

abstract id: **492**

topic: **3**
Aquifer management

3.2
Transboundary aquifers

title: **Transboundary aquifers in Russia**

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In recent years the problem of transboundary waters using has become rather actual in many countries. It concerns not only the interstate boundaries where the use of marginal or transboundary rivers (rivers crossing boundaries) in many cases is regulated by special international agreements. The agreements between Russia and China about the Amur River waters usage, the agreement between the Governments of Russia and Estonia about collaboration in the field of transboundary waters protection and regional use and other international agreements can be mentioned as the examples of it. "Convention on transboundary water streams and international lakes protection and use" accepted in Helsinki in 1992 is of great importance either. In the Convention the attention is paid to the necessity of unified principles development devoted to the interstate transboundary water objects protection and use including surface and ground waters on the basis of special agreements between countries.

The problem of transboundary water use regulation is rather acute also inside some countries (e.g. USA, Australia, Russia, India and others), where particular administrative regions (states, regions, federal divisions) have a constitutional independence and solve many problems of natural resources use independently, coordinating basic legislative acts only with neighboring countries or federal organs. Thus, for example, in Australia each state has special commissions on water resources, which give permissions for water use (including drilling of artesian water wells) and arrangement of research and designing works, definition of allowable water extraction limits for different state demands, and implement control over water quality and contamination levels by different components.

It should be noted that the problems of transboundary rivers use and protection can be solved easier than the problems of transboundary aquifers use. It is connected with the fact that the major countries have good observation networks controlling discharge and quality of river waters. Moreover, some countries have special hydrometric stations on their boundaries which are constantly measuring discharge and composition of river waters in an automatic mode. In such cases the quantity and quality of water to be kept for a neighboring country (or state) are regulated and controlled in accordance with existing special agreements. Many countries have a good experience in solving of this problem.

The matter is more difficult with the use of transboundary groundwater aquifers. As it is known, the groundwater resources unlike river waters cannot be measured directly; they can be only calculated. The methods of regional assessment both of replenished and non-replenished groundwater resources considerably differ from each other in many countries. At present, the experience of resources and quality estimation of transboundary aquifers, including firstly prospects and allowable limits estimation of their possible exploitation, is extremely limited, though such transboundary aquifers exist almost in all the countries (except island ones).

After Soviet Union disintegration the problem of transboundary aquifers studying has become rather acute for Russia as it has land boundaries with 13 sovereign countries (Zektser, 2007).

Without pointing out at the legal and juridical problems of transboundary groundwater use having the important individual value, we will consider only the primary goals of regional researches of transboundary aquifers.

Determination of prospects for groundwater use and withdrawal management is always connected with the problems of exploitation restrictions in accordance with different criteria. The latter may be both of inside and outside types (Mironova et al., 2006). The inside criteria include, above all, limitations of hydrogeological and hydrodynamical operation conditions, such as groundwater recharge rate in an annual and multi-year cross-section, tolerance dynamic level lowering throughout estimated period, risk of non-standard groundwater drawing up to a water intake from adjacent aquifers, variability of hydrogeological parameters of an exploited aquifer in plane and cross-section, and others. The outside criteria that can restrict the groundwater use are related to possible impacts of a planned water extraction upon different environmental components including river runoff, which is especially must be taken into account for aquifers of infiltration type in river valleys; suppression or death of vegetation due to excessive lowering of shallow groundwater level in the upper unconfined aquifer; activation of karst and suffusion processes; earth surface subsidence, etc. (Zektser, 2000; Yazvin, 1998).

The following basic problems of transboundary aquifers studying and use often tightly connected with each other can be distinguished:

- Quantitative assessment of natural and exploitable groundwater resources of boundary and transboundary aquifers. The method of such regional estimation is developed well enough. It is based chiefly on hydrodynamic calculations, including regional models of groundwater discharges and possible productivity of aquifers and large groundwater well fields;
- Determination of chemical, biological and radionuclide compositions of groundwater and an allowable level of its changes;
- Estimation of fresh groundwater vulnerability in transboundary aquifers to anthropogenic contamination penetrating from the earth's surface;
- Scientific and methodical substantiation of inter-country agreements on allowable limits of groundwater use from transboundary aquifers, including, firstly geoenvironmental aspects, allowable levels of groundwater extraction, a risk of aquifer contamination and depletion;
- Development of joint interstate monitoring of transboundary aquifers groundwater use and its protection.

On the border territory of Russia with the neighboring countries 13 regions (within on-land boundaries) are distinguished, where transboundary groundwater systems are spread. Some regions are subdivided into sub-regions, according to hydrogeological conditions. Brief description of these regions and sub-regions is given below.

Geofiltrational models of Russian and Estonian, and Russian and Ukrainian border regions have been developed in recent years in Russia to determine the prospects of transboundary aquifers use. Modelling results are shortly stated below.

RUSSIAN AND ESTONIAN BORDER

Russian and Estonian hydrogeologists teamwork resulted in integrated Russian-Estonian geofiltrational model of lomonosovskiy-voronkovskiy aquifer. The model was based on the analysis of available hydro-geological information on the Estonian Republic territories, the Leningrad and Pskov regions of Russia. Water containing formations of this aquifer are presented by quartz sandstones with interbedded clays with total thickness of 30 meters. The thick stratum of loptovskiy clays serves as their upper aquiclude and clays of upper Proterozoic appear as their bottom. This aquifer is subartesian with pressure value of near 100 m; water levels in wells are established at depths of 15–45 m. The aquifer is maintained in border regions of Russia and Estonia. Three possible variants of hydrodynamic situation development in Russian and Estonian border area have been considered in the regional model: They are the following: 1) the new water intake in Ivangorod with productivity of 3000 m3 per day is added to the already operating water intakes with existing productivity; 2) water withdrawal from all water intakes on the Russian territory, including the new one in Ivangorod, has increased twice, and Estonian water intakes yields remain constant; 3) Estonian water intakes yields are decreasing twice. As a result it has been determined that the groundwater overflow through Russian–Estonian border under the influence of water withdrawal is much lower than their natural discharge through it. Even double decrease in water withdrawal from this aquifer on the Estonian territory does not change the current hydrodynamic conditions. Only the high increase in water intake on Russian territories can change the hydrodynamic situation, up to the complete inversion of the natural flow.

Researches of Russian and Estonian transboundary aquifers, as outlined above, were the first and almost the only joint work of experts from neighboring countries on transboundary groundwater studying. These researches can be an example of the international cooperation on this challenge (Mironova et al., 2006).

RUSSIAN AND UKRAINIAN BORDER

The integrated base of cartographic and factual data for the general mathematical model of transboundary aquifers of Dneprovo-Donetsk artesian basin is created. The model covers the territory of 248×276 km, a grid step is 1 km. Northern part of model includes the Belgorod region of Russia, southern part comprises the Kharkov region of Ukraine. 4 aquifers and three relatively impermeable layers are considered vertically. The basic regional water intake is coincided with the second one which consists of maastriht-turonskiy and alb-senomanskiy aquifers.

On model living conditions the specifications of regional hydrodynamic flow existence for undisturbed filtration regime have been reproduced and hydro- and pezoizogips maps for 4 aquifers and a water exchange map between them have been constructed. Also the data on balance components have been obtained. Besides, graphic representation of groundwater flows for simulated aquifers concerning state borer is received.

To reproduce the disturbed filtration conditions all existing water intakes of the Belgorod region for the periods of 1970, 1980 and 1990 have been set with prolongation of ten-percentage increase in water withdrawal till 2009.

Maps of levels decrease in exploited aquifers and also tables of certain hydrodynamic balance components on calculated time steps are received.

On the basis of the analysis of structure of groundwater resistance indicators and their quality for transboundary aquifers of the Dnepr and Don river basins it is determined that the Dneprovsko-Donetskiy basin is characterized by an high resistance indicator, and the Donetsk basin has extremely low groundwater resistance indicator to anthropogenic impact (Belousova, 2005; Goldberg, 1987).

In conclusion, we should say that the constantly operating models are a reliable tool for forecasting of the practical groundwater use prospects, which meet the requirements of environmental protection limitations and prevention or minimization of damage to neighboring countries.

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abstract id: **498**

topic: **3**
Aquifer management

3.2
Transboundary aquifers

title: **Incorporating the quality dimension into the management of transboundary aquifers: determining the meeting point for International Law and Science**

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keywords: international law, aquifer quality management, groundwater dependent ecosystems, transboundary aquifer

After nearly five years of concerted effort by the hydrogeological community working with legal specialists, in December 2008, the UN General Assembly adopted a Resolution (A/RES/63/124) on the law of transboundary aquifers. The Annex to the Resolution includes Draft Articles, prepared by the UN International Law Commission, with the scientific support arranged by UNESCO's IHP, collaborating closely with the IAH TARM Commission. There is rather limited precedence in international law on the regulation of groundwater resources, and there are only a few water resources treaties that explicitly include aquifers. There are however several bi lateral treaties that address aquifers and their management, with the most striking one being the Haute Savois–Geneva Agreement that ensure that the aquifer is maintained replenished to provide a constant water resource. However the quality aspects of the agreement are a matter of interest in developing international regulations.

The Draft Articles of the UN ILC were conceived for the regulation of the "utilization of transboundary aquifers or aquifer systems" (article 1a). However, as an innovative approach they also include provisions, on the protection of the recharge and the discharge areas of aquifers (article 11), the prevention, reduction and control of pollution of water in the aquifer body (article 12) and the protection of the environment of the aquifers dependent ecosystems. Since the legal definition of an aquifer could not encompass the "recharge" and "discharge" areas, nor the dependent ecosystems these critical elements were addressed through the regulation of "other activities" that impact on transboundary aquifers or aquifer systems (article 1b). The challenge now facing the practitioners of ground water resource management is to take the provisions for the protection, preservation and management of transboundary aquifers and convert them into practice.

The paper will briefly outline the processes adopted in the development of the Draft Articles, the preparations of the global transboundary aquifers inventory and the work that is now required to promote the Draft Articles into a new international legal instrument. Such an instrument would prove to be of great value in the regions of the world where important transboundary aquifers are unregulated and Countries sharing the aquifers are seeking guidance.

abstract id: **534**

topic: **3**
Aquifer management

3.2
Transboundary aquifers

title: **TRANSENERGY – Transboundary Geothermal Energy Resources of Slovenia, Austria, Hungary and Slovakia**

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keywords: TRANSENERGY, Transboundary, Groundwater, Geothermal energy, Pannonian Basin

The aims of the "TRANSENERGY — Transboundary Geothermal Energy Resources of Slovenia, Austria, Hungary and Slovakia" project is to provide implementational tools for enhanced and sustainable use of geothermal resources. The project is carried out on a common geological, hydrogeological, hydrogeochemical and geothermal basis, ensured by the four national geological surveys (MÁFI, SGUDS, GBA, Geo-ZS) of the participating countries in the framework of the CEU Program Priority 3, Area of Intervention 3.1.: "Developing a high quality environment by managing and protecting natural resources". The project started in April 2010 and will run for 3 years.

A natural resource such as geothermal energy, whose main carrying medium is deep groundwater moving along regional flow paths, is strongly linked to geological structures that do not stop at state borders. Therefore only a cross border approach with the establishment of a joint, multi-national management system will be effective in handling the assessment of geothermal energy and defining the conditions for its sustainable use. The main goal of the project is to provide a user friendly web-based decision support tool (an interactive web portal) which is useful both for decision makers and stakeholders.

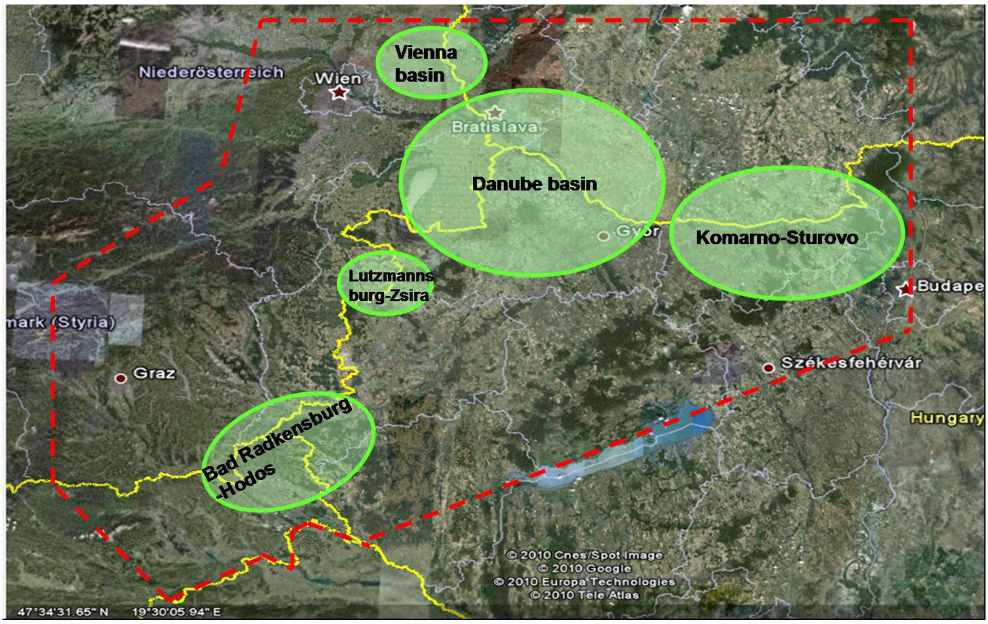

Figure 1. The project area.

The project area (Figure 1) is located in the western part of the Pannonian Basin, and includes five detailed, surveyed regions. The general "supra-regional" model area (red dashed line), includes the thermal karst of the Komarno-Sturovo area (HU-SK), the central depression of the Danube basin (A-SK-HU), the Lutzmannsburg – Zsira area (A-HU), the Vienna basin (SK-A) and the Bad Radkersburg – Hodoš area (A-SLO-HU) project areas.

The activities of the project are divided into the following six, well-defined work packages:

- WP1 — Project management and coordination (MÁFI),

- WP2 — Communication, knowledge management and dissemination (GBA),
- WP3 — Utilization aspects (Geo-ZS),
- WP4 — Transnational data management (SGUDS),
- WP5 — Cross-border geoscientific models (MÁFI),
- WP6 — Implementation tools for transboundary geothermal resource management (GBA).

The input for the implementation tools will be provided by the results of WP3, WP4 and WP5. The main tasks to be performed are the following:

- An evaluation of the results from the TRANSENERGY questionnaire for the actual (thermal water) users and authorities, screening of the utilization needs with special respect to national, EU and international legislation aspects (WP3);
- Collecting and harmonizing geoscientific data, performing additional groundwater sampling, chemical and isotopic analyses, geophysical measurements, and organizing all data in harmonized, multi-lingual shared databases (WP4);
- Producing a range of cross-border geoscientific models (geological, hydrogeological, geothermal) and performing scenario modelling for different extractions of geothermal heat/water (WP5).

In addition to the web-based decision planning tool, which is clearly a transnational tool development, the project will deliver a methodology for joint groundwater management, including utilization maps, summarizing the legal steps and actions towards a harmonized management strategy of transboundary geothermal resources, and a best practice on geothermal use.

This project is implemented through the CENTRAL EUROPE Programme co-financed by the ERDF.

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abstract id: **535**

topic: **3**
Aquifer management

3.2
Transboundary aquifers

title: **The monitoring system of the transboundary aquifer in the Polish-Czech zone of the intrasudetic basin**

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keywords: groundwater monitoring, transboundary aquifer, drinking water supply

The studied area is located in the catchment of the Ścinawka and Kudowski Potok rivers and covers major part of the intrasudetic basin, in the Czech-Polish transboundary region. The hydrological, hydrogeological and geophysical observations, including the drilling works, have been carried out since 1975. The research on the groundwater resources has been connected with the extensive groundwater exploitation in both Poland and Czech Republic (formerly Czechoslovakia). Currently the water circulation is strongly affected by the long term quarrying activities and groundwater exploitation for municipal and industrial purposes.

The main aim of the monitoring studies is to observe the hydrodynamic conditions and quality of surface- and groundwaters with special concern on drinking water supply and mineral waters. Before 2008 the monitoring was run by the Geological Enterprise "PROXIMA" S.A., and thereafter by the Polish Geological Institute – National Research Institute (PGI - NRI), Lower Silesian Branch in Wrocław. These Polish institutions always co-operated with several Czech counterparts.

The monitoring network consist of the basic network and the complementary network. The following parameters are monitored and measured: depth of the groundwater table, groundwater flow volume, water temperature as well as the basic physico-chemical properties of water. Since 2009 all the measurements at the monitoring points of the basic network are fully automatic. The newly installed automatic equipment includes: the KELLER logger DCX-22 with a compensator, digital manometers with record function LEO RECORD, float-operated shaft encoder with integral data logger (Thalimedes). At present the measurements of the groundwater table depth and temperature are taken with an interval of one hour.

The presented monitoring system is one of the most advanced in Poland, with a very long record of measurements and observations of groundwater. High quality of data results from the applied practice based on unification of measurements and assessment methods, homologation of measuring equipment and joint measurements.

The monitoring of the groundwaters in the studied area is required by the EU legislation. Up to now the monitoring programme continues and develops. All the results of investigations are discussed by the joint Czech – Polish expert group which meets twice a year. Every year two separate reports, one by the Polish Institutions and the second by the Czech ones, are produced and exchanged between the counterparts. The results clearly demonstrate the necessity of further joint hydrological and hydrogeological observations in the studied area. The challenge to this transboundary monitoring system is to achieve in the future a single network with a common database in order to build a single common groundwater model.

abstract id: **536**

topic: **3**
Aquifer management

3.2
Transboundary aquifers

title: **Groundwater chemistry, quality and man-made threats in the Polish part of the Nysa Łużycka catchment**

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keywords: groundwater chemistry, anthropopression, contamination, groundwater quality monitoring

The studied area covers the lower and middle part of the Nysa Łużycka catchment. The river is a boundary between Poland and Germany, while the catchment is located in three countries – two mentioned above and the Czech Republic. The poster shows only the results of the Polish part of the catchment. Two multiple layer aquifers were studied, namely Quaternary and Neogene ones. Each of them is constituted by two to three groundwater layers. Normally the most shallow aquifer, occurring in the sands and gravels at the depth of 0–40 metres, is not sufficiently isolated from the surface. The deeper aquifers are overlaid by the thick sediments of clay thus are less vulnerable to the man made threats originating from the land surface.

The major man-made threats identified in the studied area originate from the agricultural, industrial and urban sources. Some special type of influence is posed by the open cast lignite mining.

The groundwater chemistry was studied on 84 groundwater samples collected between 2001 and 2009 from the wells and piezometers. The groundwater samples were analysed by the Central Chemical Laboratory of the Polish Geological Institute – National Research Institute. The major chemical type of natural groundwaters for the Quaternary aquifer (n=60) was HCO_3^- – SO_4^{2-} – Ca^{2+}, while for the Neogene aquifer (n=24) two types were are nearly equally abundant: HCO_3^- – Ca^{2+} – Mg^{2+} and HCO_3^- – SO_4^{2-} – Ca^{2+}. Most of the analysed parameters, ions and elements do not exceed the maximum allowable concentrations (MAC), according to the Polish legal regulations. In case Fe^{2+} the concentrations above MAC value are rather common and refer nearly to the whole studied area. The high concentration of K^+ and Pb^{2+} occur only at some locations and are possibly connected with some anthropogenic influence.

3.3 Geophysical, geological and geochemical methods in groundwater exploration

abstract id: **110**

topic: **3**
Aquifer management

3.3
Geophysical, geological and geochemical methods in groundwater exploration

title: **The aquifer succession in the northwestern sector of the Calabrian Crystalline Basement (Southern Italy)**

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keywords: hydrogeology, aquifer succession, cristalline basement, Calabria, southern Italy

INTRODUCTION

The aim of this work is to reconstruct the aquifer succession in crystalline basement and in northwestern post-orogenic sedimentary sequences of *Calabria* (southeastern *Sila* and *Crati* river Basin). A hydrogeological study allowed the identification of the different aquifers existing in the area and the definition of their geometric characteristics and of the relationship between surface water and groundwater.

We have collected the hydrogeological and stratigraphical information recorded in the Italian Law N.464/84 Well National Database, available at the Geological Survey of Italy (Land Resources and Soil Protection Dept. of ISPRA). The data (e.g.: location, maximum depth of survey, aquifer succession, well mouth elevation) relative to hundreds of wells executed in *Cosenza* province, have been organized in a specific electronic format, geo-referenced and reported on topographical and geological maps at different scale.

GEOLOGICAL-STRUCTURAL SETTING

In the study area, transgressive Tertiary and Quaternary sediments (Miocene-Present) overlying Pre-Tortonian units of Calabrian-Peloritan Arc, extensively outcrop.

Calabrian-Peloritan Arc is considered a fragment of the Cretaceous-Paleogenic alpine belt, with European vergence, overthrusted, in the Lower Miocene, on the inner units of the forthcoming Neogenic Apennine belt, with African(*Adria*)vergence (Amodio et al., 1976).

Crati River Valley is an asymmetric half-graben, originated during Pleistocene extensional tectonic activity, with a N-S trend in the southern part and SW-NE trend in the northern part (Lanzafame & Tortorici, 1981; Ghisetti & Vezzani, 1983; Tortorici et al., 1995).

The geological succession of the study area can be summarized (Tansi et al., 2005), from bottom to top (Figure 1), as follows:

- Acid intrusive complex (Paleozoic): they are composed of quartzdiorite, quartzmonzonite, granite and granodiorite rocks. Often, granitic outcrops are intruded into metamorphic rocks.
- Biotite and garnet-biotite gneisses and schists (Paleozoic): gneisses and biotitic schists, frequently with garnet, are the prevalent lithotypes. Granitic and pegmatitic veins and masses are also included within metamorphic rocks.
- Calabrian marine deposits (Tortonian to Calabrian): they consist of sands and sandstones, sands and clays, and sands and conglomerates with gravel intercalations. In the upper part of the Miocenic series, a thin limestone, rich in algae, occurs. The deposition of these sediments was almost undisturbed by tectonic movements, with the only exception during the regional uplift phase. Often, they lean directly on metamorphic rocks.
- Post-Calabrian deposits: they are composed of conglomerates, pebbly sands and sands, deposited on surfaces which eroded older formations representing remnants of ancient marine terraces. Finally, from Holocene, alluvial sediments have filled up the Crati depression. Sometimes colluvial and eluvial deposits occur.

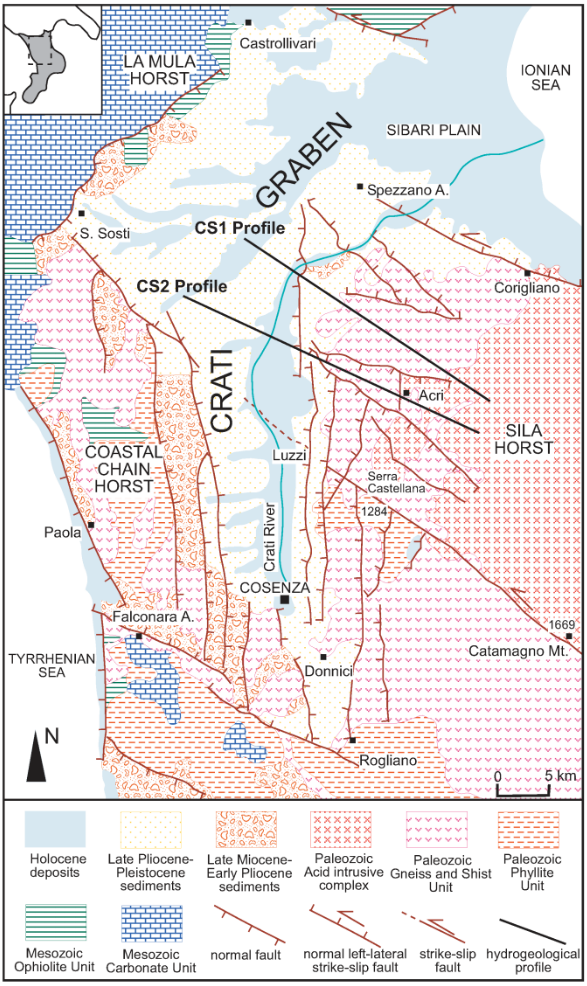

Figure 1. Lithostratigraphic and neotectonic sketch map of northern Calabria (modified after Tansi et al., 2005). The NW-SE trending black lines represent the traces of the provided hydrogeological profiles (CS1 and CS2).

The base of the post-orogenic succession is transgressive (Tortonian) on units of Calabrian-Peloritan Arc. Calabrian sedimentation is related to a subsidence phase of the Crati basin, which began in late Pleistocene and led to the ingression of the Pliocenic Sea on the present Crati valley. The Calabrian cycle ends with a regressive phase, coincident with a general uplift of Calabria region, leading to the emergence of the Crati basin and to the formation of large marine terraces.

HYDROGEOLOGICAL SETTING

This work represents a contribution to the reconstruction of the hydrogeological features of the study area. In this area, in fact, there is not an exhaustive groundwater flow characterization and the hydrodynamic properties of the aquifer are not well defined.

The study area falls into a Mediterranean climate zone (warm and dry summers; cold and rainy winters). Data coming from the thermo-pluviometric station at *Torano Scalo* show that mean annual temperatures (1960–1990 period) average 15.9°C, with the maximum value in July (25.3°C) and the minimum in January (8.6°C). Precipitations (1921-1990 period) are mainly (60%) concentrated from November through February; mean total annual precipitation is 838 mm, with the maximum monthly cumulative value in December (126 mm) and minimum in July (9 mm).

In the final part of Crati valley, once marshy and malarial, there is an artificial reservoir, obtained through the damming of the Crati River (ARSSA, 1996). Crati River, with its tributaries, is the most important river system of the area and flows initially in the northward direction, then in northeastward direction and finally flows into Ionian Sea.

Analysis of piezometric surface carried out in the study area (Celico et al., 2005) allowed to recognize, at large scale in high and middle Crati valley, the presence of a preferential groundwater drainage axis matching the paleo-bed of the Crati River (*Cassa per il Mezzogiorno*, 1977). In the inner part of Crati River Valley (Sibari Plain), the trend of isopiezometric lines and the flow directions allows to evidence the presence of substantial water contributions from carbonate reliefs, in north-western sector, through the Castrovillari Plain; while, in the hydrographical right, a preferential drainage axis directed towards the coast is evident.

On the basis of sedimentological and permeability features (Celico et al., 2005), we can recognize the following hydrological complexes:

- Igneous complex: it consists of Palaeozoic acid intrusive rocks, as granites. Aquifers are often discontinuous. The dimensions and the hydraulic potential of these groundwater bodies vary with the presence of open fractures; generally, permeability decreases with depth, both for the reduction of rock weathering blanket and for the closure of fractures, due to the increase of lithostatic load and/or filling. Permeability degree: medium-low.
- Metamorphic complex: it consists of rocks with different metamorphic grade, such as gneisses and schists. Hydrogeological characteristics are similar to those of the previous complex, even if in this case the weathering blanket is not present. Permeability degree: medium-low.
- Plio-Quaternary marine deposits:
    - Conglomeratic-sandy complex: it consists of clastic deposits, incoherent or poorly cemented and regressive (Lower Pleistocene). They have a good transmissivity, but, due to the fragmentation of groundwater flow, they have a less hydrogeological potentiality. Permeability degree: medium-low.
    - Clayey complex: it consists of transgressive marine deposits (Upper Pliocene-Lower Pleistocene). They represent a permeability boundary for the sandy-conglomeratic complex, which they are underlain to. Permeability degree: impermeable.
- Quaternary complex: it consists of clastic deposits, generally incoherent, with variable granulometry, predominantly sandy. The occurring aquifers are porous, heterogeneous and anisotropic; they host groundwater bodies, locally hydraulically independent but glob-

ally with unitary flow, which can have interactions with surface water bodies and/or be fed by neighbouring hydrogeological structures. Permeability degree: medium-high.

These complexes, then, show variable degree of permeability also within the same formation, depending on several factors including: fracturing degree, for rocks whose permeability has a secondary origin; structure, texture and mineralogical composition of grains, etc., for rocks having a primary permeability. Groundwater flow is very articulated, depending from the extreme heterogeneity of these deposits. Locally, groundwater circulation occurs in multilayer systems.

AQUIFER SUCCESSION

To define the hydrogeological features of the study area, two hydrogeological profiles, with NW-SE trend (Figure 1) were constructed using GIS software. To perform the stratigraphic profiles, we have conducted, at first, a bibliographic study with the aim to acquire an exhaustive picture about the depositional sequences of the investigated area (Cortese, Viola, 1900; Lanzafame et al. 1975; Cassa per il Mezzogiorno, 1967-1972). These data were properly integrated with the stratigraphic information of wells. Aquifer features derives from different sources; isopotential levels, position and number of aquifers have been taken from the Well National Database, while punctual and linear sources represented on the sections, have been taken from geological and topographic maps. Finally, to define the pattern of the regional aquifer, reference is made to Celico et al. (2005).

Two stratigraphic and hydrogeological profiles (Figure 2) were performed to define geometric relationships among geological formations and, where it was possible, among the crystalline basement and sedimentary sequences of the Crati River Valley.

In the Crati Valley, through hydrogeological and stratigraphic data, we have identified a series of small suspended and overlapped groundwater bodies, probably defining a multilayer aquifer; these groundwaters are hosted in gravel and sand levels and have a thickness of 5-10 meters. The dimensions and the hydraulic potentiality of these groundwater bodies vary with the not well-known horizontal extension of the layers in which they are stored, but probably they have a moderate potentiality, due to their low permeability. The blue clay formation generally represents the *aquiclude* level (Figure 2) of the sequences. The Crati River Valley aquifers are located below the riverbed, and therefore, presumably, the streamwater feeds the groundwater; this represents a potential contamination risk for this groundwater by the streamwater. Thus, for a correct water management and environmental protection, more analysis and verification must be properly carried on to evaluate the actual contamination risk.

In the hydrographical right of Crati River (CS1 Profile), the groundwater of multilayer aquifer has a more discontinuous trend. However, on the basis of the available data, it can be assumed that the aquifer is rather continuous, despite the presence of less permeable layers, which locally act as *aquitard* and sometime as *aquiclude*.

At greater depths (50 m in CS1 Profile and 100 m in CS2 Profile), it is noted the presence of a considerable aquifer of possible regional importance, hosted in light-brown sands and sandstones, separated from overlying layers by Plio-Pleistocenic clays (Figure 2).

On the other hand, the Crystalline Basement hosts a basal aquifer with a good lateral continuity and variable thickness (from 50 m to 100 m, Figure 2), even if, also due to the heterogeneity of these rocks, local groundwater circulation is very articulated. It is probable that a groundwater to streamwater exchange system is active among the water bodies of crystalline basement and those occurring in the Crati alluvial deposits. These *drainance* processes among them would improve the hydrochemical quality, contributing to dilution of potential contaminants in the alluvial aquifers.

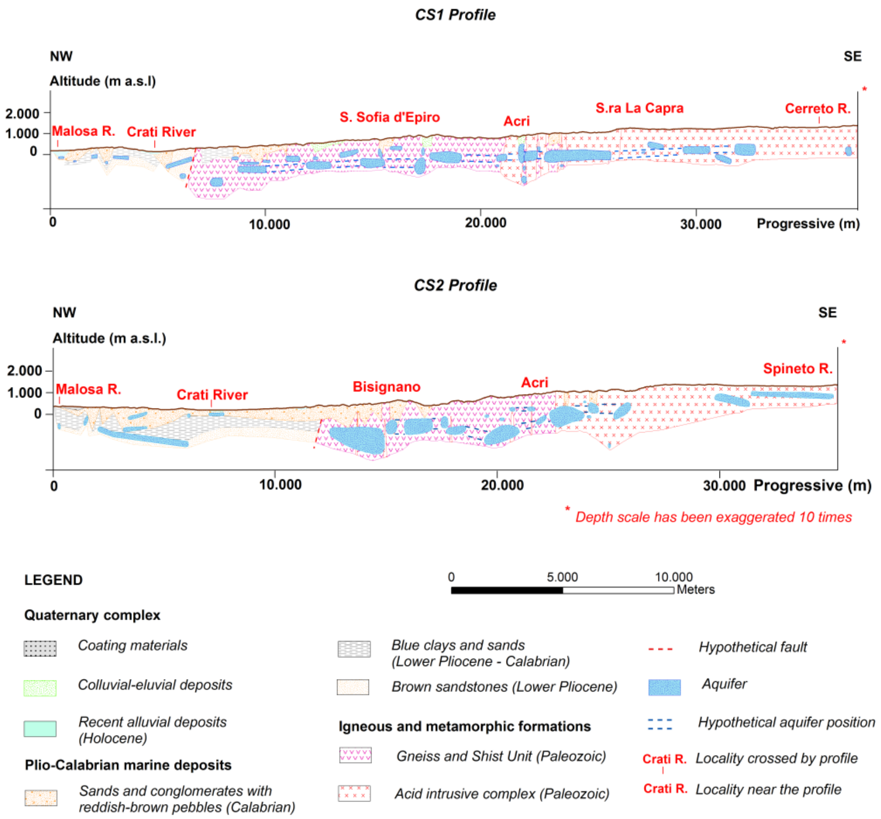

Figure 2. Hydrogeological profiles.

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abstract id: **111**

topic: **3**
Aquifer management

3.3
Geophysical, geological and geochemical methods in groundwater exploration

title: **An integrated approach of hydrogeological, geophysical and seawat modeling studies for delianating the salinity sources in central Godavari delta, A.P., India**

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keywords: hydrochemical, ionic ratio’s, resistivity imaging, SEAWAT

Oil production from 5 wells in Ravva oil field on Bay of Bengal coast in Godavari Delta has been continuing since 1991. For maintaining constant pumping rate of oil from production wells, brackish water has to be injected into the oil wells continuously. The oil company has drilled 8 tube wells inside Ravva onshore Terminal on the Bay of Bengal coast for withdrawing groundwater ~ 600 m^3/hr. The 5 bore wells in continuous operation since 1991. The large quantity of groundwater pumping has caused a cone of depression around Ravva onshore terminal. Ravva onshore terminal groundwater study covers about 250 sq km. Groundwater monitoring as well as water quality analyses have been carried out for Pre-monsoon and post-monsoon 2006 & 2007 and pre monsoon of 2008 and groundwater quality database has been generated to analyze conditions if any favorable for sea water intrusion. Delineation of aquifer geometry and high salinity areas up to 50 m depth has been carried out using Multi-electrode resistivity imaging tomography surveys. Available lithologs of pumping wells inside the Ravva onshore terminal indicate that the top layers are mainly consisted of fine sand with marine clay in the alluvium. The wells have been constructed tapping the aquifer at depths < –70 m up to –140 m (a.s.l.) to tap the highly brackish water with salt concentration > 25 000 mg/l.

Detailed hydrochemical analysis from 47 samples collected around Ravva Onshore Terminal, Central Godavari Delta, has been carried out to assess the groundwater quality for determining the seawater encroachment. The ratios of ionic concentrations with regard to Na/Cl, SO_4/Cl, Mg/Ca, Na/(Na+Cl), Cl/sum of anions, and Cl/Br ratios have been computed from groundwater quality database to identify the regions, where salinewater intrusion could be possible in the area. All the analyses have indicated that the salinewater intrusion is due to upconing of insitu salinity of groundwater in the marine clays rather than lateral movement of saline water from Bay of Bengal. The upconing phenomenon is limited to the area around the Ravva onshore terminal only. Predominant groundwater types identified in the area are Na–Cl type around Ravva onshore terminal and Na–Cl–HCO_3 type adjacent to it and Sodium, Calcium and Magnesium Type in the rest of the area. The groundwater quality data plotted on Piper and Wilcox diagrams indicate that Sodium and Salinity hazards are very high in the area. Groundwater level monitoring has been carried out for establishing the groundwater flow direction in the study area describes predominate groundwater flow direction towards the Bay of Bengal. SEAWAT model computed salt concentrations have not indicated any possibility of sea water intrusion from Bay of Bengal. Actually the groundwater pumping from Ravva Onshore Terminal is helping reducing in situ salinity of groundwater derived from marine clays in the area.

abstract id: **142**

topic: **3**
Aquifer management

3.3
Geophysical, geological and geochemical methods in groundwater exploration

title: **Magnetic resonance sounding technique**

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keywords: magnetic resonance sounding, nuclear magnetic resonance (NMR), wavelet analysis

The Magnetic Resonance Sounding (MRS) technique is a sounding (i.e. depth discriminating) surface geophysical method. In contrast to most other geophysical techniques, the MRS technique is based on two nuclear constants: the $^1H^+$ gyromagnetic ratio (γ), which provides MRS with its selectivity for water, and the nuclear magnetisation of the water molecule, M_0, which provides MRS with its absolute quantification of water content. The NMR signal is dependent not only on the in-situ groundwater content and its depth, but also on the strength of the earth's spatially dependent magnetic field, whereas the noise is related to lightning and/or artificial man-made noise sources i.e. electrical power lines etc. The evaluation of the potential use of MRS in direct detection of groundwater contamination and in tracer imaging, based on the literature study of NMR hydrocarbon detection and tracer imaging in laboratory conditions indicates that the MRS technique similar to NMR applications, is restricted to the substances containing hydrogen and that the implications of the field scale of the MRS experiment and heterogeneity involved make it additionally challenging. The main advantage of MRS as compared to other classical geophysical methods is that it is water selective, which means that an excitation is at the specific hydrogen nuclei resonance precession frequency so the response is unique for water (e.g. groundwater). The most important limitations are related to MRS investigations in electrically conductive environments, in environments with low S/N (Signal to Noise) ratio and in areas with inhomogeneous magnetic field. In electrically conductive environments, an inversion is distorted by attenuation of a signal by conductive layers. The main advantage of the MRS method as compared to other geophysical methods is in its water selectivity. MRS detects free water content, which combines retained water and gravitational water. Currently with MRS it is not possible to differentiate these two water types. Field experiments indicate that MRS is not appropriate for groundwater salinity detection. Applications of MRS: Aquifer parameterization, Water content interpretation, Hydraulic conductivity and transmissivity by decay time constant , Volumetric data integration**,** Well siting, Water in unsaturated zone and groundwater recharge, Aquifer geometry: MRS provides free water content and an estimate of permeability with depth. Therefore it can be used for evaluation of the aquifer geometry i.e. the detection of unconfined groundwater table depth and layer boundaries (tops and bottoms) both called hydrostratigraphic boundaries and in the future for evaluation of various 2D and 3D hydrogeological features.

NMR Principle: The MRS technique is a specific application of NMR to groundwater investigations conducted from the Earth's surface. In nuclear magnetic resonance (NMR), nuclear refers to the fact that the phenomenon occurs at the nucleus level of atoms (major constituents of nuclei are neutrons and protons). Magnetic refers to a field similar to the Earth's magnetic field, except that the NMR magnetic field originates from the nuclei rather than the electrons. Resonance refers to the excitation/detection mode, which occurs at specific Larmor frequency. NMR can be observed only on specific isotopes of some elements, e.g. hydrogen, carbon, phosphorus, etc., with a net nuclear angular momentum and a magnetic quantum number. Such a nucleus has a weak nuclear magnetic moment (similar to a tiny magnet), which, at steady state and on average, is aligned with the local (static) magnetic field. It has also a weak spin angular momentum. If such averaged magnetic moment is put into any other orientation by a momentary external excitation, it will precess around the local magnetic field orientation at the Larmor precession frequency, in a way very similar to the precession of a spinning top when its axis is misaligned with respect to the gravity field. The hydrogen (1H) nucleus is made of a single proton, and hydrogen nuclei ($^1H^+$) occur as one of the major constituents of the water molecule. The excitation field (B_{exc}) is used to displace the average nuclear magnetic moment from the direction of the ambient magnetic field. This excitation is usually done by energizing the volume to be investigated with an alternating (AC) magnetic field oscillating at the Larmor frequency (resonance) and oriented perpendicular to the ambient (static) magnetic field. Each isotope with a spin has a specific gyromagnetic ratio γ (with $\gamma=\mu/Lp$). For hydrogen, m is the $^1H^+$ magnetic moment (1.4×10^{-26} J/T) and L_p is its spin angular momentum (5.3×10^{-35} J s). The Larmor frequency f_l (in Hz) is (Slichter, 1996) $f_l=\gamma.B/2\pi$ where B is the static magnetic field (in T). During an NMR measurement, which is performed at a specific Larmor frequency, only nuclei with a γ corresponding to the excitation frequency are precessing. After the excitation, the precessing nuclei will return to their steady state orientation at a rate determined by various 'relaxation factors'. Important developments have also been made in the field of hydrocarbon resources exploration and quantification through advances in petrophysics and in NMR borehole logging tools, which provide direct determination of porosity, pore-size distribution and pore fluid content. In all these NMR applications, the applied static magnetic field is much larger than the Earth's magnetic field because the nuclear magnetic moment is very small and the resulting NMR signal is also very small, but proportional to the square of the static magnetic field (B^2). In practice, therefore, NMR instrument designers include the highest performance (electro)magnet in their NMR systems.

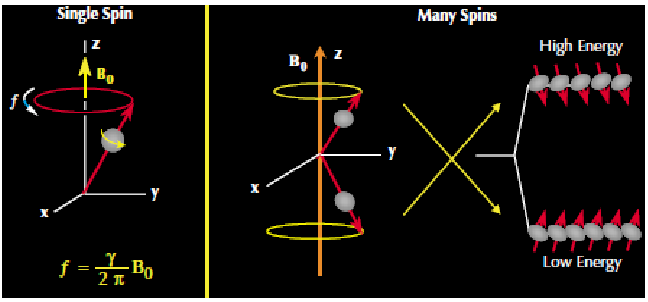

Figure 1. In an external magnetic field (left), the precessional frequency of a nucleus depends on the gyromagnetic ratio of the nucleus and the strength of the external field. The alignment of the precessional axis of the nucleus with respect to the direction of the external field (right) determines the energy state of the nucleus.

WT a useful microscope to study signals in many areas. In spectrum data processing, WT can be used in noise-data filtering, data compressing, baseline correction, peaks detection and discrimination. characteristics of Nuclear Magnetic Resonance (NMR) spectrum, how to process NMR spectrum with WT, and advantage of adopting WT to filter noise data and detect the peaks in NMR spectrum processing. Resolution of the NMR Spectrum Using Wavelet Transform: For resolution of an overlapping nuclear magnetic resonance (NMR) spectrum using the wavelet transform (WT) is applied. An NMR spectrum can be decomposed in a series of localized contributions(details & approximations) at different resolution levels, which represent the spectral information at different resolution. With the amplification of the contributions of fine resolution level and then reconstruction (inverse transform), the resolution of reconstructed NMR spectrum will increase. Therefore the resolved spectrum can be obtained from a low resolution spectrum or an overlapping spectrum. Wavelet analysis is employed for geophysical well logging signals due to its nonstatinary character. Method: Jean P Morlet (French geophysicist pioneer) first generation wavelet analysis-High resolution; Second generation wavelet transform

(SGWT)/lifting scheme –super resolution; third generation wavelet a Complex Finite Ridgelet Transform (CFRIT), to achieve the forensic dissection, morphological features from micro/nano scalar of surface topographic data. Complex Wavelet Transform is used to rectify & pacify limitations; shift sensitivity, poor directionality, and absence of phase information.

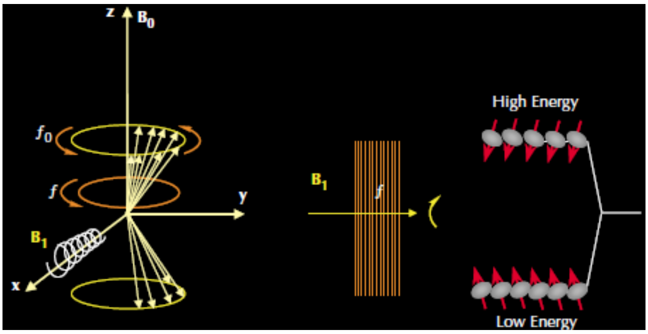

Figure 2. For effective interaction with protons (left), the oscillating magnetic field must have a substantial component perpendicular to the static field B_0 and must have frequency f equal to the proton's Larmor frequency f_l in the static field. In this case (right), the protons will precess in phase with one another and may absorb energy from the oscillating field and change to the high-energy state. Nuclear magnetic resonance thus occurs.

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abstract id: **146**

topic: **3**
Aquifer management

3.3
Geophysical, geological and geochemical methods in groundwater exploration

title: **Evaluation of groundwater occurrence of Metropolitan Lagos, southwestern Nigeria**

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keywords: Metopolitan Lagos, geophysical, geological, groundwater potential, geochemical data

INTRODUCTION

Lagos is the industrial and commercial nerve center of Nigeria and home to over 70% of the industrial and commercial activities in the country. Metropolitan Lagos covers an area of approximately 3,577 km^2 in the southwestern corner of Nigeria, with its landmass lying between longitudes 2°42’ E, west of Badagry and 4°22’ E east of Ode-Omi and latitudes 6° 22’ N along the Bight of Benin Coastline and 6°41’ N (Fig. 1) Owing to inadequate supply of pipe-borne water from the water corporation, inhabitants and industries have resorted to devising means for private water supply system by sinking of boreholes and hand-dug wells. The sinking of these boreholes and had dug wells is done without any form of control or monitoring with huge volume of water extracted on a daily basis from these aquifers without any record. This work highlights the groundwater potential of the metropolis using geophysical and geochemical and geological data.

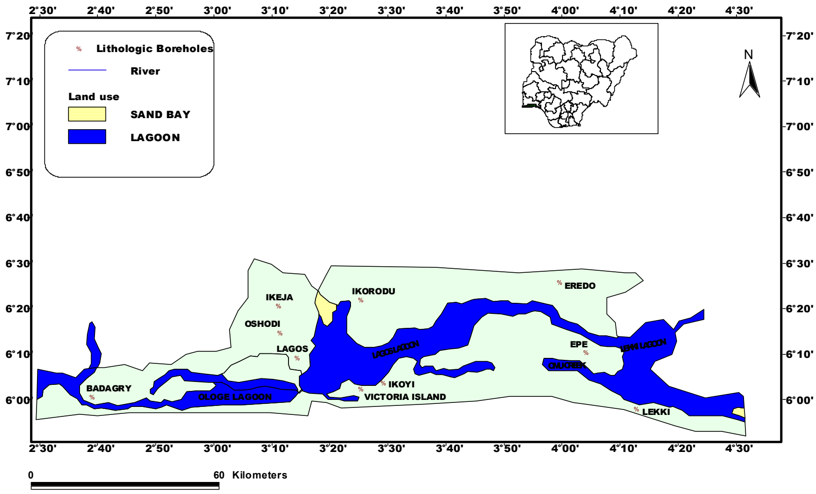

Figure 1. Location map of study area.

GEOLOGY OF LAGOS

Regionally, Lagos Metropolis is underlain by the rocks of the eastern Dahomey basin (Fig. 2).

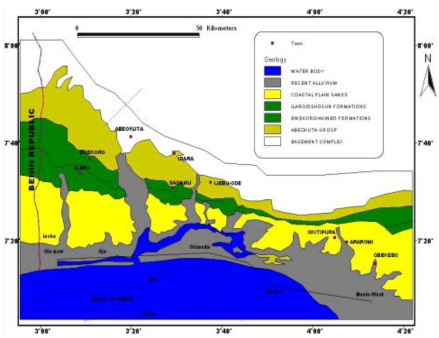

Figure 2. Geological map of Eastern Dahomey Basin (modified after Agagu, 1985).

The geology of the Lagos area is dominated by a continuous and monotonous repetition of clayey and sandy horizons. These horizons show some discernable lateral continuation and are made up of successions of sandy-clay, sands, clayey sands and gravely sands sequences. The sandy layers which are fine silty-sands to very coarse gravely sands range from reddish-brown to pinkish in colour while the clay units vary from whitish through pinkish, reddish to brown and dark–brown in colour. The sands and clay sequences are intercalated with isolated and sometimes discontinuous bands of dark-brown to black peat and lignite. An east-west traverse along the coastline from the Badagry end to Akodo showed that sands are found at the top of the section in all the boreholes along the coastline (Figs 3a &3b).

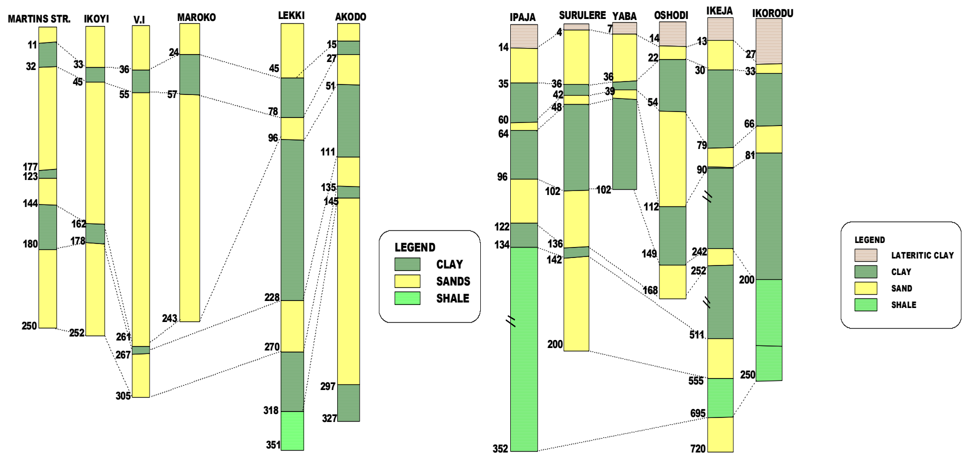

Figure 3. Stratigraphic sequence: a) from Martins Street to Akodo (E-W); b) from Ipaja to Ikorodu (E-W).

HYDROGEOLOGY, HYDROGEOPHYSICS AND HYDROGEOCHEMISTRY OF LAGOS

Borehole data revealed that most of the domestic boreholes and hand-dug wells have depths ranging from 20m to 60m while industries and the water corporation have boreholes with depths ranging from 100m to 300m with some having a depth of 700m (Olatunji, 2006). Geophysical results obtained from the metropolis revealed a plethora of apparent resistivity curves. These include the Q, K, QH, QQHA, KQHA, HKQQ, QQQ, HKQHK, HAKHK, HQKHK, KHKQK and the KHKHA types depending on the depth of penetration of the soundings. However the multi-layered curves are more dominant an indication of the chaotic depositional sequences that were responsible for the lithology. Groundwater chemistry revealed that the water samples are generally potable in terms of water quality except for some of the shallow boreholes that have been impacted by surface run-offs, saline water influence from the lagoons as well as iron contamination. The water types in the area are mainly Na–HCO_3 and Ca–(Na)–HCO_3water types (Olatunji et al., 2005; Tijani et al., 2005).

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abstract id: **187**

topic: **3**
Aquifer management

3.3
Geophysical, geological and geochemical methods in groundwater exploration

title: **Salt accumulation and groundwater recharge on granite slopes in Southeastern Australia**

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keywords: recharge, stable isotopes, tritium, radiocarbon dating, salinity

INTRODUCTION

Previous work (e.g. Hocking, 2005) has suggested that low relief, highly weathered granites in the upper Wimmera catchment in southeastern Australia are a significant source of salts exported to the catchment via groundwater, whereas high relief, less weathered granites are a source of fresh, good quality groundwater. In order to understand the processes of salt accumulation and movement in the catchment, groundwater recharge and flow has been investigated using a combination of major ion chemistry, isotope ratios $\delta^{18}O$ and $\delta^{2}H$, groundwater dating using ^{3}H and ^{14}C, soil Cl^{-} profiles and downhole EM39 logging.

The upper Wimmera catchment forms part of the Murray Darling Basin (Fig. 1) in western Victoria, Australia. The main geological units in the area are: the highly weathered and fractured basement of Cambrian-Ordovician metasediments (St Arnaud Group), the Devonian granites that intruded the metasediments, and the overlying Miocene-Pleistocene alluvial sediments of the Shepparton Formation. These three geological units also form the main aquifers of interest in the study area.

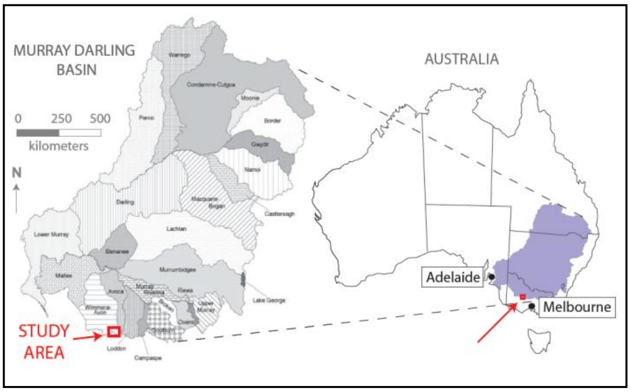

Figure 1. Study area location.

ACCUMULATION OF SALTS IN THE LANDSCAPE

Groundwater $\delta^{18}O$ and $\delta^{2}H$ composition reflects a mix of soil evaporation at a low evaporation slope (<3) and fresh local rainfall, as first outlined by Barnes and Allison (1988). A simple Rayleigh distillation calculation shows that the samples have undergone 4–20% evaporation. Assuming Cl^{-} is concentrated solely by evapotranspiration (Cl^{-}/Br^{-} ratios indicate halite dissolution is not significant), the samples have undergone 90–99.9% evapotranspiration. Hence, transpiration accounts for 76–95% of water loss and is the dominant control on salt accumulation.

GROUNDWATER RECHARGE

Tritium has been detected in bores screened as deep as 20 m, even where the groundwater is saline (up to 17 mS/cm). This cannot represent the overall piston-flow recharge rate because groundwater would be much fresher; preferential flow must occur in conjunction with piston flow in these landscapes. Radiocarbon dating shows that vertical recharge is significant in both the metasedimentary (St Arnaud Group) and granite terrain, because groundwater age increases with depth (Fig. 2).

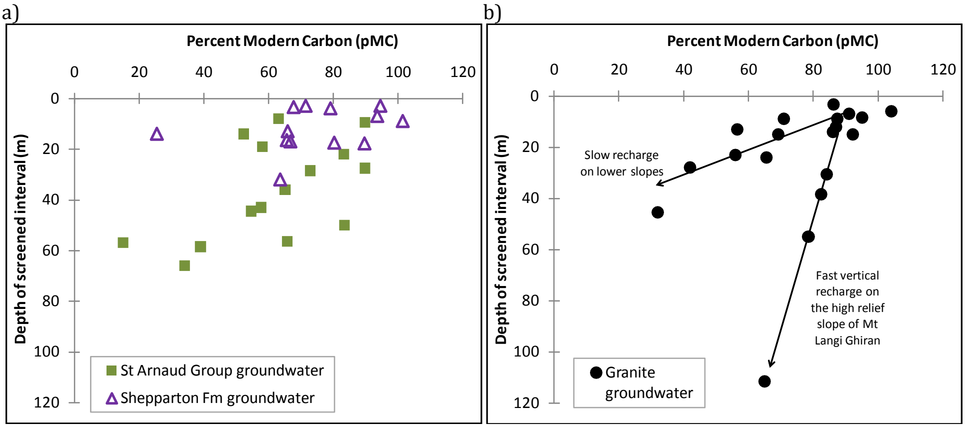

Figure 2. Groundwater percent Modern Carbon versus depth in a) St Arnaud Group and Shepparton Formation groundwater and b) granite groundwater.

Furthermore, vertical recharge on the higher relief granite slope of Mt Langi Ghiran is faster than on the slopes of the lower relief Stawell and Ararat granites (Fig. 2b). There is little evidence of vertical recharge in the alluvial Shepparton Formation; 6 out of 7 bores tested for tritium failed to detect any, and there is no evidence of increasing radiocarbon age with depth (Fig. 2a).

ACKNOWLEDGEMENTS

This project is funded by the Australian Institute of Nuclear Science and Engineering (AINSE), the Wimmera Catchment Management Authority and the Australian Government (through an Australian Postgraduate Award).

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abstract id: **197**

topic: **3**
Aquifer management

3.3
Geophysical, geological and geochemical methods in groundwater exploration

title: **Resistivity and borehole data interpretation for characterizing the hydrogeology of Western Managua, Nicaragua**

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keywords: resistivity, hydrogeology, Nicaragua, borehole, pyroclasts

INTRODUCTION

The present study took place in the western part of Managua Graben (Girard et al 2004). Several investigations have described the geological history of this graben with a complex development where different processes were involved (McBirney and Williams, 1965). The result reveals formations of volcanic origin that mainly consists of pyroclastic materials. Freundt et al (2006), Pardo et al. (2008) and Avellán (2009) describe the deposits from the stratrigraphical point of view and at the same time introducing tephra term in Managua geological setting. Tephra and tuff have to be consider as important terms for hydrogeological purposes since tephra is defined as no consolidated pyroclastic deposits (Shane, 2000). On the other hand, tuffs are consolidated pyroclastic or volcanic rocks. Based on the grain size; tuff is also the consolidated equivalent of ash (Fisher et al., 2006).

In such geological studies were also proposed several tephra and tuff successions which are mainly composed by fall and surge deposits. The fall deposits are mainly constituted by pumice and scoria materials and surge deposits by ash and lapilli. In the study area, coarse to medium lapilli and ash sizes are expected for most of the surge and fall deposits (Avellán, 2009). Fall deposits can be used as marked beds for calibrating key lithostratigraphic sections (Németh and Martin, 2007). Therefore, an interpolated stratigraphical section can be established for the borehole data in order to characterise the hydrogeological properties of the study area.

The electrical measurements were performed and analyzed for an area known as Cuajachillo, an area of special interest because it has experienced water supply problems due to a rapid housing development since 2006 (Fig. 1). In order to obtain information about the geological geometry of the area, an analysis of the resistivity values and the lithological information from boreholes was carried out. To achieve the goal, borehole data was interpreted and unified based on the stratigraphical layout of the area and then correlated with electrical profiles.

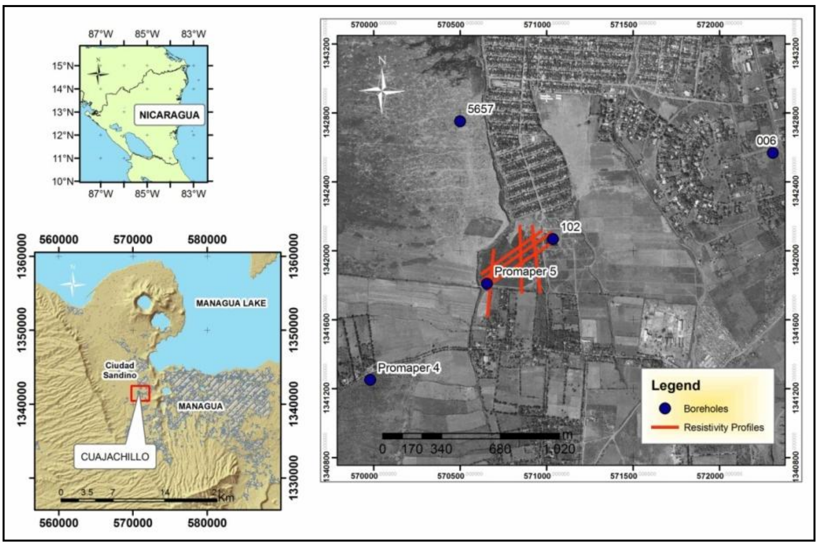

Figure 1. Location Map (1a). Orthophoto map of the Managua area (# 2952-303, right side) showing the electrical profiles and boreholes (1b).

METHODS

Resistivity measurements

A multi-electrode system called ABEM Lund Imaging System was used for resistivity data collection. The system consists of a standard resistivity meter (ABEM Terrameter SAS 4000), an electrode selector switching unit (ES10-64), and five electrode cables, each with 21 take-outs, steel electrodes and various connectors. In the field survey, four electrode cables are laid out and the electrodes are connected directly to them. The electrode cables are linked to the switching unit which is connected to the Terrameter (Dahlin and Zhou 2006). Two-dimensional electrical surveying was carried out along six profiles (CVES 1-6). Profiles CVES 4, 5 and 6 intersected profiles 1, 2 and 3; the space between the profiles was about 30 m. The length of profiles 1, 2, 4, 5 and 6 was 400m and profile 3 was 500 meters long. Three profiles (1, 2, and 3) were measured in the SW-NE direction and the other three in an N-S orientation (Fig 1b.). The field measurements produced apparent resistivities that were converted into true resistivities. The apparent resistivity values were processed and inverted with Res2dinv software using the least-square method (Loke 1997-1999).

Lithological analysis

The lithological interpretation was carried out in order to correlate and integrate the borehole data with the stratigraphic information. The borehole data was provided by ENACAL (Empresa Nicaragüense de Acueductos y Alcantarillados), INETER (Instituto Nicaragüense de Estudios Territoriales) as well as drilling companies: McGregor, and PROMAPER (Proyecto Integrado de Managua Periferia). All the data was interpreted according to the pyroclastic deposits present in the Managua city and its vicinity. To describe and define volcanic deposits, several parameters were also taken into account such as the grain size characteristic of the deposit unit, the grain shape description, borehole location according to volcanic source and lithological composition (Németh and Martin, 2007). The borehole interpretation also provides important data about the aquifer depth, groundwater properties and saturated thickness.

RESULTS

A 3D fence is presented in a diagram (Fig. 2) for the six profiles with the robust inversion (V/H 1.00). In general, the six images illustrate the existence of three different layers with medium to high resistivities. This figure also illustrates a low and a high zone in a good agreement. Overall, three different values of resistivity can be observed in profiles in CVES's 1, 2 and 3. There is low resistivity in the top layer; the bottom layer has medium resistivity. In the second layer of CVES 2, a small discontinuity is observed; in CVES 3 the layer is well defined.

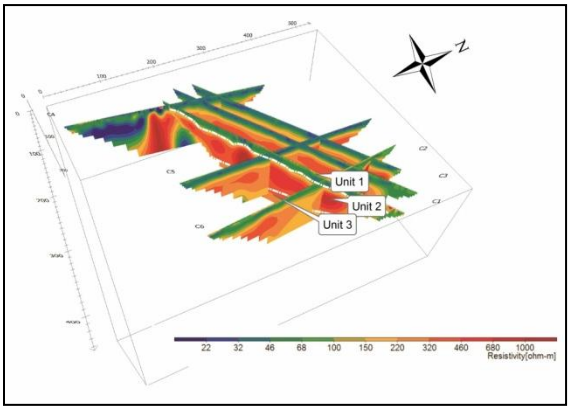

Figure 2. 3D fence diagram. Least squares inversion results (V/H: 1.00) of the electrical profiles.

In this study we emphasize the illustrations corresponding to CVES 3 since the availability of extensive lithology data from boreholes makes possible a highly reliable analysis of the inversion data. According to the Managua stratigraphy, the deposits belong to Chiltepe Tephra (CT), Masaya Tuff (MT), Masaya Triple Layer (MTL) and Satélite Tephra (ST), which are mainly composed of pyroclastic surges and fall deposits) (Fig. 3). The lithological information was added to the CVES 3 inversion results in order to establish the geoelectrical layers. Finally, three distinct resistivity layers were observed in this profile with values from 60 ohm m to 320 ohm m; these layers were correlated with geological units described in the borehole data (Fig. 3).

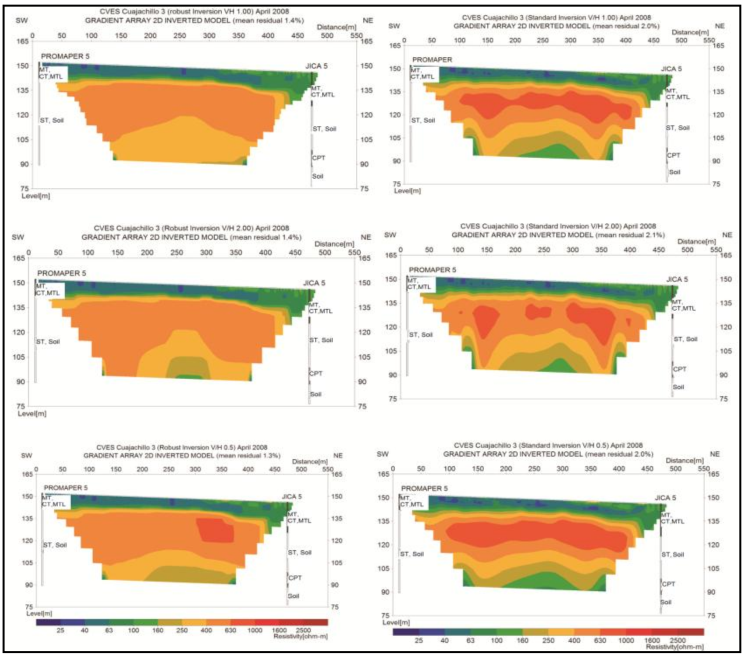

Figure 3. CVES 3 with different inversion results (V/H: 0.5, 1 and 2). Borehole data is also shown in the figure (Promaper 5 and JICA 5).

In the profile 3, the resistivity values of the top and bottom parts of the image indicate a relationship between fine materials and low resistivity values. The values are around 60 ohm m. The values are interpreted as materials with fine to coarse grain size, which in volcanic terminology would be defined as fine ash and lapilli. The medium layer has high resistivity values, from 150 ohm m to 320 ohm m, related to coarse lapilli. Based on the lithological information, the bottom and top layers have fine sediments. In addition, the high resistivity values are related to coarse materials. The lithological interpretation of the borehole data and the outcrops investigated show that the Cuajachillo aquifer was formed by pyroclastic deposits. The materials mainly come from the Cuesta El Plomo Tuff (CPT) and Las Sierras Ignimbrites (BAI) with very high porosity. Groundwater is around 40 m and the water saturated zone is approximately 70 m.

DISCUSSION

The resistivity profiles revealed unique layers in the vadose zone of Cuajachillo aquifer. In addition, a good correlation was obtained between the resistivity values and the lithological borehole information. As a consequence, it was possible to make a detail correlation between the grain size of volcanic deposits and resistivities values. High resistivity in all profiles constantly indicated coarse grain size pointing out good permeable layer and the characterization of the Cuajachillo aquifer as unconfined. Finally, an interpolated stratigraphy section for the borehole data was established showing one main aquifer system (Fig. 4).

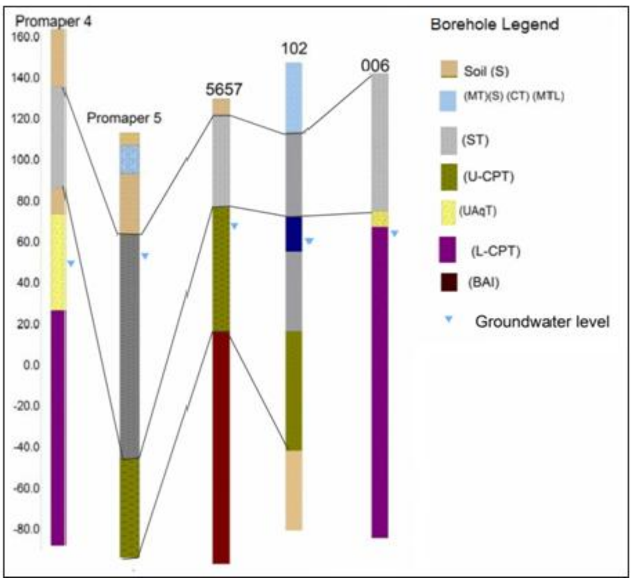

Figure 4. Borehole interpolated stratigraphy section.

In order to improve the information about the aquifer in the area, a detailed lithological borehole interpretation was performed using volcanic deposits classifications. According to these lithological results, the surge pyroclastic deposits called Cuesta El Plomo Tephra were found to have the best aquifer properties. Such volcanic deposits have a high infiltration capacity since most of them are mainly unconsolidated pyroclastic deposits.

The resistivity values obtained in this survey show similar results with previous electrical data. The Japanese International Cooperation Agency (JICA) performed vertical soundings in two boreholes near the study area in 1993. This data can be correlated with the resistivity data produced in this investigation. In addition, resistivity values below 50 meters of depth can be assumed. According to JICA measurements, resistivity values for the materials range from 10 to 700 ohm m. Another correlation is revealed when comparing the JICA measurements and the borehole data. The values from 50 to 130 m depth show low resistivity with 130 ohm m. These values are probably related to Upper Cuesta El Plomo Tephra (U-CPT) with interbedded volcanic soils. The low resistivity can be associated with the fine grain size of these deposits and the existence of a water saturated zone. Below this unit (130 m), a layer with 40m thickness and very low resistivity is also present. The values of this layer are about 24 ohm and could associate with Las Sierras Ignimbrites (BAI) and Lower Cuesta El Plomo Tephra (L-CPT) deposits. These deposits correspond to welded ignimbrites and surge pyroclastic deposits with ash and lapilli grain size (Fig. 5).

Our data			Electrical prospecting (JICA, 1993)					
CVES 3			S-8			S-11		
Layers	Depth (m)	Values (ohm)	Layers	Depth (m)	Values (ohm)	Layers	Depth (m)	Values (ohm)
1	0-15	60	1	0-5	88	1	0-6	82
2	15-35	600	2	5-26	108	2	6-42	410
3	35-50	150-320	3	26-41	700	3	42-130	137
			4	41-130	408	4	130- 450	24
			5	130-170	3	5	450-750	456

Figure 5. Comparison between JICA and electrical profiles.

CONCLUSIONS

The resistivity results, from data obtained in this survey and from the JICA data, indicate the presence of four resistivity layers. The top and bottom layers (1 and 4) have low values and the medium layers (2, 3) have high and medium values, respectively. In the study a well delimited vadose zone has been revealed with three main resistivity layers. JICA data and borehole data was evaluated in order to identify the electrical properties of the aquifer. According to the analysis of the lithological borehole logs and the electrical data, all the layers are interpreted as pyroclastic materials belonging to different tephra deposits of the Managua area. One main aquifer unit has been defined as belonging to Cuesta El Plomo Tephra. The variation in the resistivity can be associated to the differences in volcanic deposits and its properties such as grain size, consolidation and lithological composition.

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IAH 2010
Krakow

abstract id: **199**

topic: **3**
Aquifer management

3.3
Geophysical, geological and geochemical methods in groundwater exploration

title: **Estimation of hydraulic conductivity by applying slug test in a volcaniclastic-deposits aquifer**

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keywords: slug test, hydraulic conductivity, volcanic deposits, Nicaragua, Las Sierras aquifer

INTRODUCTION

The study was carried out in an aquifer called Las Sierras located in Managua Nicaragua, an area where water supply issues are becoming increasingly important. In the study area pumping tests had been used previously to calculate hydraulic properties. However, the purpose of performing these measurements had not been aquifer characterization but rather calculation of the specific capacity of the production wells. This study attempts to investigate the applicability of slug tests as a well-testing method for use in Managua, where lack of data is a main problem.

According to JICA & INAA (1993) the study area is mainly composed of volcanic rock and volcanic sediment ranging in age from plio-pleistocene to recent. Three principal water–bearing formations are present: a). Alluvial deposits with Quaternary pyroclastic materials (Qal) consisting of mixed sediments of volcanic ash (scoria and pumice) and debris; b) Masaya Group Volcanic (QvM) composed of basaltic lavas and pyroclastic materials (volcanic breccia, scoria and ash), c) Middle Las Sierras Group (TQpsM). This last group consists of massive and compact basaltic to andesitic agglomerate with tuffbreccia (lapilli tuff) and tuff. The groundwater flow is mainly domain by the topography. The thickness of the aquifer varies between 100 m in the recharge zone and 300 meters in the discharge zones, which are close to the shore of the Xolotlan Lake. The depth from the ground level to the water table is in the range from 3 m to more than 230 m. In total five study sites were tested by carrying out multiple slug tests in each of them.

METHODS

The study was based on the evaluation, analysis and interpretation of data collection on hydraulic parameters from Las Sierras Aquifer. New data was acquired for this purpose by applying slug tests and then comparing them with hydraulic parameters obtained from previous pumping test performed by the national water supply company, ENACAL. This company manages more than 110 wells distributed over the entire Managua area and also controls the production and location of private wells. Most of the wells located in the Managua area were drilled during the 70s and 80s. Consequently, some of them are out of service, thus providing accessible places for carrying out slug testing. For the processing of the data, additional borehole information was collected regarding well completion and lithological description. The availability of such information was an essential consideration when selecting field study sites (Ciudad Sandino, Altamira, San Cristobal, Las Mercedes, Managua Fase II) see figure below.

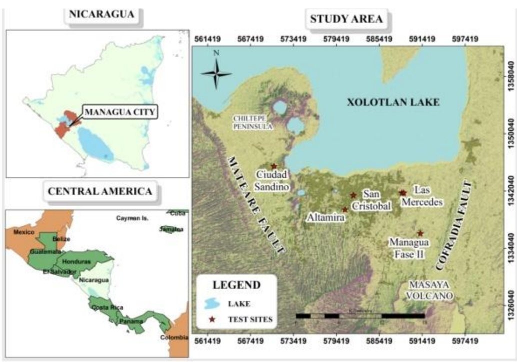

Figure 1. Location study area and tested sites.

From the five above-mentioned study-sites, the hydraulic conductivity of seven wells were assessed using a hydraulic method commonly known as a slug test. This method, introduced by Hvorslev in 1951, has many advantages: it is low-cost, both in terms of manpower and equipment, simple to carry out and relatively rapid to execute, see Butler (1998). Its mechanisms consist of generating a sudden change in the water level and subsequently measuring the return to static condition.

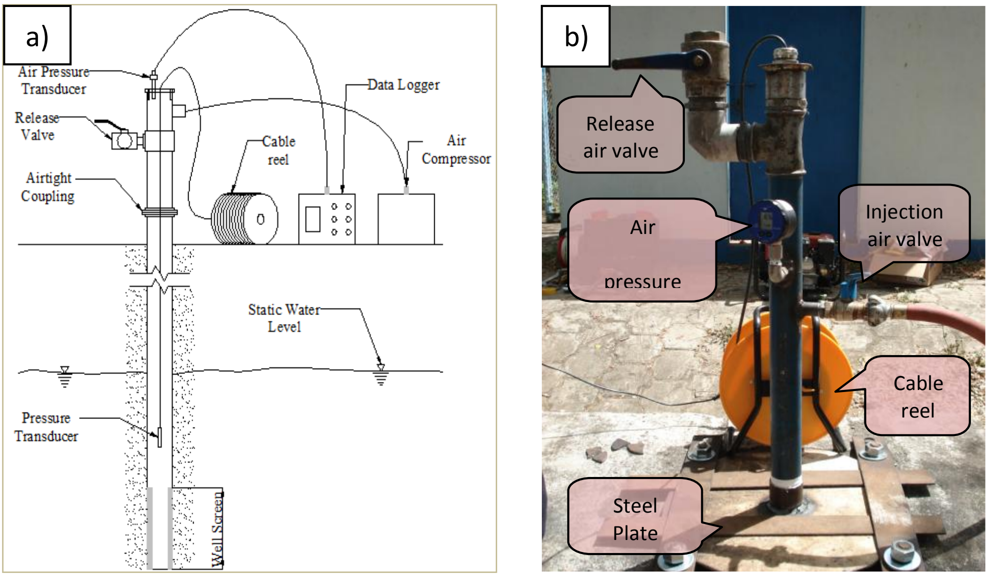

Figure 2. a) Pneumatic Method (Butler, 1998); b) Slug test equipment.

The slug test in this study was initiated by applying the pneumatic approach (Fig. 2a). This approach involves pressurizing the air column in a sealed well by the injection of air; the pressurization produces a depression of the water level, as water flows out of the well in response to the increased pressure (Prosser, 1981). Two pressure transducers are needed: one that measures the pressure in the air column and the other one which records the change of pressure in the water column. The advantages of the pneumatic slug test are: no water needs to be handled and a rapid test initiation can be performed, see Butler (1998). An issue when conducting the pneumatic approach in our study was the need for an air-tight coupling between the casing wells and the slug test equipment. Such a device was constructed by welding steel plates, and rubber rings were required (Fig. 2b).

RESULTS AND DISCUSSION

The lithological description reveals that a combination of three geological units constitutes the water-bearing formations in the tested places. Such formations yield the different values of the hydraulic conductivities obtained for each study site (Table. 1). The accuracy of the slug test data was checked by comparing the values with hydraulic parameters obtained from previous pumping tests. The results demonstrate that slug test can provide consistent and viable data regarding hydraulic conductivities for volcanic environments. Hence the information acquired during this investigation provides valuable data that is required for developing future studies such as numerical modelling and groundwater flow simulations.

Table 1. Estimated Hydraulic Conductivities (K).

Test site	Total tests	Total casing (m)	Water table (m)	Screen length (m)	Well Diameter (cm)	*Geological deposits	K (m/sec)
Las Mercedes							
12	8	131.1	21.82	32.02	20.32 (8”)	Qal + QvM + TQpsM	1.4E-4
13	8	164.63	20.42	35.37	20.32 (8”)		1.5E-4
San Cristóbal							
2008	7	152.44	49.86	58.96	30.48 (12”)	TQpsM	8.1E-6
2009	5		50.83				
Managua Fase II	4	200	45.68	68	30.48 (12”)	QvM + TQpsM	1.2E-5
Altamira	5	204	92.27	33.54	30.48 (12”)	QvM + TQpsM	1.3E-5
Ciudad Sandino	8	125	52.58	28.58	25.4 (10”)	Qal + QvChiltepe	5.2E-5

*Geological description proposed by JICA & INAA 1993. Qal —Sand clay sediments with pyroclastic material, debris deposits; QvM — Basaltic andesitic agglomerate, tuffbreccia, tuff, fossil soil, tuffaceous sand and silt; TQpsM & QvChiltepe — Pyroclastic flows and pyroclastic fall deposits.

Las Mercedes well field: eight slug tests were performed in two wells (Las Mercedes 12 and 13) by lowering the water level.

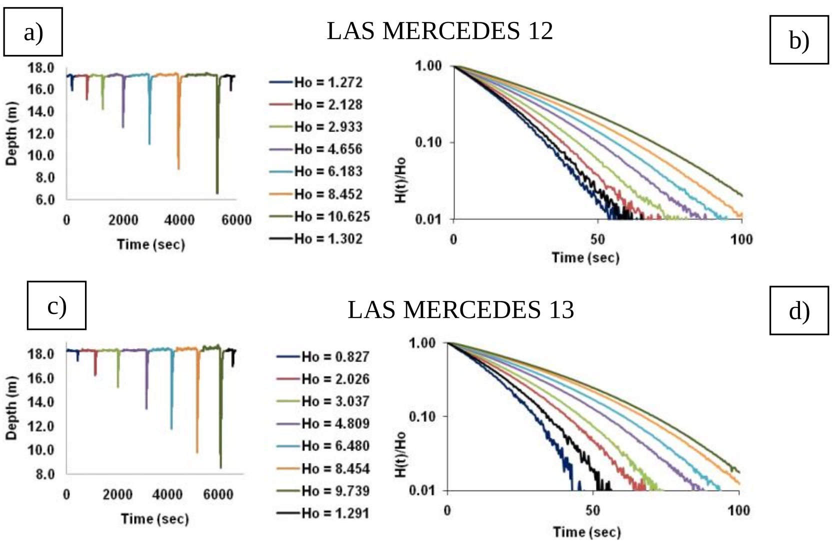

Figure 3. a) Measurements at Las Mercedes 12 b) Normalized head from Las Mercedes 12, c) Measurements at Las Mercedes 13 d) Normalized head from Las Mercedes 13.

Measurements of the normalized head versus the time are plotted in Fig. 3b and 3d for Las Mercedes 12 and Las Mercedes 13 respectively. As can be seen the plots present a concave downward curve characteristic of a nonlinear flow, as discussed by McElwee and Zenner (1998). This means that the data is not adequate for analysis with the linear models. The best fit was achieved by using the McElwee-Zenner (1998) solution. By doing this separately for each of the eight tests performed, the average hydraulic conductivity (K) was found to equal 1.4E-04 m/s and 1.5E-04 m/s for Las Mercedes 12 and Las Mercedes 13 respectively. These values were compared with the ones obtained from previous pumping tests performed by ENACAL in others wells located in the well field. It can be said that the K are in good agreement. The average K estimated from previous pumping test data is around 1.4E-04 m/s.

San Cristobal study site: The data were acquired during two periods. Seven tests were performed during February 2008, in this case the data were obtained from the slug tested well (San Cristobal 2) and an observation well (San Cristobal 3). Others 5 tests were carried out during April 2009 (measuring only in the tested well). The purpose was to check the accuracy of the data, the reproducibility of the method and the subsequent reliability of the results. The logarithms of the normalized heads versus the time are plotted in Fig 4b and Fig 4d for 2008 and 2009 respectively. There is clearly seen the double straight line effect discussed by Bouwer (1989). Almost the same values were obtained by plotting the data measured in the tested well one year later. In the case of San Cristobal 2, the estimated K = 8.1E-06 m/s, which includes the results gathered from the two dates. Regarding San Cristobal 3 in the upper part in Fig. 4a it can be seen an evident influence created by the tests carried out 15 meters away. This contributes to the findings of previous researchers that slug tests affect greater areas in the formation than just those in the vicinity of the well.

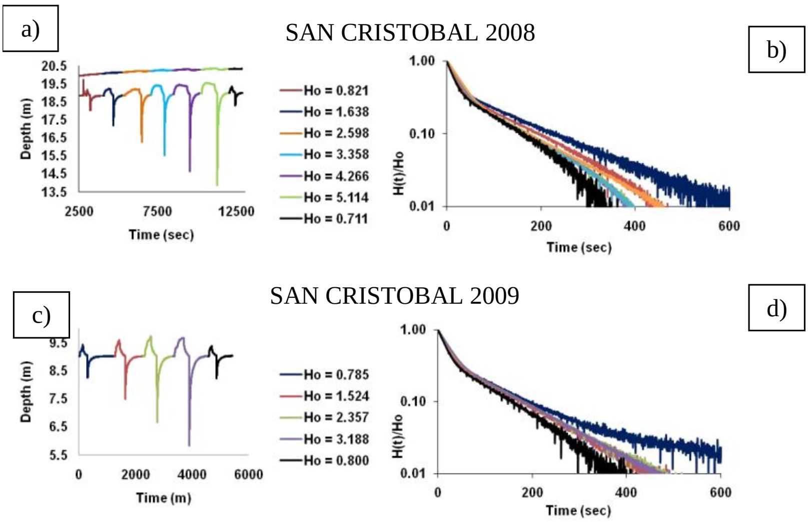

Figure 4. Measurements at San Cristobal a) during 2008, b) Normalized head obtained in 2008, c) during 2009, d) Normalized head obtained in 2009.

Managua Fase II study site: four slug tests were carried out at this site by lowering the water level 0.72, 2.19, 1.39 and 0.65 m. Plots of the data in a semi logarithmic format are shown in Fig. 5. It is clear that the variation in the response of the well is negligible. Very good matching was obtained by applying the Hvorslev (1951) solution. Thus the average transmissivity was T = 8.7E-04 m2/s, which resulted from multiplying the aquifer thickness by the hydraulic conductivity. The average K was 1.2E-05 m/s, which was much lower than the hydraulic conductivity in Las Mercedes.

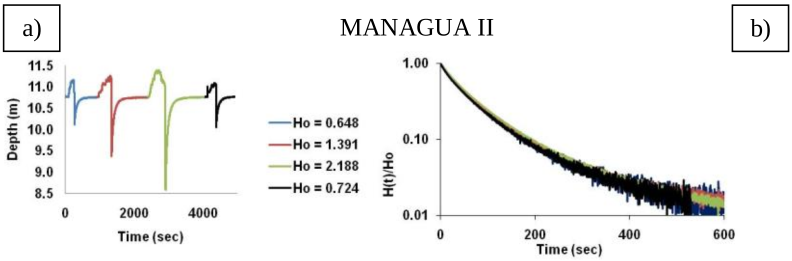

Figure 5. a) Measurements at Managua II, b) Normalized head.

Altamira study site: as can be seen in the Fig 6b, the plots present a similar behavior to the obtained at San Cristobal site. The double straight line effect is evident. The estimated K = 1.3E-05 m/s, which is relatively close to the values obtained from a previous pumping test: K = 1.1E-05 m/s, thus demonstrating that the two methods provide similar results.

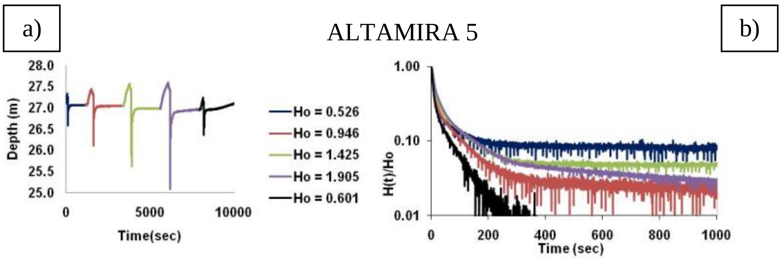

Figure 6. a) Measurements at Altamira , b) Normalized head.

Ciudad Sandino study site: the same behavior (Fig.7) as the one in the Las Mercedes well field was obtained from the tests performed in this well. The plots present a concave downward curve if plotted in a semi-logarithmic format and K = 5.2E-05 m/s was obtained by using the McElwee-Zenner (1998) solution. The value is in good agreement with the obtained through a pumping test carried out in another well, in which K was equal to 5.6E-05 m/s.

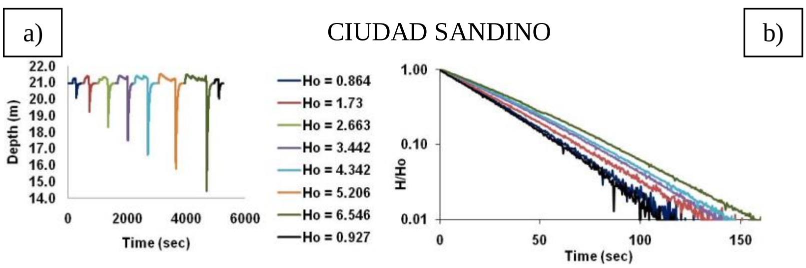

Figure 7. a) Measurements at Ciudad Sandino , b) Normalized head.

CONCLUSION

The results obtained for each study site show that slug tests can provide consistent and viable data regarding hydraulic conductivities for volcanic environments such as the one studied. The hydraulic conductivities have been effectively compared with the results from pumping tests and a good agreement has been demonstrated between the two methods. In addition, the K values estimated are closely related to the different type of deposits (the tree water bearing formations) that were found in the study sites. Finally, due to its ease of implementation and low cost, this method provides an effective alternative for application in developing countries, where lack of data and economical resources are part of the problem.

ACKNOWLEDGEMENTS

This investigation was carried out with financial support provided by the Swedish International Development Agency (SIDA-SAREC), as part of a multidisciplinary research program directed by Centro de Investigaciones Geocientíficas (CIGEO/UNAN-Managua) with the close cooperation of the Engineering Geology Department at Lund University.

Especial Acknowledgements to the staff working at Hydrogeology Department from Empresa Nacional de Acueductos y Alcantarillados (ENACAL-Nicaragua), for its significance collaboration regarding data supplying and the accessibility to the tested wells.

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abstract id: **211**

topic: **3**
Aquifer management

3.3
Geophysical, geological and geochemical methods in groundwater exploration

title: **Geophysical and geochemical groundwater exploration (Essaouira Basin, Morocco)**

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keywords: Essaouira, aquifer system, flow patterns, geophysical, geochemical

INTRDUCTION

The coastal town of Essaouira located on the Atlantic Ocean is exclusively supplyed of drinking water mobilized from springs and wells situated in the valley of the Ksob river The history of the search for new underground water resources to satisfy the increasing demand of the city is marked by several failures about the two aquifers which exist in the zone.

The hyrogeologic study of reference is that carried out in 1976 by Mousanif which has the merit to cover a large territory but remains of order general and consequently imcapable to direct research able to mobilize other water resources, The purpose of the study undertaken was to work in a restricted area and proximale of the town of Essaouira in order to improve our state of hydrogeologic knowledge of the system in the neighbourhoods of the town of Essaouira.

HYDROGEOLOGICAL SETTING

The zone of study covers a surface of 300 km^2 and seems to draw a hydrogeologic unit well individualized (Figure 1) limited to the West by the ocean, in the south by an intermittent wadi said Tidzi wadi, in North by the Ksob river which is perrenne in its down stream part, and in the east by the diapiric accident. The zone of study belongs to the large secondary basin of l Essaoi-ura characterized by a succession of synclines and anticlines, disturbed locally by triassic diapiric formed by clays and salts.

The secondary rocs do not totality show on the surface of the basin, since a band of marine plioquaternary deposited hide them in the western parts.

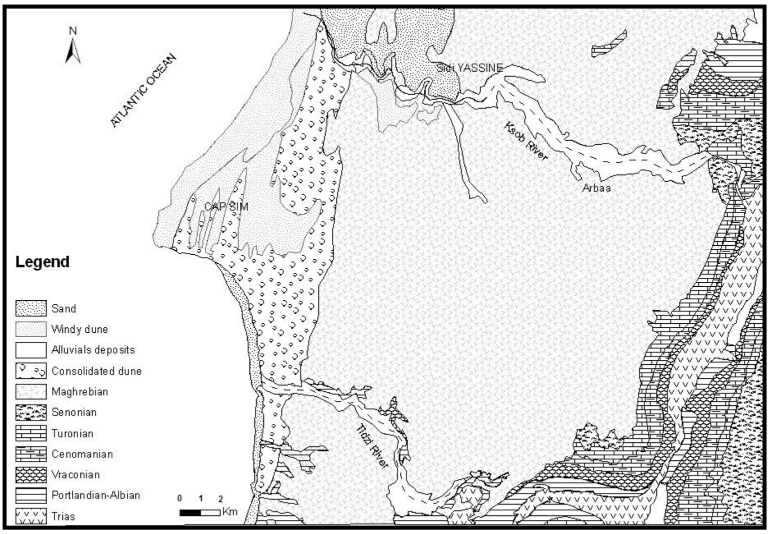

Figure 1. Geological map

A piezometric map was elaborate (Figure 2) starting from the measurements taken on the level of the existing wells in the zone of study. we note in this respect that the wells are very few and badly distributed, with an almost total absence in the Western part dominate by consolidated dunes and barkhanes.

This map shows a flow which is carried out in a total way of the south east towards western north in agreement with the map worked out in 1976, the hydraulic gradient increases in the direction of flow, the ksob river feed the aquifer in its perennial part upstream.

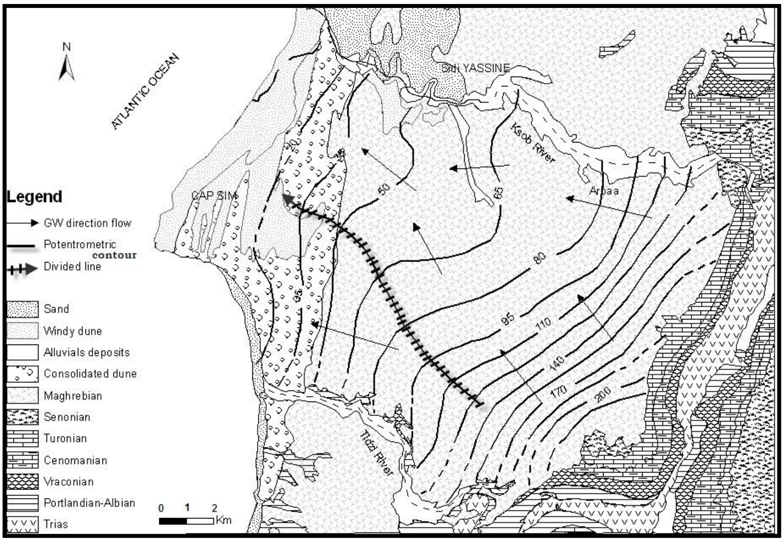

Figure 2. Groundwater levels map.

In parallel an electric map of conductivities was elaborate (Figure 3) starting from the measurements taken on the ground, shows a regular increase as of its values in the direction of the flow what appears a normal phenomenon of with the interaction prolonged of the contact of water with the matrix. However in the southern part one notices concentric curves of equal values which cannot be explained suitably (Fekri, A. 1993).

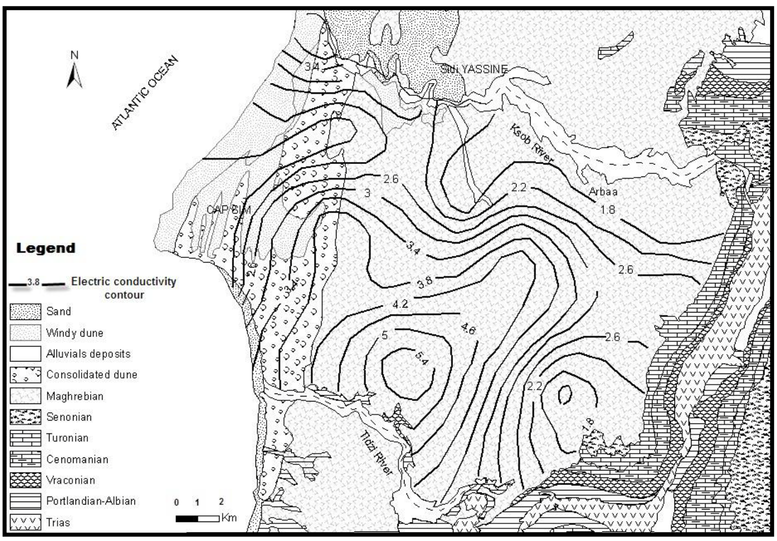

Figure 3. Electric conductivity map (μs/cm).

GEOPHYSIC DOCUMENT

Documents were collected at the ONAREP and of SCP proved very useful especially the map of topography of the substratum (Figure 4) which brings back two facts (i) The Western part whose topography high was always allotted to the dunes is actually due to a rise in the substratum caused by anticlinal due to diapiric tectonics which affects the zone, (ii) The existence of a zone having a directed slope SW.

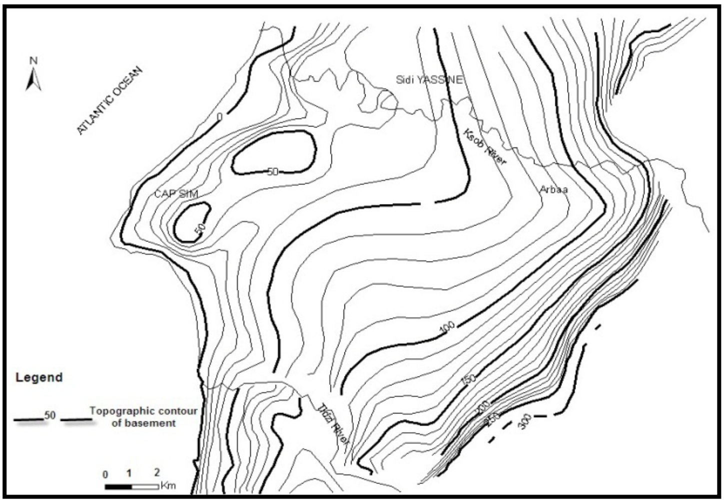

Figure 4. Map of the basement topography.

The confrontation of the piezometric map and that of the topography of the substratum made it possible on the one hand to delimit dry zones materialized by impermeable area (Figure 5) which constitute a barrier to the flow of the plioquaternary groundwater which is reorientate towards the southern part favoured by the already detected slope.

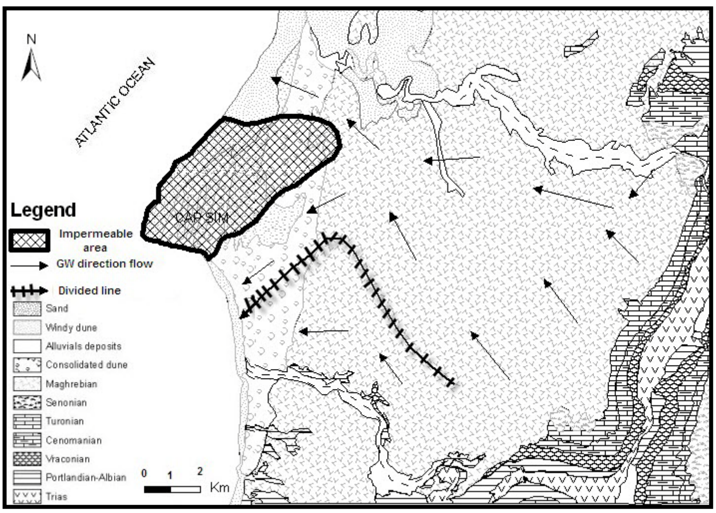

Figure 5. Map of suggested flow direction.

These results led to the establishment of a new diagram of the flows of the plioquaternary aquifer. This diagram seems to be able to correctly interpret the configuration obtained of the curves of equal values of electric conductivity. Water of the northern part being charged is conveyed by the slope towards the south; the forms concentric thus result from the interpolation with higher values which characterize the southern zone.

ISOTOPIC ANALYSIS

It also remains has to determine the origin of the springs in the bed of the Ksob river in the zone known as of Sidi Yassine. The two aquifers being feed by water of the same river the distinction between water of the two aquifers by using this tool proves to be unfruitful and consequently the request of the isotopic tool seems more suitable. Some water points were carefully selected for isotopic deuterium analyses, the points concerned are the ksob river upstream springs of sidi Yassine, a drilled well, a turonien spring, an athor spring whose origin is unknown and a well located in the southern part.

The results of the analyses are distributed according to two groups, turonian and plioquaternairy, this difference made it possible on the one hand to confirm the communication between the two parts of the plioquaternary aquifer and to allot a turonian origin to the springs of sidi Yassine and the second spring whose origin was unknown too.

The contribution of this tools used in this study leads to confirm the diagram suggested of the circulation of groundwater in the plioquaternary aquifer and to specify the turonian origin of the ksob river's springs in its downstream.

CONCLUSION

The work undertaken in the zone of study made it possible to improve our state of knowledge of the aquifer system which has leads to the development of a conceptual model.

such a document is useful in the program scheduling of mobilization of new water resources of the town of Essaouira but raises also other questions on certain aspects, such relations between the two aquifers in the zones where they come into contact.

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abstract id: **220**

topic: **3**
Aquifer management

3.3
Geophysical, geological and geochemical methods in groundwater exploration

title: **Hydrogeological researches for vertical closed loop heat exchanger system assessment in an experimental pilot site (Vicenza, Northern Italy)**

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keywords: confined aquifers, heat transport, ground-coupled heat pump, ground heat exchangers

The geological assessment in the Province of Vicenza shows in general considerable thickness of alluvial quaternary sediments and subsurface materials. In the porous media, composed by sandy gravels, very important artesian aquifers, as concerns the water production for human use of the whole Veneto Region, are located.

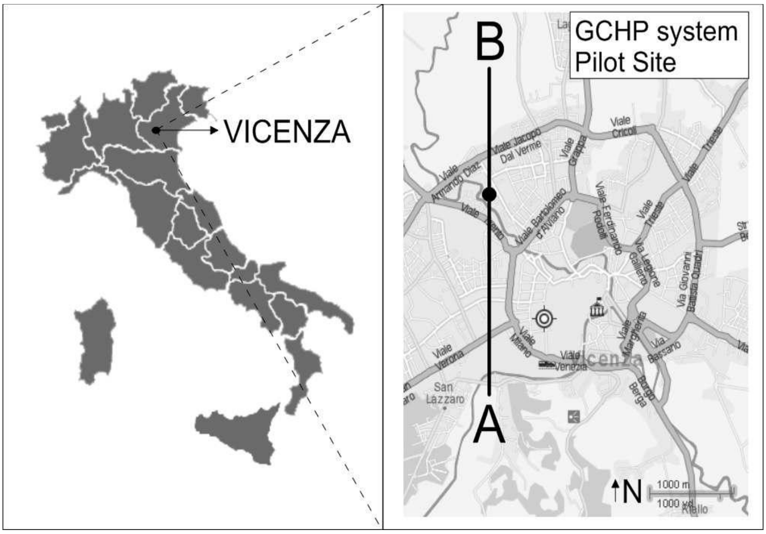

Figure 1. Location of the studied area.

In the town of Vicenza, in particular up to 100–120 m of depth from the ground there's an hydrogeological multiaquifer system, where some high hydraulic transmissivity structures are confined between clay and impervious layers. As in the rest of Europe also in this territorial context ground heat exchangers (GHEs) are quickly developing in order to ensure the best available technologies in environmental practices, by means of low-enthalpy geothermal energy exploitation.

The ground-coupled heat pump (GCHP) system, used for space heating and cooling, is discussed in the present case-study. Locally the GHEs systems aren't completely defined by any law in terms of operational and executive provincial regulamentation so, studies to acquire experimental data and researches to improve the in-situ parametric assessment are organized in partnership with the competent Autorities.

In this paper the objectives and the preliminary issues achieved in the pilot site of Vicenza are presented. The project of GCHP system, combining a heat pump with a ground heat exchanger (closed loop systems), is recently authorized with a temporary permission, waiting for the results of the following monitoring phase, which will start up in the next months.

The area of matter is located near the center of the town (Fig. 1), where an executive building is interested by restructuration and foundational works. In order to guarantee the energetic requirements of the building about 40 Borehole Heat Exchangers (BHEs) with a depth of 100 m are made. The method of drilling carried out using a double head rotary machine and provisional coating of the borehole, able to assure that the confined aquifers will not become in hydraulic and hydrochemical interconnection. After the Ground Response Test (GRT) performance the underground average values about initial temperature (14.9°C), geothermal conductivity (2.3 W/mK) and heat exchange rate (50 W/m) are estimated.

First some monitoring vertical installations are expected in the geothermal low enthalpy field, to verify the long-terms behavior of the temperature, due to the working of the plants. Two of these are respectively located upgradient and downgradient at 65 m of distance in the experimental field, compared to the regional groundwater flow, whereas the third takes a central position. Finally into the boreholes thermometric probes are installed with a regular spacing of 10 m below the ground level to the maximum depth of BHEs (Fig. 2).

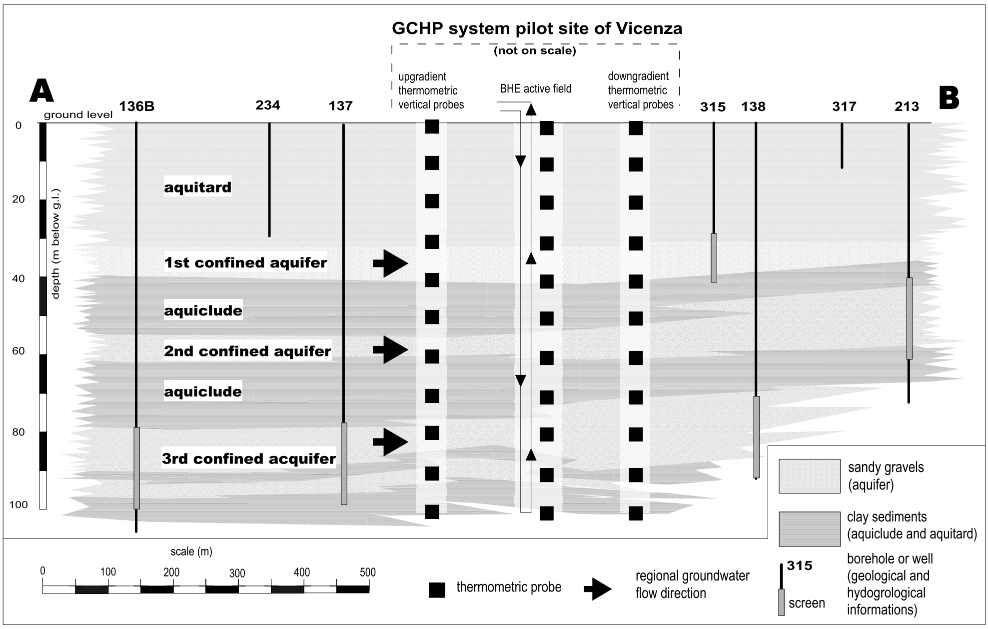

Figure 2. Section assessment of the pilot site.

In the external installations the thermometers are directly dipped into the concrete-bentonite sealing mixing of grouting. The central monitoring point presents the probes skin-coupled with the tubes where the anti-freeze liquids used in borehole heat exchangers are pumped.

The thermal measurements net actually consists in 30 probes, connected with appropriate electronic circuits for signal amplification and filtering and then with data loggers.

In the next period initial data concerning the ante-operam spatial and temporal geothermal log will be collected, while, after the beginning of heat pumping, the same measurements can be used to understand the amount of possible interferences related to the GCHP system.

In progressing of researches a numerical modeling study is planned: the model will be calibrate using field-survey data to simulate the temperature trends into the aquifers intercepted from the public water board wells. The numerical analysis can consider also the effects of heterogeneous subsurface conditions and the groundwater thermal dilution due to the natural and artificial groundwater flow. These technical argumentations will also help Authorities in a reference protocol arranging about BHEs drilling procedures and in a GCHP systems regulamentation improving.

Afterwards the conclusions of this pilot study can be useful in order to complete the specific knowledge of the local application for vertical closed loop heat exchanger system in particular hydrogeological and environmental situation, marked from the presence of most excellent aquifers in Italy, both in terms of qualitative features and quantitative peculiarities.

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abstract id: **223**

topic: **3**
Aquifer management

3.3
Geophysical, geological and geochemical methods in groundwater exploration

title: **Estimation of groundwater recharge in arid regions through unsaturated zone studies**

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keywords: groundwater recharge, Arid hydrogeology, unsaturated zone studies

Semi-arid and arid regions represent 30% of global terrestrial surface area expanding (Dregne, 1991). The above fact gives rise to the necessity for accurate determination of groundwater recharge; an issue of paramount importance for the “smart mining” of groundwater resources in such hydrologically sensitive regions. Scanlon et al. (2002) categories the main approaches for groundwater recharge estimation into: (a) surface water, (b) unsaturated zone and, (c) saturated zone studies.

This paper refers to the investigation of the soil moisture content profile within the unsaturated zone through field as well as lab techniques. The field techniques include in-situ measurements of the volumetric soil water content at different depths using Time Domain Reflectometry (TDR). TDR is a geophysical technique (Stacheder et al., 2009) based on the relation between the permittivity of soil and its volumetric water content. Robinson et al. (2003) quote that the majority of the reported case studies regard the installation of TDR equipment within a depth of 60–80 cm from the ground surface.

By applying advanced “direct-push” sounding methods, specially designed TDR sensors can installed at significant depths within the unsaturated zone, providing continuous readings of the soil moisture content. The investigation of the unsaturated zone is also complemented with the determination of the temperature profile for the unsaturated column.

Additionally, multilevel undisturbed soil sampling for the extraction of the containing pore water is applied for the dating of the groundwater through the determination of its isotopic composition. The determination of different isotopic signals such as $\delta^{18}O$, $\delta^{2}H$, ^{3}H, and ^{36}Cl, mainly aim to the investigation of groundwater transit times as well as preferential flow paths through the unsaturated zone. The unsaturated zone experiments are carried out at selected field sites in the Kingdom of Saudi Arabia, representing different potential groundwater recharge scenarios in arid regions. It is expected that the result will lead to a sufficient quantification of present and historic groundwater recharge in arid environments.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the cooperation between Technical University of Darmstadt (Germany), Helmholtz-Centre for Environmental Research-UFZ (Leipzig, Germany), GTZ-IS (Riyadh Offices, Saudi Arabia) and the Ministry of Water and Electricity-MoWE, Kingdom of Saudi Arabia. Funding is provided by the German Ministry of Education and Research (BMBF) through the research program IWAS (http://www.iwas-sachsen.ufz.de/).

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abstract id: **273**

topic: **3**
Aquifer management

3.3
Geophysical, geological and geochemical methods in groundwater exploration

title: **Evaluation of the accuracy of determination of the chemical denudation in the Biały Potok Watershed, using numerical geochemical modeling**

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keywords: chemical denudation, geochemical models, Tatra Mts.

INTRODUCTION

Chemical denudation, understood as a set of processes that lead to the removal the rock material dissolved in water from the land masses, is one of the components of the chemical elements cycle in nature which significantly influences chemical composition of surface water and groundwater in the zone of hypergenesis. Chemical denudation is also one of the processes actively reshaping the Earth's surface, and understanding of these processes (dissolution-transport-deposition) allows to determine the nature of this mechanism and rates of the present geomorphic processes (Pulina, 1992, 1999; Manecki et al, 1994; Langmuir, 1997; Faure, 1998; Kehew, 2001).

Processes occurring in the phreatic zone have not been typically considered in quantitative evaluation methods of chemical denudation. These methods use the "black box" model. They estimate chemical denudation, without including processes occurring in the phreatic zone, based on recharging and discharging water chemistry and flow volumes (Pulina, 1999; Zambo, Ford, 1997; Andrejchuk, 2000; Bouchard, Jolicoeur, 2002; Hodson et al., 2002).

A new approach which uses a numerical, and includes processes occurring in the phreatic zone, allows to evaluate how these processes affect the chemical denudation (Małecki, Szostakiewicz, 2004, 2006, 2008; Szostakiewicz, Małecki, 2006).

FIELD EXPERIMENTAL STUDY AREA

This research has been conducted in the drainage basin of the Biały Potok, located south of town of Zakopane, within the West Tatra Mountains. The experimental field area is mainly composed of carbonate sediments – dolomites and limestone from the Triassic Lower Regle Series (Fig. 1).

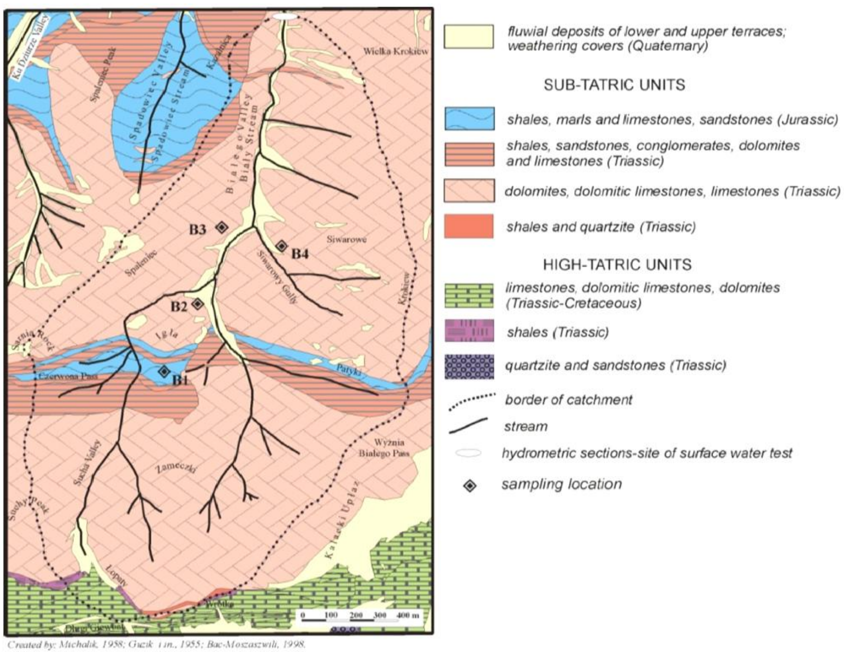

Figure 1. Geology of the experimental field area.

Dolomite and calcite are dominant minerals in the series. Clastic rocks mainly composed of quartz, calcite and dolomite occur locally. Minor amounts of clay minerals (mainly illite), plagioclase feldspar, iron and manganese oxides and silica occur infrequently. Pyrite accumulations in calcite veins also occur (Turnau- Morawska, 1953; Pawlikowski et al., 1997). Groundwater in the Biały Potok drainage basin are recharged from the infiltrating atmospheric precipitation, and they are discharged by streams and springs. Multi-year water budget from this area indicates that there are no lateral flows from and to this drainage basin resulting in deficits or surpluses. If lateral flows existed, they would add or remove unknown amounts of chemical load, making close to impossible evaluation of chemical denudation.

Surface waters and groundwater in the Biały Potok drainage basin are weakly alkaline and their total dissolved solids (TDS) between 200 and 300 mg/L. They have intermediate hardness (using classification of Pazdro, Kozerski, 1990), with significant dominance of the carbonate hardness, which is associated with lithology of the drainage basin rocks. Values of the oxidizing-reducing potential (300-400 mV) indicate oxidizing conditions in the aquifer. This range of Eh values accompanied with pH ranging from 7,5 to 8,1, is characteristic for groundwater in the active chemical transfer zone in carbonate rocks regolith (Macioszczyk, Dobrzynski, 2002). Calcium, magnesium and bicarbonate ions dominate in surface waters and groundwater. They are HCO_3-Ca-Mg type according to Szukariew-Priklonski classification.

QUANTITATIVE EVALUATION OF CHEMICAL DENUDATION

Quantitative determination of chemical denudation requires information about discharging flow from the experimental field area and the mass dissolved in this flow. Quarterly monitoring of physico-chemical properties of atmospheric precipitation, surface waters and groundwater, including temperature, pH, redox, electic conductivity and chemical composition, has been conducted in years 2008-2009 in the Biały Potok drainage basin in order to collect this information. Concentration of major ions and of iron, manganese, aluminum, and silica has been determined in water samples. Automatic flow measurements in the hydrometric profile characterizing the total discharge from the drainage basin, was conducted every 30 minutes, which allowed evaluation of the surface water flow in the basin. Field and laboratory data collected, and mineral composition of the dominant sediments in the studied drainage basin, were used in geochemical modeling.

Conceptualization and simplification of hydrodynamic and hydrochemical conditions comprised the first phase of the modeling. There are several simultaneous processes in the aquifer, which interactions are difficult to present in numerical modeling. Therefore, numerical models do not perfectly reflect the real conditions. The following assumptions were used in modeling:

- Groundwater recharge is exclusively from infiltration, and discharge occurs only in surface water flows and springs.
- Lateral inflows and outflows are insignificant based on the determined water budget in the drainage basin.
- Chemical composition of groundwater and surface waters is affected by chemical composition of atmospheric precipitation, evapotranspiration, physico-chemical properties of aqueous solutions, and dissolution and precipitation of minerals.

- Dissolution of carbonates occurs in the open system with unlimited access to carbon dioxide and its constant partial pressure. This assumption was considered appropriate based on the partial pressure of carbon dioxide determined in groundwater. Determined logarithms of partial pressure ranging from -1,5 to -2,5 are characteristic for groundwaters where calcite dissolution occurs in open systems (Appelo, Postma, 1993).
- Feldspars do not precipitate from surface water and groundwater, and clay minerals form as products of their weathering (Allen, 2000).
- It was assumed that aqueous solution is in the quasi-equilibrium with the solid and gas phases, characterized by saturation indexes with respect to minerals occurring in the drainage basin.
- Anthropogenic factors influencing physico-chemical properties of surface waters and groundwater were neglected.

The authors understand that assumptions used simplify the natural hydrochemical system, however they do not significantly compromise the validity of the results.

In the next phase, a modeling program, which allows numerical modeling reflecting hydrogeochemical processes occurring in the study area, was selected. Program PHREEQC v.2.11 with compatible thermodynamic data base phreeq.dat was selected. This program allows to: characterize aqueous solution, perform forward and reverse modeling, consider temperature effects in the infiltrating water, and increase of concentration caused by evapotranspiration. This geochemical modeling program is also most frequently used and verified in the world (Macioszczyk, Witczak, 1999; Parkhust, Appelo, 1999; Ženisova et al., 2002; Ozdemir, Nalbantcilar, 2002; Lachmar et al., 2006; Demirel, Cuneyt 2006).

Supporting reverse models were prepared in the following phase which allowed to identify which minerals were likely to dissolve or precipitate in the aquifer water.

Physico-chemical parameters of water samples and mineral composition of the sediments in the Biały Potok drainage basin, were used as input data in the reverse model. The models were constructed based on physico-chemical properties and ionic composition of waters that were in contact in conceptual hydrologic cycle.

The output results from the reverse models were consequently used in forward models. Atmospheric precipitation water equilibrated with respect to carbon dioxide was used as the input aqueous solution. Evaporation and temperature changes along the infiltration path were used in addition to dissolution and precipitation reactions in forward models.

The results of the modeling were verified by comparing them to field and laboratory measurements. The level of agreement exceeded 95% (Tab. 1).

Table 1. Verification example of the forward geochemical modeling (November 2008).

Atmospheric precipitation water				**Water sample - surface water**				**Error***
		Dissolved Phase		*Simulated physico-chemical parameters*		*Observed physic-chemical parameters*		
	mol/L		**mol/L**		**mol/L**		**mol/L**	**%**
Na	1.96E-05	Calcite	2.86E-05	Na	3.27E-05	Na	3.26E-05	-0.06
K	4.86E-06	Dolomite	3.78E-04	K	8.32E-06	K	8.44E-06	0.75
Ca	1.37E-04	CO_2(g)	7.36E-04	Ca	8.03E-04	Ca	8.21E-04	1.10
Mg	6.17E-06	Potassium feldspar	6.42E-06	Mg	5.73E-04	Mg	5.78E-04	0.45
Fe	5.37E-08	Albite	1.39E-05	Fe	5.39E-08	Fe	5.37E-08	-0.11
Mn	9.10E-09	Hematite	1.14E-08	Mn	1.81E-08	Mn	1.82E-08	0.44
Al	1.89E-06	Piroluzite	2.93E-09	Al	3.76E-07	Al	3.71E-07	-0.67
SiO_2	8.32E-07	Siderite	4.95E-09	SiO_2	1.68E-05	SiO_2	1.68E-05	0.06
Cl	6.60E-05	**Precipitated Phase**		Cl	8.14E-05	Cl	8.18E-05	0.25
SO_4	2.60E-05	Halite	1.17E-05	SO_4	2.64E-05	SO_4	2.60E-05	-0.78
HCO_3	2.98E-04	Gypsum	8.40E-06	HCO_3	2.86E-03	HCO_3	2.79E-03	-1.36
		Illite	9.56E-06					
pH	6.93	SiO_2(a)	1.72E-05	pH	8.09	pH	8.08	
pe	7.42			pe	5.95	pe	5.95	

Calculated as (observed data-simulated data)/(observed data+simulated data)*100%

Mass transfer obtained from forward modeling allowed to determine potential amounts of dissolved and precipitated mineral phases in the study area. Dissolved masses of specific minerals and their densities determined in geochemical forward model were used to calculate (Eq. 1) the total volume of dissolved minerals in unit solution volume.

$$d = \sum_{j=1}^{n} \frac{m_j}{\varsigma_j} \qquad (1)$$

Where:

d — total volume of dissolved minerals in unit solution volume (Allen, 2000)

m_j — mineral j dissolved mass in unit solution volume [g/dm^3]

ς_j — mineral density [g/dm^3]

These data combined with the measured flow volumes in the drainage basin and the drainage basin surface area (calculated using program ArcView GIS 9.3) were used to quantitative estimation of chemical denudation in the experimental study area. The study period was divided onto time intervals because of temporal fluctuations in flow volumes and total volumes of dissolved minerals (Fig. 2).

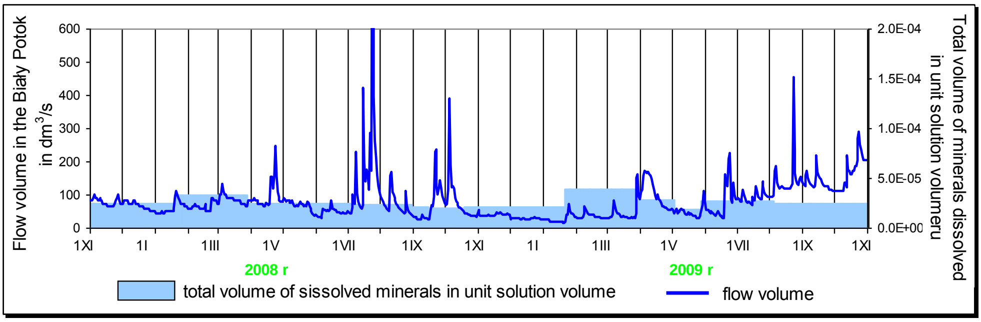

Figure 2. Discretization of the flow volume in the Biały Potok and total volume of dissolved minerals.

Average arithmetic values were used for flow volumes and total volume of dissolved minerals in each of the time intervals. Chemical denudation was therefore calculated from equation 2.

$$D_{ch} = \frac{\sum_{i=1}^{n} Q_i \cdot \Delta t_i \cdot d_i}{\sum_{i=1}^{n} \Delta t_i} \cdot P^{-1} \cdot 0{,}365 \qquad (2)$$

where:

D_{ch} — chemical denudation [m³/km² ·year]

P — basin surface area [km²]

Q_i — total discharge flow in a time interval delta ti [dm³/day]

d_i —total volume of minerals dissolved in a given time interval delta ti in a unit solution volume (Allen, 2000)

Δ ti — time interval used [days]

Obtained results were compared with chemical denudation values in the study area for the same time intervals calculated frequently used hydrologic equation by Pulina (1999), eq. 3.

$$D_{ch} = \alpha \cdot \frac{\Delta T \cdot Q}{P} \qquad (3)$$

where:

D_{ch} — chemical denudation [m³/km² ·year]

α — proportionality coefficient (Numerical coefficient alpha depends on density of soluble rocks. It allows to use the same dimensions in the equation 3. Value of 12.6 is assumed for carbonates, sulfates, and chlorides) (Allen, 2000)

$\Delta T = T - T_a$, where ΔT – total dissolved solids, resulting from mineral dissolution in karstified study area [mg/dm³], T – amount of dissolved salts in discharging water leaving the karstified drainage basin [mg/dm³]

Q — average annual outflow from a karstified drainage basin or study area [m³/s]

P — the real surface area of the karstified basin or study area [km²]

Values of chemical denudation in the Biały Potok drainage basin calculated using the new method described in this paper based on results of geochemical modeling (Eq. 2) are significantly lower than those calculated using hydrologic method (Eq. 3, Fig. 3).

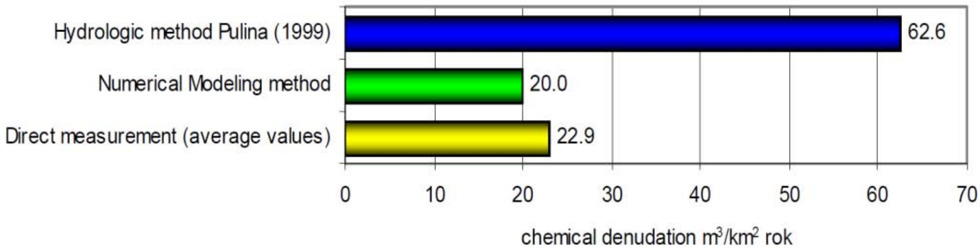

Figure 3. Comparison between different methods of estimation of chemical denudation in the Biały Potok drainage basin.

VERIFICATION OF CHEMICAL DENUDATION RESULTS

Results of estimated chemical denudation using both methods, the hydrologic approach and the numerical modeling approach, significantly vary from each other. In order to establish validity of both methods, the direct verification method was used.

Qualitative verification was based on observation of weathering alterations in thin sections, cut from rocks comprising the experimental field area and buried in the aquifer. Open thin sections were photographed and their mineralogical and petrographic composition was characterized in optical microscope in passing light. These thin sections were then placed in the aquifer where were exposed to weathering processes. They were recovered after 1.5 year from the aquifer and their mineralogical and petrographic composition was examined again. Thin sections from two rocks characteristic for the Biały Potok drainage basin were examined: dolomites outcropping over more than 90% of the study area (sample B4) and clastic rocks (quartz sandstone, sample B1) exposed in the central part of the study area (Fig. 1). Time interval of reaction of 1.5 year appeared to be too short to result in changes significant enough to be observed in optical passing light microscope.

Similar studies were simultaneously conducted in two other experimental field stations: the Suchy Potok drainage basin (Podhale Region) composed mainly of sandstones and shales, and the Macelowy Potok drainage basin (Pieniny Klippen Belt) composed of both sandstones and shales as well as carbonates. In thin sections from Globo-trunkana limestone collected in the Macelowy Potok drainage basin, that were exposed in the aquifer to weathering conditions, significant weathering alterations were observed. Zones filled with calcite, mainly microfossils (planktonic foraminifera from Globotruncana genus), became recrystallized, forming a series of finer crystals or losing entirely its crystalline nature. Previously clearly seen microfossils became barely visible (Fig. 4).

Initial observations, despite a very short sample exposure time to weathering, are in agreement with results of geochemical modeling. They confirm a hypothesis that mainly carbonates, especially calcite, undergo denudation processes in the studied drainage basins.

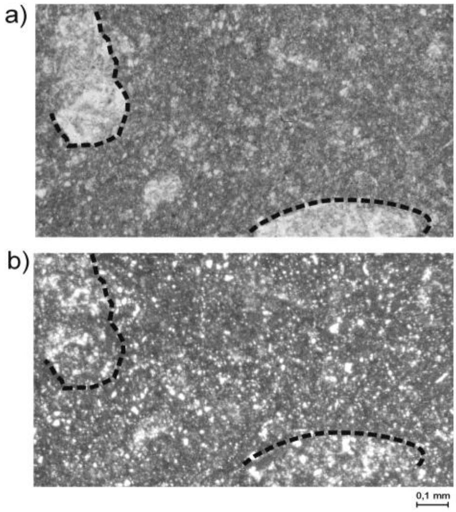

Figure 4. Weathering in Globotruncana limestones: Photograph taken before the sample was exposed to weathering Photograph taken after the sample has been exposed to weathering for 1.5 year.

The second phase of verification of the new quantitative method based on numerical modeling was direct measurement of the dissolved rock mass. In order to accomplish goal, discs of diameter 5 cm and height of 2 cm, and weight ca 100 g, were cut from the rocks comprising the study area. They were then placed on the ground surface exposed to atmospheric precipitation and buried in the vadose zone of the aquifer in the study areas. These discs were accurately weighted before and after exposure to weathering processes. To avoid weight differences caused by varied sample moisture content, all samples were first over dried at temperature 105^{o}C during 24 hours, and then cooled down to the room temperature in exicators (Matsukura et al. 2001).Temperature of 105^{o}C allows to remove water molecules not attached to the mineral lattice in the studied rocks, and simultaneously not causing disintegration of minerals comprising the aquifer material, such as carbonates, which would alter its natural solubility.

Based on the discs evaluation, it was observed that rock discs placed on the ground surface and in direct contact with atmospheric precipitation, underwent more intense weathering than the rock disc buried in the aquifer (Fig. 5). It agrees with the modeling analysis results, indicating much greater potential mineral dissolution in atmospheric precipitation water than in water infiltrating through the vadose zone.

The results of the modeling were also verified by comparing them with the rates of chemical denudation calculated from empirical equations. Direct chemical denudation measurement method was used to accomplish this goal (Kotarba 1972; Thorn et al., 2002). In this method, the lost mass from the rock discs, is divided by the rock density and presented relative to the sample surface area.

The calculated results of chemical denudation in the studied drainage basin using the direct method are consistent with the values determined from numerical modeling and significantly lower than the results obtained using the hydrologic approach (Fig. 3). In views of the authors, it confirms validity of the analysis based on the numerical modeling.

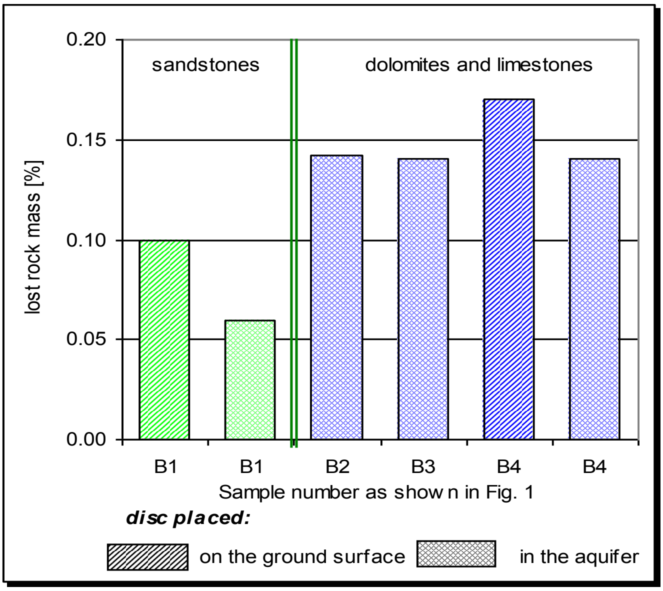

Figure 5. Average mass loss of the rock core discs.

The hydrological approach computations lead to excessive values. The differences between the values calculated using the hydrologic approach and the numerical modeling results from not considering the following factors in the hydrologic approach:

- Contribution of carbon dioxide in carbonate dissolution. This factor significantly affects chemical denudation in the study area, as the Biały Potok drainage basin is mainly composed of carbonates.
- Field evaporation, resulting in increased concentration of elements dissolved in atmospheric precipitation water.
- Variability in density and solubility of minerals, parameters required to correct assessment of the removed rock volume.

In conclusions, empirical studies of denudation processes conducted in the studied drainage basin (qualitative and quantitative) confirm validity of the results obtained from numerical modeling. Rates of chemical denudation determined previously from the hydrologic approach are significantly higher than from numerical modeling. Thus, commonly used hydrologic methods, might lead to underestimation of the karst massive morphology, by as much as 30%.

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IAH 2010
Krakow

abstract id: **314**

topic: **3**
Aquifer management

3.3
Geophysical, geological and geochemical methods in groundwater exploration

title: **Efficiency of magnetic resonance soundings applied to the characterization of aquifers**

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keywords: magnetic resonance sounding, geophysics, transmissivity, geometry, water table

INTRODUCTION

In our changing world, improved groundwater development and resources management based on comprehensive knowledge of aquifers are required. Especially, aquifer properties as reservoir geometry, storage-related parameters and flow-related parameters are most needed for both well setting in complex environments and for supplying groundwater flow models that are commonly used for resource management. One of the most reliable ways to gather aquifer properties is drilling exploration boreholes and carrying out hydraulic tests. However, in situ estimates of aquifer properties are often scarce because dense field surveys are expensive in terms of time and money.

Non-invasive surface geophysical methods capable of providing rapid, dense and low cost data coverage can be very useful if they provide accurate estimates of aquifer properties. However, most geophysical parameters result from several factors including, but not limited to groundwater. As compared to other geophysical methods, magnetic resonance sounding (MRS) is selective with respect to groundwater (Legchenko and Valla, 2002). This distinctive feature makes it possible to use MRS parameters for characterizing aquifers.

MAGNETIC RESONANCE SOUNDING

The physics and mathematics of the method are beyond the scope of this paper and are available in numerous publications (e.g., Legchenko, Valla, 2002). MRS is based on exciting the nuclei of the hydrogen atoms in groundwater molecules, i.e. protons, and measuring the magnetic resonance signal that is generated by the precessing nuclei after the stimulation signal is terminated. To conduct field measurements, a loop of electrical wire is laid out on the ground (Figure 1). The shape of the loop is usually square, and measures 20 to 150 meters on a side, depending on the required maximum depth of the investigation (the greater the size of the loop the deeper the investigation).

Figure 1. MRS equipment (Numis device from Iris Instrument).

A pulse of alternating current is then generated in the loop. The energizing pulse causes a deflection of the magnetic moments of hydrogen nuclei from their equilibrium position. When the pulse is switched off, the nuclei revert to their pre-pulse position creating an alternating electromagnetic field that is measured usually with the same loop. To carry out a sounding, signals are recorded while the pulse moment is varied $q = I_0 \cdot \tau$ (where I_0 is the current and τ is the pulse duration): the higher the pulse moment the deeper the investigation.

HYDROGEOLOGICAL RELEVANCE OF MRS PARAMETERS

Two parameters of the recorded magnetic resonance signal are instructive for hydrogeological applications: the initial amplitude $E_0(q)$ and the decay rate $T_i(q)$ of the signal. The higher the initial amplitude of the signal the higher the number of hydrogen nuclei that generated the signal and thus the higher is the water content of the investigated rocks. The decay rate of the recorded signal is sensitive to the geometry of the pores that contain water: the longer the decay rate of the signal the larger are the pores of the rocks. The interpretation of the recorded $E_0(q)$ and $T_i(q)$ gives the distribution of the MRS water content $\theta_{MRS}(depth)$ and decay rate $T_i(depth)$ with depth (Legchenko and Valla, 2002). Note that the recorded signal is an integral signal over the investigated volume. The maximum investigated volume of a MRS can roughly be approximated by an area of 1.5 times the loop size for a depth corresponding to the loop size (Vouillamoz et al., 2003). Considering a typical size of 100 meters length (square shape loop), the output MRS parameters are integrated values over $150^2 \cdot 100 \approx 2 \cdot 10^6 m^3$. This scale of measurement makes the MRS result comparable to the result of a pumping test commonly used in hydrogeology for characterizing aquifers.

MRS storage related parameters

The MRS water content is defined as the volume of water which is measured with the instrumentation, over the total volume sampled by the MRS sounding (Legchenko et al., 2002). The signals which are undetected with the actual instrumentation likely reflect bound water, i.e. water which is attached to the rocks due to the forces of molecular attraction. In sediments where unconnected and dead-end pores are negligible, this leads to the assumption that θ_{MRS} is comparable to the effective porosity n_e: $\theta_{MRS} \approx n_e$ (Vouillamoz et al., 2005). In unconfined aquifers, storativity is mainly described by a gravitational component represented by the specific yield S_y (the elastic storage is negligible). Specific yield and effective porosity have comparable values for coarse grain rocks. However, in fine-grained rocks and particularly in clayey materials $n_e > S_y$ and thus (Vouillamoz et al.,2007b):

$$\theta_{MRS} \approx n_e \geq S_y \tag{1}$$

In confined aquifer, storativity is described by an elastic component that is quantified by the storage coefficient. The storage coefficient can be calculated with the MRS parameters using its hydrogeological expression (Vouillamoz et al., 2007b):

$$S_{MRS} = \rho \cdot g \cdot \Delta z \cdot \left(\alpha + \theta_{MRS} \cdot \beta \right) \tag{2}$$

where ρ is the mass per unit volume of water, g is the acceleration of gravity, α and β are the compressibility coefficients of the water and the aquifer respectively and Δz is the saturated thickness obtained from MRS result.

MRS flow related parameters

As the well-known formulations used by hydrogeologists to estimate the permeability from the porosity and from the size/geometry of grains (e.g. the Hazen and the Kozeny-Carman formula), Seevers (1966) proposed to estimate the intrinsic permeability from θ_{NMR} and T_i . Indeed, the decay constant T_i of the MRS signal is linked to the ratio of the pore volume to the pore surface V_{pore}/S_{pore} . For hydrogeological applications, Legchenko et al. (2002) proposed to estimate the hydraulic conductivity K_{MRS} and the transmissivity T_{MRS} as:

$$K_{MRS} = C_k \cdot \theta_{MRS}{}^a \cdot T_i^b$$
$$T_{MRS} = K_{MRS} \cdot \Delta z \qquad (3)$$

Several studies assessed the values of exponents *a* and *b* in several geological contexts (Vouillamoz et al., 2007a). Usually $a = 1$ and $b = 2$ as proposed by Seevers (1966) and C_k is a parametric factor that need to be calculated comparing pumping test and MRS results at parameterization sites.

USEFULLNESS OF MRS FOR HYDROGEOLOGY

Comparisons between the geometry, the transmissivity and the storativity of saturated aquifers estimated by MRS and by borehole/pumping test indicate that MRS contribution to characterize aquifers down to about 100 meters deep is highly valuable in rocks that behave as non or poorly-consolidated aquifer, that are young sediments and sandstones, weathered and fissured hard-rocks, densely fissured or highly interstitial porous carbonates (Vouillamoz et al, 2007a). In rocks that behave as fractured aquifer, that are low density fractured crystalline basements and limestone, MRS is a useful complementary method but is not always effective for common engineering studies. Indeed, MRS is nowadays not appropriate to characterize saturated aquifers when the water content is less than about 1% (depending on the thickness and depth). For example, a fractured and weathered zone in a granitic rocks that is 5 meters width and 20% of specific yield have a water content integrated over the MRS sampled volume of 0.7% (use of a square loop of 100m per side). Moreover, fractured aquifers and karsts have usually to be characterized in 2 or 3D because of their structural heterogeneities. However, 2D measurements and interpretation are not yet easily accessible for engineering work, but experiences of interpolated 1D or 2D inversion of MRS (used with complementary geophysical methods) has been efficient to characterize weathered and fractured crystalline basement (Legchenko et al., 2004 and 2006) and to localize shallow water-filled karst conduit (Vouillamoz et al., 2003; Boucher et al., 2006). Note that the recent development of MRS spin echo methodology makes it possible to carry out measurements in presence of magnetic rocks that are quite common in hard rocks context (dykes, volcanic rocks) (Legchenko et al., in press).

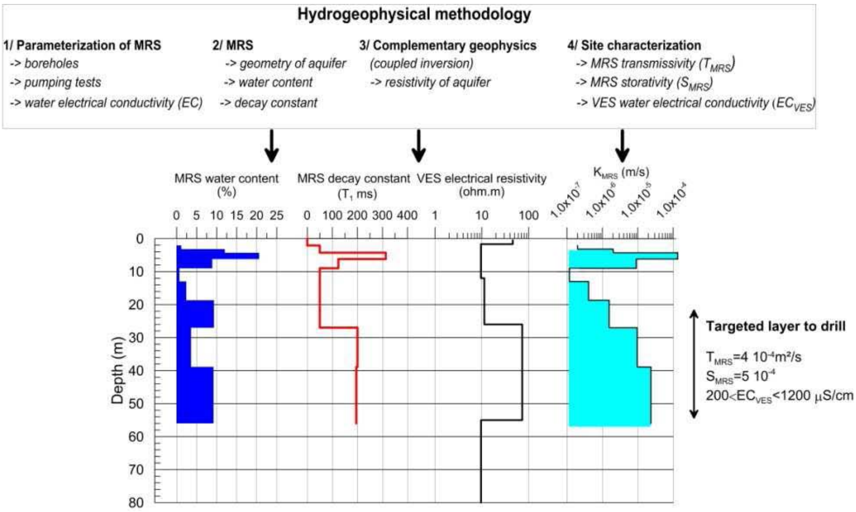

Figure 2. Use of MRS and VES in Myanmar (modified from Vouillamoz et al., 2007b).

For hydrogeological applications, experiences showed that the characterization of aquifer using MRS can efficiently be used:

- To improve boreholes setting in a variety of hydrogeological contexts including coastal aquifers (Vouillamoz et al, 2002; Vouillamoz et al., 2005; Vouillamoz et al, 2007b). The aquifer characterization is improved when MRS is used in the framework of a hydrogeological methodology and jointly with complementary geophysical methods. An example of joint use of MRS and vertical electrical sounding (VES) to implement boreholes in young alluviums of Myanmar is presented Figure 2. MRS and VES results are first compared to boreholes and pumping tests results to parameterize Equations 2 and 3, and then MRS and VES are jointly used to locate the best sites to drill (Vouillamoz et al., 2007b).
- To better constrain groundwater model (Boucher et al, 2009, Vouillamoz et al, 2008). MRS results can be used to analyse the distribution of specific yield and hydraulic conductivity and to choose the best range of acceptable values used to setup the numerical model.
- To estimate the groundwater recharge by supplementing observations of water table fluctuations (Vouillamoz et al., 2008), and by time laps measurements of MRS water content (Descloitres et al., 2008).

MRS estimate of water table

MRS estimates the depth of saturated layer that is the water table in unconfined aquifer, but MRS can not estimate the static water level of a confined aquifer. The average difference d between the water table measured in wells and estimated by MRS is $d \approx \pm 13\%$ (considering, Sandstone in Niger, Figure 3). MRS supplements but can not replace a monitoring well, but MRS can be useful in area with few existing data for estimating initial head condition in groundwater modelling for example.

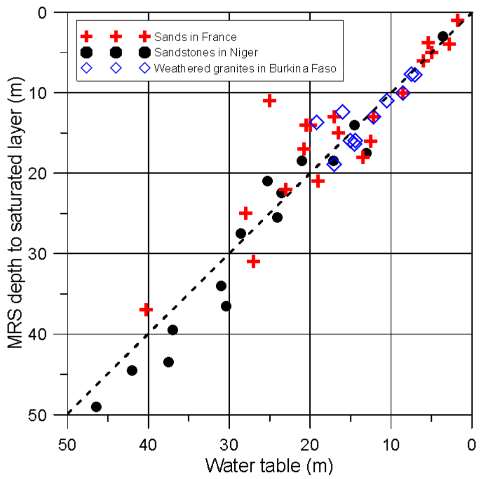

Figure 3. Examples of MRS estimate of the depth to water table (modified from Vouillamoz et al. 2005; 2007a).

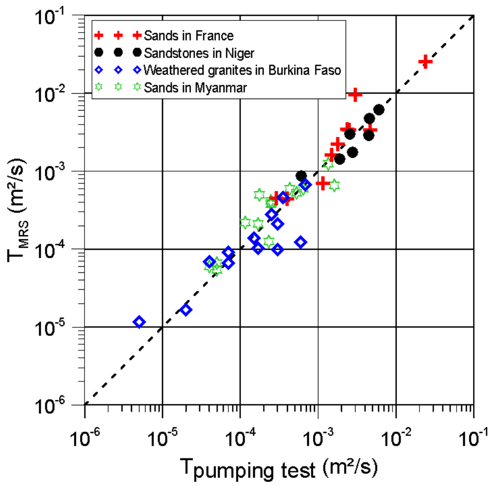

Figure 4. Examples of MRS estimate of the transmissivity (modified from Vouillamoz et al. 2005; 2007a; 2008).

MRS estimate of transmissivity

Equation 3 has been used in several geological contexts to estimate aquifer transmissivity (Figure 4). The appropriate C_k value is calculated comparing T_{MRS} and transmissivity obtained from pumping test interpretation (Vouillamoz et al., 2007a). The average difference d between transmissivity estimated from MRS and from pumping test is $-50\% \leq d \leq +100\%$. Note that this difference is comparable with the average uncertainty on transmissivity estimated from pumping test.

MRS estimate of storativity

As predicted by Equation 1, values of θ_{MRS} are usually higher than specific yield obtained from pumping test interpretation (Vouillamoz et al., 2005). However, usable relationship between MRS water content and specific yield has not yet been proposed mainly because dedicated studies still need to be conducted (Boucher et al., 2009). For confined aquifer, Equation 2 gave acceptable results in Myanmar with a difference between storage coefficient estimated from MRS and pumping tests results of $-2\% \leq d \leq +76\%$ (Vouillamoz et al., 2008).

CONCLUSION

One the one hand, MRS has already proved its unique interest to characterize saturated aquifers. On the other hand, MRS is a geophysical method that has common limitations in the field of geophysics (limited range of resolution, non-uniqueness of the solution…). Nowadays, the main limitation to the use of MRS is the electromagnetic noise that makes urban areas difficult to survey. But works are already in progress for reducing the vulnerability of MRS to electromagnetic noise. It will hopefully improve in a near future the capability of the method to investigate urban area, but also low porosity rocks as hard rock reservoirs and probably unsaturated zone. It will also make the 2/3D measurements more accessible to engineering work.

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abstract id: **315**

topic: **3**
Aquifer management

3.3
Geophysical, geological and geochemical methods in groundwater exploration

title: **Integrated groundwater flow system characterization in the Trans-Tisza region of Hungary**

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keywords: integrated methods, faults, fluid-potential anomaly, hydrocarbon entrapment, Hungary

INTRODUCTION

According to a regional scale hydrogeological study of the Great Hungarian Plain, Eastern Pannonian Basin of Central Europe (Tóth, Almási, 2001), near the villages of Berekfürdő and Kunmadaras a significant positive anomaly can be observed in the fluid potential field. The anomaly appeared as a “potential plume” on the NNW-SSE oriented (H4) hydraulic cross section of Tóth and Almási (2001, Figure 22). The authors explained the development of this phenomenon by hypothesizing the presence of structural elements, which cut through the thick and regionally extensive low-permeability (aquitard) Neogene strata. They supposed that these hypothetic faults facilitate water-upwelling and pressure dissipation from the overpressured Pre-Neogene basement into the shallower aquifers.

Basically, faults can both be barriers (seals) and conduits (leaks) for fluid flow. It depends on several factors, such as the petrophysical properties (porosity, permeability, capillarity) of the fault zone and the undeformed host rock, the relative orientation and dip-angle of the fault plane, the present stress state, as well as the spatial and temporal variation of these factors. The model of Matthäi and Roberts (1996) shows an example for the case when the distribution of fluid potential causes the spatial variability in a fault’s hydraulic behaviour. They distinguished different cross-sectional models of faulted sand-shale sequences characterised by pressure-driven fluid flow systems, and found that in those situations where the fluids upwelling along the high permeability fault can flow out of the fault into intersected sands, no fluid flow occurs across the fault. In this case, the high permeability fault is acting as a fluid flow direction dependent barrier.

The objective of the present work was to characterize the geological framework and particularly the faults, as well as the groundwater flow system in the surroundings of Berekfürdő, in order to explain the development of the fluid-potential anomaly.

THE STUDY AREA

The Study Area (Figure 1) is located in the Trans-Tisza Region of the Great Hungarian Plain, Eastern Pannonian Basin. The Pre-Neogene basement of this sedimentary basin is divided into a number of deep local basins and troughs. Lithologically, it comprises brittle flysch, carbonate and metamorphic rocks. Hydrostratigraphically, the Pre-Neogene formations make up one unit, the hydraulic properties of which cannot be established reliably due to insufficient data. The 100-7000 m thick semi- to unconsolidated clastic basin fill of Neogene age has been divided into five regional units based on chronostratigraphic divisions, lithologic facies types, and reported values of permeability (Tóth and Almási, 2001; Mádl-Szőnyi and Tóth, 2009). The lowermost unit of the basin fill is the Pre-Pannonian Aquifer with an estimated hydraulic conductivity of $K \approx 10^{-6}$ $m \cdot s^{-1}$, which is primarily due to tectonic fracturing and faulting. The superjacent Endrőd Aquitard is a regionally extensive but discontinuous unit of generally low-permeability ($K \approx 10^{-9}$ $m \cdot s^{-1}$) calcareous and argillaceous marls. The following Szolnok Aquifer shows a cyclic alternation of sandstones, siltstones and clay-marl beds of the prodelta facies characterized by hydraulic conductivity of $K \approx 10^{-7}$-10^{-6} ms^{-1}. It is regionally discontinuous and occurs only in the deep subbasins. The lithology of the next Algyő Aquitard ($K \approx 10^{-8}$–10^{-7} $m \cdot s^{-1}$) representing delta facies is sand-dominated above the basement highs, giving aquifer properties to the regional aquitard locally. Consequently, the regionally extensive Algyő Aquitard is leaky due to its sedimentological discontinuities and cross-cutting fractures and faults. The uppermost Great Plain Aquifer ($K \approx 10^{-5}$ $m \cdot s^{-1}$) is characterized by the good spatial connectivity of highly permeable bodies of silts, coarse sands, and gravels.

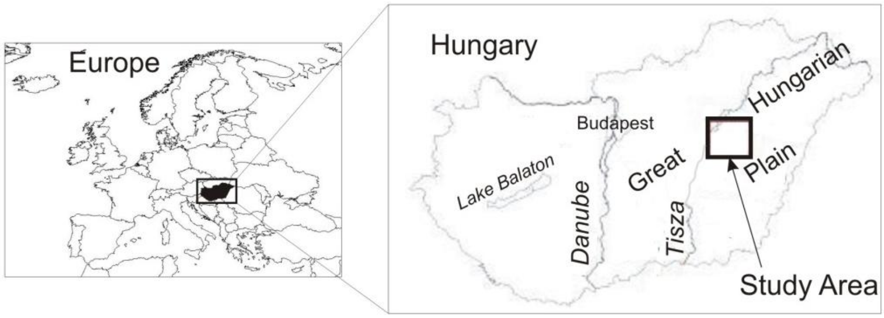

Figure 1. Location of the Study Area in Hungary, Central Europe.

Based on the interpretation of the observed subsurface fluid-potential patterns, Tóth and Almási (2001) have separated two superimposed and laterally extensive groundwater flow-domains characterized by different driving forces and water types in the Great Hungarian Plain. The lower domain of slightly saline water (TDS: 10–30 $g \cdot L^{-1}$) is strongly overpressured (10–35 MPa in excess of hydrostatic pressure), whereas the upper regime of fresh water (TDS: 0.4–2.5 $g \cdot L^{-1}$) is driven by gravity due to elevation differences of the topography (nearly hydrostatic pressure conditions). Communication between the two domains occurs by diffusion across geological strata and/or through discrete high-permeability structural and sedimentological discontinuities. The source of the saline (NaCl type) water (average TDS: 22 $g \cdot L^{-1}$, and Cl^-: 11.9 $g \cdot L^{-1}$) in the lower overpressured domain is probably the Pre-Neogene basement. On the other hand, in the Neogene hydrostratigraphic units $NaHCO_3$ type waters can be found, characterized by two orders of magnitude decrease in the TDS and Cl^- concentration compared to the waters of the Pre-Neogene basement (Mádl-Szőnyi, Tóth, 2009). Consequently, the appearance of Cl^- (above the 0.03 $g \cdot L^{-1}$ maximum value of infiltrated meteoric water) at shallower depths can be regarded as a natural tracer of the deep, basement origin water, and the mixing of the two water types.

DATA EVALUATION AND APPLIED METHODS

According to the study's objective, a wide range of data types were analyzed by applying geological, geophysical, hydraulic, and geochemical analyses.

First, 15 two-dimensional digital reflection seismic sections, as well as digital geophysical logs (spontaneous potential) were used to interpret the hydrotectonics and hydrostratigraphy of the Study Area. Additionally, lithostratigraphic subdivision data of Juhász (1992) were also applied during the hydrostratigraphic interpretation of the available well-logs. The structural interpretation was accomplished by creating two structural maps in 1700 ms and 400 ms depth, respectively.

Subsequently, archival hydraulic and hydrochemical data were analyzed in a depth interval extending from the Pre-Neogene basement to the shallowest appearance of the plume, in order to study the hydraulics and hydrochemistry of the Study Area. The data were collected from the original well documentation of government institutions and MOL Hungarian Oil & Gas Plc. The regrettably unfavourable quality and deficient quantity of data necessitated a profound culling, which consisted of the filtering and qualifying of hydraulic and water chemical data. The main selecting criteria were the (1) date of drilling, (2) date of measuring, (3) start of water or hydrocarbon production, and (4) type of measurement. Following these first steps of data processing, 61 hydraulic (pore-pressure and stabilized water level) data of 50 wells were chosen for further evaluation among 100 data of 64 wells.

During the hydraulic calculations pore pressure data were converted to hydraulic heads, and vice versa depending on which data was available. Afterwards, the results of the analyses were interpreted based on creating five p(z) profiles and two hydraulic cross sections.

From the numerous accessible hydrochemical parameters only the Na^+, Cl^-, and H_2SiO_3 data were chosen for further analyses, because these show the strongest correlation with the origin — Pre-Neogene basement or Neogene sediments — and the subsurface residence time of groundwater in the Study Area (Driscoll, 2003; Mádlné Szőnyi et al., 2005). As a result of data culling 184 water chemical analyses of 74 wells were selected among 233 analyses of 80 wells. The spatial distribution of these data was interpreted by creating hydrochemical cross sections, which did not show significant correspondence with the hydrogeological framework, and a depth distribution diagram of the standardized Na^+, Cl^-, and H_2SiO_3 values.

RESULTS

Based on the evaluation of seismic profiles, a north-south striking Pre-Neogene basement high located between Berekfürdő and Kunmadaras was identified (Figure 2).

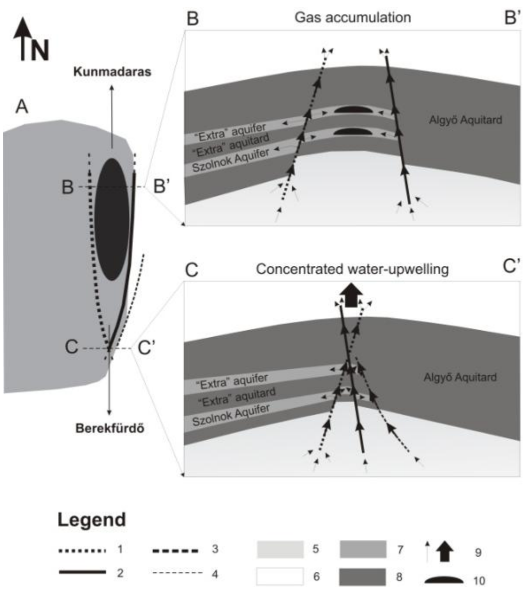

Figure 2. Diagram of the interpreted phenomena in the study area. Explanations: A — The Local Study Area in top view; BB', CC' — Cross sections from the northern and southern part of the local research area; 1, 2 — strike-slip master faults; 3 — reverse fault; 4 — trace of cross section; 5 — Pre-Neogene basement; 6–7 — aquifer units; 8 — aquitard units; 9 — fluid flow direction; 10 — gas field.

This basement high is bounded by two fault zones on its western and eastern margin (Figure 2).

These strike-slip faults are rejuvenations of basement normal faults, and both approach the land surface too. Additionally, they intersect each other to the south of Berekfürdő, in about -1200 m a.s.l. depth. Based on the seismic and well-log hydrostratigraphic analyses, beside the well-known aquifer and aquitard units of the Great Hungarian Plain (Tóth, Almási, 2001; Mádl-Szőnyi, Tóth, 2009) two more units could be identified on the Study Area (Figure 2). One of them is an ("Extra") argillaceous aquitard unit on the top of the Szolnok Aquifer, whereas the other is a ("Extra") sandy aquifer unit between the newly identified argillaceous aquitard and the Algyő Aquitard. These units are tectonically bounded by the strike-slip fault zones to the east and south, but their extent is unknown to the north and to the west. The pools of the Tatárülés-Kunmadaras gas field accumulated in the turbiditic sandstone groups of the "Extra" sandy aquifer unit and the Szolnok Aquifer located above the basement high, and between the two strike-slip fault zones.

The pressure-elevation profiles denote a deep source of hydraulic energy, which causes significant overpressure in the Pre-Pannonian Aquifer and Endrőd Aquitard, as well as consequently causes fluid-upwelling. Although, most of this energy is consumed during fluids flowing across the Endrőd Aquitard, moderate overpressure can be observed even in the Algyő Aquitard. Due to the quality and quantity of the available data, the pressure style of the Great Plain Aquifer is a little bit uncertain, but it might be characterized as close to hydrostatic. However, on the hydraulic cross sections stationary fluid flow field could not be established, partly because of the lack of data, and on the other hand because of the fluid potential reducing effect of gas and water production being typical of the Study Area. However, a boundary surface could be assigned. Below this boundary the system is overpressured, and above that the system is approximately hydrostatic within the limits of analytical error. The peak of this "overpressure-front" coincides with the basement high and the junction of fault zones in the south of Berekfürdő.

In the course of hydrochemical analysis the depth distribution of standardized Na^+, Cl^-, and H_2SiO_3 values could be interpreted. On one hand, the high H_2SiO_3 (max 226.2 mg·L^{-1}, standardized value: 2.73), Na^+ (max 23.4 g·L^{-1}, standardized value: 5.86), and Cl^- (max 36.1 g·L^{-1}, standardized value: 5.90) values beneath -1300 m a.s.l. depth refer to this water type having a deep, basement source. While on the other hand, the low Na^+ and Cl^- values (both 0-1.0 g·L^{-1}, standardized value: -0.88) above -1300 m a.s.l. depth indicate mixing with meteoric water.

The combined interpretation of the integrated geological, geophysical, hydraulic, and geochemical analyses have allowed the characterization of the groundwater flow system and the elucidation of the hydraulic role of those identified faults, which intersect each other near Berekfürdő. Furthermore, the presence of the thermal water at Berekfürdő, as well as the Tatárülés-Kunmadaras gas field was also explained.

On one hand, both fault zones are acting as a conduit for fluids in vertical direction. Consequently, the overpressure can dissipate from the basement along the fault, and at the same time causes water upwelling, as well as the development of the "potential plume" in the fluid potential field. On the other hand, both fault zones are acting as barriers for the transversal fluid flow, although the reasons are different respectively. The eastern fault (zone) impedes fluid flow across the fault plane, because a thick and homogeneous low-permeability sequence (Algyő Aquitard) was juxtaposed on the eastern side of the strike-slip fault zone against the Szolnok and “Extra” sandy aquifers on the western side (Figure 2B). Whereas, in the case of the western fault (zone), there is no fluid flow across the vertically conduit fault, because the ascending fluid flows out of the fault zone into the intersected sands of the Szolnok and the “Extra” sandy aquifer unit (Figure 2B). Eventually, these transversally barrier fault zones may act as lateral seals of the Tatárülés-Kunmadaras gas field, and might also ensure the active water pressure of the reservoir system.

The junction of the vertically conducting and transversally sealing fault zones represents the southern limit of the hydrocarbon bearing Szolnok and “Extra” sandy aquifer (Figure 2C), i.e. the gas field. At the same time, the junction of these faults causes more intensive water upwelling (Figure 2C), which induces the peak of the “overpressure front” near Berekfürdő. The Spa of Berekfürdő produces its thermal water from this overpressure peak or “potential plume”.

The hydrochemical conclusions have corroborated the results of the hydraulic interpretation. The depth distribution of the normalized Na^+, Cl^-, and H_2SiO_3 values confirming the NaCl-type water upwelling — with high H_2SiO_3 content — up to about -1300 m a.s.l. correlates with the basement faults, most of which do not approach the surface, but terminate upward around -1300 m a.s.l. On the other hand, this deeper saline water can mix with meteoric water at shallower depth due to the presence of the Pannonian or younger growth fault zones, which can recharge the deeper aquifers.

SUMMARY

The present work displays an integrated geological, geophysical, hydraulic, and geochemical analysis, which has resulted in the characterization of the Study Area’s groundwater flow system, and the hydraulic role of structural elements in it. In the Trans-Tisza Region of Hungary, basement fault zones approaching also the surface were identified and mapped on several seismic lines near Kunmadaras and Berekfürdő, while the heterogeneity of the Algyő Aquitard was established. Fluid potential data proved overpressure in the Pre-Neogene basement and indicated induced positive fluid potential anomaly (“potential plume”) also in the shallower Pannonian strata near Berekfürdő. The presence of NaCl-type water upwelling with high H_2SiO_3 content was confirmed. This observation correlates with the basement faults, most of which do not approach the surface. The deeper saline water is mixing with meteoric water at shallower depth. The identified faults, which attach to the basement high and approach the land surface, represent direction dependent control over the fluid flow systems, cause deep water upwelling and might contribute to the development of the petroleum fields of the Study Area.

ACKNOWLEDGEMENTS

The study was financed by the Hungarian Oil & Gas Company Plc (MOL Nyrt.) and based on their data.

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abstract id: **317**

topic: **3**
Aquifer management

3.3
Geophysical, geological and geochemical methods in groundwater exploration

title: **Use of geophysical methods for the assessment of migration of contaminants from the coal-mining waste dumps**

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keywords: coal-mining waste dumps, water contamination, georadar method, geoelectrical method

INTRODUCTION

Faculty of Geology, Geophysics and Environment Protection at AGH University of Science and Technology in Cracow (Department of Hydrogeology and Engineering Geology and Department of Geophysics) together with Faculty of Earth Sciences at Silesian University in Sosnowiec for more than a dozen years have conducted research on the application of hydrogeological and geophysical methods for monitoring of migration of different liquid contaminations in the geological medium (Golebiowski et al., 2010; Marcak, Tomecka-Suchon, 2009; Marcak, Golebiowski, 2006; Wzientek et al., 2005).

In the paper there is shown an attempt of correlation of the results of geophysical and hydrogeological research, which were conducted in the region of the selected mine waste dump in Upper Silesia. A strong impact of stored mine waste on mineralization of groundwater was observed in the area under investigation (Twardowska et al., 1988).

Nowadays in Poland, mineralization of groundwater is estimated mainly on the basis of laboratory analysis of physicochemical properties of water samples collected from the selected places. Such analysis allows to construct, among others, the maps showing variation of mineralization of groundwater in the examined area. In order to increase the accuracy of these maps, more places for collection of water samples should be designed. However such a solution is costly and time and work consuming. An alternative may be geophysical research, which gives continuous information about the distribution of anomalies in the geological medium. Among the wide range of geophysical methods, the most appropriate for monitoring of mineralization of groundwater are electric and electromagnetic techniques.

On the basis of laboratory analysis carried out by many researchers, e.g. Plewa and Plewa (1992), a relationship (1) was established between the increase in water mineralization, and the decrease in electrical resistivity of electrolytes, which is tantamount to the increase in electrical conductivity of solutions.

$$\rho_{fluid} = \frac{1}{\sigma_{fluid}} = \frac{10}{\sum\left(C_{ai}V_i f_{ai} + C_{ci}U_i f_{ci}\right)} \tag{1}$$

where: ρ_{fluid} [Ωm] – electrical resistivity of electrolytes, σ_{fluid} [S/m] – electrical conductivity of solutions, C_{ai}, C_{ci} [mol] – concentration of i-th anion and i-th cation in solution, V_i, U_i [$\Omega m \cdot cm^2 \cdot mol^{-1}$] – electrolytic mobility of anions and cations, f_{ai}, f_{ci} [-] – conductivity coefficient for anions and cations.

In 1942, Archie connected electrical conductivity of porous medium with electrolytic conductivity of liquid filling the porous space, by the relationship (Plewa and Plewa 1992):

$$\sigma_{geological\_medium} = \frac{1}{\rho_{geological\_medium}} = a\phi^m s^n \sigma_{fluid} \tag{2}$$

where: $\sigma_{geological\_medium}$ [S/m] – electrical conductivity of medium, $\rho_{geological\_medium}$ [Ωm] – electrical resistivity of medium, a [-] – tortuosity factor, ϕ [%] – porosity of medium, m [-] – cementation factor, n [-] – wettability factor, s [%] – fluid saturation.

For shallow geophysical research, carried out in a small area, it is correct to assume that the examined volume of the geological medium will be characterised by a constant value of tortuosity (a) and porosity (ϕ) factors, constant values of m and n factors and the assumption that the s value for the saturation zone is constant is also correct. Given the above assumptions, the values of $\sigma_{geological\_medium}$ and/or $\rho_{geological\_medium}$, measured with geophysical methods, will be, according to the formula (2), only functions of σ_{fluid}, thus functions of water mineralization.

Electrical permittivity of the geological media saturated with mineralized water with high value of electrical conductivity, is described by a complex number, in the following form (Plewa and Plewa 1992):

$$\varepsilon_{geological\_medium} = \varepsilon_{real} - i\varepsilon_{imag.} = \varepsilon_{real} - i\frac{\sigma_{geological\_medium}}{\omega\varepsilon_0} \quad (3)$$

where: $\varepsilon_{geological\_medium}$ [F/m] – electrical permittivity of medium, $\varepsilon_0 = 8.85 \cdot 10^{-12}$ [F/m] – electrical permittivity of vacuum, i – imaginary unit, ω [rad/s] – angular frequency.

For the range of frequencies used in engineering geophysical methods, it is correct to assume that $\varepsilon_{geological\_medium}$ is not a function of frequency ω. As it results from the relationship (3) also the value of the complex electrical permittivity of the geological medium should depend on the variations in electrical conductivity, thus depend on the amount and the mineralization of groundwater.

This short theoretical description, presented above, shows that the amount of water and, above all, the change in mineralization of groundwater will influence the change of electrical properties of the geological medium. Therefore, methods which base on the variation of mentioned properties ($\varepsilon_{geological\_medium}$, $\sigma_{geological\_medium}$, $\rho_{geological\_medium}$), where chosen for the geophysical research, i.e. electrical imaging technique and georadar method. Among various measurement techniques using in georadar method, constant-offset reflection profiling was chosen for the research. This technique uses reflected waves, and the reflection coefficient R [-] on surface dividing clear medium (aeration zone) and medium with changeable mineralization (saturation zone) is described as follow (Annan 2001):

$$R = \frac{Z_{aeration} - Z_{saturation}}{Z_{aeration} + Z_{saturation}} \quad where \quad Z = \sqrt{\frac{i\omega\mu_{geological\_medium}}{\sigma_{geological\_medium} + i\omega\varepsilon_{geological\_medium}}} \quad (4)$$

where: Z [Ω] – impedance of medium, μ [H/m] - magnetic permittivity of medium.

For georadar measurements it is correct to make the following assumptions for the relationship (4): magnetic permittivity μ has a constant value equal to the value for the vacuum, i.e. $\mu_0 = 4\pi \cdot 10^{-7}$ [H/m] and impedance Z is not a function of frequency ω. Given these assumptions, impedance Z will be a function of $\varepsilon_{geological\_medium}$ and $\sigma_{geological\_medium}$, so as it results from the formulae (2 and 3), R will depend on the amount and mineralization of groundwater.

HYDROGEOLOGICAL CONDITIONS

The above-ground mine waste dump, where the researches were conducted, has an area of 140 hectares and pollutions are stored on cone dumps (up to 350 m above sea level), settling ponds and spoil banks. The waste was supplied to the dump for a few dozens of years, till the year 2000.

The waste was stored without appropriate precautions. As a result water from precipitation infiltrated into the stored waste material and then to the ground. The penetration of water through the waste caused lixiviation of ions (mainly Cl^- i SO_4^{-2}), which had a strong impact on the physicochemical composition of groundwater. The water which infiltrates into the ground in the area of the dump drain off into the nearby streams.

Moreover, since 2003, in the selected area of the dump, coal has been reexploitated from the waste, which results in further contamination of the groundwater.

The geological medium in the surrounding of the dump is built of Quaternary and carboniferous formations. Carboniferous formations contain mudstone series and Upper Silesia sandstone series. Triassic formations (marls, sands and mudstones) occur locally, directly on carboniferous rocks. Neogen formations contain mainly loams and mudstones, locally with interbeddings of sands and sandstones. The Quaternary Period is represented by tills, dusts, peats, sands and gravels (Strzetelska-Smakowska, Hojka 2008).

In the region of the dump, within the Quaternary groundwater level, two aquifers, divided by poorly permeable clays, may be distinguished. The upper aquifer, fed by infiltration of water from precipitation, is built of river sands and glacier sands ($k = 2.31 \cdot 10^{-7} \div 1.83 \cdot 10^{-4}$ m/s). The groundwater table of this aquifer is located at the depths from 0.35 m to 8.2 m and its position undergoes significant seasonal changes (about 1 m on average). The flow of groundwater towards of streams valleys is observed. In the southern part of the dump a watershed occur. Alimentation of carboniferous formations occurs in the areas of outcrops and through the water-bearing Quaternary deposits. The main alimentation region comprises the area of the dump.

The quality of ground and surface water in the area of the dump is evaluated on the basis of local monitoring grid, which allows to observe the influence of the dump and reexploitation of the waste to the physicochemical composition of water. The monitoring system consists of 20 measurement points, i.e.: 5 piezometers and 8 household wells for examination of groundwater quality and 6 points in the streams and 1 in the drainage ditch for examination of surface water quality.

Unstable indicators, i.e. electrolytic conductivity and pH, are measured directly in the terrain. In the same time samples of water are collected and later submitted for detailed laboratory analysis (ICP-MS) to determine the macro-components (among others: Na^+, K^+, Ca^{+2}, Mg^{+2}, Fe^{+2}, Mn^{+2}, Zn^{+2}, Cl^-, SO_4^{-2}, HCO_3^{-2}).

Electrical conductivity of the geological medium is the most important physical value which can be examined by the proposed geophysical methods in the area of the dump. Therefore electrolytic conductivity of mineralized water, measured with hydrogeological methods was chosen for the correlation with the results of geophysical surveys. Spatial distributions of electrolytic conductivity of groundwater obtained in June 2009 (Fig. 1A) and in September 2009 (Fig. 1B) should be treated as a point of reference for the geophysical measurements carried out in July 2009.

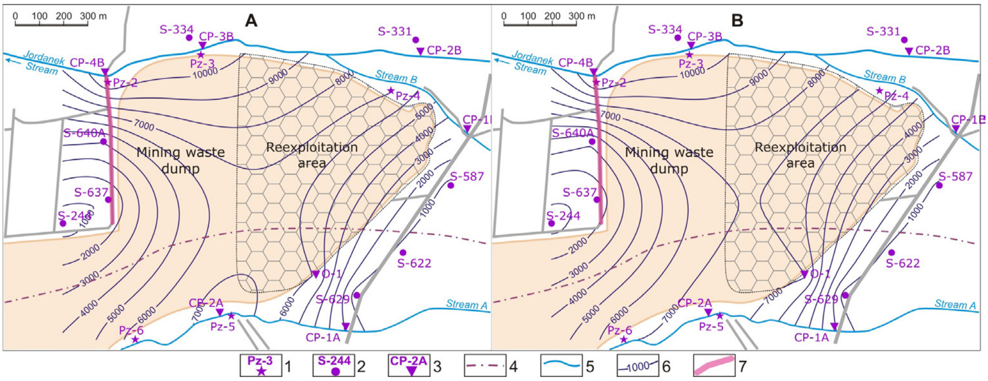

Figure 1. Spatial distribution of electrolytic conductivity of groundwater in the area of the dump: in June 2009 (A) and in September 2009 (B). Explanations: 1, 2, 3 — hydrogeological monitoring points: 1 — piezometers, 2 — household wells, 3 — surface watercourse; 4 — approximate course of the watershed, 5 — watercourses, 6 — conductivity isolines, 7 — profile for georadar and electrical imaging measurements.

GEOPHYSICAL MEASUREMENTS

The area of the dump, where a strong changeability of mineralization of groundwater was observed, was chosen for the geophysical research (Fig. 1). The measurements were carried out in July 2009 along one profile (Fig. 1) designed by the boreholes: Pz-2, S-640A and S-637. The geophysical research was conducted in two stages.

In the first stage, an examination of the near-surface zone in the area of the first water table was carried out (Fig. 2B). The measurements were conducted with georadar (GPR) method with the use of 500 MHz antenna, with the mean resolution of about 0.05 m and maximum depth penetration in grounds of about 5 m. The measurements, with the use of ProEx georadar, were carried out in the standard of reflection profiling and traces were recorded along the profile every 0.025 m. Digital processing of the radargrams and their visualisation were made with ReflexW computer program.

As it was discussed in the introduction, mineralization of groundwater influences the value of the reflection coefficient of the electromagnetic (georadar) wave. Therefore the level of water mineralization was examined by the analysis of reflection coefficients distribution. From the radargrams a time window around the first water table was cut out, i.e. from 20 ns to 35 ns (Fig. 2B). The envelopes (energies) for such a window were calculated on the basis of Hilbert transformation (Annan 2001). Then the values of envelopes were averaged vertically and horizontally to calculate the trend of the energy change (Fig. 2A – blue dots). In the last stage, the curve (3rd degree polynomial) was calculated to approximate the distribution of mean energies along the whole profile (Fig. 2A – red line). In order to correlate the results of geophysical and hydrogeological research, in Fig. 2A the results of measurements of electrolytic conductivity were shown (Fig. 2A – green lines).

In the surrounding of the piezometer Pz-2, where mineralization of groundwater is high, the high energies of the reflected GPR signals are observed. When we move away from the piezometer Pz-2, the energies of the GPR signals decrease rapidly. The character of the energy change (Fig. 2A – red curve) is similar to the curves representing the change in the values of electrolytic conductivity (Fig. 2A – green curves). Beyond the borehole S-640 low-amplitude fluctuation of the GPR energies is observed.

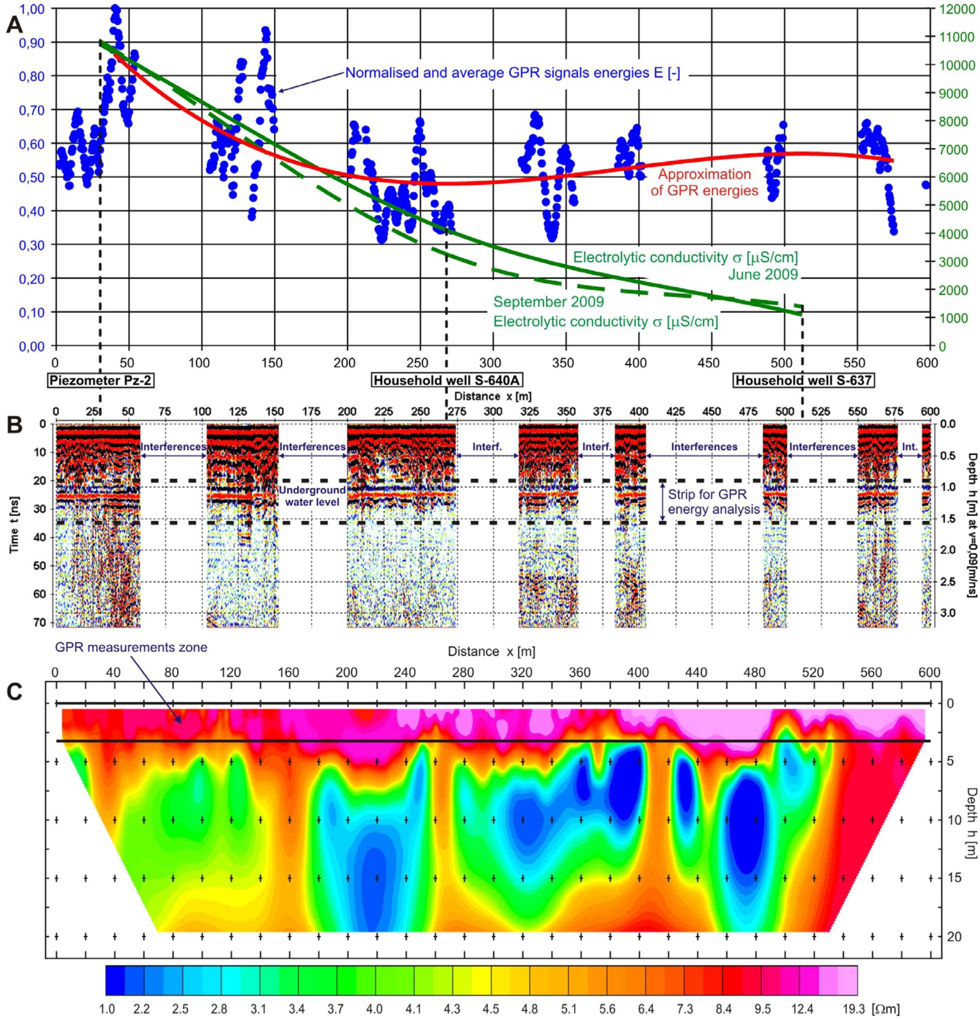

Figure 2. Results of the geophysical measurements: A) distribution of the georadar signals energies along the profile (July 2009) and the change of electrolytic conductivity of groundwater obtained from the hydrogeological measurements (June and September 2009); B) Radargram after processing – white vertical strips are removed zones with high interferences; C) Distribution of electrical resistivity along the profile (July 2009).

In the second stage, the measurements to the depth of about 20 m were carried out, in order to determine the distribution of deeper located, contaminated zones of the ground. On this stage, the surveys with electrical imaging were conducted with the use of multi-electrodes Lund Imaging device.

Electrical measurements were carried out with the following assumptions: constant distance between electrodes equal to 2.5 m, Schlumberger S measurement scheme, standard deviation 1 %, currents min. 50 mA and max. 200 mA. For the interpretation of the results, Res2Dinv software was used and Oasis Montaj program was used for graphical presentation of the resistivity cross-section (Fig. 2C). The cross-section in Fig. 2C is characterised by very low values of resistivity, varying from 1 Ωm to 20 Ωm.

The results of electrical imaging surveys show that in the examined area the geological stratification is strongly disrupted. Very low resistivity may indicate the presence of loam and sand-loam deposits highly saturated with water. One of the crucial factor which determines such low resistivity is undoubtedly, in the region under investigation, high mineralization of groundwater.

Resistivity in the shallow zone of the ground (to the depth of about 5 m), tends to increase in the direction towards the end of the profile, which confirms the changes which were observed for hydrogeological analysis and for the results of georadar measurements.

CONCLUSIONS

Laboratory examination of water samples, collected from the monitoring points, allow to determine, in a detailed way, physicochemical properties of water in selected places. Spatial distribution of physicochemical properties obtained on the basis of laboratory analysis has, however, certain limitations. First of all such analysis provide only information from the sampling points. These points are usually several dozens or even several hundreds of meters away one from another. Therefore spatial distribution of physicochemical properties of water is uncertain, because is the consequence of localisation of monitoring points, the density of points distribution and the depth from which the samples are collected. A solution is to complement the hydrogeological measurements with geophysical surveys, which allow the continuous examination of the geological medium, e.g. allow the continuous visualisation of changes of groundwater mineralization, between the monitoring points.

ACKNOWLEDGEMENTS

The works presented in the paper were financed by the Polish Ministry of Science and Higher Education as the grants no.: N525-398034 and N525-169335.

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abstract id: **324**

topic: **3**
Aquifer management

3.3
Geophysical, geological and geochemical methods in groundwater exploration

title: **Geophysical investigations for groundwater augmenting in sand dunes area, BinhThuan, Vietnam**

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keywords: geophysical tool, investigation, groundwater augmenting, monitoring well

INTRODUCTION

The study area is a driest part of Vietnam which extensive red-sand coastal dunes occur by mostly of hills and coastal plains with variable relief from west to east. The main objective of the present study was to delineate the subsurface distribution of groundwater in this sand dunes area — Binh Thuan, Vietnam by geophysical techniques. In addition to this result, the relationships between the surface/subsurface layer's parameters are proposed and shown to be useful in identifying new sites that are suitable for groundwater monitoring and exploitation wells on the studying area.

Geoelectrical methods are commonly employed in hydrogeological investigations, as they have been proven to be successful and are cost-effective. The direct current (DC) resistivity method is a popular tool for groundwater exploration, and usually the Schlumberger and Wenner layouts are preferred (Vertical electrical sounding — VES and Electrical profiling — EP). Like other geophysical methods however, resistivity data have a non-unique solution. Non-uniqueness of the interpretation makes it difficult to select the best model (i.e. that is closest to the real geological model). This non-uniqueness can be reduced by combining different geophysical methods.

In the present study, layered models have been obtained not only by using a stable interactive interpretation program but also by including other geophysical tools as well as magnetic prospecting (MP), magnetotelluric sounding (MTS), very low frequency electromagnetic method (VLF), transient electromagnetic method (TEM), magnetic resonance sounding (MRS) and seismic refraction (SR) for hydrogeological targets. The sites of prospecting and monitoring boreholes were located by the combinated geophysical interpretation data on the studying area.

OVERVIEW OF THE STUDYING AREA

The study area is located between 11°01'00 and 11°05'00 N, and 108°15'00 and 108°22'00 E (Fig. 1). The general climatic conditions in the coastal area are characterized by low rainfall and a long, hot, dry season. There is suitable agricultural land that can only grow crops during the very short wet season. Extensive red-sand coastal dunes occur throughout studying area. Geological units of the coastal sand dunes area of Binh Thuan are mainly Pleistocene sediments, consisting of marine-aeolian sediments of Phan Thiet formation (mvQII-IIIpt), alluvial-marine (amQII-III), and marine (mQI, mQIII) sediments. Pleistocene aquifers are unconfined but in some places groundwater is confined with low pressure head. Aquifer lithology is from fine- to medium-grained quartz sand, mixed with some silt and clay, of typical red color.

Underlying Quaternary and Neogene sediments are hard rocks of igneous and metamorphic origins like dacite-ryodacite with very low permeability which cannot be considered as likely aquifers. Groundwater is exploited through direct pumping where the aquifer emerges (Ta Zon, Bau Trang) or through shallow hand-dug wells. Surface water is only from rain-water collected on rooftops or by artificial reservoirs E and W of mount Bau Thieu but the quality of water there is not satisfactory (Fig.1).

Figure 1. The location of geophysical stations and profiles on the sand dunes studying area Binh Thuan, Vietnam (VES — Vertical Electrical Sounding; EP — Electrical Profiling; VLF — Very Low Frequency; MTS — Magnetotelluric Sounding; MP — Magnetic Prospecting; MRS — Magnetic Resonance Sounding; TEM — Transient Electromagnetic Method; SR — Seismic Refraction; LK1 — Well number 1).

METHODOLOGY

DC resistivity method: The acquisition and interpretation of Vertical Electrical Sounding (VES) data are based on assumptions that the earth is composed of a finite number of horizontally stratified, homogeneous and isotropic layers. In the application of VES to groundwater exploration, water resources management and water pollution studies, the concept of an isotropic, homogeneous and stratified earth is valid. The theory and practice of VES is well documented in the literature (Keller, Frischknecht, 1966; Zhdanov, Keller, 1994; Griffiths, King, 1986). The apparent resistivity for various electrode configurations can be computed from the expression for surface potential (V) and the current injected (I) into the ground through current electrodes using the expression:

$$\rho_a = K\frac{\Delta V}{I}$$

where: ρ_a — the apparent resistivity; K — a geometric factor that depends on electrode array; ΔV — the potential difference between measuring electrodes. he depth of investigation in the Schlumberger sounding configuration varies between 0.25 L and 0.5 L (Roy, Elliot, 1981).

Magnetic prospecting maps variations in the magnetic field of the earth that are related to spatial changes of structure or magnetic susceptibility in subsurface rocks. Sedimentary rocks generally have a very low susceptibility compared to igneous or metamorphic rocks that have higher iron oxide content, and so most magnetic surveys are designed to map magnetic basement. Interpretation of magnetic data is subject to the non-uniqueness inherent to all potential field methods. To locate the position and estimate the strength of the magnetic sources, the algorithms of reduction to the pole and combine with analytic signal were used.

The electromagnetic (EM) methods provide significant advantages for shallow geophysical exploration and useful for aquifer's location. Among these techniques, the Magnetic Resonance Sounding (MRS) and the Transient Electromagnetic Sounding (TEM) are used for hydrogeological structure and water content estimation. But, before using these tools, the tests measuring should used on the studying area for reducing the noise and increasing the signal for choosing optimum configuration. Datasets are proceessed and interpreted by modeling program for investigation of hydrogeological condition, as well as layering structure and aquifers (Lubczynski, Roy, 2004).

FIELD DATA ACQUISITION

Fourty-eight VES stations were conducted by Schlumberger configuration with maximum distance between current electrodes AB=1000 m to delineate the depth and thickness of the layers, so that the 10 proposed profiles in the area were covered. Those profiles are distributed on 3 sub-regions (mount BauThieu, NuocNoi pond and TaZon). All data were collected by a Terrameter SAS 300C and 4000. A pragmatic approach was used for data interpretation. The starting model of the electrical resistivity distribution is constructed and updated by hand after comparison of its calculated response with the observations. The values of resistivities or thicknesses of every layer of the model can be modified instantaneously by various steps from 0.1 to 1000 Ωm or meters for this approach. This procedure allows the interpreter to see directly on the screen the influence of each layer and to use his geological knowledge in order to choose the most suitable model for the hydrogeological problem.

Seven profiles of magnetic exploration in study area have been carried out using the ENVI-MAG proton magnetometter to measure the total intensity of the geomagnetic field. Those profiles are distributed on sub-region Bau Thieu and Nuoc Noi with 6500 m of total length. The observed data have been corrected the time variation, then subtracted the averaged value to obtain the magnetic anomaly field. The depths of the magnetic basement are estimated by the power-density spectrum technique.

Magnetotelluric method was used for understanding deep geological structure by period range 10^{-3}-10^{3} sec and by MT Geo-Instrument system.

VLF-WADI is used for collecting data along 1250m of profile1 with a 5 m spacing by frequency of VLF transmitter 19.8 kHz. 8000 m of seismic refraction by 3 profiles were carried out by Terraloc Mk6 24 channels for location of bedrock in the studying area. Two profiles of MRS by 12 stations were measured by Numis Plus equipment for water content estimation and 1200 m of TEM profile were investigated for aquifer location by Protem 57 instrument.

RESULTS AND DISCUSSIONS

The criterion for geoelectrical interpretation is based on the range of resistivity values for different kind of geological formations. As we know that the sediment of study area consists of mainly red sand and white sand. The samples of those materials are collected and measured resistivity and shown in the Tab. 1.

Table 1. The range of resistivity for sedimentary materials of studying area.

Sedimentary material	Resistivity in Ωm	Sedimentary material	Resistivity in Ωm
Red dry sand	1500–2500	White moistured sand	200–400
Red moistured sand	300–600	White saturated sand	40–100
Red saturated sand	80–150	Moistured clay	20–40
White dry sand	1000–1600	Saturated clay	10–20

The result of VES and EP interpretation give useful information regarding the water table.There are two sub-regions in the studying area were chosen for their groundwater potential on the basis of geoelectrical investigations. The first is the sub-region TaZon where the water table is at 40–50 m. The second sub-region is NuocNoi where the water table is at 50m (Fig. 2). Ground water in the aquifers is fresh because the values of resistivity calculated by geoelectrical data are about 20 Ω·m.

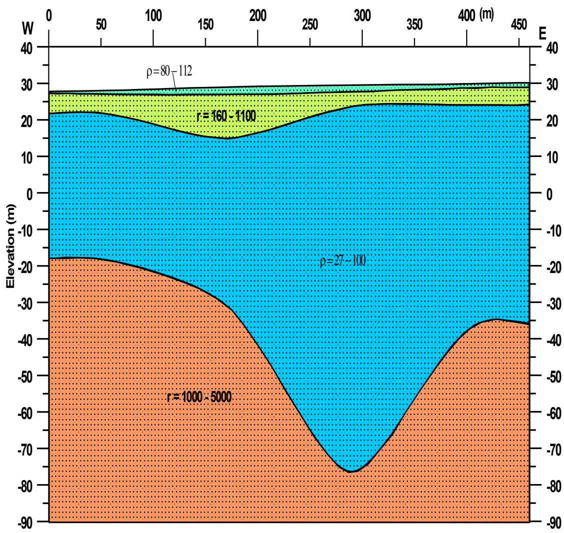

Figure 2. The geoelectrical cross-section by Vertical Electrical Sounding (VES) data for sub-region Nuoc Noi. (Aquifer = third layer = 27-60 Ω.m.).

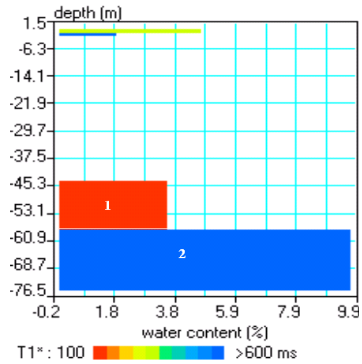

Figure 3. The inversion of MRS for 40/10 station (water content for aquifer1=3.6% and aquifer2=9.8%).

The magnetotelluric sounding curve has been modeled by a 1D structure consisting of 7 layers. The two first layers are identified as sand and fractured dacite by 28–140 Ω.m and 45–120 m.The depths of the magnetic basement are estimated by the power-density spectrum technique and we show that the depth to the magnetic basement in Nuoc Noi varies from about 50 to 150 m. The MRS and TEM data were processed and interpreted by modeling program for investigation of hydrogeological condition as well as layering structure and aquifers. There are two aquifers of groundwater (Fig. 3). The shallow aquifer is located from 20–40 m of depth with poor groundwater (3.6% of water content) and the second aquifer is located from 60–90 m of depth with a good potential groundwater (9.8% of water content). The complex geophysical interpretation by electromagnetic data shows that the MRS and TEM are good correlation tools for location and assessment of aquifer on sand dune area.

The seismic refraction investigation was carried out by means of a 8,000 m long section for the depth to bedrock determination. Fig. 4 shows the fragment of cross seismic section in Binh Thuan (Giang et al., 2006). The interpretation of the seismic data indicates the occurrence of the ryo-dacitic bedrock at depths between 60 and 140 m below ground level, and the occurrence in the sand deposits of a potential aquifer of the same thickness.

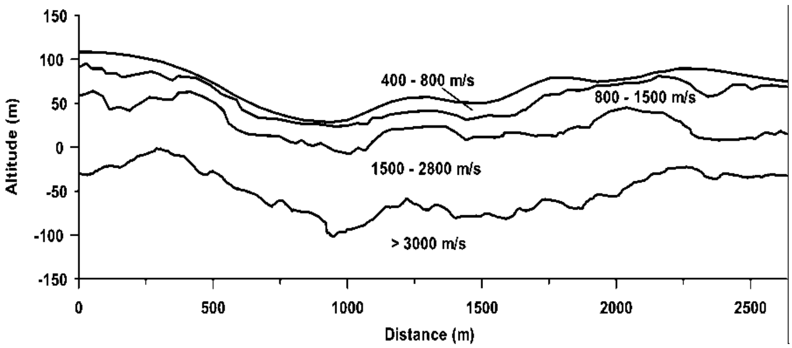

Figure 4. The fragment of 8000 m seismic cross-section on studying area (the values of seismic velocity >3000 m/s indicate basement = ryodacit rock).

The shallow geological structure for sand dunes area Binh Thuan, Vietnam is determined by complex geophysical interpretation on the basis of datasets by geoelectrical , electromagnetic, magnetic and seismic techniques. There are two aquifers which are located by MRS, TEM, VES in sediments and the basement (bedrock) is located by SR and MP. The results of geophysical investigation show the sites for suitable making wells. There are 6 monitoring and prospecting wells which made in the period 2005–2007 year (Thoa et al., 2006) For example the well LK1 which is located by coordinator: 11°03'30"N; 108°21'30"E and made in November 10-28, 2007 by 95.8 m of depth. There is a potential aquifer which consists of medium- coarse sand, located from 46 to 71 m of depth.

The investigation included the acquisition and interpretation of existing data, acquisition of geophysical surveys, topographic, geological and hydrogeological maps, aerial and satellite photos, precipitation data, groundwater physio-chemical parameter measurements and groundwater sampling for water quality and isotopes analyses (Bono et al., 2004) show that pH = 4.79–8.42; temperature =26–34°C; electrical conductivity =50 – 1,500 µS/cm for surface and groundwater on the studying area. Then there is suitable for carrying out Management of Aquifer Recharge (MAR) project on the typical sand dunes area in Binh Thuan, Vietnam (Dillon, 2002). During the period of 162 days pumping test, they supplied 220 m^3/day for residents using in 2007 year of good groundwater quality.

CONCLUSIONS

- The geophysical techniques have played an important role in understanding the hydrogeological conditions for studying area. The complex geophysical interpretation by using VES, TEM and MRS show the optimal techniques for aquifers location and the MP with SR are good combination for basement investigation.
- The most important for geophysical application to this kind of dry sand at the surface of the studying area is to choose a suitable period for collecting data, i.e. during the rainy season for good contact of materials by using VES, EP, SR and during the dry season can be use TEM, MRS, VLF and MP.
- There are two aquifers which are located by complex geophysical interpretation data for hydrogeological conditions on sand dunes area. The shallow aquifer (10-25 m of depth) is limited of groundwater and more sensibility of pollution from surface water, but the deeper aquifer (40-80 m of depth) is potential of groundwater augmenting in this area. The results of geophysical investigation are proved by 6 monitoring, prospecting and supplying wells on the studying area.

ACKNOWLEDGEMENTS

The research is supported by MOSTVietnam (DTDL 2004/07), UNESCO IHP 2004-2007.

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abstract id: **346**

topic: **3**
Aquifer management

3.3
Geophysical, geological and geochemical methods in groundwater exploration

title: **3D aquifer characterisation: integrating depositional facies architecture and downhole geophysical logs to map heterogeneity and salinity in the Leederville Aquifer, Perth, Australia**

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keywords: 3D aquifer characterisation, depositional facies architecture, salinity distribution, downhole geophysical logs, western Australia

Groundwater management of heterogeneous sedimentary aquifers can be difficult due to complex patterns of porosity distribution, groundwater flow and recharge. In such cases a combination of depositional facies architecture and downhole geophysical logs can be used to characterise the aquifer. Depositional setting, interpreted from available drill core, can help predict the geometry and distribution of porous sedimentary units. 3D interpretation and correlation of porous sedimentary units using downhole gamma-ray logs is also aided by the application of depositional facies models. 3D salinity distribution, calculated from downhole resistivity logs, can be used to highlight preferential flow and recharge patterns. We present a 3D model of the Leederville Aquifer, a heterogeneous sedimentary aquifer located in the northern Perth metropolitan area, Western Australia, where this approach has been applied (Fig. 1).

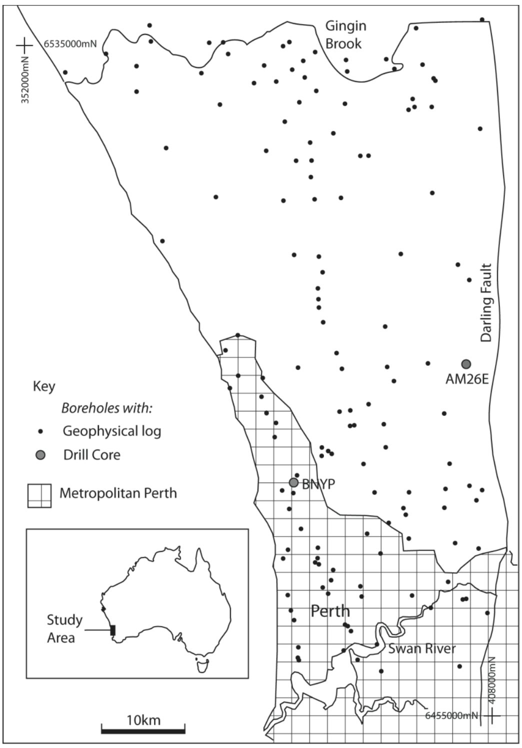

Figure 1. Map showing study area and borehole locations.

The Leederville Aquifer sediments comprise interbedded sand and silt with geological heterogeneity on scales from a few mm to several km. Previous work by the Western Australia Department of Water has identified an irregular salinity distribution that reflects the complexity of recharge and flow patterns. The aquifer is a vital groundwater resource that provides 20% of Perth's water supply and artificial recharge is being trialled in the aquifer as a groundwater management tool. It is one of several sedimentary aquifers within an extensive aquifer system, and is composed of ~300m of Early Cretaceous sedimentary strata deposited in the Perth Basin following break-up of India and Australia, currently divided into 3 members according to geophysical signature. The aquifer is semi-confined and recharge occurs north of Perth where overlying confining beds are absent.

Facies analysis based on sedimentary logging of two cores (140 and 190m long) though the Leederville Aquifer led to the identification of ~20 lithofacies, including clean well-bedded sands, bioturbated silty sands, heterolithic silty sands and silt. These lithofacies are grouped into seven associations that we interpret as representing deposition in tidal, fluvial and shoreface settings in an overall tidally influenced deltaic system (Fig 2). Tidal sand bodies are sand flats with sheet geometry, while fluvial sand bodies are lenticular channel fills and lobate crevasse splays (Fig. 3b). The tidal and fluvial associations have distinct gamma-ray signatures that we have used to map the distribution of these associations in ~180 boreholes across the basin. The tidal signature is common throughout the study area, while fluvial signature is confined to the eastern margin of the basin (Fig. 3a).

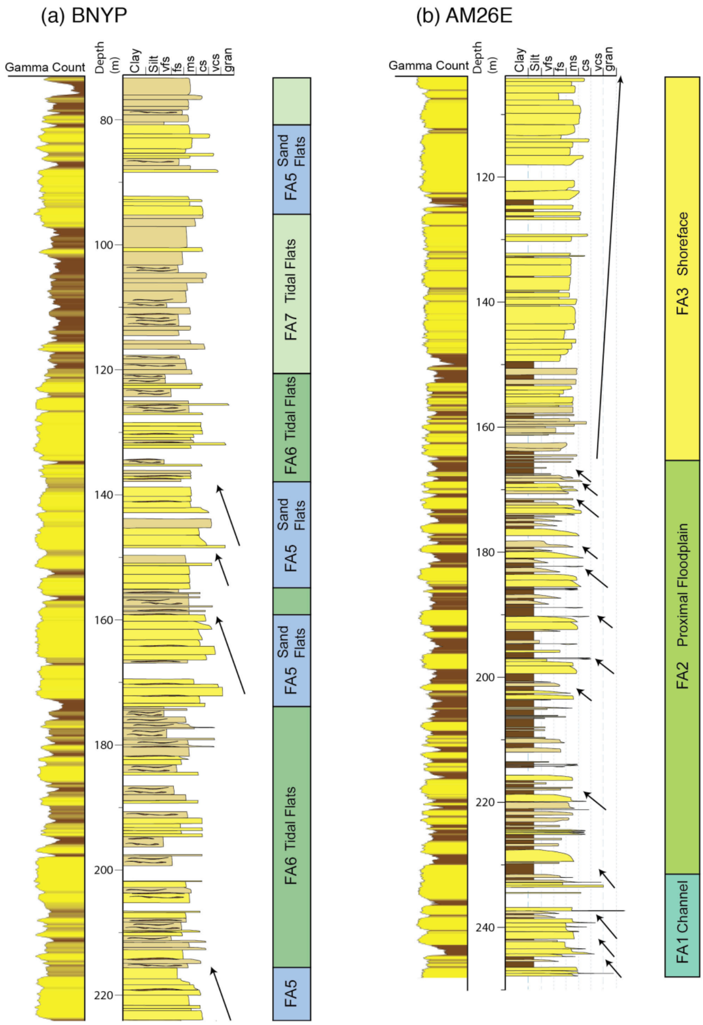

Figure 2. Graphical sedimentology logs of drill cores (a) BNYP and (b) AM26E (dark brown – silt, light brown – silty sand/sandy silt, yellow – sand) showing grainsize trends (arrows) and interpreted facies associations FA1 to FA7. Accompanying gamma-ray logs showing blocky tidal signature and zig-zag fluvial signature.

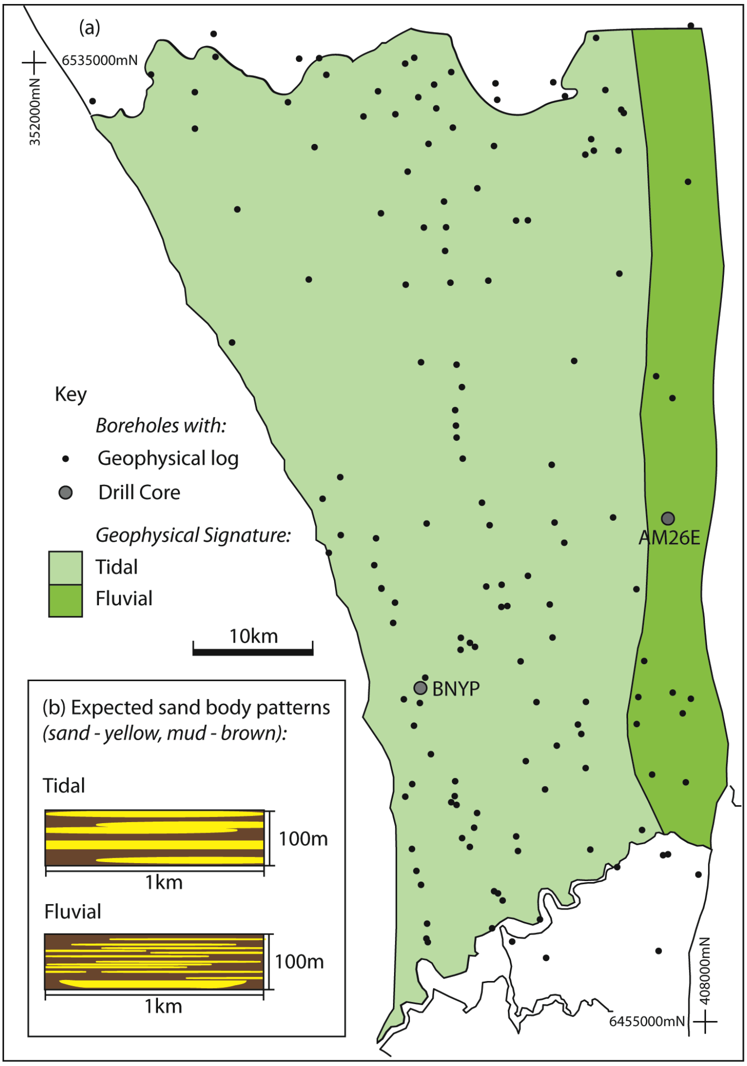

Figure 3. (a) Map showing zones of tidal and fluvial geophysical signature. (b) Cross sections showing expected heterogeneity.

Borehole gamma-ray logs were categorised, interpreted and correlated in 3D, and we outline zones (~10km wide and ~100m thick) of uniform geophysical signature. We redefine the geophysical signature of the three geological members, recognising lateral changes in signature due to variation in depositional setting. Isopach modelling has helped identify previously unrecognised faults and an improved structural model for the aquifer has been constructed, suggesting increased connectivity between the Leederville and overlying and underlying aquifers. The relationship between formation resistivity and pore-water salinity has been established, and synthetic salinity logs have been used to recognise hydrofacies and map a network of water-quality bodies in 3D. Ultimately these geological and salinity models will provide a basis for reassessment of the existing Department of Water numerical groundwater management model.

abstract id: **377**

topic: **3**
Aquifer management

3.3
Geophysical, geological and geochemical methods in groundwater exploration

title: **Integrated hydrochemical assessment of the carbonate aquifer of the Ivanšćica Mountain**

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keywords: carbonate aquifer, hydrochemistry, major cations and anions, stable isotopes, tritium

INTRODUCTION

Groundwater is the dominant source of drinking water in Croatia. The main carbonate aquifers are situated in karstic part of Croatia. Also, some smaller but very valuable carbonate aquifers are situated in Panonian part of Croatia. Environmental isotopes such as $\delta^{18}O$, $\delta^{2}H$ and ^{3}H and chemical data represent powerful tool to determine the origin of water, water dynamics, the storage properties of karstic catchments (Maloszewski et al., 2002; Einsiedl, 2005; Katz et al., 2001). The stable isotopes ($\delta^{18}O$ and $\delta^{2}H$) and tritium are particularly suitable for tracing the origin of water in the hydrological cycle because they are constituents of water molecules (Maloszewski et al., 2002). The chemical data and environmental isotopes in combination with conventional hydrogeological methods provide additional information on investigated area. The Mt. Ivanšćica, mainly built of Triassic dolomites and limestones, is situated in the north-west part of Croatia and represent the main drinking water resource for the Ivanec town and surrounding settlements. The catchment area of about 6 km² is drained by four springs: Žgano Vino, Bistrica, Beli Zdenci and Šumi (Fig. 1).

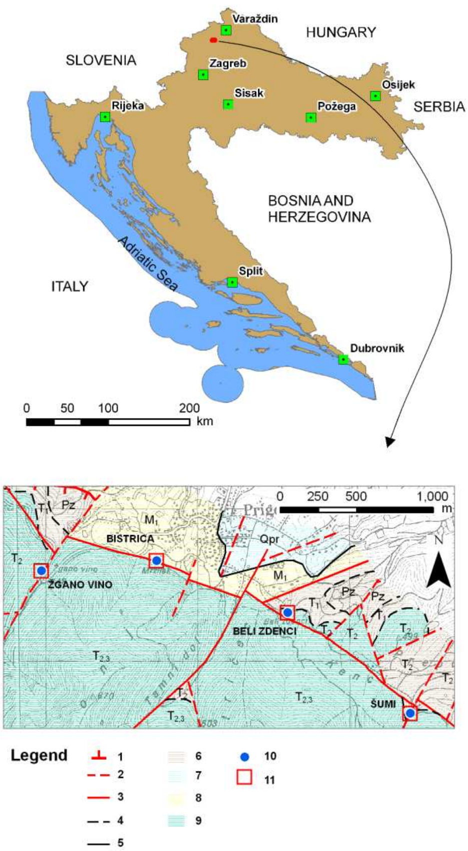

Figure 1. Location and hydrogeological map. 1 — reverse fault; 2 — supposed fault; 3 — fault; 4 — supposed geological boundary; 5 — geological boundary; 6 — Paleozoic (Carbon – Perm), lower and middle Triassic sediments, Pz, T_1, T_2, — dominantly impermeable rocks; 7 — Quaternary proluvial sediments, Q_{pr} — permeable rocks; 8 — lower Miocene sediments, M_1 — dominantly impermeable rocks; 9 — middle and upper Triassic sediments, T_2, $T_{2,3}$ — permeable rocks; 10 — spring; 11 — intake.

During the hydrogeological investigations for determination of the sanitary protection zones of springs, environmental isotopes and chemical data were used as additional tool for better characterization of groundwater renewability, circulation and geochemical evolution.

HYDROGEOLOGICAL SETTING

The study area (Mt. Ivanšćica) is located in the north-west part of Croatia (Fig. 1). Ivanšćica is the highest mountain in this area with the highest peak 1061 m a.s.l. The mean annual precipitation is about 1200 mm/a, and the mean air temperature is 10.4°C.

The mountain is built of Carbon-Perm, Triassic, Cretaceous, Miocene and Quaternary sediments (Šimunić et al., 1979; Šimunić et al., 1983; Šimunić, 1992). The oldest Carbon-Perm sediments are clastic deposits which are generally impermeable. Lower Triassic silts, shales and sandstones, as well as middle Triassic volcano-sedimentary complex, are also dominantly impermeable rocks. Carbonate rocks of middle and upper Triassic age are dolomite and limestone which are the main aquifer. Cretaceous clastic carbonate sediments, as well as clastic and volcanic rocks of Miocene age, are also impermeable rocks. The permeable rocks of Quaternary age are proluvial sediments mainly found on slopes.

The catchment area of about 6 km^2 is drained by four springs: Žgano Vino (Fig. 2b), Bistrica (Fig. 2a), Beli Zdenci and Šumi, which are situated on the NW side of the mountain. The springs were formed on the fault zone which is the contact between permeable carbonate sediments and impermeable sediments. The water from the springs is tapped for the water supply system of Ivanec town and surrounding settlements. The highest mean yield has Bistrica — 60 l/s, Žgano Vino and Šumi follow with 20 l/s, and the lowest mean yield has Beli Zdenci — 4 l/s.

a)

b)

Figure 2. Photos of a) Bistrica and b) Žgano Vino.

METHODS

Groundwater was sampled from all springs in July and September 2008 and in February 2009. Prior to taking water samples from individual springs, the following parameters were measured “in situ” by probes of WTW company: EC, TDS, T, pH, turbidity and oxygen content in waters. At the Hydrochemical Laboratory of the Department of Hydrogeology and Engineering Geology — Croatian Geological Survey, the concentrations of the basic anions and cations were measured. The content of chlorides, sulphates and nitrates were measured by ion chromatograph of the LabAlliance company, whereas the concentrations of orthophosphates and ammonium were measured by the spectrophotometer DL/2010 of the HACH company. The concentrations of calcium, manganese, sodium and potassium were measured by the atomic adsorber of the Perkin Elmer company. The content of HCO_3^- was determined by titration. The results for ions were processed using the Netpath software. Data quality was further assessed using the charge balance between the sum of cations and anions (expressed in meq/l), which was always <±5%.

The ratios of stable isotopes of δD and $\delta^{18}O$ in sampled water were measured at the Joanneum Research Forschungsgesellschaft mbH Institute of Water Resources Management (WRM) Hydrogeology and Geophysics in Graz, Austria and tritium was measured at Hydrosys, Budapest, Hungary.

RESULTS AND CONCLUSIONS

According to major cations and anions of the spring waters, they belong to the CaMg-HCO_3 hydrochemical type. This is the primary water type which is principally derived from dissolution of carbonate minerals (calcite and dolomite) that compose the aquifer.

The spring water EC values vary from 408 to 439 µS/cm (Fig. 3).

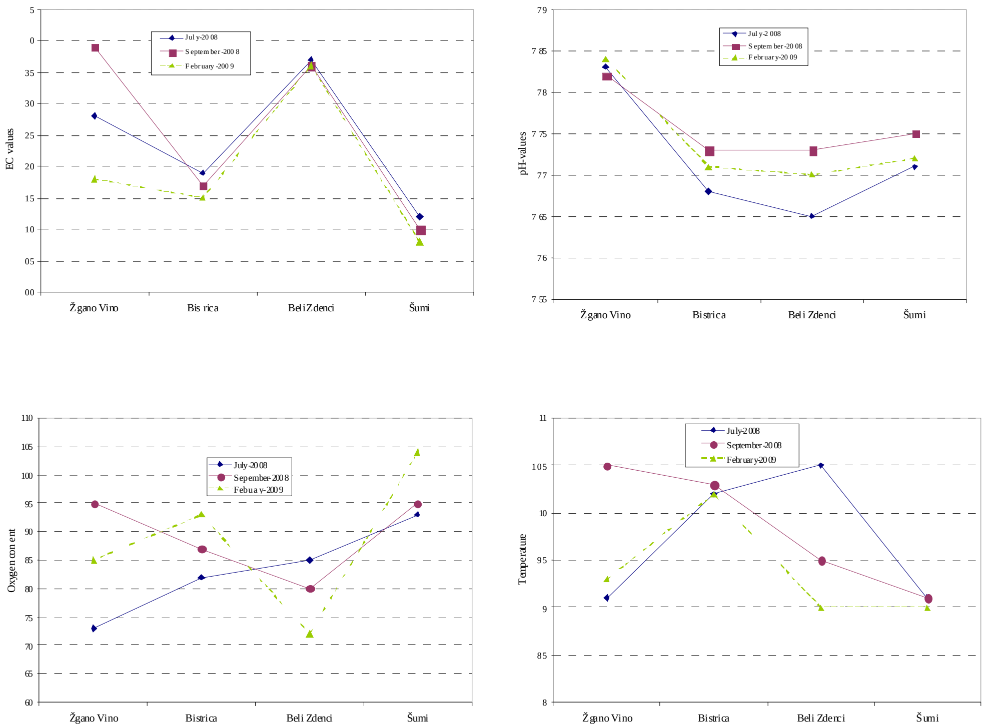

Figure 3. Distribution of EC, pH, oxygen and temperature in spring waters.

The highest values were measured in the spring water of Žagano Vino and Beli Zdenci and the lowest in the other two springs. It was observed that the EC values were uniform in all springs throughout the monitored period. The water temperatures at the springs were in accordance with the annual air temperature of the springs recharge area. In the karst areas, it prevails quick and turbulent groundwater flows, and the water temperature of the spring can be considerably influenced by seasonal changes in air temperature (Goldscheider, Drew, 2007). In the investigated area the water temperatures are uniform as EC values throughout the monitored period. Uniform distributions of EC and T indicate a low degree of underground krastification.

Spring waters are characterized by very low concentrations of nitrate, sulfate and chloride. Concentrations of nitrates vary from 3.5 to 5 mg/l (Fig. 4). Sulfate concentrations are between 4 to 7.5 mg/l and chloride concentrations vary from 1.7 to 2.6 mg/l. Sampled spring waters have not been affected by anthropogenic influence in catchment areas. Concentrations of ammonium and phosphate were below detection limit of the instruments. The spring waters are not micro-biological polluted.

a) b)

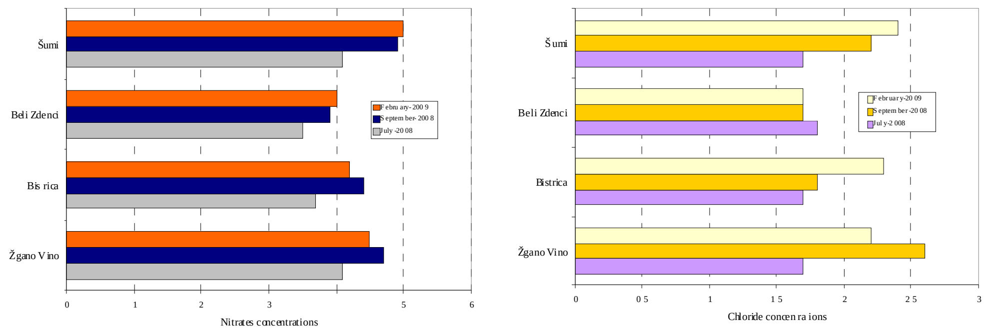

Figure 4. Distribution of a) nitrates, b) chloride.

The measured hydrogen and oxygen ratios of sampled spring waters lie on or near the LMWL and clearly are derived from local precipitation that substantially homogenized in the under-ground (Fig. 5).

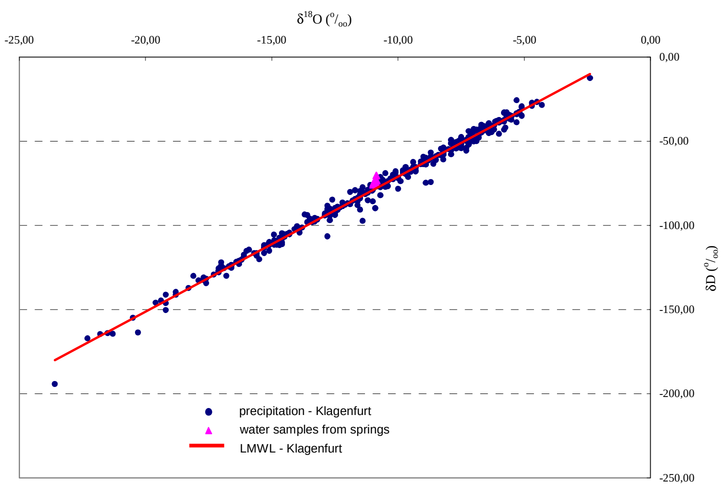

Figure 5. Stable isotope composition of water samples collected from springs relative to the meteoric water line for Klagenfurt.

The most depleted ratios of $\delta^{18}O$ were measured in the waters from spring Šumi (Fig. 6). In general, the spring which recharge is at the higher altitudes where temperatures are lower precipitation will be isotopically depleted (Gat, Gonfiantini, 1981; Clark, Fritz, 1997; Maloszewski et al., 2002; Einsiedl et al., 2009; Land, Huff, 2010). Large variations in ratios of $\delta^{18}O$ were not observed in sampled spring waters (Fig. 6). Also, the discharges of the springs are uniform through the monitored time.

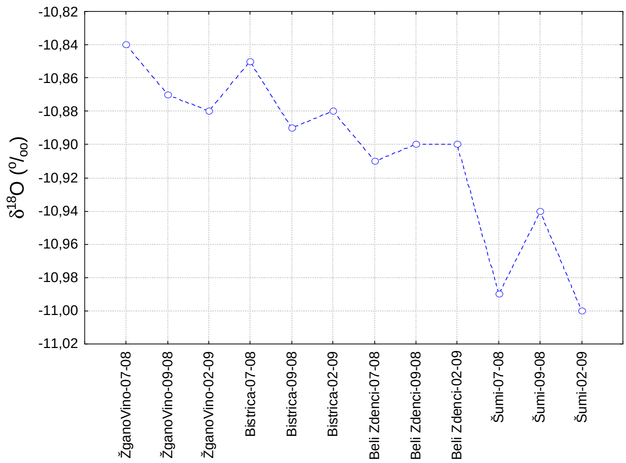

Figure 6. Distribution of $\delta^{18}O$ in sampled spring waters.

The lowest tritium content was measured at spring waters of Beli Zdenci. It varies from 3.9 TU (in July) to 5.8 (in February) (Fig. 7). The measured ^{3}H concentrations suggest a mixture between submodern and recent recharge at that spring (Clark, Fritz, 1997). Also, very low concentrations of ^{3}H were measured at spring Bistrica (Fig. 7). The highest values were measured in spring waters of Šumi. They varied from 9 (in July) to 11 (in February) TU (Fig. 7). The variation of the spring discharge was from 21.3 l/s to 25 l/s. The tritium content and ratio of $\delta^{18}O$ of the spring Šumi indicate groundwater renewability by precipitation from higher altitudes.

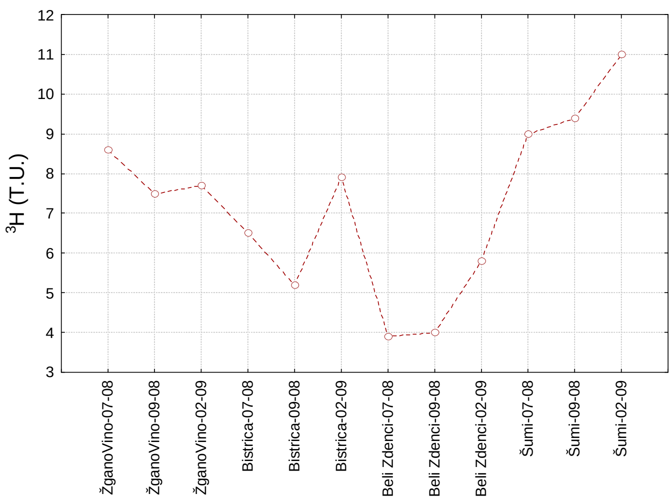

Figure 7. Distribution of tritium in sampled spring waters.

The measured hydrochemical and isotopical data of the investigated area showed that the underground system of the springs is a good mixer, consisting of a regularly distributed network of fractures with absence of conductive channels. Also, the underground system has large storage volume. In the process of defining the protection zones for the springs, particularly during the definition of the II. zone of sanitary protection, these data helped.

ACKNOWLEDGEMENTS

The research was carried out in the framework of the research project of the Croatian Ministry of Education, Science and Sports: Basic hydrogeological map of Croatia.

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abstract id: **452**

topic: **3**
Aquifer management

3.3
Geophysical, geological and geochemical methods in groundwater exploration

title: **Heterogeneity characterization to identify hydrofacies in Barreiras Aquifer, Rio de Janeiro State, Brazil**

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keywords: hydrofacies, aquifer characterization, Barreiras Formation, Brazil, hetereogeneity

ABSTRACT

The Barreiras Formation deposits, which occur on the northern coast of Rio de Janeiro- Brazil, in the onshore portion of the Campos Basin, are usually composed by tabular layers of sandstones, interbedded with mudstone lenses, associated to braided rivers deposits. The present study consisted of establishing a bridge between techniques for sedimentary and hydraulic characterization of the Barreiras granular aquifer, poorly studied, but widely used for urban and industrial water supply. In this study, sedimentological and permoporous tests were conducted in two outcrops, in order to characterize the heterogeneity, to define hydrofacies and to evaluate the quality of the Barreiras aquifer. As a result, it was recognized that the deposits are predominantly composed of muddy sandstone (labeled as lithofacies Aca and Am), and in minor proportion of sandy mudstones (lithofacies La). The sandstone lithofacies has low permeability, with hydraulic conductivity ranging between 10^{-4} to 10^{-5} cm/s, and is defined as hydrofacies 1, comprising the reservoir layers of the Barreiras aquifer. The mudstone lithofacies has a hydraulic conductivity between 10^{-5} and 10^{-8} cm/s, and is defined as hydrofacies 2, representing hydraulic barriers to the groundwater flow. According to these results, the Barreiras aquifer is characterized as a poor aquifer, with low permeability, differing from the typical braided stream deposits (recognized as good reservoirs) due to a high concentration of clay, possibly introduced by post-depositional processes such as mechanical infiltration of clays, feldspars weathering and bioturbation.

INTRODUCTION

Advances in the study of granular reservoirs, due to increased demand for exploitation of fluids, has led to the consolidation of a multidisciplinary approach. The stratigraphic and sedimentological studies applied to hydrogeology, based on techniques originally developed in the hydrocarbon industry, result in the concept of hydrofacies (Faccini et al., 1999), which are defined as sedimentary bodies interconnected with similar hydraulic properties (Anderson et al., 1999). The relationship of lithofacies and hydrofacies can be quantitatively assessed using outcrops accessible and good exposure, allowing detailed in situ mapping and laboratory measurements of the permoporous aspects of rock formations. Once a geological unit outcrop stratigraphical aspects and lithofacies are similar to the aquifer, it can be regarded as an analogue of this aquifer. It representsmaterials readily available for the study of 3D geometry and in situ measurements of hydraulic parameters on a detailed scale (Klingbeil et al., 1999).

The results of integrated studies aiming to characterize the hydrofacies allow the understanding of water groundwater flow, besides characterizing the heterogeneity of the aquifer. Such studies, besides providing an improvement in productivity, also offer important collaboration for the protection and remediation of groundwater resources due to contamination.

In this context, the present study consisted of establishing a bridge between techniques for sedimentary and hydraulic characterization of Barreiras Formation deposits, important source of freshwater for rural populations in the regions of occurrence. The Barreiras Formation deposits occur throughout more than 4000 km along the Brazilian coast, In the area of study, located in Rio de Janeiro State northern coast, emerse portion of Campos Sedimentary Basin (Fig. 1), are usually composed of tabular sandstone layers, interbedded with mudstone lenses, and are associated to braided rivers deposits.

Campos Sedimentary Basin comprehends low altitude tablelands; alluvial and coastal plains, corresponding to cenozoic sedimentary deposits, partially consolidated, and loose neocenozoic sediments.

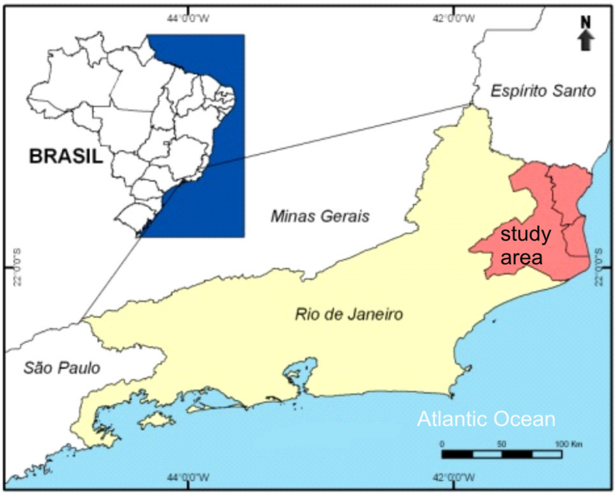

Figure 1. Location of study area in Rio de Janeiro State.

METHODS

In the present study, sedimentological and permoporous tests were conducted in two outcrops according to Klingbeil *et al.* (1999), as shown in Figures 2 and 3. In both outcrops, section Barra de Itabapoana and section Córrego Sucupira, two sandstone lithofacies are identified: a sandstone with cross stratification (Aca) and a massive sandstone without apparent structures (Am), and a lutite-mudstone (La). The sandstone facies predominate in relation to the pelitic one. The most representative lithofacies is Am, which represents 63% of the deposits.

Laboratory and field tests were carried out in order to define porosity and hydraulic conductivity according to methods by Ezzy *et al.* (2006), Elrick *et al*., (1989) and Fetter (2001) and textural aspects of Barreiras Formation sediments, to characterize heterogeneity and define hydrofacies (Anderson *et al.*, 1999; Anderson, 1989) and to evaluate the reservoir quality of the Barreiras aquifer (Dickinson, 1970; Folk, 1980).

RESULTS AND CONCLUSIONS

Sedimentary deposits are predominantly composed of muddy sandstone (lithofacies *Aca* and *Am*), and secondarily of sandy mudstones (lithofacies *La*). The muddy sandstones are quartzose and present about 30% of clay content, due to post-depositional processes that obliterated the primary porosity. The porosity is dominantly secondary, mainly by shrinkage of the clay material (Beard and Weyl, 1973).

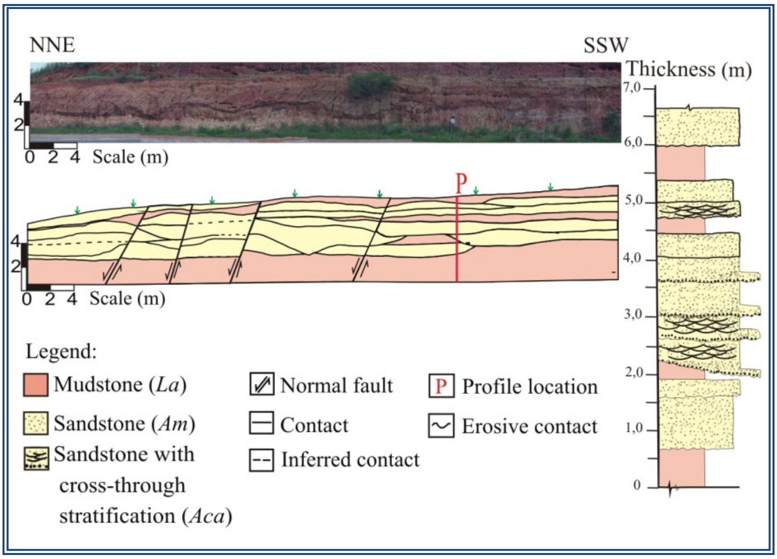

Figure 2. Photo mosaic interpreted and lateral facies of the section Córrego Sucupira.

The lutite sandy lithofacies present distinct sedimentary and hydraulic characteristics. In *Am* and *Aca* facies the values of hydraulic conductivity, porosity and concentration of clay were very similar, clearly distinguished from facies *La*, in general, with lower values of hydraulic conductivity and effective porosity and higher concentration of clay and greater total porosity (Fig. 4).

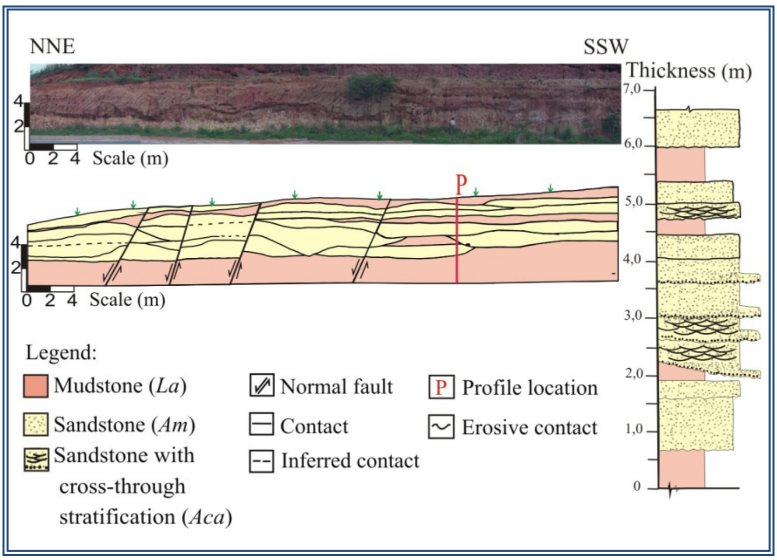

Figure 3. Photo mosaic interpreted and lateral facies of the section Barra Itabapoana.

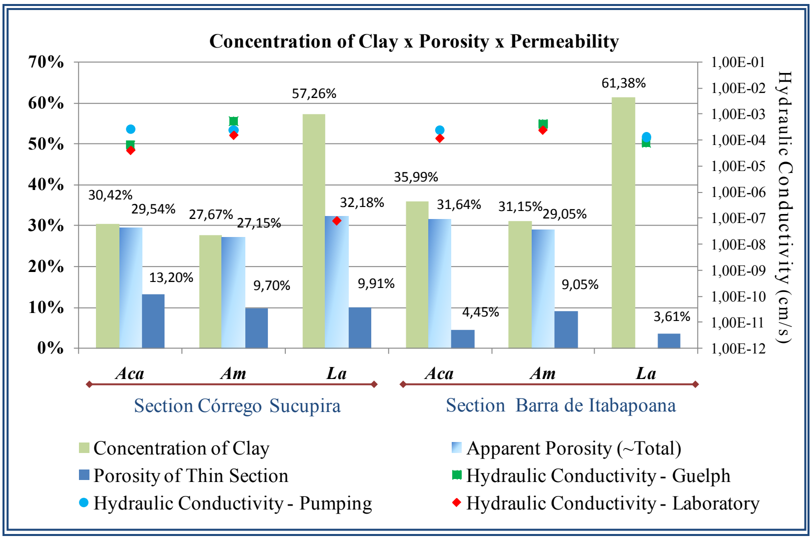

Figure 4. Bar graph with the concentration of clay and porosity (~ total) and dots with the values of hydraulic conductivities obtained with laboratory (variable head permeameter) and field (Guelph permeameter and pumping) tests.

The average values of hydraulic conductivity of each facies were calculated from the averaged values of laboratory tests (X axis), infiltration and pumping tests, as shown in Table 1.

From the characterization of porosity and permeability of lithofacies it was possible to define two hydrofacies in both sections of the aquifer Barriers, hidrofácies 1 and 2, as Table 2 and Figure 5.

Table 1. The mean values of hydraulic conductivity (K) of facies Aca, Am and La.

Facies	Variable Head Permeameter K (cm /s)	Infiltration Tests (Guelph) K (cm /s)	Pumping Tests K(cm /s)	K (cm/s)
Aca*	6.75×10^{-4}	6.54×10^{-5}	2.49×10^{-4}	3.30×10^{-4}
Am**	1.45×10^{-4}	2.37×10^{-4}	2.41×10^{-4}	2.08×10^{-4}
La***	7.61×10^{-8}	7.76×10^{-5}	1.30×10^{-5}	3.02×10^{-5}
Relationship of facies	Am ≥ Aca >La	Am>Aca≥La	Am ≥ Aca≥La	Am ≥ Aca>La

* Aca (sandstone with cross stratification);
** Am (sandstone massive);
*** La (mudstone massive).

Table 2. Hydrofacies defined according to and lithofacies and hydraulic conductivities and their variation, compared with Zappa et al. (2006).

Hydrofacies	Description	Associated facies	Mean K (cm/s)	Range K (cm/s)	Zappa et al., (2006) K (cm/s)
1	muddy sandstone *laminated or without apparent structure*	Aca e Am	2.69×10^{-4}	$10^{-4} - 10^{-5}$	$10^{-1} - 10^{-2}$
2	sandy mudstones	La	3.02×10^{-5}	$10^{-5} - 10^{-8}$	***

*** Without reference.

The hydrofacies 1 consists of the lithofacies Aca and Am formed by poorly sorted argillaceous sandstone, quartz, with or without cross bedded apparent structure. It consists of layers with extensive sub-tabular lenses, with good connection between the sandy strata. It has a mean hydraulic conductivity of 1.53 $\times 10^{-4}$ cm/s, ranging from 10^{-4} to 10^{-5} cm/s, and average porosity of 29.35%, consisting generally of secondary porosity, with pores randomly distributed. This hydrofacies relates to the reservoir layers of the Barreiras Formation.

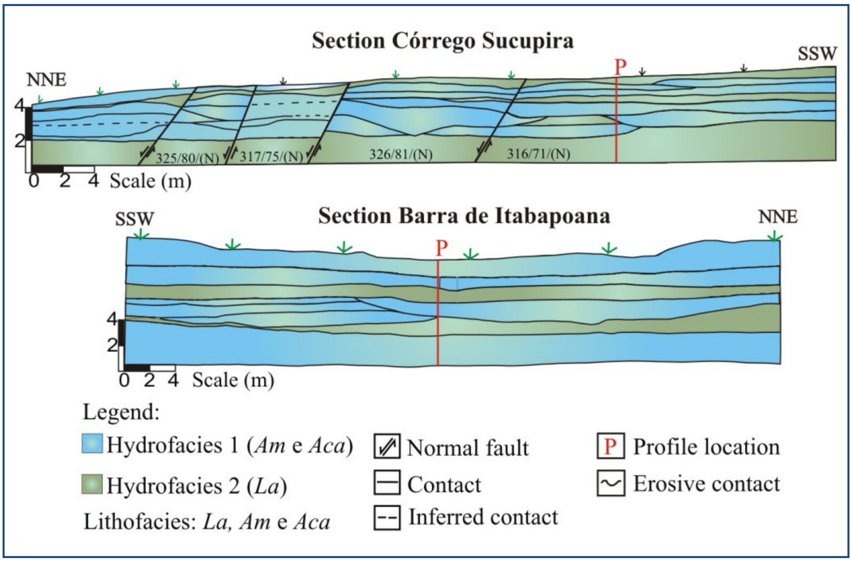

Figure 5. Hydrogeological sections of the sections Córrego Sucupira and Barra Itabapoana, with their hidrofacies.

The hydrofacies 2 consists of the facies La, formed by sandy mudstones, with 70% clay content, less permeable than hidrofácies 1, since mean hydraulic conductivity is equal to 6.92 x10-5cm/s ranging from 10^{-5} to 10^{-8} cm/s. Occurs in areas with lower degree of bioturbation and without the influence of faulting. The hydrofacies 2 can be considered as layers that behave as aquitards, acting as hydraulic barriers in Barreiras Formation.

The results of hydraulic conductivity obtained in a hidrofácies 1 differ from those obtained in similar hydrofacies in braided fluvial deposits, up to two orders of magnitude (Table 2). According to these results, the Barreiras aquifer is characterized as a poor aquifer, with a low permeability, differing from the typical braided stream deposits, generally recognized as good reservoirs (Zappa *et al.*, 2006), due to a high concentration of clay, introduced by post-depositional processes such as chemical weathering of feldspars, mechanical infiltration of clays and bioturbation, typical of tropical climates.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the funding and support from FAPERJ – Fundação de Amparo à Pesquisa do Estado do Rio de Janeiro and CAPES – Coordenação de Aperfeiçoamento de Pessoal de Nível Superior.

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abstract id: **481**

topic: **3**
Aquifer management

3.3
Geophysical, geological and geochemical methods in groundwater exploration

title: **The SkyTEM method, a high resolution mapping tool for hydrogeological investigation**

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keywords: helicopter-borne geophysical method, hydrogeological mapping, groundwater resources, aquifer extension and vulnerability

INTRODUCTION

The SkyTEM helicopter-borne transient electromagnetic system is developed in Denmark and designed for hydrogeological and environmental investigations. Since 2004 the system has been intensively used in Denmark for large scale mapping of groundwater resources and worldwide, more than 150.000 line km of airborne data has been collected with the SkyTEM system. The method has shown its ability in mapping shallow geological structures as well as deep buried aquifers related to coarse-grained sediments or structural elements in the subsurface. The system is a substantial element in the Danish national mapping of groundwater resources - including investigation of aquifer extension and vulnerability. At this stage no SkyTEM projects has yet been carried out in Poland, but the method is proposed as a powerful tool for future geological and hydrogeological mapping here as well.

The presentation will include a description of the SkyTEM method and results from selected cases.

THE SKYTEM SYSTEM

The SkyTEM system is a helicopter borne time domain system designed to provide electromagnetic sounding data of similar quality as is possible with high quality ground based TEM systems.

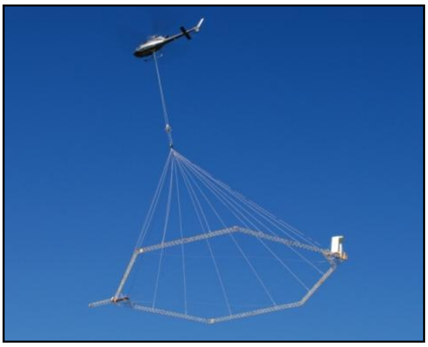

Figure 1. Picture showing the SkyTEM system in operation (Photo: SkyTEM ApS).

The SkyTEM equipment is carried as an external sling load independent of the helicopter's electrical system. The transmitter loop is mounted around the perimeter of the lightweight lattice frame, while the receiver of the vertical Z-component is rigidly mounted in a null-position with respect to the transmitter loop. This ensures a well defined geometry at all times. A unique feature of SkyTEM is the capability of operating in a dual transmitter mode. Detailed information of shallow structures is obtained in Low Moment (LM) mode, while information in depth is obtained in High Moment (HM) mode.

The system is "one-time calibrated" and there is no drift in the instrumentation, and therefore regular excursions to high altitude to monitor the bias response are not necessary.

The system provides calibrated electromagnetic data over a wide time range and has excellent lateral and shallow resolution combined with a depth of exploration of up to 400 m in favourable geological settings.

THE SKYTEM RESISTIVITY MAPPING CONCEPT

A SkyTEM survey project basically includes airborne data acquisition, data processing through several steps and imaging of the results.

Data are collected along parallel flight lines, which within Danish groundwater mapping procedures normally are planned with a line spacing of 180–250 metres.

When mapping close to urbanized areas, influence on electromagnetic geophysical measurements from man-made installations must be anticipated. During data processing, SkyTEM data influenced by non-geological structures are removed before the final inversion and interpretation is performed.

From the high density data along the flight lines, TEM soundings are averaged at a distance of 20-30 meters, which makes it possible to apply advanced inversion techniques such as 1D Laterally Constrained Inversion (1D-LCI) (Auken et al., 2000). For each TEM sounding, a 1D resistivity model is calculated. The LCI technique implies that the parameters of the resitivity models are linked during inversion and their mutual divergence constrained within specified limits. The LCI technique has proven valid in sedimentary geological environments and leads to a significant improvement of model resolution especially in the deepest part of the models i.e. at late times, where TEM data can be heavily influenced by background noise (Auken et al., 2004).

The final result of the 1D-LCI data inversion can be visualized either as horizontal slices for specific level intervals or as vertical sections. Figure 2 shows a vertical section with 1D-LCI resistivity models and information from boreholes within a distance of 100 meters from the profile. Also seen in the section, is a calculated depth of investigation depicted as upper and lower limits (grey lines). This is only indicative but suggests (in this case) penetration depths up to 200 metres.

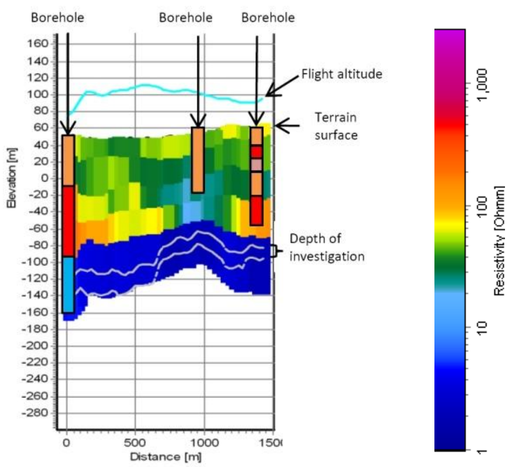

Figure 2. Image of the subsurface illustrated by a vertical section of 1D resistivity models shown as colorized bars. Information from boreholes are shown with red colors indicating sand- or gravel deposits and brownish colors clayey sediments. Light blue color corresponds to older tertiary clay deposit.

The resistivity of specific sediment- or rock types thus makes it possible to interpret the results in a hydrogeological perspective. Typical resistivity levels for Danish conditions are shown in Table 1.

Table 1. Resistivity levels [ohmm] for typical Danish deposits (HydroGeophysics Group, 2003).

Deposit	Resistivity
Clay till	20–50 (typical 40)
Alluvial sand and gravel	> 60
Paleogene clay	1–12
Chalk deposits	> 80 (typical)
Saline groundwater	< 10

To illustrate the SkyTEM resistivity mapping concept used in a hydrogeological perspective, a general example is presented in Figure 3. In this case limestone and sand/gravel deposits (both highly resistive) constitute aquifers with groundwater stored in fractures and pore holes. In this case the clayey sediments (low resistivity) will reflect the delimitation of aquifers due to its low hydraulic conductivity. It should be noted that the SkyTEM method is also able to map the presence of saltwater. This is of great importance in coastal areas or where pumping causes intrusion of saltwater affecting the groundwater quality.

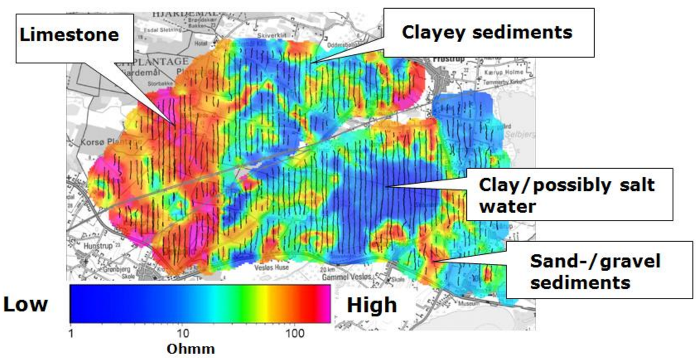

Figure 3. Horizontal slice of 1D resistivity models based on 360 line kilometers of SkyTEM data. The image represents resistivity values within a depth interval of 20–30 meters.

Two recent SkyTEM examples from the Danish national groundwater mapping program are presented in the following. These and other SkyTEM cases of relevance concerning groundwater issues will be included in the final oral presentation.

LARGE SCALE MAPPING ON THE ISLAND OF FUNEN

In 2007 the Environment Centre of Odense commissioned a large scale SkyTEM survey of roughly 650 square kilometers covering an area of special groundwater interests on the Island of Funen (central part of Denmark, small map Figure 4). The results have added valuable information to existing geophysical surveys and borehole information on the island, and will constitute an important basis for a hydrogeological model in the area. Figure 4 shows the average resistivity between 50 and 60 metres b.s.l. The subsurface resistivity distribution shows regional sedimentary structures including structures that are interpreted as eroded valleys within the subsurface Tertiary clay deposits. Also note the area with high resistivity in the southern part of the map (marked with a circle). This area is interpreted as a possible aquifer consisting of sand and/or gravel and is now a subject for further investigations. Thus, investigation drilling is carried out at selected locations to support the hydrogeological interpretation of the SkyTEM resistivity survey.

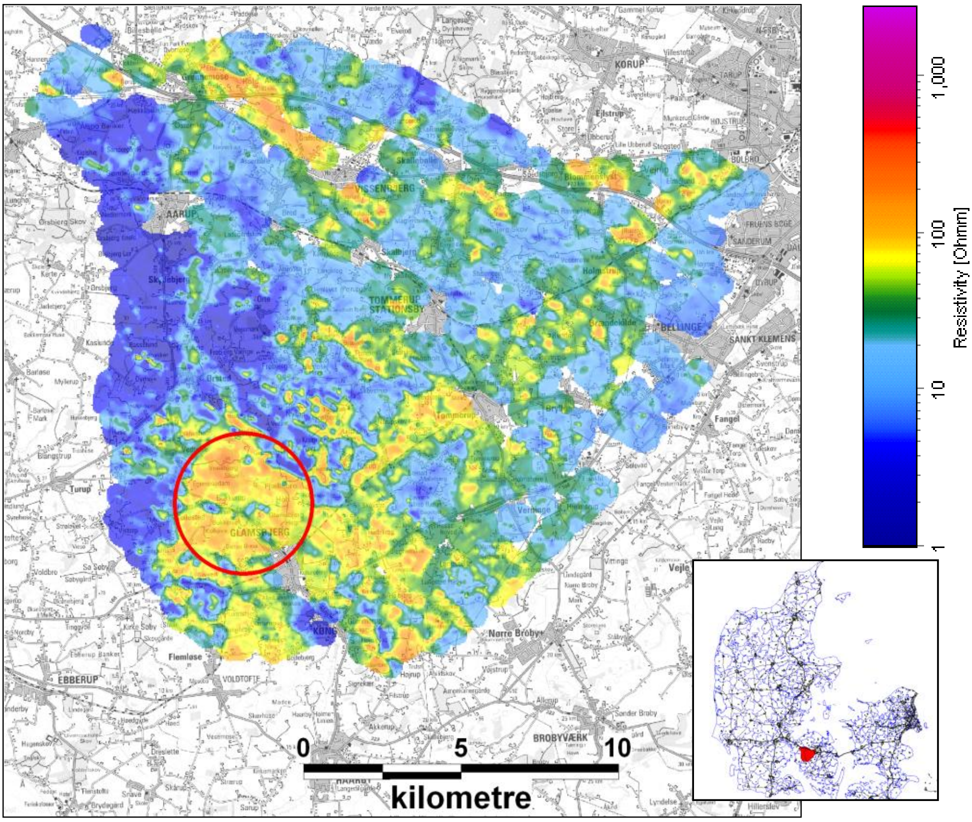

Figure 4. Image illustrating the electrical resistivity (ohmm) based on SkyTEM data from the Funen survey (Interval of 50-60 metres below sea level). Focus area framed by red circle.

MAPPING OF BURIED VALLEY STRUCTURES IN CENTRAL JUTLAND

This survey was carried out in 2009 for the Environment Centre of Ringkøbing in the western part of Denmark. The investigation covers an area of almost 150 square kilometers. The subsurface shows different sedimentary settings ranging from a lithology consisting of Quaternary deposits of sand, gravel and till over a limestone bedrock to a more distinct sedimentary environment with glacial Quaternary deposits on top of Tertiary clays.

Figure 5 shows the elevation of the top of a bottom layer with a resistivity of 8 ohmmeters or less. This geophysical boundary agrees well with the geological boundary between Quaternary sediments and Tertiary clays. Freshwater aquifers are not expected to exist below this level and the map shown in figure 5 therefore is of particular interest from a hydrogeological perspective.

The elongated lows appear often in Danish surveys and are interpreted as eroded valley structures in the Tertiary clay cover. To a great extent, the valleys are filled with quaternary sediments of sand and gravel from which groundwater extraction can take place. In the particular case a drilling campaign is carried out in extension to the SkyTEM survey in order to verify the results.

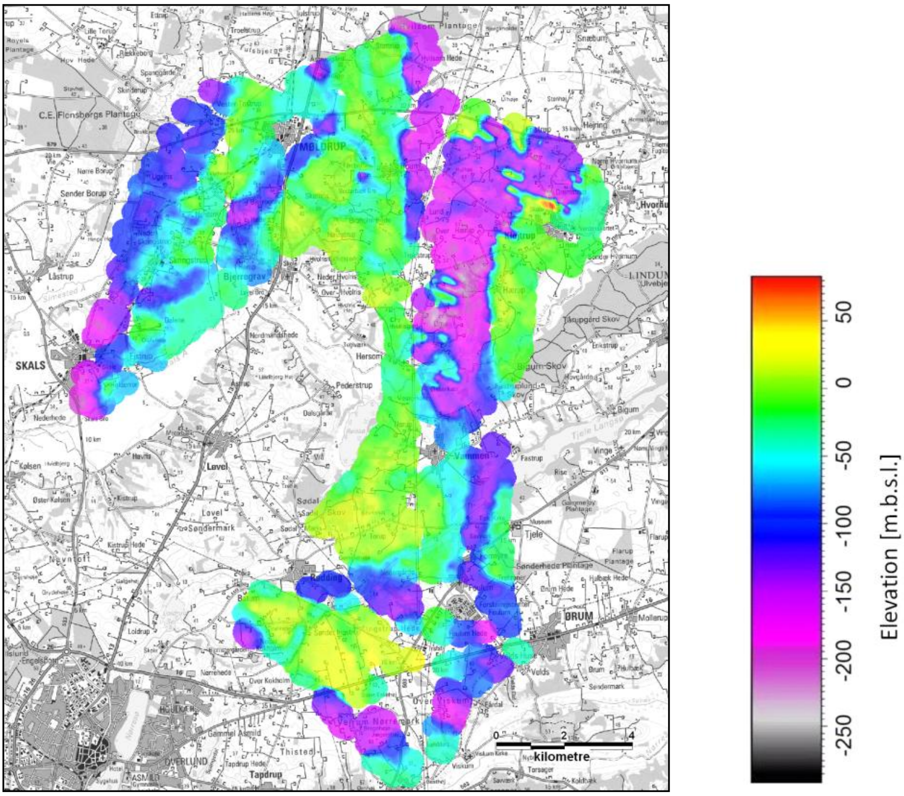

Figure 5. Image illustrating the elevation of a deep level good electrical conductor based on SkyTEM models.

ACKNOWLEDGEMENTS

The survey examples presented are carried out by the Danish Ministry of Environment as a part of the Danish national mapping of groundwater resources. The authors wish to thank the The Environment Centres of Odense, Ringkøbing and Aalborg for the permission to use the presented SkyTEM data in this presentation.

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abstract id: **489**

topic: **3**
Aquifer management

3.3
Geophysical, geological and geochemical methods in groundwater exploration

title: **New hydrogeophysical method for hydrogeologists called MRS for quantification of water in subsurface and groundwater management**

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ITC, University of Twente, Netherlands, lubczynski@itc.nl

keywords: groundwater, Magnetic Resonance Sounding (MRS)

The new Magnetic Resonance Sounding (MRS) technique is probably the most exciting and certainly the most quantitative, non-invasive hydrogeophysical technology ever developed. This is because it applies NMR principle, known also in medical brain scanning as MRI that allows for better water selectivity and lesser ambiguity in subsurface water assessment than any other classical geophysical technique (Lubczynski, Roy, 2004).

The idea of the MRS originates from 60's in United States, while its first implementation from 70's in Russia (Siberia) where first MRS instrument called HYDROSCOPE was developed. In Europe the MRS method is known only since 80's when French MRS instrument called NUMIS was developed. Since 1996 NUMIS is commercially available in France at the BRGM associate called IRIS and recently also in USA.

Below there are listed selected current capacities of the MRS technology. The MRS can (Lubczynski and Roy 2007):

- quantify water content in subsurface (saturated and unsaturated) in depth-wise manner, maximally down to 150 m;
- evaluate extractability of water in subsurface; this extractability is correlated with hydraulic conductivity of the medium so MRS can distinguish and differentiate rocks having similar water contents but different hydraulic conductivities;
- provide hydrostratigraphy of subsurface;
- provide estimates of hydrogeological parameters such as aquifer storage and aquifer transmissivity after calibration;
- evaluate unsaturated zone conditions and contribute to recharge assessment;
- contribute to well siting;
- contribute to groundwater modelling.

MRS has already been tested by many researchers in various hydrogeological conditions. It proved to be quite accurate and cost effective in water resources assessment projects. However there are still sites where MRS surveys cannot be performed. This applies mainly to environments where signal-to-noise ratio is too low. Other MRS survey constrains and benefits will also be discussed.

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3.4 Environmental and artificial tracers in hydrogeology

abstract id: **121**

topic: **3**
Aquifer management

3.4
Environmental and artificial tracers in hydrogeology

title: **Experimental evaluation of selected tracers in different environmental conditions for tracing water resources**

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keywords: groundwater tracing, temperature, salinity, adsorption, chlorine

Tracing is one of the most precise and reliable methods in hydrogeology in which it is an important task to select a proper tracer. To achieve this aim, it is necessary to have enough knowledge of the physical and chemical behaviors of various tracers in different field conditions. In this research, effect of some factors such as pH, sunlight, temperature, adsorption onto porous media, salinity and chlorine on different tracers is evaluated and discussed in a chemical laboratory. Uranine, eosin and rhodamine B (fluorescent dye tracers), $KMnO_4$ (non fluorescent dye tracer) and NaCl and KCl (chemical tracers) have been selected for this study. Results of experiments show that uranine losses its florescence in acid environments, while in alkaline conditions its florescence increases (Figure 1, 2, 3). Table 1 show the results of change fluorescent tracer in different pH condition. Other tracers were stable in different pH. Results also show that because of photochemical decay, fluorescent decrease whit time (Figure 4, 5, 6). Eosin is the most unstable tracer if subjected to sun light (Figure 5). NaCl and KCl were stable on sun light in large time. $KMnO_4$ turns to brown under sun light.

Table 1. Effect of pH in fluorescent of some tracers.

Tracer	Acidic pH	Alkaline pH
Uranine	Very instance decrease in pH less than 6	Very instance increase in pH more than 8
Eosin	decrease in pH less than 4	no effect
Rhodamine B	decrease in pH less than 5	no effect

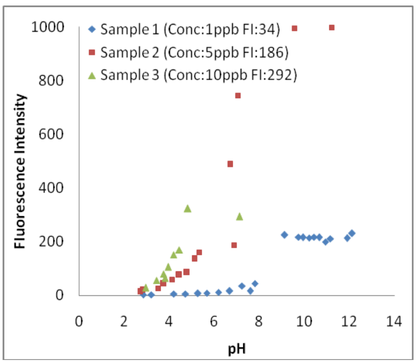

Figure 1. Effect of pH on uranine fluorescence.

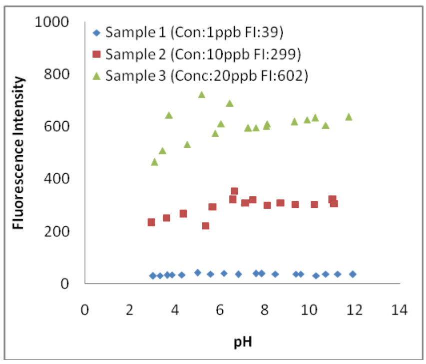

Figure 2. Effect of pH on eosin fluorescence.

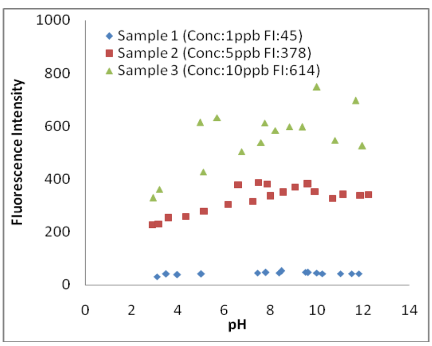

Figure 3. Effect of pH on rhodamineB fluorescence.

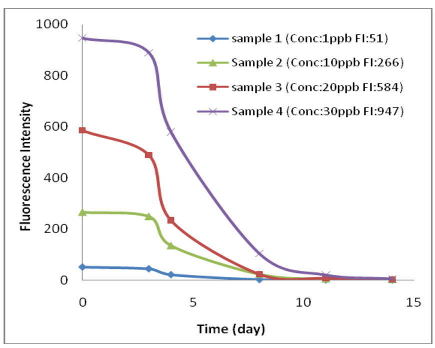

Figure 4. Photochemical decay of uranine.

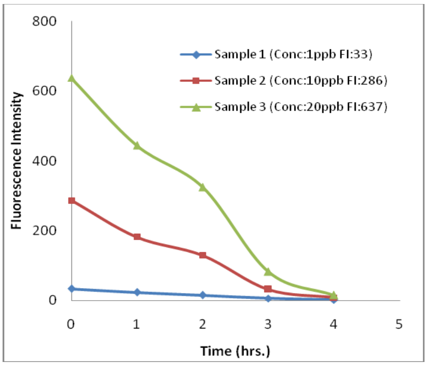

Figure 5. Effect of pH on eosin fluorescence

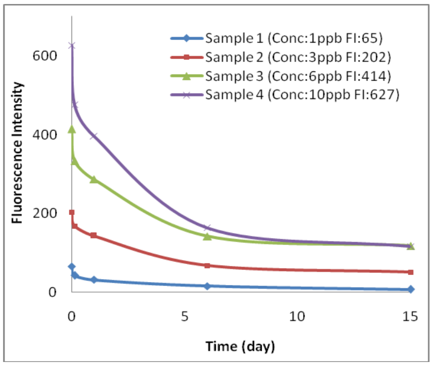

Figure 6. Photochemical decay of rhodamineB

Also, $KMnO_4$ turns to brown under higher temperature conditions and may lose its characteristics as a tracer. The fluorescence intensity of rhodamineB decreases with increasing temperature and NaCl and KCl induced salinity (Figure 7, 8). Uranine and eosin have high resistance against high temperature and salinity.

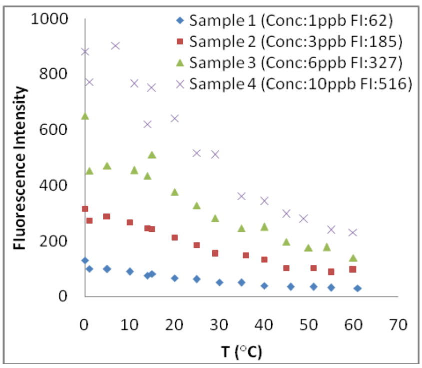

Figure 7. Effect of temperature on rhodamineB.

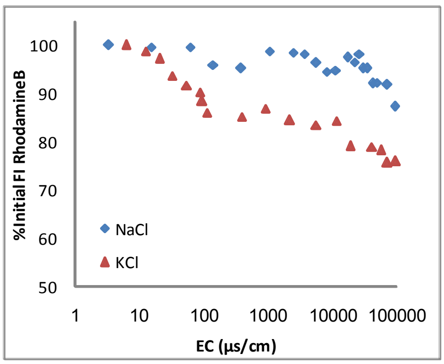

Figure 8. Effect of salinity on rhodamineB.

Absorption of tracer to the aquifer material is among the most important factors which should be considered when a tracing program is considered. With regards to adsorption in porous media, column method (Figure 9) that used and results show that rhodamine B and $KMnO_4$ would easily adsorb in fine grain porous media while uranine and eosin have high resistance against adsorption (Figure 10). Chlorine used in drinking water treatment is a strong oxidizer even in low concentrations and may lead to elimination of fluorescence of uranine, eosin and rhodamine B.

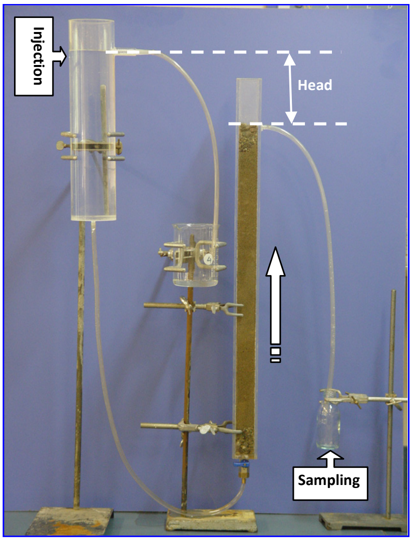

Figure 9. Absorption model whit column method.

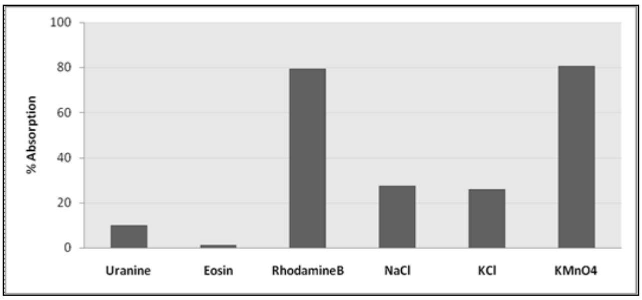

Figure 10. Compare presentage of tracer absorption in porous media.

On the result of this experiments we can consequence that at the tracing plan select a proper tracer whit consider hydrological conditions of aquifer, chemical compound of water is very important.

ACKNOWLEDGEMENTS

This research execution to protect of Water Research Institute of Iran.

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IAH 2010
Krakow

abstract id: **123**

topic: **3**
Aquifer management

3.4
Environmental and artificial tracers in hydrogeology

title: **The gas chromatographic method in measurements of helium concentration in groundwater**

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keywords: gas chromatography, helium, groundwater dating

INTRODUCTION

Helium concentration in groundwater is a fine indicator in water dating in a range from a hundred to tens of thousands of years and ^4He is also used for dating young waters (Andrews, 1989; Zuber et al., 2007).

Applications of helium method known so far, consisted of ^4He concentration measurements using special mass spectrometers (Beyerle et al., 2000). Such measurements unfortunately are expensive and not available in Poland. That is why this problem is tried to be solved using cheaper gas chromatographic method. The rate of $^3He/^4He$ in the atmosphere in temperature of 10°C, amounts to $140 \cdot 10^{-8}$ and is often signified by R_A. Helium originated only from the Earth's crust should have $R_c/R_A = 0.01$, and one that originates only from the Earth's mantle $R_m/R_A = 8$. This datasets show that $(^3He/^4He)_c = 140 \cdot 10^{-10}$ and $(^3He/^4He)_m = 1.1 \cdot 10^{-5}$, so the highest concentration of $^3He = 1.12 \cdot 10^{-5} \cdot {}^4He$. Measurements of ^4He for groundwater dating can be substituted for the measurements of total helium concentration, because concentration of ^3He is in this case considerably low.

The aim of research was the elaboration of chromatographic measurement method of helium concentration in groundwater for hydrogeological purpose. In order to helium concentration in groundwater determination by gas chromatographic method, Thermal Conductivity Detector (TCD), head-space technique of gas extraction from water samples and cryogenic method of helium enrichment at abated pressure with the use of activated carbon was used.

EXPERIMENTAL

Measurement procedure

The determination of helium concentration in groundwater using developed GC method require: (1) sampling groundwater (from the well) without the contact with the air, (2) gas extraction from the water sample using head-space method, (3) cryogenic enrichment of gaseous sample, (4) analysis of the sample in chromatographic system equipped with the Thermal Conductivity Detector (TCD), (5) measurement results handling.

Sampling groundwater without the contact with the air

Groundwater samples are taken to the stainless steel vessels of volume equal to 2900 cm^3 designed in a way that application of head-space method is possible (Śliwka, Lasa, 2000). The vessel has two outlets ended with a spherical valves Z5, Z6. Used valves allow for easy connection of vessel with the system of pipes employed to sampling groundwater from the wells and allow to extract gases from sample in the laboratory. A scheme of the system of groundwater sampling is presented in Figure 1.

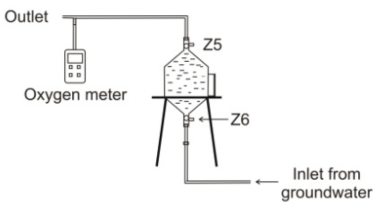

Figure 1. Scheme of the system of groundwater sampling.

During sampling the vessels are flushing with groundwater of volume equal to thirty liters. As noble gases are highly volatile it is very important to avoid gas exchange between the water sample and the atmosphere during sampling, transport or storage. To control the leaktightness of the sampling system during the sampling concentration of oxygen in the groundwater is measured. When the concentration of oxygen is higher than 2 mg/l sampling is being stopped.

Extraction of gases from groundwater samples using head-space method

The head-space method of gas extraction from the sample consist in analysis of gases (of volume of about V_{HS}, Figure 2(D)) from the space above (head space, HS) the measured groundwater sample closed in leak tightness vessel, after the previous bringing such system liquid-gas to the state of thermal equilibrium. In head-space method it is necessary to accomplish few activities. The first one is to introduce gas which doesn't consist helium to the measurement vessel filled with sample. Gas brought under pressure to the Z5 valve (Figure 2(D)) force out water from the vessel through the plastic drain pipe to the syringe. To accelerate establishment of thermal equilibrium state between gas and liquid phases vessel with created head-space phase is being shacked on the shaker for 30 minutes. Such gas phase is ready to analyze in chromatographic system.

Cryogenic enrichment and analysis of gas sample in the gas chromatographic system

A scheme of the measurement system developed in the Institute of Nuclear Physics in Cracow is presented in Figure 2. The system consists of a gas chromatograph equipped with a Valco TCD detector of 2μl volume; 10 port valve V10; three chromatographic columns K1 (1.5 m), K2 (7 m) and K3 (2 m); sample loop V_p; system of helium enrichment and the vacuum pump, P. As a carrier gas argon 6.0 is used.

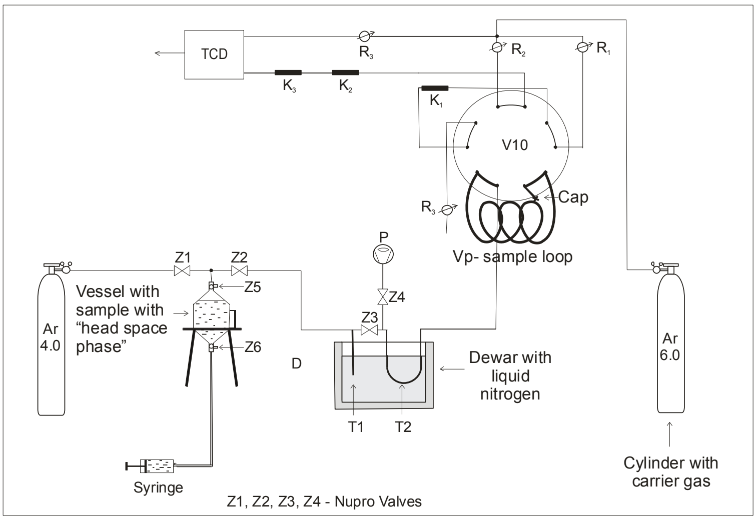

Figure 2. Scheme of the chromatographic system measuring the helium concentration in groundwater.

Water samples are taken to the stainless steel containers of volume 2900 cm³ with a special procedure without contamination with air. The construction of stainless steel vessels allow to apply the head space (HS) method for helium extraction from water (Śliwka, Lasa, 2000). The gas sample of volume V_{HS} = 200 cm^3 obtained using the head-space method passes through a system of two (vacuumed earlier) traps, T1 and T2 immersed in liquid nitrogen, D. In the first trap T1, the water vapour is stopped. In the second trap T2 filled with activated charcoal, oxygen and nitrogen are adsorbed whereas helium and neon are not adsorbed and fill the volume of the sample loop Vp, the trap T2 and a pipe connections (also earlier vacuumed). After changing the position of V10, helium and neon from sample loop are dosed to the first column K1 (filled with molecular sieve 5A) (Sugisaki et al., 1981; Sugisaki et al., 1987). When helium and neon gets to the second column K2 (also filled with molecular sieve 5A), the position of V10 is changed back and the compounds which remained in the column K1 are removed from the system. The columns K1 and K2 are working in the "back flush" mode. For a better separation, both gases (i.e. helium and neon) pass through the third column K3 (filled with a mixture of molecular sieve 5A and activated charcoal 50%/50% (Zieliński, 1961)) to the TCD detector. The signal from the detector is registered in a computer equipped with appropriate software.

RESULTS

The difficulties with measurements of helium concentration in groundwater derive from: (a) lack of proper detector for He detection and (b) difficulty with separation helium from neon in room temperature. Peaks of helium and neon appear together, when columns are in room temperature. To separate them long columns (K1-1.5m., K2-7m., K3-2m) in room temperature were applied. Additionally, application of a third column K3 packed with a mixture of molecular sieve 5A and activated charcoal, gave advisable effects. The detection limit for the TCD detector obtained in this system is 2,8 ng He. The results from the analyses of helium concentration in groundwater and in the atmosphere, obtained through the chromatographic method described above are shown in Figures 3a, 3b and 3c.

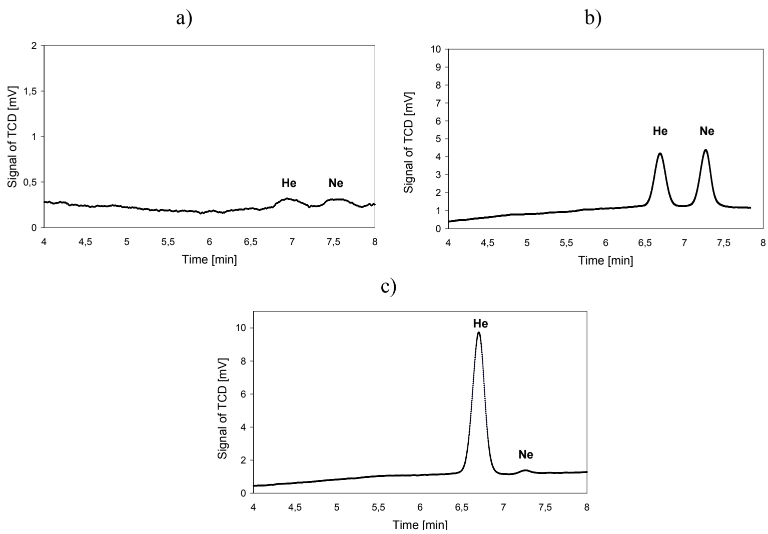

Figure 3. The chromatograms of helium concentration analysis in: a) 10 cm^3 of air without using the system of enrichment (LOD of TCD: 2.8 ng He), b) 200 cm^3 of air with using the system of enrichment, c) groundwater of glacial age in Cracow with using the system of enrichment.

Result from measurement of helium concentration in the atmosphere without using the system of enrichment is shown in Figure 3a. In Figure 3b result from measurements of helium concentration in the atmosphere with the use of system of enrichment in a trap T2 is presented. Example of the chromatogram of the helium concentration analysis in groundwater from Kraków obtained through the chromatographic method described above is shown in Figure 3c. Figure 4 shows the results of calibration of the system with the standard 101±5 ppm helium in argon (produced by Linde Gas).

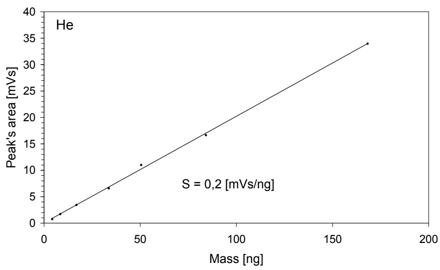

Figure 4. The results of the calibration of the TCD detector, (S - sensitivity of detection for helium 0,20 mVs/ng He; 1 ng = 560·10-8 cm3 STP).

In aim of verification of elaborated method groundwaters of Cracow's area were analysed and the results were compered with the results obtained using mass spectrometer (MS) technique in 1992 (Zuber et al., 2004). Examples of comparisons of He analyses performed with the aid of GC system with those performed earlier by MS technique in groundwater of glacial age in the Cracow's area are shown in Table 1.

Table 1. Helium concentration in 10^{-8} cm^3STP/g measured by MS in 1992 (Zuber et al., 2004) with uncertainty lower than 4%, and by GC in 2006.

Well	^{4}He (MS)	He (GC)
11	185	184±13
15	212	225±16
16	225	240±19

On the basis of the results shown in Table 1 one can see that results obtained by chromatographic method overlap the results from MS technique in the margin of error. In conclusion, the developed system can be regarded as suitable for helium determinations in groundwater for dating purposes.

CONCLUSIONS

The developed chromatographic system described here, can be used for measurements of helium concentration in groundwater. The obtained level of helium detection for groundwater samples of volume equal to 2900 cm^3, where helium was extracted to 200 cm^3 head-space gas phase, amounts to $0{,}67 \cdot 10^{-8}$ cm^3STPg/g_{H2O}.

ACKNOWLEDGMENTS

The authors wish to acknowledge Prof. A. Zuber for his support. This work was accomplished as part of grant No. N N525 348838 from the Ministry of Scientific Research and Information Technology.

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abstract id: **128**

topic: **3**
Aquifer management

3.4
Environmental and artificial tracers in hydrogeology

title: **Vulnerability of waters in the area of the Fruitland Formation, southeastern Colorado**

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keywords: tritium, groundwater age, coal bed methane, vulnerability

There remains considerable uncertainty about how coal bed methane (CBM) production from the Fruitland outcrop in Southwestern Colorado USA, may affect the quantity and quality of nearby surface waters, springs, wetlands, and groundwater systems. The Upper Cretaceous Fruitland Formation of the San Juan Basin is presently the second largest gas producing basin in the United States, with total reserves estimated at 1.4×10^9 m^3 (Choate et al., 1984; Kuuskraa and Boyer, 1993; Fassett, 2000). Snyder and Fabryka-Martin (2007) have shown that the basin is also one of the most extensively studied in the world, with a wealth of information available from chemical and isotopic investigations (Scott et al., 1994; Snyder et al., 2003; Riese et al., 2005; Zhou et al., 2005; Zhou and Ballentine, 2006), geophysical logging (Clarkson et al., 1988; McCord et al., 1992), stratigraphic analyses (Ayers and Kaiser, 1994; Fassett, 2000) and well production histories extending over 25 years.

Yet, for all the research activities that have occurred in the area, there remain many controversies regarding the age of formation waters, the extent to which portions of large basins are subject to active hydrologic throughflow or whether they are relatively static, and how CBM production may affect nearby surface—groundwater interactions, particularly at the margins of the gas field. With data collected as part of a basin-wide hydrologic modeling project (3M Project, 2000), Snyder et al. (2003) and Riese et al. (2005) interpreted values of $^{129}I/I$ ratios between 100×10^{-15} and 200×10^{-15} as indicating minimum iodine ages close to 60 Ma. They further suggested that if these ages are corrected for the addition of fissiogenic ^{129}I, they are compatible with the depositional age of the Fruitland Formation (Late Cretaceous) and indicate a static hydrologic system. The implication of these results is that CBM production would have no affect on local hydrologic systems.

However, Zhou and Ballentine (2006) estimated groundwater ages in the Fruitland Formation using ^4He. They report dates on the scale of 30,000 BP. Their ^4He groundwater dates in the center of the underpressured area using average crustal flux rates are consistent with ages of major recharge events (22,000 years BP) reported for the San Juan Basin (Phillips et al., 1986). These dates also agree with the ^{14}C dates and are close to the hydrological modelling dates up to the distance of 20 km from the basin margin recharge area (Mavor et al., 1991). Zhou and Ballentine (2006) state: "*Our results do not support the groundwater ages of ~60 Ma reported by (Snyder et al., 2003) in any sense or form.*"

Based on these new analyses, Snyder and Fabryka-Martin (2007) have re-interpreted the results of Snyder et al. (2003). They show that ^{129}I and ^{36}Cl signatures from the mixing of brine and meteoric waters early in the development of a sedimentary basin are quantitatively different from those imparted by the mixing of old brines with recent meteoric waters. Thus, interpretation of isotopic results is sensitive to the type of hydrologic end-members and the relative mixing of those end-members.

In 2009 a sampling program in Southeastern Colorado near Durango was begun to determine the chemical and isotopic properties of surface and groundwaters near the Fruitland Outcrop coal formation. This data represents a baseline for waters in the area that soon may be perturbed by increased CBM production. Water samples were collected in 2008 and 2009 from existing CBM wells, domestic wells, piezometers, springs and surface waters in neighboring La Plata and Archuleta counties (Figure 1) and analyzed for tritium content.

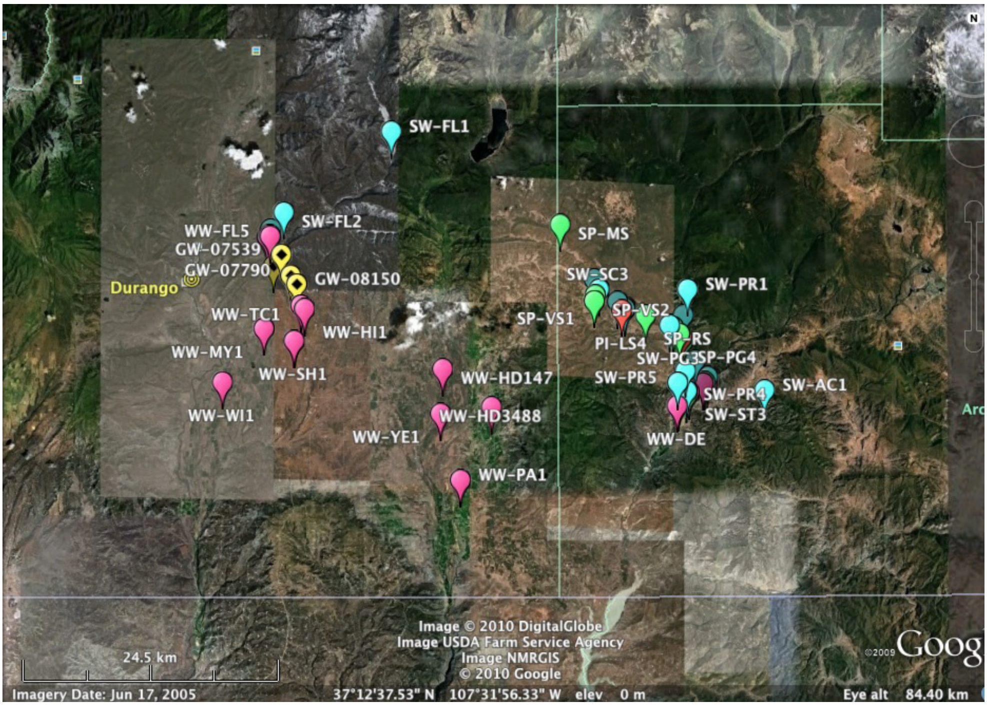

Figure 1. Location of the Fruitland Coal outcrop east of Durango, Colorado. WW = domestic wells, SW = surface water, SP = springs, PI = piezometers, GW = CMB wells.

Approximately 103 samples have been analyzed to this point, and the tritium distributions are bimodal with about 7 percent of the concentrations less than 1.5 TU and about 88% ranging between 4.5-7 TU (Figure 2). Tritium concentrations in all water bodies other than CBM wells approximated post-bomb precipitation levels and showed little seasonal variation. Mean values were as follows: domestic wells, 4.58 TU; piezometers, 5.46 TU; springs, 5.14 TU, and surface waters, 5.85 TU. One-way analyses of variance showed more variance in tritium within water bodies than among them.

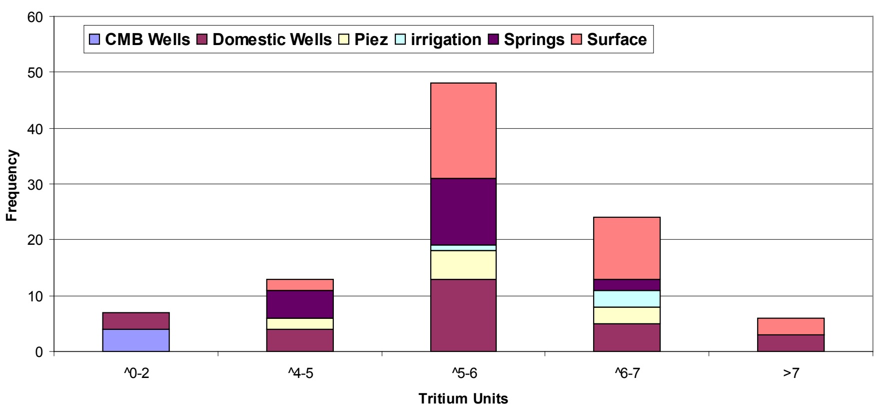

Figure 2. Histogram showing the distribution of tritium in samples measured during this program.

To properly understand the implications of the data, it is necessary to determine the tritium input function. The study area is heavily impacted by moisture moving north from the gulf, especially in summer. As a result, tritium concentrations are lower than those found in northern Colorado as noted in work on the Arkansas River (Michel, 2004). The most representative choice to estimate tritium concentrations in precipitation for this area is a long-term station at Albuquerque, New Mexico. Measured data and concentrations estimated from the Vienna correlation were used from a long term precipitation station at Albuquerque, NM to develop a precipitation input function for tritium. Using the Albuquerque precipitation input function, an exponential model was applied to this data set (Revelle and Suess, 1957; Michel, 2004). Estimates of tritium concentrations for various mean ages of water are shown in Figure 3.

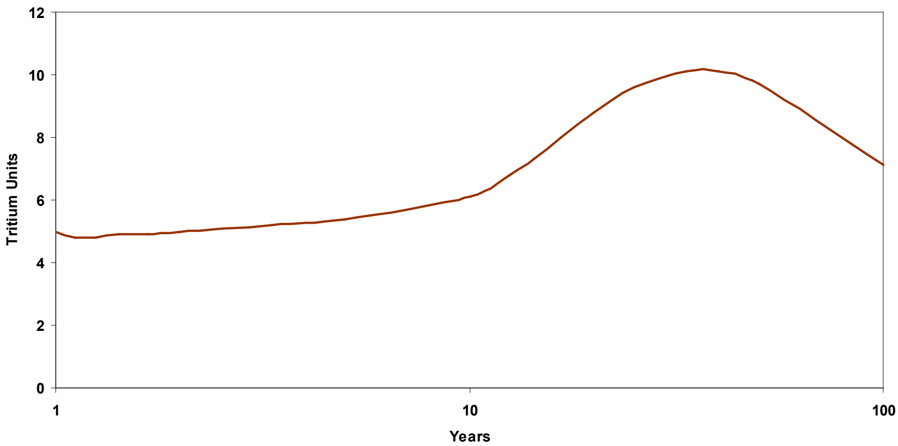

Figure 3. Estimates of tritium concentrations for waters with mean ages between 1–100 years. An input function for precipitation was derived from the Albuquerque, New Mexico precipitation data.

Using the age estimates of mean ages for water in this area derived from Figure 3, it can be seen that the tritium concentration range for this data set falls primarily within an age range of less than 15 years with the vast majority of samples fall in an age range of less than 1 decade. Three samples fall with an age-range of 20–40 years and 7 samples indicate a pre-bomb origin. These results suggest tighter hydrologic connections and more circulation than expected, and may indicate a system that is already over-drafted by existing CBM production and heavy domestic well use.

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abstract id: **143**

topic: **3**
Aquifer management

3.4
Environmental and artificial tracers in hydrogeology

title: **Stable carbon pattern in Belgrade catchment area, Serbia**

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keywords: carbon isotope, dissolved inorganic carbon, particular organic carbon, Belgrade

INTRODUCTION

Rivers are important regulators of carbon (sinking or evaporating) which influence transport fluxes of nutrients and pollutants, production of organic matter, precipitation of carbonates or evaporate. In the catchment area, rivers undergo major changes in spatial and seasonal scale and are also influenced by anthropogenic activities. In order to distinguish between carbon sources we have to know the isotopic composition of the various contributors and understand the isotopic fractionation processes in the water. Dissolved inorganic carbon (DIC) in freshwater systems originates mainly from dissolution of carbonate minerals, soil CO_2 derived from root respiration and from microbial decomposition of organic matter (often mainly of terrestrial origin but also including aquatic production), and exchange with atmospheric CO_2. The major processes removing riverine DIC are carbonate mineral precipitation, CO_2 degassing, and aquatic photosynthesis. The isotopic composition of dissolved inorganic carbon ($\delta^{13}C_{DIC}$) in freshwater systems, together with its concentration, is widely used to trace organic matter production and decomposition and presents a powerful tool to study the sources of carbon as well as the impacts of biological recycling of the carbon (Jedrysek et al., 2006). There are three major types of particulate organic matter (POM) in the riverine system: natural terrigenous materials consisting mainly of soils and bedrock-derived sediments, anthropogenic wastes and autochthonous materials from the aquatic system. The isotopic composition of suspended particulate organic carbon ($\delta^{13}C_{POC}$) reflects the relative proportions of allochthonous terrestrial organic matter (probably dominated by detritus from C3 plants and C3 plant-dominated soils), and autochthonous particles (derived from plankton and algae, aquatic macrophytes, and fragments and faecal materials from invertebrates and fish in the river) (Deines, 1980). These two sources can, in theory, be distinguished based on the ratio of organic carbon (OC) to organic nitrogen (molar C:N) (Kendall et al., 2001).

In this work, we have studied the stable isotopic composition of DIC and POC in the surface and ground waters of Belgrade area in order to use ^{13}C natural abundance as a complementary tracer to improve the current knowledge of atmospheric and geochemical processes governing water quality.

STUDY AREA AND MEASUREMENTS

Belgrade (44° 49' 7" N, 20° 28' 5" E), the capital of Serbia, is situated in south-eastern Europe on the Balkan Peninsula and lies at the point where the Sava River merges into the Danube. It is the largest urban settlement in Serbia with 1.6 million inhabitants spreading over the area of 763.87 km^2. Downstream part of Sava alluvium and Danube-Save interfluves characterized by natural bank-filtered area, supplying drinking water for Belgrade, covering about 40-50% of its demand. The Sava and the Danube rivers' valley presents a region for Belgrade combined water supply using three-quarters of groundwater exploited from alluvial sediments using 99 wells with horizontal drains settled along the river Sava River and one quarter of water tapped from the main stream of the Sava and partly from the Danube. Considering the size (wells are placed in line of 50 km along the left and right river banks), the total capacity is about 4 m^3/s (Fig. 1).

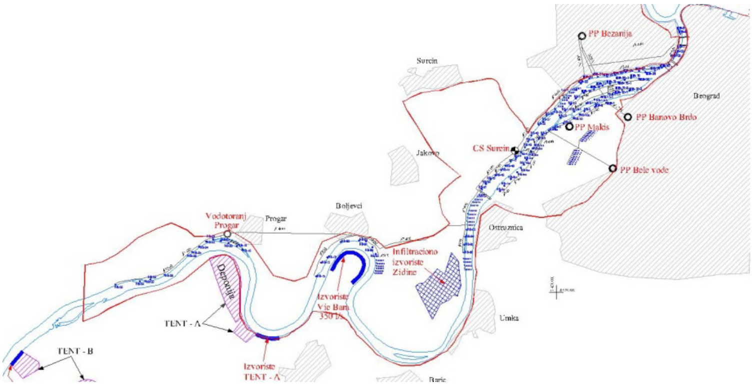

Figure 1. Map of surface and groundwater sources in Belgrade area.

Hydrological and geophysical properties of the Belgrade alluvial aquifer indicates a large accumulation of groundwaters in Upper Quaternary sediments (thickness up to 25 m) generally fed from two sources: by filtration of the river water along the bank and by infiltration of the precipitation through the surface layer or along the edges of the aquifer. The aquifer mainly consists of sandy-gravel, sand and has less permeable upper layer. The total depths of Quaternary sediments are 25 to 30 m. Hydraulic conductivity values of the water-bearing layer mostly range from 10^{-9} to 10^{-5} m/s. On the significant part of the alluvial plane, aquifer is divided with a less permeable layer-aquitard (Dimkic et. al., 2007). In some locations floor is made of limestones dating from lower-Cretaceous and Sarmat. In the area of Ostruznica village alluvial aquifer lies over upper-Cretaceous (Ostruznica) flysch.

Collected samples of surface and groundwater were analyzed for major chemical parameters (HCO_3^-, Ca^{2+}, Mg^{2+}, Na^+, K^+, NO_3^-, SO_4^{2-}, Cl^-, SiO_2) in the laboratory of Jaroslav Černi Institute for Development of Water Resources, Serbia as well as measurements of the water quality parameters pH, specific conductivity (SC), and temperature (T) in the field. Analyses of stable carbon isotopes of DIC and POC have already been described in previous work (Ogrinc et al., 2008). The measurements were performed on Europa Scientific 20–20 with ANCA SL preparation module for solid and liquid samples and/or ANCA TG preparation module for trace gas samples in the Department of Environmental Sciences at Jožef Stefan Institute, Ljubljana, Slovenia. All stable isotope results are reported using conventional delta (δ)-notation in per mil (‰) relative to the V-PDB standard. The precision of measurements were 0.2‰ for $\delta^{13}C_{DIC}$ and $\delta^{13}C_{POC}$. The partial pressure of CO_2 (pCO_2) and mineral saturation states for calcite and dolomite were calculated using the PHREEQC speciation program (Parkhurst, Appelo, 1999).

RESULTS AND DISCUSSION

Water samples were collected in March, May and July of 2008 and 2009 in the area of Belgrade from surface water (the Sava River, lake and channels) and groundwater (piezometers and production wells). Most of the water samples were Ca–Mg–HCO_3 type with an evident correlation between Ca^{2+}(r = −0.59) and Mg^{2+}(r = −0.79) ions with measured pH. High concentrations of dominant dissolved ions such as HCO_3^-, Ca^{2+}, and Mg^{2+} is affected by carbonate (calcite and dolomite) dissolution by carbonic acid indicating by (eq. 1 and 2).

Calcite: $CaCO_3 + CO_{2(g)} + H_2O \leftrightarrow Ca^{2+} 2HCO_3^-$ (1)

Dolomite: $CaMg(CO_3)_2 + 2CO_2 + 2H_2O \leftrightarrow Ca^{2+} + Mg^{2+} + 4HCO_3^-$ (2)

Most of analyzed samples have a 2:1 mole ratio of HCO_3^- to $Ca^{2+} + Mg^{2+}$ (Fig. 2a) according to the stoichiometry of the reactions (see Eq. 1 and 2) and the predominance of dolomite dissolution in groundwater aquifer (Fig. 2b). Saturation index (S.I.) calculated for analyzed water samples indicated that surface waters and half of groundwaters were saturated (S.I. = 0) and super-saturated (S.I. > 0) with respect to calcite while less than half of the groundwaters were under-saturated (S.I. < 0) with respect to calcite.

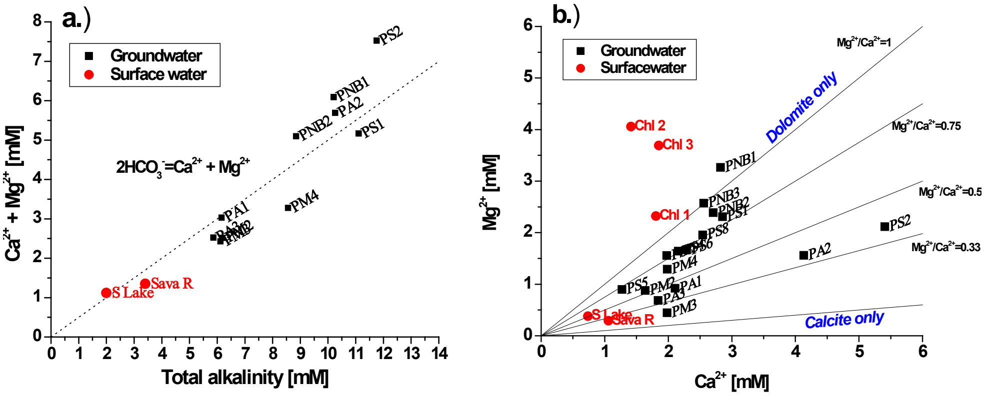

Figure 2. a) $Ca^{2+} + Mg^{2+}$ ratio versus alkalinity; line 1:2 indicates weathering of carbonates. b) Mg^{2+} versus Ca^{2+} indicates the dominance of dolomite dissolution in groundwater aquifer.

The $\delta^{13}C_{DIC}$ in analyzed area is highly variable and distinct between surface water (–11.8 to –4.9‰) and groundwater (–16.8 to –10.8‰) indicating different evolution pathways of carbon. The values for the Sava River ($\delta^{13}C_{DIC}$= –11.2 ± 0.8‰, n = 3) containing predominantly groundwater with $\delta^{13}C$ values of the HCO_3^- fraction of –11‰ with varying amounts of additional biogenic CO_2 are in excellent agreement with results obtained near its mouth in 2006 (Ogrinc et al., 2008). Enriched values found for $\delta^{13}C_{DIC}$ in channels and lake in the range of –9.8‰ to –4.9‰ (Fig. 3a) pointed out an occurrence of intensive photosynthetic activity of phytoplankton in summer which is significantly controlled by water temperature (r^2 = 0.9). On average, the $\delta^{13}C_{DIC}$ values in groundwaters were lower than in stream waters, with rather uniform mean values of –12.9±0.8‰ (n=20) and –12.8±1.1 (n = 17) for operation wells (Fig. 3b.) and for piezometers (Fig. 3c), respectively. These values are the combined average $\delta^{13}C$ values of the soil CO_2, originating mainly from the decomposition of C_3 plant cover organic matter ($\delta^{13}C$ about –28‰) and the other half as a result of carbonate dissolution from parent materials such as limestone ($\delta^{13}C_{Ca}$ ~ 0.0‰) and dolomite ($\delta^{13}C_{Mg}$ ~ 2.0‰). The exceptions are the operation well (WM2) and piezometer (PNB1) with more depleted values of –16.8 and –15.5‰, respectively. Consideration of the proportion of dissolved CO_2 species of DIC indicated the increase of CO_2(aq) in respect to HCO_3^- that is caused probably by the process of microbial respiration. The bacteria present in contaminated waters are readily able to transform components of the crude oil ($\delta^{13}C$ ~ –30‰) into inorganic carbon (Medina-Bellver et al., 2005), which leads to a decrease in the $\delta^{13}C_{DIC}$ relative to the value in unpolluted water.

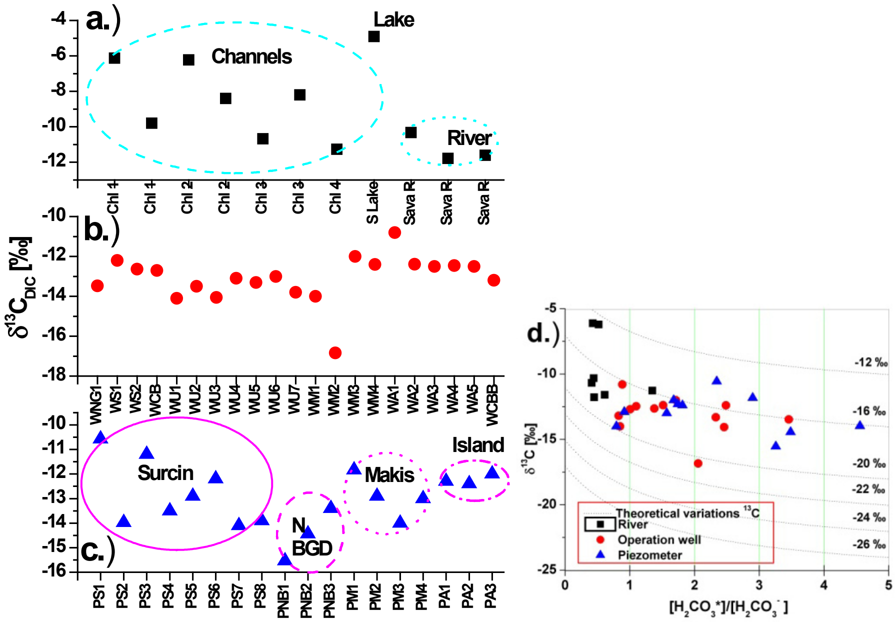

Figure 3. Spatial variations of $\delta^{13}C_{DIC}$ and $\delta^{13}C_{POC}$ in a) surface waters, b) operation wells, c) piezometers, and d) relationship between the $\delta^{13}C_{DIC}$ and the ratio $[H_2CO_3^*]/[H_2CO_3^-]$ in Belgrade area.

The variations of $\delta^{13}C$ values are controlled by the proportions of the concentrations of aqueous CO_2 $[H_2CO_3^*]$ and of bicarbonate ions $[H_2CO_3^-]$ in solution. The relationship between the $\delta^{13}C_{DIC}$ in surface and groundwater of the Belgrade area and the ratio $[H_2CO_3^*]/[H_2CO_3^-]$ is plotted in Fig. 3d. In the same diagram, the theoretical variations of $\delta^{13}C_{DIC}$ in equilibrium with different isotopic composition of soil CO_2 calculated as a function of the concentrations of dissolved carbonate species together with their respective $\delta^{13}C$ values and from the temperature dependence of isotope enrichment factors are plotted (Amiotte-Suchet et al., 1999). All samples are in apparent isotopic equilibrium ($\delta^{13}C_{DIC} = -16‰$) with ^{13}C enriched gaseous soil CO_2. The DIC is not in isotopic equilibrium with the soil CO_2 originated from C3 vegetation (–23 to –24‰). The enrichment in ^{13}C of the DIC is caused by the dissolution of carbonate from limestone and dolomite and by isotopic equilibration with the atmospheric CO_2 as well (open system). At a given sampling date, the $\delta^{13}C$ values appear to be more or less controlled by the relative ratio of $H_2CO_3^*$ to $H_2CO_3^-$. Nevertheless, the trends of points often cross the theoretical curves, indicating that the isotopic composition of the gaseous phase is spatially changing.

$\delta^{13}C$ signatures of suspended POC in analyzed waters varied between –38.3 and –25.0‰. The majority of values were observed in a narrow range of –29.6 to –25 .0‰, averaging at –27 .8 ± 1.1‰ (n=16) indicating that the main source of POC in the river system is soil OC. Markely more depleted $\delta^{13}C_{POC}$ values of –38.1‰,–38.3‰, and –35.1‰ found in operating well (WA4), piezometer (PS8), and channel (Chl1) respectively, are associated with the presence of anaerobic bacterial decomposition of organic matter producing very depleted methane with $\delta^{13}C$ values between –50 and –80‰ (Sivan et al., 2007). At the locations where bacterial activities were observed, a strong positive linear relationship (r = 0.94, n=7) between the carbon isotopic compositions of DIC and POC is obtained probably due to a major fraction of POC was derived from allochthonous matter.

CONCLUSIONS

The major solute composition of analyzed surface and groundwaters was dominated by carbonic acid dissolution of calcite and dolomite. The $\delta^{13}C_{DIC}$ of about –13‰ is in agreement for value originated from dissolution of soil carbonate minerals by soil organic CO_2 derived from C3 land vegetation. Negative $\delta^{13}C$ values below –14‰ would be indicative of biological activity, i.e. a relatively large contribution of biogenic (soil) CO_2 with low $\delta^{13}C$.

The POM from surface waters showed considerable variations in carbon isotopic compositions depending on the potential sources of organic matter. It seems that most important source of the particulate organic matter is soil which is not bioavailable.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the Ministry of Sciences for financial support to complete this work under the Project ON142039. Part of the work was conducted within the bilateral Slovenian-Serbian cooperation entitled "Stable isotope applications in hydrologic studies of Slovenian and Serbian river systems" supported by the Slovenian Research Agency (ARRS) and the Serbian Ministry of Sciences and Technological Development.

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abstract id: **149**

topic: **3**
Aquifer management

3.4
Environmental and artificial tracers in hydrogeology

title: **Event based monitoring and early warning system for groundwater resources in alpine karst aquifers**

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BACKGROUND AND AIM OF RESEARCH

Water resources from alpine and other mountainous karst aquifers play an important role for water supply in many European countries. As regulated in the WFD (Water Framework Directive), karstic catchments require a sustainable protection. The increasing impact to such regions and the different utilization in the watersheds of karst springs are important reasons to establish early warning systems and quality assurance networks in water supplies. These systems rely heavily on in-situ measurements and online and near real-time availability of the data. With a satellite based networking of measuring and sampling stations it was possible to carry out precipitation triggered event monitoring campaigns at different karst springs (Stadler et al., 2010) combining on-line measurements of hydrological parameters with field-laboratory based analyses of microbial faecal indicators (Stadler et al., 2008).

The targets in the study were (1) to investigate the dynamic of chemical parameters, environmental isotopes and microbial faecal pollution indicators at a high resolution time scale during hydrological events, (2) to evaluate the in previous investigations established parameter SAC254 as an appropriate real-time pollution proxy for optimised spring water abstraction management within an early warning system and (3) to implement also automated sampling of event-causing precipitation in the catchment area to carry out isotopic analyses.

ORBCOMM SATELLITE SYSTEM

Based on extensive technical and cost comparisons and on validation measurements, e.g. (Skritek et al. 2001, Stadler & Skritek 2004), the ORBCOMM LEO Satellite system was chosen. ORBCOMM is a "Little-LEO" system, with 30 servicing satellites in 6 orbit planes of 800 km altitude. It provides bi-directional "short message" data-transfer at 2.4/4.8 kbps, with data blocks preferably less than some 100 Bytes. ORBCOMM operates at frequencies about 140 MHz, providing large satellite footprints, and requires only low-cost/low-power equipment, allowing, e.g., simple whip-antennas as well as small solar-panels for power supply and transmission even from forests. The ORBCOMM modem transmits its data to the satellite, from where downlink transmission is performed either directly to one of the Gateway Earth Stations (GES) or as "globalgrams" (data stored in the satellite and forwarded to earth when the satellite passes the desired GES). The GES emails the data to the receiver via internet or re-transmits it to any "nomadic" ORBCOMM modem again via satellite.

ASSEMBLING, CROSS-LINKED STATIONS AND DATA STREAMS

The precipitation station (PS) is located in the catchment area of the spring, where the event sampling will be carried out. It is equipped with a tipping bucket, a data logger and a LEO-Satellite modem. It can be supplemented with additional meteorological sensors and sampling devices. The monitoring and sampling site at the spring (spring sampling station, SSS) is equipped with an additional data logger, a pressure probe to register the changing of discharge, two automatic sampling units (one for the reference sample and one for the periodic samples) and a LEO-Satellite modem for real-time control and data transmission. It can be supplemented with additional hydrological or meteorological sensors.

Stream of data and information. As soon as the trigger-level is exceeded in the catchment area at the PS (predefined amount of precipitation in a definite period, both parameters are selectable) a trigger report is sent to the SMS via satellite. There the reference sample is taken automatically. In addition, the PS starts sending via LEO-Satellite continuously data about the rainfall to the CMS. The SMS is now ready to wait until the second trigger-level (increase of discharge, also programmable) is exceeded. If this happens, the periodic sampling within the event sampling starts automatically and the status information and measured values are continuously sent via satellite to the CMS and the local service team is informed.

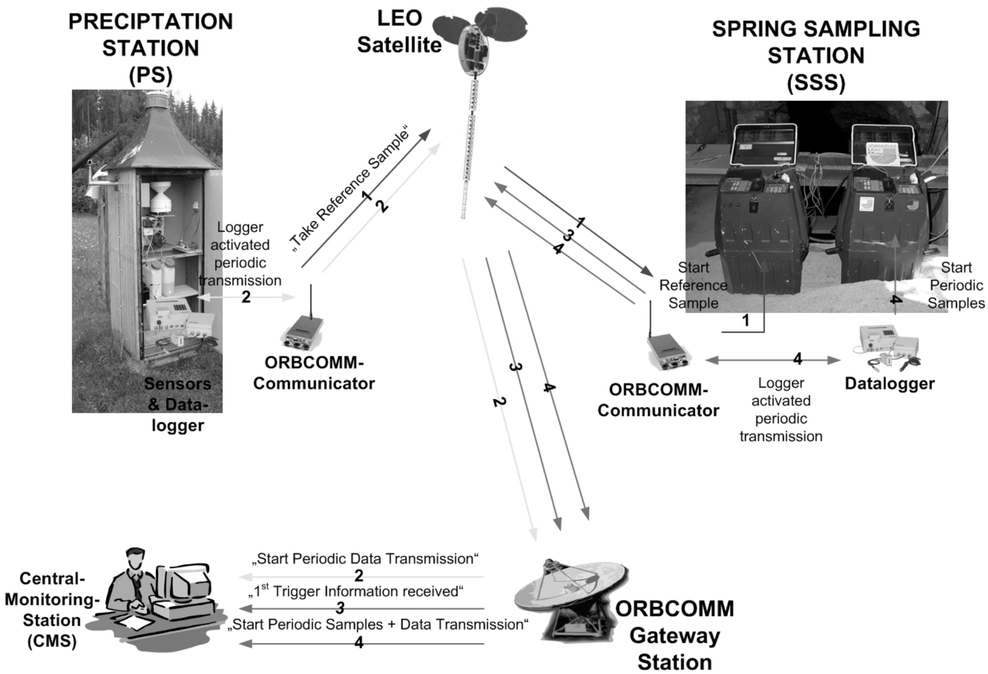

Figure 1. Block-Diagram of Assembling. Stream of data and information of an event-triggered LEO Satellite Hydrology Network.

Precipitation Station (PS). It records rainfall and other meteorological data. From the intensity and the recorded amount of precipitation a specific trigger criterion is derived. If this trigger-level is exceeded, the PS activates one or more SSS via satellite (Data Stream 1, Fig. 1) to take the reference sample. This happens before the event affects the discharge of the spring. The CMS is also informed via satellite by receiving periodic data sets from the PS to observe the further trend of precipitation (Data Stream 2, Fig. 1).

Spring Sampling Station (SSS). As soon as the activation data-set is received, the automatic sampling unit takes the reference sample. The status is sent to the CMS (Data Stream 3, Fig. 1).This procedure can be repeated several times, depending on the number of sampling bottles in the automatic sampling device. This is necessary because due to the hydrological boundary conditions the upcoming event at the spring is worth sampling.

Now the SSS is waiting during a specified period of time for the increase of the discharge, which is the second trigger event. The trigger level is derived from the increase of the gauge height within a period of time and is chosen according to the characteristics of the spring. This trigger criterion is activated from the data logger. If the predefined trigger level is exceeded, periodic sampling is started automatically. The information is sent via satellite to the CMS. The SSS starts also periodic data transmission to the CMS to trace this event (Data Stream 4, Fig. 1).

Central Monitoring Station (CMS) and Web-Interface. There the information from all stations is collected. Additionally the local service team is informed from the CMS automatically of important facts like starting of rainfall (1st trigger) and starting of the sampling procedure at the SSS (2nd trigger) via GSM cell phones. Depending on the sampling time increment and the number of bottles in the automatic samplers, they can plan their next visit at the SSS to maintain the station.

The CMS provides an online Internet-Portal for access to these environmental data. It is built around the server-based operating system Debian, which is a stable free software, providing perfect interaction and performance with the server. Among others, the server comprises a RAID-system for fault-tolerant operation.

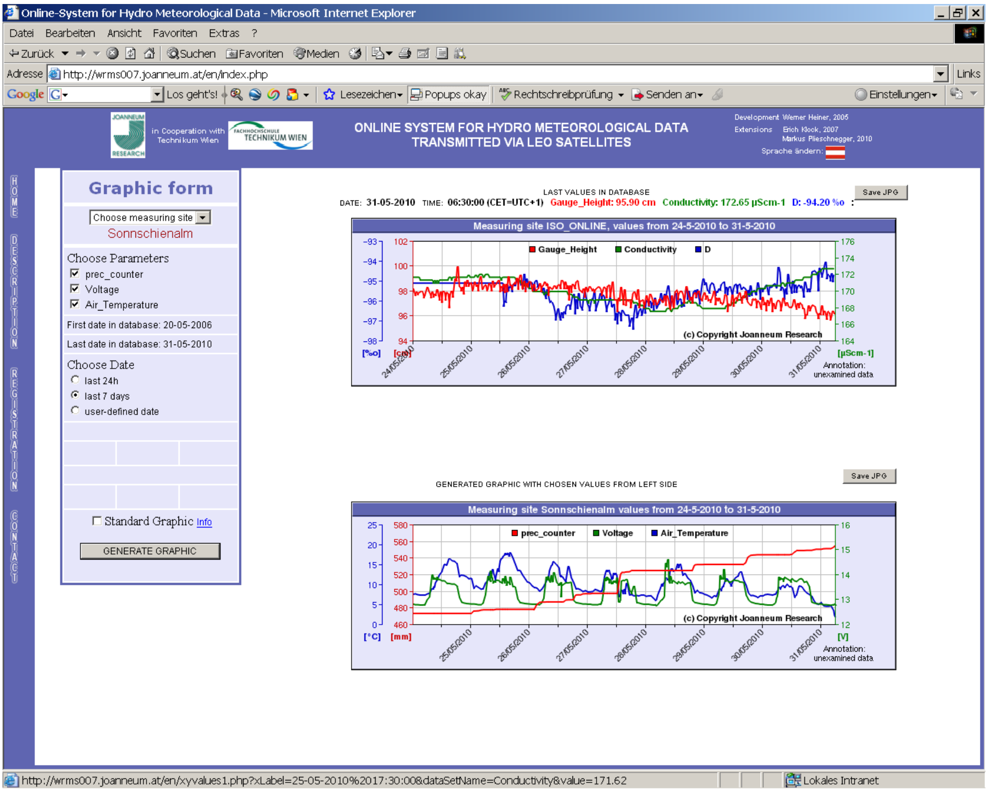

Figure 2. Dynamically generated Website for Online Data.

To provide on-line communication with access to the stored measurement data via the Internet, an ApacheWeb server was implemented on the Debian-Server. The dynamically generated online website can be viewed under http://wrms007.joanneum.at. The start-page is shown in Figure 2.

The freeware PHP was used for programming these interactions between the Internet users and the CMS. Furthermore, PHP can also interpret other interface languages, e.g., XML or JavaScript, using standardized modules, which makes the chosen implementation very flexible for on-line environmental communication.

Additional to the online graphical presentation, all co-workers and public access users may also download these graphics to their local machine. Using password-protection, several access levels to the data and visualization are feasible for different user groups, e.g., general public access to environmental information vs. individual access for specific in-depth data for research-project co-workers (Heiner, 2005).

STUDY AREA AND METHODS

The investigations were carried out in a karstic catchment area of the Northern Calcareous Alps. The event at the karst spring LKAS1 was caused by an aestival thunderstorm with 40.2 mm precipitation measured in the watershed at 1520 m a.s.l. The samples at the spring (n = 157) were taken with automatic sample devices from August 21 to August 31, 2009 at ambient spring water conditions and treated for the different analyses not later than 24 hours after sampling. The rain water was stored after automatic sampling in an air-tight container for 16 hours before treating. *E.coli* was analyzed by the colilert system (IDEXX) directly at a field laboratory as previously described (Stadler et al., 2008). Hydrological in situ measured on-line parameters were collected with an increment of 15 minutes. To study microbial faecal pollution *E.coli* was chosen as indicator organism. In contrast to other standard faecal indicators, detailed previous investigations highlighted its excellent applicability as a general faecal pollution indicator in alpine karstic environment (i.e. high prevalence and abundance in human, live stock and wildlife excreta, low or non prevalence in alpine soils, halve life time of *E.coli* in spring water in the range of the average event period length, Farnleitner et al., 2010).

RESULTS

The integration of on-line measured data, laboratory and field laboratory analyses, all of them recovered with high time resolution, allows a deep insight to these sensitive aquatic systems. Especially the combination with environmental isotopes (Fig. 4) generates new knowledge of the dynamics, mass transport conditions with different transfer behaviour of the particular substances being of fundamental importance for the sensible use of early warning systems. As an example the correlation between SAC254 (Spectral Absorption Coefficient at 254nm) and *E.coli* during the course of the event is shown in Figure 3. Very important for the use of SAC254 as an early warning proxi is the lead time of SAC254 to *E.coli*, which enables reactions times for water abstraction management.

The comparison of the Oxygen-18 as a proxy of the aquifer-dynamic and turbidity or the SAC254 as indicators of mass transport of substances with different transfer behaviour show the very different behaviours of these parameters.

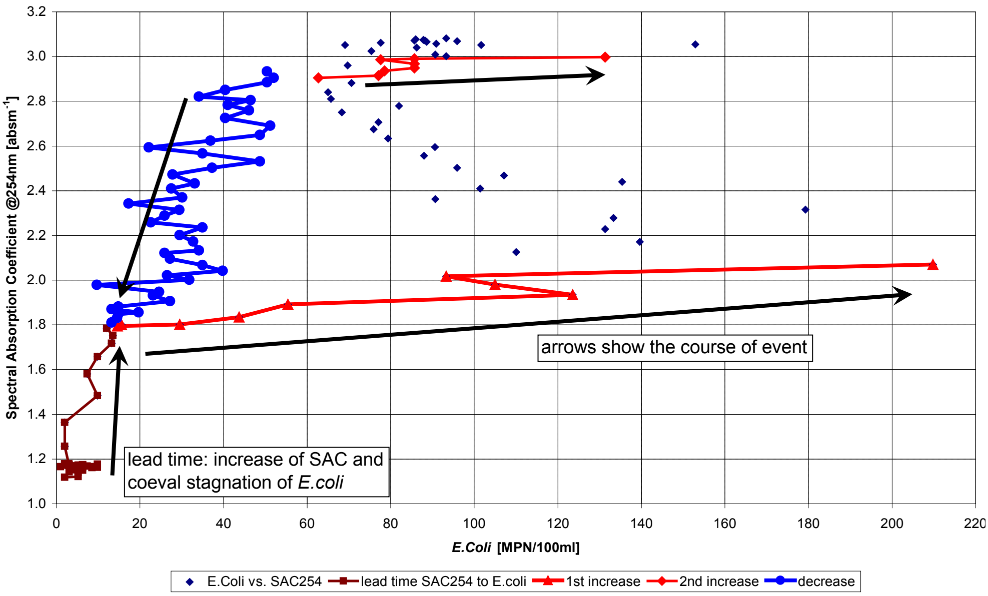

Figure 3. Correlation of SAC and E.coli during the observed event.

The difference of both of them to the hydraulic reaction, indicated by the course of discharge is also obvious. SAC254 and turbidity show in this karst system different behaviour. As SAC254 is more or less surface related and turbidity is mainly an indicator of particles, activated in the karst system by increasing pressure flow velocity, they show different reactions, as shown in Figure 4.

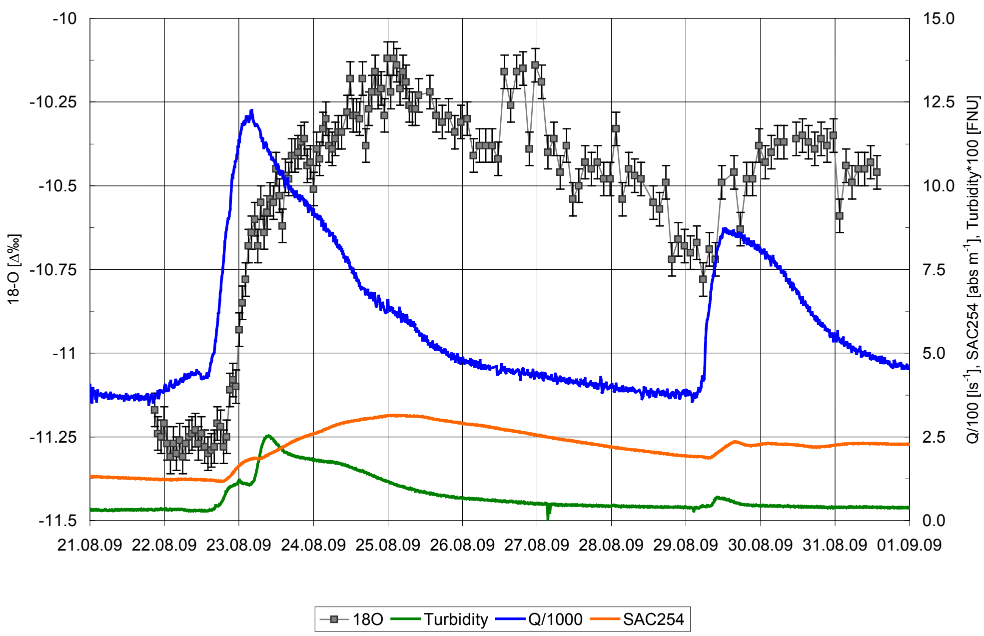

Figure 4. Course of in-situ measured parameters and Oxygen-18 from laboratory analyses during event.

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abstract id: **158**

topic: **3**
Aquifer management

3.4
Environmental and artificial tracers in hydrogeology

title: **Hydrochemical and isotope analysis of deep groundwater from the Nubian Aquifer system in the Egyptian Oases**

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keywords: Nubian aquifer system, Egyptian Oases, isotopes, hydrochemistry

INTRODUCTION

The groundwater of the Nubian Aquifer System is the vital source for the water supply of the Egyptian oases in the Eastern Sahara (Western Desert of Egypt). It has been the subject to various studies in more than 100 years. Most recently groundwater flow and transport models were developed by numerical modelling approaches e.g. of Heinl & Brinkmann (1989), Gossel et al. (2004), Sefelnasr (2007), Gossel et al. (2008) and Gossel et al. (2010). The drinking water and irrigation water in the oases was taken in former times from the uppermost aquifer, today it is mostly extracted from deep wells with a depth of 500 – 1200 meters to ensure high quality and safe yield. The potentiometric surfaces of the confined aquifers reach about 2 – 50 meters below ground, in some cases the wells are free flowing. Due to the great depth the groundwater temperatures range from about 40°C to 60°C and thus the hydrochemistry is influenced by dissolved minerals. Therefore the recent study focuses the main component analysis, the analysis of metals and the isotopic measurements of hydrogen and oxygen. For these analyses samples were taken at the locations in Fig. 1. The ages of the groundwater of some of the wells and other deep wells in these Egyptian oases were published by Du et al. (2006) and range from 200 to 1000 kyr. The isotopes of hydrogen and oxygen were also subject to diverse studies in the last decades but led to an indifferent picture of the climatic conditions during the recharge times. The numerical groundwater flow model, the hydrochemical and isotope analyses were expected to give a consistent picture of the paleoclimatic recharge conditions of this very old groundwater, the hydrochemical conditions of this part of the aquifer and the fate of dissolved minerals during pumping and use.

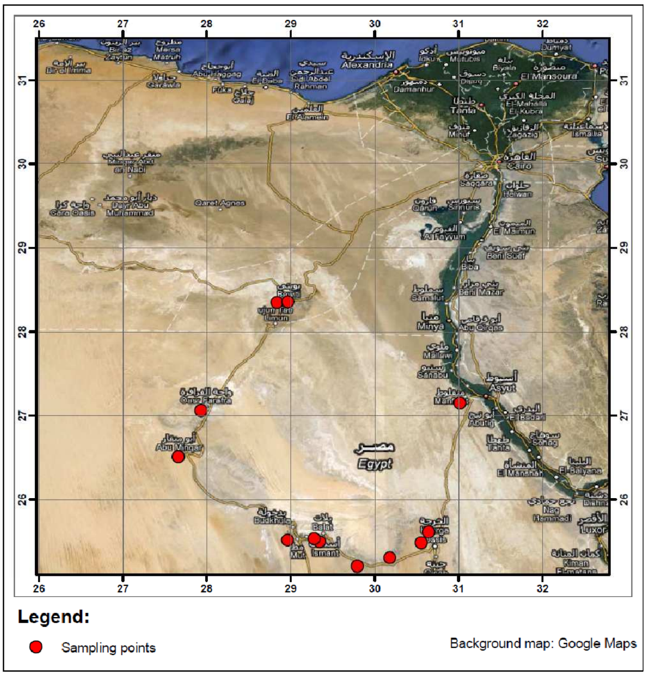

Figure 1. Sampling locations of the Egyptian oases and Assiut.

METHODS

The groundwater samples were taken at the locations outlined in Fig. 1. The main components were analysed by ion chromatography, the metals by ICP-MS and ICP-OES and the isotopes were analysed with an equilibration device-IRMS system. The results of the hydrochemical analyses were used for a statistical analysis and further modelled by using the geochemical code PhreeqC to obtain a consistent picture of the redox conditions in the aquifer and the rock – water interaction. The threedimensional numerical model based on the model described in Sefelnasr (2007) in detail and in Gossel et al. (2010) in an enlarged area. Based on the flow model the pathlines and retention times of the groundwater were calculated.

RESULTS

The hydrochemical analyses and model results showed that the groundwater is in most cases under reductive conditions. This leads to high contents of iron, manganese but only in rare cases of other metals. A factor- and cluster analysis showed a differentiation between groundwater from the edge of the Nile Valley near Assiut, the North of Kharga Oasis and the locations in the other oases. The factors can be gathered into 4 groups (components): In the first group sodium chloride dominates with factor loadings > 0.9, in the second group calcium, magnesium and iron have the highest loadings. The third group is dominated by sulphate and strontium and the fourth group is marked by copper and barium. The cluster analysis was carried out based on all parameters. A classification into four clusters gives the most reasonable results. As expected the sample from the edge of the Nile Valley and from the North of Kharga Oasis could be obviously distinguished from the other samples into a unique group whereas the other samples divide into two quite similar groups.

The interpretation of the measurements of the iron and manganese species as well as the sulphur species with inverse modelling in PhreeqC showed that the groundwater is under reductive conditions. Medium range iron and manganese contents that fall out when pumped and flowing under oxidative conditions can not be explained by high temperatures of the water and subsequent cooling. The contents of other trace metals are very low although they play an important role in the factor and cluster analysis. The sulphate content marks also a special group and can be explained completely by an oxidation of sulphide.

A comparison of the ages of the groundwater reported by Du et al. (2006) with the results of the groundwater models showed a good accordance. In Fig. 2 the backward pathlines with isochrone markers are shown. They indicate that the groundwater is flowing from South to North and that the retention time is in the frame of several 100,000 years. In this time the hydrologic conditions (precipitation, evapotranspiration and vegetation) have changed several times significantly in the recharge areas and thus the mixture of water from different times is evident.

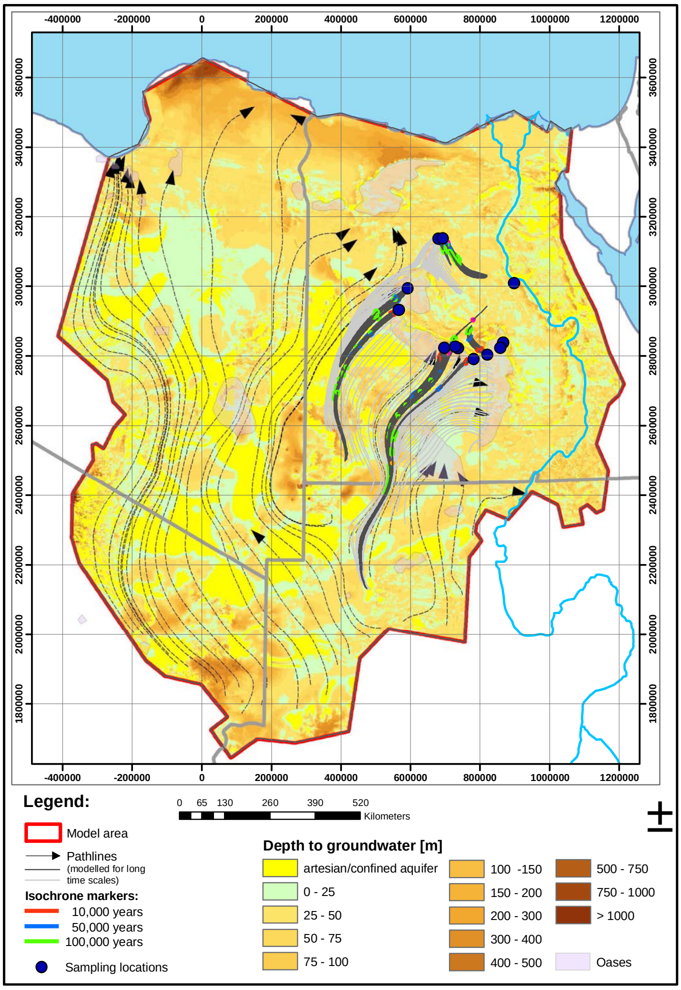

Figure 2. Pathlines calculated by the numerical groundwater model for a time horizon of 10000 b.p. are shown on the background of the depth to groundwater. The isochrone markers show the long retention time between infiltration and discharge in the Oases.

The results of the isotope analyses (Fig. 3) are also consistent with the former investigations but maybe have to be interpreted completely new. The highly negative excess of both the hydrogen and oxygen isotopes is not explained sufficiently by the former reports. In combination with the ages the question of the climatic conditions during the recharge of the groundwater has to be focussed again. About 300 to 1000 ky ago the infiltrating water from precipitation must have undergone a long history of evaporation and condensation processes.

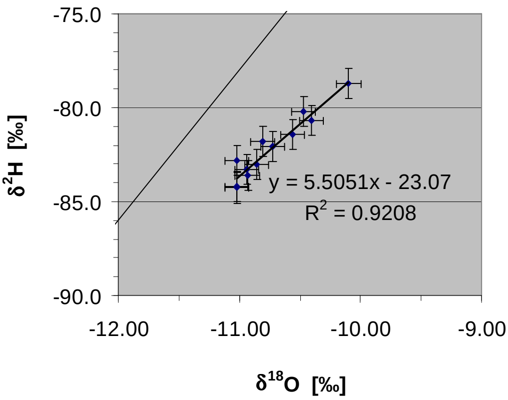

Figure 3. Results of the isotope analysis δ2H and δ18O of the water of the Egyptian Oases. The sample from the edge of the Nile Valley is not plotted.

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abstract id: **159**

topic: **3**
Aquifer management

3.4
Environmental and artificial tracers in hydrogeology

title: **U-decay series radionuclides in different aquifer systems at Paraná sedimentary basin, Brazil**

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keywords: uranium isotopes, radon, aquifers in Paraná basin, leaching experiments

INTRODUCTION

The use of isotopic methods in Earth Sciences investigations gained widespread acceptance among several professionals. Well-established techniques such as using stable isotopes of hydrogen and oxygen as markers of water source have been applied in water resource investigations for several decades. Isotope methods became an integral part of geochemical studies in groundwater projects as constituted powerful tools when applied to the intractable problems of source attribution for the most common groundwater contaminants, including nitrate, VOCs, and perchlorate. The co-interpretation of geochemical and environmental isotope data within the hydrogeological context provided hydrogeologists with a powerful problem-solving tool not only restricted to research programs. Thus, non-conventional environmental radionuclides have been utilized for dating meteoric waters and groundwaters under time scales from 2.5 years up to more than 1 million years like ^{22}Na, ^{32}Si, ^{39}Ar , ^{36}Cl, ^{4}He radiogenic and the natural uranium isotopes ^{234}U and ^{238}U (Ivanovich, Harmon, 1982). This study was held in São Paulo State, Brazil, and involved the sampling of different aquifer systems for evaluating the hydrochemistry and radioactivity due to the nuclides ^{238}U, ^{234}U, ^{222}Rn and ^{226}Ra in order to investigate their potential use as natural tracers of the water provenance in the area.

STUDY AREA

Multiaquifer systems mainly comprising sandstones and basalts plus sediments from Passa Dois Group (PDG) behaving as aquitards have been proposed to represent the hydrostratigraphy of the Paraná sedimentary basin in Brazil (Araújo et al., 1999), where the study area is located. Groundwater occurs within the interflow zones and along cooling joints in basalts and diabases from Serra Geral Formation (SGF), where interbedded sediments greatly increase the average porosity of large volumes of rocks. The sandstones of Cretaceous age (Bauru Group) are moderately cemented, and exhibit adequate properties to storage water. The Paleozoic sediments (Devonian-Permian age) also provide water that is relatively mineralized in the central parts of the basin and contains H_2S in some wells. The Guarani aquifer of Triassic-Jurassic age has continental dimensions and is composed of silty and shaly sandstones of fluvial-lacustrine origin, as well variegated quartzitic sandstones that were accumulated by eolian processes under desert conditions. Several investigations have focused the Guarani aquifer system, under different approaches (Araújo et al., 1999; Sracek and Hirata, 2002; Bonotto, 2006; etc.). This study was held in São Paulo State, Brazil, and involved the groundwater sampling in 20 municipalities situated along the sections AB, CD and EF in Fig. 1. Only Três Lagoas city was located in Mato Grosso do Sul State, close to the border of São Paulo State (Fig. 1). The groundwater samples (79) were collected from free-flowing and pumped tubular wells for physical and chemical analyses, including radionuclides.

Beyond cutting the superficial weathering mantle, the wells intercepted most of the stratigraphic units of the Paraná basin (Paleozoic–Cenozoic) (IPT, 1981): the Paraná Group, represented by coarse to mean grained whitish sandstones in a kaolinitic matrix, locally intercalated by micaceous/silty/clayey or fine sandstone layers, where about 1 m-thick conglomerates often occur in the base; the Tubarão Group, comprising the Itararé Subgroup (sandstones, conglomerates, diamictites, tillites, siltstones, shales and rythmites) and Tatuí Formation (siltstones, shales, silex and sandstones with local concretions); the Passa Dois Group, comprising the Irati Formation (siltstones, mudstones, black betuminous shales and limestones) and Corumbataí Formation (mudstones, shales and siltstones); the São Bento Group, comprising the Pirambóia Formation (sandstones, shales and muddy sandstones), Botucatu Formation (sandstones and muddy sandstones), Serra Geral Formation (basalts and diabases) and related basic intrusives; the Bauru Group, characterized by mean to fine sandstones with local occurrence of cement and carbonate nodules, arkoseous mean to very fine massif sandstones, fine to very fine sandstones exhibiting cementation and carbonate nodules with sandy siltstone lenses and massif mudstone layers, sandstones with clayey cement and elongated shales lenses, conglomerates, siltstones and limonitized sandstones.

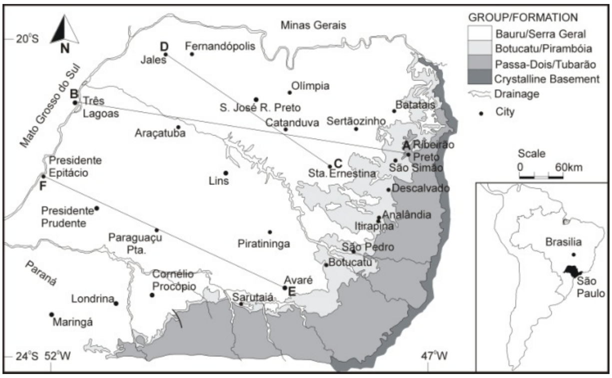

Figure 1. The three sections in São Paulo State, Brazil, that were utilized for selecting tubular wells drilled in Bauru, Serra Geral and Guarani aquifers.

ANALYTICAL METHODS

The groundwater samples (45–50 kg) were stored in polyethylene bottles, with the temperature, pH and Eh (redox potential) readings being performed in the field. The pH measurement was performed by a digital portable meter coupled to a combination glass electrode; buffer solutions equilibrated with the sample temperature were utilized to calibrate the equipment before the analyses. The Eh measurement was realized with the same pH digital portable meter after disconnecting the pH electrode, selecting the "mV" position, and connecting a combination platinum electrode — Ag/AgCl reference element. Such electrode was previously calibrated on using a prepared Zobell I reference solution (Zobell, 1946). A bench digital meter provided conductivity readings obtained though a 1 cm^2 area platinum electrode calibrated with KCl standards. The total alkalinity of the samples was determined by titration using a titrator with sulfuric acid standard solution to an end point evidenced by the color change of a standard indicator solution (APHA, 1989). The obtained values corresponded to bicarbonate, carbonate and hydroxide concentrations.

Aliquots were divided for evaluating the major/trace elements/compounds, and radionuclides. The suspended solids were separated on filtering each sample through a 47 (90)-mm diameter Millipore membrane of 0.45-μm porosity. The dry residue (DR) (~ total dissolved solids, TDS) content was evaluated on evaporating the filtrate to dryness in a weighed flask that was dried to constant weight at 180°C, with the increase in flask weight representing DR (APHA, 1989). Filtered aliquots preserved with HCl or HNO_3 were used for obtaining the chemical composition in waters. The analyses of dissolved sodium were done using an atomic absorption spectrophotometer, whereas standard procedures were utilized for characterizing dissolved potassium, calcium, magnesium, silica, nitrate, sulfate and chloride by colorimetry (Hach, 1992), after adding reagents to the samples that are able to produce colored complexes read by a program stored in Hach DR/2000 spectrophotometer previously calibrated in variable concentrations at different wavelengths. Fluoride was potentiometrically measured, after adding a known amount of ionic strength adjustor to each sample; then, an Orion ion-selective electrode coupled into a digital meter was used, where standards containing variable concentrations of fluoride were utilized for preparing the calibration curve consisting on a logarithmic straight line involving the potential and concentration readings.

The ^{222}Rn activity concentration in water was measured using an Alpha Guard PQ2000PRO (Genitron GmbH) equipped with an appropriate unit (Aquakit), following a protocol proposed by the manufacturer (Genitron, 2000). Alpha Guard is an ionizing chamber which measures radon via alpha spectrometric techniques. For measurement with Aquakit, the water samples were forced to degas their radon content within a radon tight assembly, which consists of two glass vessels and the Alpha Guard unit. ^{226}Ra was evaluated from ^{222}Rn data obtained in 1-L aliquots that were inserted in glass bottles fitted with inlet and outlet stopcocks, as well outgassed with ^{222}Rn-free N_2 to remove the ^{222}Rn originally present in the sample. The radon removal was performed only after waiting a time of about 25 days for ^{222}Rn to reach radioactive equilibrium with ^{226}Ra. The aliquots (20–25 kg) for U analysis were acidified to pH less than 2 on using HCl, about 500 mg of $FeCl_3$ plus 3.39 dpm of ^{232}U were added, and U was coprecipitated on $Fe(OH)_3$ by increasing the pH to 7–8 through addition of concentrated NH_4OH solution; the precipitated was recovered, dissolved in 8M HCl and Fe^{3+} was extracted into an equal volume of isopropyl ether. The acid U-bearing solution was purified by anion exchange, first on a Cl^- and then on a NO_3^- column of 100–200 mesh AG1-X8 resin. U was finally eluted from the NO_3^- column with 0.1 M HCl and after evaporation to dryness was dissolved in 10 mL of 2M $(NH_4)_2SO_4$ electrolyte and transferred to an electrodeposition cell. The pH was adjusted to 2.4 and electrodeposition of U on a stainless steel planchet was complete after 3 hours at a current density of 1 Acm^{-2}. The U content was measured by alpha spectrometry. The α-activities were determined with four 0.1 mm depletion depth, 200/450 mm^2 area silicon surface barrier detectors. The spectra for natural U and ^{232}U tracer extracted were recorded on an EG&G ORTEC 919 Spectrum Master Multichannel Buffer. The Decision Level L_c (Currie, 1968) for acceptance of a positive measurement in the ^{238}U and ^{232}U energy regions was 0.00082 and 0.00225 cpm, respectively. The concentration data were calculated by isotope dilution from the counting rates of ^{238}U and ^{232}U peaks, where the analytical details for these measurements were reported elsewhere (Ivanovich, Harmon, 1982).

Diabase gravels belonging to the Serra Geral Formation were also subjected to experimental etch/leach on a laboratory time-scale. Their specific surface area S ($cm^2 \cdot g^{-1}$) was determined on counting a large number of particles randomly selected and on measuring their maximum and minimum lengths. Then, after evaluating the average length, the assumption of a spherical geometry allowed estimate S by the equation $S = 3/\rho r$, where ρ is the rock density (2.91 $g \cdot cm^{-3}$). The mean diameter and S values were, respectively, 1.54 cm and 1.34 $cm^2 \cdot g^{-1}$. The freshly crushed and sized diabase sample was submitted to chemical dissolution in the laboratory under controlled conditions, where the gravels were initially washed with distilled water to remove any finely divided material. After drying, 16 kg of diabase gravels were weighed into a 20 L glass bottle and subjected to chemical etch/leach at room temperature (~ 20°C) with distilled water equilibrated with the atmosphere (p_{CO2}~$10^{-3.5}$ atm). The solution was daily circulated through the rock aggregates, periodically removed for analysis and replaced by a fresh one, where etching/leaching was continued in this sequential manner for up to 306 days. The etch/leach solutions were filtered through a 0.45 μm Millipore membrane and acidified to pH<2 for the U content and $^{238}U/^{234}U$ activity ratio determinations. These parameters were also evaluated in the diabase itself, as well in others selected rock samples from Paraná sedimentary basin, after their complete solution with HF, HNO_3 and HCl.

RESULTS AND DISCUSSION

The chemical data obtained for the studied groundwaters were plotted in an Eh-pH diagram (Krauskopf, Bird, 1995), which showed the following trends: Section AB — reducing (Bauru and Serra Geral aquifers), transitional + reducing (Guarani aquifer); Section CD — reducing (Bauru, Serra Geral and Guarani aquifers); Section EF — reducing (Bauru and Serra Geral aquifers), transitional + reducing + oxidizing (Guarani aquifer). Thus, most of the data fell into the reducing field, even under the more acidic and basic conditions. The software *Aquachem 4.0* of *Waterloo Hydrogeologic* allowed determine the ionic strength (ranged from 0.61×10^{-3} to 10.14×10^{-3}) and define the dominant hydrogeochemical facies from the acquired data, i.e. the anion bicarbonate was dominant in practically all wells along the three sections, whereas sodium was the dominant cation in most of them.

The analytical uncertainty for the radiometric data was often ± 10% (1σ standard deviation). The range of the values obtained for groundwater samples from Bauru aquifer (n = 35) was: ^{238}U = 0.007–0.20 μg/L (mean = 0.04 μg/L); $^{234}U/^{238}U$ activity ratio = 0.90–4.84 (mean = 2.14); ^{222}Rn = 0.78–11.76 Bq/L (mean = 3.80 Bq/L); ^{226}Ra = 0.07–1.44 Bq/L (mean = 0.33 Bq/L); $^{222}Rn/^{226}Ra$ activity ratio = 1.57–73.50 (mean = 20.97). The range of the values obtained for groundwater samples from Serra Geral aquifer (n = 16) was: ^{238}U = 0.002–0.09 μg/L (mean = 0.02 μg/L); $^{234}U/^{238}U$ activity ratio = 0.96–3.44 (mean = 2.08); ^{222}Rn = 0.93–21.18 Bq/L (mean = 6.70 Bq/L); ^{226}Ra = 0.001–0.32 Bq/L (mean = 0.14 Bq/L); $^{222}Rn/^{226}Ra$ activity ratio = 13.55–8370.0 (mean = 757.79). The range of the values obtained for ground water samples from Guarani aquifer (n = 28) was: ^{238}U = 0.02–7.47 μg/L (mean = 1.19 μg/L); $^{234}U/^{238}U$ activity ratio = 1.33–5.56 (mean = 2.87); ^{222}Rn = 0.23–50.46 Bq/L (mean = 13.71 Bq/L); ^{226}Ra = 0.03–1.17 Bq/L (mean = 0.20 Bq/L); $^{222}Rn/^{226}Ra$ activity ratio = 1.66–624.33 (mean = 105.50). The variability in radionuclides data suggests some influence of the underlying Paleozoic sediments in the composition of waters from Guarani aquifer, as already pointed out by Bonotto (2006). The $^{234}U/^{238}U$ A.R. for dissolved uranium was generally greater than unity and related to the ^{234}U-enhancement in the liquid phase as a consequence of the water-rock interactions. The $^{222}Rn/^{226}Ra$ A.R. greatly exceeded unity in the three aquifer systems, as already pointed out in the literature (Andrews, 1983), due to the low ^{226}Ra activity concentration generally found in groundwaters. The $^{222}Rn/^{226}Ra$ ratios are significantly higher in waters coupled to fracture flow (Serra Geral aquifer) relatively to those associated to porous flow (Bauru and Guarani aquifers).

There were significant correlations among pH, conductivity, bicarbonate and dissolved uranium in groundwaters from Bauru and Serra Geral aquifers, as well verified in Guarani aquifer. The relationships suggest that U-migration may be occurring through the complexation of the uranyl ions (UO_2^{2+}) with bicarbonate/carbonate anions. However, the U mobility coefficient associated to groundwater dissolution is 2×10^{-5} g·cm^{-3} for Bauru aquifer and 7×10^{-6} g·cm^{-3} for Serra Geral aquifer, which are greatly lower than the estimate of 1.7×10^{-3} g·cm^{-3} for Guarani aquifer. Thus, the U content and ^{222}Rn/^{226}Ra A.R. are potentially useful parameters for indicating the water provenance. The amount of uranium etched/ leached in the laboratory experiments held with the diabase sample was 0.12–0.28 µg/kg that is within the range of 0.07–1.09 µg/kg obtained by Bonotto and Andrews (2000) for the etching/leaching of exposed areas of calcite/dolomite surfaces at the same conditions. Therefore, the volcanic rocks of the Paraná basin release bicarbonate, uranium and others compounds during the water-rock interactions occurring in the fractures flow, but the uranium transfer to the liquid phase is less accentuated if compared with that involving the flow through the porous media.

ACKNOWLEDGEMENTS

FAPESP (Foundation Supporting Research in São Paulo State) and CNPq (National Council for Scientific and Technologic Development) in Brazil are greatly thanked for financial support of this investigation.

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abstract id: **163**

topic: **3**
Aquifer management

3.4
Environmental and artificial tracers in hydrogeology

title: **Using environmental tracers to characterize recharge conditions in the strongly exploited aquifer system of the North China Plain**

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keywords: tritium-helium-3 dating, stable isotopes, recharge rate, irrigation return flow

INTRODUCTION AND STUDY AREA

The North China Plain (NCP) is one of the most densely populated regions in eastern Asia. Increasing exploitation of the NCP aquifer system has led to a decline of groundwater levels since the 1970s. Despite several studies addressing the water balance in the NCP (e.g. Chen et al., 2005; Kendy et al., 2004), considerable uncertainty with regard to recharge mechanisms and rates as well as vertical and horizontal flow velocities remains. In this study, we employ the ^{3}H–^{3}He method to determine the age structure in the recharge area. The study focuses on the piedmont plain around the city of Shijiazhuang. It is based on a ~120 km transect starting at the eastern rim of the Taihang Mountains, crossing the piedmont plain in south-eastern direction, and extending into the central part of the NCP (Fig. 1). This section is part of a longer transect sampled for a paleoclimate study (Kreuzer et al., 2009).

Figure 1. Map of the study area in the North China Plain showing sampled wells

RESULTS AND DISCUSSION

Although we only have a composite age profile for the entire recharge area, it seems possible to derive an overall vertical velocity and thus a recharge rate from the slope of the age-depth relationship (Fig. 2), where the depth of the saturated zone is used to account for the fact that ^{3}H-^{3}He ages only reflect the groundwater residence time in the saturated zone.

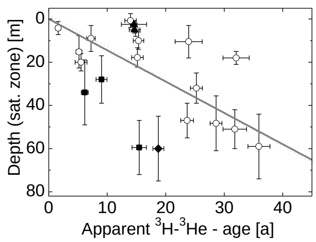

Figure 2. Vertical profile of the apparent ^{3}H–^{3}He age versus saturated depth

Excluding a few wells from the mountain area and a depression cone around Shijiazhuang, linear fits to the "regular" samples (open symbols) yield a well-defined slope of about 1.5 m/a.

This value reflects the relative vertical velocity by which the water moves ahead of the falling water table and hence the rate of annual water input. This input is due to areally distributed infiltration and can be translated into a recharge rate of 0.3 m/a (using an effective porosity of 0.2).

Despite this substantial active recharge, the system is in net discharge because the pumping rate equivalent to about 0.5 m/a exceeds the recharge rate. The deficit between pumping for irrigation and recharge of about 0.2 m/a explains the mean observed groundwater table descent of ~ 1 m/a. The $\delta^{18}O$-values of the modern samples show a decreasing trend with ^3H–^3He age, i.e., an increasing trend with time over the past 40 a. This recent enrichment trend is probably the result of the anthropogenic impact on the recharge regime, such as less seasonality in the recharge, a higher contribution of enriched water from the adjacent mountain area, or evaporation during flood irrigation in the pumping and re-infiltration cycles. Unusually high ΔNe values in some of the modern samples from the recharge area may be related to increased seasonal water table fluctuations due to pumping.

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abstract id: **166**

topic: **3**
Aquifer management

3.4
Environmental and artificial tracers in hydrogeology

title: **Isotopic constraints on recharge and age of groundwater in the Songnen Plain, Northeastern China**

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keywords: semiarid regions, stable isotopes, groundwater recharge, residence time

INTRODUCTION AND STUDY AREA

The Songnen plain (121°21'~128°18'E and 43°36'~49°26'N), lies between the Greater and Lesser Hinggan and the Changbai ranges in northeastern China. it is made up mainly of the alluvial deposits of the Songhua and Nenjiang rivers. The plain covers about 178,000 km^2 and is populated by about 35 million people. It consists of the piedmont plain in the northern and western part, the central low plain, and the high plain in the eastern part. The unconfined aquifer consists of Quaternary coarse-grained gravel and sand with a thickness up to 200 m in the piedmont plain, and fine and silty sand in the central low plain but Cretaceous formation in the high plain with a thickness less than 50 m. The confined aquifer mainly occurs in the central low plain and consists of medium to fine and silty sand, which correspond to the Pleistocene and Tertiary formation. Groundwater movement has historically been oriented primarily from plain margins toward the central part. However, there has been a steady increase in ground-water pumping and resulted in substantial declines in water levels. A depression in the water-level surface is apparent in the vicinity of Daqing and have resulted in ground-water movement being directed into the major pumping centers.

Multiple sources of recharge to the aquifer system are present across the basin. Despite the presence of irrigation has added to the potential sources of recharge. But infiltration through mountain stream channels and shallow subsurface inflow, probably is one of the most important sources of recharge to the plain. In this study, chemical and isotopic data from groundwater and surface water throughout the Songnen Plain, were used together with classical hydrogeological information to study the sources of recharge and estimate groundwater age in the plain.

RESULTS AND DISCUSSION

The tracer data indicated that major sources of water to unconfined aquifer included (1) recharge from mountains along the margins along the west, north and southeast, (2) precipitation inside the plain, (3) seepage from the rivers, (4) irrigation return. Mountain-front recharge probably is one of the most important sources of recharge to the basin. Tracers distribution mainly depth dependend suggested the active groundwater recharge zone has a thickness of ~100 m in the piedmont, ~80 m in the central plain and a less than 50m in the high plain. The recharge rate estimated by tracers were 126 mm/yr, 60 mm/ yr, 59 mm/yr for the piedmont plain, central plain and high plain, respectively. These waters were younger than 50 years and therefore were renewable.

The ranges of δ-values for groundwater within quaternary confined aquifer were close to those of the samples collected from unconfined aquifer. The relationship between δ-values of oxygen-18 and deuterium for samples collected from the area near piedmont and in the central low plain show the different slope of fitted line. Groundwater samples in the western and northern part of the piedmont lay to the right of the LMWL and plot along an evaporation line with slope of 4.9. The original isotope values of the recharge water by extrapolating the evaporation line to the intersection with the LMWL fall in the range of mountain rivers. However, groundwater samples collected from the central low plain plot along an evaporation line with slope of 3.6 which is close to the slope of the evaporation line of unconfined aquifers in the same region. The original isotope values of the water prior to evaporation inferred by extrapolating the evaporation line to the LMWL close to the weighted mean value of Qiqihaer precipitation, which reflects that recharge water comes from the local precipitation. These findings suggest that two recharge mechanisms for deep groundwater possibly occurred in the Quaternary confined aquifer. One involved recharge via leakage from the unconfined aquifer, and the other involved lateral recharge from mountains through fractures and from the east high plain. Modern recharge for this confined aquifer mainly occurred at the west piedmont plain and the east high plain along Qi'an–Zhaozhou. The recharge rate estimated by tracers was 6.2 mm/yr. Groundwater age dated by carbon-14 range from modern to 10 kaBP.

The groundwater samples of deep Tertiary confined aquifer were mainly collected from the central low plain. These groundwaters are tritium free and have C-14 activity less than 40 pmc. Most samples plot below, but nearly parallel to, the local meteoric water line. The difference of the intercept between the regression line and the one of LMWL probably reflects the different recharge conditions of these paleowaters from the modern waters. Modern recharge of this confined aquifer is limited at the outcrop area in the northwest part of piedmont and recharge rate very low. Ages for groundwater in the central plain dated by carbon-14 range from 10 kaBP to 25 kaBP. This resource is inherently finite and limited.

abstract id: **188**

topic: **3**
Aquifer management

3.4
Environmental and artificial tracers in hydrogeology

title: **Quantifying groundwater dynamics in a semi-arid silicate aquifer, Murray Basin, Australia**

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keywords: environmental tracers, isotope geochemistry, hydrogeology

INTRODUCTION

The semi-arid Lower Murrumbidgee region of Australia's Murray Basin (Figure 1) comprises unconsolidated, flat-lying, fluvio-lacustrine, regolith aquifers produced during Cenozoic weathering of the Lachlan Fold Belt, with the shallow and deep aquifer systems separated by a clay aquitard (Brown, 1989). Over the last century the Lower Murrumbidgee has been subject to extensive agricultural development, with irrigation water sourced from both the Murrumbidgee River and regional aquifers.

Historically, vertical gradients between aquifers were small, limiting the flux of salt from the saline shallow aquifer into the fresher deep aquifer. However, changes in the vertical gradient (dh/dz up to 0.2 m/m) attributed to irrigation, groundwater extraction, and the recent period of below-average precipitation present a potential for saline water intrusion into the deep aquifer system.

This paper summarizes the results from the first part of a three-year study of groundwater dynamics in the 33,000 km^2 Lower Murrumbidgee region. Bore hydrographs and environmental tracer concentrations measured in over 250 surface water and groundwater samples are reviewed for evidence that the altered hydraulic gradients have enhanced leakage of saline groundwater into the deep aquifer and to assess if regional salt fluxes are influenced by the presence of the aquitard windows identified by Timms and Ackworth (2002).

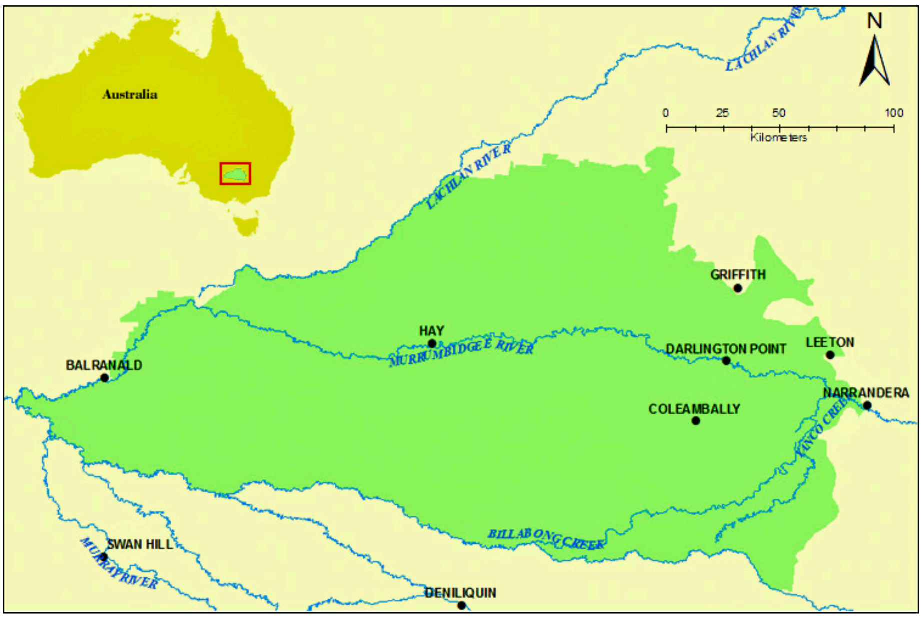

Figure 1. The Lower Murrumbidgee groundwater management area within Australia.

METHODOLOGY

Field work was conducted during several field trips between March 2009 and May 2010. Samples were collected from surface water bodies and aquifers across the region, with sampling concentrated around the two major irrigation areas: the 6,600 km^2 Murrumbidgee Irrigation

Area (MIA) located near Leeton and Griffith; and the 790 km^2 Coleambally Irrigation Area (CIA) located near Coleambally.

Groundwater samples were collected from discrete, aquifer-specific monitoring bore nests. Agricultural production bores (data not presented) screened across multiple units were also sampled in the MIA and CIA. Monitoring bores were sampled using a submersible pump set at the mid-point of the bore screen. Groundwater temperature, pH, EC, dissolved oxygen, and redox potential were measured in the field using calibrated Orion Three-Star meters and electrodes and, prior to sampling, monitoring bores were pumped at a constant flow rate until measured parameters stabilized. Samples from production bores were collected from the bore discharge point following a minimum of 30 minutes of operation. Initial grab samples of surface waters were collected adjacent to the channel bank in March 2009, followed by a ten-site river transect from Balranald to Narrandera in January 2010. During the 2010 event samples were collected from multiple depths in the channel thalweg, including a grab sample from the top 20-40 cm and 1-2 additional samples collected at depth using a 2 L Niskin bottle. An aliquot of water from each production bore and surface water sample was analysed for field parameters.

All water samples were field-filtered using 0.45 µm cellulose nitrate filters, and field analysis of alkalinity was conducted by acid titration using a Hach digital titrator and methyl-orange indicator. Select samples were field analysed for ferrous iron and sulphide using a Hach portable spectrophotometer. Samples for cations, anions, and $^2H/^{18}O$ analysis were collected in HDPE bottles filled to minimize headspace and refrigerated until analysis, with duplicates collected every ten samples. Cation samples were preserved to pH < 2 using 50% HNO_3.

Major, minor and trace cation and anion concentrations were measured at the Research School of Earth Sciences at the Australian National University, Canberra. Cations were analysed using a Varian ICP-AES and Varian ICP-MS, and anions were analysed using a Dionex ion chromatograph. Uncertainties in ion concentrations are estimated to be ±5%.

Oxygen and hydrogen stable isotopic ratios were measured by isotope mass spectrometry at GNS Science, New Zealand. ^{18}O analyses were conducted on CO_2 equilibrated with water at a constant temperature, and ^2H analyses were conducted on H_2 produced via reduction of water samples in a chromium injection furnace. Stable isotope ratios are expressed as deviation from Vienna Standard Mean Ocean Water (VSMOW) in parts per thousand (‰). Uncertainties are estimated to be ±0.1 ‰ for ^{18}O and ±1 ‰ for ^2H.

RESULTS AND DISCUSSION

The results show a strong correlation between chloride and the other major ions (Figure 2) in surface water and groundwater samples, following a marine-like trend. However, the terrigenous sedimentary aquifers were deposited in a freshwater environment and modern groundwater recharge is via leakage from the Murrumbidgee River and lateral inflows from adjacent catchments, with irrigation return flow substantially contributing to recharge of the shallow aquifer in cultivated regions. Given the fresh water environment, combined with regional groundwater ages (Drury et al., 1984) which indicate that several pore volumes have been flushed from the aquifers since their deposition, it is unlikely that connate sea water accounts for the observed groundwater composition.

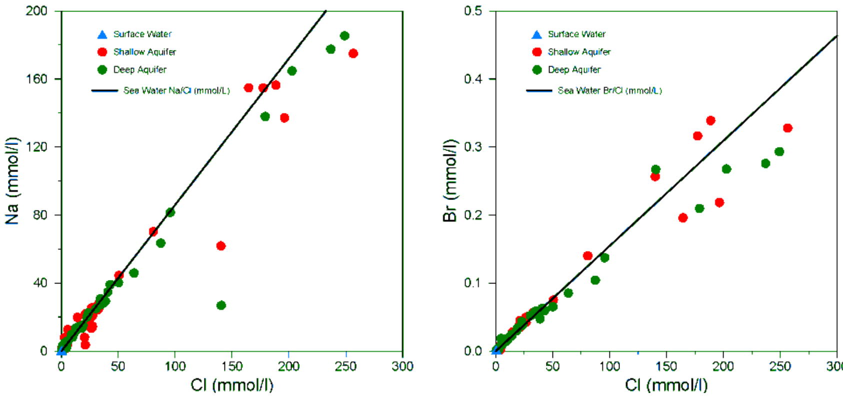

Figure 2. Scatter plots of sodium and bromide versus chloride in surface water and groundwater samples showing a marine-like signature in ion ratios for Cl concentrations less than 100 mmol/L.

The marine-like ratios are consistent with other catchments within the Murray Basin (Herczeg et al., 2001; Cartwright, Weaver,2005; Petrides et al., 2006), which have resulted from mixing of evapoconcentrated meteoric and irrigation water with regional groundwater, modified by ion exchange, water/rock interaction, and precipitation of silicate clays, with the linear Br/Cl relationship (Figure 2) indicating that dissolution of halite (NaCl) is not a significant source of dissolved solutes.

Major ion proportions for groundwater samples collected from monitoring bores follow a few constrained trends (Figure 3). In irrigation areas, groundwater compositions reflect a trend of mixing between fresh Ca-Mg-HCO_3 type groundwater with more saline Na-Mg-Cl type groundwater, whereas samples collected outside of the irrigation areas plot below the mixing line indicating water rock interaction and ion exchange are the dominant processes controlling groundwater composition.

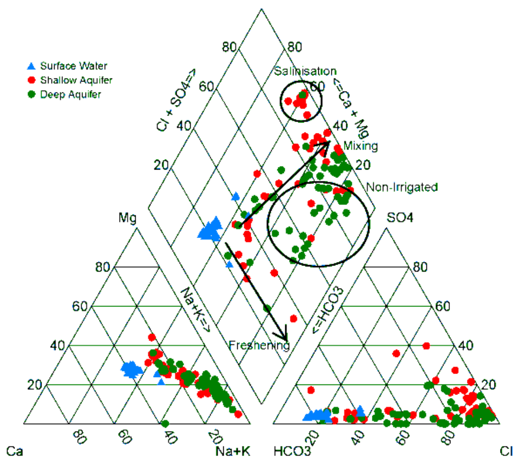

Figure 3. Piper plot of surface water and groundwater samples. Groundwater samples collected from depth-specific monitoring bores.

A few groundwater samples collected adjacent to surface water channels show ionic ratios consistent with aquifer freshening, indicative of groundwater recharge from the Murrumbidgee River and major irrigation canals, while evidence of aquifer salinisation is seen in groundwater samples collected from a region with historically pronounced groundwater mounding where the water table was less than 2 m below grade.

A groundwater mixing trend is also apparent in a plot of ^2H vs. ^{18}O (Figure 4). Groundwater samples plot along a trend line (slope ~ 4.3) parallel to, but displaced from, summer surface water samples (slope ~4.7). Neither the surface water nor the groundwater trends are consistent with meteoric water lines measured for coastal (Melbourne) or inland (Alice Springs) locations in Australia which reflects either a markedly different local meteoric water line or the effects of evapoconcentration, the latter of which is most likely given the positive correlation between total dissolved solids and ^{18}O (not illustrated).

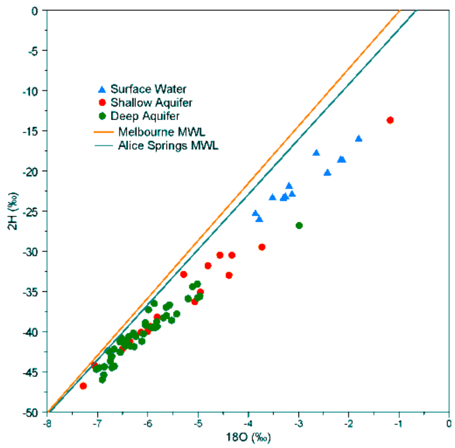

Figure 4. δ2H and δ18O values (VSMOW) in surface water and groundwater samples. Meteoric water lines for Melbourne and Alice Springs plotted for comparison.

SUMMARY AND FUTURE RESEARCH

Outside of the major irrigation areas, groundwater compositions indicate that there is a gradual regional prograde hydrogeochemical evolution from Ca-Mg-HCO_3 to Na-Cl, resulting in deep groundwater with a relatively light $^2H/^{18}O$ signature. In the irrigation areas, however, this gradual evolution is punctuated by mixing of fresh regional water and more saline, isotopically heavier waters, indicating the recent enhancement of vertical gradients has increased the flow of saline groundwater from the shallow aquifer into the deep aquifer.

The difference in salinity between the irrigation areas and non-irrigated areas can be used to estimate the additional salt loading occurring as a result of the modified hydraulic gradients. Future research will include high-frequency sampling of select monitoring bores to identify seasonal trends in leakage, as well as isotopic measurements (e.g. ^{14}C) to further constrain leakage rates across the aquitard and to refine historical groundwater age estimates.

ACKNOWLEDGEMENTS

The authors thank Prem Kumar of NSW Office of Water for advice on the catchment, bores and land owners, and Liz Webb of Parsons Brinckerhoff for advice and networking. This research was funded by an Australian Research Council Linkage Grant.

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abstract id: **214**

topic: **3**
Aquifer management

3.4
Environmental and artificial tracers in hydrogeology

title: **Investigation of well vulnerability in a river bank infiltrated aquifer using high resolution surface and groundwater temperature measurements**

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keywords: artificial tracer, river bank infiltration, well vulnerability, residence time

Larger waterworks in Norway using groundwater are typically based on river bank infiltration in shallow fluvial- or glaciofluvial deposits. Often, short distance between the river course and the wells, in addition to steep gradients and high permeability, give short residence time in the subsurface for extracted groundwater. These water supplies may therefore be vulnerable towards surface water contamination. Nevertheless, the water quality from water works based on river bank infiltration is normally surprisingly good, and based on reports from the Norwegian health authorities on drinking water quality in Norway, there are few reported cases of pathogen bacteriological contamination of groundwater.

Due to the normally good drinking water quality in river fed aquifers in Norway vulnerability assessment of these water supplies is seldom performed. Long term analytical records, showing good bacteriological groundwater quality, are often used as the only documentation for assuming that the aquifers and wells have acceptable hygienic protection against contamination of nearby surface water. Due to economical limitations, more comprehensive investigations, like tracer tests and groundwater modelling, are rarely performed to assess the aquifer vulnerability.

A commonly used method in Norway to estimate the residence time on groundwater from riverbed infiltration to extraction in production wells is to monitor the temperature fluctuations in surface water and extracted groundwater over a longer period of time. Recorded delays in temperature response in groundwater relative to surface water give evidence of groundwater residence time between infiltration and arrival at the wells. In order to obtain large contrasts in measured surface water temperatures the monitoring period covers normally the summer period and at least one of the colder seasons.

Although this method is commonly used in Norway, the validity of the method is not very well documented under Norwegian conditions, and there has until now not been reported any field experiments where long time temperature measurements have been combined with tracer tests.

In a river fed aquifer in the glaciofluvial fan at Mølleneset, near Alta in Northern Norway, NGU has, in close collaboration with Alta municipality, preformed long term surface- and groundwater temperature measurements in addition to a tracer test to evaluate the residence time for groundwater in the aquifer. The field site is display in Figure 1.

High frequent temperature measurements (each hour) over a period of more than a year using temperature loggers where performed in the Mølle river and three nearby wells. During the monitoring period well 1 and 2 were pumped with a capacity of 10–12 l/s while well 3 was only used as a monitoring well. The flow in the Mølle river change from app. 700 l/s during the spring flood to as low 60–70 l/s in the winter period. Based on monthly water sampling during the monitoring period, the groundwater from the pumped wells was found to have good drinking water quality.

As shown in figure 2, the temperature record for the river water showed both large and rapid temperature changes over the year. Similar temperature changes were also recorded in well 2 and 3, and the recorded groundwater temperature changes appeared almost simultaneously with the changes in the river temperature. Notably, the recorded water temperature changes in well 1 displayed a totally different pattern over the year compared to the river and the two other wells, with relatively slow seasonal temperature variation with no rapid temperature changes.

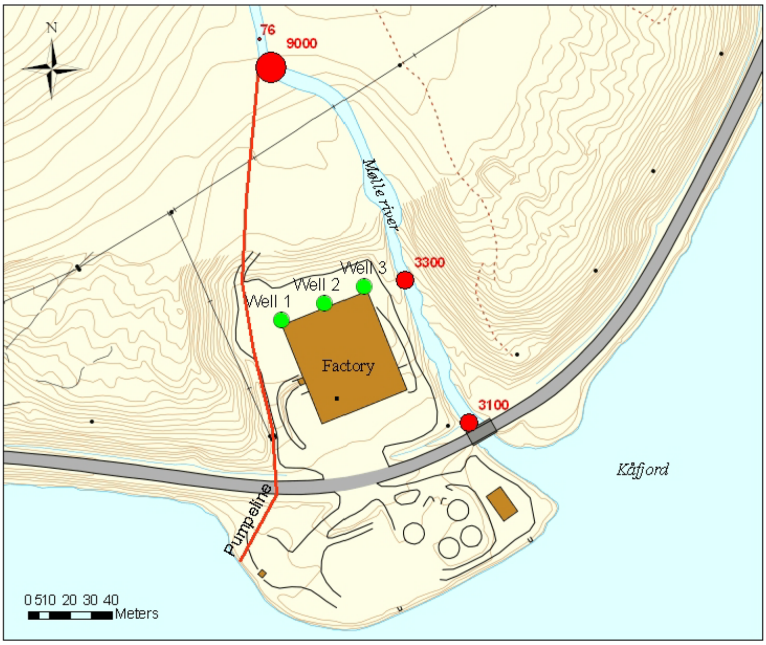

Figure 1. Field site with wells, pump line for seawater and measured EC in red (us/cm) in Mølle river after 5 hours of seawater pumping (20 l/s).

Based on these observations the groundwater in well 2 and 3 have very short residence times from river bed infiltration to the wells, whereas the groundwater in well 1 has a residence time closed to two months.

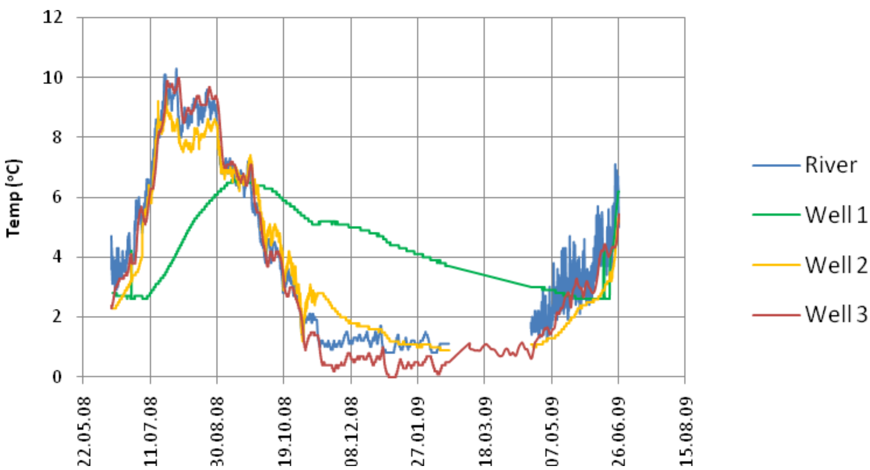

Figure 2. Long time temperature measurements in Mølle river and groundwater at Møllenes.

To validate the estimated residence time for groundwater based on temperature measurements a tracer test was performed at the well site. As the alluvial fan is close to the fjord, seawater was used as an ionic tracer and pumped into the river upstream of the groundwater wells. The seawater injection resulted in a major change in the river water's electrical conductivity (Figure 1). The seawater injection continued for a whole day with concurrent automatic logging of electric conductivity in the three wells. A quick arrival for the salt pulse and nice breakthrough curves were recorded in the well 2 and 3 (Figure 3), the same wells that displayed simultaneous temperature fluctuations in groundwater as the river water. Well 1, that displayed a slow temperature variation compared to the river water, did not show any significant change in the electrical conductivity that could be related to the seawater injection.

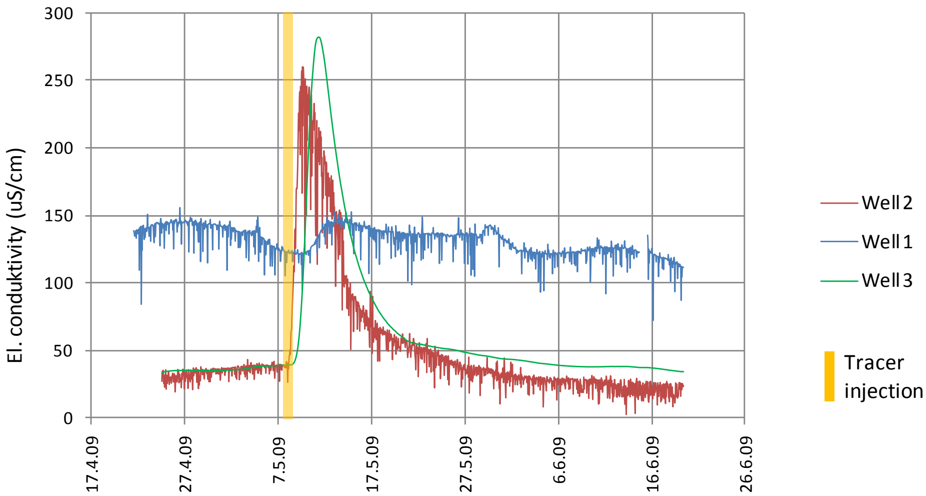

Figure 3. EC measurements in groundwater wells before, during and after seawater introduction to the Mølle river.

This experiment clearly demonstrates that there is a very good correlation between residence times estimated on river- and groundwater temperatures, and estimations based on the ionic tracer test at Mølleneset well site. The experiment supports therefore the use of the more simple methodology based on long term surface- and groundwater temperature measurements, instead of using more complicated and costly tracer test, in evaluating residence time for groundwater in an aquifer.

IAH 2010
Krakow

abstract id: **218**

topic: **3**
Aquifer management

3.4
Environmental and artificial tracers in hydrogeology

title: **Long-term migration of solutes in thick, surfical, clay-rich aquitards using multiple environmental tracers**

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keywords: iostopes, tracers, aquitards

Over the past decade, high resolution 1-D depth profiles of multiple tracers (^3H, δD and $\delta^{18}O$, ^{14}C-DOC and -DOC, ^{36}Cl, ^4He, and major ions) and hydraulic data were applied to study residence times, transport mechanisms, and source areas of pore water and solutes in a thick aquitard system in Southern Saskatchewan, Canada. The dual aquitard system consisted of 80 m of plastic clay-rich Battleford till discomformably overlying 77 m of late Cretaceous plastic marine claystone (Cretaceous Snakebite Member of the Bearpaw Formation; 72 Ma to 71 Ma BP). The surficial 3 to 4 m of till is oxidized (brown color) and visibly fractured, whereas the underlying till and claystone aquitards are massive, unoxidized (dark gray color) and nonfractured. We found that individual and independent tracers yield consistent findings. They showed that late Pleistocene age pore water is present in the till aquitard between 35 and 55 m below ground. Transport modeling revealed that this water was emplaced between 15 ka–20 ka BP during ice retreat and till deposition and that the late Holocene glacial-interglacial climatic transition occurred between 7 ka–10 ka BP. The multiple tracer profiles further confirmed that transport of solutes in the aquitard system is by molecular diffusion. This detailed compilation and comparison of environmental tracers showed that solute transport in clay-rich aquitards can be predicted for time scales well in excess of 20 ka, providing clear evidence that aquitards may be suitable for the long-term isolation of hazardous and nuclear wastes.

abstract id: **241**

topic: **3**
Aquifer management

3.4
Environmental and artificial tracers in hydrogeology

title: **Groundwater age and paleoclimate information derived from environmental tracers in a regional aquifer system in semiarid Northwest India**

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keywords: noble gas temperatures, stable isotopes, radiocarbon, radon

INTRODUCTION AND STUDY AREA

Stable isotopes and noble gases in groundwater in combination with dating based on ^{14}C and He are well-established tools to derive paleoclimate records. This study aims to provide the first noble gas temperature record from tropical south Asia. The regional aquifer system in the Cambay Basin situated in Northern Gujarat, India, is suitable for climate reconstruction over the last 30 to 50 ka (Agarwal et al., 2009). The region has a semi-arid, monsoon-dominated climate. In such a climate, stable isotopes and excess air may hold information about past changes in monsoon intensity (Kreuzer et al., 2009). Dating is provided by tracers such as SF_6, ^{222}Rn, ^{4}He, ^{14}C and ^{3}H–^{3}He. Sampling campaigns took place in early 2008 and 2009, following two transects along the groundwater flowpath (lines A'–A and B'–B in Fig. 1). Samples were collected from wells equipped with submersible pumps at farms and villages.

PRELIMINARY RESULTS

^{4}He and ^{14}C data confirm an increasing age with flow distance along the transects, enabling the use of He as an age proxy. Exceptions are thermal springs in the area, which show a strong radiogenic He component and high ^{222}Rn concentrations at large well depths. SF_6 concentrations in groundwater are abnormally high in some wells; possible correlations with He and Rn still have to be investigated. As SF_6 of natural origin appears to be prevalent, the use of this tracer as a dating tool is prevented.

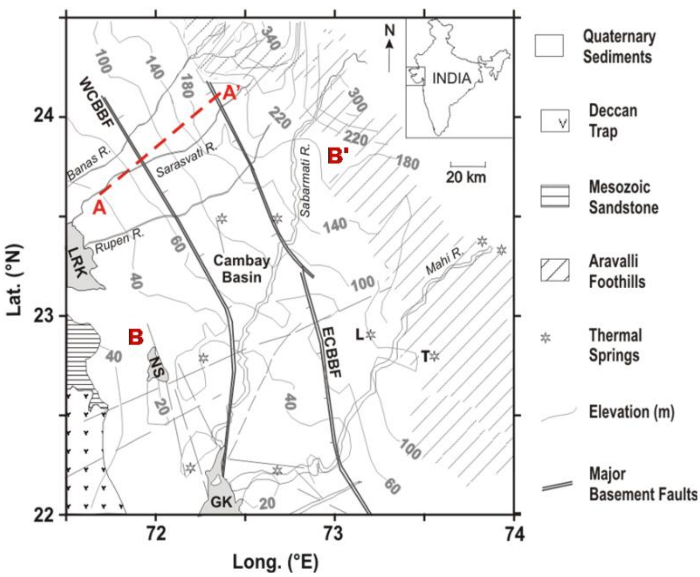

Figure 1. Map of the North Gujarat – Cambay region showing sampled transects.

$\delta^{18}O$- values obtained in 2008 along the northern transect increase with age, i.e., decrease from glacial towards modern times (Fig. 2). This trend may be a signal of increasing precipitation amount, i.e. a strengthening monsoon over the past ~20 ka. While stable isotopes show a rather linear trend, the deuterium excess exhibits an abrupt change around 7 ka (Fig. 2).

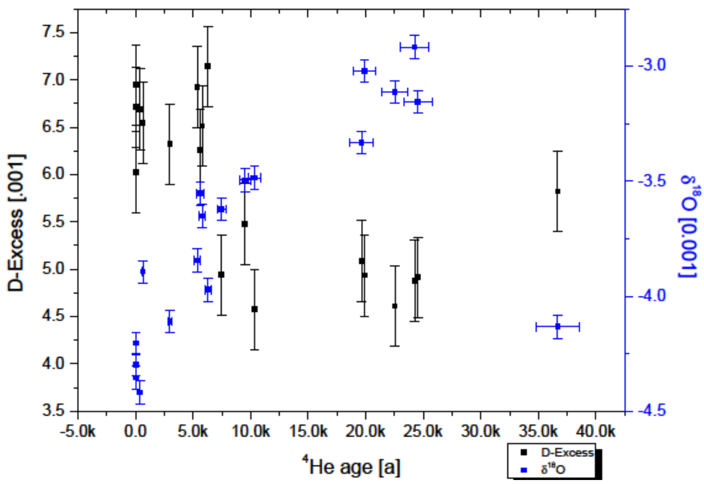

Figure 2. $\delta^{18}O$ and deuterium excess of the northern transect versus groundwater age.

Noble gas temperatures (NGTs) of both transects show a general drop in temperature with increasing age. NGTs in the recharge area are around 29°C (north) to 31°C (south) and are well reflected by recent groundwater temperatures in the recharge area, while being higher than the local mean annual air temperature (27.5°C at Ahmedabad). Cooler NGTs in older samples show a drop of around 2.5°C (north) to 4°C (south). Nonetheless, the temperature scatter in the recharge area is quite high, which may be due to an interference with older, deeper aquifers, as wells accessing the shallow aquifers in the recharge area are quite rare.

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abstract id: **244**

topic: **3**
Aquifer management

3.4
Environmental and artificial tracers in hydrogeology

title: **Rapid response in a gneissic bedrock fracture network to surface loading of nutrient- and pathogen-surrogate tracers in an agricultural watershed, Canada**

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keywords: fractured rock aquifers, tracer experiments, pathogen and nutrient transport

Crystalline aquifers are often the primary drinking water source for well owners in rural North America; however these aquifers are susceptible to agricultural contamination, especially when overburden is thin. Pathogens and nutrients in manure can pose a significant health risk when transported to a well, while the inherent anisotropy of crystalline fractured rock aquifers makes it difficult to characterize transport mechanisms. Nitrates are very soluble and readily leached (Nolan, 1999; Nolan et al., 2002), and are thus transported with groundwater flow while bacteria, alternatively, are generally transported like a colloid (McCarthy, Zachara, 1989). The structure of a fractured rock aquifer provides the framework for groundwater flow and contaminant transport (Lapcevic et al., 1999). Most fractured rock aquifers rely on flow in fractures or secondary porosity to transport water and contaminants within the aquifer system (Domenico, Schwartz, 2002). Fractures are generally not planar, as the cubic law suggests, but exhibit extreme variability in surface roughness causing straining of materials the size of colloids, such as bacteria (Taylor et al., 2004). To explore these issues, a regional-scale monitoring study and surface-to-fracture tracer experiments adjacent to a rock outcrop were initiated in the Precambrian Shield of Ontario, Canada.

The study area is characterized by sparsely-fractured Precambrian syenite-migmatite overlain by 0–3m of sandstone. Rock outcrops are common in this terrain, but overburden thickness can be greater than 4m. Twenty-two bedrock wells were drilled between 2004 and 2008 to depths from 30–45m below ground surface (bgs) in a 40 km^2 area. Hydraulic testing to identify horizontal fracture features was completed on each well and most were instrumented with multilevel piezometers. Results from a regional monitoring program indicate that areas of minimal overburden must create direct transport pathways for pathogens, such as *E. coli*. Little overburden coupled with recharge events creates an optimal environment for the introduction of pathogens to fractured rock aquifers. Bacteria occur most often in shallow piezometer sections indicating direct connection to the surface. However, bacteria were also found in deep piezometers (~30m bgs) suggesting that vertical fractures encourage transport to deeper horizontal fractures.

Initial tracer experiments were completed using Lissamine FF to explore conservative transport. A final tracer experiment was completed in September 2009 by applying 10^{11} particles/mL of 0.3 μm and 10^{11} particles/mL of 1.75 μm microspheres and 0.3 g/L of Lissamine to a dammed area adjacent to a rock outcrop. A single packer was positioned at 4 m bgs creating a seal where water and tracer solution could be collected above the packer. The dammed area was filled by pumping 1200 L of water from TW8. Once the pool was filled, the flow rate was reduced to 7 L/min to create steady state conditions, where the pool remained full throughout the duration of the experiment. The deep section was pumped at a rate of 7 L/min using a submersible pump fed through the upper packer to create a downwards hydraulic gradient in the closest well (5m from the pond) and to retain a saturated flow loop with the pool. The upper section of the closest well and the shallow section of another nearby piezometer (15 m from the pond) were pumped continuously at a rate of approximately 0.6 L/min using peristaltic pumps. The tracer experiment was executed over a period of 72 hours. Bulk samples were collected from three intervals at 15-minute intervals for the first two hours and at 4-hour intervals toward the end of the experiment. The Lissamine samples were analyzed using a Turner Designs Au-10 field fluorometer. Microspheres were enumerated using epifluorescence microscopy and computer imaging software with counting capabilities.

Tracer experiments indicate that transport times can be very fast, with arrival times between 30 minutes to five hours after tracer application on the rock outcrop. Microspheres arrive earlier than the conservative flow, but straining is evident. The dominant flow likely occurs through a semi-vertical fracture from the pond area and trickles down into the closest well (5 m from the pond). Some of the tracer is flowing downwards to a larger fracture deeper in the deeper interval in the same well. Significant tracer reaches the nearby well (15 m from the pond) through shallow horizontal and vertical fractures. All results from the tracer experiments indicate that wells drilled on rock outcrops are extremely vulnerable to surface contamination from agricultural processes.

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abstract id: **254**

topic: **3**
Aquifer management

3.4
Environmental and artificial tracers in hydrogeology

title: **Monitoring groundwater circulation during tunnel works by environmental tracers**

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keywords: recharge, CFC, tritium, hydrochemistry, groundwater

INTRODUCTION

Construction of new railroads for more rapid trains is often having an impact on the groundwater recharge and circulation patterns. In particular when dealing with long tunnels and deep excavations there is a risk for permanent disturbances of the hydrogeological system and environmental consequences. This study aims to developing a methodology for monitoring groundwater circulation times in and contacts between different aquifer units as an effect of groundwater drainage at large tunnel projects.

The Hallandsås horst, southern Sweden, is selected as study area as hundreds of observation wells have been installed there during the on-going railway tunnel works (Fig. 1).

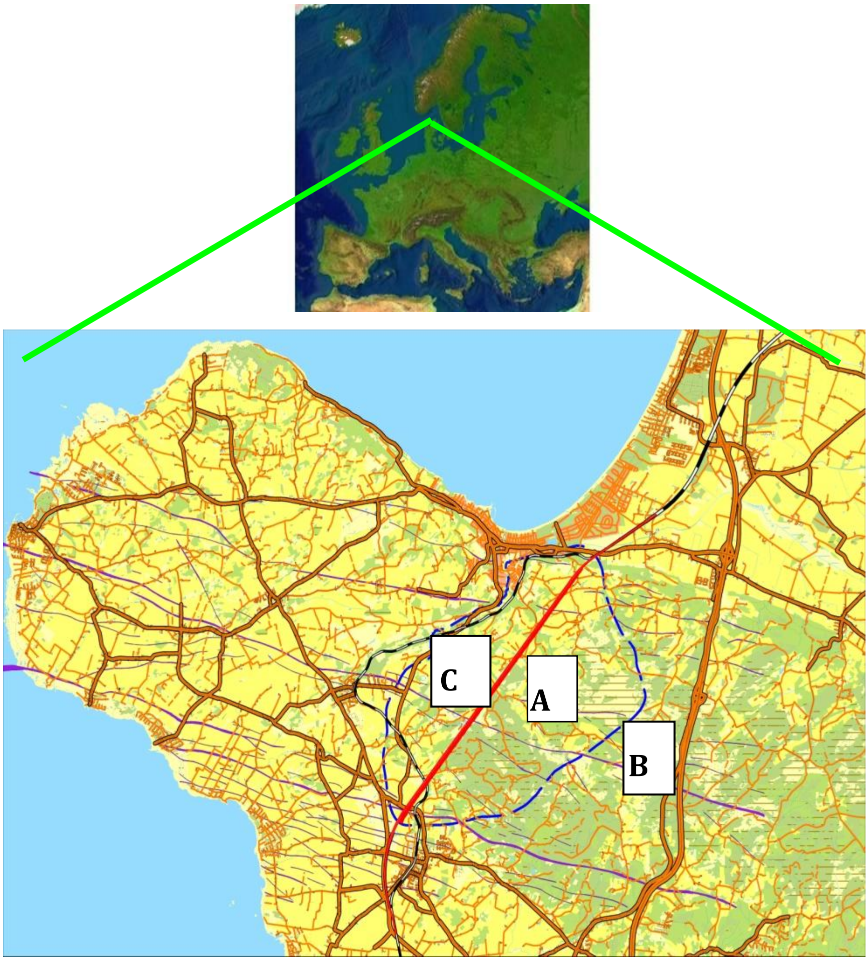

Figure 1. Overview of Europe (top map). The Hallandsås horst, southern Sweden, is situated where the two green lines are meeting. The western part of the horst and the Bjäre peninsula is shown on the bottom map. The two parallel 8.6 km long railway tunnels are marked with a thick red line, which also gives an approximate scale of the map. North is upwards on the maps and the blue dashed line around the tunnels shows the outer limit of the estimated area, where the groundwater levels could be influenced by the tunnel works. The letters A-C mark sampling positions explained below.

Many of the wells are still accessible and they are in contact with the aquifers of fractured and often weathered Precambrian rocks at different levels. There are also shallow observation wells in the relatively thin soil cover (typically 5–15 meters thick), mainly consisting of dense till.

Environmental tracers occur by natural processes or as a result of large-scale human activities. If the tracers mainly follow the movements of the groundwater they may provide a relatively direct and independent assessment of groundwater velocity and age. The residence time or age of groundwater is the mean travel time of water from the point of recharge to the point of collection and can be used to characterize flow, transport processes and to reconstruct past releases of contaminants to aquifers (Bockgård et al., 2004). In this study the main selected metods of monitoring have been measurements of the contents of different CFC's and the contents of the radioactive isotope tritium. These values have been interpreted together with results from analyses of the major ions dissolved in the groundwater, general hydrochemical properties and the contents of oxygen-18.

METHODOLOGY

Three shallow (less than 7 metres deep) and sixteen deep (40–174 metres deep) observation wells have been sampled. The shallow wells represent an unconfined aquifer in the top soil layer (chiefly consisting of till), while the deep wells represent confined or leaky confined aquifers in the fractured crystalline basement rocks. The sampling sites are situated at different distances from the on-going tunnel works at Hallandsås. The deep wells have been sampled by a simplified depth specific method using two submersible pumps with different capacities simultaneously. The sample is supposed to represent the upper part of the well when it is extracted by the upper, low capacity, pump. The latter pump is lowered below the high capacity pump when a sample from the lower part of the well is desired. The samples have been analyzed by GEUS, Denmark, as regards major hydrochemistry and contents of CFC-11, -12 and -113 (detection limit 1 pg L^{-1}). The analysis was following the methodology described by Busenberg and Plummer 1992. The recharge temperature was assumed to be equal to the estimated average air temperature (8 ºC) for all sites. Ten selected samples have also been analyzed by Geological & Nuclear Sciences, New Zeeland, concerning contents of tritium and using electrolytic enrichment and calibration by deuterium concentration (detection limit 0.04 TU).

RESULTS AND DISCUSSION

Results regarding nitrate, tritium and CFC-based ages from different parts of the study area are shown in table 1. Tritium values below 1 T.U. indicates an average circulation time longer than 55 years in southern Sweden, while 8-10 T.U. in todays groundwater could correspond to very recent recharge as well as mixes of groundwater, mainly recharged 10-40 years ago.

The content of oxygen-18 is about -9.0 — -9.2 ‰ vs. SMOW in all sampled wells which supports the assumption of an equal recharge temperature, which facilitates a reliable estimation of CFC-based ages. The results in table 1 can be split in two major groups, one where the different analytical results are pointing towards the same direction and a second one where the different results are partly contradictory.

Table 1. Contents of nitrate and tritium and also age based on contents of CFC in different parts of the studied aquifer system in January 2006.

Well No. Type	Sampling depth (m b s)	Site characteristics	Nitrate (mg/L)	Tritium (T.U.)	CFC-based age (years)
GVR610 Shallow **A** in Fig. 1	6	Not very close to tunnel area. Recharge area	6.00	8.46	< 5
GVR720 Shallow **A** in Fig. 1	5	Not very close to tunnel area. Discharge area	0.46	8.48	18
BP31 Deep	39 (above 45)	Not very close to tunnel area.	< 0.02	10.18	30
C in Fig. 1	46 (45–150)	Not very close to tunnel area.	< 0.02	1.81	49
MI23 Deep	35 (above 42)	Outside area of influence	7.01	8.66	17
B in Fig. 1	46 (42–52)	Outside area of influence	20.19	8.23	17
MI26 Deep	28 (above 31)	Outside area of influence	< 0.02	0.021	56
B in Fig. 1	35 (31–40)	Outside area of influence	< 0.02	0.052	60

The wells GVR 610 (position A in figure 1) and MI26 (position B in figure 1) are corresponding to the first group even if they have very different characteristics. GVR610 is a shallow well in the top soil layer of a recharge area with high contents of nitrate and tritium and a low CFC-based age. Furthermore the content of oxygen is very high in this shallow well. This situation corresponds to the shallow well, marked by a red vertical bar, to the left at the local hill in the schematic sections of figure 2 (no tunnel) and 3 (drainage into a partly unsealed tunnel).

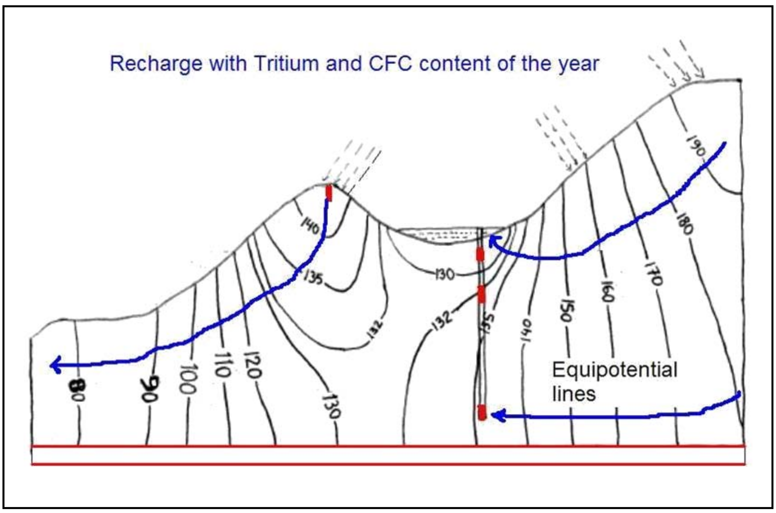

Figure 2. Schematic groundwater flow-net in a vertical section along the planned railway tunnel (see Fig. 1). Blue lines indicate the qroundwater flow direction and the black lines are equipotential lines (m.a.s.-l.). No drainage of water into the future tunnel in this situation.

The groundwater composition and the groundwater circulation is not plausible to change due to tunnel works in such a position. MI26 is a deep well situated far away from the railway tunnel works, outside the estimated area of influence. Groundwater from this well has very low contents of nitrate and tritium and a high CFC-based age at all sampled depths. The contents of oxygen is close to zero. This situation corresponds to the two lowest sampling points of the deep well to the right in the schematic section of figure 2 (no tunnel). The groundwater has a very long circulation time in this situation. However, if this well somehow should become affected by the drainage towards the tunnel works, the groundwater age will decrease substantially and the situation will correspond to the lower part of the deep well of figure 3.

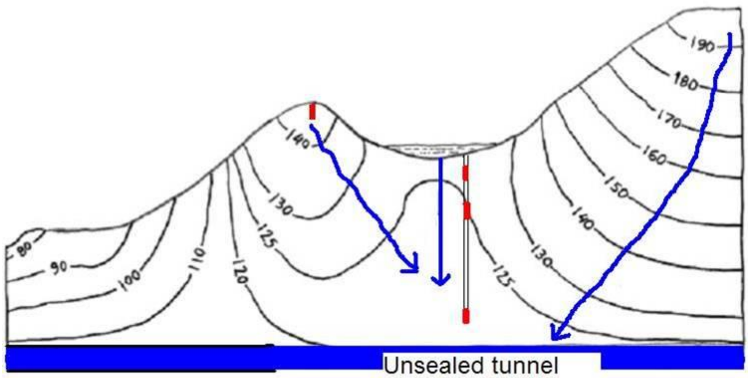

Figure 3. Schematic groundwater flow-net in a vertical section along the planned railway tunnel (see Fig. 1). Blue lines indicate the qroundwater flow direction and the black lines are equipotential lines (m.a.s.-l.). The section is identical to figure 2, but in figure 3 there is a considerable drainage of groundwater into the unsealed tunnel.

However, there are also intermediate cases like GVR720, a shallow well in the top soil layer of a discharge with a low but not negligible content of nitrate, a high content of tritium and a moderately low CFC-based age. This situation corresponds to the upper sampling point of the deep well to the right in the schematic section of figure 2 (no tunnel). The groundwater has a longer circulation time in this situation compared to the one of GVR610 but not as long as in the case of MI26. The composition of the groundwater in GVR720 will most probably change to something similar to GVR610 if water is drained into the tunnel (see figure 3).

In BP31 (position C in figure 1) there is a significant difference in the tritium content in the water flowing into the upper part of the well (high value) compared to the lower part (low value). Also the CFC-based age is higher in the lower part of the well while the contents of nitrate are negligible in all parts of the well. This situation is not very easy to interpret in an unambiguous way. The position corresponds to the two lowest sampling points of the deep well to the right in the schematic section of figure 2 (no tunnel). The groundwater has a long circulation time in this situation, which is supported by the low nitrate concentration and the relatively high CFC-ages. The upper part of well BP31 could be in contact with a fracture in the crystalline bedrock, which supplies the well with groundwater mainly recharged during the 60-ies and early 70-ies with a high content of tritium.

Well MI23 (position B in figure 1) is situated in the fractured crystalline bedrock outside the estimated area of influence around the tunnel works. The groundwater in the well has a high content of nitrate and tritium but with a moderately low CFC-based age. Most probably there is an inflow to the well of young water with a high content of nitrate due to fractures and/or leakage along the well construction.

As some of the last cases indicate, the water samples could of course consist of mixtures of groundwater from different levels and then the CFC-age has no real meaning (Laier 2004) and it is necessary to use several conservative tracers with different input functions to be able to calculate the relative contribution of the different components of the groundwater mixture (Bockgård et al. 2004).

CONCLUSIONS

A combination of hydrochemical, tritium and CFC analyses seems to make it possible to monitor variations in groundwater circulation times at large-scale infrastructural projects. However, more detailed interpretations of the observations are necessary and mixing of flow within a fractured aquifer makes some interpretations difficult. Furthermore, other tracers, detailed groundwater potentials and fracture maps are often necessary for a detailed interpretation.

ACKNOWLEDGEMENTS

The study has received funding and technical support from the Swedish National Railroad Administration (Banverket) and from the Hallandsås project, which is hereby thankfully acknowledged. A major part of the laboratory analyses were carried out by Troels Laier, GEUS, Copenhagen, and he also gave a highly appreciated and important support during the sampling campaigns, here gratefully acknowledged.

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abstract id: **262**

topic: **3**
Aquifer management

3.4
Environmental and artificial tracers in hydrogeology

title: **A study on recharge of groundwater by hydrogen and oxygen stable isotopes in Lin-Bian river basin**

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keywords: groundwater recharge, groundwater flow direction, hydrogen and oxygen stable isotopes

Pingtung County is an agricultural developed region, the surface water of Kaoping, Tungkang and Linpeing Rivers become the main water resource in Pingtung Plain. In terms of measurement data (WRA 2008),Typhoons and thunderstorms during the wet season from May to October bring about 80% of annual precipitation(2,503mm), primarily in the mountains region, while only 10% of the rainfall occurs during the dry season (November to April), a great quantity of annual rainfall in this area. This uneven distribution in the monthly rainfall poses a major problem to the planners is difficult to utilize. Hence, groundwater became the main water resources in Pingtung Plain, Taiwan. Owing to the property of groundwater was stable on the quality, temperature, quantity, receptivity, and lacking of management and sustainable utilization viewpoint groundwater has long been overdrawn improperly that caused serious land subsidence, seawater intrusion, and soil salinity.

In order to solve these problems, local government initiatives have been launched to utilize and manage the water resources and developing artificial recharge of groundwater schemes. If the assessment and management of groundwater resources could effective employed in Pingtung Plain, the groundwater pumping rate, recharge and sources need in accurately control of the situation under stable for long-term. In view of this, the purpose of this study are (1) employ the hydrogen and oxygen isotopes as natural tracer to analyze groundwater flow direction, and (2) employ the groundwater hydrograph to estimated the groundwater recharge amount by at Linpeing River in Pingtung Plain.

In this study, stable isotopic compositions of groundwater, stream water and precipitation from different seasons are analyzed to discuss the infiltration process in detail. Oxygen and hydrogen isotopic compositions of water have served for decades as a natural tracer all over the world to characterize the provenance of water mass, including groundwater and surface water. Learning how the water resources recharge into aquifer at Pingtung Plain wills important issue, Hence, Using natural tracers to identify the groundwater sources and find relation of each out, Oxygen and hydrogen isotopic compositions of water have served for decades as a natural tracer all over the world to characterize the provenance of water mass, including groundwater and surface water.

Stable hydrogen isotopic compositions is extracted from reduction of water to H2 using zinc shots made after VG MM602D isotope ratio mass spectrometer by Biogeochemical Laboratory of Indiana University (Coleman et al., 1982). Stable oxygen isotopic compositions were analyzed by well-known CO_2–H_2O equilibration method (Epstein and Mayeda, 1953).The equilibrated CO_2 gas was measured by a VG SIRA 10 isotope ratio mass spectrometer. Both analyses were conducted with isotope ratio mass spectrometers at the Isotope Hydrology Laboratory of Academic Sinica, Taiwan.

Basically, the isotopic ratio base on V-SMOW (Vienna Standard Mean Ocean Water) and SLAP (Standard Light Antarctic Precipitation) standard are $\delta D = 0‰$, $\delta^{18}O = 0‰$ and $\delta D = -428‰$, $\delta^{18}O = -55‰$, respectively. The oxygen and hydrogen isotopic ratio results are reported using δ-notation as per mil (‰). In this study, the analytical precision (1σ) is 0.1‰ for$\delta^{18}O$ and 1.5 ‰ (1σ) for δD.

Finally, according to the hydrogen and oxygen isotopic mass balance analyses of the groundwater recharge sources in Lin Bian River basin, the aquifer F1 has the highest ($\delta^{18}O = 16\%$, $\delta D = 19\%$) and F3 has the lowest ($\delta^{18}O = 9\%$, $\delta D = 7\%$) proportions of rainfall recharge, respectively.

On the other hand, F3 has the highest ($\delta^{18}O$ = 91.3%, δD = 93%) and F1 carries the lowest ($\delta^{18}O$ = 84%, δD = 81%) proportions of lateral recharge from the mountain area, respectively. These results show that the groundwater for the deeper aquifer of Lin Bian River area has relatively higher recharge from the mountain river, while in the shallower aquifer the rainfall recharge is the dominant factor.

The annual groundwater recharge amount in Lin Bian River basin is estimated as about 460 million cubic meters in 2006. The total annual water extraction amount plus the water loss is estimated as about 410 million cubic meters; thus, these two parameters are within the extraction allowance, except for some coastal areas. The groundwater flow direction in Lin Bian River basin is generally from northeast to southwest, by combining the evidence of findings in water quality project, with the groundwater level and isotopic studies, the phenomenon of sea water invasion along the coastal area has been identified and still continues to move towards inland.

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abstract id: **276**

topic: **3**
Aquifer management

3.4
Environmental and artificial tracers in hydrogeology

title: **Identification of recharges of the springs in Liddar watershed of Kashmir Himalaya, India**

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keywords: springs, recharge, oxygen isotope ratio, Himalaya

Geological, hydrological and $\delta^{18}O$ data of precipitation, streams and springs was used to identify the sources and origin of recharge of the springs in Liddar water shed, Kashmir Himalayas in India. The study area is characterised by temperate climate with an average annual precipitation of 1200 mm. The winter and spring seasons receive most of the precipitation in the form of snow and rain. The winter temperatures are mostly sub zero and the maximum temperature in summer season is about 37 degree centigrade. The data generated indicated the spatial and temporal variability of $\delta^{18}O$ of precipitation was dominantly controlled by temperature, altitude and amount effects. The $\delta^{18}O$ of precipitation ranged from –0.04 to –12.98‰, with 60% of the values greater than –5‰. The $\delta^{18}O$ of each precipitation site showed a large negative shift (>10‰) during January which coincide with low temperature and high amount of precipitation. A good relationship was found to exist between the mean local temperature and mean $\delta^{18}O$ of the precipitation, with depleted $\delta^{18}O$ values during lower temperature and enriched values during higher temperature. However, a marked discrepancy, higher temperature and depleted $\delta^{18}O$ values during September may be attributed to the amount effect and/or local source of the clouds. The isotope ratio showed a depleted trend eastward indicates the main rains brought by westerly winds. The recharge altitude of the springs was calculated as 2700–3600 m a.s.l. according to a mean altitude effect of about –0.2‰/100 m rise, which is the representative for the precipitation at higher altitudes. The altitude effect, however, varied seasonally being lowest in May (–0.5‰/100 m) and highest in September (0.1‰/100 m). The stream waters were more depleted than low level precipitation due to their headwaters at higher altitudes. The $\delta^{18}O$ values of the streams ranged from –11.56 to –6.92‰, the depleted $\delta^{18}O$ value being observed at headwaters and enriched values at lower part of the watershed. This is attributed to fractionation due to evaporation during the journey of melt water from mountainous regions to the plains. The melting and fractionation of snow pack releases more depleted waters to streams during May (<–10‰) and enriched waters in September (>–6.5‰). The depleted $\delta^{18}O$ values of spring waters (–6.3 to –10.05‰) than precipitation and positive Spatio-temporal correlation with stream water indicates that the catchment stream was the major contributor of groundwater recharge, but the enriched isotopic character of some springs showed significant recharge by local precipitation or snow melt.

abstract id: **311**

topic: **3**
Aquifer management

3.4
Environmental and artificial tracers in hydrogeology

title: **The investigation of groundwater-surface water linkages using environmental and applied tracers: a case study from a mining-impacted catchment**

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keywords: longwall mining, applied tracers, environmental tracers, groundwater-surface water interaction

INTRODUCTION

Longwall mining can have a significant impact on surface hydrology, groundwater systems and water quality as a consequence of subsidence (Booth, 2003, 2006). In the vicinity of creeks and rivers, mine subsidence can reactivate existing fractures, joints, lineaments and faults, and cause new fractures and fracture zones. The impact of subsidence on surface waterways is characterised by fracturing of riverbeds and rockbars, resulting in diversion of surface water to subsurface flow, changes to stream alignment, increased interaction between surface water and groundwater and deterioration in water quality (Kay et al., 2006). Depending on the depth of coal mining, and vertical extent of cracking, surface water may either be lost permanently or temporarily from longwall mining impacted waterways with the possibility of some water re-emerging downstream of mining related subsidence area.

Numerous surface waterways, including creeks and swamps, in Sydney's drinking water supply catchments, located in south-eastern Australia, have been affected by longwall mining activities and subsequent subsidence. One affected catchments, the Waratah Rivulet catchment, was selected for a detailed investigation to provide a more comprehensive understanding of long-wall mining impacts on groundwater and surface water connections. A three year study using environmental isotopes including both stable isotopes (oxygen-18 (^{18}O) and (deuterium (^{2}H)) and radiogenic isotopes (radon-222 (^{222}Rn), radiocarbon and tritium), and applied tracers was undertaken to assess changes in groundwater-surface water linkages and quantify surface water loss (if any) in the mining-impacted part of the rivulet.

ENVIRONMENTAL SETTING

The Waratah Rivulet catchment is located approximately 45 km southwest from Sydney in the southern part of the Sydney Basin (Figure 1).

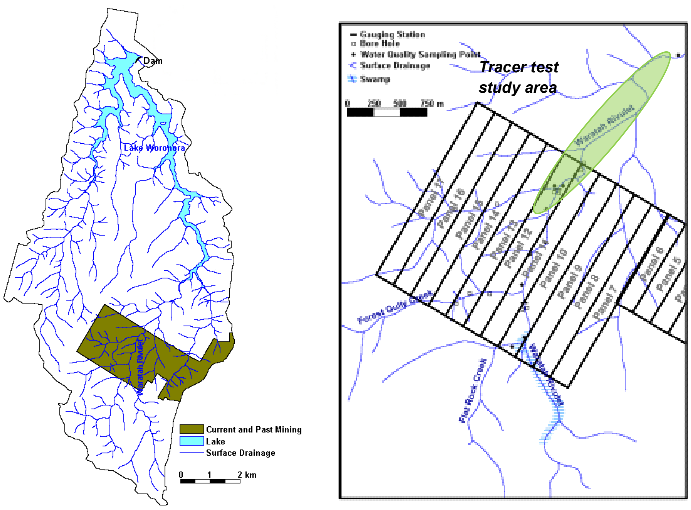

Figure 1. Study area location, longwall panel layout and location of tracer test

The catchment terrain is characterised by sandstone ridges, steep slopes and valleys, and the surface topography ranges from 170 metres Height Datum (AHD) to 360 m AHD. The geology of this area is primarily Permo-Triassic sedimentary sequence (Parkin, 2002) which is underlain by undifferentiated sediments of Carboniferous and Devonian age. The surface geological unit exposed through much of the catchment is the Triassic Hawkesbury Sandstone which has a thickness of greater than 100 m and overlies sandstones, claystones and shales of the Triassic Narrabeen Group. The Narrabeen Group has a thickness of more than 430 m and over lies the Permian Illawarra Coal Measures. The target seam for longwall extraction, the Permian Bulli Seam, has a thickness of 3.2–3.6 m across the catchment.

The main surface waterway in the catchment is the Waratah Rivulet which flows and discharges into Woronora Lake, one of Sydney's water supply storage systems. Seventeen longwall panels have been mined to date and are located directly underneath the catchment in southwest-northeast direction, 400–500 m below ground level (Figure 1).

From 2001 longwall mining progressed beneath the Waratah Rivulet catchment and its tributaries. By 2006 the impacts of mining subsidence on the bed of Waratah Rivulet and adjacent creeks was evident, with extensive cracking and tilting of the sandstone bed and rock bars occurring as a result of upsidence and subsidence. Particularly under conditions of low flow and rainfall large sections of the Rivulet were without surface water flow, in addition, rapid declines in pool levels were also recorded.

Analysis of the surface water in the Waratah Rivulet has shown elevated electrical conductivity and metals (mainly iron and manganese) and reduced dissolved oxygen content. The change in water quality can be attributed to loss of surface water through cracks to the subsurface, resulting in enhanced water-rock interactions between oxygenated and slightly acidic surface water recharge and newly exposed rock in fractures and bedding planes. The change in water quality has resulted in the precipitation of iron and manganese oxides and hydroxides and development of large, thick bacterial mats during low flow conditions.

METHODOLOGY

Surface water and groundwater samples were collected on a quarterly basis for two years for stable isotopes (^{18}O and ^{2}H) and ^{222}Rn analysis. Samples for radiocarbon and tritium analysis were collected on one sampling occasion. Groundwater samples were collected using a 12V submersible pump after purging a minimum of three well volumes. The stable isotopes of water ^{18}O and ^{2}H were analysed at CSIRO Land and Water Laboratory, Adelaide, Australia. This laboratory analysed samples using a Europa Scientific Geo 20-20 isotope mass spectrometer. Tritium was analysed at GNS Science Tritium and Water Dating Laboratory, Lower Hutt, New Zealand, using low-level liquid scintillation spectrometers, with a detection limit of 0.03–0.04 TU, Bq/kg (0.004–0.005). The carbon-14 activity of groundwater and surface water samples was determined by atomic mass spectrometry (AMS), at the Rafter Radiocarbon Laboratory, Institute of Geological and Nuclear Sciences at Lower Hutt, New Zealand. Samples for radon-222 analysis were collected in 1.25 L PET bottles, ensuring no air bubbles or head space remained. The radon-222 from the 1.25 L groundwater and surface water samples was concentrated into mineral oil in 20 ml vials prior to sending to CSIRO Land and Water Laboratory in Adelaide, for analysis using a Qantulus scintillation counter.

Two applied tracer tests were undertaken; the involved the application of fluorescent dye (fluorescein) to the shallow groundwater system and monitoring breakthrough. 20 L of fresh water spiked with 600 g of powdered dye was injected into two monitoring bores. The dye solution was flushed through the boreholes with a further 1,000 L of fresh water obtained from Waratah Rivulet. Breakthrough was monitored at various locations along the riverbed, and in down-gradient monitoring bores. Concentrations of fluorescein dye (Abbey Color) were determined using a dual channel, Turner Design Aquaflor Fluorometer.

The second tracer test involved application of a salt solution to surface water in Waratah Rivulet. A volume of 250,000 L was spiked with a brine solution to produce a final tracer solution with an EC of 1,000 μS/cm. The tracer was applied to the rivulet at a rate of 12 L/s and breakthrough monitored at various surface water and groundwater monitoring locations. EC was measured continuously using Greenspan EC sensors.

ENVIRONMENTAL ISOTOPES

The stable isotope results (Figure 2) show clear mixing between shallow groundwater and surface water in the mining-impacted part of the rivulet. Stable isotopic signatures for shallow groundwater are more enriched in the impacted zone (average $\delta^{18}O$ = -4.92‰, $\delta^{2}H$ = -22.03‰) than the non-impacted zone (average $\delta^{18}O$ = -5.08‰, $\delta^{2}H$ = -23.19‰) due to mixing with surface water which has an enriched isotopic signature due to evaporative enrichment (average $\delta^{18}O$ = -4.58‰, $\delta^{2}H$ = -19.97‰).

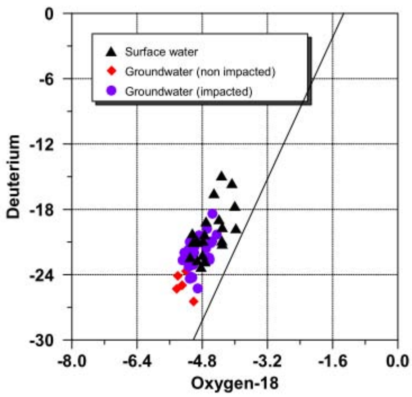

Figure 2. Stable isotope data, showing mixing between groundwater and surface water in the mining-impacted zone

Tritium and ^{222}Rn values also confirm groundwater-surface water mixing in the mining-impacted zone. In groundwater in a non-impacted part of the catchment, tritium and ^{222}Rn values are approximately 0.4 TU, and 20 Bq/L, respectively. In the impacted part of the catchment, tritium values in groundwater range from 1.0 to 1.3 TU, and are similar to surface water values (1.35 TU to 1.6 TU). Radon values in the impacted zone are much lower, due to mixing with surface water, and range from 4 to 16 Bq/L. Corrected radiocarbon ages also indicate that groundwater in the shallow aquifer system is modern (<50 years BP).

Radon mass balance calculations were undertaken for each monitoring round to estimate the fraction of groundwater present in the stream (or vice versa, stream water loss to groundwater) according to Equation 1.

$$R_s (Q_s) = R_{gw}(Q_{gw}) + R_b(Q_s - Q_{gw}) \quad (1)$$

where R_s = ^{222}Rn concentration in the stream; R_{gw} = ^{222}Rn concentration in groundwater; R_b = background concentration of ^{222}Rn in the stream, based on estimated loss of ^{222}Rn resulting from gas exchange; Q_s = stream discharge; Q_{gw} = groundwater discharge and Q_{gw}/Q_s = fraction of stream discharge that is surface water.

The results presented in Table 1 show that over a 2 km stretch of the rivulet there is a net loss of surface water, ranging from 0.20 ML/day and 0.48 ML/day. These calculations were undertaken during relatively low flow conditions (<12 ML/day), and indicate that not all surface water lost to the subsurface through fractures in the creek bed has returned by the most downstream gauging station.

Table 1. Radon mass balance calculations for Waratah Rivulet.

Monitoring period	Stream flow (ML/day)	Calculated stream flow reduction (ML/day)
Sep 2007	5.57	0.47
Jan 2008	2.81	0.30
Mar 2008	6.35	0.20
Sep 2008	10.0	0.48
Dec 2008	1.58	0.28
Feb 2009	11.82	0.38

APPLIED TRACER TESTS

The fluorescent dye tracer test was undertaken to assess the connectivity of the fracture system, measure solute transport regime, identify groundwater discharge zones and quantify groundwater baseflow. This test was completed under high flow conditions. Visual breakthrough of fluorescein tracer from the shallow groundwater system into the surface water system was incredibly fast, with breakthrough occurring 15 min after injection, at a location 50 m downstream of the injection point. Breakthrough in the downstream monitoring bores occurred within 1.5 hours, at a distance 250 m down-gradient from the injection bores. These results equate to a groundwater velocity of 4,000–4,800 m/day. Breakthrough curves (Figure 3) showed strong peaks with very little tailing, indicating limited dispersion of the dye as it moved through the shallow groundwater system. Numerical integration of the tracer breakthrough curves indicate that 100% of the fluorescein was recovered at the most downstream surface water monitoring point (located 2 km downstream of injection point) within 48 hours.

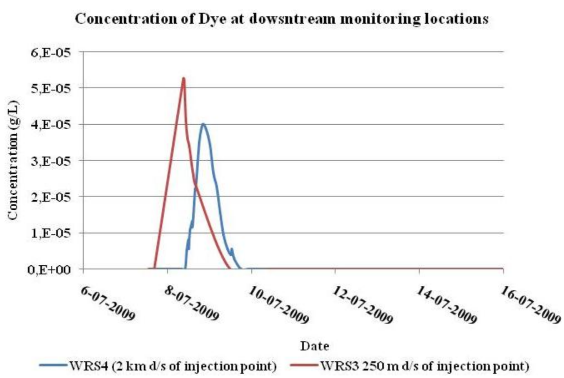

Figure 3. Dye tracer breakthrough curves.

The salt tracer test was undertaken to quantify stream loss (if any) to the subsurface. Breakthrough occurred within 12 min at the first surface water monitoring location, 50 m downstream of the injection point. Numerical integration of the breakthrough curves indicate that approximately 100% (94%–100% recovery of salt tracer) of the salt is present at the first surface water monitoring location (50 m downstream of injection point), but between the first and second monitoring locations (50 to 250 m downstream of injection point) around 20% of the surface water is lost (80%–86% recovery of salt tracer). However by the final monitoring location all of the surface water that had been lost to the subsurface had returned (100% recovery measured).

The two applied tracer tests were undertaken during a high flow event, with a total flow of 78.08 ML/day over of the three days of tracer testing. The results show that under high flow conditions, any surface water lost to the subsurface has returned by the most downstream surface water gauging station, and there is no net loss in surface water flow. If any loss of surface water occur is possibly masked by high flow during the time of tracer test.

CONCLUSIONS

The environmental isotopes and applied tracer tests provided new data which enhanced the understanding of groundwater-surface water interactions in the Waratah Rivulet and provided quantitative data on groundwater-surface water fluxes in the mining impacted area under different flow conditions. Applied tracer studies have demonstrated that in the Waratah Rivulet, secondary permeability has been enhanced by subsidence in the shallow aquifer system and the primary mechanism for groundwater-surface water interaction (both gains and losses) is through fracture zones within the riverbed. Radon mass balance calculations have shown that under relatively low flow conditions (<12 ML/day) there is a net surface loss within the mining-impacted part of Waratah Rivulet. The applied tracer studies showed that under high flow conditions (>50 ML/day) there was a net loss of surface water in sections of the rivulet, but all lost surface water had returned by the most downstream gauging station within the study area.

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abstract id: **335**

topic: **3**
Aquifer management

3.4
Environmental and artificial tracers in hydrogeology

title: **Oxygen isotopic composition in a riverbank filtration system — case study on Szentendre Island, Hungary**

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keywords: riverbank filtration, oxygen isotope, Danube

INTRODUCTION

Hungary's capital. Budapest and several settlements nearby. are supplied with drinking water from the Danube. The main goal of our study was to improve the knowledge on the riverbank filtration system on Szentendre Island to the north of the city. At first the Vác and Szentendre arms of the Danube. which surround the island. were examined. If the chemical and physical composition of the two arms differ significantly more complex models should be applied. Parallel to this water samples were also taken from a multiple collector well the greater part of whose water supply caming from the Vác arm of the Danube. Besides physical and water chemical components stable isotopic compositions (hydrogen and oxygen isotopes) were also measured. The use of isotopic composition in riverbank filtrated systems was developed by Maloszewski et al. (1990) based on a south-west German aquifer. A general infiltration model on the nearby Csepel Island has been constructed by Fórizs et al. (2005) and Fórizs (2008) (Fig. 1). Their water samples were taken every second week from a water producing well and more frequently (daily or twice a week) from the Danube. By this the transit time of the water from the Danube to the well could be estimated. Although the isotopic composition in our sampled autumn period was supposed not to be very much variable the goal of this study was to improve the mentioned model and apply it to the Szentendre Island by daily sampling.

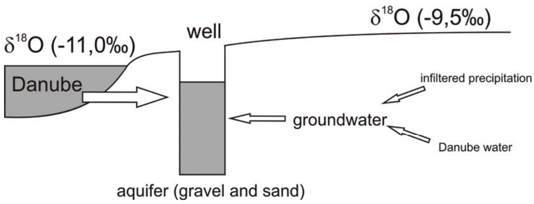

Figure 1. Schematic diagram of a riverbank filtration aquifer with average $\delta^{18}O$ values of potential sources (Danube water groundwater from precipitation and older Danube water) (Fórizs, 2008).

SAMPLING

Daily water samples were taken from the Vác arm of the Danube and the Kisoroszi-2 water supplying multiple collector well from 29 October 2008 to 21 December 2008. Weekly sampling was undertaken from the Szentendre arm as well. Conductivity and temperature were measured in situ. Water samples for chemical analysis were taken six times. Sampling dates are shown on Table 2.

APPLIED METHODS

Oxygen isotopic measurements were done at the Institute for Geochemical Research of the Hungarian Academy of Sciences on a Finnigan delta plus XP mass spectrometer. Isotopic ratios are reported in δ value with respect to the international V-SMOW standard and in permill according to the formula of McKinney et al. (1950):

$$\delta^{18}O = \frac{\left(\frac{^{18}O}{^{16}O}\right)_{\text{sample}} - \left(\frac{^{18}O}{^{16}O}\right)_{\text{standard}}}{\left(\frac{^{18}O}{^{16}O}\right)_{\text{standard}}} * 1000‰$$

. Uncertainty: ±0.1‰.

Chemical compositions and physical parameters were determined at the Waterworks of Budapest Ltd. Twenty chemical components and physical parameters were defined (electric conductivity, chemical oxygen demand, Cl^-, NO_3^-, NO_2^-, NH_4^+, UV absorption, SO_4^{2-}, pH, PO_4^{3-}, F^-, Ca^{2+}, K^+, Fe_{sum}, Mn_{sum}, Mg^{2+}, Na^+, turbidity, total organic carbon, UV absorption).

RESULTS AND DISCUSSION

The oxygen isotopic composition of the two arms of the Danube and the K-2 multiple collector well as well as temperature and electric conductivity are shown on Table 1, chemical compositions and physical parameters on Table 2.

Table 1. Conductivity, temperature and $\delta^{18}O$ values of the Vác and Szentendre arms and the Kisoroszi-2 well between 29 October and 21 December 2008.

Date	**Vác arm**			**Szentendre arm**			**Kisoroszi-2 well**		
	Conductivity	*Temperature*	*$\delta^{18}O$*	*Conductivity*	*Temperature*	*$\delta^{18}O$*	*Conductivity*	*Temperature*	*$\delta^{18}O$*
29.10.2008	412	10.7	-10.45				405	12.5	-10.69
30.10.2008	416	11.3	-10.31				406	12.6	-10.71
31.10.2008	418	11.3	-10.28				403	12.7	-10.65
01.11.2008	425	11.7	-10.30				405	12.8	-10.63
02.11.2008	425	11.6	-10.34				401	12.9	-10.61
03.11.2008	419	11.9	-10.22	421	12.0	-10.30	403	12.9	-10.58
04.11.2008	420	11.3	-10.39				402	12.9	-10.69
05.11.2008	420	11.9	-10.28				399	13.0	-10.55
06.11.2008	425	11.7	-10.31				402	12.9	-10.58
07.11.2008	428	11.5	-10.29				401	13.0	-10.66
08.11.2008	431	11.5	-10.34				405	13.0	-10.60
09.11.2008	428	11.7	-10.39				405	13.1	-10.73
10.11.2008	423	11.3	-10.42	426	11.4	-10.45	407	13.1	-10.71
11.11.2008	424	10.1	-10.44				409	12.9	-10.73
12.11.2008	428	10.5	-10.46				406	13.1	-10.55
13.11.2008	429	10.2	-10.46				409	13.1	-10.67
14.11.2008	429	10.1	-10.41				409	13.2	-10.61
15.11.2008	429	9.7	-10.43				410	13.1	-10.63
16.11.2008	429	9.3	-10.38				408	13.1	-10.75
17.11.2008	436	8.8	-10.31	439	9.3	-10.32	412	13.2	-10.56
18.11.2008	439	6.6	-10.28				411	13.1	-10.62
19.11.2008	432	7.7	-10.34				412	13.0	-10.61
20.11.2008	428	7.4	-10.31				412	13.2	-10.61
21.11.2008	427	7.8	-10.40				415	13.2	-10.65
22.11.2008	431	6.3	-10.43				412	13.1	-10.66
23.11.2008		5.6	-10.41				412	13.3	-10.62
24.11.2008	431	5.4	-10.48	431	5.7	-10.40	413	13.4	-10.68
25.11.2008	428	5.3	-10.28				408	13.6	-10.56
26.11.2008	431	4.6	-10.47				412	13.5	-10.65
27.11.2008	439	4.8	-10.46				410	13.5	-10.60
28.11.2008	430	4.7	-10.57				415	13.3	-10.61
29.11.2008	425	4.3	-10.59				412	13.6	-10.52
30.11.2008	427	5.1	-10.52				415	13.5	-10.40
01.12.2008	434	5.1	-10.48	427	5.1	-10.43	415	13.5	-10.59
02.12.2008	424	5.3	-10.51				416	13.6	-10.59
03.12.2008	422	5.5	-10.33				416	13.5	-10.56
04.12.2008	430	5.2	-10.38				417	13.6	-10.59
05.12.2008	436	5.4	-10.33				416	13.7	-10.53
06.12.2008	440	5.4	-10.15				417	13.7	-10.50
07.12.2008	434	5.2	-10.29				417	13.9	-10.52
08.12.2008	440	4.4	-10.24	444	4.4	-10.23	419	13.7	-10.47
09.12.2008	446	4.0	-10.26				417	13.5	-10.57
10.12.2008	443	4.1	-10.26				421	13.5	-10.59
11.12.2008	444	4.0	-10.28				419	13.5	-10.61
12.12.2008	446	4.0	-10.20				421	13.6	-10.55
13.12.2008	449	4.0	-10.24				420	13.6	-10.54
14.12.2008	442	4.4	-10.16				421	13.8	-10.58
15.12.2008	444	4.8	-10.30	443	4.7	-10.30	421	13.8	-10.47
16.12.2008	443	4.8	-10.33				422	13.5	-10.49
17.12.2008	446	5.0	-10.29				423	13.7	-10.48
18.12.2008	440	5.5	-10.21				423	13.6	-10.52
19.12.2008	427	4.9	-10.24				426	13.4	-10.44
20.12.2008	440	4.7	-10.22				425	13.7	-10.48
21.12.2008	448	4.5	-10.33				424	13.8	-10.39

Table 2. Chemical composition of the Vác and Szentendre arms and the Kisoroszi-2 well between 29 October and 21 December 2008.

Sampling location	Date	Conductivity (µS/cm 20°C)	Chemical oxygen demand$_{pm}$ (mg/l)	Cl^- (mg/l)	NO_3^- (mg/l)	NO_2^- (mg/l)	NH_4^+ (mg/l)	UV absorption (1/m)	SO_4^{2-} (mg/l)	pH (-)	PO_4^{3-} (mg/l)	F^- (mg/l)	Ca (mg/l)	K (mg/l)	Fe_{sum} (µg/l)	Mn_{sum} (µg/l)	Mg (mg/l)	Na (mg/l)	Turbidity (FNU)	TOC (mg/l)	UV (%)
Vác arm	03.11.2008	417	1.9	21.1	7.3	<0.03	<0.04	5.35	35.4	8.08	<0.1	0.12	59.9	3.2	54	11	15.8	14.9	4.45	1.89	
Szentendre arm	03.11.2008	421	2	15.8	5.3	<0.03	<0.04	5.3	29.1	8.1	<0.1	0.13	60.1	3.2	61	18	15.9	15	4.54	1.97	
Kisoroszi-2 well	03.11.2008	401	0.4	18.7	7.3	<0.03	<0.04	1.45	36.2	7.6	<0.1	0.12	61.5	2.7	17	3	15	11.5	0.04	0.77	
Vác arm	10.11.2008	416	2.3	20.1	7.6	<0.03	<0.04	4.95	40.7	8.09	<0.1	0.1	59.4	2.9	72	8	15.6	14.3	4.88	1.81	88.29
Szentendre arm	10.11.2008	418	1.8	20.4	7.6	<0.03	<0.04	4.9	41	8.1	<0.1	0.1	59.4	3	76	9	15.6	14.4	5.6	1.78	88.622
Kisoroszi-2 well	10.11.2008	400	0.8	16.3	5.7	<0.03	<0.04	1.2	29.7	7.6	<0.1	0.13	60.5	2.6	<5	<5	14.6	11.2	0.02	0.72	97.277
Vác arm	17.11.2008	437	2.2	22.1	8.2	0.03	<0.04	6.1	37.9	8.02	0.29	0.28	59.7	3.5	60	7	16.3	17	4.6	2.2	
Szentendre arm	17.11.2008	440	2.3	22.6	8.4	<0.03	<0.04	6.15	43.5	8.1	<0.1	<0.1	59.6	3.5	78	10	16.6	17.8	5.03	2.23	
Kisoroszi-2 well	17.11.2008	414	0.7	16.7	6	<0.03	<0.04	1.8	30.8	7.6	<0.1	0.14	62.1	2.8	9	<5	15.2	11.5	0.06	0.79	
Vác arm	24.11.2008	415	2.1	19.3	8.6	<0.03	<0.04	5.3	33.7	8.10	<0.1	<0.1	60	2.9	145	28	15.4	14.1	16	1.98	
Szentendre arm	24.11.2008	417	1.9	18.7	8.3	<0.03	<0.04	5.35	34.1	7.9	<0.1	<0.1	59.4	3	155	26	15.3	14.3	16.9	2.08	
Kisoroszi-2 well	24.11.2008	404	0.8	16.4	5.8	<0.03	<0.04	2	29.9	7.6	<0.1	0.1	60.8	2.6	160	<2	14.7	11.1	0.02	0.82	
Vác arm	15.12.2008	426	2.2	20.9	9	<0.03	<0.04	6.8	36.4	8.15	<0.1	<0.1	62.5	3	92	14.4	15.8	15.2	6.63	2.23	87.33
Szentendre arm	15.12.2008	427	2.1	20.7	9	<0.03	<0.04	6.1	36.5	8.1	<0.1	0.1	62.9	3	59	11.9	16	15.3	5.08	2.1	87.654
Kisoroszi-2 well	15.12.2008	411	0.7	17.5	6.1	<0.03	<0.04	1.5	39.4	7.7	<0.1	0.12	62.7	2.8	<5	0.5	15.2	11.7	0.02	0.74	96.484
Vác arm	08.12.2008	422	2.1	22.1	10.3	0.06	0.05	7.95	35.4	8.09	0.17	0.12	60.8	3.1	250	21	15.1	15	11	2.66	
Szentendre arm	08.12.2008	427	2.1	22	10.1	0.06	0.04	7.35	34.7	8.1	<0.16	0.11	61.3	3	180	15	15.2	15.4	7.71	2.31	
Kisoroszi-2 well	08.12.2008	410	0.3	17.6	6.4	<0.02	<0.04	2.05	32.5	7.6	<0.16	0.12	61.8	2.7	<5	<5	14.9	11.4	0.06	0.87	

Comparison of the Vác and Szentendre arms of the Danube

Conductivity (Fig. 4) and temperature (Fig. 2) as well as isotopic composition in both arms are the same within the error of measurement. The average $\delta^{18}O$ value was -10.35‰. Chemical data of seven weekly water samples (Table 2) also show high similarity at both locations. This means that neither arm experienced additional water or contamination during the sampling period. Sampling sites are located 6 km from the tip of the island on the Szentendre arm and 7.5 km on the Vác arm.

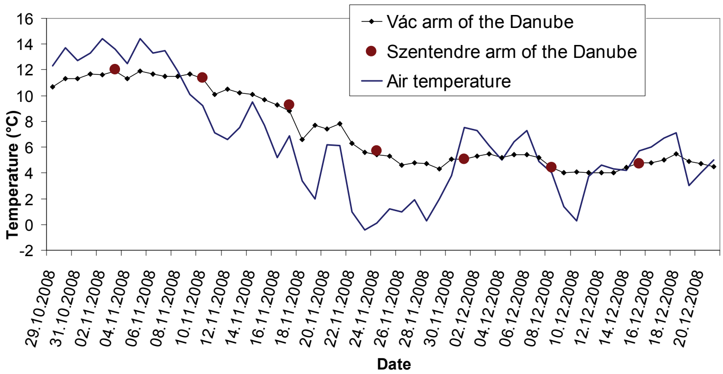

Figure 2. Temperature in the Vác and Szentendre arms of the Danube and air temperature between 29 October and 21 December 2008.

Increased turbidity, UV absorption, NH_4^+, NO_2^-, Fe_{sum}, Mn_{sum} and TOC values on 24 November and/or 8 December are linked to the sudden water level rise of the Danube on 24 November by 1.2 m (Fig. 3).

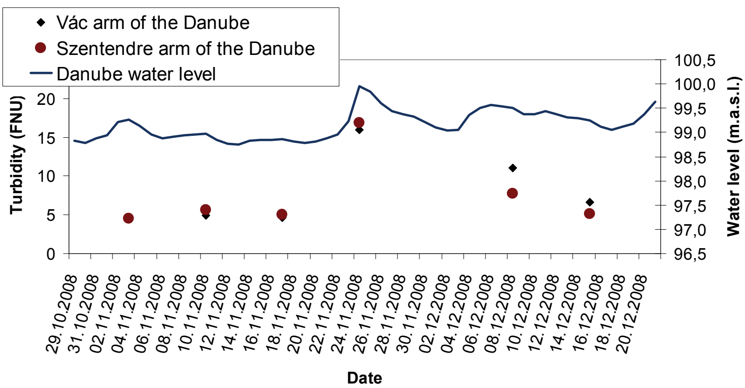

Figure 3. Turbidity and water level changes between 29 October and 21 December 2008.

All physical and chemical parameters of both arms of the river agree within error of measurements. Temporal changes also show matching tendencies. This means no separate sampling will be needed in the future and that data can be used in both arms for modelling.

Comparison of the Kisoroszi-2 well and the Vác arm of the Danube

The trend in conductivity was similar but the changes had smaller amplitudes in the Kisoroszi-2 well. This can be attributed to diffuse filtration (Fig. 4).

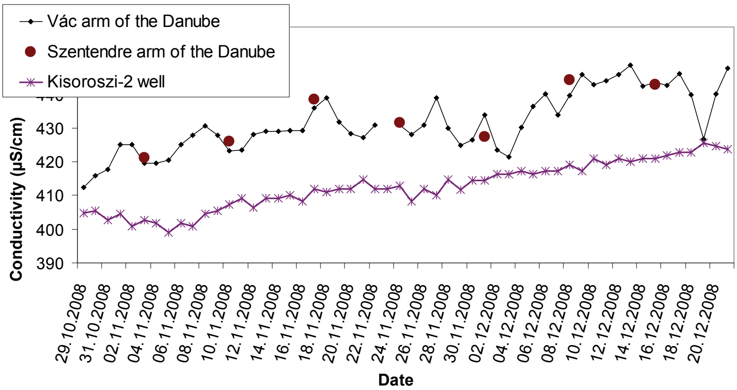

Figure 4. A Conductivity between the Vác and Szentendre arms of the Danube and Kisoroszi-2 well (29 October and 21 December 2008).

Average conductivity in the well is 18 µS/cm less than in the river meaning a smaller amount of dissolved ions. Longer sampling periods would be needed to fully understand whether this was only a seasonal feature or not. An amount of 5-10% of limestone and dolomite cobbles the likely source of Ca^{2+} and Mg^{2+} in the Szentendre Island gravel has been determined by Serfőző (2001). Na^{+} and K^{+}can be dissolved from degrading feldspars. However this suggested increase in cations was not measurable in the examined well. Almost all physical and chemical parameters showed smaller values in the well than in the river. The decrease in Fe_{sum} and Mg^{2+} concentration can be attributed to biological filtration. This is also corroborated by the UV absorption and TOC values. However Ca^{2+} concentrations in the well are slightly larger. Mg^{2+} values are smaller in the well than in the Danube but no significant differences were seen (Table 2). This means that the aquifer between the river and the well does not affect the cation composition of water a feature yet to be examined by longer data sets.

The hydrodynamic model of Waterworks of Budapest accounts for 37% background water component in the Kisoroszi-2 well during the sampling period (average well production 4800 m^3/day average river water level 97.5 m; Zoltán Molnár oral communication). The model gave travel times in the model changed between 24–40 days while the measured oxygen isotopic composition of the Danube varied between -10.59 and -10.15‰. with an average of -10.35‰.

Values in the Kisoroszi-2 well ranged between -10.75 and -10.39‰. with an average of -10.59‰. To interpret isotopic data (Table 1) the above mentioned modelled results were taken into acount. Background water consists of local precipitation and old Danube water infiltered probably during the previous years. Monitoring wells that are more than 0.5 km from the river but within 5 km of the Kisoroszi-2 well were selected. Their $\delta^{18}O$ values measured by Fórizs and Deák (1998) and Kármán (2009) were averaged (Table 3). This gives an estimated average $\delta^{18}O$ values of -10.64‰ (except for a monitoring well in a special position). Based on the measured $\delta^{18}O$ values in the Vác arm the estimated composition of the Kisoroszi-2 well can be calculated as follows:

$$\delta^{18}O_{K-2_{estimated}} = 0.63\,x\left(\delta^{18}O_{Danube}\right) + 0.37\,x\left(-10.64\ ‰\right)\cdot$$

Table 3. Oxygen isotopic composition of monitoring wells based on Fórizs és Deák (1998)* and Kármán (2009)**. The discrepancy of the F.5 well has been omitted from calculation.

Date of sampling	Monitoring well	$\delta^{18}O$ (‰)
August-September 1995 *	F.11	-10.63
August-September 1995 *	F.14	-10.52
August-September 1995 *	F.17	-10.79
August-September 1995 *	F.21	-10.31
August-September 1995 *	F.22	-10.93
May-June 1995 *	F.3	-10.53
May-June 1995 *	F.5	-9.58
May-June 1995 *	F.6	-10.12
May-June 1995 *	F.7	-10.91
May-June 1995 *	F.8	-10.69
May-June 1995 *	F.9	-10.79
May-June 1995 *	F.11	-10.90
May-June 1995 *	F.54	-10.74
24 November 2008 **	F.11	-10.45
	Average	**-10.64**
	Deviation	0.25
	Minimum	-10.93
	Maximum	-10.12

Because travel time range 24 and 40 days dispersion had also to be calculated. Because its equation has not been resolved yet data have been shifted by the average transit time i.e. 32 days (Fig. 5). In this case curves agree within the error of measurement.

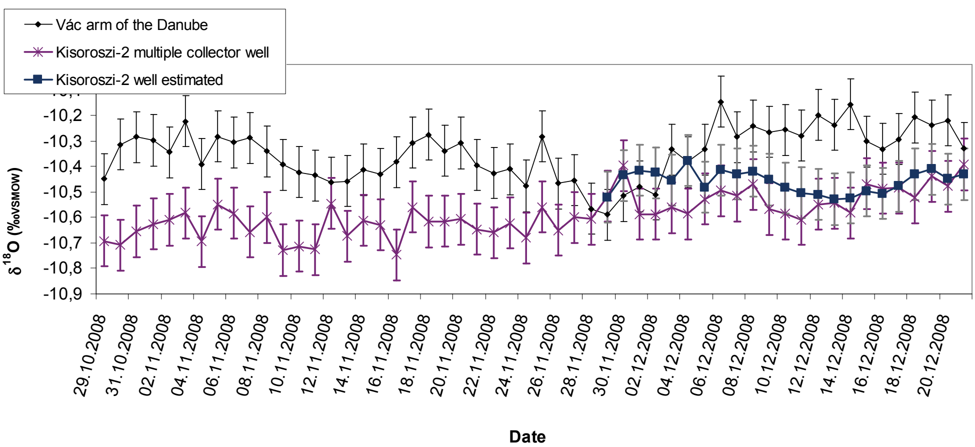

Figure 5. Measured $\delta^{18}O$ values in the Vác arm and the Kisoroszi-2 well as well as the estimated values of the Kisoroszi-2 well shifted by 32 days.

SUMMARY

Clear correlation has been shown between air and river temperature changes. Temperature, conductivity, $\delta^{18}O$ data examined physical and chemical parameters between the Szentendre and Vác arms showed a close match meaning that these arms can be treated as equal. Positive peaks in turbidity, UV absorption, NH_4^+, NO_2^-, Fe_{sum}, Mn_{sum}, TOC can be attributed to sudden rises of the river water level.

Comparing the hydrodynamic model of Waterwork of Budapest with measured oxygen isotopic data a formula for the estimation of $\delta^{18}O$ values in the Kisoroszi-2 well has been constructed. This proves the efficiency of the hydrodynamic model.

ACKNOWLEDGEMENTS

We appreciate the help of Waterworks of Budapest, especially that of László Debreczeny, Dávid Csaba Szabó, Zoltán Molnár, János Davidesz and István Kármán.

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abstract id: **338**

topic: **3**
Aquifer management

3.4
Environmental and artificial tracers in hydrogeology

title: **Groundwater recharge estimations in the Densu River Basin, Ghana, using environmental isotope data (δ2H, δ18O)**

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keywords: environmental isotopes, groundwater recharge, unsaturated zone, Densu River Basin

Accurate estimation of groundwater recharge is essential for reasonable management of aquifers. A study of environmental isotope (δ^2H, $\delta^{18}O$) depth profiles was carried out to estimate groundwater recharge in the Densu River Basin in Ghana. Three observation sites were chosen that differ in their elevation, geology, climate, and vegetation. Water isotopes and water contents were analyzed with depth to determine the flow processes in the unsaturated zone. The measured data showed isotopic enrichment in the soil water near the soil surface due to evaporation. Seasonal variations in the isotope signal of the soil water was observed to a depth of 2.75 m. Below, the isotope signal was attenuated due to high diffusion/dispersion and low flow velocities. The groundwater recharge was determined by numerical modeling of the unsaturated water flow, resulting in a contribution of 6–13% of the precipitation to the groundwater recharge in the catchment area which equals 94–182 mm/a. Besides, the approximate peak-shift method was applied to give information about groundwater recharge rates. Here, slightly different values (110–250 mm/a) were calculated giving a mean groundwater recharge of 11–14% of the annual precipitation. The calculated groundwater recharge rates indicated that more water is renewed than consumed nowadays. However, with an increasing trend in population more clean water is required and the knowledge about groundwater recharge rates is necessary to improve the groundwater management in the Densu Basin.

abstract id: **341**

topic: **3**
Aquifer management

3.4
Environmental and artificial tracers in hydrogeology

title: **Investigation of recharge pathways and recharge rates using environmental isotopes (2H, 18O, 14C and 3H) in the Maules Creek Catchment, NSW, Australia**

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keywords: isotopes, groundwater, recharge, surface water groundwater interactions

INTRODUCTION

Groundwater resources are increasingly being relied upon for irrigation in arid and semi-arid regions especially in periods of drought. The often large volumes abstracted for irrigation purposes have the potential to deplete groundwater resources that are relied upon for stock and domestic water uses, and to reduce surface water flows in streams and rivers. The processes and timescales at which these impacts operate and the mechanisms of replenishment (or recharge) are generally not well understood. In addition, quantifying these processes in the field is expensive and time consuming. Consequently, groundwater management decisions are often based on numerical models of an aquifer system where the recharge rates are evenly distributed and represent a constant fraction of the average rainfall. Furthermore, the connection to surface water is often poorly conceptualised due to a lack of data. This has implications for the usefulness of such models as predictive tools. In part, this difficulty has arisen due to a scarcity of field based studies identifying zones of recharge, and surface water groundwater exchange, and estimating the rate at which this occurs and its temporal variability. Groundwater dating using environmental isotopes, in addition to traditional hydrogeologic methods, can aid in the understanding of recharge mechanisms and rates, as well as the surface water groundwater interaction processes.

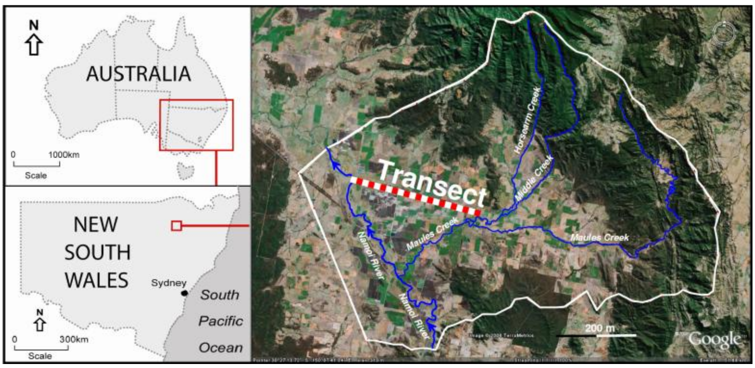

Figure 1. Location of study catchment and aquifer transect.

AIM & STUDY SITE

The objectives of this study were to assess recharge pathways and rates for the Maules Creek Catchment (NSW), a sub-catchment of the Murray-Darling Basin (Fig. 1). Surface water and groundwater were sampled for environmental isotopes ^{2}H, ^{18}O, ^{14}C and ^{3}H. Within the catchment, groundwater abstraction used mainly for the irrigation of cotton, has been carried out since the mid 1980s. As a result of these abstractions, an average decline of groundwater levels of about 4–5 m has been observed (McCallum et al., 2009). Flow in the main river, the Namoi River, also appears to have become more intermittent over the same period.

STABLE ISOTOPE DATA

The ^{2}H and ^{18}O data from the catchment shows that there is a large contrast between the regional groundwater and the river water, with the river water having a distinct evaporative signature. Shallow groundwater (<20 m) in proximity of the river (0.1–1 km) generally shows a mixed stable isotope signature indicating river water recharging the aquifer and mixing with the regional groundwater (Andersen et al., 2008). Although this data is useful in identifying end-member sources, it does not provide an indication of the groundwater residence time or rate of river recharge.

RADIOISOTOPES

The recharge rates of the aquifer were investigated using ^{3}H and ^{14}C data. Whilst ^{14}C mainly provides information on average groundwater residence times prior to the commencement of groundwater abstraction, ^{3}H can give information on groundwater recharge over the past 4 to 5 decades as illustrated by groundwater samples from the transect in Fig. 2. The uncorrected ^{14}C (Fig. 2a) and the ^{3}H (Fig. 2b) results generally indicate increasing apparent groundwater ages with depth beneath the ground surface. However, noticeable differences to this pattern are observed. Near the Namoi River, older groundwater is generally found at much shallower depths than anticipated (red circles in Fig. 3). This indicates up-welling of deeper groundwater eventually discharging into the river (gaining river conditions).

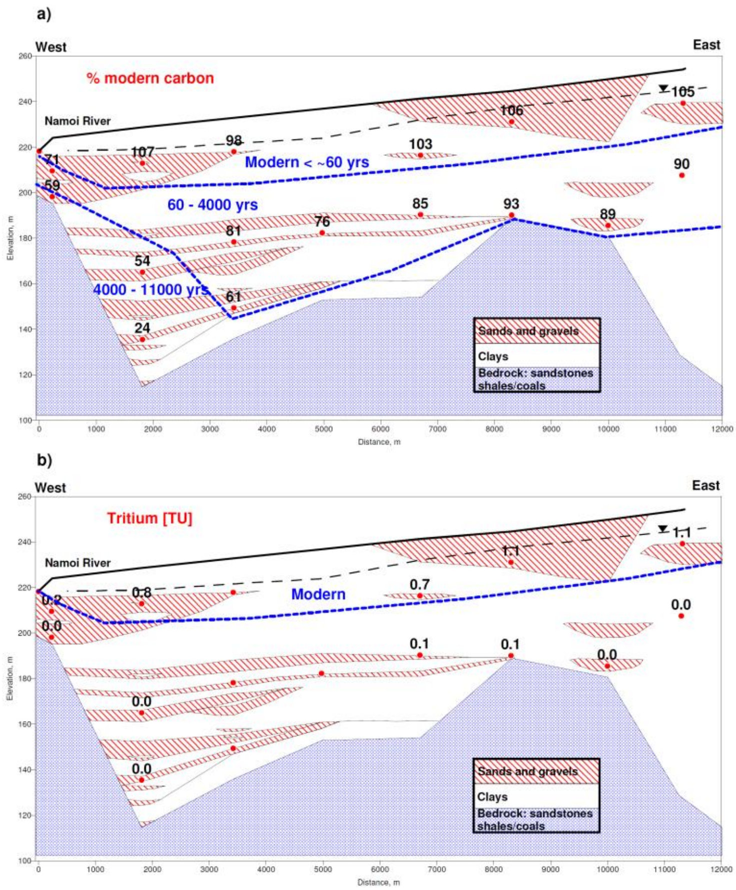

Figure 2. Transect through the Maules Creek aquifer (location shown in Fig. 1): a) Percent modern carbon and; b) 3H in tritium units (TU).

It is possible that this is a relict of past discharge patterns since presently there appears to be little or no discharge of groundwater to the river based on evidence from river level and groundwater head data (McCallum et al. in prep). In other wells, the opposite pattern is observed with modern water found at depths of up to 60 m (yellow squares in Fig. 3). These wells are located in areas near the river, where groundwater abstraction is causing large seasonal drawdowns. It appears that the origin of this modern groundwater is recently infiltrated river water (losing river conditions) entering the aquifer due to the lowered groundwater levels caused by groundwater abstractions.

RECHARGE ESTIMATES

The diffuse (rain-fed) recharge to the aquifer has been estimated in this study by ignoring the samples close to the river which are considered to be either recharge or discharge zones. A simple exponential age-depth relationship was obtained by assuming a homogeneous isotropic box-shaped aquifer with uniform depth (95 m) and porosity (0.3). Based on this, a long term diffuse recharge of 4-10 mm/yr was estimated (Fig. 3). This is an initial estimate of recharge conditions for the system and is subject to changes in the age distribution caused by deviations from the assumptions of homogeneity and isotropy. The scatter observed in the data shows that the aquifer is most likely not homogeneous and isotropic.

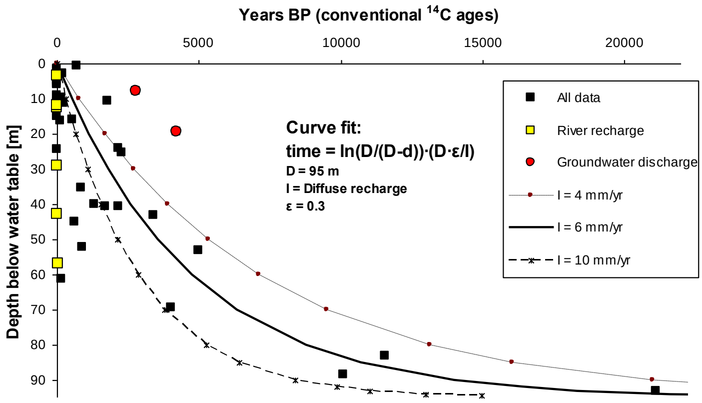

Figure 3. 14C ages vs. sampling depths in the saturated part of the aquifer. The curves represent the age-depth distribution given a diffuse recharge of 4, 6 and 10 mm/yr, respectively. They are fitted assuming exponentially increasing ages with depth in a 95 m deep, rectangular shaped homogeneous aquifer with a porosity of 0.3 (see Appelo and Postma, 2005).

CONCLUSION

This study shows that the changes in the surface water/groundwater interactions impact on the catchment water balance and especially on the fluxes entering the river from the aquifer. This data suggests the aquifer in the Maules Creek catchment is experiencing unexpectedly low recharge rates, which will have further implications for sustainable groundwater management in this part of the Murray-Darling Basin.

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abstract id: **360**

topic: **3**
Aquifer management

3.4
Environmental and artificial tracers in hydrogeology

title: **Groundwater flow system in the Nakano-shima Island, Japan, based on the spatial distribution of major components, CFCs, and 3H**

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keywords: island hydrology, fractured rocks, CFCs, ^{3}H, Japan

INTRODUCTION

Securing fresh water resources is vital for the human beings, and is especially critical at arid regions and isolated islands. Therefore, appropriate use and management of fresh water resources are critical issue for these areas, and it is necessary to understand the hydrological circulation for achieving sustainability of the society. This study attempts to reveal the groundwater flow system in the Nakano-shima Island, Japan, using major dissolved components, CFCs, and ^3H as tracers.

The Nakano-shima Island is situated in the Sea of Japan (Figure 1). The Oki–dozen Islands, one of which is the Nakano-shima Island, were formed by late Miocene (9-5 Ma) volcanism. The Islands are composed of somma, caldera, and central cone. The Nakano-shima Island is a portion of somma.

The Island is composed mostly of trachy-basalt and trachy-andesite rocks and partly of alkali olivine basalt lava (Figure 2) (Tiba et al., 2000). Fractures are frequently observed in basalt/andesite rocks, and groundwater exists manly in fractures (Tsukimori, 1984).

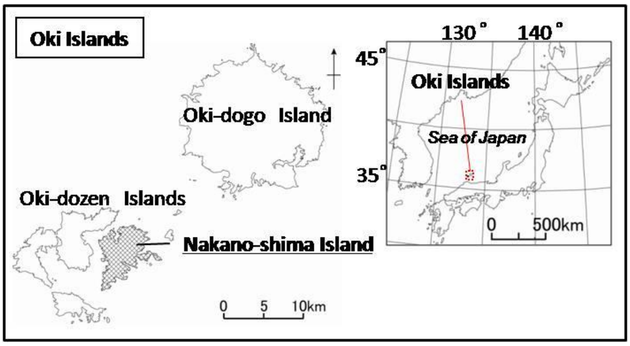

Figure 1. Location of the Nakano-shima Island.

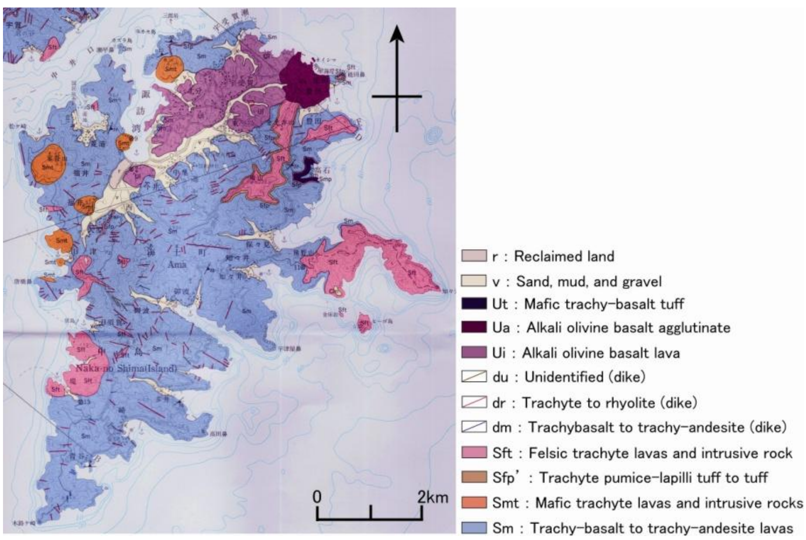

Figure 2. Geology of the Nakano-shima Island (Tiba et al., 2000).

METHODS

Water samples were taken from twelve deep wells, three shallow wells, six springs, and three surface streams in the Island in June and September 2009, and February 2010. Field parameters, including temperature, pH, electrical conductivity, dissolved oxygen concentrations, and oxidation-reduction potential were measured before sampling. All samples were analyzed for major dissolved components (Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, Cl^{-}, HCO_3^{-}, SO_4^{2-}, NO_3^{-}). All groundwater samples were analyzed for CFCs, and several samples were also analyzed for ^{3}H.

RESULTS AND DISCUSSION

Samples obtained from surface streams, springs, and shallow wells show Na^{+}-Cl^{-} type (Figure 3). Water samples from springs and shallow wells showed higher concentrations of both Ca^{2+} and HCO_3^{-} compared with surface streams. Samples from deep wells tend to show Ca^{2+}-HCO_3^{-} type. Major dissolved components of surface water and shallow groundwater are considered to be influenced by sea salt because the Island is surrounded by the sea. Particularly, surface streams which have shorter residence time are strongly affected by the sea salt.

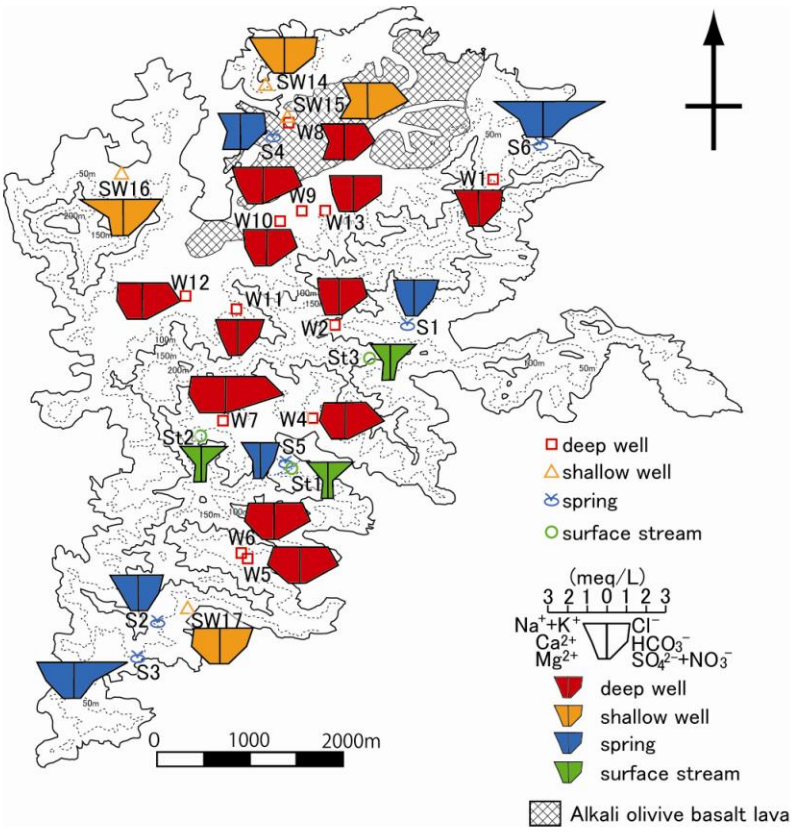

Figure 3. Major dissolved components of surface water and groundwater.

All samples obtained from the area covered by alkali olivine basalt lava showed Mg^{2+}-HCO_3^{-} type. Alkali olivine basalt lava contains higher MgO content compared with trachy-basalt and trachy-andesite rocks (Tiba et al, 2000). It is considered that groundwater with higher Mg^{2+} concentration described above is due to the water-rock interaction with alkali olivine basalt lava.

The correlations between the total amount of major dissolved components, bicarbonate, calcium, and magnesium concentrations, and the altitudes of springs and screen zones of wells were recognized, suggesting that groundwater of deeper part tends to have longer residence time (Figure 4).

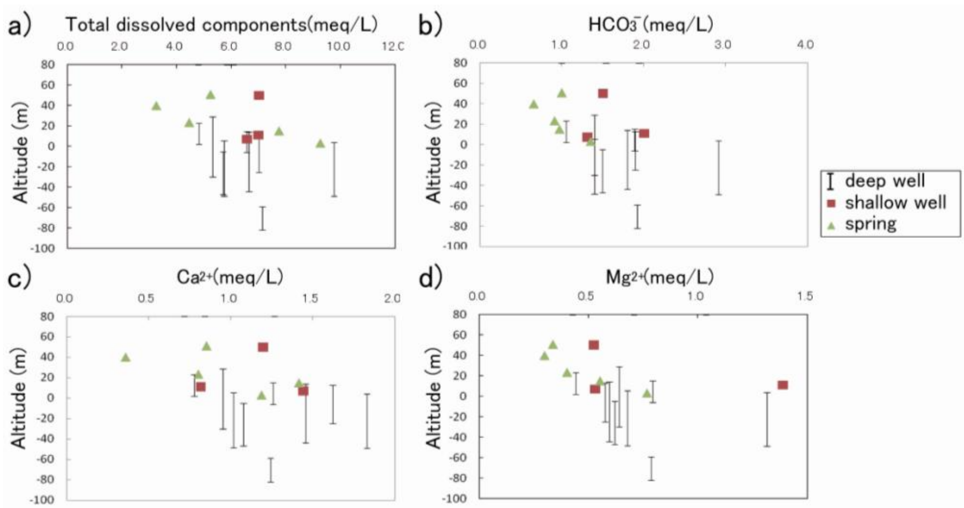

Figure 4. Relations between altitude and a) total major dissolved components, b) HCO_3^-, c) Ca^{2+}, and d) Mg^{2+}.

Water samples obtained from several wells showed that equivalent atmospheric concentrations of CFC-12 and CFC-11 were considerably higher than modern atmospheric concentrations. This result was considered to be due to the contamination by possible local CFCs sources, thus these data were not used for the discussion.

Good correlations between CFCs concentrations and ^3H concentrations were recognized (Figure 5). Also, negative correlations between both CFCs and ^3H concentrations and altitude of discharge of springs and screen zones of wells were found (Figure 6). These results suggest that deep groundwater tends to have longer residence time, which is consistent with the result obtained from major dissolved components.

^3H concentrations of two deep wells, W4 and W7, were 0.3 tritium unit (T.U.) and 0.6 T.U., respectively, much lower than other samples. CFCs concentrations of these samples were also lower, even though the altitude of the screen zone of W7 is similar with other deep wells. It suggests either the existence of groundwater flow system with longer residence time at least locally or the mixing with older/deeper water.

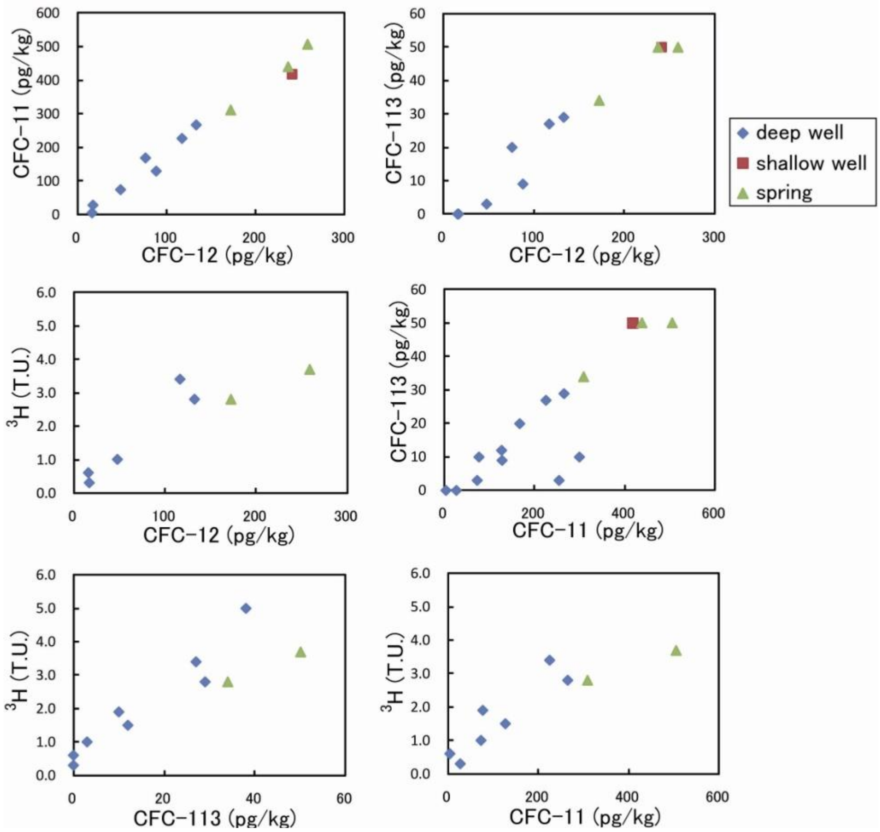

Figure 5. Concentrations of CFCs and ^3H of the groundwater samples.

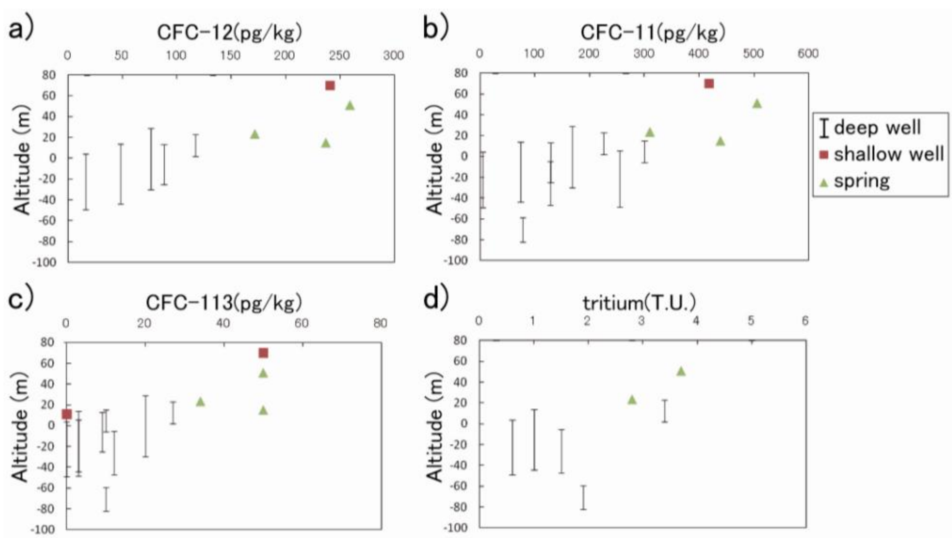

Figure 6. Relations between altitudes and a) CFC-12, b) CFC-11, c) CFC-113, and d) ^3H.

SUMMARY

Major dissolved components of shallow groundwater tend to show Na^{+}-Cl^{-} type. It is considered to be influenced by the sea salt. Deep groundwater tends to show Ca^{2+}-HCO_3^{-} type. Samples obtained from the area covered by alkali olivine basalt lava showed Mg^{2+}-HCO_3^{-} type, and it is considered to be due to the water-rock interaction. Relation between major components, CFCs, ^{3}H, and altitude suggests that deep groundwater tends to have longer residence time. Spatial distribution of CFCs and ^{3}H concentrations suggest the existence of the groundwater flow system with longer residence time at least locally or the mixing with older/deeper water.

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abstract id: **364**

topic: **3**
Aquifer management

3.4
Environmental and artificial tracers in hydrogeology

title: # Groundwater exchange between porous and karstic aquifer in deep mountain valley – Southern Karavanke, Slovenia

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keywords: karstic aquifer, porous aquifer, mine hydrology, tracer experiment, Karavanke

INTRODUCTION

In higher mountainous regions of Central Europe very often groundwater appearance is related to the extensive aquifers developed in karstic rocks. Due to high relief and intensive glacial processes in the geological past slopes and valleys are covered and filed with porous aquifers. The media in these aquifers is represented by heterogeneous slope and glacial sediments of different hydraulic conductivities. It can happened that in deeper valleys groundwater flow is directed from the karstic rock to the porous aquifer and then back to the karstic aquifer where can latter appear as a karstic spring.

In the study we have illustrated the appearance of extensive Košuta karstic aquifer in the trans-boundary water body Karavanke (between Austria and Slovenia) in the region Lajb north of city Tržič — Slovenia. In the area extensive discharge (between 500 and 1500 l/s) from the karstic Košuta aquifer along strong normal fault is present in the group of springs on the both sides of the deep valley filed with fluvioglacial sediments. Springs are forming river. After several meters of flow part of the river water sinks in the bottom of the valley and appears again on the surface as a karstic spring Črni gozd that is captured for water supply. It is also detected that groundwater from the porous aquifer in the valley flows back into the karstic aquifer in down gradient direction. The situation is additionally complicated with the existence of old abandoned mercury mine Sveta Ana where some tunnels are crossing valley perpendicular to the river flow.

METHODS

Detailed geological mapping and analyses of Sveta Ana mine archive were done. Results represented as geological map and profiles were formed basis for the construction of observation boreholes and planning of the tracing experiment in the area of spring appearance along the fault. Tracing experiment was performed with the uranine tracer. Concentrations of the tracer were measured by sampling at Črni gozd springs and with the passive sampling with the charcoal bags exposed to some points in the mine and in the boreholes. The distance between injection point and sampling point in spring was 1100 m. Breakthrough curves of the tracing experiment were modeled with the multi dispersion model calculated by our own macro procedures written in Excel 2003 – Microsoft.

RESULTS AND DISCUSSION

First arrival time of the tracer to the spring is t_{max}=10,25 hours that is equal to maximum velocity of v_{max}=0.030 m/s, efective time is t_{eff}= 15.2 hours with the effective velocity of v_a=0.020 m/s and the average time of the whole breaktrough curve is t_{mean}=17.9 hours with the velocity v_{mean} =0.017 m/s. Basic parameters are shown in the Figure 1a.

a)

b)

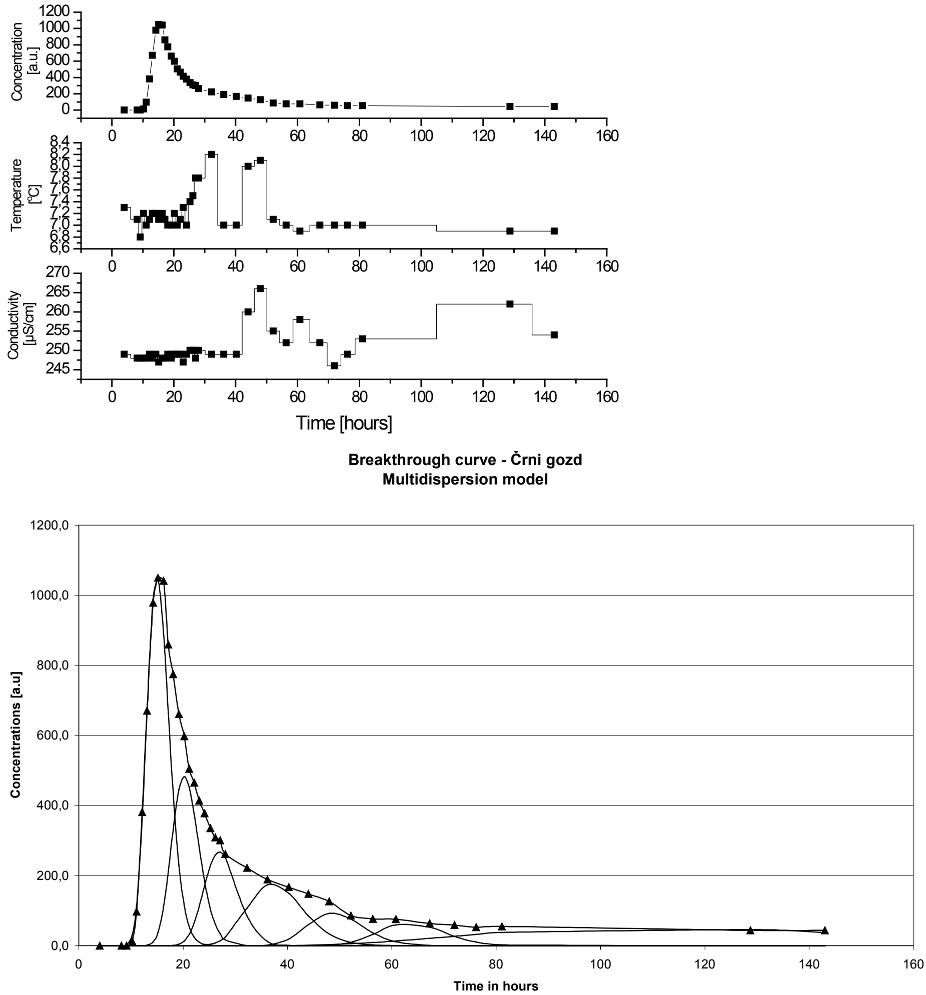

Figure 1. Results of tracing experiment in the Košuta aquifer in the region of Lajb Črni gozd — Slovenia.

During the tracing experiment rainfall was present reflecting in rise of the temperature and electrical conductivity. We have modeled breakthrough curve with the dispersion model of seven components (Fig. 1b) with mean velocities from 0.02 to 0.003 m/s.

The most important result of the experiment is conclusion and approval that in the area groundwater in the relatively short distance is flowing from the karstic aquifer into fluvioglacial and slope sediments and back into the karstic aquifer.

abstract id: **369**

topic: **3**
Aquifer management

3.4
Environmental and artificial tracers in hydrogeology

title: **Tracing nitrate contamination using isotopes: the Luanhe catchment case, North China**

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keywords: nitrate, groundwater, pollution, nitrogen isotope, north China

THE PROBLEM

Non-point sources pollution of groundwater by nitrates has been found rather serious and has profound effect on human health in some areas of North China. In order to control the pollution, it is necessary to understand the mechanism of pollution and identify sources of pollutants. For this purpose we have chosen Tangshan area as an example to conduct a detailed study, using isotope techniques in particular (Fig. 1).

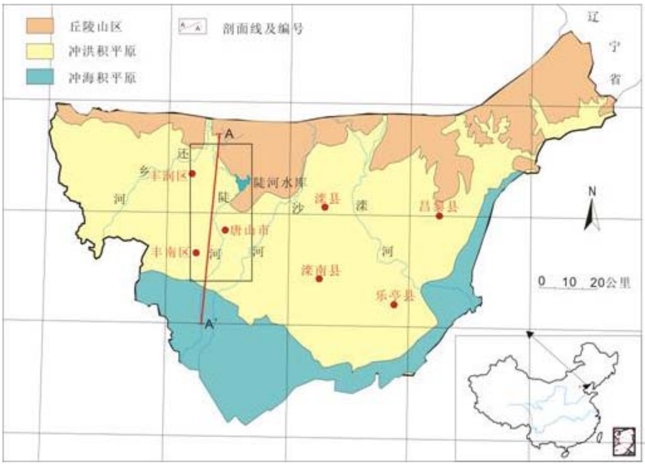

Figure 1. Location of Tangshan area.

Nitrate concentration in shallow groundwater is based on samples of 76 wells. Results show that groundwater from 33 wells exceeds the drinking water limit (50 mg/L-NO_3), with the maximum concentration of 226 mg/L. Sampling transects have been designed to go acroos these areas of high nitrate (Fig. 2).

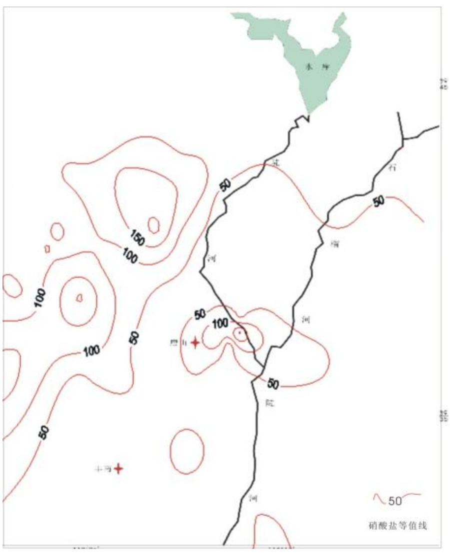

Figure 2. Isolines of nitrate concentration in groundwater.

SAMPLING AND ANALYSES

In order to define the sources of pollutants, we sampled natural waters from reservoir, river and water supply wells. Analyses include: water chemistry, oxygen and hydrogen isotopes, tritium, nitrate isotopes, sulfate isotopes, carbon-14 as well as CFCs.

MAIN CONCLUSIONS

It has been found that groundwater carries strong evaporative isotopic signature (Fig. 3). The top aquifer Q4 is recharged by precipitation, irrigation water. It is connected to the second aquifer Q3 but has limited connection to deeper aquifers. The Karst aquifer is recharged by precipitation in the mountains and is basically independent from the overlying aquifers.

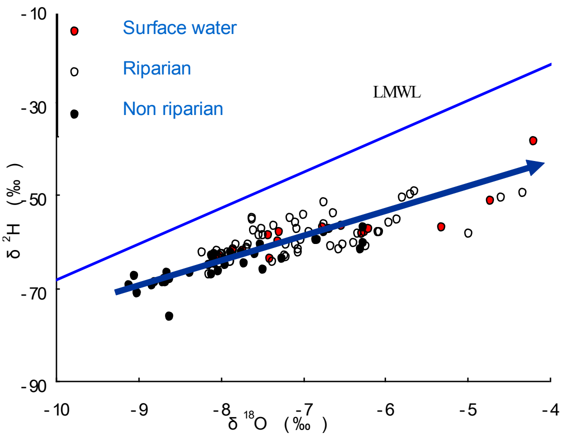

Figure 3. The relationship between δ^2H and δ^{18}O in the samples from the study area.

The average resident time of the karst aquifer is 20 a, changing to 27a towards central part of the plain. Tritium concentration varies with depth, and top one has the shortest residence time.

Other aquifers vary from 50a to 5a. Local circulation system is controlled by groundwater extraction. Q1 aquifer in the deepest part of the system was recharge by the water older than 50 a, and its stable isotopes indicate that the water is from early Pleistocene with cold and wet climate conditions. The high ^{15}N of river water shows that the source is sewage, there is no signs of denitrification or plant uptake in the river. Nitrate in groundwater is the mixture of manure and synthetic fertilizer, and later contributes about 60%. Non-riparian zone groundwater keeps the original δ^{15}N signature. Riparian zone groundwater has undergone denitrification of different extent.

abstract id: **388**

topic: **3**
Aquifer management

3.4
Environmental and artificial tracers in hydrogeology

title: **An investigation of heterogeneous water flow and transport processes in an oxidized glacial till using environmental isotope (δ2H, δ18O) profiles**

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keywords: glacial till, aquitard, environmental isotopes, heterogeneity, transport processes

The heterogeneity of flow and transport processes in a surficial glacial till was investigated by studying the stable environmental isotopes of water (^{18}O and ^{2}H) in the upper 6 m of the clay rich till at a site in Southern Saskatchewan, Canada. At the site, the transition between oxidized and unoxidized sediments occurred at a depth of 3 and 4.5 m below ground and the water table fluctuated seasonally (1–3 m below ground). Continuous core samples from three vertical sites located over a maximum spatial distance of 65 m were collected three times during 2009. Samples were analyzed for grain size distribution, bulk densities, and water contents. Additionally, transient, high-resolution (0.2 m) profiles of $\delta^{18}O$ and $\delta^{2}H$ in pore waters were measured using a $H_2O_{(liquid)}$-$H_2O_{(vapor)}$ pore water equilibration and laser spectroscopy technique. The depth profiles of the grain size analysis, water contents and bulk densities indicated a highly heterogeneous structure in the upper 6 m. This complex system was supported by the spatial distribution of the water isotopes resulting in distinctly different isotope depth profiles from each site. The temporal distribution of the isotopes in the pore waters indicated variable upward and downward fluxes in the upper two meters. Below this depth, flow appeared stagnant and diffusion was the dominating transport process. The water table fluctuations did not influence the isotope contents. Assuming one-dimensional equilibrium flow and transport processes, the profiles at only one of the sites could be simulated. The isotopic profiles at the other two sites were influenced by either fractured flow or lateral flow at different depths and suggested winter infiltration to greater depth. The combination of water contents, sediment properties, and water isotopes defined the heterogeneous flow and transport processes in this glacial till.

abstract id: **391**

topic: **3**
Aquifer management

3.4
Environmental and artificial tracers in hydrogeology

title: **Use of specific conductance in streams as a tracer to map groundwater recharge and discharge across the commonwealth of Virginia, USA**

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keywords: hydrograph, baseflow, recharge, evapotranspiration, specific conductance

Recharge is an important quantity that partly determines the long-term sustainability of groundwater resources. Quantifying the recharge flux in space and time is a challenge that has been undertaken by many scientists using many different techniques (Scanlon et al., 2002). For the purposes of water sustainability estimates and model calibration, the long-term average recharge rate is often the sought after value. In many watersheds, groundwater discharge (or baseflow) to the stream is related directly to the groundwater recharge rate within the watershed through the groundwater budget equation $RA = B + RET - U + \Delta S$, where R is recharge, A is the watershed area, B is the baseflow to the stream, RET is riparian evapotranspiration, U is the net underflow to the watershed (usually relatively small in Virginia watersheds), and ΔS is the change in storage (negligible over decades). Automated graphical hydrograph separation (*GHS*) techniques (Rutledge and Daniels, 1994) have been employed widley along these lines to make estimates of baseflow and recharge. One potential problem with this approach is that natural chemical tracers (which provide additional information) in watersheds usually indicate that during storm events more of the peak flow is groundwater discharge than simple graphical separation techniques would indicate. In this study we have used specific conductance (*SC*) as a tracer of groundwater discharge at real-time stream-gaging sites throughout Virginia to estimate baseflow and recharge using chemical hydrograph separation (*CHS*).

The real-time stream gages were instrumented at 72 sites across four physiographic provinces of Virginia with *SC* probes for a period of one to two years. Discharge and SC were measured every 15 minutes. Total evapotranspiration (*TET*) also was estimated using the difference between long-term (1971–2000) average stream flow (Q) and precipitation (P) associated with each gaged site and its watershed, where $TET = P - Q/A$. A regression equation then was made for *TET* as a function of P and the average annual minimum and maximum daily temperatures (T) (over 1971–2000) for the watersheds (data from Daly et al., 2008). The real-time Q at each site was divided into two components, B and *Ro* (runoff), based on *SC* and then adjusted to the long-term average Q. The one-to-two-year results were compared with estimates from the automated GHS program PART (Rutledge, 1998) made using the discharge data from the same one-to-two-year periods. The estimated average baseflow index, $BI = B/Q$, using the *CHS* was 0.71, as compared to 0.61 from using PART. This result is consistent with the many reported studies indicating that small forested watersheds have a large fraction of groundwater discharge during storm events (Rice and Hornberger, 1998).

The long-term average recharge, R, can be calculated based on the water balance relation $RA = B - RET$. The *RET* is typically a relatively small component of *TET* and was estimated independently in this study as a fraction of *TET*. Of all the landscape characteristics, the *BI* and *RI* (Ro/Q) were found to correlate most with physiographic province and rock type. Little additional improvement was made to the regression by including the topographic slope, land cover type, or soil permeability, partially because strong correlations exist between those other landscape parameters and rock type. The *ET* regression based on climate and discharge data explains about 80% of the variance in *ET*, and the runoff regression explains about 70% of the variance in *Ro*. These regressions were then applied to the entire Commonwealth of Virginia to create maps of *ET*, baseflow, runoff, and recharge.

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abstract id: **412**

topic: **3**
Aquifer management

3.4
Environmental and artificial tracers in hydrogeology

title: **The distribution of saline groundwater and its relation to the hydraulic conditions of aquifers and aquitards, examples from Israel**

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keywords: aquitards, aquifers, chemistry, separation

This study deals with the effect of separation by aquitard layers on the hydraulic conditions and distribution of saline groundwater in coastal aquifers. Two examples of Israeli coastal aquifers are given, the Mediterranean Sea and the Dead Sea, both are built of several sub-aquifers. The clayey aquitard layers in the Dead Sea area form vertical separation even in cases where its thickness is only ~1 meter. This is exhibited by large differences in hydraulic heads (2–5 m differences), salinity (TDS = 50–350 g/l) and chemical composition (e.g. Na/Cl variations in the range of 0.30–0.55). Spatial variability in salinity, on the horizontal dimension, occurs in this aquifer due to variability representing the sediments according to the specific location in the alluvial fan (gravel at the active flow and clayey material away from the flow stream).

Similar feature is evidenced in the Mediterranean coastal aquifer, although the separating aquitard layers are thicker (~5–10 meters). Here, the different sub-aquifers host groundwater of different ages (variation ^{14}C ages from several tens to thousands years), as well as different chemical compositions.

The main factors controlling the salinity of groundwater in specific sub-aquifers in coastal aquifers are its connection to the sea, existence of brines, salinization and flushing rates and separation by aquitard layers.

abstract id: **413**

topic: **3**
Aquifer management

3.4
Environmental and artificial tracers in hydrogeology

title: **Use of multiple isotopic and chemical tools under semi-arid climate: case of recharge residence time of groundwater in the Tadla basin (Morocco)**

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keywords: isotopes, chemistry, water, resources, Morocco

Groundwater resources in Tadla basin are provided by rivers and by different water bodies forming a multilayered aquifer which host one of the most important groundwater reservoirs of Morocco. The hydrodynamic functioning, i.e. the relationship between all regional aquifers, recharge, and the residence time of waters, pose a serious problem for current water management and future exploitation. A combined Hydrogeologic and isotopic investigation using hydrochemical and isotopic tracers such as ^{18}O, ^{2}H, ^{3}H, ^{13}C and ^{14}C, was carried out in order to determine the sources of water recharge to the aquifers, the groundwater flow system, and the residence time of these waters. More than one hundred point measurements distributed throughout the study area in varying surface waters, rivers, wells, boreholes and springs have been accomplishes. The chemical results indicate an important influence of carbonate sediments in the composition of waters from each of the Tadla aquifers. The chemical and stable isotopes results indicate the existence of two groups of groundwater, which can be distinguished by their chemical and isotopic characteristics. The two groups correspond to the unconfined aquifer to the north and the confined aquifer to. Stable isotopes, as well as ^{3}H, and ^{14}C data indicate that the High Atlas mountains in the South and East of the basin, which are characterized by high rainfall and low $\delta^{18}O$ and $\delta^{2}H$ values (–5.5 to –7.5‰ and –30 to –50‰), are currently the major source of recharge to the Tadla aquifers, particularly in the south-east and Tassaout parts for the shallow aquifer. A significant zone of recharge lies in the northern part of the basin where all the aquifers outcrop. However, all isotopes demonstrated that the springs located in the South-West of the basin, which were previously supposed to be the natural outlet of the deep aquifers, are comprised of young waters, with ^{18}O and ^{2}H signatures suggesting a high altitude (Atlasic recharge type). The unconfined parts of the aquifers show enriched values of ^{18}O indicating an evaporation phenomenon which occurs during infiltration or recharge from irrigation. The confined zones show the impoverished values of ^{18}O which corresponds to the signature of Atlas Mountain and/or to paleo-recharge (≥–6.5‰. The mixing process of old and recent waters is confirmed by ^{14}C and ^{3}H. The recent isotopic data indicates probable interaction between the different aquifers. The mixing processes that were hinted at by hydraulic, and supported by hydrochemical and geological data, are defined in great detail when the isotopes data are examined. The data generated in this study will certainly permit the revision as well as improve the mathematical water resources model in the Tadla basin. The results provide the framework for a comprehensive management plan in which water exploitation should shift towards the areas where current recharge occurs where young and high quality groundwater is found.

abstract id: **487**

topic: **3**
Aquifer management

3.4
Environmental and artificial tracers in hydrogeology

title: **Assessment of denitrification rates in fissured-karstic aquifer near Opole (SW Poland): combined use of gaseous and isotope tracers**

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keywords: fissured-karstic aquifer, denitrification, gas chromatography

INTRODUCTION

Unconfined groundwater systems, particularly fissured-karstic aquifers, are vulnerable to anthropogenic pollution and the resulting deterioration of groundwater quality. Dissolved nitrate is among the most common pollutants occurring in shallow groundwater systems in Europe. Under natural conditions, denitrification is the only process leading to reduction of nitrate content in groundwater. The end-product of this process is gaseous nitrogen. The intensity of denitrification process is controlled by redox potential, availability of labile organic matter and presence of denitrifying bacteria in the system.

Here we discuss nitrate pollution in a groundwater system situated near Opole, south-west Poland (Kryza, Staśko, 2000). The investigated aquifer is of high economic value as a source of drinking water for the Opole region. Since more than three decades a substantial deterioration of water quality is observed in the southern, unconfined part of the system, resulting mainly from elevated concentrations of nitrates, often exceeding the maximum permissible concentration allowed by Polish law (50 $mgNO_3/dm^3$). However, it was observed that the nitrate concentrations drop abruptly in the northern, confined part of the system, which needed to be explained. From several possibilities, the authors suggested denitrification process as being the main reason for those observations. This possibility has been examined in the framework of the presented study by combined use of two independent tracers of the denitrification process: (i) the nitrogen and oxygen isotope composition of the dissolved nitrate, and (ii) the excess of dissolved nitrogen in groundwater. Assessment of denitrification rates in various parts of the studied system is of importance for effective management of available groundwater resources and for planning of new production boreholes.

DENITRIFICATION IN GROUNDWATER SYSTEMS

There are several ways of identifying the denitrification processes in groundwater systems: (i) microbiological identification of specific strains of denitrifying bacteria in groundwater (Barabasz, 1985), (ii) exploring the links between redox potential of groundwater and occurrence of denitrification process (Mariotti, 1986), (iii) identifying specific proteins in groundwater characteristic for the denitrification process (Santoro, 2009), (iv) measuring the excess concentration of nitrogen gas in groundwater (Heaton et al., 1983), and (v) analysing nitrogen and oxygen isotope composition of the dissolved nitrate (Böttcher et al., 1990). The last two methods were employed in the framework of the present study and are discussed below in some detail.

Tracing the denitrification process using excess nitrogen concentration in groundwater

The measured concentration of gaseous nitrogen dissolved in groundwater (C_m) can be separated into three components (e.g. Heaton et al, 1983; Cook, Herczeg, 2000; Żurek, Mochalski, 2010):

$$C_m = C_{atm} + C_{exa} + C_{den} \quad (1)$$

The atmospheric component (C_{atm}) represents equilibrium concentration of atmospheric N_2 dissolved in the infiltrating water under pressure and temperature conditions characteristic for the recharge area of the given groundwater system. The excess air component (C_{exa}) stems from the fact that the infiltration process usually leads to dissolution of some additional air in groundwater, when compared to the equilibrium amount dissolved under given pressure and temperature conditions. The denitrification component (C_{den}) represents gaseous N_2 produced during the denitrification process. In order to derive the denitrification component from the measured concentration of N_2 in groundwater, the remaining two components have to be measured or assessed.

Isotopic composition of nitrate as an indicator of denitrification process

Physical, biological and chemical processes associated with nitrogen cycling in nature lead to isotope differentiation of substrates and products in the course of various chemical reactions and transformations of nitrogen compounds. They may influence stable isotope ratios of nitrogen ($^{15}N/^{14}N$) or oxygen ($^{18}O/^{16}O$) or isotopic composition of other elements (such as hydrogen) present in some of those compounds.

During denitrification processes isotopically light molecules of NO_3^- are favoured. Isotopic fractionation can be expressed by the following approximate formula:

$$\varepsilon_{product\text{-}substrate} = \varepsilon_{p\text{-}s} \approx \delta^{15}N_{product} - {}^{15}N_{substrate} \quad (2)$$

where $\varepsilon_{p\text{-}s}$ stands for effective isotope depletion in ^{15}N of the product, when compared to the substrate. Similar expression can be formulated for ^{18}O although in this case there are two substrates (NO_3^- and H_2O) and two products (HCO_3^-, CO_2) containing oxygen atoms, associated with the denitrification process.

Isotopic evolution of the product(s) and substrate(s) during the denitrification process can be described by the so-called Rayleigh model. The following approximate formula applies for calculating the nitrogen isotope composition of nitrate remaining in groundwater, when the initial isotopic composition ($\delta^{15}N_{si}$) and the isotope depletion $\varepsilon_{p\text{-}s}$ is known (e.g. Mariotti et al., 1988):

$$\delta^{15}N_{sf} = \delta^{15}N_{si} + \varepsilon_{p\text{-}s} \cdot \ln(F) \quad (3)$$

where F is the fraction of nitrate left in the system from the beginning of the process. Similar equation can be written for ^{18}O.

Denitrification processes observed in the field usually reveal a linear relationship between ^{18}O and ^{15}N isotope enrichments in the remaining nitrate pool, the ratio being between 0.5 and 0.7 (Aravena, Robertson, 1998; Kendall et al., 2007). However, in the laboratory denitrification experiments with isolated strains of denitrifying bacteria Ganger et al. (2004, 2008) found the ratio of ^{18}O to ^{15}N enrichment close to one. The denitrification process in groundwater can be then identified by the characteristic shift towards more positive $\delta^{15}N$ and $\delta^{18}O$ values measured in the dissolved nitrate, associated with the reduction of NO_3 content (e.g. Leibundgut et al., 2009).

STUDY AREA

The studied aquifer (Major Groundwater Basin No. 333) is located in south-west Poland, in the vicinity of Opole (Fig. 1). This is a fissured-karstic system filled with Muschelkalk sediments consisting of carbonate and dolomite rocks with presence of fissures, cracks and karstic voids which control the flow of water. Water-bearing Permian-Triasic complex is composed of horizons of Bunter Sandstone and sediments of Roethian formation (Staśko, 1992; Kryza, Staśko, 2000) Hydrological conditions on the investigated area are determined by monoclinal structure of geological layers (Fig. 2). Outcrops of the water–bearing layers are located south of Opole, in the Strzelce Opolskie region (Fig. 1).

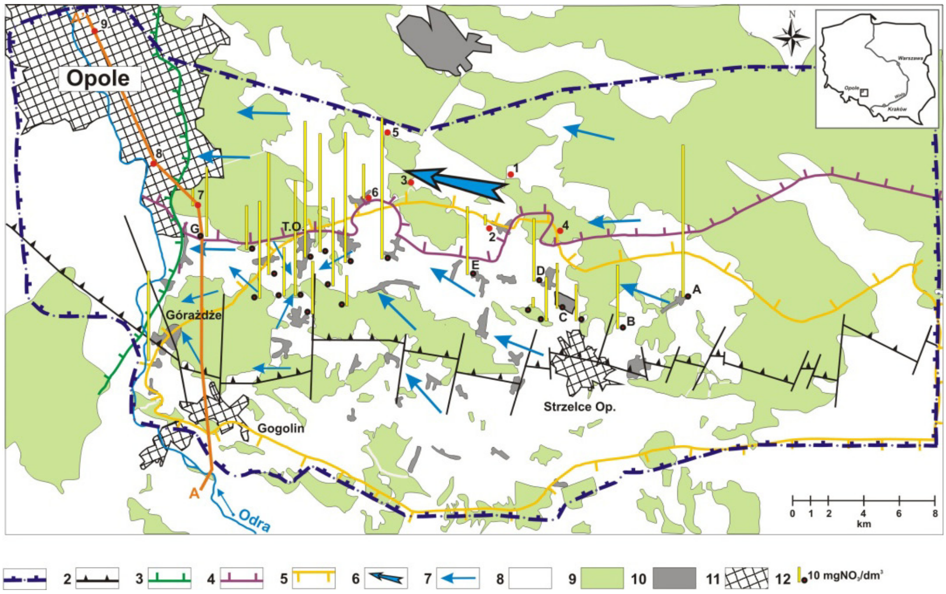

Figure 1. Hydrogeological and land-use map of the study area. The wells discussed in the text are labeled by letters (A to G) and numbers (1 to 9). Explanations: 1 — boundaries of the aquifer; 2 — range of Muschelkalk formation; 3 — range of Cretaceous formation; 4 — range of impermeable Keuper deposits; 5 — range of Quaternary cover; 6 — regional direction of groundwater flow; 7 — local directions of groundwater flow; 8 — agricultural areas; 9 — forests; 10 — rural areas without sewage system; 11 — towns with central sewage system; 12 — monitoring points with nitrate concentration in $mgNO_3/dm^3$; T.O. — Tarnów Opolski.

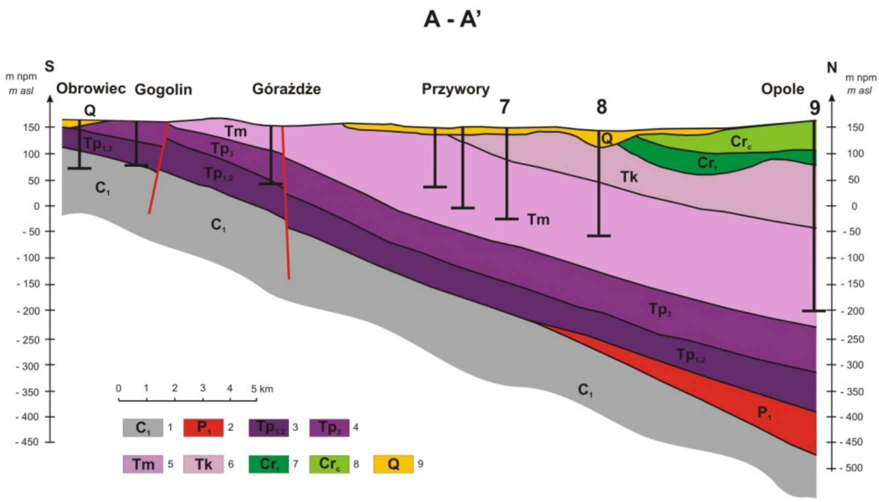

Figure 2. Geological cross-section A-A' (Poprawski, 1987; Staśko, 1992 — modified). Explanations: 1 — Lower Carboniferous: grauwackes, schists, conglomerates; 2 — Lower Permian: conglomerates and sandstones; Triassic (3-7): 3 — Lower and Middle Bunter Sandstones: sandstones, mundstones, conglomerates; 4 — Roethian: dolomites, marls, limestones with evaporite; 5 — Muschelkalk: limestones, marls and dolomites; 6 — Keuper: claystones, mundstones, marls and sandstones; Cretaceous (7-8): 7 — Turonian: marls and mundstones; 8 — Cenomanian: sands, sandstones; 9 — Quaternary: sands, gravels, glacial till.

Natural conditions of water circulation in the aquifer are varying spatially, reflecting diverse geological structure and changing permeability of the main water-bearing layer. In southern part of the system, where well-permeable zone of Muschelkalk outcrops is located, only partly covered with thin Quaternary sediments, preferable conditions for recharge and groundwater flow occur. Under natural conditions, the main groundwater flow direction was to the west, towards Odra river (Fig. 1). Recharge in northern part of the aquifer is very limited due to sick cover of loamy sediments of Keuper. Present-day flow conditions in the system are heavily modified due to intensive abstraction (municipal pumping stations) and dewatering of local quarries supplying raw material for cement industry. Large depression cones have developed particularly in the area of Opole, Strzelce Opolskie, Tarnów Opolski, and Górażdże.

METHODS

In the framework of the present study nine wells located in the confined part of the system were selected for combined measurements of excess gaseous nitrogen and analysis of ^{18}O and ^{15}N isotope composition of dissolved nitrate (wells 1 to 9 in Fig. 1). Those analyses were supplemented by measurements of dissolved nitrate and tritium content. For those wells also basic physico-chemical characteristics measured in-situ (temperature, pH, Eh, electrical conductivity, dissolved oxygen) are available (Żurek, Mochalski, 2010). For comparison, seven wells located in the unconfined part of the system, on the general direction of groundwater flow, were selected (wells A to G in Fig. 1). Oxygen and nitrogen isotope composition of dissolved nitrate, supplemented by nitrate and tritium content, are available for those wells from former studies (Kleczkowski et al., 1987, Różański et al., 2007).

Isotopic composition of nitrogen and oxygen in dissolved nitrate was measured in mass spectrometry laboratory of the Environmental Physics Group, Faculty of Physics and Applied Computer Science, AGH University of Science and Technology. Details of sample preparation technique are described in Chmura et al. (2009). The results of isotope analyses are reported as relative deviations of the measured isotope ratios ($^{15}N/^{14}N$ and $^{18}O/^{16}O$) from generally excepted standards, expressed in per mill. The standards used are atmospheric nitrogen (Mariotti, 1983) and the international reference material VSMOW (Coplen, 1996) for $\delta^{15}N$ and $\delta^{18}O$, respectively. Measurement uncertainties of $\delta^{15}N$ and $\delta^{18}O$ (1 sigma) were in the order of 0.3 ‰ and 0.6 ‰, respectively (Chmura et al., 2009).

Nitrogen gas associated with the denitrification process was measured in the laboratory of the Department of Physicochemistry of Ecosystems, Institute of Nuclear Physics PAN, using gas chromatographic method. Details of sample preparation and measurement technique are presented elsewhere (Mochalski et al., 2006; Żurek, Mochalski, 2010).

Measurements of nitrate concentration in the investigated samples were performed by spectrophotometry with the standard uncertainty in the order of 0.1 $mgNO_3^-/dm^3$. Tritium content in water samples was measured in the tritium laboratory of the Environmental Physics Group, Faculty of Physics and Applied Computer Science, AGH University of Science and Technology, using electrolytic enrichment followed by low-level liquid scintillation spectrometry (Florkowski, 1981; Kuc, Grabczak, 2005). Tritium results are reported in tritium units (TU). One TU corresponds to the isotopic ratio $^3H/^1H=10^{-18}$ (1TU = 0.1192 Bg/kg of water). Measurement uncertainties are in the order of 0.3 TU.

RESULTS AND DISCUSSION

The data discussed in the present work are summarized in Table 1.

Table 1. Nitrate content, $\delta^{15}N$ and $\delta^{18}O$ of nitrate, tritium, nitrogen from denitrification, equivalent nitrate concentration and oxygen content in sampled wells.

Well symbol	NO_3^- [mg/dm³]	$\delta^{15}N$ (NO_3) [‰]	$\delta^{18}O$ (NO_3) [‰]	^3H [TU]	$N_{2\,den}$ x10^{-3} [cm³$_{STP}$/cm³]	$NO_3^-{}_{den}$ [mg/dm³]	O_2 [mg/dm³]
Uncovered S part of aquifer							
A	100.5	5.4	14.3	10.3 (02.11.2005)*	n. m.	n. m.	n. m.
B	42.0	4.5	14.3	10.5 (02.11.2005)*	n. m.	n. m.	n. m.
C	30.0	8.9	4.4	11.4 (02.11.2006)*	n. m.	n. m.	n. m.
D	50.2	5.4	14.5	11.3 (02.11.2005)*	n. m.	n. m.	n. m.
E	45.0	7.1	17.0	11.7 (02.11.2005)*	n. m.	n. m.	n. m.
F	93.0	4.9	15.1	13.0 (08.11.2005)*	n. m.	n. m.	n. m.
G	45.4	5.5	15.5	12.5 (08.11.2005)*	n. m.	n. m.	n. m.
N part of aquifer covered with Keuper sediments							
1	2.4	18.9	16.2	0.0	0.74±0.53	4.1±3.1	0.00
2	2.7	18.5	10.3	0.6	<0.6	<3.5	0.35
3	0.6	21.1	6.0	0.4	<0.6	<3.5	0.30
4	0.5	23.5	20.2	0.0	<0.6	<3.5	0.26
5	0.3	23.5	35.5	0.3	n. m.	n. m.	n. m.
6	22.3	6.1	15.5	3.7 (08.11.2005)*	<0.6	<3.5	9.0
7	12.5	6.0	16.6	6.9 (08.11.2005)*	3.23±0.61	17.0±3.5	6.4
8	<0.1	n. m.	n. m.	0.0**	<0.6	<3.5	0.09
9	<0.1	n. m.	n. m.	0.0**	<0.6	<3.5	4.5

* - Różański et al. 2007; ** - Kleczkowski et al. 1987.

$\delta^{18}O$ of dissolved nitrate is plotted as a function of $\delta^{15}N$ in Fig. 3, on the background of typical ranges of these values observed in different compartments of nitrogen cycle (Kendall et al., 2007).

The group of wells (A to G) representing unconfined part of the system reveals high nitrate content (between ca. 30 and 100 mg NO_3/dm³) accompanied by high tritium content (between 10.3 and 13 TU), comparable to tritium concentration in present-day precipitation in southern Poland. This confirms relatively fast infiltration and presence of fresh water in this part of the aquifer supporting high pumping yields of the production wells, in agreement with the fissured-karstic character of the system.

The isotopic composition of dissolved nitrate in this group of wells forms a tight cluster bordering the area typical for NO_3 from fertilizer input. This strongly suggest that major input of nitrate to groundwater in this area is most probably from agriculture. The only exception is the well C which reveals distinctly lower $\delta^{18}O$ and higher $\delta^{15}N$ values, associated with lowest nitrate content (30 mg/dm-3) when compared to the remaining wells in this group. In contrast to other wells, nitrate in this case may originate from point source (persistent application of manure or leaking septic wastes in the vicinity of the well).

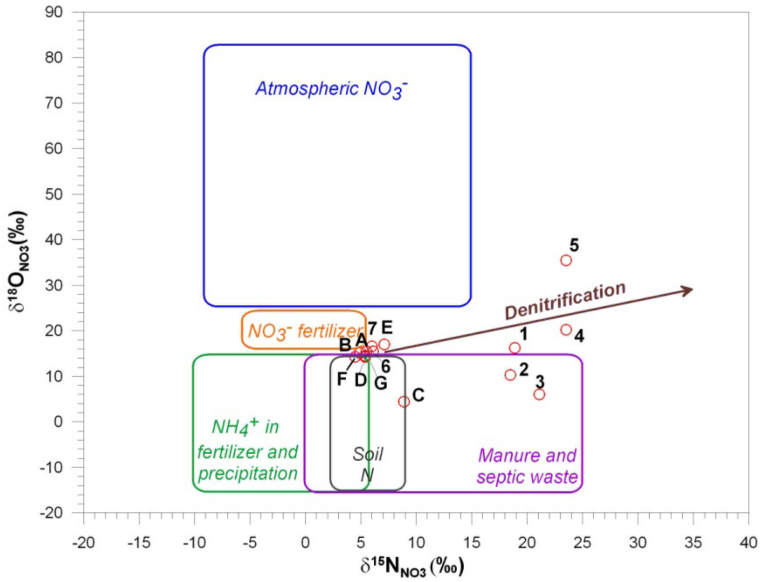

Figure 3. δ15N(NO3) - 18O(NO3) relationship for the data presented in Table 1. Ranges of 15N and 18O isotope signatures of different sources of nitrate are shown after Kendall et al. (2007).

The wells located in the confined part of the system, with the exception of well no.6 and no.7, reveal greatly reduced nitrate content, between ca. 0.3 and 2.7 mg NO_3/dm^3 (wells 1 to 5). Such decrease of nitrate content together with $\delta^{18}O$ and $\delta^{15}N$ data for those wells suggest well-advanced denitrification process. They are shifted on the $\delta^{18}O$-$\delta^{15}N$ plot to the right-hand side with respect to the data representing unconfined part of the system, clustering along the denitrification line with the slope of ca. 0.5. The enrichment in ^{15}N varies between ca. 15‰ (wells nos. 1, 2 and 3) and 20‰ (wells nos. 4 and 5) which corresponds to ca. 3 to 5-fold reduction of the initial nitrate content (Ganger et al., 2008), suggesting that the initial nitrate content varied between ca. 1.5 and 3 mg NO_3/dm^3 for wells nos. 3, 4 and 5 and between ca. 7 and 12 mg NO_3/dm^3 for wells nos. 1 and 2. Water in those wells does not contain any significant amounts of tritium, strongly suggesting its pre-bomb age, in agreement with natural ranges of initial nitrate content assessed above. It is apparent from Table 1 that the detection limit of the nitrogen excess method is in the order of 3.5 mg/dm^3 of decomposed NO_3^-. It is, therefore, not surprising that in case of wells nos. 3 and 4 no nitrogen associated with denitrification could be detected (well no.5 was not measured). Well no.1 falls just at the border of the sensitivity of the method. The assessed initial concentration of NO_3^- in this well derived from excess of nitrogen (ca. 3.4 to 9.6 mg NO_3/dm^3) falls within the range suggested by the isotopic composition of nitrate (7 and 12 mg NO_3/dm^3) possibly indicating some (if any) input of anthropogenic nitrate. Traces of tritium in well no.2 (0.6 TU) might indicate small admixture of fresh water.

Well no.6 is located just at the border of the confined part of the system (cf. Fig. 1). It reveals elevated nitrate content (22.3 mg NO_3/dm^3) with its ^{15}N and ^{18}O isotopic composition lacking any sign of denitrification (cf. Fig. 3). Also the excess of nitrogen is below the detection limit. These indicators, combined with significant tritium content (3.7 TU) clearly demonstrate that although the well is located already within the confined part of the system, the travel time of water to this well from the recharge area is apparently too short for the denitrification process to leave significant imprint either in the isotopic composition of nitrate or in the excess of nitrogen.

Well no.7 is located in the western part of the system, close to Opole municipal area. Water from this well contains significant amount of nitrate (12.5 mg NO_3/dm^3). Isotopic signature of nitrate does not reveal any signs of the denitrification process. Tritium content is relatively high (6.9 TU), pointing to recent recharge. Surprisingly enough, this water reveals high N_2 excess, equivalent to ca 17 mg NO_3/dm^3 of decomposed nitrate. Such high value cannot be reconciled with significant tritium content in this water and with the isotopic signature of nitrate nor revealing any signs of the denitrification process. High concentration of dissolved oxygen equal 6.4 mg/dm^3 (Table 1) and high redox potential (344 mV) reported by Żurek and Mochalski (2010) for this well essentially exclude any significant denitrification in this case. Therefore, other reasons for high N_2 excess detected in this water must be thought.

Wells no. 8 and 9 are located within Opole municipal area, in the north-west corner of the study area. Nitrate content in these wells is below the detection limit of the method used (<0.1 mg NO_3/dm^3). Water is tritium-free and no traces of N_2 excess could be detected. All these indicators suggest significant age of groundwater and (almost) complete denitrification of the natural nitrate. Interestingly enough, well no.9 revealed noble gas temperature equal ca. 3.6°C (Żurek, Mochalski, 2010), pointing to glacial origin of this water. Glacial origin of water in this part of the system is also suggested by significantly reduced ^{2}H and ^{18}O content in this water when compared to recent recharge (Kleczkowski et al., 1988), providing independent proof of its great age.

CONCLUDING REMARKS

The investigated groundwater system located in south-west Poland revealed a broad range of nitrate concentration. The measured nitrate content varied from below detection limit (<0.1) to ca. 100 mg/dm^3. A dominant role of diffuse source of nitrate (fertilizers) was confirmed, based on oxygen and nitrogen isotopic composition of nitrate. The measured concentration of tritium in the analyzed groundwater samples also varied in relatively broad range, from 0 to ca. 13 TU.

Two contrasting groups of wells (one group located in the unconfined part of the system, representing presumable recharge area, and the second one located in the confined part) analyzed in the present study allowed a deeper insight into the fate of nitrate in the system. Isotope fingerprint of the denitrification process was clearly identified in several wells located in the confined part. Water from these wells was generally tritium-free and revealed very low nitrate contents which isotopic signature pointed to well-advanced denitrification process.

The measured ^{18}O and ^{15}N isotope enrichments in the remaining nitrate in the wells located in confined part of the investigated system indicate that initial nitrate concentrations were generally within the natural range or close to it (< 10 mg/dm^3) suggesting that water being pumped by those wells was recharged before significant input of nitrate from fertilizers occurred in this area. This is consistent with absence of tritium in these wells. In turn, this would mean that the plume of anthropogenic nitrate did not yet penetrate substantially into confined part of the system and with time the wells located in this part may also experience elevated nitrate contents.

Wells nos.6 and 7 which are located already within the confined part of the system, at the distance of ca. 0.5 and 2 km to the unconfined part, respectively, allowed an interesting glimpse into the dynamics of the denitrification process. Isotopic composition of nitrate from these wells did not revealed any signs of denitrification, despite the fact that tritium content was reduced to ca. 40-50% of the values recorded in the unconfined part, suggesting not negligible travel time of water to those wells within the confined part. Also other indicators (Eh, dissolved oxygen) clearly showed that appropriate conditions for denitrification were not yet reached in these two cases.

The method of identifying denitrification process in groundwater via excess of gaseous nitrogen turned out to be not sufficiently sensitive to detect denitrification of natural nitrate which concentrations in groundwater in the study area are thought to be generally well below 10 $mgNO_3/dm^3$. Nevertheless, this method remains an attractive tool for quantification of the denitrification processes in systems where denitrification of anthropogenic nitrate is already underway.

The presented study demonstrated that combining isotope analyses of nitrates with tritium or other transient tracers may provide additional insights into the dynamics of water and nitrate movement and transformation in groundwater systems.

ACKNOWLEDGEMENTS

Financial support of this work through Ministry of Science and High Education (grant No. NN 525 2058 33) and through the statutory funds of the AGH University of Science and Technology (project No. 11.11.220.01 and No. 11.11.140.139) is kindly acknowledged.

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abstract id: **518**

topic: **3**
Aquifer management

3.4
Environmental and artificial tracers in hydrogeology

title: **Tritium (3H) as an indicator of the connection between river and groundwaters**

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keywords: tritium (3H), river, aquifer, pollution and protection

The paper presents results of analyses of ^3H content in the ground and river waters, as the indicator of possible connection between ground and surface flows. In that sense, the most endangered are alluvial aquifers since they are mostly used for water supply. The analysis of these relations has been carried out on Ljubičevo profile, which belongs to the developed valley of the Great Morava. There are significant sources of ground water used for municipal water supply of Požarevac. The source of this town uses alluvial aquifers, which primarily originate from the river flow of the Great Morava. The level of ground water oscillates during a year. It is directly connected with the level of the river flow of the Great Morava. Thus connected hydraulic bond between river and ground flows enables the intrusion of the aggressive pollutant into the ground water, which might lead to contamination of the alluvial aquifer that is mostly used for municipal water supply.

In order to reach the cognition of degree of possible connection between the river and ground waters, the analysis of tritium content was carried out on the composite samples taken from observation piezometers and exploitation wells of the Požarevac source and from the Great Morava flow near source. Sampling was done for every season. The biggest concentration of the tritium in the river and ground water was noticed during summer period, while the least concentration was noticed during winter and spring period. The reason for such ratio should be sought in a greater evaporation of the river waters during summer when light molecules evaporate, since heavy ones are lagged behind and water is then richer with tritium. Very approximate ratio between tritium concentrations in river and ground waters points out an intensive connection between the river and ground water which confirms the possibility of fast intrusion of pollutant from the river into the aquifer. Their mutual connection represents a joint medium that can be degraded by irresponsible man's activities towards environment, while every deterioration of the quality of the water from river flow directly endangers the quality of ground water. Applied method that used tritium (^3H) as a tracer confirmed functional bond which exists between river and ground flow. Such a bond is possible in the other parts of the Great Morava course. Therefore research on isotopic composition of natural waters in its basin should be systematic and long-term so as to acquaint with hydrodynamic principles, which governs the system river-aquifer. In that sense specified method can serve to ascertain the origin of the water, part of individual components in mixed water, velocity of the water, characteristics of the process of infiltration of surface water into ground water. Ascertainment of these parameters is of significance regarding alluvial aquifers, which are mainly in inundatiory area of the river courses where the most excessive pollution occurs.

3.5 | Social, ecological and economic implications

abstract id: **455**

topic: **3**
Aquifer management

3.5
Social, ecological and economic implications

title: **Estimating agricultural extractions, use of a model for the validation of the hypotesis: Case of the Camp de Tarragona (Catalonia, Spain)**

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keywords: agricultural extraction, hydric stress, irrigation

INTRODUCTION

The Catalan Agency of Water (the Agency) has full competences concerning the control, management and planning of water resources in approximately the Eastern half of the Catalan territory, in NE Spain. The Agency has commissioned a model of the aquifers defined in the Camp de Tarragona region, at the southern part of Catalonia, mainly for management purposes (Fig. 1).

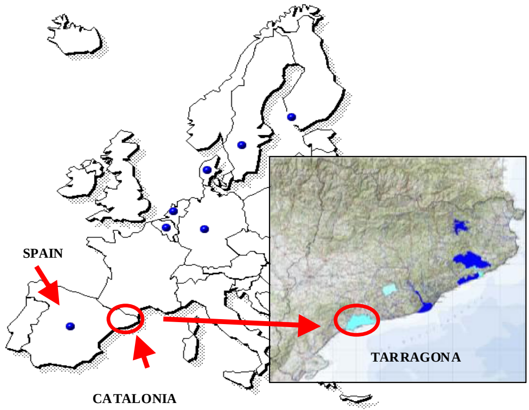

Figure 1. Situation of the Camp de Tarragona aquifers.

The model has been calibrated in flow and transport. It was initially developed with Visual Modflow (VMod) and afterwards with Feeflow due to numerical issues.

The study area is characterized by a very complex geology, which has been simplified in the model. This considers four different layers representing a porous, isotropic and homogeny medium, with a total of 86.921 are active cells, for a transient period comprised between 2000 and 2007, monthly distributed.

Boundary conditions are of three types: no flux, prescribed flux and prescribed head for the contact aquifer-sea (Fig. 2). 132 injection wells were implemented to simulate the prescribed flux. The industry and supply extractions are accounted for by means of 166 real wells with monthly series. Virtual wells were defined to represent the agricultural withdrawal; they were assigned in proportion to the irrigated surface.

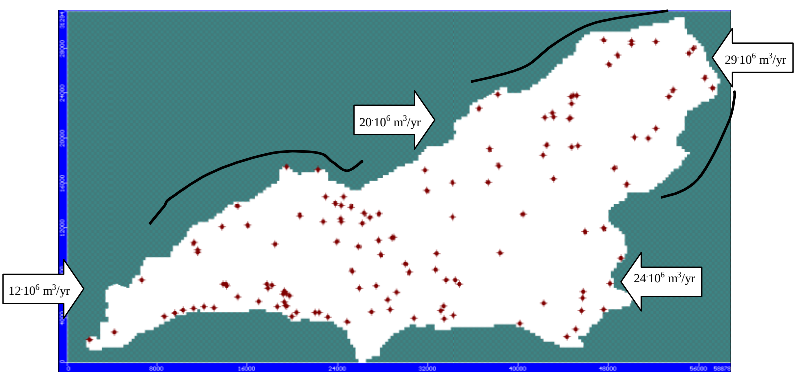

Figure 2. Contour conditions: no flux, in black line, and imposed flux, with arrows (summing up 85·106 m³/yr). The dots indicate supply and industrial wells.

GROUNDWATER PUMPING FOR IRRIGATION

One of the key issues when building-up a management-oriented groundwater numerical model is how to quantify agricultural extractions, at least in regions where it is the most important activity in the zone, as it occurs in Tarragona (Figure 2: soil uses). This determination is not simple because of the lack of enough gauging devices and a reliable wells' inventory, which demands estimating surfaces and taking into account social, economical and technical aspects.

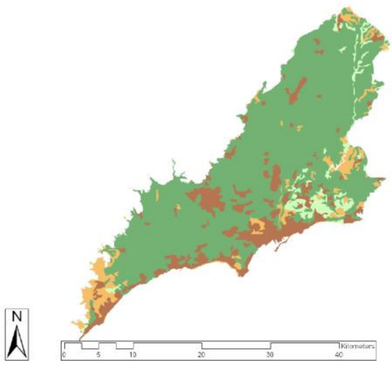

Figure 3. Soil distribution use; in green: agricultural area. (The Agency, 2009).

Pumping for crop irrigation is very important in the *Camp de Tarragona*, and may represent about 80% of total groundwater extraction on a yearly basis. This occurs because the industrial and urban supply are served preferably by surface water coming from the Ebro river transfer in a high percentile (Table 1). There is also another fraction from local surface water reservoirs, but this is a smaller amount as compared with the mains sources of water.

Table 1. Water consumption within the Camp de Tarragona region.

Origin	Irrigation ($\times 10^6$ m^3/yr)	Urban + industry ($\times 10^6$ m^3/yr)
Ebro river transfer	12	60
Groundwater	68	12
Total	80	72

Assessing groundwater withdrawal is therefore essential, and requires defining not only the total yearly amount but also its monthly distribution. Mediterranean climate is so variable that strong differences may arise between consecutive years.

The irrigations needs were estimated with the code GARCO (Agency, 2007), which considers different variables and makes use of real meteorological data, the type of crop and conventional parameters. The figure obtained per hectare and for each kind of crop was implemented in a GIS map. Figure 4 and Table 3 show the results obtained for the irrigation needs of apple trees.

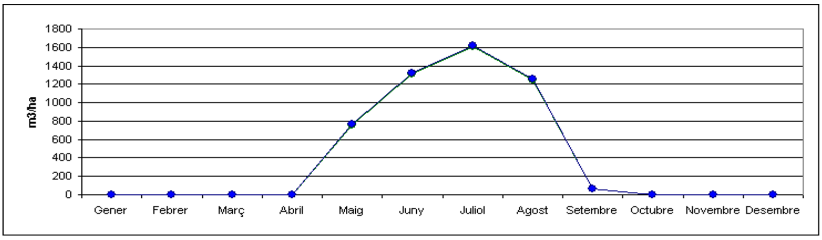

Figure 4. Mensual distribution of the extraction for the apple crop.

Table 3. Irrigation needs for apple-tree crops as obtained with GARCO in the Camp de Tarragona. Irrigation efficiency is assumed at 90%, whilst the effective precipitation is set at 70% of registered rain. The guarantee criterion is that, during 70% of the total period (on a monthly basis), the whole surface can be irrigated.

Meteorological station - MAS BOVE-CONSTANTI	
Guarantee Criteria - 70 %	
Inici: 1-1-93	Final: 31-12-07

Effective precipitation - 70 %
Apple
Irrigation efficiency- 90 %

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Averg	70 %
Jan	0	0	0	0	0	0	0	3	0	0	0	0	2	0	0	0	0
Feb	0	0	0	0	0	0	0	13	0	0	0	0	0	0	0	1	1
Mar	0	1	0	0	0	0	0	12	0	0	0	0	0	0	0	1	1
Apr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
May	657	844	961	661	920	675	427	725	881	511	514	670	641	1087	1236	761	769
Jun	1453	1529	1223	1354	781	1423	1203	750	1531	1309	1221	1469	1348	1501	1570	1311	1326
Jul	1388	1863	1672	1599	1509	1850	1405	1693	854	1750	1702	1553	1532	1857	1828	1603	1621
Aug	1055	1482	1154	1037	1236	1066	1348	1447	1641	869	1367	1309	885	1438	1310	1243	1257
Sep	56	0	66	72	124	108	1	0	0	55	135	0	0	0	338	64	64
Oct	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Des	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	4609	5719	5076	4723	4571	5122	4384	4643	4906	4494	4939	5002	4408	5882	6282	4984	5039

However, implementing the irrigation allocations obtained with GARCO for all the agricultural needs (Table 3) in the numerical model (Agency, 2010) did not yield the expected results, because it demanded lower pumping values to reproduce the measured piezometric heads. It became clear that agricultural pumping should be lower than the theoretical needs, which posed the question whether (1) the calculation method was incorrect or (2) it would be necessary to take into account additional assumptions.

As for the first topic, i.e. determining the reliability of the theoretic calculations on irrigation consumption, a comparison with a well-known real case was done: estimating the water needs of a golf playground according to GARCO's results and to pumping data registered in wells for a certain period. Both figures matched very well, thus validating the computations.

This is why the analysis focused on identifying additional factors to amend de estimations. In order to understand the observed disagreements, it was decided to organize a meeting with specialists in local agriculture. The technical staff belonging to the Agricultural Department (DAR) and the Institute of Techno-Alimentary Research (IRTA) was most helpful to clarify the points that affect on the calculation carried out initially.

The point is that farmers in Tarragona irrigate principally with groundwater, coming from deep aquifers (100 to 150 meters deep wells), which implies a cost in their activity, so they take care not to irrigate if it is not indispensable. Farmers do prefer to reduce the crop yield instead of increasing the final cost. The irrigation habits in the area consist of applying low irrigation techniques, such as water stress (which may imply not to irrigate during summer, in July and August) and of course not irrigating all the soil area that is included in the GIS maps.

Therefore, a percentile reduction had to be applied to agricultural extractions, mostly during the summer period, when the water stress approach is adopted. The final allocation of water per hectare was in the end set at 2.000 m^3/yr. This amount matches with the IRTA and DAR estimations. The values before and after considering this are presented in Table 3.

Table 3. Consumption of agriculture, calculated initially and after modifications (finally implemented).

Year	Waste of GW for agriculture ($10^6 m^3$/year)	
	Before modification	After modification (economic and social aspects)
2000	75	63
2001	69	67
2002	64	52
2003	74	62
2004	73	61
2005	70	58
2006	95	83
2007	107	95
Average	78	68

The balance results with this extraction series is shown in the Table 4. With this adjustments the model outcome matches well with the piezometric heads, so it seems that this is a satisfactory solution.

Table 4. Balance on case basis. All numbers in 10^6 m^3/yr.

	Sea inputs	Sea outputs	Lateral inputs	Extraction	Recharge	Variation
2001	0	–24	85	–85	32	8
2002	0	–26	85	–91	23	–9
2003	0	–26	85	–75	3	–13
2004	0	–29	85	–86	45	15
2005	0	–30	85	–85	50	20
2006	0	–31	85	–79	80	55
2007	0	–33	85	–105	31	–22
2008	0	–33	85	–116	29	–35

This solution is not needed everywhere, at least not within the territory of the Catalan inner basin (Eastern half of Catalonia). It depends on the local particularities, i.e. on the economic and social (also historic) aspects related to water management by the final users as concerns groundwater pumping, before implementing the right values in a model.

In parallel, the Agency is making a Water Management Plan of all Catalonia, which requires estimating the consumption of water for each activity. Issues about the reliable extractions arose in a similar way for future scenarios at a regional scale. The same concept has been applied in the Management Plan.

CONCLUSIONS

In short, quantifying groundwater pumping for irrigation purposes is essential to improve water management but it requires both a technical and a socio-economic approach, and dealing with local stakeholders, in order to obtain the expected results. This is a specially critical issue when numerical modelling is involved.

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4 | Mineral and thermal water

4.1 | Geothermal resources

abstract id: **102**

topic: **4**
Mineral and thermal water

4.1
Geothermal resources

title: **Geothermal potentialities of Morocco**

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keywords: hot water, geothermal resources, Morocco

Morocco counts more than 10 hot aquifers and 50 thermal springs whose emergence temperature varies between 30 and 54°C. Therefore these important hot springs and reservoirs revealed by hydrogeologic and oil wells place the country as promising target in geothermal energy and thermal waters.

Geodynamic studies linked the zones showing geothermal gradient and heat flow exceeding 50°C/Km and 100 mW/m^2 respectively, to Neogene–Quaternary volcanic and neotectonic activities. However these thermal phenomena are still not developed and their exploitation limited to drinkable water distribution or to balneotherapy "ancient Hamam".

The Moroccan subsoil has potentialities in geothermal energy still unexploited. The most promising zones are North-Eastern Morocco and the sedimentary basins of the Sahara. Many warm water reservoirs place Morocco as country where average to high geothermal enthalpy could be used in several specific applications, but geothermics is still not enough developed and the interest to this energy source was up to now negligible in comparison to other renewable sources.

abstract id: **107**

topic: **4**
Mineral and thermal water

4.1
Geothermal resources

title: **Western extension of the Himalayan geothermal belt**

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keywords: hydrochemistry, hot springs, reservoir temperatures

INTRODUCTION AND TECTONIC SETTING

The Himalayan Geothermal Belt (HGB) was first defined by Tong and Zhang (1981). It has been described as a 3000 km long belt with at least 600 hot and warm springs, stretching from the Pamir terrain through Tibet into Yunnan (Hochstein and Regenauer-Lieb, 1998). Hochstein and Yang (1995) described the main characteristic features of the geothermal systems and the magnitude of heat transfer by fluids within the central and eastern parts of the HGB (Figure 1).

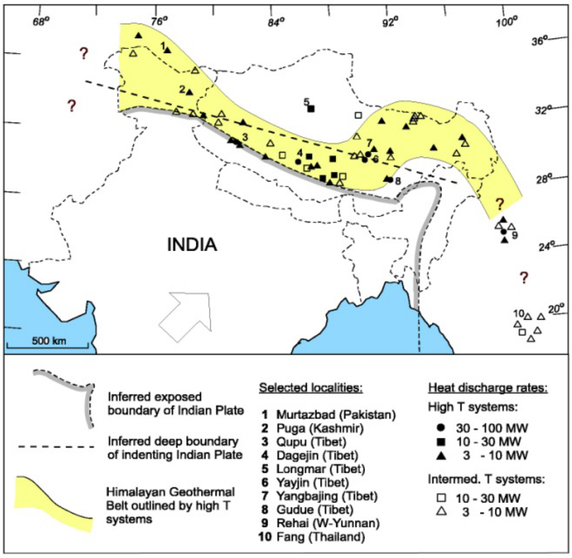

Figure 1. The Himalayan Geothermal Belt (modified from Hochstein and Yang 1995).

The Himalaya is commonly divided into four tectonic provinces that can be followed for at least 2400 km along almost the entire orogenic belt (Figure 2):

1. The Himalayan Foreland (composed of the Muree and Siwalik Formations of Miocene to Pleistocene molassic sediments, products of the erosion of the Himalaya). The foreland formations are thrust over the Quaternary alluvium along the Main Frontal Thrust (MFT).

2. The Lesser Himalaya (composed mainly of Precambrian detrital sediments and some granites and acid volcanics) thrust over the Subhimalaya along the Main Boundary Thrust (MBT). The Lesser Himalaya often appears in tectonic windows.

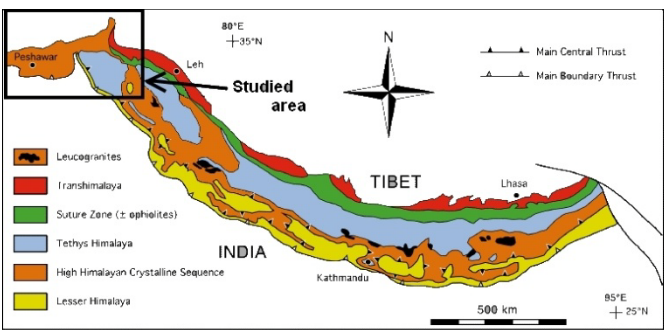

Figure 2. The Himalayan tectonic provinces (after Le Fort, 1988).

3. The High Himalaya encompassing the areas with the highest topographic relief is commonly separated into four zones:

- The High Himalayan Crystalline Sequence (HHCS), a major 30 km thick nappe of mostly Proterozoic to early Paleozoic medium- to high-grade metamorphic sequence of metasediments thrust over the Lesser Himalaya along the Main Central Thrust (MCT); the HHCS is in places intruded by granites of Ordovician and early Miocene.
- The Tethys Himalaya (TH) consist of ca 100 km wide synclinorium of weakly metamorphosed, intensely folded and imbricated sedimentary formations of almost complete Paleozoic and Mesozoic sequence.
- The Nyimaling-Tso Morari Metamorphic Dome, NTMD formed of greenschist and eclogitic metamorphic rocks as the northern extension of the TH in the Ladakh region.
- The flysch and turbiditic Lamayuru and Markha (LMU) Late permian to Eocene formations of the northern continental slope of the Indian Plate.

4. The Indus Suture Zone (ISZ) is the actual zone of collision between the Indian Plate and the Transhimalaya Karakoram-Lhasa Block. It represents the northern limit of the Himalaya. The Transhimalaya Karakoram-Lhasa Block is the South-Eurasian active continental margin of the Andean type volcanic arc.

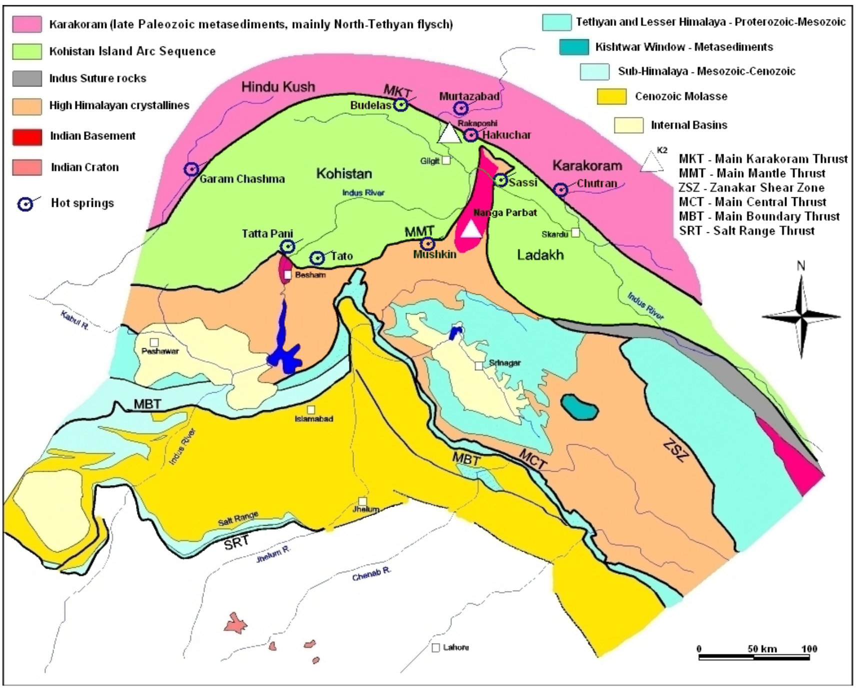

Figure 3. Geology of Western Himalaya (adapted from Edwards et al. 1997).

WESTERN EXTENSION OF THE HGB

Geothermal manifestations at the west end of the HGB are limited to hot springs (Figure 3) associated exclusively with the still active Main Karakoram Thrust (MKT) and the Main Mantle

Thrust (MMT). The MKT separates the Paleozoic metasediments, consisting of turbidities and flysch of the early Tethyan geosynclinorium (Hindukush and Karakoram) in the north, from the Kohistan Island Arc constructed on the ocean floor during late Jurassic and Cretaceous times. The MMT separates the Kohistan Island Arc formation from the HHCS granitoids, divided into peraluminous collisional granites of Proterozoic, Pan-African and Palaeozoic periods and Himalayan alkaline granites of Carboniferous-Triassic extensional regime (Syed Shahid Hussain, 2005).

Although overthrust faults are usually tightly sealed with cataclastic or mylonitized breccias such as the MMT (Dipietro et al., 2000; Singh, 2003), thus rendering them impervious to groundwater flow, yet unquestionably the two overthrusts serve as a conduit to the ascending thermal water. Yousafzai et al. (2008) concluded that the topography-driven pressure along these faults from the highest ridges to the north of the study area may attain a maximum of 25 MPa as compared to the tectonic stress of 90 MPa computed by Lisa et al. (1997). Thus, it would seem that the overall tectonic pressure within the basin is high enough to overcome this obstacle. Indeed, Yousafzai et al. (2008) have demonstrated in their numerical model for ground water flow in the area an existence of excess pressure head along the two fault-lines commensurate with the elastic response to the tectonic stress of 90 MPa. Moreover, a substantial amount of heat is presumably generated by frictional movement along these faults (Todaka et al., 1988).

The Nanga Parbat Haramosh Massif

During the last 10 m.y., the Nanga Parbat Haramosh Massif in the northwestern Himalaya (Figure 3) has been intruded by granitic magmas, has undergone high-grade metamorphism and anatexis, and has been rapidly uplifted and denuded. Chamberlain et al. (1995, 2002) suggested on the basis of their isotopic studies that the rapid uplift of the massif created a dual hydrothermal system, consisting of a near-surface flow system dominated by meteoric water circulating through shear zones and a system of faults and fractures within the upper 5–6 km of the crust, while the deeper brittle/ductile hydrothermal system consists of unconnected magmatic/metamorphic volatiles/fluid inclusions. Craw et al. (1997) concluded that the geothermal system within the upper 5-6 km can be further divided into deep liquid-dominated zone following a boiling-point relationship down to 3 km, overlaying a deeper zone of dry steam with fluid densities from 0.36 to as low as 0.07 g/cm^3.

Water-dominated systems

Manzoor et al. (2005) determined that the thermal waters of the Northern Pakistan originate from the meteoric recharge. They have in general low concentrations of dissolved solids and are neutral to slightly alkaline, usually dominated by Na-HCO_3. They found the Murtazabad Hot Springs yielding "mixed waters" with equilibrium temperature of the thermal end-member is in the range 185°C–225°C. However, the equilibrium temperature range indicated by the $\delta^{18}O(SO_4\text{-}H_2O)$ geothermometer is 130°C–185°C. Narrower ranges were found for the springs of Tatta Pani, where the equilibrium temperatures determined by the Na-K, K-Mg and quartz geothermometers yield reservoir temperatures in the range 100°C–130°C, and the $\delta^{18}O(SO_4\text{-}H_2O)$ geothermometer indicates equilibrium temperatures around 150°C. Somewhat higher reservoir temperatures were obtained for Tato Springs where the silica and cation geothermometers suggested equilibrium temperatures in the range of 175°C–200°C, while the $\delta^{18}O(SO_4-H_2O)$ geothermometer indicated equilibrium temperatures of 170°C.

Yousafzai et al. (2010) investigated chemical composition of water sampled from Garam Chashma Hot Springs and about 70 ground water wells located between SRT in the south and beyond MKT in the north. They found that large number of the groundwater wells and springs located in proximity of the MMT and MKT yielded water at a significantly elevated temperature over the local mean annual air temperature. While Garam Chashma is renown for discharging water at the "balmy" 67°C, many water wells used for either irrigation or domestic use yielded ground water with the temperatures in excess of at least 6°C over the local mean annual air temperature. They found a significant correlation between that temperature excess and several hydrochemical anomalies, notably elevated silica, boron and strontium concentrations for the sampled springs and water wells. They concluded that the thermal and hydrochemical anomalies result from admixture of the deep thermal water along the faultlines and entering into the shallow aquifer taped by the water wells. They demonstrated such mixing systems using Piper (1944) trilinear diagrams. Yousafzai et al. (2010) estimated the source reservoir temperature using silica and various cation geothermometers obtaining widely ranging temperatures. However, by assumming the mixing system indicated by several bivariate chemical concentration and orifice temperatures they narrowed down the range of 116°C–155°C. Also, the reservoir temperature calculated using Mg-Li falls within this range.

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abstract id: **203**

topic: **4**
Mineral and thermal water

4.1
Geothermal resources

title: **Criteria for the definition of the protection areas in the Viterbo hydrothermal area (Central Italy)**

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keywords: thermal water, protection areas, volcanic aquifer, central Italy

The definition of the protection areas of thermal springs and wells is a recurring problem, which is locally approached depending on the specific complexity of the hydrogeological conceptual model. Unlike the wide literature concerning the protection areas of drinking water, a lack of specific criteria for the hydrothermal areas results. In some cases, the drinking water criteria have been applied to the thermal springs and wells. It should be noted that the methods used for the protection areas of drinking water mainly consider the horizontal component of flow in the saturated aquifer and pollutants coming from the ground; moreover specific quality standards must be attained. Therefore these methods are hardly applied to the hydrothermal resource, if one considers the special chemical characteristics of the thermal waters, the vertical component of fluid circulation and the possible interactions among overlapped aquifers.

This study examines the delineation of the protection areas of the thermal waters in the Viterbo area (central Italy) tapped either directly at the springs or in wells and used primarily for the supply of thermal spas and pools for public use. In this area hot waters (30–60°C) of the sulphate-alkaline-earthy type, result of deep circulation, co-exist with fresh water circulating in the shallow volcanic aquifer. A suitable method was developed to define the protection areas based on the hydrogeological model, optimisation of the use of the hydrothermal resource, and considering the conjunctive use of the shallow aquifer for drinking and irrigation purposes. The historical, cultural and environmental values of the area were taken into account as well.

The plan was focused on the safeguard of the quality and quantity of the hydrothermal resource and interacting groundwater of the shallow volcanic aquifer. The hydrogeological equilibrium between the thermal aquifer and shallow volcanic aquifer, the impact of the withdrawals from the thermal aquifer and the economic importance of the spas were considered. At the same time the maintenance of the withdrawals from the shallow volcanic aquifer supplying drinking water and irrigation were taken into account. The different uses of groundwater often clash each other.

Three protection areas with different restraints were determined (Fig. 1): an immediate protection zone of the thermal springs and wells (ZT), an intermediate protection zone (ZPI) and a distant protection zone (ZPII); ZPI and ZPII zones are indispensable for the hydrogeological and environmental safeguard of the hydrothermal area.

The ZT immediate protection zone covers restricted areas near the springs and flowing wells of thermal waters. This is the consequence of the fact that the thermal waters are naturally protected to pollution from ground due to the vertical hydraulic gradient existing between the overlapped aquifers.

The ZPI intermediate protection zone includes all areas surrounding the ZT zone. This zone has been identified considering: i) the present and past locations of the thermal springs, ii) the outcrops of travertine, and iii) the areas of the shallow volcanic aquifer in which mixing between the thermal and fresh waters were found. Restraints and appropriate land use have been set for the ZPI zone to safeguard quality and quantity of the hydrothermal resource.

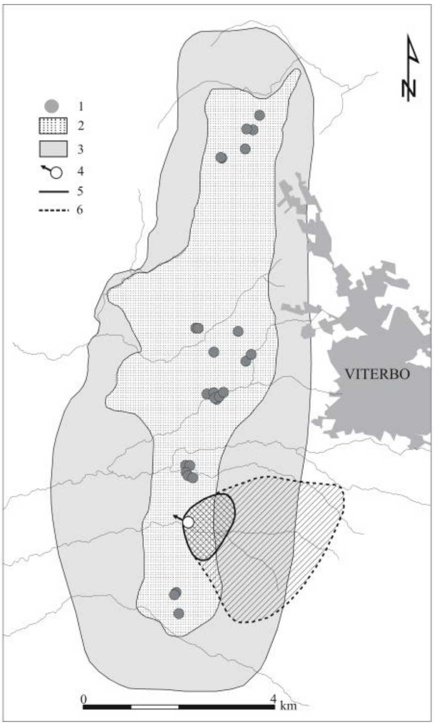

Figure 1. Protection zones of the hydrothermal area of Viterbo: 1) thermal spring and well, and ZT immediate protection zone (not to scale); 2) ZPI intermediate protection zone; 3) ZPII distant protection zone; 4) drinking water spring; 5) 90-day isochrone for drinking water spring; 6) 365-day isochrone for drinking water spring.

The ZPII distant protection zone has been determined considering the hydrostratigraphy and structural setting, and the heat flow map. In this zone it is important a control of the withdrawals from the shallow volcanic aquifer, based on its recharge rate and hydraulic characteristics, in view of a correct usage of groundwater with different qualities.

abstract id: **215**

topic: **4**
Mineral and thermal water

4.1
Geothermal resources

title: **3D-seismics to detect preferential groundwater pathways and reservoirs in the deep buried geothermal carbonatic upper Jurassic aquifer in Greater Munich (South Germany)**

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keywords: hydrogeothermal energy, carbonate rocks, 3D-seismics, hydrogeological model, Germany

INTRODUCTION

The carbonatic Malm aquifer of the South German Molasse Basin represents the biggest hydrogeothermal reservoir in Germany. The first doublet system (array of extraction and injection wells) for heat production was implemented in Greater Munich in 2003. Seven doublet systems are in use and five other doublets and one triplet are under construction presently. To support the sustainable operation of the power plants for heat and electricity production the potential hydraulic and thermal interaction of several doublets is the object of investigation in the project "Geothermal characterization of karstic-fractured aquifers in Greater Munich" (South Germany) under the leadership of the LIAG (Leibniz Institute for Applied Geophysics) and the LfU (Bavarian State Office for the Environment).

STUDY AREA — GEOLOGY

In the greater area of the Bavarian capital Munich the upper Jurassic strata is outcropping in the North (Swabian-Franconian Alb) and in general dipping gently to the south-east to about 5000 m depth south of Munich according to the general downbending of the European crust towards the Alps (Fig. 1).

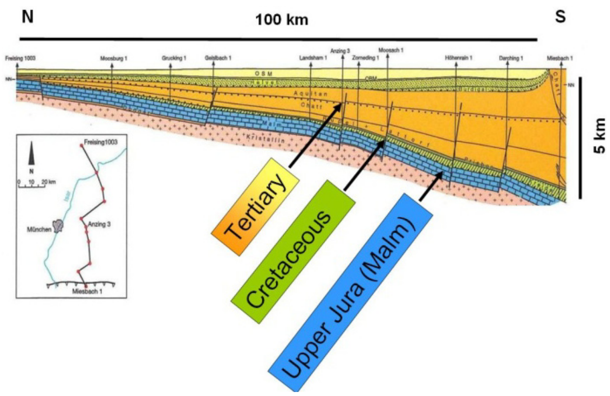

Figure 1. Downbending of the European crust towards the Alps (source: Bayerisches Staatsministerium für Wirtschaft, Infrastruktur, Verkehr und Technologie, 2010, after Lemcke 1988).

In the upper Jura a vast carbonate platform with sponge reefs mainly distributed in the Malm delta and some coral reefs in the uppermost Jurassic strata stretched out over the study area. Diagenesis has lead to the formation of dolomites and dedolomites, which represents nowadays zones with higher secondary porosities. Main fault zones penetrating Jurassic and Tertiary strata are E-W and NE-SW striking syn- and antithetic normal faults with throws of more than 200 m (Fig. 2).

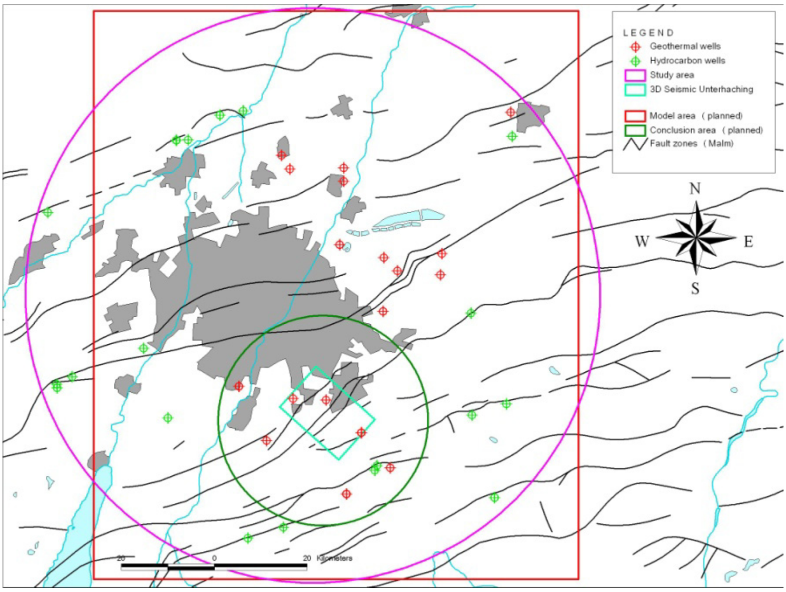

Figure 2. Greater Munich (study area).

As an analogue to the Danube rupture at the Northern border of the Molasse Basin, main tectonic structures strike 60-70° N ("swabian") and 45° ("erzgebirgisch").

HYDROGEOLOGY

In the study area well productivity of the deep buried and confined Jurassic aquifer is high. Transmissivities in a range between 0,1 to > 3000 m^2/day reflect the heterogeneity of the carbonatic aquifer. In general, and sometimes after massive acidification the doublets have production rates up to 150 l/s. Whereas the permeability of the Malm is slightly decreasing towards the south and as supposed by many authors, also the degree of carstification, temperatures are rising because of the greater depth (Fig. 3).

Inflow zones, derived from flowmeter measurements, zones of total loss of drilling fluid or geophysical borehole measurements (Temp log, FMI, etc.), vary in depth related to Top Malm from well to well. In a broader view over the Molasse Basin some wells indicate 2 or 3 zones of potential inflow associated with carstification: A carstified zone at Top Malm, sometimes showing total loss of drilling fluid, sometimes with collapse structures like dolines and two carstification levels in depths of ca. 100 m and ca. 250–300m beneath Top Malm. Except one well in the study area groundwater composition indicates a connected groundwater body. Regional groundwater flow is directed in the northern Greater Munich from Northwest to Southeast, whereas in the south eastern part they are very difficult to explain. Recharge for the deep buried upper jurassic limestones lie in regions North and west of Munich with a long travel time and low flow velocities, indicated by interpretation of the stable isotopic composition (ages of more than 10.000 years).

TEMPERATURES

Temperatures are rising from about 70°C in the north with increasing depth to 150° to the SE, in general according to the dip of the jurassic dolo- and limestones (Fig. 3).

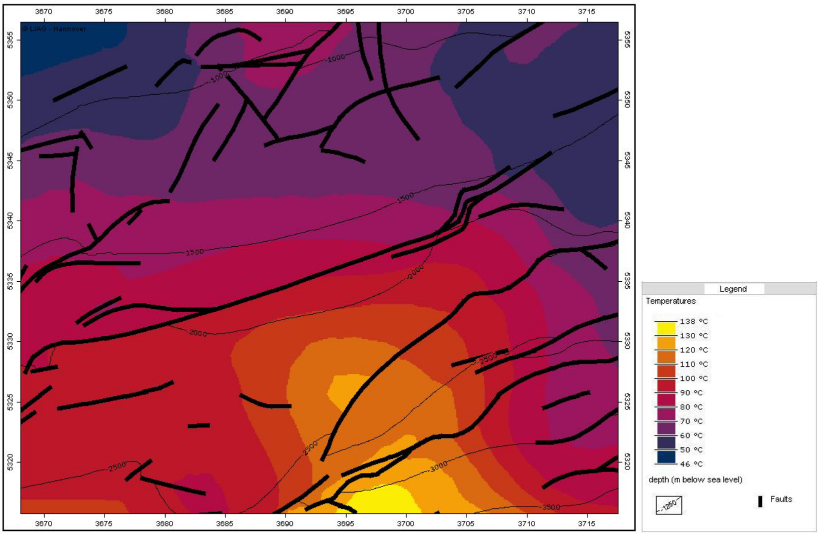

Figure 3. Temperature distribution TOP Malm. Isolines showing m bsl. (LIAG, 2009).

Temperature anomalies in the region are supposed to have their origin in convective heat transport linked to fault zones.

3D SEISMICS

In a first step a 3D-seismic survey was carried out in the central investigation area "Unterhaching" (5×5 km, see Fig. 2 and 4).

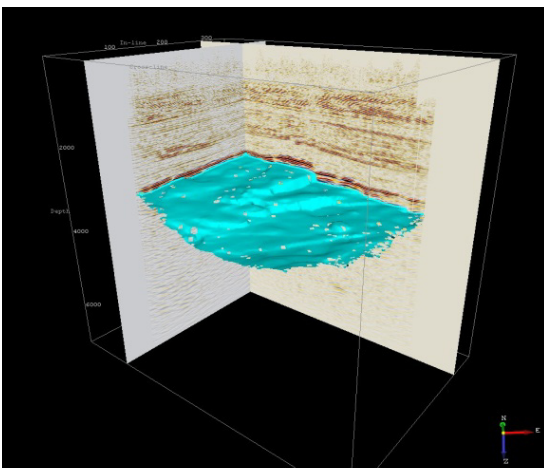

Figure 4. 3D-Cubus of the 3D Seismic research area "Unterhaching" (blue: Top Malm horizon with main fault zones).

Collapse structures with round appearance are often seen on coherency depth slices in the Malm (Fig. 5). Crossing points of different faults with different water hydrochemistry might be the reason because of the effect of mixing corrosion in carbonates. On the other hand, in the regional strike-slip framework north of the Alps, pull-apart-basins could also be a possible geometrical initial process to enhance karstification. An overlay of amplitudes and coherency directly underneath one collapse structure show a nearly vertical anomaly (Fig. 6, black arrow is pointing to the collapse structure seen in Fig. 5). In general faults and layering/facies differentiation could be displayed very well with an overlay of the amplitude section and coherency attribute.

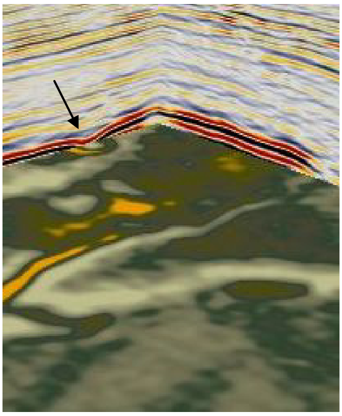

Figure 5. Subset of 3D cube with potential sinkhole (collapse structure, diameter ca. 50 m), view from south, inline 301, crossline 163, depthslice 2466 m below sea level).

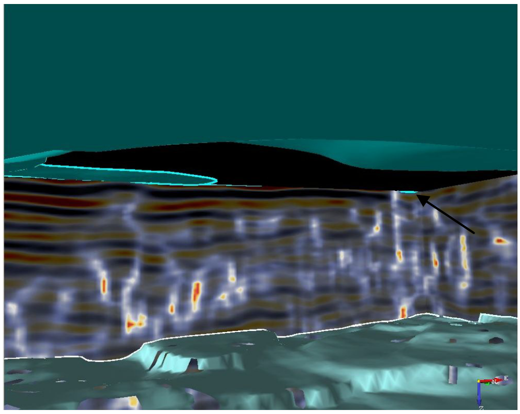

Figure 6. Subset of 3D cube, view on potential sinkhole (arrow, see fig. 5) from below, blue horizons: Top and bottom Malm, amplitude overlayed by coherency attribute).

CONCLUSION — FORECAST

It turned out to be that 3D-seismics is a very useful tool to characterize potential water-bearing fracture zones and facies, which are supposed to control the hydraulic behaviour and even the process of karstification. The high resolution of tectonic structures provided by the 3D-seismic model will be linked to the coarser 3D-model for greater munich, which was derived from 2D seismic profiles.

Studies of the tectonic evolution indicate that the present stress field of the region might be related with the newly registered micro-seismicitiy encountered since February 2008 SE of Munich.

Today, seven geothermal power plants in Greater Munich are producing ca. 65 MW geothermal energy and thus contribute ecologically to the energy consumption of the area. In order to get deeper insights to flow and transport mechanisms in the carbonatic aquifer detailed processing of the seismic data at the LIAG in combination with borehole logs and hydraulic tests will lead to a better understanding of the fractured and karstified carbonatic series. This will cumulate in a hydrogeological model (HGM) for Greater Munich. Finally, based on the HGM a numerical thermo-hydraulic model will be applied to simulate the interaction between neighbouring doublets.

ACKNOWLEDGEMENTS

The project "Geothermal characterization of karstic-fractured aquifers in Greater Munich" is financed by the BMU (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety of Germany).

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abstract id: **227**

topic: **4**
Mineral and thermal water

4.1
Geothermal resources

title: **Hydrothermal model of the Euganean Geothermal Field (EGF) — NE Italy**

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keywords: hydrothermal modelling, Hydrotherm, Euganean geothermal field, low-enthalpy thermal field

INTRODUCTION

The Euganean geothermal field (EGF) is the most important thermal field in the northern Italy. It is located in the Veneto alluvial plain, southwest of Padova (NE Italy). The EGF extends on a plain band of 36 km^2 located immediately northeast of the Euganei Hills. In this area about 100 mining claims and more than 400 wells have been drilled. Thermal waters are mainly used for cure and wellness, with a subsidiary use as energy to heat hotels and greenhouses. At present about 250 wells are active and the total average flow rate of thermal fluids is about 17 Mm^3/year. The aim of this study is to reconstruct the structural constraints driving the thermal waters flow and to apply a mathematical groundwater flow and heat transport simulation model.

THE CONCEPTUAL MODEL OF EGF

In 1976, Piccoli et al. proposed a conceptual model for the hydrothermal circuit of the Euganean thermal waters based on field observations and chemical analyses of the hot waters, later improved by Gherardi et al. (2000) (Fig. 1). The thermal groundwaters are of meteoric origin and infiltrate at about 1500 m a.s.l. in the Pre–Alps, 70 km to the north of the Euganei Hills. The waters reach a depth of about 3000 m and warm up by a normal geothermal gradient, flowing into a fractured carbonate reservoir. Near the Euganei Hills, the waters intercept a regional fault system (Schio–Vicenza fault system) that act as a barrier for the groundwater flow. The high fracturing of the rocks in this area allows the hydrothermal fluid to rise quickly.

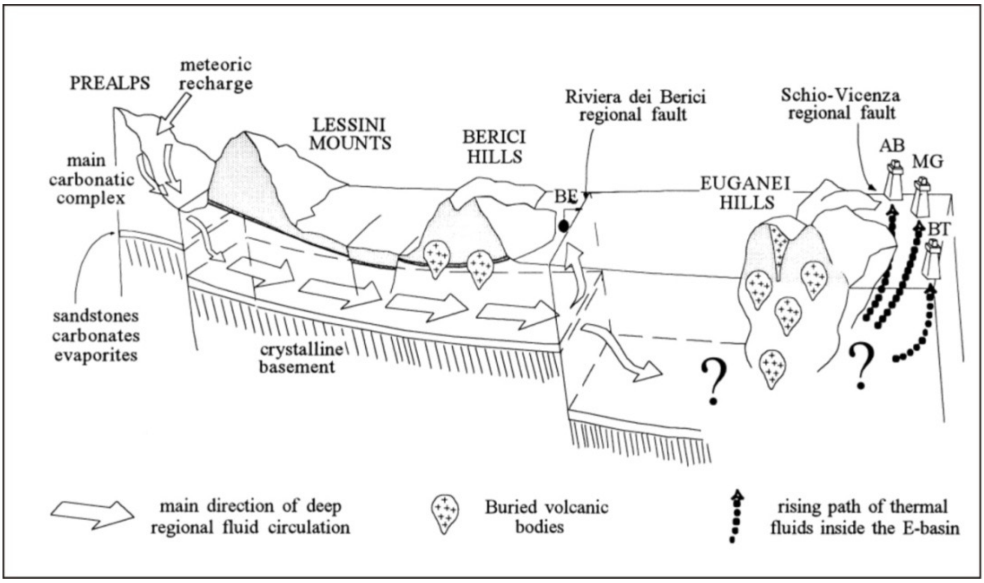

Figure 1. Hydrogeological model of the hydrothermal circulation in the Euganean area (from Gherardi et al., 2000). The outflow may be controlled by a local extensional zone developed at a bend of the Schio-Vicenza fault.

Physical and chemical parameters of the EGF were statistically analyzed by Fabbri and Trevisani (2005). The temperature of thermal waters ranges from 60°C to 86°C, and their TDS is approximately 6 g/L with a primary presence of Cl and Na (70%) and secondary of SO_4, Ca, Mg,

HCO_3, SiO_2. Tritium and ^{14}C AMS measurements suggest a residence time of much more than 60 years, probably in the order of some thousand years.

Recently, Zampieri et al. (2009) propose that the EGF is located near an extensional geological structure linked to the Schio–Vicenza fault system. The local extensional regime, caused by the structure, and the recent activity of the fault system enhance the outflow of the thermal fluid. Evidence of this structure is given by some seismic sections, that we use as starting point for the subsurface geological reconstruction of EGF using 3D modelling techniques.

We use the software Hydrotherm (Kipp et al., 2008) to perform a starting mathematical hydrothermal model of the EGF. Hydrotherm simulates thermal energy transport in three-dimensional, two-phase, hydrothermal, ground-water flow systems. The governing partial differential equations, which are solved numerically, are (1) the water-component flow equation, (2) the thermal-energy transport equation. Finite-difference techniques are used for the spatial and temporal discretization of the equations.

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abstract id: **375**

topic: **4**
Mineral and thermal water

4.1
Geothermal resources

title: **Reactive transport simulations of geochemical processes induced by the ATES operations in the Dogger aquifer (Paris Basin)**

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keywords: heat storage, geochemical modelling

ABSTRACT

A project of Aquifer Thermal Energy Storage (ATES) in the deep carbonate Dogger aquifer in the Paris Basin (France) is under development. Before effective ATES operations, this study aims to identify the geochemical impacts of a cycle of heat storage and production on the properties of the aquifer and of the geothermal fluid.

A geochemical study using scenarios of different temperature perturbations is built up in three stages of complexity using reactive transport codes PHREEQC and MARTHE-REACT. The simulation results show potential occurrences of precipitation/dissolution processes that could damage the reservoir porosity and the ATES equipments. This study was done within the framework of the "GEOSTOCAL" Project co-funded by the French National Research Agency (ANR) of the call for proposals "Stock-E".

BACKGROUND

Aquifer Thermal Energy Storage (ATES) offers a promising solution to store excess energy into the ground when available for later use when needed. A previous study revealed that Ivry-sur-Seine (Ile-de-France, France) has attractive potential for an ATES technology: an excess of heat production in summer, a relevant heat networks adapted to the winter demand and a suitable aquifer (Dogger aquifer, 1500 m deep)
(http://www.colloques-2009-anr.fr/pdf/2/STOCKE_3_GEOSTOCAL_poster.pdf).

The excess energy and the use of the stored energy are managed by the district heating network of CPCU (Compagnie Parisienne de Chauffage Urbain). The heat vehicle used in the geothermal loop is the aquifer native water. Due to the temperature variation (between 40 to 95-110°C) the consequences of the disturbance of the initial thermodynamic equilibrium between reservoir phases (water - rock) could be dramatic if they lead to reservoir porosity decrease or damaging the storage equipments (clogging/corrosion of well casings, etc.). The study of detailed geochemical processes aims to identify the geochemical reactivity changes of carbonate reservoir submitted to a cycle of ATES exploitation. This step is crucial to evaluate the scaling risks to be considered and integrated in the development of the management strategies of the system.

SITE DESCRIPTION AND ATES OPERATIONAL DETAILS

The proposed storage site is located within the city of Ivry-sur-Seine (Ile-de-France, France); near an abandoned low enthalpy geothermal doublet. The targeted aquifer is the oolithic limestones of the Dogger reservoir which are situated approximatively 1500 m depth. Its main physical and petrophysical characteristics, derived from drilling reports of the abandoned geothermal doublet, are listed in Table 1.

Table 1. Physical and petrophysical properties of the oolithic limestones aquifer.

Depth	~ 1470	m (vertical)
Productive thickness	10	m (vertical)
Temperature	65	°C
Porosity	15	%
Intrinsic permeability	3.5	D
Formation heat conductivity	2.5	W/m/K
Wall heat conductivity	2	W/m/K
Longitudinal thermal dispersivity	20	m
Transverse thermal dispersivity	10	m
Salinity	18.5	g/L
Reservoir pressure	~ 160	kg/cm^2

No cutting sample is available within or close to the storage area. Therefore, the mineralogy used for the modelling (Table 2) is based on the literature (Rojaz et al., 1989 and Azaroual et al., 1997). It consists mainly of carbonates (80% in mass fraction) with some silicates. Minerals allowed to precipitate as secondary phases during the ATES operations are also introduced (with a mass fraction as 0).

Table 2. Oolihic limestones mineralogy and minerals allowed to precipitate in the reservoir during the ATES operations.

	Mass percent	**Minerals introduced in the model**		**Mass percent**	**Minerals introduced in the model**
Calcite	70	Calcite	**Anhydrite**	0	Anhydrite
Disordered dolomite	10	Dolomite-dis	**Chalcedony**	0	Chalcedony
Quartz	5	Quartz,alpha	**Magnesite**	0	Magnesite (Natur)
Albite	5	Albite_low	**Gibbsite**	0	Gibbsite
K-Feldspar	5	Microcline	**Kaolinite**	0	Kaolinite
Barite	5	Barite	**Illite**	0	Illite-Al
			Smectite	0	BeidelliteNa

In contrast, several samples of the formation water were taken during the geothermal exploitation of the doublet. Thus, the water sample collected in the geothermal production well (GIV2) for the Rojaz et al. (1989) study is selected as a representative for the oolithic limestones reservoir. However, in order to overcome the unreliability of the aluminium concentrations data, this water is equilibrated with albite (one of the supposed Dogger mineral) by means of geochemical software (*i.e.* PHREEQC). The physical chemical characteristics of the native fluids used for the modelling are given in Table 3.

Table 3. Initial composition of the formation water.

T (°C)	65	**Cl**	3.04E-01
pH *in situ*	6.29	**K**	2.35E-03
Alcalinité	5.68E-03	**Li**	2.79E-04
Al	3.91E-08	**Mg**	8.26E-03
B	1.24E-03	**Mn**	1.86E-05
Ba	1.41E-06	**Na**	2.60E-01
Br	8.18E-04	**S**	8.71E-03
C	8.97E-03	**Si**	5.76E-04
Ca	2.38E-02	**Sr**	4.87E-04

The considered ATES technology operates through two artificial heat sources, a "cold bubble" and a "hot bubble", generated and regenerated in the Dogger aquifer using geothermal wells. During the heat storage phase (summer season), water is extracted from the cold area, warmed by transfer of excess energy from an incinerator plant (heat exchanger) and finally re-injected into the warm storage area (Figure 1). Then, during the winter season (heat exploitation phase), the hot water is extracted, transferred in the heat exchanger to supply the district heating network. To close the geothermal loop, the cooled water down is finally re-injected into the cold storage area.

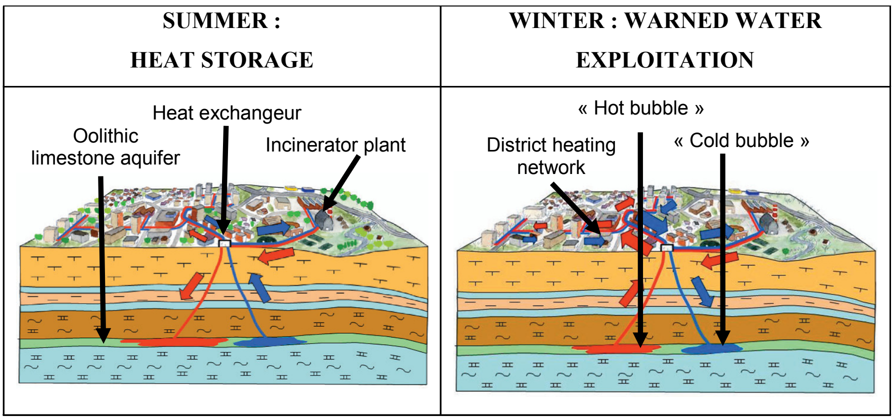

Figure 1. Sketch of the ATES technology examined (courtesy of IFP).

MODELLING APPROACH

The carried out modelling method involves three stages of analysis: (1) equilibrium batch modelling; (2) kinetic batch modelling and (3) a 1D reactive transport model integrating thermo-kinetic processes of mineral dissolution/precipitation reaction. The three approaches focus on the geochemical changes occurring both in the wells and in the "bubbles". The modelling is performed using the database Thermoddem (Blanc et al., 2009) and the numerical codes PHREEQC (Parkurst, Appelo, 1999) for the two first stages and MARTHE-REACT for the last stage.

Two scenarios are used in each of the stages. Both concern the first geothermal loop of the ATES operations and differ by the heat storage temperature (Table 4).

Table 4. Operational details of the two scenarios tested differing by the heat storage temperature (95 or 110°C).

	Heat storage phase (summer season)	Warmed water exploitation phase (winter season)	Units
Duration	17	31	week
Flow rate	300	165	m^3/h
Temperature	95 / 110	40	°C

In the stages two and three, kinetic rate laws of the following form (equation (1) are used for mineral dissolution and precipitation (Palandri and Kharaka, 2004):

$$r_n = \pm m_n k_n A_n \left|1 - \Omega_n^{\theta}\right|^{\eta} \quad (1)$$

Parameters *m*, *k* and *A* are the instantaneous mass of mineral *n* (in mol), the rate constant (in mol/m²/S) and the reactive surface area (in m²/mol), respectively. *Ωn* represents the saturation index of the mineral *n* (Ωn = Q/K). *θ* and *η* are two empirical positive parameters assumed equal to 1 (Palandri and Kharaka, 2004).

Dependency of k_n with temperature and pH is given by:

$$k_n = k_{25}^{N} \exp\left[\frac{-Ea^{N}}{R}\left(\frac{1}{T} - \frac{1}{298.15}\right)\right] + k_{25}^{A} \exp\left[\frac{-Ea^{A}}{R}\left(\frac{1}{T} - \frac{1}{298.15}\right)\right] a_H^{n_A} + k_{25}^{B} \exp\left[\frac{-Ea^{B}}{R}\left(\frac{1}{T} - \frac{1}{298.15}\right)\right] a_H^{n_B} \quad (2)$$

where E_a is the activation energy (in J/mol), k_{25} is the rate constant at 25°C, *R* is the gas constant (8.314 J/mol/K), *T* is the temperature (in K) and a_H is the activity of H^+. The indices *N*, *A* and *B* refer to neutral, acid and alkali mechanisms, respectively.

Precipitation rate laws only consider the neutral mechanism.

The parameters of the precipitation kinetics are assumed equal to the parameters of the dissolution kinetics. Moreover, the precipitation of feldspar (albite and K-feldspar) and then of quartz are inhibited in favour of the precipitation of clays and chalcedony respectively.

The values of the kinetic parameters (Table 5) and the reactive surface areas used for the modelling come from the literature.

Table 5. Kinetic parameters used for the modelling. The mechanisms for which the values are in grey are negligible at the pH conditions simulated. Thus, they are not considered in the simulations.

	Acid Mechanism			Neutral Mechanism		Carbonate Mechanism		
	log k25 [mol/m²/s]	Ea [kJ/mol]	n [-]	log k25 [mol/m²/s]	Ea [kJ/mol]	log k25 [mol/m²/s]	Ea [kJ/mol]	n [-]
Calcite	-0.30	14.40	1.000	-5.81	23.50	-3.48	35.40	1.000
Disordered dolomite	-3.19	36.10	0.500	-7.53	52.20	-5.11	34.80	0.500
Quartz	–	–	–	-13.99	87.60	–	–	–
Albite	-10.16	65.00	0.457	-12.56	69.80	-15.60	71.00	-0.572
K-Feldspar	-10.06	51.70	0.500	-12.41	38.00	-21.20	94.10	-0.823
Barite	-6.90	30.80	0.220	-7.90	30.80	–	–	–
Anhydrite	–	–	–	-3.19	14.30	–	–	–
Chalcedony (as quartz)	–	–	–	-13.99	87.60	–	–	–
Magnesite	-6.38	14.40	1.000	-9.34	23.50	-5.22	62.80	1.000
Gibbsite	-7.65	47.50	0.992	-11.50	61.20	-16.65	80.10	-0.784
Kaolinite	-11.31	65.90	0.777	-13.18	22.20	-17.05	17.90	-0.472
Illite	-11.71	46.00	0.600	-15.05	14.00	-12.31	67.00	0.600
Beidellite (Smectite)	-10.98	23.60	0.340	-12.78	35.00	-16.52	58.90	-0.400

RESULTS AND DISCUSSION

The equilibrium batch modelling highlights that the ATES operations may induce clogging problems due to the following trend:

- Calcite and calcium sulfate tend to precipitate when the fluid is heated and dissolved when the fluid is cooled down. Thus, these minerals may precipitate before and after injection of the fluid in the “hot bubble” and dissolve in the “cold bubble”.
- Chalcedony, gibbsite and clays (kaolinite, illite and smectite) may precipitate when the fluid reaches a temperature of 40-50° C. These minerals are likely to precipitate before and after injection into the “cold bubble”.

The second step of the modelling involves kinetic reactions in contrast to previous equilibrium batch models. Results of the kinetic batch modelling are summed up in Table 6 and in Table 7. These tables present the consequences of the ATES operations on the wells and on the “bubbles” (near wellbore) in terms of precipitation or dissolution risk which is illustrated by the amount of mineral that could precipitate or dissolve.

Table 6. Processes of precipitation and dissolution involved during the heat storage phase.

<table>
<tr><th rowspan="2"></th><th colspan="2">Amount (order of magnitude) precipitated or dissolved in moles/kgw</th><th colspan="2">Risk: precipitation (+) dissolution (-) none (0)</th></tr>
<tr><th>Hot well</th><th>Hot bubble</th><th></th><th></th></tr>
<tr><td>Calcite</td><td>10^{-12}</td><td>10^{-4}</td><td colspan="2">+</td></tr>
<tr><td>Disordered dolomite</td><td>10^{-10} - 10^{-8}</td><td>10^{-4}</td><td colspan="2">+</td></tr>
<tr><td>Quartz</td><td>0.0</td><td>10^{-5}</td><td>0</td><td>-</td></tr>
<tr><td>Albite</td><td>0.0</td><td>10^{-5}</td><td>0</td><td>-</td></tr>
<tr><td>K-Feldspar</td><td>0.0</td><td>10^{-5}</td><td>0</td><td>-</td></tr>
<tr><td>Barite</td><td>0.0</td><td>10^{-7}</td><td>0</td><td>-</td></tr>
<tr><td>Magnesite</td><td>10^{-14}</td><td>10^{-13}</td><td colspan="2">+</td></tr>
<tr><td>Chalcedony</td><td>0.0</td><td>0.0</td><td colspan="2">0</td></tr>
<tr><td>Anhydrite</td><td>10^{-13} - 10^{-11}</td><td>10^{-14} - 10^{-4}</td><td colspan="2">+</td></tr>
<tr><td>Beidellite</td><td>0.0</td><td>10^{-5}</td><td>0</td><td>+</td></tr>
<tr><td>Illite</td><td>0.0</td><td>10^{-14}</td><td>0</td><td>+</td></tr>
<tr><td>Kaolinite</td><td>0.0</td><td>10^{-14}</td><td>0</td><td>+</td></tr>
<tr><td>Gibbsite</td><td>0.0</td><td>10^{-19} - 10^{-18}</td><td>0</td><td>+</td></tr>
</table>

Table 7. Processes of precipitation and dissolution involved during the heat exploitation phase.

<table>
<tr><th rowspan="2"></th><th colspan="2">Amount (order of magnitude) precipitated or dissolved in moles/kgw</th><th colspan="2">Risk: precipitation (+) dissolution (-) none (0)</th></tr>
<tr><th>Cold well</th><th>Cold bubble</th><th></th><th></th></tr>
<tr><td>Calcite</td><td>0.0</td><td>10^{-4}</td><td>0</td><td>-</td></tr>
<tr><td>Disordered dolomite</td><td>0.0</td><td>10^{-4}</td><td>0</td><td>-</td></tr>
<tr><td>Quartz</td><td>0.0</td><td>0.0</td><td colspan="2">0</td></tr>
<tr><td>Albite</td><td>0.0</td><td>10^{-11}</td><td>0</td><td>-</td></tr>
<tr><td>K-Feldspar</td><td>0.0</td><td>0.0</td><td colspan="2">0</td></tr>
<tr><td>Barite</td><td>10^{-14}</td><td>10^{-6}</td><td colspan="2">+</td></tr>
<tr><td>Magnesite</td><td>0.0</td><td>0.0</td><td colspan="2">0</td></tr>
<tr><td>Chalcedony</td><td>10^{-20}</td><td>10^{-18}</td><td colspan="2">+</td></tr>
<tr><td>Anhydrite</td><td>0.0</td><td>0.0</td><td colspan="2">0</td></tr>
<tr><td>Beidellite</td><td>10^{-7}</td><td>0.0 - 10^{-15}</td><td colspan="2">+</td></tr>
<tr><td>Illite</td><td>10^{-14}</td><td>0.0</td><td>+</td><td>0</td></tr>
<tr><td>Kaolinite</td><td>10^{-16}</td><td>0.0</td><td>+</td><td>0</td></tr>
<tr><td>Gibbsite</td><td>10^{-19} - 10^{-17}</td><td>0.0</td><td>+</td><td>0</td></tr>
</table>

The quantities involved in the wells are negligible except for the beidellite (risk of precipitation, up to 10^{-7} mol/kgw). In contrast, in the "bubbles", amount of mineral that could precipitate/dissolve are more significant (up to 10^{-4} mol/kgw). Feldspars, quartz and barium sulfate dissolve in the "hot bubble" while carbonates, calcium sulfate and clays (specifically beidellite) precipitate. Carbonates (calcite and disordered dolomite) and albite dissolve in the "cold bubble" whereas barium sulfate and beidellite precipitate. In each "bubble", the formation of clays is related to the feldspars alteration that notably releases Al^{3+} (Figure 2). Finally, during the first ATES operations cycle, both in wells and "bubbles", most of the secondary phases could precipitate in small quantity (< 10^{-10} mol/kgw) except beidellite and calcium sulfate that would precipitate in larger quantities. The kinetic batch modelling confirms the results of the previous equilibrium study. Additionally, they inform of the potential reaction paths and allow distinction between short term reactions (as calcite and dolomite reactions) and long term reactions (as aluminosilicate reactions). The last stage of the study (reactive transport modelling) is in process. The results of this undergoing work will be detailed during the conference.

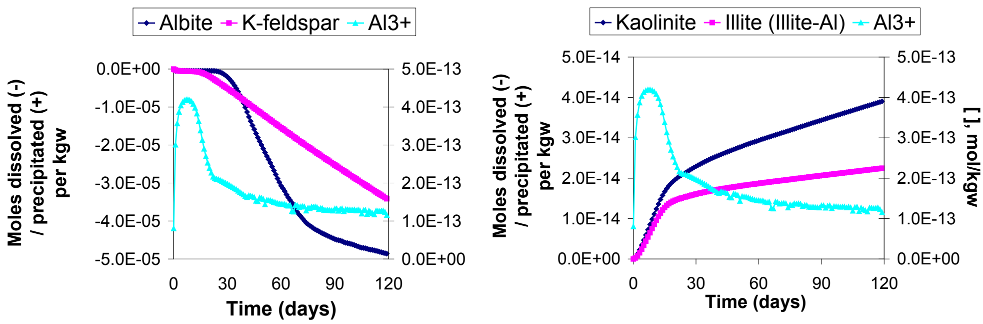

Figure 2. Evolution of Al^{3+} concentration and amounts precipitated and dissolved of feldpars and clays (kaolinite and illite) during the heat storage phase at 95°C as a function of time (Kinetic batch modelling approach).

CONCLUSION

Reactive modelling study simulating different scenarios of temperature perturbation highlights some potential clogging risks (*i.e.* precipitation of carbonate, calcium sulfate and clays minerals in the "hot bubble" and precipitation of barium sulfate and clay minerals in the "cold bubble"). Once the last stage will be completed, operating rules of the ATES technology will be defined allowing operators to plan out management strategies for future ATES sites in the Dogger aquifer.

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abstract id: **466**

topic: **4**
Mineral and thermal water

4.1
Geothermal resources

title: **The most prospective areas of use of thermal waters for heating purposes in the Polish Lowlands**

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keywords: Polish Lowlands, geothermal resources, prospective areas

Poland is characterized by significant low-enthalpy geothermal resources, connected mostly with the Mesozoic sediments. Space heating represents the most important type of direct uses. Five geothermal heating plants are in operation. The biggest one is located in the Podhale Trough in the Carpathians Mts., while the remaining operate in the Polish Lowlands: Pyrzyce, Mszczonów, Uniejów, Stargard Szczeciński (Fig. 1). Total installed geothermal power is estimated at about 44.8 MWt with annual production of energy ranging about 480 TJ/a (Kępińska, 2005).

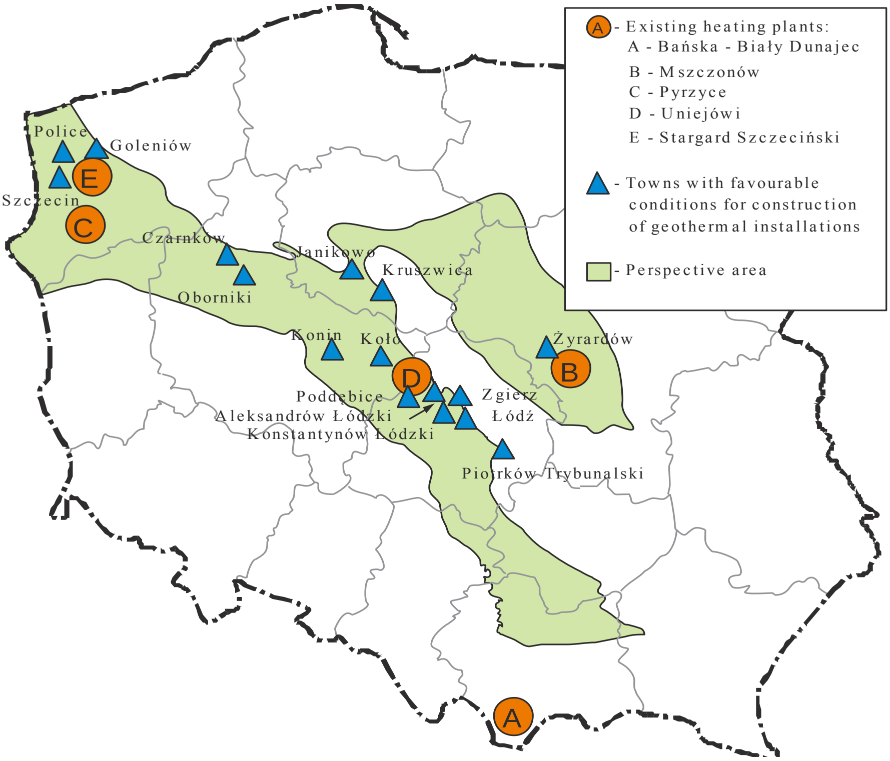

Figure 1. Location of towns with favorable conditions for construction of geothermal installations in the Polish Lowlands and existing geothermal heating plants in Poland.

Within geological sections of the Polish Lowlands, in the Early Paleozoic through Early Cretaceous formations, a number of layers which indicate possible occurrence of good geothermal aquifers can be distinguished. Hydrogeological and thermal parameters that characterize aquifers in the Polish Lowlands indicate possibility of complex utilization of thermal waters, as well for energy production as balneotherapy and recreation.

The paper presents results of assessment of geothermal energy resources accumulated within nine Paleozoic and Mesozoic aquifers in the Polish Lowlands, made within the framework of the project entitled "Geothermal atlases of the Mesozoic and Paleozoic formations — geological analysis and thermal water and energy resources in the Polish Lowlands" (Górecki (ed.), 2006a, b). The project had been commissioned by the Polish Ministry of Environment and was carried out in the years 2004–2006 by a research team composed of specialists from several scientific and commercial institutions with the AGH University of Science and Technology as a leader of the team.

The calculation area measured approximately 270 th. km^2 that represents more than 87 percent of the territory of Poland and comprises nine major aquifers in the Polish Lowlands: Lower Cretaceous, Upper Jurassic, Middle Jurassic, Lower Jurassic, Upper Triassic and Lower Triassic aquifers of the Mesozoic formation, and Lower Permian, Carboniferous and Devonian aquifers of the Paleozoic formation. The distinguished geothermal aquifers were characterized, among others, from the point of view of their geological setting (lithology, stratigraphy and tectonics), extent and depth of the aquifers, their thickness, temperature, water mineralization, discharge of water intakes and calculated resources of energy.

The calculations were made with regard to the classification of resources, in accordance with the McKelvey's diagram. The accessible, static and static-recoverable geothermal energy resources had been distinguished (Haenel, 1982; Muffler, 1975; Muffler, Cataldi, 1979; Sorey et al., 1983).

Considering the extent of the Mesozoic and Paleozoic geothermal aquifers in the Polish Lowlands, that expresses also the area of calculation (rounded up to 1 th. km^2), they can be arranged in the following order: Lower Triassic (229 th. km^2 — 73% of the territory of Poland), Middle Jurassic (205 th. km^2 — 66%), Upper Jurassic (198 th. km^2 — 63%), Upper Triassic (178 th. km^2 — 57%), Lower Jurassic (160 th. km^2 — 51%) and Lower Cretaceous (128 th. km^2 — 41%). The largest calculation area among all Paleozoic geothermal aquifers is occupied by the Lower Permian aquifer: ab. 102 th. km^2, which constitutes 37% of total area of the Polish Lowlands and 33% of the whole territory of Poland.

According to the McKelvey's diagram, the total accessible geothermal resources accumulated in the rock formations down to 3 km depth or down to the top surface of the crystalline basement amount to 7.753×10^{22} J, which is an equivalent of 1.85×10^{12} TOE (*1 TOE* — tonne of oil equivalent, 1 toe = 41.868 GJ).

The principal resources of thermal waters in the Polish Lowlands are reservoired in the Mesozoic groundwater horizons. Thermal waters are accumulated first of all in the Lower Jurassic and Lower Cretaceous formations but significant resources of geothermal energy are reservoired also in the Upper Jurassic, Middle Jurassic, Upper Triassic and Lower Triassic formations.

Total static geothermal resources which express the amounts of free (gravitational) thermal water hosted in pores, fractures or caverns expressed in m^3 or km^3 of water, recalculated after taking the water temperature into the energy units — Joules, accumulated in thermal waters of the Polish Lowlands sedimentary formations are estimated at 1.45×10^{22} J, which is an equivalent of 3.47×10^{11} TOE. The largest static geothermal resources are accumulated in the Lower Jurassic aquifer and were estimated at about 6320 km^3 of water with temperature ranging from 20 to up to 120 degC (Fig. 2).

Energy accumulated in waters of the Lower Jurassic aquifer was calculated to be 2.99×10^{21} J (7.14×10^{10} TOE). Considering the distribution of static resources per area unit, the best parameters among the Mesozoic aquifers are revealed by the Lower Jurassic aquifer — 1.86×10^{16} J of energy per 1 km^2. Mean unit static resources for the Mesozoic aquifer are equal to 9.41×10^{15} J/km^2 (Hajto, 2006).

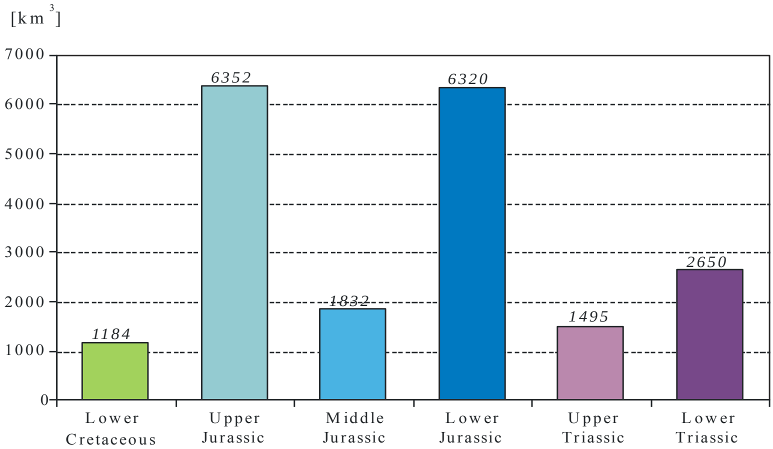

Figure 2. Static resources of thermal water within particular geothermal aquifers of Mesozoik age in the Polish Lowlands.

The amount of static-recoverable resources gives information on the fraction of geological (static) resources that can be theoretically recovered under specified technical parameters of exploitation and utilization of the geothermal medium, i.e at given cooling temperature and with given exploitation method (Gringarten, 1975, 1979). The value of Ro index depends on an exploitation method (single- or double-well system) and on relationships between the reservoir temperature, injection temperature (in doublet system) and mean annual temperature at the Earth's surface. For the calculations it was assumed that waters are exploited by a doublet and the injection temperature does not exceed 25°C. Averaged values of the recovery index calculated for all aquifers of the Polish Lowlands are ranging from 12.8% for the Upper Jurassic to 26.7% for the Lower Permian aquifer. Average Ro value calculated for all nine geothermal aquifers of the Polish Lowlands are estimated at 19.9% (Hajto, 2006).

These results demonstrate that under geological and temperature conditions dominating in the Polish Lowlands it will be possible to recover less than 20% of geological resources of accumulated geothermal energy. Total static-recoverable geothermal resources are equal to 2.9×10^{21} J. The largest geothermal resources which are possible to be produced are accumulated in the Lower Triassic aquifer and are estimated at 6.13×10^{20} J (1.46×10^{10} TOE) (Hajto, 2006).

Additional estimation of energy accumulated in particular temperature classes of thermal waters enables preliminary evaluation of ways of thermal water utilization. Application of the methodology of factor evaluation of the economic effectiveness of heat recovery (the power factor) enabled preliminary assessment of the geothermal energy utilization profitability at the regional scale and indication of prospective areas within particular aquifers, but for this purpose the appropriate market of heat consumers for a geothermal plant construction should be specified.

The area of potential locations of the new geothermal projects corresponds with the area revealing the most favourable geological and hydrogeological conditions within the main aquifers in the Polish Lowlands (Fig. 1). As regards the amount of accumulated energy, the most interesting and promising areas occur in the Warsaw Trough, Mogilno - Łódź Trough (in the central part of Poland) and Szczecin Trough (in the northwestern part of the Polish Lowlands). Utilization of thermal waters for heating purposes in particular voivodships and towns of central Poland should, first of all, be based on the resources of the Lower Jurassic aquifer. Possibilities of geothermal energy utilization in remaining areas are rather low and related to limited areas.

The Atlases were elaborated with application of digital processing of geological data and digital mapping. All calculations were run with the use of the OpenWorks integrated geological data processing system developed by Landmark Graphics Co. The software is licensed under the conditions of educational license No. 2003-COM-020272 and 2003-COM-020273.

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abstract id: **525**

topic: **4**
Mineral and thermal water

4.1
Geothermal resources

title: **Geothermal water as renewable energy source — the state and prospects of use in the world and Europe**

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keywords: geothermal water, geothermal energy uses, world, Europe, current state, prospects

Among several important functions of groundwater is its role as a carrier of Earth's heat — geothermal energy. This renewable energy source (RES) has a variety of applications including power generation and a wide sector of direct uses such as heating, bathing and others. Geothermal (thermal) waters and energy are subject of increasing interest in many countries, being considered in global, regional and state documents on climate protection and sustainable energy development (e.g. the UE-Directive on promotion the use of RES). Local geothermal resources limit the dependence on the imported energy sources thus increasing the energy safety. Constant deployment of geothermal energy has been observed in the world, facilitated by progress in reliable technologies as well as ecological and economic factors. The variety of reservoir conditions and production methods proves the variety of possibilities in which geothermal energy can be used, adjusted to local conditions and needs.

As presented at the World Geothermal Congress 2010 electricity generation using geothermal steam takes place in 24 countries. In 2009 the total installed capacity amounted to 10 715 MWe while electricity generation was 67 246 GWh. An increase of about 20% has been achieved during five years' term since 2005. The top five countries for capacity and produced electricity are USA, Philippines, Indonesia, Mexico and Italy (Bertani, 2010).

Geothermal water uses for direct applications are reported from 78 countries. In 2009 installed capacity amounted to 50 583 MWt, while heat production was 438 071 TJ (121 696 GWh). Since 2005 these figures increased by 79% and 60% (!), respectively (Lund et al., 2010) with significant share of heat pumps deployment in several countries. In terms of the amount of produced heat, the leading top five countries are China, USA, Sweden, Turkey and Japan. The main sectors for geothermal direct uses are space heating as well as bathing and swimming. Other applications include horticulture and soil heating, aquacultures, drying, industrial uses, de-icing, and some other (Lund et al., 2010).

In case of Europe electricity generation using geothermal steam takes place in Iceland, Italy, Turkey and Portugal. In recent years the interest has grown in power generation via binary schemes based on 100–120°C water: first six 0.2–3 MWe pilot installations were launched in Austria and Germany (Bertani, 2010). This is an interesting line of electricity generation but needs further works. From the other hand, Europe is leading geothermal direct uses worldwide. They are being reported from 37 countries of this continent. In 2009 installed capacity amounted to 23 469.3 MWt and heat use was 233 736.7 TJ (46.7% and 53.4% of a global share of geothermal, respectively). Geothermal uses concentrate mainly on space heating, bathing and balneotherapy, than on heating greenhouses, aquacultures, industrial uses. In a number of countries the development is based on waters exploited from wells up to ca. 3 km deep (e.g. Iceland, Turkey, Hungary, Italy, Germany, France). Some countries have been dynamically developing shallow geothermal use based on heat pumps.

In Poland geothermal waters have been used for healing in some spas for centuries. Since the early 1990s they have been also used for heating — so far five space heating plants have been on-line. It is worth to note seven new recreation centers applying geothermal water opened in recent years. At the end of 2008 the total installed geothermal capacity (heat pumps including) was ca. 281 MWt while heat sales were ca. 1501 TJ (Kępińska, 2010). The country has prospective reservoir conditions for geothermal energy development for direct uses in several regions. Further research and investment projects are underway.

Although geothermal energy is not treated as main RES in many official prognoses, its further deployment is envisaged in many countries and regions in the forthcoming years and decades. This refers to various technologies and types of uses including space heating, bathing, power generation (with different technologies). These and several other important aspects were pointed out e.g. in Bali Declaration signed during the World Geothermal Congress 2010 (www.geothermal-energy.org).

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www.geothermal-energy.org

abstract id: **527**

topic: **4**
Mineral and thermal water

4.1
Geothermal resources

title: **Hydrogeological modeling as a tool to assess geothermal water resources of Lower Jurassic formation in the NW part of Poland**

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keywords: geothermal water, Lower Jurassic, hydrogeological modeling

The paper presents part of PhD dissertation aiming at estimation of geothermal water and energy resources accumulated in Lower Jurassic formation in Szczecin Trough.

Geothermal resources were calculated in respective categories according to methodology accepted by European Union countries, but water resources were estimated by means of dynamic hydrogeological modeling. Visual MODFLOW 4.3 software was used as a tool to create hydrogeological model. As a result of dynamic modeling, water circulation system as well as water mass balance were established.

The foundations of the conceptual model were interpreted well log data, which enabled identification of water bearing formations within Lower Jurassic sediments together with their petrophysical parameters. The Lower Jurassic water-bearing formations are covered by younger Mesozoic formations. Only on a small fragment in the north part of analyzed area, Lower Jurassic sediments lies directly below Cenozoic formations. There is no Lower Jurassic outcrops on the area of research. Recharge area is situated on the Pomerania Anticlinorium, while drainage zones constitute Baltic Sea in the north and Odra valley in the south (Szklarczyk, Łapinkiewicz, 1995). Since model boundary and hydrodynamical boundary should be similar (Szczepański, 2008), analyzed area was widened to the boundary of underground water section.

Model consists of seven layers: six regional layers of Lower Jurassic formation and one Cenozoic layers only in areas where Lower Jurassic formation lies directly below Cenozoic sediments. The following structure of the model together with filtration coefficients were assumed:

- layer No 1 — Cenozoic — 1×10^{-5} m/s,
- layer No 2 — Lower Jurassic — kamienskie layers —2×10^{-6} m/s,
- layer No 3 — Lower Jurassic — gryfickie layers — 1×10^{-10} m/s,
- layer No 4 — Lower Jurassic — komorowskie layers — 1×10^{-5} m/s,
- layer No 5 — Lower Jurassic — lobeskie layers — 1×10^{-10} m/s,
- layer No 6 — Lower Jurassic — radowskie layers —2×10^{-5} m/s,
- layer No 7 — Lower Jurassic — mechowskie layers — 4×10^{-5} m/s.

Geothermal water accumulated in the Lower Jurassic formation in NW part of Poland is characterized by temperature range of 20–90°C and TDS ranges from 20 to 150 g/dm^3.

Distribution of reduced pressure was obtained as a result of the reduction of the actual pressure to fresh water with temperature of 20°C (Szklarczyk, Łapinkiewicz, 1995). Values of reduced water pressure of Lower Jurassic vary from below 344 atm. above the reference level in the northern area and exceed 349 atm. above the reference level in the western part of research area. Reference level has been adopted at a depth of 3,293 m which is a center of the deepest sampling interval (Szczepanski, Szklarczyk, 2006). The map showing reduced pressures was created as a result of calculations. Values of reduced pressure vary from 145 m above sea level in the northern part to more than 195 m above sea level in the western part of research area.

First-type boundary condition was applied for the first layer of the model in a regions where Quaternary sediments lie directly on Lower Jurassic formation and another layers at the boundary of the model (H = constans). Second-type boundary condition was applied for the first layer as an effective infiltration. Value of infiltration coefficient depended on Cenozoic formations' lithological type and varied from 0.08 to 0.25. The average annual rainfall was set as 600 mm (according to IMiGW). Rivers were allowed for third-type boundary condition. Calibration of the model were carried out through analyses of hydrodynamical accordance of computer simulation effects with empirical hydrogeological model. Filtration coefficient was the main property subjected to calibration. Filtration coefficient after model checking was established from 5×10^{-7} to 2×10^{-5} m/s.

In order to show amount of water circulation to individual layers, zones with particulars balance were created. At the beginning balance zones for whole model were calculated. Total inflow to the model equals 2 963 375.63 m^3/day and total outflow amount to 2 963 368.81 m^3/day. As the result, model calibration achieves balance divergence 6.82 m^3/day, what is an equivalent of 0.000227781%. In order to calculate water balance for the area of Szczecin Through additional zones were created. The results of calculations allow to asses water balance for the Szczecin Through area which was subject of interest. Total inflow to the zones of the Szczecin Through area equals 1 186.5 m^3/day and total outflow amount to 1 169 m^3/day. As the result of model verification balance divergence of 16.9 m^3/day was achieved, what is an equivalent of 1.4%. In the Szczecin Through area two main direction of water circulation are observed. In central and north part of this area water circulation runs from SE to NW direction, where Baltic Sea is drainage zone. In south part of the Szczecin Through water flow from NE to SW, where drainage zone are Odra valley in area of Lower Jurassic outcrops.

ACKNOWLEDGEMENTS

This work has been sponsored from resources for science in years 2007–2009 as research project “Geological analysis and assessment of geothermal water and energy resources of Mesozoic formations in the Szczecin Trough” (agreement No 9004/B/T02/2007/33, from 29.10.2007, research project Nr N N525 2347 33).

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4.2 | Origin of mineral and thermal waters

abstract id: **117**

topic: **4**
Mineral and thermal water

4.2
Origin of mineral and thermal waters

title: **Drilling for mineral water, Hepburn Australia**

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keywords: cold carbonated mineral water, mixing zones

Drilling for carbonated mineral water, near Hepburn in SE Australia in the last decade has undertaken because of low level Coliform contamination of many of the existing springs.

During drilling with air rotary methods gas sparging strips the carbon dioxide and makes it difficult to identify the carbonated mineral water. In addition, in the spring zones there is mixing with shallow fresh water and the mixing dynamics vary from site to site. Monitoring techniques were adopted during drilling to enabled an assessment of mineral water intersection. Each drilling site is different due to the folded nature of the Lower Palaeozoic rocks and the existence of differential weathering fronts that propagate down labile strata.

The new installations as 30–130 m deep mineral water bores have resulted in the increased carbonation or gas levels and clean mineral water free of contaminants due to mixing such as Coliform bacteria.

abstract id: **118**

topic: **4**
Mineral and thermal water

4.2
Origin of mineral and thermal waters

title: **Origin of high bicarbonate and cold carbonated mineral waters of central Victora Australia**

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keywords: cold carbonated mineral water, high bicarbonate, rock water reactions

The major ion chemistry of Victorian groundwater is known from 150 years of data collection. This resource has been examined and illustrates that a statistical continuum exists in the concentrations of bicarbonate in the groundwater.

Several different geochemical facies can be identified based on cation–anion predominance. Simple geological lithological associations have been identified in local and extensive aquifer systems. High bicarbonate waters may be associated with many different aquifer types and flow systems. The most frequent lithological association are with mixed sediments such as arkose–greywacke–lithic sandstone and ligneous sands.

In Central Victoria the carbonated mineral waters are a small flux sub facies of the high bicarbonate waters and possess low chloride and sulphate concentrations. The elevated bicarbonate content is influence by carbonate solution, sulphate reduction and by ferrous–ferric equilibria controlling water pH. The waters rise from a thermodynamically closed to an open system. In the discharge zones where the waters are developed at "springs" the ascension processes can mask the nature of the rising water due to the varying role of isothermal evaporation, reflux mixing, degassing and carbonate precipitation. Taking these processes into account contiguous flow systems with evolving water chemistry have been identified in the bedrock aquifers of Central Victoria. The chemistry of the low flux deep circulating waters can be related to hydrolysis of silicate minerals, clay mineral reactions, carbonate solution and sulphate reduction and evolves down fracture based flow systems that may be traced 10–35 km from the principle recharge areas in the uplands of the catchments.

abstract id: **174**

topic: **4**
Mineral and thermal water

4.2
Origin of mineral and thermal waters

title: **Characterization of the hydrogeological boundary separating two aquifers: a multi-disciplinary approach combining geological, geochemical and hydrodynamic data (Aix-les-Bains, France)**

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keywords: mineral aquifer, structural geology, hydrogeochemistry, hydrodynamic monitoring, Aix-les-Bains

Aix-les-Bains (Savoie-France) is located on the eastern shore of Lake Bourget in the "département" of Savoie. Three establishments within a few kilometers of Aix-les-Bains currently exploit the area underground water resources: the Marlioz and Thermes Nationaux spas and the Société des Eaux d'Aix-les-Bains bottles mineral water at Raphy Saint Simon (RSS). The spas draw their water exclusively from deep boreholes, whereas the RSS bottling plant has a natural spring (RSS well) and two boreholes (RS4 and RS5), both of which are more than 500-m deep (Figure 1). Although the spas and mineral water plant are only a few kilometers apart, their waters have distinct physico-chemical characteristics, suggesting that they are derived from two different but adjoining aquifers. The present study used geological, geochemical and hydrodynamic data in order to determine the boundary between the thermal water and mineral water aquifers, and to investigate the relationship between them. It is important to determine the boundaries between the aquifers especially at depth because the waters are abstracted exclusively by boreholes.

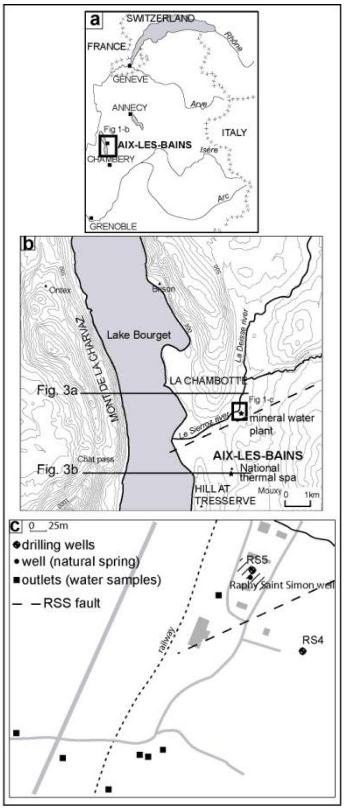

Figure 1. Location of the study area: a): regional map; b) local map; c) RSS well field.

GEOLOGICAL DATA

Geological mapping and a reinterpretation of seismic profiles produced in the 1970s for oil exploration were used to investigate the structure of the area between Aix-les-Bains and La Chambotte (8 km north of Aix). This relatively small area was found to contain two very different types of anticlinal structure: a fault-bounded anticline to the north (Figure 2a) and a box fold to the south (Figure 2b). Dip measurements for both anticlines revealed sub-vertical western flanks, less steeply dipping eastern flanks and sub-horizontal central sections. The central section of the northern anticline is much narrower than the central section of the southern anticline. Both anticlines have been thrust over their adjoining synclines; however, the thrust plane is much steeper in the north than it is in the south. As a result, equivalent strata are at a higher altitude to the north of Aix-les-Bains than they are to the south of the city. In addition, the eastern flank of the northern anticline is intersected by two backthrust faults and the southern anticline is affected by a peel thrust. Given the extremely rapid transition from one anticlinal form to another, these two structures cannot be contiguous; however, their juxtaposition can be explained by the presence of a fault oriented N065°E. This fault is not visible at outcrop but it must lie between the end of the La Chambotte anticline and the hill at Tresserve. It has been named the Raphy Saint Simon Fault (RSSF).

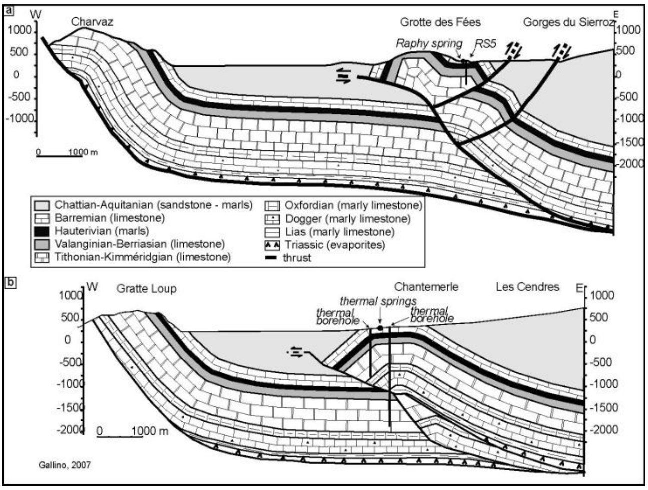

Figure 2. Geological structures to the north (a) and to the south (b) of Raphy Saint Simon field.

GEOCHEMICAL DATA

Water samples from wells and springs within a 300-m radius of the RSS well field had identical or similar major ion concentrations to the mineral waters; nevertheless, two distinct chemical facies were recognized on the basis of differences in magnesium and sulfate concentrations. For example, the sulfate concentrations of water samples from RS5 and the RSS well were five times lower than those of RS4 (20 $mg \cdot L^{-1}$ vs. 100 $mg \cdot L^{-1}$) (Figure 3). Differences were also found in the sulfur isotope signatures of samples from the two boreholes, even though both boreholes abstract their waters in the Upper Kimmeridgian limestone. The sulfur isotope signature of RS5 (8.9‰ vs. CDT) is closer to that of pyrite (-0.8‰ vs. CDT), whereas the signature of RS4 (18.9‰ vs. CDT) is closer to that of the thermal water (31.5‰ vs. CDT). These differences in sulfur isotope and major ion concentrations show that the recharge waters for the two boreholes have different sources and that the boreholes must therefore be in different geological blocks separated by the RSSF.

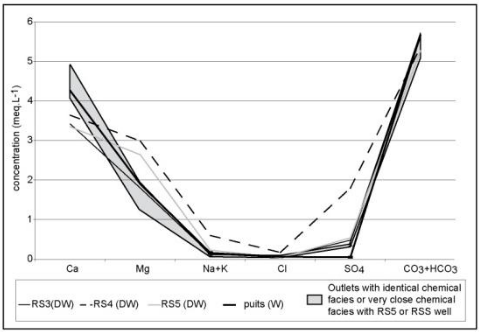

Figure 3. Schoeller Berkaloff diagram of the outlets of the RSS well field, wells and springs around the well field.

HYDRODYNAMIC DATA

Monitoring of the dynamic water levels in the boreholes and the flow rate of the RSS well allowed us to determine the hydrogeological and geological limits. Variations in the water yields of the boreholes in one block were observable in the adjoining block. Although the fault allows the transfer of pressure between the two blocks, it also leads to the water level in the northern block being 30 meters lower than the water level in the southern block.

Some phenomena were only observed in the northern, mineral-water block. For example, during rainfall events water levels were seen to drop suddenly in RS5 (Figure 4) but not in RS4.

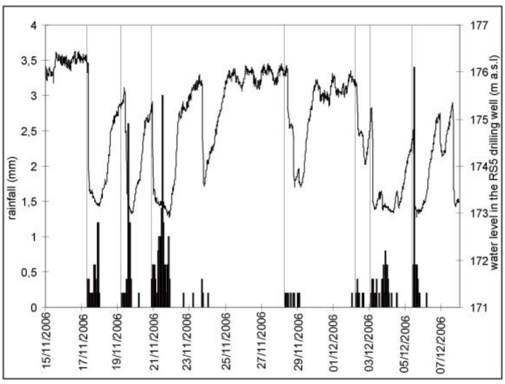

Figure 4. Variations in the dynamic water level of RS5 during rainfall events.

In addition, we observed cyclical variations in the flow rate of the RSS well, as well as variations related to atmospheric pressure (Figure 5).

These phenomena were not observed at the natural thermal water outlets in the southern block.

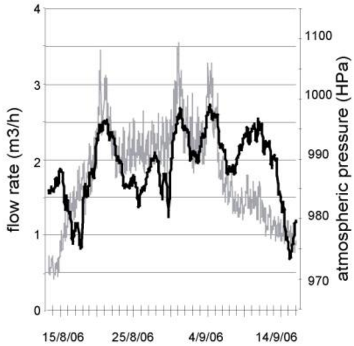

Figure 5. Variations in the RSS well flow rate related to atmospheric pressure.

CONCLUSION

The present study produced the following evidence for the existence of two distinct structural blocks:

- the different geological structures indicate the presence of two blocks separated by a fault oriented N065°E.
- Hydrogeochemical analyses revealed two distinct borehole water facies: one closer of mineral water facies and the other one closer to the thermal water facies.
- Hydrodynamic tests revealed differences between water levels in the boreholes and the existence of phenomena that only occur in the northern block. These results also indicate the presence of two aquifers with different water recharges and different ways of functioning.

Geological, geochemical and hydrodynamic data all indicate the existence of a N065°E-trending fault near the RSS well field. This fault marks the boundary between the mineral water aquifer to the north and the thermal water aquifer to the south. It maintains a difference in the water levels of the two aquifers, but allows the transfer of pressure between them.

ACKNOWLEDGEMENTS

The authors wish to thank the Société des Eaux d'Aix-les-Bains for their financial support and cooperation, and Gérard Nicoud for proposing the original idea for this study.

abstract id: **175**

topic: **4**
Mineral and thermal water

4.2
Origin of mineral and thermal waters

title: **Modelling of a pumping test conducted in the mixing zone between a thermal aquifer and a surface aquifer using physico-chemical parameters monitoring**

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keywords: thermal aquifer, pumping tests, hydrodynamical-thermal modelling, Aix-les-Bains, Alps

INTRODUCTION

The hydrodynamic behaviour of deep aquifers is often characterised using pumping tests that are interpreted with the petroleum engineering formalism (pressure instead of hydraulic head, artesian tests, permeability instead of hydraulic conductivity, etc.) (Bourdarot, 1996; Miller, 1979, Murphy et al., 1999). Moreover, for both petroleum pumping tests and geothermal pumping tests, only the temperature is measured in addition to the pressure variation (linked to the drawdown). We propose here to use both electric conductivity and temperature monitoring during a pumping test in order to obtain some information about the hydrodynamic characteristics and the position of a deep water plume emerging into a shallow aquifer. Indeed, the mixing between deep waters with thermal characteristics and surface water is common in French alpine regions. In the case of thermal spa of Aix-Marlioz (Fig.1), thermal waters from a "thermo-siphon" diffuse, after crossing an aquitard, into a more or less karstified superficial aquifer. The thermal plume outlet in the urgonian low karstified limestone corresponds to the upper part of an overthrusting anticline (Fig. 2). The spa draws their waters from a well that catches water at the bottom of the urgonian series on the western flank of the anticline.

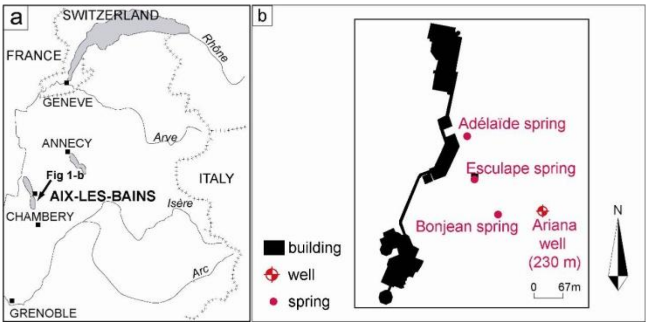

Figure 1. Location of studied area: a) regionally; b) on the locality of Aix Marlioz.

The physico-chemical characteristics of the deep flow are χ = 1000 µS·cm^{-1} and T > 17°C, whereas the shallow water ones are χ = 680 µS·cm-1 and T = 11°C. The mixing of two poles, in steady-state flow, has a conductivity of χ = 740 µS·cm^{-1} and a temperature of 17°C (Fig. 2).

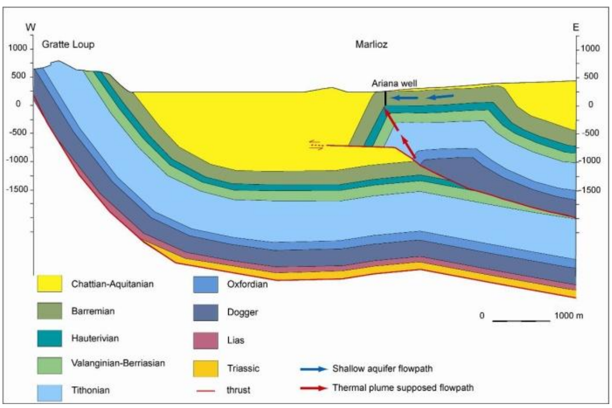

Figure 2. East-west geological cross-section of the Aix-les-Bains overlapping anticline through the locality of Aix Marlioz.

The surveys carried out prior to implantation drilling are insufficient to determine whether the thermal plume is diffuse or arrive concentrated in the base of the aquifer. The final aim of this study is to reproduce the plume behaviour, using a pumping test in which the drawdown, temperature, conductivity were monitored simultaneously. This approach aims to obtain a maximum of information from a unique pumping test performed into a single well. It is the opposite of the integral pumping tests (Bayer-Raich et al., 2006), that use a maximum of piezometers in order to obtain the characteristics of a pollution plume.

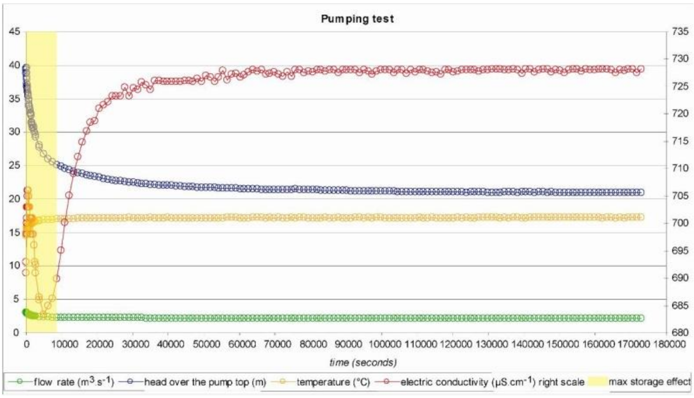

Figure 3. Plot of drawdown and electrical conductivity and temperature monitored during the pumping test on Ariana well at Aix Marlioz locality.

INITIAL INTERPRETATION OF THE PUMPING TEST

The pumping test was performed in a 230m depth well (Ariana well) with a casing from top to 171m depth (the last deeper part remains in borehole).

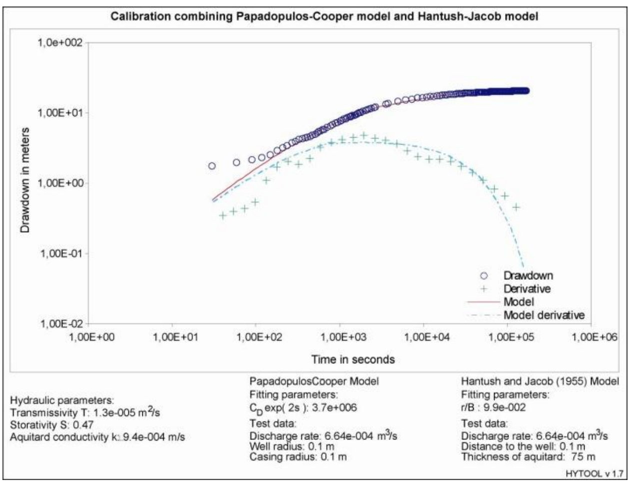

Figure 4. Diagnostic plot of the drawdown data combining the Papadopulos-Cooper model (well-bore storage effect) and the Hantush-Jacob model (leakage) showing that this interpretation is possible from a theorical point of view although the greater transmissivity of the aquitard vs the aquifer transmissivity is unrealistic.

The results of monitoring are presented on Fig. 3. As expected (karst low developed), the drawdown can be explained as an essay in porous media with a well-bore storage effect due to the depth of the well (Papadopulos-Cooper) combined with a drainance (Hantush-Jacob) (see Fig. 4). This classical interpretation from drawdown was carried out using Hytool (P. Renard, Hytool, user manual, 2003) (see Fig. 4). However, the hydraulic conductivity obtained for the aquitard is greater than that obtained for the aquifer, which is illogical. This is probably because the aquifer is not clearly identified as a both fractured and weakly karstified aquifer (failure of calibrations type Warren and Root). The interpretation of the pumping test using the drawdown only led to an unsatisfactory result from a hydrodynamic point of view.

It may be noted on Fig. 3 that conductivity and temperature showed different behaviours at the beginning of pumping. In particular, the temperature is stabilized 8 hours before the electrical conductivity. This cannot be due to the well-bore storage effect because its duration is less than 1h30. The phenomenon observed on the electric conductivity curve is then related to the water mixing in the media. On Fig. 3, the maximal time (beyond the theory) of the well-bore storage effect duration is shown in yellow.

THE MODEL

Considering that we have frequently obtained differences between total mineralization behaviour and temperature behaviour with identical transport and hydraulic parameters, we focus in the present abstract on the modelling total mineralization behaviour. The software used to perform the modelling is Feflow (Diersch, 2002), which permits both flow, mass and heat transport in saturated and unsaturated media. The calculations are done into finite element mesh (Fig.5).

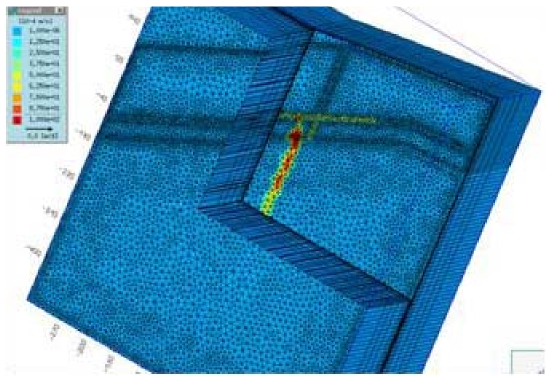

Figure 5. 3D finite element model of the Aix Marlioz locality around the Ariana well.

The information given during the drilling indicates a more fractured and productive zone between 170 and 180 m depth in the borehole. The information given by the field indicates that the thermal plume can potentially be located downstream to the well in lateral position. Indeed, the spring located upstream to the well (to the east) has chemical and thermal characteristics of the shallow aquifer, when the springs located downstream (to the west) show intermediate chemical facies that become closer to the thermal one from South to North.

RESULTS AND DISCUSSION

The simulations shown on Fig. 6 have been realised using the same set of hydrodynamic and transport parameters. Only the thermal plume position is moving. The goal here is the reproduce qualitatively the shape of the electrical conductivity curve obtained during the pumping test (in red on Fig. 3). This curve is characterised by a first increase (short in time) of the electric conductivity immediately followed by a drawdown. At the end of the curve, a new increase appears, that finishes with a stabilisation at relatively high level of electric conductivity. This shape described just above is our reference for the curves obtained on Fig. 6. In the present abstract, only one of the representative sets of parameters used is shown. The final calibration in order to reproduce more exactly the electric conductivity behaviour will be performed from the Fig. 6c thermal plume location (see after). In Fig. 6, the simulated TDS concentrations were converted into electrical conductivity.

In Fig. 6a and 6b, the pumping well and the thermal plume are in the same cross-section parallel to the natural flow into the superficial aquifer. In Fig. 6a, the plume is in upstream position regarding to the pumping well. In Fig. 6b, the plume is in downstream position regarding to the pumping well. It appears on Fig. 6a that only the first increase of the electric conductivity appears, followed by a long drawdown (too long to be reduced enough after calibration). On Fig. 6b, only a correct drawdown of the electrical conductivity appears. The first peak and the final stabilisation are missing. On Fig. 6c, all the characteristics expected are present. This last test is obtained with a thermal plume located in a downstream position regarding to the pumping well, but not exactly in the cross-section of natural flow that intersects the well. The plume is into a flow section in a lateral position. When we modified the hydrodynamic parameters or the transport parameters, we often obtain a curve of electrical conductivity with this shape. It indicates that such position correspond probably to the position of the plume regarding to the well. Moreover, we know that the spring with the physico-chemical characteristics closer to the thermal plume is really in such a position regarding to the pumping well. In the present example, the monitoring of the electric conductivity really permits to give more indications on the position of the thermal plume into the shallow aquifer (more that the single interpretation of the drawdown curve).

CONCLUSION

We have therefore tried to use both the electrical conductivity data and the temperature data to reduce the scope for interpretation of a pumping well. In the present case, the test is successfull only after the electric conductivity data qualitative interpretation. We need now to confirm this first result by a complete model including temperature data, and if possible, give a quantitative solution to the problem and not only a qualitative one as presented here.

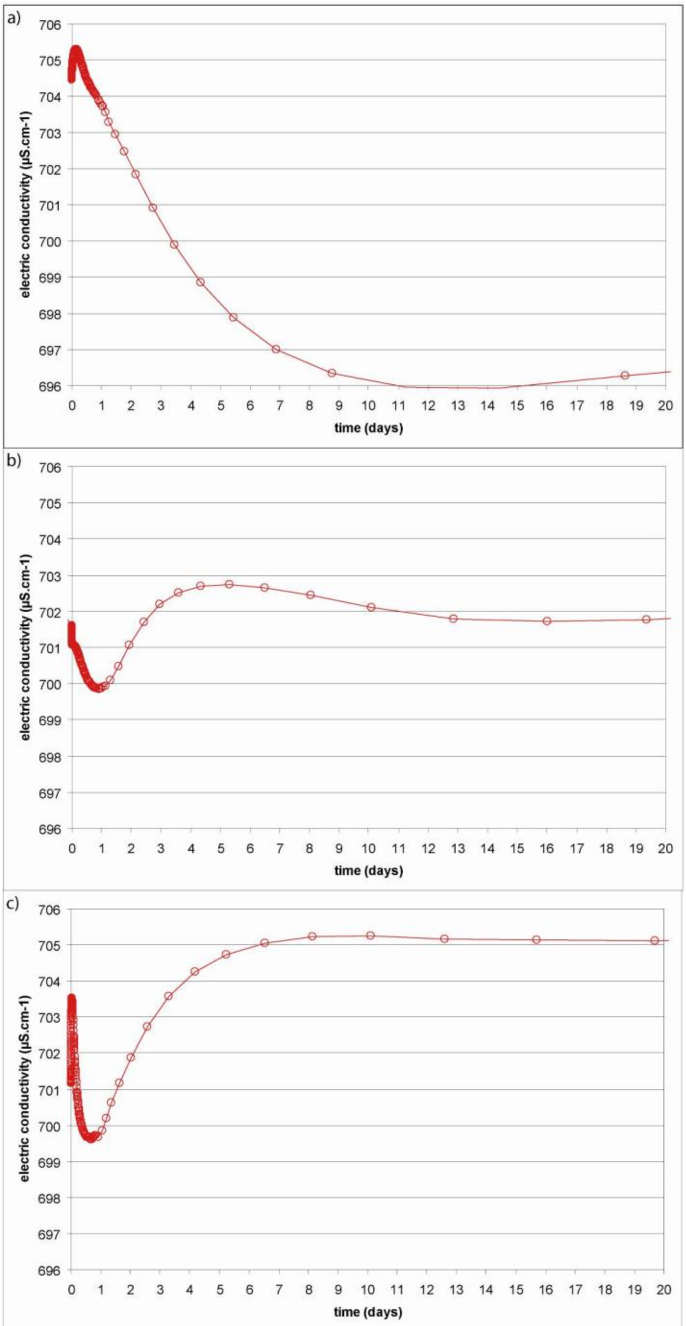

Figure 6. Results of simulations made in the two hypotheses: a1 concentration when the thermal plume is located upstream to the well; a2 temperature when the thermal plume is located upstream to the well; b1 concentration when the thermal plume is located downstream to the well; b2 temperature when the thermal plume is located downstream to the well.

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abstract id: **271**

topic: **4**
Mineral and thermal water

4.2
Origin of mineral and thermal waters

title: **Hydrogeochemistry and origin of thermal-mineral waters in Western Peloponnese (Greece)**

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keywords: thermal-mineral waters, boron isotopes, stable isotopes, Peloponnese

In this study the hydrogeochemistry and the origin of thermal–mineral waters in west Peloponnese in Greece are presented. Thermal occurrences, mainly hypothermal, in western Peloponnese are related to the tectonic activity of the broader area. The region being very close to the Hellenic Trench is one of the most active (seismic and tectonic) regions in Greece. Deep fault systems or fissured zones induced by salt diapisrism act as preferential pathways for the rise on the surface of ground waters, producing water occurrences with specific characteristics, such as rotten egg smell, relatively high temperature and total dissolved solids. According to studies the thermal emergences in west Peloponnese could be connected with petroleum-generation processes in the area, which could caused the increased concentrations of the dissolved hydrogen sulphide in the thermal waters. All these manifestations tend to occur in groups, each group being related to the same geological features.

Hydrochemical investigations took place in the study area have shown that Kaiafa, Kyllini, Vromoneri and Kounoupeli springs are recognized as hypothermal–mineral waters with temperature ranges from 26.3 to 33.5°C. All the water samples present negative values of redox and pH between 6.84 and 8.43. According to electrical conductivity values, two groups are recognized. The first group shows values from 505 to 1350 μS/cm and the second group from 3.7 to 20.5 mS/cm (Kaiafa, Kyllini, Vromoneri and Kounoupeli samples). They present general hydrochemical type Na–Cl and are rich in H_2S as a result from sulphate ions reduction under suitable conditions. The radon concentrations are not high; Ranging from 2.8 KBq/m^3 to15 KBq/m^3 are comparative with the radon values in other ground waters in the study area. According to the stable isotopic data Kaiafa, Kyllini and Vromoneri spring present meteoric origin. On the contrary Kounoupeli spring is mixed water (60% meteoric water and 40% sea water).

abstract id: **281**

topic: **4**
Mineral and thermal water

4.2
Origin of mineral and thermal waters

title: **Flow pattern and water ages in thermal system of Podhale Basin, southern Poland, as deduced from environmental tracers**

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keywords: Podhale Basin, thermal waters, environmental tracers

Fissured and karstified Eocene and Mesozoic carbonate formations of the Podhale Basin represent the largest reservoir of renewable thermal water in Poland. They outcrop in the Tatra Mts. at altitudes of 1000–1800 m and deep to the north under the flysch formations. The main direction of flow is to the north for abt. 15 km, to the impermeable formations of the Pieniny Klippen Belt, where it is divided and diverted to the west and east, and next to the south to the Danube watershed in Slovakia. The temperature ranges from abt. 20°C near the outcrops to abt. 85°C at the most northern wells. The thermal water is exploited for heating (wells BA1 and BA2) and recreation (wells BA1, BA2, Z1, Z2, BU and SZ). For a better understanding of the flow pattern and water age, environmental isotopes ($\delta^{18}O$, $\delta^{2}H$, ^{3}H, ^{14}C, $\delta^{13}C$) have been used since early seventies and recently also gaseous tracers (He, Ne, Ar and SF_6) under the grant No N 525 402334 from the Ministry of Science and Education.

The C^{14} data of thermal waters range between 37 to 0 pmc with $\delta^{13}C$ from abt. 5 to 0‰; evidently exhibiting the influence of isotopic exchange with carbonate minerals, which makes the quantitative dating rather impossible. The $\delta^{18}O$ and $\delta^{2}H$ are similar to those of modern waters in springs and cold waters in wells situated near the Tatras, with several exceptions characterized by shift of $\delta^{18}O$ to heavier values, which are caused by isotopic exchange with carbonate minerals (Fig. 1). The isotopic composition of water in the Z1 well has become variable after the start of exploitation, which suggests changes in inflows to that well from different karstic channels. The isotopic altitude effect was estimated from the data of springs and wells within the Tatras area. For $\delta^{2}H$, the mean altitude of recharge area reads: $h(\delta^{2}H)$ (m a.s.l.) = $-69.1 \cdot \delta^{2}H - 4054$, with the uncertainty of about 100–200 m (Zuber et al., 2008).

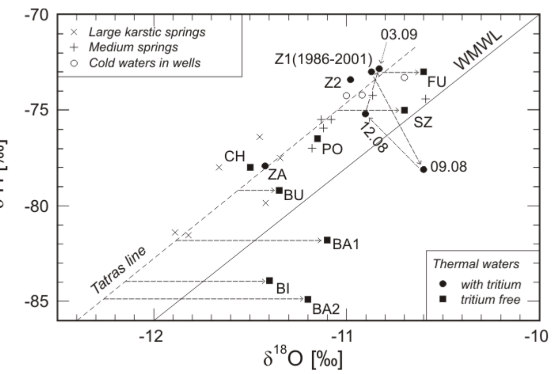

Figure 1. Isotope composition of the investigated waters with indicated shifts (horizontal lines) of $\delta^{18}O$ from the local meteoric line (see text in relation to changes in the Z1 well).

The most negative $\delta^{2}H$ values of thermal waters are close to those of large springs (Fig. 1), which may suggest their Holocene age. However, these most negative values are observed in the farthest wells whereas close to the recharge area, the $\delta^{2}H$ of thermal waters are similar to those of medium springs (Figs 1 and 2) indicating the low altitude recharge. Thus, the most negative $\delta^{2}H$ values of thermal waters observed in BI, BA1 and BA2 wells most probably result from recharge under cooler climatic conditions. Very high He excess contents and negative noble gas temperatures (NGT) derived from Ne and Ar concentrations (Fig. 2) are in agreement with such interpretation. The lack of ^{14}C with $\delta^{13}C$ values close to 0‰ in these three wells also confirms that hypothesis qualitatively.

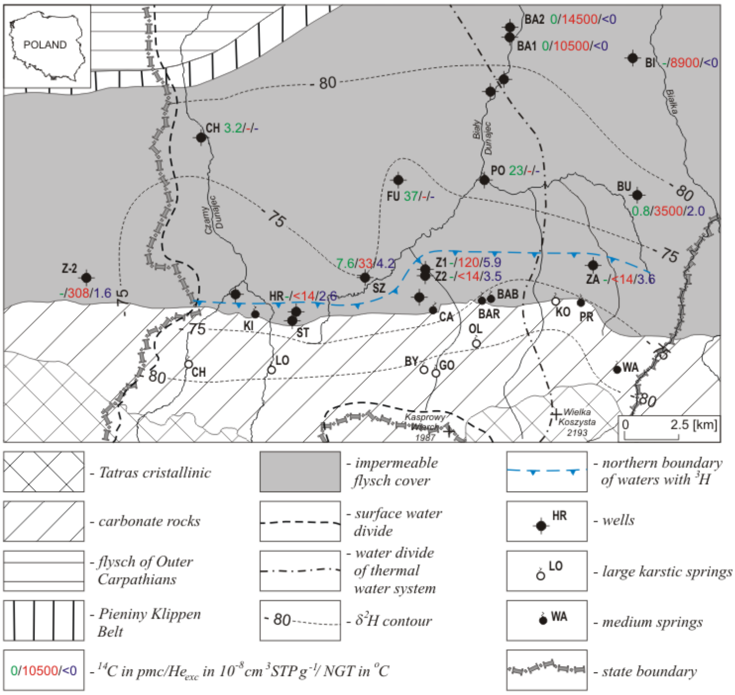

Figure 2. Environmental tracers in the Tatras and thermal waters of Podhale Basin.

According to all tracer data shown in Fig. 2, the oldest waters exist in the north-eastern part of the basin, whereas in the western part, the exchange of water is faster by one to two orders of magnitude. Such flow pattern, unexpected from the hydraulic conductivity values, probably results both from the presence of karstic channels in the western part enhancing regional permeability, and from obstacles to horizontal flow caused by fault zones in the eastern part.

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abstract id: **305**

topic: **4**
Mineral and thermal water

4.2
Origin of mineral and thermal waters

title: **On the origin of chloride waters in the Polish flysch Carpathians**

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keywords: flysch Carpathians, chloride waters, diagenetic waters

Chloride mineral waters in the Polish flysch Carpathians are exploited for therapeutical purposes in a number of spas; their origin being of interest for the determination of available resources and a proper management. All these waters in the flysch formations of the western part of the area resulted from combined effects of ultrafiltration of sedimentation water and dehydration of clay minerals during burial diagenesis, and possible mixing with meteoric waters during later infiltration stages (Zuber, Chowaniec, 2009). The diagenetic end-members are characteristic for the final stages of diagenesis with $\delta^{18}O \approx (6–7)‰$, $\delta^{2}H \approx –(20–30)‰$, and Cl^- contents of about 3.5 to 25 g/L. In some fault areas, the primary diagenetic waters ascend to the surface and mix with waters of local meteoric origin yielding two-component mixing lines in $\delta^{18}O–\delta^{2}H$ and $\delta^{18}O–Cl^-$ or $\delta^{2}H–Cl^-$ diagrams. The meteoric end-members are usually of modern ages, with $\delta^{18}O \approx –10‰$ and $\delta^{2}H \approx –70‰$.

In the eastern part of the Polish flysch Carpathians, where oil and gas fields exist, the data are not so simple, suggesting possible existence of several different end components of mixing processes (Porowski, 2006). From the data of that author presented in Fig. 1, three examples are selected and shown in Figs. 2 and 3. According to chemical data (Table 3 and 5 in Porowski, 2006) all these waters have TDS contents from several to more than 50 g/L with mNa^+/mCl^- distinctly above 1; the latter indicating the presence of diagenetic water with chemical components being of marine origin changed by ultrafiltration and diagenetic reactions (Zuber, Chowaniec, 2009). The isotope data of Fig. 1a suggest that either marine sedimentation water or highly evaporated meteoric water dominate in a number of cases. However, extrapolated $\delta^{18}O–Cl^-$ relations of examples shown in Figs. 2b and 3b lead to $\delta^{18}O$ values characteristic for the dehydration waters of the final stages of diagenesis with relatively low Cl^- contents. The $\delta^{2}H$ data in Figs. 2a and 3a completely disagree with the hypothetical mixing lines derived from the extrapolated lines given in Figs. 2b and 3b. These disagreements most probably result from shifts of $\delta^{2}H$ to heavier values, if formation water is involved in generation of hydrocarbons. The whole picture is complicated because some waters shown in Fig. 1 do not exhibit the influence of catagenesis, whereas some others have isotopic composition and Cl^- contents indicating intermediate stages of diagenesis.

In conclusion, the chloride components in all mineral waters of the Polish flysch Carpathians are of marine origin, completely changed by diagenesis of clay minerals. Majority of waters in the eastern part, have $\delta^{2}H$ values shifted to heavier values by generation of hydrocarbons.

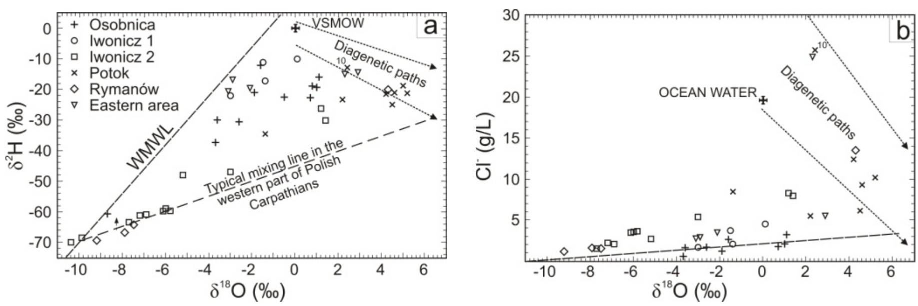

Figure 1. $\delta^{18}O–\delta^{2}H$ (a) and $\delta^{18}O–Cl^-$ (b) data of Central Carpathian Synclinorium (adapted from Porowski 2006, sample 10 from Zuber and Chowaniec 2009).

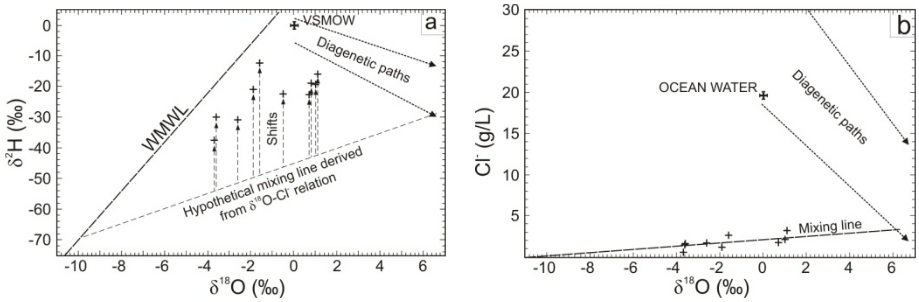

Figure 2. $\delta^{18}O$–$\delta^{2}H$ (a) $\delta^{18}O$–Cl^- (b) data of the Osobnica area selected from Fig. 1. Extrapolated $\delta^{18}O$–Cl^- relationship suggests the heavy end-member to correspond to the final stage of diagenesis whereas the $\delta^{2}H$ values in (a) do not correspond to the expected mixing line due to shifts to heavier values, which is caused by generation of hydrocarbons (catagenesis).

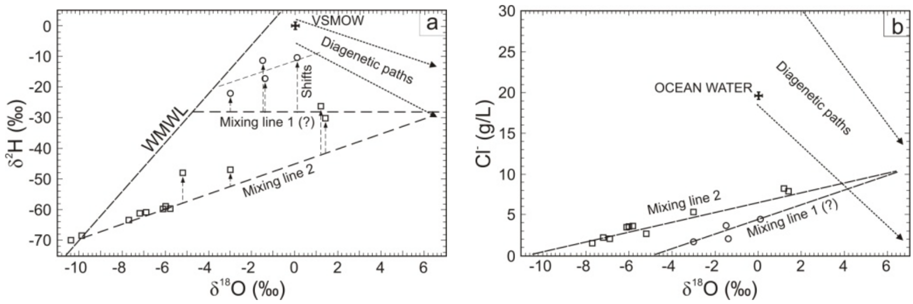

Figure 3. As in Fig. 2, but for the Iwonicz Spa area where two groups of samples can be distinguished. The $\delta^{18}O$–Cl^- relations suggest a similar isotopic heavy end-member as in Fig. 2 but with a higher Cl^- concentration. The mixing lines shown in (a) are deduced from the $\delta^{18}O$ values indicated in (b) in disagreement with the $\delta^{2}H$ values supposedly shifted by catagenesis. The hypothetical meteoric end-member for group 1 corresponds to recharge in a very warm pre-Quaternary climate.

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abstract id: **330**

topic: **4**
Mineral and thermal water

4.2
Origin of mineral and thermal waters

title: **Flow and groundwater chemical evolution in exposed salt diapirs and adjacent country rocks (Zagros Mts., Iran)**

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keywords: isotope, brine, salt diapir, arid climate, residence time

Zagros Mts. host numerous salt diapirs, which differs in activity, relief, surficial deposits etc. Some diapirs are exposed to arid conditions in low elevation, some are situated in higher altitude in less arid climate. While some diapirs are formed by vast surfaces build predominately by halite, at others the rock salt is covered by 20 m thick residuum, which even enable planting of crops (Bruthans et al., 2009). High variability of environments enabled to select distinct areas for study of water flow a chemical evolution in subsurface of diapirs. The wider surroundings of the salt diapirs are suffering by the scarcity of sources of low TDS water.

To understand the groundwater and soil water flow in various diapirs, its chemistry evolution and source of the high TDS in springs in country rocks adjacent to diapir several methods were applied:

- ^{2}H, ^{3}H, ^{18}O and ^{13}C isotopes and solute chemistry of water from saturated and unsaturated zone of diapirs and springs from country rocks were studied to estimate the residence time of water and its origin.
- Rain gages and no tension lysimeters were placed below some surfaces to study the flow via soil zone (isotopes and chemistry) and estimate the subsurface denudation rate.
- Infiltration rate on various surfaces was measured.
- To explain the water chemistry evolution along flow path, the composition of the soil, surficial deposits and rock salt was studied by means of XRD and XRF and solute chemistry was studied from water leaches of soil samples taken in various depth.
- Rain event causing flood was observed directly in the field including direct sampling on solute chemistry and ^{2}H and ^{18}O isotopes (Fig. 1).

Figure 1. Collection of the water immediately after heavy rain on the bottom of karst sinkhole causing focused recharge, which support the trees growing just ca 10 m above the halite.

Based on ^{2}H and ^{18}O isotopes, the water in all but one studied spring has meteoric origin. The residence time of groundwater in diapirs is generally short, with springs having tritium activity close to tritium activity of present rainwater. Brines from various diapirs have very similar composition, originating mainly from dissolution of the halite and gypsum. The salt exposures are virtually impermeable and water quickly drains out, causing flash floods. Given the high TDS in drainage the salt exposures are source of large amount of brines, which deteriorate the water quality in wide surroundings of the diapirs. On the contrary the surfaces build by thick soil show infiltration rates, which exceed common rain event except the most intensive ones. On some surfaces the TDS of the soil and surface water is very low (80 mg/L). As most of the water evaporate from these surfaces the amount of generated brine by deep percolation is very low. This enable to distinguish (based on aerial imaginary) the areas, which will be likely heavily polluted by brines from those potentially interesting for groundwater abstraction.

Comparison of Cl^{-}/SO_4^{2-} ratio of diapir brines and springs in country rocks shows that brines derived from diapirs are not responsible for increasing TDS of country rocks springs. Instead, the dissolved solids either originate from Gachsaran formation, which contain evaporate minerals or from dissolution of marginal parts of diapirs (formed mainly by gypsum) by groundwater from country rocks.

ACKNOWLEDGEMENTS

Research was supported by projects No. KJB315040801 of the Grant Agency of the Academy of Sciences of the Czech Republic and research project MSM00216220855 (Charles University in Prague)

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abstract id: **342**

topic: **4**
Mineral and thermal water

4.2
Origin of mineral and thermal waters

title: **Geochemistry and origin of mineral geoundwater from Fadeevskoe spa (Far East of Russia)**

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keywords: mineral groundwater, high pCO_2, CO_2 origin

INTRODUCTION

The Fadeevskoe spa is located in south part of Russian Far East, in Primorye region, in the upper reaches of the Klyuch Ivanov Creek. Yushakin was first to study this spa in 1968, in the subsequent years, nobody purposefully studied this deposit, and its further research was continued again only during works on the regional assessment of the mineral water resources. The intense drilling conducted in 1999–2001 allowed us to determine the geological and hydrogeological conditions of the deposit and to study the composition of the waters, gases, and host rocks. Four boreholes were drilled in the deposit area with core sampling from certain intervals. The deposit was studied to a depth of 100 m.

The performed studies of the underground waters, host rocks, and gas components of the Fadeevskoe deposit made it possible to determine the physico-chemical conditions of the formation and subsequent evolution of the mineral waters during their interaction with host rocks, to assess the circulation period of mineral waters, and to establish the genesis of carbon dioxide in the waters of the deposit localized in the watershed part of the Sikhote Alin Range.

GEOLOGICAL AND HYDROGEOLOGICAL SETTING

The Fadeevskoe deposit of high pCO_2 groundwater is located in the Samarka Terrane (Fig. 1) extending in the northeastern direction from the southern coast of the Primorye region to the lower reaches of the Amur River in the form of a band up to 100 km wide. The surrounding bedrock is composed of Jurassic stratified and chaotic terrigenous sediments enclosing abundant allochthonous sheets, blocks, and fragments originating from the Late Paleozoic and Early Mesozoic oceanic crust.

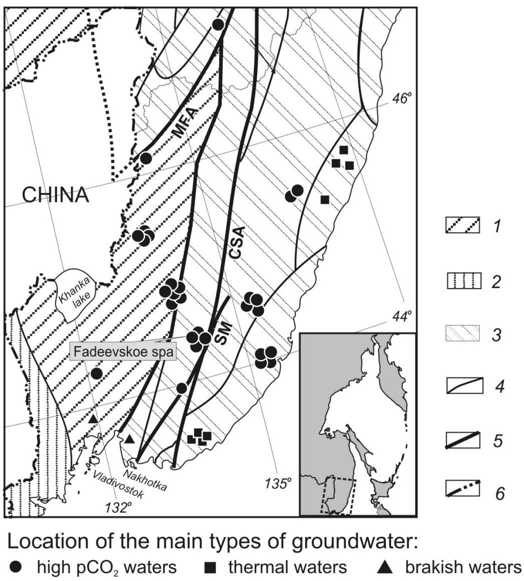

Figure 1. Tectonic scheme of the southern Russian Far East and the main types of groundwater location. 1 — Early Paleozoic superterrane; 2 — Late Paleozoic terrane; 3 — collage of Cretaceous terranes; 4 — boundaries of terranes; 5 — major faults: CSA — Central Sikhote Alin; MFA — Mishan-Fushun-Alchan; Sm — Samarka; 6 — state boundary of the Russian Federation.

The deposit is confined to the dense network of differently oriented fractures. The most significant among them is a system of near latitudinal fractures represented by thick subvertical brecciation zones best traceable along the river valleys, including the Klyuch Ivanov Creek. The system of feathering faults of northwestern strike is subordinate. The deposit is located in the Sikhote Alin hydrogeological massif and comprises two widespread aquifers: the aquifer of Quaternary fluvial sediments (aQ) and the aquifer zone of volcano_sedimentary sequences of the Upper Jurassic–Lower Cretaceous Samarka Formation (J_3–K_{1sm}).

The aquifer of Quaternary fluvial sediments (aQ) up to 3.5 m thick is ubiquitously distributed in the Klyuch Ivanov Creek valley, where it extends in the form of a relatively narrow band along its channel, being the uppermost one in the section. Its occurrence depth changes through the distribution area from zero (swamped areas) to 1.5–2.0 m. The water enclosing.

sediments are represented by sands, gravel, and boulders. The aquifer contains largely fresh waters with low mineralization and takes a limited part in the formation of carbonated mineral waters.

The aquifer of the Upper Jurassic–Lower Cretaceous Samarka Formation originates from zones of exo and endogenic fracturing. The waters from the exogenic fracturing are ubiquitously distributed in the undivided volcanosedimentary sequences of the Samarka Formation (J_3–K_{1sm}). The host rocks are represented by fractured siliceous varieties, sandstones, siltstones, and rhyolites. The zone of intense fracturing is developed up to a depth of 30 m. The aquifer is the uppermost one in the section of valley slopes and watershed areas and the second one from the surface under the water_bearing fluvial sediments of the creek. Below 30 m, the underground waters of the Samarka Formation are related to zones of endogenic fracturing. The waters are fresh with their mineralization being as low as 0.2–0.5 g/l, carbonated, ferruginous, and siliceous in composition. They were recovered by boreholes in tectonic fracturing zones in the depth interval of 30–100 m in local areas of intense water exchange that receive gas through fractures. The discharge of mineral waters to the surface is determined by the elevated pressure of the accompanying gas and is observable in the upper reaches of the Klyuch Ivanov Creek. The yield of the natural spring of mineral waters under undisturbed conditions is 0.15 l/s.

GEOCHEMISTRY OF WATERS

Surface waters. The Klyuch Ivanov Creek is the main surface water course of the area. Its drainage area is only 20 km^2. The creek is an intermittent channel, being characterized by a temporary flow; it dries up in the summer and becomes frozen over in the winter. The water consumption in the usual period is 10–15 l/s, and it manyfold increases during floods. The module of the surface runoff is 2–3 l/s from a square kilometer. The creek waters are hydrocarbonate with a mixed cation composition (Fig. 2). Among the cations, calcium, sodium, and magnesium are dominant. The chemical composition of the waters in the creek inherits to a certain extent that of the atmospheric precipitation. The water is characterized by low TDS (up to 240 mg/l) and pH (5.5–6.8). The analysis of seasonal variations in the composition of surface waters shows that their maximal TDS and concentrations of hydrocarbonate ion, Ca, and Na are observed in the spring (in March) during the period of the commencing of the snow cover thawing. This period is also marked by a decrease in the pH value from 6.8 to 5.5 and lowered Mg, sulfate ion, and chlorine ion contents.

Fresh groundwater. The fresh groundwater is confined to weathering, brecciation, and fracturing zones in the volcano-sedimentary rocks constituting the upper part of the Samarka Formation and is distributed through the entire study area. This type of groundwater are head waters and hydrocarbonate sodium and calcic in their composition with an elevated content of silica (Fig. 2). The waters are characterized by low TDS (up to 0.1–0.2 g/l), which is explained by the intense water exchange.

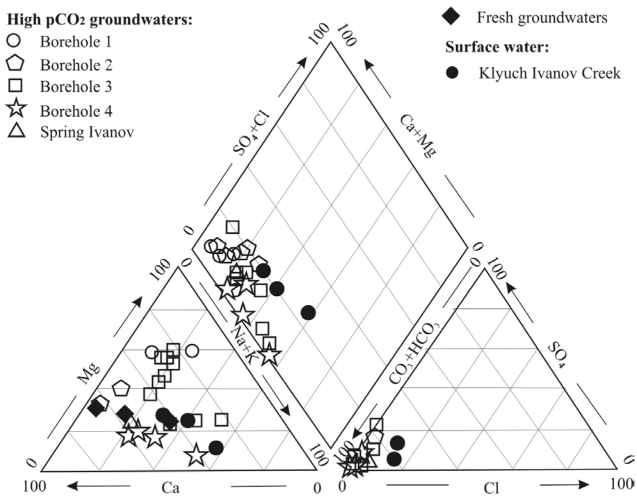

Figure 2. Piper diagram illustrated connection between the main ions in waters from Fadeevskoe spa.

High pCO_2 groundwaters. For the study of the hydrochemical section and the distribution of high pCO_2 groundwaters through the deposit, they were sampled with a step of 25–40 m. The chemical analysis of the high pCO_2 groundwaters shows that they are characterized by relatively low TDS in comparison with the other high pCO_2 groundwaters of the Primorye region (0.2–0.5 g/l). At the same time, they demonstrate relatively high concentrations of free CO_2, which is variable both through the section and laterally. Among the four boreholes that recovered high pCO_2 groundwaters in this spa, the minimal CO_2 content is recorded in Borehole 4, where it does not exceed 80 mg/l; the maximal CO_2 content (up to 2253 mg/l) is registered in the depth interval of 30–60 m in Borehole 1.

By their anion composition, the waters from all four boreholes are hydrocarbonate with different HCO_3^- contents. The highest content of HCO_3^- (1162 mg/l) was established in the sample taken in February of 2000 from Borehole 1 and the lowest one (189 mg/l) was recorded in the sample obtained in March of 2001 from Borehole 2. By the concentrations of the main cations, the mineral waters in the boreholes significantly differ from each other as well. The highest Na^+ concentration is observed in the waters of Borehole 4, while the concentrations of this element in the spring are almost three times lower. The highest (up to 168 mg/l) and lowest (up to 16 mg/l) Ca^{2+} contents are recorded in the waters from boreholes 4 and 1, respectively. The Mg^{2+} concentrations are also highly variable in the different boreholes with the highest (up to 66.8 mg/l) and lowest (7.3 mg/l) values being registered in the waters from Borehole 1 and the spring, respectively. By their geochemical type, the high pCO_2 groundwaters of the spa in the examined boreholes are also different. The Mg–Ca-HCO_3^- type of groundwater was found in boreholes 1–3, while borehole 4 yielded Ca–Na-HCO_3^- type of groundwater. The mineral waters from the spring belong to the Ca–Mg-HCO_3^- type.

The comparison of the concentrations of the hydrocarbonate ions with that of the sodium and calcium ions shows that the enrichment of the mineral waters with these elements almost directly depends on the content in the waters (Fig. 3), which is, in turn, proportional to the partial CO_2 pressure in the system. Precisely the influx of CO_2 into high pCO_2 groundwaters is responsible for the proceeding reaction: $H_2O + CO_2 \leftrightarrow H^+ + HCO_3^-$.

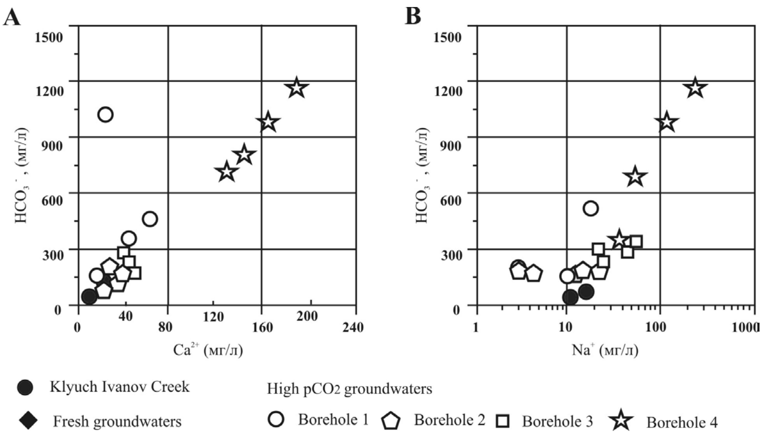

Figure 3. Correlation between HCO_3^- and Ca^{2+} (A) and HCO_3^- and Na^+ in waters from Fadeevskoe spa.

This type of groundwaters is ferruginous. Similar to the other components, the concentrations of Fe_{total} are highly variable through the area. The maximal (up to 45.56 mg/l) and minimal concentrations of Fe_{total} are recorded in the waters from boreholes 3 and 4, respectively. It is established that the waters from boreholes 1 and 2 are characterized by a positive correlation between the concentrations of ferrous iron and chlorine ion in the waters. A particular feature of the chemical composition of the high pCO_2 groundwaters is the high SiO_2 concentrations (17–69 mg/l), which is untypical of the mineral waters from the other manifestations in the Primorye region. The elevated silica content in the waters was presumably determined by its relatively rapid leaching from the rock cement. The high pCO_2 groundwaters are characterized by extremely low contents of the minor elements (Cu, Zn, Mn, Al, and others). This property is most likely explained by the high water exchange rate, i.e., the short term interaction in the water–rock system.

For establishing the correlation between the contents of the major components, as well as the pH and the TDS, we carried out the statistical processing of the chemical analysis. The results shows that the waters from Borehole 1 are characterized by positive correlations between the Fe^{2+} and Cl^-, HCO_3^- and Cl^-, Na^+ and HCO_3^-, and Fe^{2+} and HCO_3^- contents, as well as between TDS and the concentrations of Cl^-, Fe^{2+}, and HCO_3^-. For the mineral waters from Borehole 2, positive correlations with high correlation coefficients (>0.87) are recorded between the Mg and Na ions, the sulfate and sodium ions, the sulfate and Mg ions, the ferrous Fe and Cl, the Si and hydrocarbonate ion, TDS and hydrocarbonate ion content, and TDS and Si content. Negative correlations with high correlation coefficients are observed for the ions of Na and Cl, Mg and Cl, and Fe and Mg; the sulfate and Cl; the sulfate and ferrous Fe; and the CO_2 and pH. The groundwaters from Borehole 3 show a different correlation pattern between the components. The only positive correlation (with a moderate correlation coefficient of 0.7) is noted between the concentrations of hydrocarbonate and sodium ions. Also noteworthy is the negative correlation between the concentrations of Cl ions and the CO_2. Between the remaining components of the underground mineral waters, no significant correlations are recorded. The proportions of the components in the groundwaters from Borehole 4 are similar to their relations in the water from Borehole 1: positive correlations with relatively high correlation coefficients (>0.83) between the HCO_3^- and TDS, the HCO_3^- and Na^+, the Na^+ and CO_2, and the Fe^{2+} and Cl^-; a negative correlation between the pH and CO_2. Some of the compositional features of the groundwaters from Borehole 4 are determined by the stable correlations between the concentrations of the Mg ions and TDS ($r = 0.97$), the concentrations of the Fe^{2+} and Cl^- ($r = 0.96$), and the concentrations of the Fe^{2+} and CO_2 ($r = 0.99$).

The distinct positive correlations observable for some of the components in the high pCO_2 groundwaters from the boreholes in question allow the inference that their TDS (at least in three of the four boreholes (1, 2, 4)) directly depends on the content of HCO_3^- and is practically indifferent to the concentrations of the cations in the waters. This fact confirms the above assumption that the high pCO_2 groundwaters from the Fadeevskoe spa are characterized by very rapid circulation, which prevents their sufficient saturation with salt components during the interaction in the water–rock system. This assumption is also supported by the geological and hydrogeological structure of the deposit. The distribution of the high pCO_2 groundwaters is consistent with the formation of the fresh groundwater in this area. The high pCO_2 groundwaters waters replace partly fresh groundwaters to form a flow in common. They are characterized by the same movement direction, consumption, and main sources of resource formation, except for the chemical and gas compositions.

The hydrogen and oxygen isotope ratios first obtained for the aqueous phase of the mineral waters from the Fadeevskoe deposit are well consistent with similar data on other deposits of the Primorye region and characterize them as being of the atmospheric infiltration type.

Gas phase. Table 1 presents data on the chemical and isotopic composition of the freely released gas. The high pCO_2 groundwater contain 0.5 to 1.6 g/l of dissolved CO_2 gas. The waters in the central part of the studied area exhibit elevated pressure on account of the spontaneous gas release. The partial pressure of the CO_2 calculated for the mineral and fresh underground waters is 0.7 and 0.1 bar, respectively. The free gas is represented by carbon dioxide and nitrogen with an insignificant methane and oxygen admixture. The nitrogen is of atmospheric origin, while the insignificant hydrocarbon concentrations may be explained by the transformation of organic matter in the section. The carbon isotope composition ($\delta^{13}C$, ‰) indicates that the carbon dioxide is of deep mantle origin. The $\delta^{18}O$ value in the CO_2 is also lighter as compared with that in the water, which indicates their different geneses and short-term interaction in the rock–gas system.

Table 1. Composition of the escaped gas from the Fadeevskoe spa.

Sampling data	CO_2,%	O_2-Ar, %	N_2, %	CH_4, %	$\delta^{13}C$,‰	$\delta^{18}O(CO_2)$,‰
03.08.2001	98.84	0.17	0.99	0.0001	—	—
26.02.2008	97.10	0.28	2.59	0.0027	–9.9	–23

CONCLUSIONS

So, the geochemical study of bedrocks, underground and surface waters, and associated gases in the Fadeevskoe deposit of carbonated waters (Sikhote Alin, Primorye region) revealed that the chemical composition of these waters is formed in the zone of active water exchange in the limited area of the discharge zone. The high pCO_2 mineral groundwater has s short residence period. Calculations of the saturation indices show that the mineral waters are undersaturated with carbonates and aluminosilicates. The main factors that influence the water mineralization are the excess carbon dioxide in water and the circulation time.

abstract id: **384**

topic: **4**
Mineral and thermal water

4.2
Origin of mineral and thermal waters

title: **Factors of thermomineral groundwater origin at Josanicka banja spa, Central Serbia**

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keywords: groundwater origin, thermomineral waters, fluorides, silica

The Josanicka Banja Spa is situated in central part of Serbia on slopes of Kopaonik Mountain. It is characterised by significant thermo mineral resources, both as to quality and quantity (Q>15 l/s, T up to 79°C). The occurrence of thermo mineral waters in the territory of the Josanicka Banja Spa is related to the young (Neogene) magmatism and tectonic activity taking place in the Kopaonik region.

Qualitative characteristics of the Josanicka Banja Spa thermo mineral water have been formed in various geological, hydrogeological, geochemical and hydro chemical, processes in co action of water, rocks and gases. Factors of thermo mineral water formation can be both the main and auxiliary ones, or direct and indirect. Factors affecting the formation of thermo mineral groundwaters in the Josanicka Banja Spa are presented in Table 1.

Table 1. Factors affecting the formation of thermo mineral groundwaters in the Josanicka Banja Spa.

FACTORS OF THERMOMINERAL WATER FORMATION IN JOŠANIČKA BANJA SPA					
PHYSICO-GEOGRAPHICAL	GEOLOGICAL	HYDROGEOLOGICAL	PHYSICO-CHEMICAL	PHYSICAL	ARTIFICIAL

Physico-geographical factors. The separated relief in the Josanicka Banja Spa region conditions more intensive water exchange, which is favourable to the formation of low mineralized water (M~0.2 g/l). A thick hydrographic network is favourable to the intensive process of water exchange in water-bearing horizons, which conditions the formation of low mineralized waters(M~0.2 g/l). Climatic elements (precipitation, air temperature, and evaporation) do not affect the formation of the chemical composition of the Josanicka Banja Spa thermo mineral water significantly.

Geological factors The Kopaonik region, to which the Josanicka Banja Spa also belongs, is characterized by heterogeneous geological structure. It is made of igneous, sedimentary and metamorphic rocks of varied ages, from the youngest Quaternary alluvial placers of the Josanica River to the oldest Palaeozoic slates. Tectonic movements having taken place in the Josanicka Banja Spa region resulted in a large number of faults, creating a favourable predisposition for the formation, circulation, and discharging of thermo mineral water in the Josanicka Banja Spa region.

Hydrogeological factors The complex geological structure and setting of the study area have conditioned the formation of various aquifer types. In the Josanicka Banja Spa region, on the basis of structural type of porosity, there have been singled out the following aquifer types: a compact aquifer, within alluvial sediments of the Josanica River, a fissure aquifer, and a karst-fissure (complex type) aquifer. Thermo mineral groundwater in the Josanicka Banja Spa region was formed within a fissure aquifer. This aquifer type has been developed in igneous (granodiorite, and quartz-diorite, harzburgite) and metaphoric rocks (phyllite, chlorite-epidote-actinolite shale and serpentinite).of which the Josanicka Banja Spa region is mostly formed. A tectonic activity taking place in the Kopaonik area resulted in numerous faults. Two faults are most pronounced in the Josanicka Banja Spa region. The first one stretches along the valley of the Josanica River striking east-west, while the other one is vertical in relation to it, and goes along the valley of the Velestica River striking north-south. At the spot of the crossing of these two faults, there is a seepage spring of thermo mineral water characterised by thermomineral water temperatures ranging from76°C to 78°C. Going westward from the mentioned spring, the temperature of thermomineral water decreases, thus in the B-3 and B-6 abstraction boreholes situated about 500 m from the thermomineral springs in the centre of the Josanicka Banja Spa the temperature of groundwater ranges from 52–56°C, while at the distance of about 2 km west of the spring in the Josanicka Banja Spa , at the Slaniste locality, the thermo mineral water is characterised by the water temperature ranging from 36 to 37°C. The formation of thermo mineral water qualitative characteristics in the Josanicka Banja Spa region is related to younger deep-seated igneous and, by their activity, caused thermo metamorphic processes having taken place in the Kopaonik area during Neogene. The thermo mineral waters of the Josanicka Banja Spa (according to the classification by Ivanov, 1977) belong to the group of *nitrogen low mineralized silicon thermo mineral waters of atmospheric origin*. These waters are genetically related to massive crystalline rocks, within which hydrogeologically uncovered fault structures, enabling the infiltration of the waters of atmospheric origin and their warming at higher depths, are readily formed and long preserved. Waters formed in such conditions are characterised by low mineralization from 173.8 to 256.4 mg/l), with the prevailing sodium ion, the high content of silicon acid (32 to 90 mg/l) and a pronounced alkaline reaction (pH from 8.4 to 9.7). Analyses of qualitative properties of thermo mineral waters were carried out in four locations in the Josanicka Banja Spa (Tab. 2).

Table 2. Survey of qualitative properties of thermo mineral waters in Jošanička Banja Spa region.

Occurrence/ Parameter	**Q (l/s)**	**T (°C)**	**pH**	**M (mg/l)**	**Na^+ (mg/l)**	**CO_3^{2-} (mg/l)**	**SO_4^{2-} (mg/l)**	**Cl^- (mg/l)**	**F^- (mg/l)**	**SiO_2 (mg/l)**	**H_2S (mg/l)**
Jošanička spring	15	76–78	>8.4	243.9	89.0	60	60	14	4.48	90	1.50
Slanište spring	2	36–37	>8.4	256.4	98.0	60	70	28.4	5.6	90	0.12
B-3 borehole	1.5	52	>8.4	173.8	71.5	66.0	15.0	21.3	4.4	32	1.02
B-6 borehole	3	56	9.7	185.0	63.4	54.6	32.4	10.1	3.75	79.5	2.1

Physico-chemical properties. The migration ability of elements (Na, Li, and F) depends to a large extent on the pH index. If we increase the temperature, the pH index of deposited hydroxide increases (to 9.7).The solubility of a salt plays a significant role in the formation of anion – cat ion composition. Thus, a sodium ion, a carbonate ion, and a silicon ion occur as characteristic ones for low mineralized waters (from 183 to 256.4 mg/l).

Physical factors. As the temperature increases, the ability of solubility changes. In ordinary conditions the solubility of silicon acid is highly low. At high temperatures silicon–carbonate–sodium–waters often occur, which is the case with Josanicka Banja Spa waters. As the temperature increases, the pressure increases as well, which affects the ability of water for solubility to a significantly lesser degree?

Artificial factors. By monitoring of thermo mineral water exploitation at the abstraction boreholes (B-3 and B-6) in the Josanicka Banja Spa, the trend of the yield decrease is observed(B-3 from 3 l/s to 1.5 l/s, B-6 from 7 l/s to 3 l/s, after more than 25 years of exploitation). On the other hand, the exploitation of many years has affected the temperature increase (B-3 from 50 to 52, B-6 from 52.5 to 56).

abstract id: **392**

topic: **4**
Mineral and thermal water

4.2
Origin of mineral and thermal waters

title: **Stable isotope study on the origin of sulphate in the thermal waters of Budapest and its surroundings**

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keywords: thermal water, sulphate, stable sulphur and oxygen isotopes, karst, Hungary

INTRODUCTION

The karstic thermal water flow system of the Dunazug Mts. (Hungary) supplies plenty of luke-warm (18–30°C) and warm (30–77°C) water for balneological, recreational and wellness purposes with variegating chemical composition in Budapest, capital of Hungary. All of these waters coming from different depth (10–1000 m) are characterized by significant, but varying amount of dissolved sulphate (100–400 mg/l). For the origin of this sulphate there are two hypotheses; 1) Sulphate originates from the oxidation of pyrite in the Tard Clay Formation contacting the karstic aquifer; 2) Sulphate originates from the dissolution of gypsum and anhydrite contained in Permian and/or Triassic marine evaporites and carbonate rocks (lime-stone and dolomite). Stable sulphur and oxygen isotopic measurements have been made on the dissolved sulphate in order to determine its origin.

RESULTS AND DISCUSSION

Twelve thermal water well and four luke-warm spring were sampled for stable S and O isotopic measurements. The dissolved sulphate was precipitated as $BaSO_4$ by means of 10% solution of $BaCl_2$ on spot. The stable S and O isotopic measurements were made in the Mass Spectrometry Laboratory of the Institute of Physics, University of Marie-Curie Skłodowska, Lublin (Poland) (for details see Hałas, Szaran, 2001, 2004; Hałas, 2007).

The sulphur isotopic composition of dissolved sulphate in the thermal warm water (30–77°C) of Budapest is characterized by rather positive $\delta^{34}S$ values varying between 10.2 and 17.7 $[‰]_{CDT}$ (mean is 13.6‰); however those of luke-warm water rages from -5.7‰ to -2.5‰ (mean is -4.2‰). This characteristic difference between the $\delta^{34}S$ values of warm and luke-warm waters indicates different genesis.

Vető et al. (1999) published $\delta^{34}S$ values for the total sulphur (pyrite) in the Tard Clay Formation between –20‰ and +15‰ with a mean of 2.6‰. While the $\delta^{34}S$ values of Upper Permian evaporites are from 9.51‰ to 20.93‰ (mean value is 12.78‰; Hámor, 1997), and Lower Triassic evaporates are from 15.98‰ to 33.01‰ with large dispersion (mean $\delta^{34}S$ value is 24.28‰, Hámor, 1991). Based on these data the dissolved sulphate in the warm thermal water of Budapest originates from the Upper Permian evaporates, while that in the luke-warm water originates mostly from oxidation of pyrite in the Tard Clay Formation.

The $\delta^{18}O$ value of the dissolved sulphate in the warm thermal water varies in a very narrow range; from 4.2 to 6.4 $[‰]_{VSMOW}$, which is significantly lower than the marine sulphate of Triassic and Permian age (10–15‰). The water temperature ranges between 40 and 80°C, because cold water mixes to the upwelling hot water. An explanation for the lower $\delta^{18}O_{SO4}$ values can be isotope exchange between the oxygen atoms of sulphate and water molecules. The maximum temperature of water calculated by means of the formula given by Kusakabe and Robinson (1977) based on the oxygen isotope fractionation between water and sulphate is 70–90°C, which matches well with the measured bottom well temperatures. This indicates that the oxygen isotopic equilibrium in the water-sulphate system can be reached at around 80°C within the time frame of 20 thousand years (the age of thermal water is estimated to be between 13 and 20 ka, Deák, 1979)

ACKNOWLEDGEMENTS

This work has mostly been financed by the Hungarian Scientific Research Fund (OTKA 60921 project).

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IAH 2010 Krakow

abstract id: **400**

topic: **4**
Mineral and thermal water

4.2
Origin of mineral and thermal waters

title: **Origin of mineral water from Rogaška Slatina (Slovenia)**

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keywords: Rogaška Slatina, mineral water, origin, sustainable management

INTRODUCTION

Rogaška Slatina is famous by mineral water, which was discovered in this place in the time of Old Romans. The Bottling Company of Droga Kolinska d.d. is one of the powerful economic activities in Rogaška Slatina today. It produces natural mineral waters (Donat Mg, Tempel and Edina), spring water and soft drinks. Besides, aquifers with mineral water are exploited also for spa needs.

Numerous investigations of Rogaška groundwaters were subjects to balneology and to larger exploitation quantities (Nosan, 1975) that is why information are missing that are essential for definition of the Rogaška aquifer system and for its protection. Questions on the groundwater recharge area and dynamics, on connections between aquifers and on solute transport have remained open, which is closely connected with the field geology and structure. The latter is very complicated - three regional faults intersect in this area, which is folded to anticlinal and synclinal folds. The nature of geological structures, their mutual relations and extent haven't been explained at a satisfactory level in many parts.

With regard to results of previous hydro-geochemical investigations (Nosan, 1975; Pezdič, 1997) it was presumed that the Boč massif near Rogaška Slatina is a catchment area of Rogaška mineral waters, although geological data did not support this hypothesis (Aničić & Juriša, 1984). Hence, complex geological, hydrogeological, chemical, geochemical, isotopic and microbiological investigations were performed in this area during a period 2008-2010 to answer the discussed open questions.

STUDY AREA

The study area with its broader surroundings is geologically one of the most complex parts of Slovenia. It is the juncture of three major regional fault systems, separating three tectonic units (Figs.1 and 3). The Boč massif belongs to the Southern Karavanke unit. It borders to the south with Donat line on the narrow tectonic unit between the Donat line and Šoštanj fault close to which the town of Rogaška Slatina is situated. To the north, the Dravinja fault as part of the Periadriatic line separates the Southern Karavanke unit from the Upper Austro-Alpine unit. The ongoing dextral strike-slip motion along the Periadriatic line and the Šoštanj fault and associates eastward extrusion of the Eastern Alps as a result of the northward shift and counter-clockwise rotation of the Adria microplate that were recently observed using the GPS (Vrabec & Fodor, 2006; Weber et al., 2006). The complexity of the study area is reflected in lithological heterogeneity as a result of faulting into many small tectonic blocks, which are relatively displaced and folded (Figs. 1 and 3). Most of the area is composed of massive limestones and dolomites of Carnian age. They are capping the Boč mountain crest. Oligocene and Miocene beds, covering the northernmost part of the territory and the lower slopes north of Rogaška Slatina, are composed of alternating sandstones, sands, shaly claystones and marlstones and conglomerates in the lower parts. A wide belt of volcanic rocks (andesite, its tuffs and volcanic breccias) is also present in within these units. The upper part is almost entirely composed of hard and bituminous marlstones (Aničić, Juriša, 1984).

Mineral water is stored in fractured layers of the Oligocene tuff covered by the Upper Oligocene and Lower Miocene beds (Fig. 1). The disccused water belongs to a magnesium-sodium-hydrogen carbonate-sulphate facies. It could be exploited from five boreholes that are 24 to 600 m deep (Fig. 1). Donat Mg is the most famous among Rogaška mineral waters. It has the highest mineral content (Tab. 1) and contains more than 1000 mg/l of Mg.

Spring water and thermo mineral water are also exploited from the study area (Fig. 1). The former is stored in fractured Triassic carbonate rocks and Miocene sandstones of the Boč massif and the latter in a dolomitize keratophyre at depths between 1500 and 1700 m.

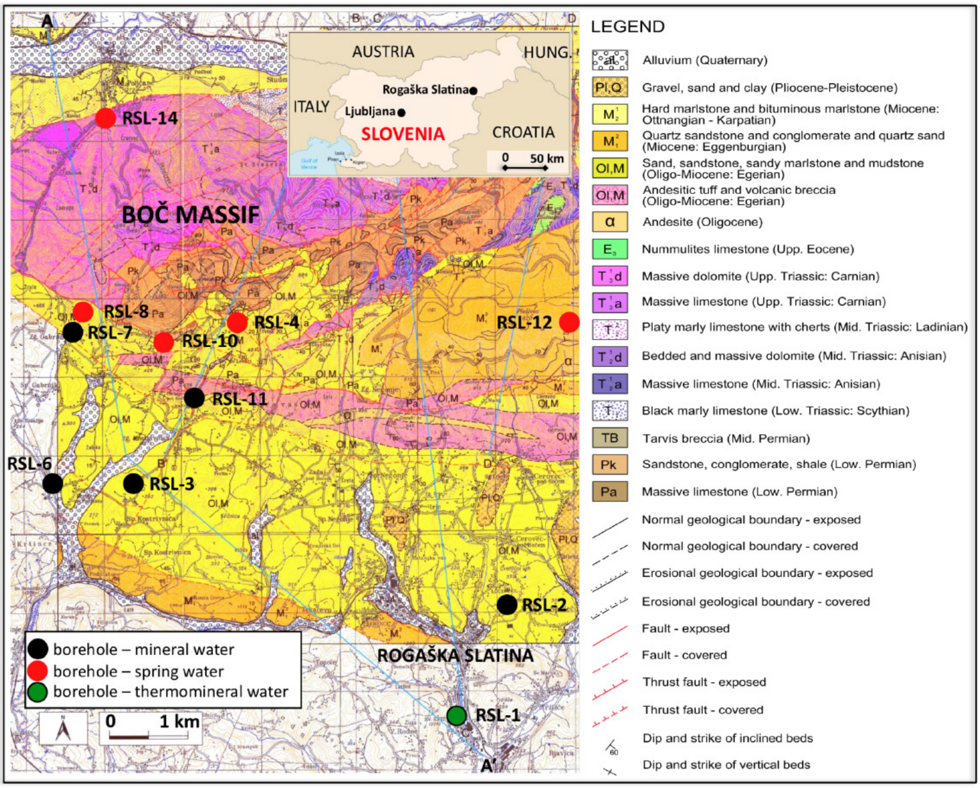

Figure 1. Geological map of the study area with locations of boreholes with mineral, thermo mineral and spring water.

THE RESEARCH METHODOLOGY

Detailed geological, hydrogeological, chemical, biological and isotopic investigations were performed in the study area with the aim to construct a local hydrological model that will provide the ability to predict flow and solute transport in the observed aquifer system and to asses the optimal balance between environmental protection and economic use of Rogaška groundwaters. However, only geological, hydrogeological and isotopic investigations are the topic of this paper.

A detailed structural-geological mapping was performed in the study area. Mutual relations of geological structures and lithological units were shown and also the type and extent of fractured zones that are main factors controlling the development of a hydrological network.

Hydrogeological investigations based on a so-called quantity monitoring, performed during a period of two years at important springs and boreholes of the study area. Besides, precipitation was monitored at four locations. The hydrological balance of the Boč massif will be calculated in 2010. It has not been made up to now, but it is a relevant method for definition of the fractured aquifer system with mineral and drinking water and for validation of the hypothesis that the Boč massif is the catchment area of Rogaška mineral waters.

Isotopic, chemical and microbiological investigations were fundamental for studies of groundwater dynamics and solute transport in aquifers with mineral and spring water and among them. They based on a so-called quality monitoring that run parallel with the quantity monitoring. The monitoring was performed in 5 boreholes with mineral water (RSL-2, RSL-3, RSL-6, RSL-7 and RSL-11) and 1 borehole with thermo mineral water – RSL-1 (Fig. 1 and Tab. 1). Additionally spring water from limestone (RSL-4, RSL-10), dolomite (RSL-8, RSl-14) and sandstone (RSL-12) was monitored (Fig. 1, Tab. 1). The quality monitoring included in-situ measurements of groundwater temperature, specific electroconductivity and pH and the water sampling for laboratorial analysis that was performed monthly as a rule. The geochemical laboratory of Joanneum Research, Institute of Water Resources Management (WRM) was responsible for isotopic investigations that based on analyses of groundwater ^{3}H, ^{13}C-DIC and ^{14}C composition.

Table 1. Average values of sampled water discharges (Q), specific electroconductivity (SEC), mineralisation (M), temperature (T) and pH in the period 2008–2010.

	Mineral water					**Thermo mineral water**	**Spring water fromlimestone**		**Spring water from dolomite**		**Spring water from sand-stone**
Borehole (depth)	RSL2 274 m	RSL3 24 m	RSL6 606 m	RSL7 603 m	RSL11 170 m	RSL1 1700 m	RSL4 215 m	RSL10 130 m	RSL8 170 m	RSL14 38 m	RSL12 100 m
Q (l/s)	0.5	0.2	1	0.4	0.1	6.0	2.2	2.1	1.4	40.0	2.0
M (g/l)	12.75	5.80	11.80	8.65	8.08	6.00			0.5		
SEC (µS/cm)	10999	5165	10539	8627	7102	6418	459	379	570	481	382
T (ºC)	14.6	11.9	28.4	15.1	12.0	55.4	12.6	11.	11.7	12.9	9.9
pH	6.8	6.4	6.9	6.5	6.5	7.1	7.1	7.5	7.3	7.5	7.7

RESULTS

A new structural-geological map of the study area was made. It serves as grounds for construction of a conceptual model of the discussed aquifer system and for evaluation of natural background of mineralization. Field maps include the following elements: lithological data (rock types, rock structures and their ages), structural data (bedding dips, faults, folds and fractured zones), hydrological and geomorphological data (springs, wets, vertical shafts, sinkholes and dolines). The data clearly indicate the dependence of a hydrological network on the geological factors. All springs, swallow holes, shafts and dolines are tied to lithological contacts and fault zones. However, the most important outcome of the structural-geological mapping is the better understanding of the Boč massif tectonic structure, which contradicts previous interpretations. According to our model, Upper Paleozoic to Lower Mesozoic carbonate complex of the Boč massif is not thrusted to the north over the Miocene clastic rocks as it is illustrated in the Basic Geological Map 1 : 100,000 (Aničić & Juriša, 1984). It was found out that the contact between the discussed rock units in the northern slope of the massif is inclined at about 75° to the N-NW direction. This finding is especially important to prove our research hypothesis that the Boč massif could be the recharge area of Rogaška mineral waters (Figs. 2 and 3). Previous models do not permit such an interpretation since the fractured carbonate aquifer system would be cut off with thrust fault in relativelly shallow depths and impermeable Miocene clastic rocks below the supposed contact would not allow a deep groundwater flow (Figs. 2 and 3).

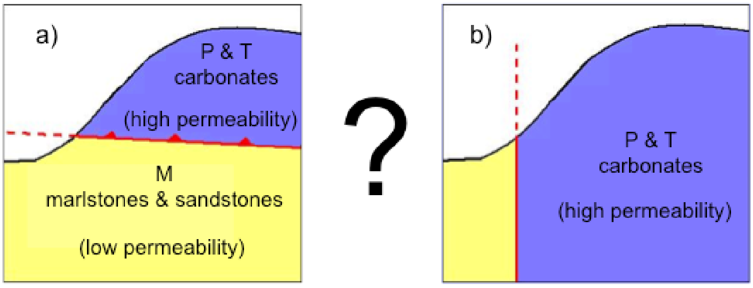

Figure 2. Open question one the contact between the P-T and M rocks in the northern side of the Boč massif.

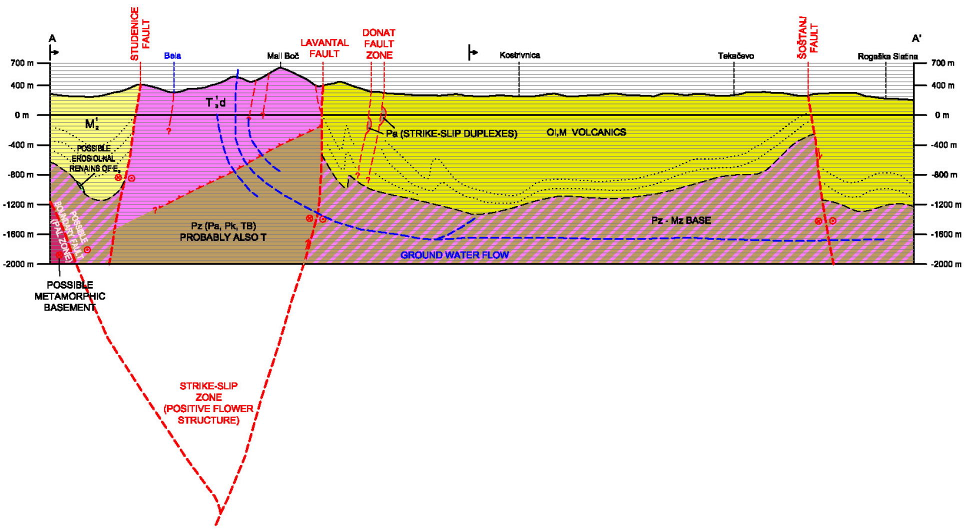

Figure 3. Geological cross section A-A' of the Rogaška Slatina area (see Fig. 1).

The existing structural boreholes indicate that the Permian basement is present at very different depths in the study area. This reflects great displacements along nearly sub-vertical faults at relatively short distances as well as the presence of an important strike-slip zone trending ENE-WSW parallel to the Ljutomer fault. Our model is also in accordance with structural-geological models of a broader region in which an astomosing sub-vertical system of NW-SE and E-W trending dextral strike-slip faults are arranged in a positive flower structure in a trenspressional tectonic regime (Márton et al., 2002).

The Rogaška mineral waters discharge with a help of a gas lift, thermo mineral water discharges with a help of a thermo lift, while spring waters of boreholes RSL-4, RSL-8, RSL-10 and RSL-14 are artesian. Average values of sampled water discharges, specific electroconductivity, mineralisation, temperature and pH during a monitoring period are presented in Table1.

The results of tritium (^3H) analyses in sampled groundwater are illustrated in Figure 4. They indicate older and younger groundwaters (younger than 55 years) and reflect a mixing of groundwaters. Old groundwaters refer to RSL-1, RSL-2, RSL-6, RSL-7 and RSL-11 (Fig. 1, Tab. 1). These waters are thermo mineral and mineral waters, respectively. RSL-3 is also mineralized, but it should be mixed with young fresh water. Other groundwaters are younger than 55 years and are categorised as spring water.

The ^{13}C isotopic composition of the dissolved inorganic carbon in sampled groundwater is also presented in Figure 4. The figure points out groundwaters that are influenced by the volcanic CO_2: RSL-2, RSL-3, RSL-6, RSL-7 and RSL-11. These waters are highly mineralized, as it is evidenced in Table 1. The RSL-1 water has a lower mineralization, which is reflected in ^{13}C-DIC values.

DISSCUSION AND CONCLUSIONS

The presented results confirm the research hypothesis so far. They gave important information on the recharge area and on the groundwater origin, on mixing processes and groundwater residence times and with that on hydrodynamic connections among individual aquifers. They will be combined with the results of other investigations in a hydraulic model of the Rogaška Slatina area, developed with a help of computer tools MIKE SHE (DHI Water & Environment) during the next research phases. The model will provide the ability to determine the optimal balance between environmental protection and economic use of mineral and spring water resources in the Rogaška Slatina area and it will contribute to an efficient management of the discussed groundwater resources.

a) b)

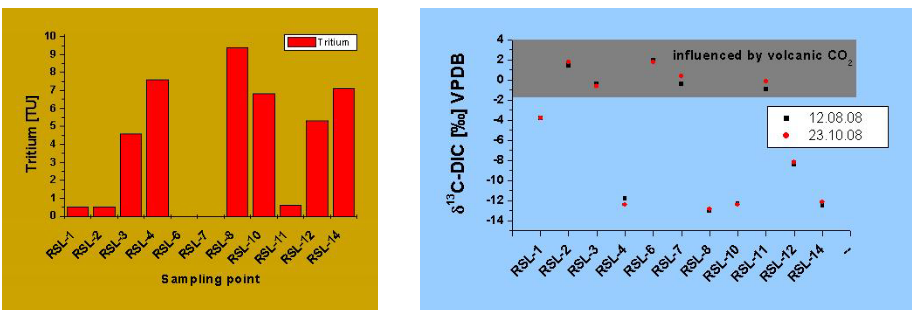

Figure 1. a) Tritium concentrations, b) ^{13}C isotopic composition of dissolved inorganic carbon in groundwater, sampled in the Rogaška Slatina area.

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abstract id: **415**

topic: **4**
Mineral and thermal water

4.2
Origin of mineral and thermal waters

title: **Verification of conceptual model of the Budapest karstwater regime by environmental isotopes**

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keywords: conceptual karstwater model, stable isotopes, radiocarbon dating, tritium, ice-age groundwater

INTRODUCTION

Conceptual models describing the working mechanism of thermal karstic reservoirs around Budapest were developed and verified by geological, hydrological, hydraulical, geothermal, water quality and isotope hydrological data. Results of detailed environmental isotope (^{14}C, ^{3}H, $\delta^{2}H$, $\delta^{18}O$ and $\delta^{13}C$) studies accomplished in this project are presented.

CONCEPTUAL MODEL

Natural spring (of 20 to 65°C) activity occurs at the border of the Buda-Pilis Mountains close to the Danube River (the regional karstic base level of this area) along tectonic lines. These springs are mixtures of a colder component arriving directly from the nearby mountains and of a warm component from the pressured, confined part of the karstic aquifers where the overlying clayey sediments determine the flow-paths. By reaching the deepest point of the flow-path (at the boundary of Mesozoic basement) the flow moves towards the springs where it enters the surface, after some mixing with cold or lukewarm karstic waters.

VERIFICATION OF MODEL BY ENVIRONMENTAL ISOTOPES

$\delta^{2}H$ and $\delta^{18}O$ data of more than 90 wells and springs are close to Meteoric Water Line ($\delta^{2}H = 8.4 \cdot \delta^{18}O + 12.3$ [‰]) proving that both cold and warm components originate from precipitation fallen in the Buda-Pilis Mountains. $\delta^{2}H$ and $\delta^{18}O$ of the cold component (–70 and –9.5‰ respectively) is similar to the annual mean of precipitation while of the thermal component is lighter down to –95‰ and –12.5‰. These data indicate that the temperature at the infiltration of warm component was 2 to 8°C lower than today, i.e. the termalwater is „Ice-age" groundwater.

^{14}C groundwater ages of thermal component, are more than 10 thousand years (estimated by $\delta^{13}C$ correction), supporting the Ice-age origin. Both ^{14}C and stable isotope data prove that the cold component is younger to be infiltrated in the Holocene ages. In case of springs the ^{14}C "ages" are fictitious because of the mixing process and are characteristic of the mixing rate.

Vulnerability of the thermal karst regime was investigated by tritium (^{3}H) data. Karst water of the thermal wells is tritium less (<0.5 TU) i.e. protected against the modern (after 1952) anthropogenic pollutions. On the other hand greatest part of the springs contains detectable tritium originating from the fresh, shallow local groundwater, so the thermal karstic springs along the Danube River can be considered as the most sensitive spots of flow regime. The thermal waters are used only for balneo-therapeutical and mineral water bottling purposes and are under very strict management.

TDIC (Total Dissolved Inorganic Carbon) content (mainly free CO_2) grows via temperature in Budapest thermal karst regime. Origin of surplus CO_2 (post volcanic or metamorphic) was investigated by $\delta^{13}C$ and chemistry data. Using equations of isotope dilution and mass balance the intercept of the $\delta^{13}C_{measured}$ via 1/TDIC represents the $\delta^{13}C$ of the surplus CO_2. The intercept was found as +3‰ indicating metamorphic origin at temperature higher than 200°C. Volcanic origin of surplus CO_2 can be excluded because these gases are characterized by more lighter (–5 to –7‰) $\delta^{13}C$.

ACKNOWLEDGEMENTS

The research was performed in the framework of OTKA 60921 project (2007 to 2010) financed by the Hungarian Academy of Sciences.

abstract id: **495**

topic: **4**
Mineral and thermal water

4.2
Origin of mineral and thermal waters

title: **Thermal conditions of eastern part of Polish Carpathians inferred from hydrogeochemical studies of mineralized and thermal waters**

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keywords: thermal waters, oil-associated waters, chemical geothermometers, clay minerals dehydration

INTRODUCTION

The main reservoirs of thermal waters in Poland occur within the sedimentary basins of Polish Lowlands and crystalline massifs of the Sudetes Mts. The Polish part of the Carpathian Mts. constitutes the so-called Carpathian Geothermal Province which consists of two geologically distinct parts: (i) the Inner Carpathians – the southern part, composed of crystalline rocks and Mesozoic sediments, folded during the Late Cretaceous; (ii) the Outer Carpathians (Flysch Carpathians) – the northern part, composed of Cretaceous and Paleogene sedimentary formations, folded during the Neogene (Fig. 1).

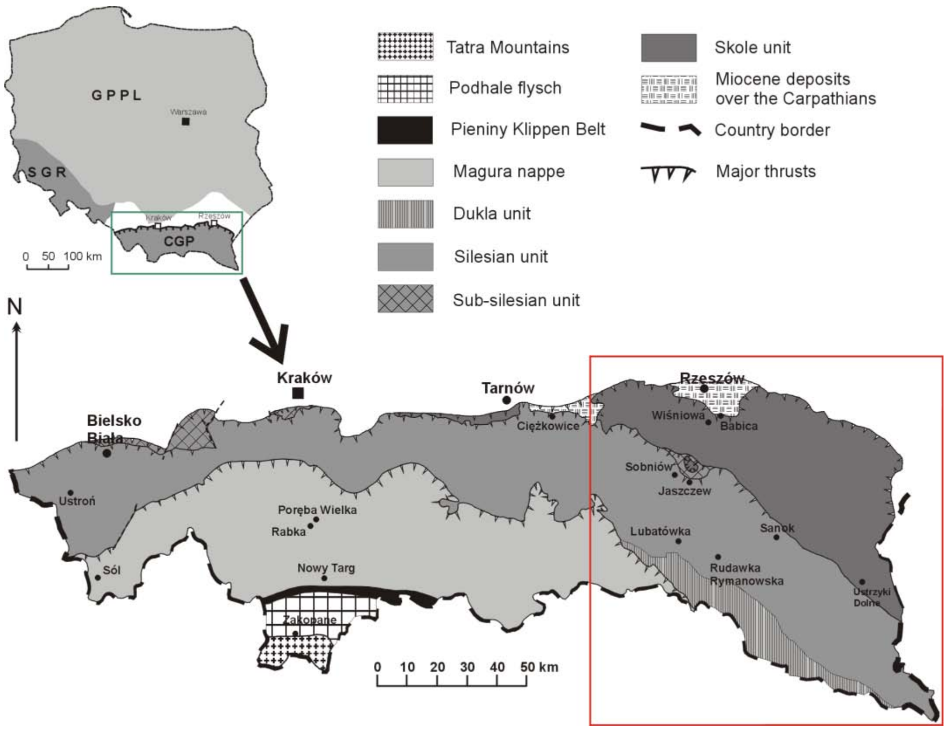

Figure 1. Generalized structural sketch of the Carpathian Geothermal Province (CGP). The red square shows the study area. GPPL – Geothermal Province of Polish Lowlands, SGR – Sudetic Geothermal Region.

Especially the Outer Carpathian Geothermal Region is the area where thermal water potential is still under investigation. Due to complex geological and tectonic structure and hydrogeological settings this region is poorly recognized with respect to thermal water occurrence, resources and possibilities of their utilization. This paper is focused on the eastern part of the Outer Carpathian Geothermal Region, especially on the Silesian Unit. To evaluate the potential occurrence of hydrogeothermal systems in this region in the light of their prospectiveness to further exploration of thermal waters, we took an attempt to apply the selected isotopic and chemical geothermometers to assess the maximum possible temperatures which may be encountered at depth. The results of the geothermometric studies have been compared with actual geothermal gradient, origin of waters and thermal conditions of main geochemical processes responsible for the formation of mineralized and thermal waters encountered in this region.

HYDROGEOLOGICAL SETTINGS IN THE AREA OF STUDY

The Outer Carpathians are composed entirely of flysch-type sedimentary rocks deposited in a deep sea (Książkiewicz 1972, 1975; Kuśmierek, 1995). Dominant are detritic rocks as claystones, mudstones, sandstones, conglomerates, and shales. The sedimentary sequence shows a continuity of marine sedimentation from Late Jurasic (western part) and Early Cretaceous (eastern part) to Oligocene. The characteristic feature of the Outer Carpathians is complex, folded and thrusted structure. They are composed of several nappes that were thrusted over one another approximately from the south (Fig. 1). The nappes differ in tectonic style and litho-stratigraphic inventory as a consequence of regional differentiation of sedimentary systems and the distance from the alimentation zones. One of the largest and best developed is the Silesian Nappe. The easternmost part of the Silesian Nappe constitutes a large tectonic structure called the Central Carpathian Synclinorium built of the thickest sequence of flysch, dominated by coarse-grained sediments of the Upper Cretaceous to Oligocene. Within the Central Carpathian Synclinorium from seven to eight thrusted anticlines (folds) are distinguished (Ślączka 1977). Almost all of these folded structures in their ridge parts contain hydrocarbon deposits and associated mineralized waters.

It is well known that Polish Part of the Carpathians Mts. abounds with mineralized waters utilized in many spas for balneological treatment.

Many aspects of the occurrence of such waters, chemical and isotopic composition, resources and origin have been investigated and discussed in wide literature, for example: Dowgiałło 1976, 1980; Dowgiałło and Sławiński 1979; Dowgiałło and Leśniak 1980; Leśniak 1980; Zuber and Grabczak 1985, 1986, 1987; Chowaniec 1989, 2009; Chowaniec et al. 2001; Porowski 2001a, 2001b, 2001c, 2004, 2006. However, the waters of temperature at least 20°C at the outflow were not studied here sufficiently. They have been encountered only in several exploratory drillings (in majority connected with oil and gas exploration and were liquidated if missed) for example: in the vicinity of Ciężkowice, Lubatówka, Rudawka Rymanowska, Wetlina and Polańczyk; in Skole Unit - in the vicinity of Wiśniowa and Babica (Fig. 1), (Chowaniec et al. 2001). The maximum outflow temperature of 84°C was found in water extracted from Wiśniowa-1 exploratory borehole, where water bearing horizons occurred in Lower Cretaceous sandstones at depth intervals 3696 – 3698 and 3790 – 3793; surprisingly the water had a quite low value of TDS in the range of 7 g/dm^3. Generally the vast majority of thermal waters in the eastern part of the Outer Carpathians is brackish and saline, in various degrees associated with oil and gas deposits encountered in folds, local thrust or flexure structures. Thus they represent both, the typical oil-field brines (because they are extracted together with oil as a byproduct, for example waters from wells Jaszczew 32a and Sobniów 29) or the so-called edge oil-field waters (i.e. these which are not in direct contact with oil deposits, like for example water from the well Lubatówka 12 belonging to Iwonicz Zdrój spa and extracted for production of mineral bathing salts). Both types of waters are additionally enriched in various degrees in specific compounds as bromine, iodine, boron, barium, strontium, lithium; in the gas phase CH_4 is dominant.

Usually, the perspective horizons with thermal waters occur in depth of about 1000 m and more. Their TDS values vary from below 10 g/dm^3 up to about 60 g/dm^3; outflow temperatures usually do not exceed 45–50°C, but exceptionally may reach 84°C (for example vicinity of Wiśniowa). The geochemical types of thermal waters are variable from HCO_3-Cl-Na through Cl-

HCO_3-Na to Cl-Na. Nevertheless, the distinction of individual hydogeothermal systems in the area of Outer Carpathians is hardly possible. Moreover, there is no significant differences in chemical and isotopic composition of thermal and mineralized waters in this area. The recharge areas for thermal as well as mineralized waters are still not known, their origin is poligenetic and their resources might be limited.

DISCUSSION

Mineralized and thermal waters in the area of study are always linked to flysch sediments. The isotopic composition of 54 waters from working mineral and thermal water wells and oil wells from the area of Silesian and Magura nappes show their complex and diverse origin (Fig. 2). Majority of them are at least two component mixtures of meteoric waters (these of modern and/or palaeoinfiltration) and connate seawater-like end-member of diagenetic or methamorphic origin (Dowgiałło and Leśniak 1980, Leśniak 1980, Zuber and Grabczak 1985, Oszczypko and Zuber 2002, Porowski 2004a, 2004b, 2006). Previous studies have shown that the most probable geochemical process which is responsible for the formation of such isotopically enriched end-members is dehydration of clay minerals (Leśniak 1980; Oszczypko and Zuber 2002; Porowski 2004a, 2004b, 2006).

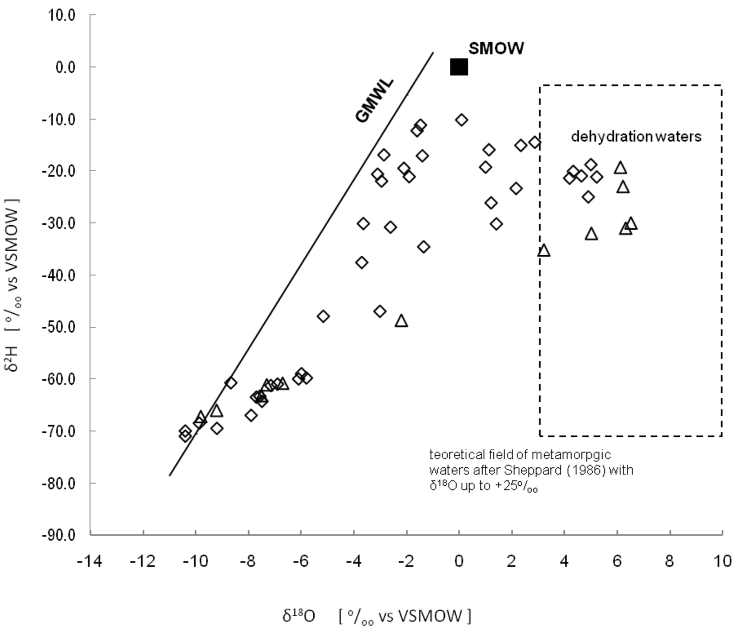

Figure 2. Isotopic composition of Carpathians mineralized and thermal waters. Rhombs represent waters form Central Carpathian Synclinorium, Silesian nappe; triangles – represent selected waters form Magura nappe: Rabka, Wysowa, Szczawa and Szczawnica (data after Oszczypko and Zuber, 2002; and Leśniak, 1980) . SMOW refers to Standard Mean Ocean Water, GMWL – Global Meteoric Water Line (after Różański et al. 1993). For further explanations see the text.

The most significant modifications are observed in illite/smectite dominated shale systems, where the increased temperature and pressure induce the dehydration of clay minerals (Powers 1967, Burst 1969, Perry and Hower 1972, Yeh and Savin 1977, Yeh 1980, Morad *et al.* 2000).

The process of dehydration itself is a mineralogical reaction in which smectite is transformed into illite, i.e. hydrated smectites lose water and form illites within illite/smectite mixed-layers:

- smectite + Al^{3+} + K^{+} $\rightarrow$ illite + Si^{4+} (Hower et al., 1976), or
- smectite + K^{+} $\rightarrow$ illite + Si^{4+} + cations (Ca^{2+}, Mg^{2+}, Na^{+}, Fe^{2+}) (Boles & Franks 1979).

During this process, the dissolution of smectite and subsequent crystallization of illite occurs, resulting in the increase of the amount of illite in the illite/smectite mixed-layers. The crystallization of a new mineral occurs in isotopic equilibrium with surrounding interstitial water. According to Perry & Hower (1972), dehydration should occur in each sedimentary basin where shale sediments are subjected to increased temperatures during diagenesis. These authors stated that geothermal gradient of about 2.4°C/100 m would be enough to initiate dehydration at the depth of about 3000 m. Taking into account the geological settings of the Outer Carpathians it seems very probable that this process could occur here. First of all, the flysch sediments include numerous thick shale intervals, where clay minerals constitute about 70% of rock. The dominant is mixed-layer illite/smectite (J. Środoń, personal information). The geothermal gradient in the CCS is in the range 2.3 – 2.6°C/100 m (Plewa, 1994). The observed petrographical effects of diagenetic processes suggest that temperatures during the periods of maximum burial were higher than those ones observed nowadays (Porowski 2004b). Moreover, in typical sedimentary basins the generation of oil occurs in temperatures ranging from 50 to 175°C, with maximum intensity in temperatures of about 90°C (Hunt, 1979). The isotopic composition of the crystalline structure of clay minerals always reveals considerable enrichment in ^{18}O and also considerable depletion in D relative to VSMOW, which is in agreement with systematic of isotopic composition of dehydration waters in the studied area (see fig. 2). An attempt of model the isotopic composition of water in equilibrium with mixed-layer smectite/illite undergoing dehydration in particular temperatures and particular water-to-rock ratios was presented by Porowski (2006). Despite of the specific assumptions needed to be taken to calculations, the results showed, that calculated final isotopic composition of seawater in equilibrium with mixed-layer clay minerals in the temperature range 103–173°C and rock/water ratio 5%, is in the range of $\delta^{18}O$ from +5.5 to +10.3‰, and $\delta^{2}H$ from -14.4 to -18.1‰, respectively. Such promising results of calculations strongly suggest that dehydration waters encountered in the flysch Carpathians may be considered as indicators of thermal conditions in the geological system at least at depth of their origin and time of dehydration.

On the other hand, an attempt of application of selected chemical geothermometers was made in order to estimate the possible "signal" of maximum temperatures which could be carried out by dehydration waters. The geothermometers have been applied for all the waters considered as dehydration ($\delta^{18}O \geq \sim 3$‰) and for a few thermal waters from eastern part of the Outer Carpathians. As can be seen from Table 1, the maximum reservoir temperatures estimated by chemical geothermometers are diverse and variable. The chalcedony geothermometer indicate the lowest range of reservoir temperatures and estimate quite well the outflow temperatures of some waters. It strongly suggest, that this geothermometer is sensitive on re-equilibration and indicate the last phase of groundwater flow and cooling down. The Na-K geothermometer presented here is derived for the Na and K exchange equilibria with some clay minerals (Arnórsson 1998).

Table 1. The results of application of selected chemical geothermometers to the assessment of possible thermal conditions in the outer flysh Carpathians. D – total depth, TDS – total dissolved solids, to – temperature measured at the outflow, tG – bottom hole temperature calculated from geothermal gradient, tCh - temperature estimated by chalcedony geothermometer (Arnórsson et al. 1983), tNa-K - temperature estimated by Na-K geothermometer (Arnórsson 1998), tMg-Li - temperature estimated by Mg-Li geothermometer (Kharaka and Mariner 1987). For explanation see the text.

Name of well	D [m]	Chemical type	TDS [mg/dm^3]	$\delta^{18}O$	δ^2H	t_o	t_G	t_{Ch}	t_{Na-K}	t_{Mg-Li}
Lubatowka 12	958.0	Na-Cl-HCO_3	19215.8	1.2	-26.2	21.2	31.9	19.8	51.9	105.2
Sobniów 29	2240.0	Na-Cl	21148.75	5.2	-21.2	25.2	63.4	54.6	94.9	125.7
Jaszczew 32a	2530.0	Na-Cl-HCO_3	15400.9	4.9	-25.0	22.1	70.5	50.0	70.7	116.4
Rudawka 11a	407.1	Na-Cl	29650.7	4.3	-20.1	14.8	18.5	13.5	67.1	143.2
Moderówka 7	1800.0	Na-Cl	20087.7	4.6	-21.0	16.6	52.6	28.6	38.9	121.1
Iskierska 18	345.6	Na-Cl	27825.0	4.2	-21.4	13.0	16.9	12.5	32.0	88.2
Łodyna 76	546.1	Na-Cl	48967.2	2.3	-15.1	12.0	21.9	9.9		87.7
Jajko	1000.0	Na-Cl	12516.0	2.9	-14.5	10.5	33.0	4.1	23.1	61.1
Wysowa, well Aleksandra[1,2]	100.0	Na-HCO_3-Cl + CO_2	24980.0	6.5	-30.0	12.5	11.0	14.8	92.9	151.8
Wysowa, well 14[2]	50.0	Na-HCO_3-Cl+ CO_2	20388.0	3.2	-35.2	9.9	-	8.9	97.1	133.6
Szczawnica, Magdalena spring[1,2]	spring	Na-HCO_3-Cl + CO_2	26304.0	5.0	-32.0	10.8	-	44.2	91.0	108.9
Szczawno: well Szczawa II[1]	100.0	Na-HCO_3-Cl + CO_2	27848.0	6.3	-31.0		11.0	19.3	31.1	126.9
Rabka: well-18[1]	120.0	Na-Cl	25727.9	6.2	-23.0		11.5	3.3	50.2	159.9
Rabka: well Krakus[1]	20.0	Na-Cl	21167.0	6.1	-19.3		-	22.9	75.4	148.4

[1] – data after Dowgiałło (1976); [2] – data after Lesniak (1980, 1998);

Although, for some waters it indicate the reservoir temperatures more than 60°C (the temperature of 60°C is considered to be the border from which the dehydration process may start in favorable geological conditions) the influence of clays-water ion-exchange reactions in low temperature conditions surely affect the final concentration of Na and K in water. The Mg-Li geothermometer is the most interesting here. It is specially recommended for estimation of reservoir temperatures in the areas of oil fields (Kharaka and Mariner 1987). The maximum temperatures estimated by this geothermometer are between 61–159°C. That range of temperatures in geological system of flysh Carpathians, although quite wide (probably connected with isotopic composition of water) agrees with probable range of temperatures of dehydration of clay minerals and generation of dehydration waters encountered in this area. Moreover, such range of temperatures is in good agreement with thermal conditions of Carpathian oil generation. It is difficult to answer the question, whether these temperatures are possible nowadays for deep groundwater horizons in this part of the Carpathians? This problem needs of course further investigation taking into account the complex origin of waters in this area.

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4.3 Hydrogeochemical characteristics of mineral and thermal waters

abstract id: **115**

topic: **4**
Mineral and thermal water

4.3
Hydrogeochemical characteristics of mineral and thermal waters

title: **Distribution and variation of geochemical signatures in mineral waters from the Portuguese mainland**

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keywords: mineral waters, geochemistry, country wide variation, distribution

ABSTRACT

In the present study we propose the use of the chemical composition of mineral/thermal waters as a tool for geochemical mapping. In this case, unlike conventional geochemical mapping, where surface samples (such as stream water, sediments and soils) are analysed, by analysing mineral and thermal waters, the deeper geology and the chemical processes that take place at depth are monitored. Using this approach it is shown that chemical characteristics of mineral/thermal waters follow regional variations ascribed both to the geology and geochemical processes that take place in the mapped area. This approach is tested in the Portuguese mainland, a country with a very high density in mineral and thermal waters. The preliminary results presented here show that the chemical composition of mineral and thermal waters reflects the chemical geology of the country.

INTRODUCTION

Inventories of the richness in mineral and thermal springs in Portugal were already made centuries ago. Henriques (1726) published the first countrywide overview of waters with therapeutic characteristics. This list was recently reviewed at the Institute of Social Sciences of Lisbon University, who published an on-line database of 668 locations with one or more waters with therapeutic qualities, mainly according to local tradition (Bastos, 2008). The chemistry of the most important of these "medicinal-mineral" waters have been analysed from early on, starting in the 19th century. Most mineral and thermal waters with a concession were analysed by Charles Lepierre and António Herculano de Carvalho in the first half of the 20th century (see e.g. Acciaiuoli, 1952). Several modern studies are known, but they all only have a local/regional focus (e.g. Marques et al. 2003, 2006, 2008, 2010). Therefore, we believe that it is extremely important to have a countrywide overview of the chemistry of mineral and thermal waters.

Mineral waters can be defined as natural (spring) waters that show a distinct chemistry and which composition and temperature are not varying over time, indicating a deep source. Mineral waters normally are issued along faults and have a recharge area which is often several kilometres form the springs/boreholes. The water gets its chemical composition as a result of water-rock interaction between the recharge area and the discharge location. Using stable isotope ratios of hydrogen and oxygen Aires-Barros et al (1995) showed that the original infiltrating water in the recharge areas is rainwater which contains only very little dissolved solids. Marques et al (2003, 2006, 2008, 2010), using this technique, showed that the recharge area in many Portuguese cases (e.g. Caldas do Moledo, Chaves, Cabeço de Vide, Caldas da Rainha) is rarely more than 10 km from the mineral springs/boreholes. As such, the chemistry of the mineral waters represents only the results of water-rock interaction of this relatively small area fairly close to the springs/boreholes. This way the water is representative for the water-rock interaction in an area close to the springs, and as such it could potentially be used for geochemical mapping.

Geologically the Portuguese mainland can roughly be divided in two regions (Figure 1). Along the west and south coasts Mesozoic and Cenozoic sedimentary rocks are found. To the east and north of this region, Proterozoic and Palaeozoic bedrocks are found which are intruded in large areas (especially widespread in the north) with Palaeozoic magmatism.

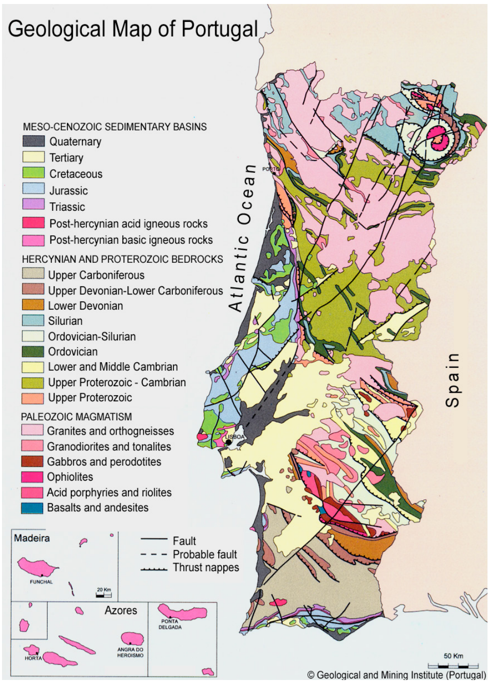

Figure 1. Geological map of Portugal.

Geochemical mapping using mineral and thermal waters is potentially a good complement to the more conventional geochemical mapping techniques. In conventional geochemical mapping techniques the chemical composition of surface materials, such as stream water, stream sediments or soils (Inácio et al., 2008) is normally analysed. As water–rock interactions take place to depths of about 2 kilometres or more (Marques et al., 2003) mineral and thermal waters give us the possibility to take into account chemical processes that take place at a greater depth, and show effects of the deeper geology.

DATA COLLECTION

Analyses from Portuguese mineral and thermal waters were collected, from published literature and the internet. We collected 822 analyses from 606 springs from about 500 locations on the Portuguese mainland. Multiple analyses from the same source (from different years) were averaged. Compositions from sources from which multiple analyses are available (sometimes representing a period of over 100 years) generally showed only little variation over time, showing that mineral and thermal waters have constant compositions, and also that older analyses are of equal quality as more modern analyses. Data were analysed using Golden Software's Surfer® program to produce maps showing the distribution of the parameters over the country. The oldest analysis is from 1850 (Pimentel, 1852), and the majority of data have been taken form important classic publications such as Luzes et al. (1930, 1934, 1935), Acciaiuoli (1952) and Almeida & Almeida (1966, 1970, 1975, 1988) which represent the period from about 1890 until 1970. More recent data are taken from papers reporting individual areas (e.g. Marques et al., 2003, 2006, 2008; Ferreira Gomes, 2001; Calado & Chambel, 1999). Most data from the

Alentejo region in the south of Portugal are taken from ERHSA (2000). Considering the great variety of the publications it is to expect that the quality of the dataset is very diverse. For example from virtually all analyses only a limited number of parameters have been measured. Most importantly many of the "general" parameters (e.g. NO_3^-, F^- and HS^-) often are below the detection limit. Other parameters are just not measured for all samples. For example in the works by Almeida and Almeida (1966, 1970, 1975, 1988) the standard analyses consisted of Na, Ca, Mg, Fe, Cl, HCO_3 and SO_4, while NO_3, F and HS were only determined (or reported) while above the detection limit. Most strikingly K is not normally reported. In this contribution we present maps for Total Dissolved Solids (TDS), determined for each spring by adding up analytical results for all known parameters, and for Na, Cl, Ca, HCO_3+CO_3 (total carbonate) and F. Of these only the F concentration is not known for the majority of springs. In those cases where F is not known it is assumed that it was not measured or reported because the value is below the detection limit, and in the database the value of 0.01 mg/l is entered for F. Na, Cl and Ca are known in almost all locations, while the carbonate content is calculated from the ion balance. The reason for doing this is that, in several (mainly older) analyses, the carbonate content is reported including the free carbon dioxide, and as such the sample was way out of balance. As most analyses have an acceptable ionic balance, the total carbonate content is determined by calculating the ion balance without the carbonate species, and subsequently balanced by adding carbonate species. For the majority of samples the calculated and measured sum of carbonate species is in very good agreement, indicating the acceptability of this approach.

RESULTS AND DISCUSSION

Total dissolved solids (TDS)

To show the general variation in composition, distribution of the total dissolved solids over the country is shown in Figure 2a. Clear differences are shown over the country. Highest TDS values are found in areas where salt deposits from the Lower Jurassic Margas da Dagorda formations do occur. These formations are mainly ascribed to the western basin north of Lisbon and along the south coast (Algarve region). Highest TDS values are found in locations where salt diapirs do approach the surface very closely such as in Rio Maior where the diapir is so shallow that the spring contains 137 g/l TDS (containing 98% NaCl) and is used to extract and commercialise the salt (Eggenkamp et al., 2010).

Na/Cl

Comparing the two maps representing the distribution of Na and Cl (Fig. 2b and 2c) in the mineral and thermal waters one can conclude that while in the south and the west of the country the two maps are more or less similar, in the north of the country large regions with very low Cl concentrations are found, while Na is in many samples significantly more concentrated. These differences can be explained by the large difference in geology and structure of the two parts of the country. In the south and the west both Na and Cl are regulated by dissolution of salt deposits from the lower Jurassic. In the north the geology is dominated by granite rocks which intruded into Palaeozoic rocks, which are heavily folded and metamorphised. In this area many very deep faults are found. Through these faults mantle CO_2 and other gases escape to the surface and dissolve in the shallower groundwaters (Carreira et al., 2010).

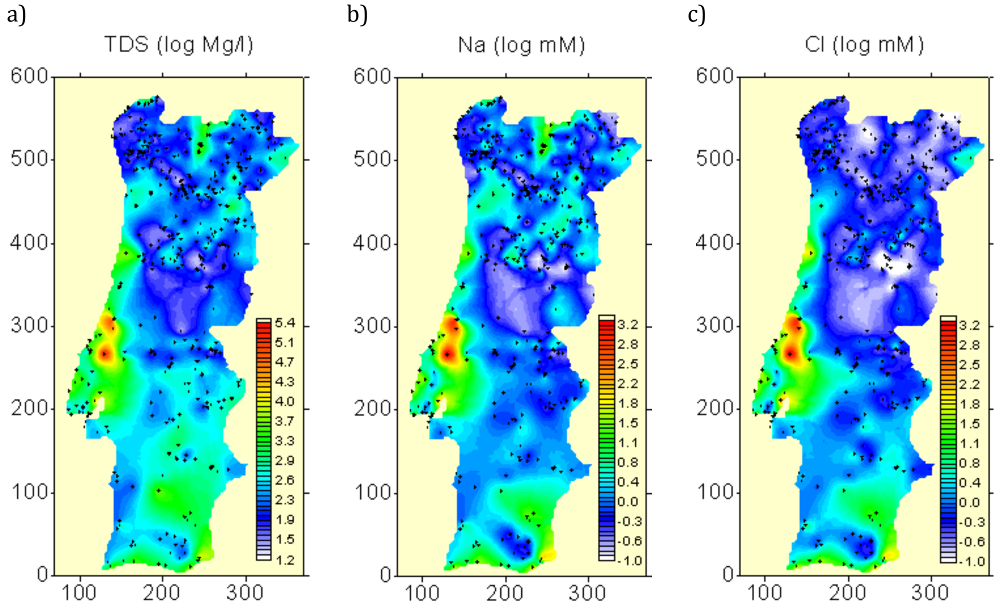

Figure 2. Distribution of a) TDS; b) Na; c) Cl in mineral and thermal waters from the Portuguese mainland.

As granitic rocks contain more Na than Cl, in this area water-rock interaction results in relatively increased Na contents in waters. Mantle CO_2 balances the Na mainly as HCO_3 in this water, resulting in Na-HCO_3 dominated waters. Along the deepest faults the amount of CO_2 escaping can be so high that the waters are supersaturated in CO_2 and can be described as Na-HCO_3-CO_2 type waters (Marques et al., 2006). As Na is the major cation in the majority of mineral and thermal waters issuing in the Portuguese mainland there is a good agreement between the TDS and the Na maps for the Portuguese mainland. Only in the northern part of the Alentejo region (southern half of Portugal, north of the Algarve) Ca is the dominant cation in most mineral and thermal waters, resulting in one of the few divergences between the TDS and Na maps.

Ca/HCO_3/F

The distribution of Ca (Fig. 3a) in the Portuguese mineral and thermal waters is also clearly related to the geology of the country. Roughly three regions can be recognised: high concentrations in the west, low concentrations in the north and intermediate concentrations in the south. The high concentrations in the west are also the result of dissolution of evaporite minerals (mainly gypsum) from the Lower Jurassic *Margas da Dagorda* formation. In the southern half of the country Ca concentrations are intermediate due to dissolution of carbonate minerals. In this area, the HCO_3 concentrations (Fig. 3b) are also relatively high (with the same order of magnitude as Ca), while in the western part of the country HCO_3 is significantly lower. In the north of the country Ca shows very low concentrations. This is the result of water-rock interaction between water and calcium-poor rocks (e.g. granites and schists). In the northeast of the country ultramafic Ca-rich rocks are present, which is reflected in the slightly higher Ca concentrations in mineral and thermal waters from that area. It is encouraging that the Ca distribution on this mineral and thermal water map correlates well with the Ca distribution on the soil geochemical map (Inácio et al., 2008).

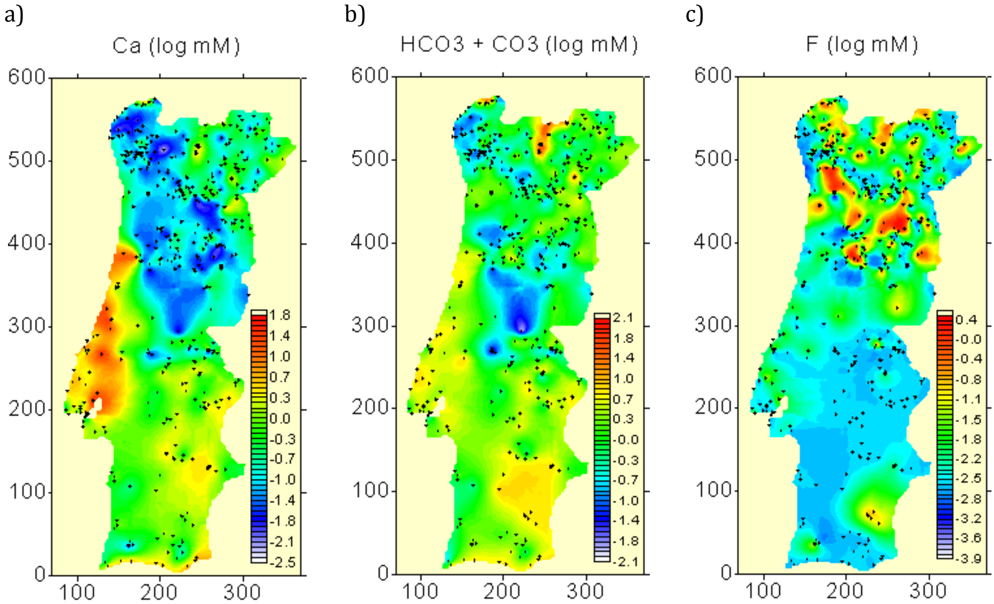

Figure 3. Distribution of a) Ca; b) (bi)carbonate; c) F in mineral and thermal waters from the Portuguese mainland.

High bicarbonate concentrations which are found in some areas in the north of the country are related to very deep faults where mantle CO_2 escapes to the surface. Fluoride concentrations in mineral and thermal waters are normally restricted by Ca due to the low solubility product of fluorite (CaF_2). As Ca has very low concentrations in mineral and thermal waters from north Portugal, there is potential for higher F concentrations. Indeed higher F concentrations are found in this area (Figure 3c). Fluoride concentrations are especially high along major faults in the granitic areas, with maximum values above 20 mg/l.

CONCLUSIONS

It is shown that maps prepared from the chemical composition of mineral and thermal waters do describe the geology and chemical processes properly. Variations in chemical parameters found on maps can be explained with the known variations in geology in the studied regions. Based on the present dataset more maps can be produced and it is encouraged that new analyses will be done on mineral and thermal waters preferably by ICP-MS so that also minor and trace components can be determined.

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abstract id: **162**

topic: **4**
Mineral and thermal water

4.3
Hydrogeochemical characteristics of mineral and thermal waters

title: **Hydrogeochemistry of bottled mineral waters of Serbia**

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keywords: chemistry, geology, water

INTRODUCTION

According to the density of occurrences and the diversity of physical properties and chemical features of the mineral waters, the territory of Serbia belongs to the one of the most resourceful areas of the European continent, but only a small quantity of these mineral waters is used for bottling. Currently, there are 30 bottling mineral water plants which delivered around 560 000 m^3 of bottled water to the market in 2008.

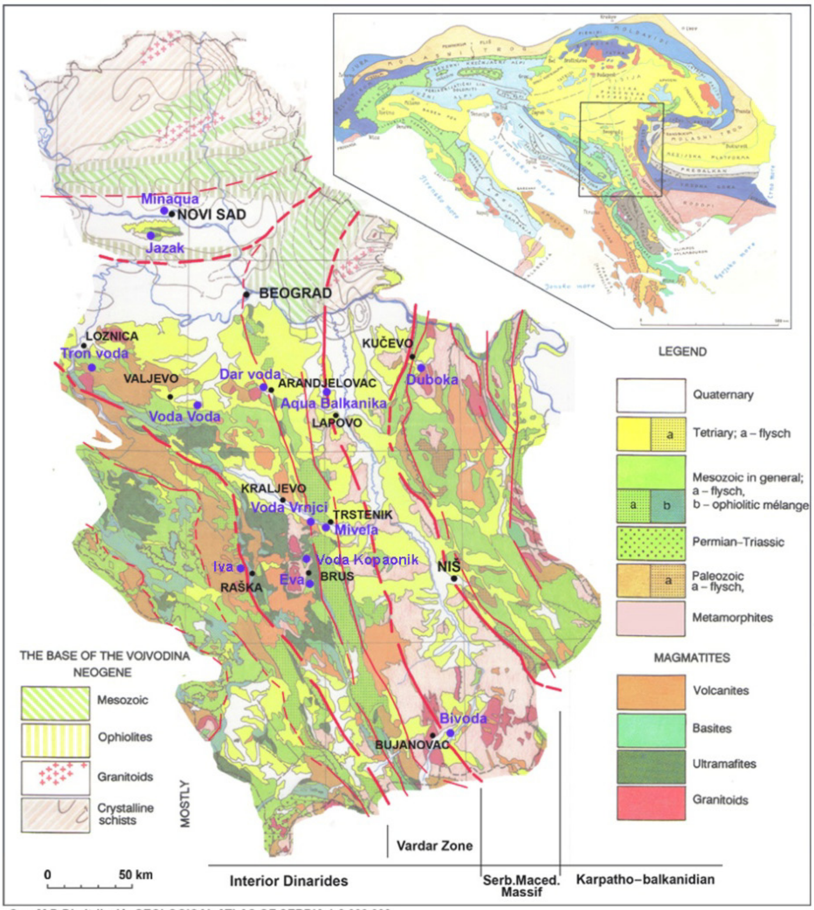

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Figure 1. Features on the geological map of Serbia (Dimitrijevic, 1994).

The territory of Serbia is divided into 5 regional geological systems (Figure 1): Pannonian, Interior Dinarides, Vardar zone, Serbian-Macedonian massif and Carpatho-Balkans, which are significantly different according to the quantity and quality of ground water. In the Pannonian basin water is predominantly accumulated within the Neogene sediments, in the Dinarides and Carpatho-Balkans areas water is accumulated within limestone, and in the central part (Vardar zone, Serbian-Macedonian massif) within different rocks of a metamorphic complex. The geological conditions dictate the speed of water exchange, but they do not correspond completely to the quality of the ground water.

PRESENTATION OF ANALYZED OCCURRENCES AND THEIR QUALITY

EuroGeo Survey Geochemistry workgroup (Reimann, Birke, 2010) examined 13 mineral water samples from the teritory of Serbia. The total of 71 parameters were examined for each sample, and some of the results are given in the Table 1.

Table 1. Review of the chemical composition of the analyzed mineral waters.

Mineral water	Class	Subclass	Specific components	TDS (mg/l)
Minaqua	HCO_3-Cl	Na	J, NH_4, B, Fe	1151
Jazak	HCO_3	Ca, Mg		352
Dar voda	HCO_3	Na	Fe, Mn, F, Li, Cs, Cu, Rb, B	592
Bivoda	HCO_3	Na	B, Sr, Ge, K, Si	3317
Aqua Balkanika	HCO_3	Ca		363
Voda Vrnjci	HCO_3	Na	Cs, Rb, Li, Sr, Ge, Si, Ni	1081
Mivela	HCO_3	Mg	Rb, Si	1286
Eva	HCO_3	Ca	Sb, Ni	184
Voda Kopaonik	HCO_3	Na	Cs, Li, Sr, Ge, Fe, F	1086
Iva	HCO_3	Ca, Mg		234
Voda Voda	HCO_3	Ca	Ti, W, Sb	364
Tron voda	HCO_3	Ca, Mg		320
Duboka	HCO_3	Ca		836

Within the Pannonian basin we have analyzed the Minaqua and Jazak water.

Minaqua is genetically related to the Neogene sediments of the Pannonian basin. Since the water is formed in anaerobic conditions, higher concentrations of J (0.686 mg/l) and HN_4 (4.4 mg/l) in the mineral water have been observed and they are of a natural, organogenic origin. Higher concentrations of NH_4 indicate that the water was formed in areas where oil and gas are generated. All of the analyzed waters are HCO_3 according to their anionic composition, only Minaqua is HCO_3-Cl, which indicates that the waters are formed in a shallow environment of the Pannonian basin. From a medical point of view, iodine strengthens memory, mood, normal functioning of the thyroid gland, quality of hair, skin, teeth and nails, which gives this water a special value.

Jazak water from horst Fruska Gora, is being captured from Triassic sediments, which were developed in carbonated facies (limestone, dolomite) (Vukicevic, Demic, 2005). That is confirmed by a ratio of rCa/rMg of 1.68. The water is HCO_3-Mg, whereby we can say that a considerable amount of Ca (77.0 mg/l) and Mg (45.6 mg/l), as well as a low amount of Na (6.9 mg/l) and Cl (5.53 mg/l) contribute to the good water quality. It emerges through fracture-karst springs of a considerable volume, and according to these features the location is not typical for the Pannonian basin.

In the area of Interior Dinarides **Iva** water (Grabovacka banja – spa) is bottled. Water flows under pressure out of Middle Triassic limestone. The recharge is done through the infiltration of atmospheric water in the open part of the karst aquifer located North-East of the spa. The geological structure of the terrain is made of phyllite, schist and metasandstone, within layers of a Paleozoic age, above which Triassic sediments (marbly limestone) occur. Thick-bedded and massive dolomites and limestone are situated above them. The terrain is in tectonic respect significantly fractured which enables inflow of the water from serpentinite (Letic, Djokic, 2008).

Mineral water Iva is HCO_3-Ca, Mg. The ratio of rCa/rMg (2.83) as well as a total water hardness of 12.2 to 13.9° dH, indicate carbonate rocks as its primary circulation and accumulation environment, and the presence of serpentinite as the source of its chemical composition. Hydrochemical parameters are within the limits for drinking water which make it very suitable for bottling.

The majority of the analyzed samples of mineral water from the territory of Central Serbia contains higher concentrations of Cs, Li, Rb, and Sb, which indicate that the water emerges from granite intrusions. Higher concentrations of U, Th and K, which have been observed in **Bivoda** and **Dar Voda** confirm that the water emerges from acid igneous intrusions, and that they are related to **Voda Vrnjci** as well. Their specific chemical composition is the result of the forming and outflow of mineral water. The primary spring is fed by an infiltration of atmospheric water through the fault system in uncovered parts of the terrain built up of modified rocks and granite. Enrichment caused by mineral substances and generation of the primary chemical composition occur in deeper spring parts (Vujanovic et al., 1971). Water circulates through the fault system whereby it is enriched by gas CO_2 from the faults and then it arrives to the reservoir rocks in the Neogene sediments (sands), where it is captured.

Dar Voda (water) is drilled in the Bukovac fault. The pH value of 5.6 indicates a low acid environment, while according to water hardness (14.0-17.3°dH) it is classified as a fairly hard water (according to Clut). Higher concentrations of Fe (0.101 mg/l) and Mn (0.465 mg/l) in Dar Voda can be related to the decomposition of granite rocks, or the presence of basic rocks which are not found on the surface, or in the borehole. The presence of fluorine F (1.39 mg/l) in the water is related to minerals of igneous rocks (granitoide of Bukulja), apatite, biotite, fluorite (Dangic, Protic, 1995). By studying the migration of fluorine in the mineral waters of Serbia it was noted that the content of fluorine is the most common in the HCO_3- Na water, with nitrogen gas composition. With the increase in the ratio of rNa / rCa + Mg, the content of fluorine increases by certain regularity (Papic, 1994).

Considerable concentrations of CO_2 (600-1580 mg/l) give the water an acidic nature. Based on the balneology value of Dar Voda, the water is classified as a Na HCO_3-Li-F-Si-CO2-cool mineral water and it is recommended for the prevention of gastritis, stomach diseases, gall and liver diseases, diabetes and osteoporosis.

According to its ionic composition **Bivoda** has high contents of HCO_3 (3290 mg/l) and Na (1212 mg/l). This hydrochemical type of underground water is related to acidic igneous rocks such as granite and its products. The water is characterized by considerable amount of free CO_2 which emerges out of deep fault structures and gives the water an acidic flavor (Zlokolica-Mandic, 2000). The presence of free CO_2 is also related to the pH value which is somewhere at the cross point between low acid water and neutral water with a pH of 6.5. The quantity of Sr (1.9 mg/l) in higher concentrations is a direct consequence of the high mineralization (4891.0 mg/l) of Bivoda. The origin of B (5.66 mg/l) in Bivoda hasn't been definitely determined. The high percentage of boron indicates that boron in the ground water derives from a mineral named tourmaline, which emerges in pegmatite, present in the area of Bujanovac (Dragisic, 1997); but it is most likely that the origin of boron with carbon dioxide comes from deep fault structures. This water is rich with minerals which are recommended for the people exposed to the physical exertion.

The natural carbo-acidic water **Aqua Balkanika** is also related to igneous rocks. The presence of free CO_2 in the water is related to processes of regional metamorphism (cooling and solidification) of igneous intrusions in deeper parts of the Earth's crust. During magma crystallization, easily evaporating components, CO_2 among them, are partly built into the rock minerals, and a considerable part of them is released during consolidation with ground water. Water moves along joints and faults toward the terrain surface (Komatina, Popovic, 1994). Underneath these Neogene sediments there is crystalline schist with a considerable presence of calcschist and marble. In the south of the location, these rocks appear on the surface in the recharge area. The water is HCO_3-Ca of the low TDS (363.0 mg/l), and higher concentration of Ca (78.5 mg/l).

Vrnjacka Banja is the most popular spa-touristic center in Serbia. There are several springs of healing water in it. The „Sneznik" spring, which is used for balneotherapy, is also used for water bottling under the name **Voda Vrnjci**. Next to the spring there is a borehole made in serpentinite rocks. The oldest rocks in the wider area are Paleozoic schist and amphibolites, with layers of marble through which considerable quantities of mineral water circulate. The water circulates through serpentines and gabbros, that are tectonically quite disturbed, which implies very good filtration characteristics and also increased concentrations of Mg ions (55.4 mg/l) (Nikolic, 2009). The presence of geochemical assemblage Cs, Rb, Li, Sr, Ni, Ge, indicates a contact of this water with granodiorite, which is located 10 km to the South-East of Vrnjacka Banja (Zeljin, Crni Vrh), while higher content of Ni (9.12 mg/l) indicates the presence of ultrabasic rocks (gabbros and diabase). Voda Vrnjci is characterized by an increased TDS (1081 mg/l) and increased contents of CO_2 (700–1044 mg/l).

Mineral water **Mivela** is bottled in the Trstenik area (Veluce place). The water is HCO_3-Mg with a water hardness of around 80°dH, which means that it falls into the category of very hard waters, according to the Clut classification. The water is characterized by an extremely high concentration of Mg (324.0 mg/l), which is most probably due to the circulation of water through serpentine, peridotite and fault structures. Due to its high concentration of Mg, it is very helpful for the prevention of hypertension, regulation of blood sugar levels, heart arrhythmia, endocrinologic diseases and nervous system diseases.

At the foothill of the Kopaonik mountain (Brzece-Brus), the bottling of mineral water **Eva** is performed. The water is characterized by its low TDS of 184 mg/l, which classifies it among low mineralized water. The high content of Sb (2.03 mg/l) originates from hydrothermal alteration of serpentinite. According to the Alekin classification, the water is HCO_3-Ca, which indicates a limestone origin.

Voda Kopaonik is located in the vicinity of Eva water, yet has significantly different qualities. Voda Kopaonik is HCO_3-Na, according to its ionic composition. Increased concentrations of Cs, Li, Sr, and Ge indicate contact with igneous rocks. The presence of fluorine F (2.39 mg/l), like in Dar water, is in direct connection with the ratio of rNa/rCa + Mg (Papic, 1994). However, the presence of Ni, which is also found in Voda Kopaonik, is related to the presence of ultrabasic rocks (gabbro and diabase).

Voda Voda is bottled in the area of Gornja Toplica (Mionica). The water is HCO_3-Ca, originating from limestone found in the bottom of Neogene sediments, discharging in the form of a flowing well. Higher concentration of Ti, W and Sb are related to diabase and spilite.

The natural spring water from the Devet Jugovica spring is bottled under the name **Tron** water. Content of Na (1.8 mg/l) is the extremely low. The ratio of rCa/rMg (=2.144), indicates dolomite and dolomitic limestone as the primary environment for water circulation.

Natural mineral water **Duboka** of Kucevo belongs to the Carpatho-Balkanian hydrogeothermal province. It is characterized by increased concentrations of HCO_3 (956 mg/l) and Ca (241 mg/l) as a result of the decomposition of limestone and calcium feldspars in magmatic rocks (granite monzonite). The water temperature is 20°C, so it is classified as a thermomineral water. Based on the geological structure, it is obvious that the granodiorites, which are located near the mineral water findings below the limestone, have a great deal of influence on the water temperature. The content of CO_2 (450 mg/l) makes it a low acid water.

CONCLUSION

The analyzed mineral waters of Serbia significantly vary regarding the TDS, from 184 to 3317 mg/l (Table 1). All waters are HCO_3, except Minaqua which also contains Cl among the leading anions. In the cation composition, there are two major groups: with a dominant content of Na, and with a dominant content of Ca or Ca+Mg. In this grouping, Mivela is an exception, because it is dominantly Mg ion. Generally, Na water contain a large number of micro components, which is of course a consequence of their high mineralization, but also of genetic relation to the presence of acidic igneous intrusions in the zone of mineral composition forming. However, these rocks are not always seen on the surface, in the nearest zone of infiltration, and are not registered in the exploitation wells. The analyses of mineral water prove the direct correlation between the hydrochemical composition of water and complex geological settings in which the formation and movement of water have been taking place, throughout the geological history.

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abstract id: **245**

topic: **4**
Mineral and thermal water

4.3
Hydrogeochemical characteristics of mineral and thermal waters

title: **Hypogene karst development in a hydrogeological context, Buda Thermal Karst, Budapest, Hungary**

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keywords: hypogene karst, thermal waters, regional discharge zone, discharge features

Europe's largest naturally flowing thermal water system is exposed in Budapest, Hungary. The springs and wells that supply the thermal baths of Budapest discharge from a regional Triassic carbonate aquifer system. As the result of the interaction of discharging waters, extensive cave systems has developed and still developing today. These caves belong to the group of hypogene caves, based on their special morphology (spherical cavities, corrosion niches) and peculiar mineral assemblage (abundance of calcite).

A comprehensive hydrogeological study was carried out for the characterization of processes acting today and their resulting products at the discharge zone of the Buda Thermal Karst. Methods included hydraulic, hydrogeochemical, mineralogical investigations.

Among the results of the study, several processes were identified which can be responsible for cave development and formation of minerals. Furthermore, the role of the adjacent sedimentary basin was reevaluated. These results bring a new insight into the processes acting at a regional discharge zone which could be responsible for hypogene cave development. The Buda Thermal Karst system can be considered as the type area and in same time the modern analogue for hypogene karsts.

abstract id: **248**

topic: **4**
Mineral and thermal water

4.3
Hydrogeochemical characteristics of mineral and thermal waters

title: **CO2-rich mineral waters from the area of Benedikt and Ščavnica Valley, North-Eastern Slovenia**

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keywords: mineral waters, hydrogeochemistry, water-rock interaction, Mura Basin

INTRODUCTION

The Mura Basin, North-Eastern Slovenia, belongs to the south-westernmost extending of the system of Pannonian basins. It is filled with Neogene, Pliocene and Quaternary sediments developed mainly as clastic deposits in marine, brackish and continental – limnic and fluvial environment. Along the western basin margins, mineral waters are locally abundant, particularly in the Radenci, Benedikt and Ščavnica valley areas (Kralj and Kralj, 2000). Mineral waters occur in shallow aquifers or spring out along fault systems (Kralj, 2001, 2004). The main cause of their formation is penetration of carbon dioxide from pre-Tertiary basement towards the surface (Kralj et al., 2009).

MINERAL WATER COMPOSITION

At Benedikt and in the Ščavnica valley, mineral waters occur in shallow aquifers composed of Badenian and Sarmatian clastic sediments. Their composition is relatively variable; the waters belong to the Na-Ca-HCO_3, Ca-(Na)-HCO_3, or Ca-Mg-(Na)-HCO_3 hydrogeochemical facies (Tab. 1).

Table 1. Composition of mineral waters from Benedikt and Ščavnica valley.

Major ions (mg/L)	**P 1**	**P 2**	**A 1**	**A 2**	**I**	**O**	**St**	**Sp**
NH_3^+	0.41	1.74	4.83	2.05	3.07	0.90	0.86	0.44
Na^+	20	36	51	69	104	685	162	30
K^+	3.4	8.8	21	20	15	65	13	4.8
Ca^{2+}	246	420	800	660	487	417	375	570
Mg^{2+}	69	94	180	123	203	69	32	23
Fe^{2+}	4.56	8.40	7.20	2.90	6.63	1.22	2.67	0.84
Mn^{2+}	0.525	0.340	0.170	0.100	0.143	0.178	0.352	0.540
J^-	0.01	<0.05	<0.05	0.10	0.02	0.21	0.05	<0.01
F^-	0.10	0.13	0.04	0.10	<0.01	0.78	0.22	0.22
Cl^-	9.2	5.0	3.5	4.5	7	170	25	8
HCO_3^-	980	1800	3400	2900	2590	2970	1690	1620
SO_4^{2-}	15	14	23	22	2	118	19	37
Elements, gases, compounds, parameters								
CO_2	2000	1900	1830	1800	2500	3800	3300	2600
P	0.104	0.015	<0.015	0.024	0.016	0.058	0.023	0.180
SiO_2	17	27	43	80	18	15	17	30
TOC	1.5	1.7	1.3	1.0	0.9	0.8	0.6	0.8
TDI	1349	2391	4536	3885	3420	4499	2320	2295
pH	6.00	6.10	6.37	6.42	6.22	6.22	6.01	6.22
Trace elements (ppb)								
As	0.4	3.6	0.2	0.2	0.1	0.7	0.5	1.9
B	30	60	80	46	100	1400	200	34
Ba	98	230	520	350	640	63	210	170
Cd	0.04	<0.01	3.1	<0.01	0.21	0.13	0.01	1.3
Co	1.1	2.0	2.0	0.8	0.8	0.5	1.1	<0.1
Cr	7.3	1.0	0.4	0.5	6.7	5.5	0.7	0.3
Cs	<0.01	0.13	1.5	1.0	0.88	11.5	0.01	8.3
Cu	0.1	9.1	2.2	0.4	<0.1	10.0	1.4	5.4
Ni	16	14	24	16	32	20	25	1.9
Rb	13.9	24.8	106	82.4	53.4	346	61.2	213
Sc	7.8	7.7	13.4	8.9	25.9	23.2	9.3	1.9
Se	0.4	0.9	0.5	<0.1	0.7	9.4	1.8	2.1
Sr	577	1120	2330	1540	8180	1090	2170	876

P 1, P 2 — Pavla; A 1, A 2 — Ana; I — Ivanjševci, O — Očeslavci; St — Stavešinci; Sp — Špindler

The amount of total dissolved ions ranges from about 900 mg/L to over 4.5 g/L. In the Benedikt area, three shallow boreholes – Helena (H), Pavla (P) and Ana (A), reached a depth of 30 m, 60 m and 100 m, respectively. A natural spring of Špindler (Sp) occurs about 1 km southerly from the Helena, Pavla and Ana boreholes. In the Ščavnica valley, mineral waters are captured by boreholes at Očeslavci (O), Ivanjševci (I) and Stavešinci (St).

DISCUSSION

Three main processes are involved in the formation of mineral waters: 1, cooling and chemical change of deep thermal waters that rise from deeper parts of the Mura Basin, 2, their mixing with normal ground-waters from shallow aquifers, and 3, penetration of carbon dioxide from pre-Tertiary basement and water-rock interaction.

The waters originating from deeper thermal aquifers essentially belong to Na-HCO_3-(Cl) hydrogeochemical facies. The water captured in Očeslavci contains the highest recognised amount of sodium and chloride ions, potassium, sulphate, bromide, iodide and fluoride ions, boron, rubidium and cesium (Tab. 1; Fig. 1). A minimum proportion of modified thermal water in mineral water from Očeslavci is estimated to 25%. Mineral water from the Ščavnica valley captured at Stavešinci contains a lower proportion of modified and cooled thermal water – its content is estimated to 5–6%.

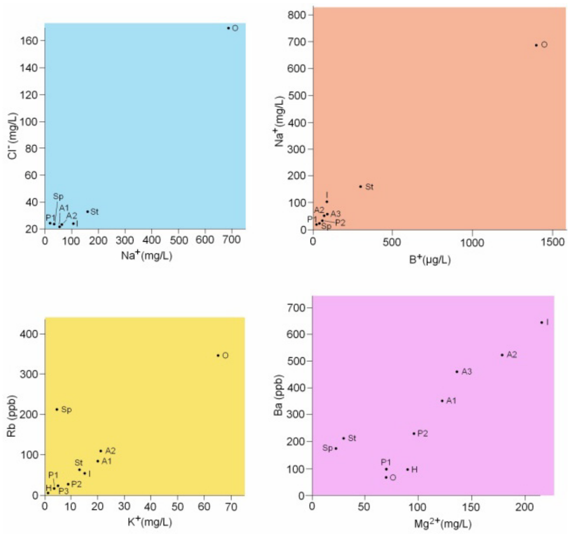

Figure 1. Elemental ratios in mineral waters from the Benedikt and Ščavnica valley areas: Na^+ vs. Cl^-; B^+ vs. Na^+; K^+ vs. Rb; Mg^{2+} vs. Ba. For sample explanation see Tab. 1.

Mineral waters captured in the wells Helena (H), Pavla (P) and Ana (A), and in the spring of Špindler (Sp) in the Benedikt area, are essentially ground waters having an increased amount of total dissolved solids owing to the penetration and mixing of carbon dioxide in the aquifers, and the consequent enhanced water-rock interaction. Calcite dissolves preferentially, while the dissolution of dolomite and illitic clays tends to become more intensive in deeper aquifers (Fig. 1, the diagrams K^+ vs. Rb and Mg^{2+} vs. Ba). The amount of magnesium seems to depend on local abundance in the aquifer sediment. The highest abundance of magnesium was recognised in the water from Ivanjševci. Barium mainly follows magnesium, the shift from the main trend (Fig. 1) can be related to preferential near-surface adsorption of magnesium on clay minerals leaving more barium in the solution. Chemical composition of carbonate precipitate from the Ana well in Benedikt (Tab. 2) has shown that the Mg/Ba ratio in the solid precipitate is relatively low and amounts to about 11, while the ratio in the water averages to 350. The Mg/Ba ratios in the precipitate and water do not indicate preferential incorporation of magnesium in the solid which would fractionate the elements towards the enrichment of barium in the water.

Potassium and rubidium originate from both, cooled thermal waters and from water-rock interaction (Fig. 1). They are higher in deeper aquifers in the Benedikt area and indicate that water-rock interaction probably affects to some extent illitic clays, too. Anomalously high rubidium with respect to potassium was analysed in the water from the spring of Špindler. It can be related either to preferential adsorption of the potassium ions on clay minerals or precipitation of solids that easily incorporate potassium and cause fractionation of potassium and rubidium. The content of both, potassium and rubidium was below their detection limit in the precipitate from the Ana spring, and no further conclusions can be done. Several other trace elements were analysed but their abundance was below their detection limits by the combined ICP-MS analytical method.

Table 2. Chemical composition of carbonate precipitate at the Ana spring, the Benedikt area.

Oxide (%)	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	P_2O_5
HB-1/05	0.31	<0.1	0.04	0.87	0.51	53.50	0.02	<0.04	0.02

Oxide (%)	MnO	FeO	LOI	TOT C	TOT S	CO_2	H_2O^+	Sum
HB-1/05	0.03	0.19	44.6	12.12	0.05	42.00	9.27	99.91

Element (ppm)	Ba	Sr	Ni	Co	Cu	Mo	Th	Y
HB-1/05	270.4	862.1	3.7	0.7	2.8	0.1	0.1	0.2

Element (ppm)	Zn	Pb	As	Sb	Se
HB-1/05	14	0.8	0.8	0.1	0.5

CONCLUSION

The formation of mineral waters in the Benedikt area and Ščavnica valley is rather complex. It is related to the mixing of deep waters and subsurface ground waters, and the reactions of carbon dioxide that penetrates from pre-Tertiary basement and dissolves in the waters. Higher proportions of cooled and chemically modified deep waters were recognised in mineral waters from the Ščavnica valley where the old thermal waters rise to the surface along deep faults. Carbon dioxide that mixes with, and dissolves in the waters enhances water/rock interaction which further modifies chemical composition of mineral waters towards the enrichment in calcium and magnesium ions.

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abstract id: **274**

topic: **4**
Mineral and thermal water

4.3
Hydrogeochemical characteristics of mineral and thermal waters

title: **Comprehensive geochemical studies of new mineral water found in the Sudetes Mts., Poland. Its origin, age, and reaction rates**

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keywords: geochemical modelling, groundwater dating, reaction rates, groundwater mixing, the Sudetes Mts.

In Sokołowsko, south of Wałbrzych town (the Intra-Sudetic Synclinorium, the Sudetes Mts., SW Poland), sulphate mineral water has been found. The groundwater does not comply with drinking-water standards, but shows the chemistry unique against a background of the Sudetes Mts., where CO_2-rich mineral water with varied cationic composition dominate. The geochemical investigations which included aqueous chemical and isotopic composition, chemistry of mineral phases, geochemical modelling, and tritium and radiocarbon groundwater dating were performed for: (1) elucidating the origin and the age of mineral water, and fresh groundwater which occur in the same hydrogeological system, and (2) explaining the spatial pattern of the groundwater chemistry.

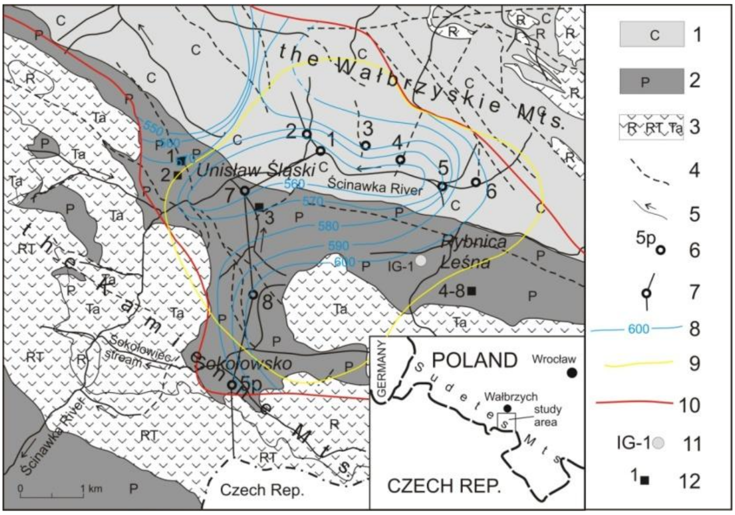

Figure 1. Hydrogeological sketch map of the area studied (after Dobrzyński, 2009). Explanations: 1 — Carboniferous sedimentary rocks; 2 — Permian sedimentary rocks; 3 — volcanic rocks: rhyolites (R), rhyolitic tuffs (RT), trachyandesites (Ta); 4 — faults; 5 — water-courses; 6 — wells; 7 — geological cross-section line (see Fig. 2); 8 — hydroizohypses; 9 — limit of depression cone; 10 — boundary of the hydrogeological unit; 11 — deep borehole; 12 — sites of carbonate rock sampling.

Groundwater was sampled in the well 5p in Sokołowsko and in wells (nos. 2, 1, 7, 8) located in the vicinity of the village of Unisław Śląski (Fig. 1). Physico-chemical analysis of groundwater comprises: field measurement (T, pH, E_H, specific electric conductivity (SEC), and gases (O_2, H_2S)), determination of main anion and cation solutes, and trace elements. Isotopic research covered stable ($\delta^{34}S$-SO_4, $\delta^{13}C$-DIC, $\delta^{18}O$, $\delta^{2}H$) and unstable (^{3}H, ^{14}C) isotopes in groundwater, $\delta^{13}C$ and $\delta^{18}O$ in carbonate minerals, and $\delta^{34}S$ and $\delta^{18}O$ in gypsum. Determination of radiocarbon activity was performed by the AMS method, and tritium by liquid scintillation spectrometry. The lumped-parameter approach (the FLOWPC code; Małoszewski & Zuber, 1996, 2002) was applied to obtain the mean tritium ages of water and the age distribution functions. Tritium input function was prepared upon tritium data in precipitation (from Cracow station, extrapolated to Vienna and Ottawa data (the GNIP database) using correlation parameters (Duliński et al., 2001, IAEA, 2002)), and monthly precipitation records from the nearest station. The PHREEQC code has been applied for the geochemical modelling of groundwater.

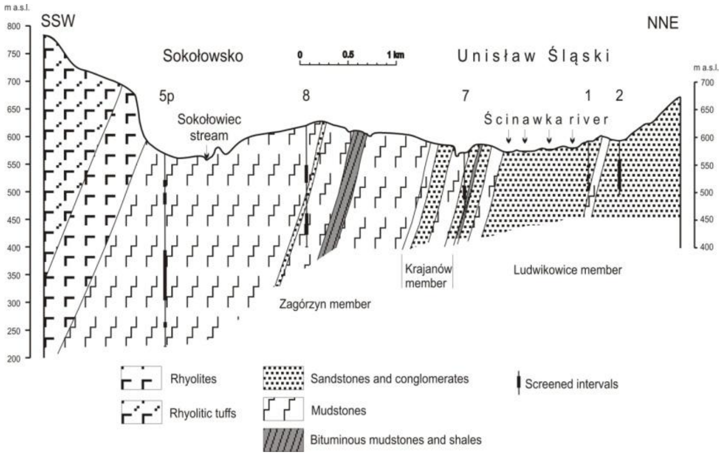

Figure 2. Schematic geological cross-section (after Dobrzyński, 2007a).

The Intra-Sudetic Synclinorium is filled by a thick complex (up to 10 km) of Carboniferous-Permian terrestrial clastic sediments with volcanogenic rocks. The Carboniferous-Permian succession is locally overlain by a thin cover of terrestrial Lower Triassic sandstones and Upper Cretaceous marine deposits. In the study area the bedrocks are conglomerates, sandstones, mudstones with clays and limestones of Late Carboniferous-Early Permian ages (Fig. 1) comprising the Ludwikowice Member (Upper Stefanian), and the Krajanów and Zagórzyn members (Lower Autunian) (Fig. 2). In the southern part of the area, Permian volcanogenic rocks occur. Sulphate mineral water in Sokołowsko occur in mudstones and claystones, with sandstones. Argillaceous-siliceous and ferrous cements are dominant in bedrock. The most reactive phases in the aquifer rocks are gypsum, calcite, dolomite, siderite, illite, kaolinite, and dispersed pyrite and organic matter.

The chemical and isotopic data acquired evidence gradual changes of groundwater composition (Table 1), from fresh water in well 2 (in an unconfined part of the aquifer) to mineral water in well 5p. The salinity of the groundwater and the concentration of most solutes increase southwards, towards the centre of the sedimentary basin. The wells (2, 1, 7, 8, 5p) are situated along the dip of the beds. However, the hydrogeological conditions indicate that wells are not located on the same single flow path, and the groundwater chemistry pattern could not be considered to be a result of chemical evolution.

The studied hydrogeological system is treated as a system of flows of two end-member waters: (1) the modern, tritium-bearing, fresh groundwater (MTW), and (2) the pre H-bomb, Holocene sulphate mineral water (SMW) (Dobrzyński, 2007b). The mixing of these components is the main process responsible for the spatial pattern of aqueous chemistry. Observation during pumping in well 5p and isotope evidences revealed that the MTW component occurs also in the sulphate mineral water horizon (Dobrzyński, 2007a, 2009). The ratio of mixing components was quantified by using geochemical modelling. The SMW to the MTW component ratio in the well 5p was estimated to be 0.65/0.35 (Dobrzyński, 2007b).

Table 1. Selected physico-chemical parameters of groundwater. Concentrations in mg/L (for complete isotopic data see Dobrzyński, 2009).

Parameter	Well no. 2	Well no. 1	Well no. 7	Well no. 8	Well no. 5p
T [°C]	11.2	9.3	10.1	15.46	15.3
pH	7.73	7.80	7.47	7.74	7.60
pe	6.373	6.151	5.969	5.556	1.278
SEC_{25} [μS/cm]	249	460	598	1230	2070
DOX	4.47	2.32	2.87	<0.01	0.60
H_2S	<0.01	<0.01	0.03	0.01	0.44
SiO_2	17.0	18.0	17.3	30.4	19.8
SO_4	38.8	126	205	625	1113
HCO_3	84	111	123	95	116
Cl	7.12	9.5	2.4	0.2	0.2
F	0.11	0.10	0.10	0.01	0.01
NO_3	8.11	8.9	4.46	1.94	0.00
Ca	33.5	56.5	98.4	197.7	322.9
Mg	5.8	16.6	9.4	25.9	20.2
Na	6.0	12.6	16.1	54.9	129.5
K	1.1	1.5	1.9	0.3	1.5
Al	0.004	0.010	0.006	0.006	0.045
As	0.0062	0.0036	0.0092	0.0887	0.1023
B	0.022	0.048	0.144	0.304	1.114
Ba	0.127	0.044	0.038	0.017	0.011
Fe	0.005	0.010	0.010	0.060	0.66
Li	0.005	0.011	0.031	0.035	0.121
Mn	0.0005	0.001	0.011	0.086	0.126
NH_4	<0.05	<0.05	<0.05	<0.05	0.13
Sr	0.086	0.291	1.045	8.942	7.836
Zn	0.016	0.018	0.054	0.017	1.052
^3H [TU]	10.18 ÷ 9.59	10.62 ÷ 7.55	16.20 ÷ 6.50	4.00 ÷ 2.86	3.20 ÷ 2.44
^{14}C [pmC]	56.39 (±0.23)	46.19 (±0.26)	36.79 (±0.19)	41.68 (±0.27)	26.94 (±0.19)
PCC[1]	Ca-HCO_3-SO_4	Ca-Mg-SO_4-HCO_3	Ca-SO_4-HCO_3	Ca-SO_4	Ca-Na-SO_4

[1]prevalent chemical character according to ion concentrations exceeding 20% meq/L.

Main reactions which formed chemistry of the SMW component were quantified by applying inverse mass balance modelling, which was performed between recharge fresh groundwater (input water) and sulphate groundwater (output water). The chemical composition of the groundwater from well 2 was taken as representative of fresh groundwater recharging the system (Dobrzyński, 2008). The chemistry of the mineral water from well 5p was equilibrated with gypsum, and in this way modified composition assumed as composition of output water in the inverse modelling (Dobrzyński, 2009). Solid, gas and exchange phases are included in the mass balance model. Dissolution of gypsum and Mg, Fe, Mn, Zn-bearing carbonates was included. The sulphate mineral water is supersaturated with respect to calcite and barite and the minerals are assumed to be precipitating. Both celestite and strontianite minerals were considered as source phases for strontium. Of silicate phases, biotite (phlogopite), chlorite and kaolinite were included in the model. Organic matter is incorporated into the model as CH_2O. The sulphate mineral water contains H_2S and is supersaturated with pyrite (SI=16.6), which mineral is considered as a possible sink phase for iron released from siderite. Ion exchange between sodium (adsorbed onto clay minerals) and calcium solute is assumed to be a sodium source. Precipitation of halite and fluorite is not thermodynamically possible (SI<0), but both minerals are incorporated as sink phases for explaining the decrease in chloride and fluoride, respectively. Sulphur and carbon stable isotopes on aqueous and solid phases (after the author's own and cited data — Dobrzyński, 2009) have also been included in the inverse model for balancing the chemical reactions. According to the two inverse models found (Dobrzyński, 2009), the main chemical features of the sulphate mineral water are controlled by gypsum dissolution, dedolomitization, organic matter decomposition and cation exchange. Sulphate solutes are reduced by bacterial mediation with the decomposition of organic matter, and iron sulphide might form. Sulphate reduction raises pH and additionally contributes to calcite supersaturation. The models found differ in the source phase for strontium. Model with strontianite dissolution as a source of strontium, probably better fits the sulphate mineral water than model with celestite dissolution. Investigation of carbonate chemical composition shows that carbonates from the study area contain about 0.5% of Sr, whereas gypsum is very poor in strontium (ca. 0.03% mol.) (Dobrzyński, 2009). Therefore, dissolution of carbonates is assumed to be a main source of Fe, Mn, Zn, and Sr solutes in the sulphate groundwater. The increase in porosity due to the reactions which formed chemistry of SMW is calculated to be lower than 0.04%. Dedolomitization driven by gypsum dissolution is a well recognized process, and has been documented in several aquifers on a regional scale (e.g., in Mexico, USA, Spain). In the study area, similar significant effects of gypsum dissolution and dedolomitization on groundwater quality have been found on a much smaller, local aquifer.

The tritium age of MTW component in well 5p was calculated by using lumped-parameter approach (e.g., Małoszewski & Zuber, 1982). Tritium data from the sulphate mineral water horizons in well 5p fit best the dispersion model (with β=0.65, P_D=0.20, Σ=0.125) and the exponential-piston flow model (β=0.65, η=1.38, Σ=0.131) with a mean residence time (MRT) of 98.3 years and of 126.4 years, respectively (where β — extra water component with zero tritium concentration, from the mixing geochemical modelling; P_D — the dispersion parameter (reciprocal of the Peclet number); η — the ratio of the total water volume to the volume with the exponential distribution of transit times; Σ — goodness of fit in the FLOWPC code defined by Małoszewski & Zuber (1996)). Dispersion model is more adequate to local hydrogeological conditions. The MRT larger than the period of the H-bomb era arises from assumed flow model (flow distribution) in the lumped-parameter approach. The presence of flow lines with groundwater of residence time of hundreds of years seem to be realistic and might result from retarded draining of small fissures and matrix micropores.

The radiocarbon age of the SMW component was estimated after complex corrections. Initial ^{14}C activity in recharge zone was assumed for two variants, for closed and semi-closed conditions with respect to soil-CO_2. Effects of mixing (MTW and SMW waters) and chemical water-rock reactions in saturation zone (after inverse mass balance modelling), as well as calibration for variations of atmospheric ^{14}C in the Holocene were taken into account. The calibrated radiocarbon-age of SMW is estimated to be of 5.9(±0.3) ka BP and 12.4(±0.5) ka BP for closed and semi-closed systems, respectively. Inverse mass balance models indicate system closed with CO_2, and it much better fit radiocarbon activity (Fig. 3). Consequently, the radiocarbon age of 5.9(±0.3) ka BP was assumed as more adequate for the SMW component.

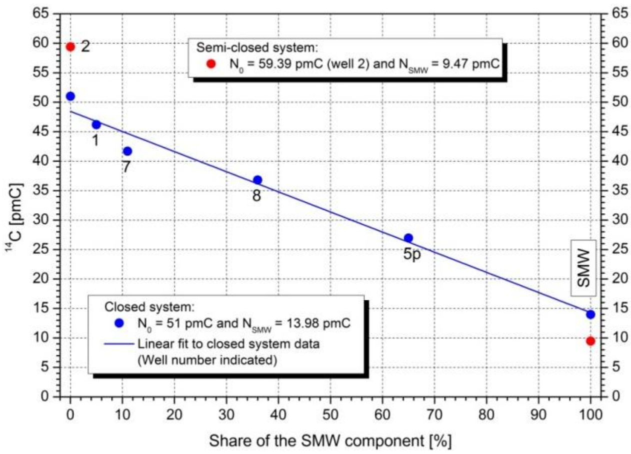

Figure 3. Radiocarbon activity in groundwater versus water mixing ratio (after Dobrzyński, 2009)

The mean apparent reaction rates for the chemistry of SMW were estimated based on phase mole transfers (from inverse model) and radiocarbon dating, and are calculated to be: dissolution of gypsum (2.85 μmol/L/year) and dolomite (0.21 μmol/L/year), calcite precipitation (0.20 μmol/L/year), and organic matter decomposition (0.08 μmol/L/year) (Dobrzyński, 2009). The studied hydrogeological system has about 40 km^2 only. One should be noticeable that the reaction rates found are well consistent with the reaction rates for a vast regional Madison aquifer, USA (e.g., Busby et al., 1991), where a very similar set of geochemical reactions is currently responsible for groundwater quality formation.

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abstract id: **280**

topic: **4**
Mineral and thermal water

4.3
Hydrogeochemical characteristics of mineral and thermal waters

title: **Occurrences, origin and vulnerability of therapeutical waters in the western part of the Polish Carpathians**

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keywords: Carpathians, therapeutical waters, water origin, water age, water chemistry

In Poland, the most abundant resources of different types of therapeutical waters occur in the western part of the Carpathians and in their fore-deep area. Mineral waters (i.e. with TDS > 1000 mg/L), specific waters (e.g. with I^-, Fe^{2+}, H_2S or H_2SiO_3 in required contents), CO_2-rich waters (with free CO_2 > 1000 mg/L) and thermal waters (>20°C) can be regarded as therapeutical by law, if they are free of pollutants and characterized by satisfactorily constant physical and chemical parameters. Typical examples of such waters are presented below.

Common CO_2-rich waters are of purely meteoric origin and occur in flysch Carpathians, mainly along the Poprad river valley where deep seated CO_2 of metamorphic origin travels along fault zones to the ground surface. Their mean ages range from less than 10 years for small springs to pre-Holocene ages in some wells several hundred meters deep. The most common age values of exploited waters are between several tens and 300 years. Elevated concentrations of nitrates are observed only in some small springs whereas all other intakes are free of pollutants. The youngest waters are of HCO_3–Ca types with TDS up to 3 g/L whereas in the oldest ones Mg^{2+} and Na^+ dominate among cations with TDS usually in the range of 3 to 5 g/L, and in extreme cases up to 12 g/L. CO_2-rich chloride waters also occur only in the flysch formations. They differ from common CO_2-rich waters by admixtures of ascending chloride waters which result from dehydration of clay minerals during diagenesis. These waters are of Na–Cl type (mNa^+/mCl^- >1); their chemical constituents being remnants of the sedimentation marine water modified mainly by ultrafiltration and chemical reactions accompanying the burial diagenesis. In areas without CO_2 flux, the diagenetic waters, if travel to the ground surface, mix with fresh waters. In Rabka Spa the TDS contents in diagenetic waters reach abt. 20 g/L.

Within the area of the Outer Carpathians, Devonian and Carboniferous carbonates and sandstones of the flysch bedrock contain brines of paleometeoric origin with TDS contents exceeding 100 g/L. However, the bedrock of flysch in the Podhale Basin (Inner Carpathians) is represented by Eocene and Mesozoic carbonates, which outcrop in the Tatra Mts. at altitudes of abt. 1100–1800 m. These fissured and karstified formations contain waters with ages ranging from modern to pre-Holocene. They are thermal with temperatures up to abt. 85°C and TDS up to 3 g/L.

Flysch formations are characterized by numerous sulfide springs with mean ages up to 200–300 years, which are related to occurrences of diffused pyrites and organic matter. Only waters of one site (Wapienne) are regarded as therapeutical with H_2S contents up to 6 mg/L (HCO_3–Ca type with TDS up to 0.4 g/L).

Quite different sulfide waters situation occur in the area of the Carpathian fore-deep which is filled-in by Miocene (Badenian) marine sediments. Sulfide waters in marls and gypsum formation of Kraków-Swoszowice are very young (described be exponential model with the mean age of 50 years). They are of SO_4–HCO_3–Ca–Mg type with H_2S contents of 60–80 mg/L and TDS of 2.6 g/L. Confined sulfide waters in Neogene sands of Kraków-Mateczny are of glacial age with admixture of modern water in one well. They are of SO_4–Cl–Na–Mg–Ca type with H_2S up to 6 g/L and TDS up to about 4.5 g/L. Their mineralization is related to the dissolution of salt and gypsum inclusions in Miocene clays. Sulfide water in Krzeszowice occur in a confined formation of Badenian gypsum; in the Main Spring, it is of SO_4–HCO_3–Ca type with TDS of about 3 g/L and H_2S content of 4 mg/L.

The most valuable sulfide waters occur over a large area in the region of Busko Spa. Confined Cenoman sands and sandstones are the main water bearing formation with unknown recharge area somewhere at the north-west, whereas natural drainage area is at Busko Spa. They are of Cl–Na and Cl–SO_4–Na types with H_2S contents of 20–40 mg/L and TDS of about 12–14 g/L. The chemistry of these waters evidently results from leaching of salt and gypsum formations. Environmental tracers strongly suggest their meteoric origin related to the last interglacial.

Jurassic limestones in Busko Spa contain Cl–Na brines of pre-Quaternary age, which were recharged after the last sea regression in the Badenian. Cl–Na and Cl–SO_4–Na sulfide brines of presumably similar age occur in the area of Solec Spa which is situated to the south-east of Busko Spa, in the direction of the Vistula river valley.

Abundant presence of highly mineralized waters of the post-Badenian ages is the only remnant of Badenian salt and gypsum deposits which presumably existed in the recharge area(s). Gypsum formations are preserved only in the south-east part of the area where no conditions for the recharge existed.

Hydrogeology and ages of all discussed waters indicate that most of them are not susceptible to potential anthropogenic pollutants, if properly managed and not over exploited. Only the youngest waters can be endangered, especially those in Swoszowice and Wapienne.

abstract id: **321**

topic: **4**
Mineral and thermal water

4.3
Hydrogeochemical characteristics of mineral and thermal waters

title: **Hydrogeochemistry and noble gas geochemistry of geothermal waters from the Chungcheong province, central South Korea**

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keywords: geothermal waters, chemical composition, noble gases, stable isotopes, $^{3}He/^{4}He$ ratios

An investigation of geothermal chemistry in South Korea has given insight into the degassing and circulation of volatile elements in this tectonic transition zone between island arc and continent. Fifteen geothermal water and gas samples from eight hot spa sites and one deep well test site were obtained from the Chungcheong Province of South Korea.

We measured chemical composition as well as the stable and noble gas isotopic ratios of the samples and found composition varied according to tectonic location. Water temperatures at the sample sites range from 21.4 to 47.0°C. All waters are alkaline (pH 7.6–9.8) with electrical conductivity of 224–495 μS/cm, the one exception being the CO_2–rich Neungam sample, whose waters are weakly acidic (pH 6.3) with very high electrical conductivity (2,780 μS/cm), high P_{CO2} (0.998 atm) and the highest $^3He/^4He$ ratio (1.76×10^{-6}) observed amongst our samples. The Chungcheong geothermal waters can be grouped into three chemical types related to temperature: Ca–HCO_3, Ca(Na)–HCO_3 and Na–HCO_3 (Fig. 1a). $\delta^{18}O$ and δD values range from –10.4 to –7.9‰ and from –77.9 to –58.8‰, respectively, and plot below the meteoric water line.

A wide range of $^3He/^4He$ ratios is observed (0.036 to 1.76 ($\times10^{-6}$)), showing evidence that while radiogenic ^4He is dominant in these samples, He of mantle-origin is also supplied to these waters. $^{40}Ar/^{36}Ar$ ratios are close to or slightly higher than the atmospheric value. Concentrations of ^3He and $^4He/^{20}Ne$ ratios increase with increasing water temperature within a single hot spa area, which may be explained by local groundwater mixing by mantle-derived He found in the high temperature waters (Fig. 1b). The concentration and isotopic composition of other noble gases (Ne, Ar, Kr and Xe) measured from the samples indicate that they are atmospheric in origin.

a) b)

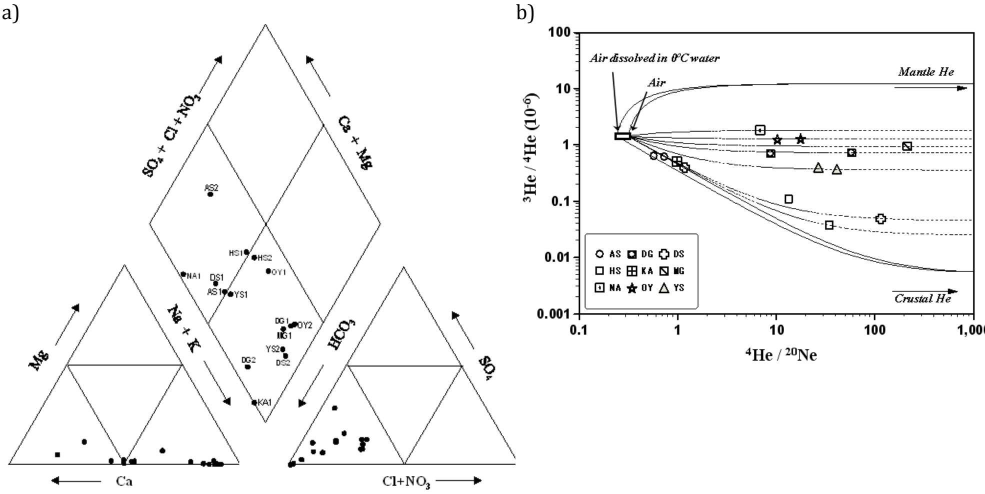

Figure 1. Trilinear Piper diagram of major ion compositions of geothermal water Samales (a), and plot of $^3He/^4He$ versus $^4He/^{20}Ne$ ratios for waters and gases (b).

From a broad geographical view point, the observation that the maximum $^3He/^4He$ ratio for our samples is lower than those observed for volcanics from the Japanese Islands is consistent with the increasing depth of the subducted oceanic plate beneath the Korean Peninsula (Zhao et al., 2004, 2007). The observed mantle He signatures show no relationship with basement rock type such as granitoid, high-grade gneiss or schist, temperature of waters and/or location of geothermal water site. The discharge rate of mantle He might be controlled by underground structures such as deep-seated faults. We speculate that a deep-seated fault system and a stagnant subducting plate beneath the Korean Peninsula play an important role in the release of mantle volatiles in a transitional tectonic setting.

ACKNOWLEDGEMENTS

This work was supported by a grant (R01-2004-000-10759-0) from the Basic Research Program of the Korea Science and Engineering Foundation.

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abstract id: **368**

topic: **4**
Mineral and thermal water

4.3
Hydrogeochemical characteristics of mineral and thermal waters

title: **Two contrasting geothermal systems — towards the identification of geochemical reaction pattern and groundwater temperature, the Sudetes, Poland**

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keywords: groundwater geochemistry, geochemical modelling, geothermometers, the Sudetes, Poland

The Sudetes Mts. (SW Poland) is a region rich in curative mineral waters used in balneotherapy. Two main types of mineral waters occur in the Sudetes Mts.: (1) low-enthalpy CO_2-rich water with various cationic composition (mainly Ca, Mg, Na), and (2) thermal Ca or Na bicarbonate and/or sulphate waters, usually fluoride-rich, containing H_2S and/or Rn. Thermal waters are exploited in two spas: Lądek Spa and Cieplice Spa (Fig. 1).

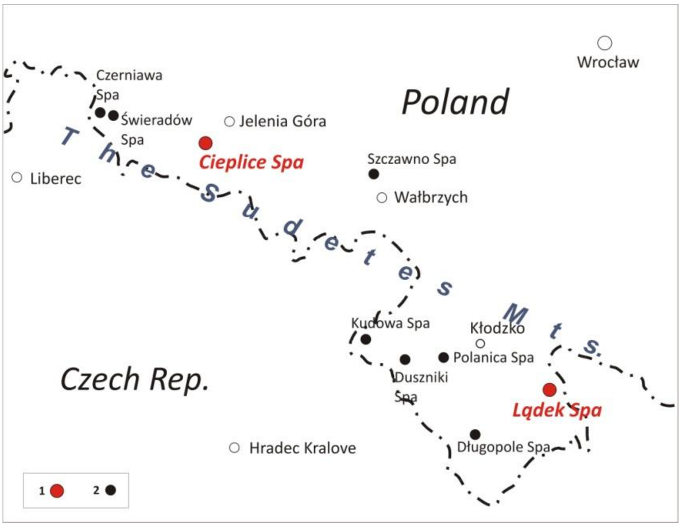

Figure 1. Location of Lądek and Cieplice spas (The Sudetes Mts., SW Poland). Explanations: 1 — spas with thermal waters in The Sudetes Mts.; 2 — other spas in The Sudetes Mts., which provide low-enthalpy curative waters.

The water temperatures in these spas reach 44°C and 59°C, respectively (Tab. 1).

Table 1. Chemical characteristics of thermal water from Lądek (L-2 borehole) and Cieplice (C-2 borehole), The Sudetes Mts., Poland. Concentrations in ppm.

Parameter	L-2	C-2	Parameter	L-2	C-2
pH	9.22	8.20	Li	0.032	0.182
SEC[1]	777	237	Mg	0.215	0.053
E_H [mV]	-159	-141	Mn	0.010	0.008
T [°C]	44.3	58.8	Na	47.778	169.773
T[2] [°C]	80±5	110±10	Ni	0.002	0.001
$logPCO_2$[3]	-4.50	-2.75	P	0.024	0.026
$logPCO_2$[4]	-2.50	-1.05	Rb	0.010	0.038
Al	0.040	0.052	Si	48.212	85.302
As	0.001	0.047	Sr	0.038	0.205
B	0.043	0.236	Zn	0.105	0.006
Ba	1.577	0.011	F	11.50	12.00
Br	0.041	0.262	Alkalinity[5]	59.568	152.227
Ca	5.822	9.235	SO_4	15.20	148.96
Cs	0.005	0.027	Cl	8.86	43.61
Cu	0.005	0.003	$N\text{-}NO_3$	0.007	0.002
Fe	0.033	0.027	$N\text{-}NH_4$	0.536	0.008
K	0.772	4.900	H_2S	3.66	<0.01

1 — specific electric conductivity (in µS/cm) compensated for 25°C; 2 — temperatures at depth, estimated; 3 — calculated CO_2 pressure at outflows; 4 — CO_2 pressure at depth, estimated; 5 — alkalinity in $mgCaCO_3/L$

Due to the high cost of drilling and equipment there is a continuous interest in a priori estimation of temperatures in geothermal systems. Most of the developed chemical geothermometers entail only a selected set of water parameters. Moreover, in such an approach all geothermometers are valid only if – even partial and/or local – chemical equilibrium in the system is reached and maintained. At temperature lower than equilibrium temperature and/or if other suit of minerals are in equilibrium with waters the usage of geothermometers might fail. In this study a multi-component chemical calculation of chemical equilibrium proposed by Reed & Spycher (1984) were applied to estimate water temperature at depth.

Two contrasting by temperature and water chemistry geothermal systems in the Sudetes Mts., Poland, were considered. Exploited, most deep waters from wells L-2 and C-2 in Lądek and Cieplice, respectively, represent the chemical end-member compositions. The Cieplice/Lądek thermal waters differ mainly in pH, calculated PCO_2, E_H, and concentration of main solutes (Ca, Mg, Na, SO_4, alkalinity), silica and hydrogen sulphide (Tab. 1). Speciation/solubility modelling and reaction path modelling were performed by using the PHREEQC code (Parkhurst, Appelo, 1999) with LLNL thermodynamic database.

The method of Reed and Spycher (1984) of estimating temperature in the aquifer relies on using the composition of water of interest to find a temperature, where a plausible minerals of the given system are computed to be in equilibrium with aqueous phase. This is provided by plotting the saturation index of minerals versus temperature. This method was adapted previously to the Sudetes thermal waters (Leśniak, Nowak, 1993), although the lack of Al concentration could affect partially the results. Currently obtained temperatures (Figs. 2, 3) are higher than proposed earlier by Ciężkowski at al. (1992), Leśniak & Nowak (1993), and generally are close to the recent estimate by chemical and isotopic geothermometry (Dowgiałło, 2000; Dowgiałło et al., 2005). At calcite equilibrium and $\log PCO_2$ of -2.50 and -1.05, respectively, the estimated temperature for Lądek is 80 ±5°C and for Cieplice is 110 ±10°C (Tab. 1).

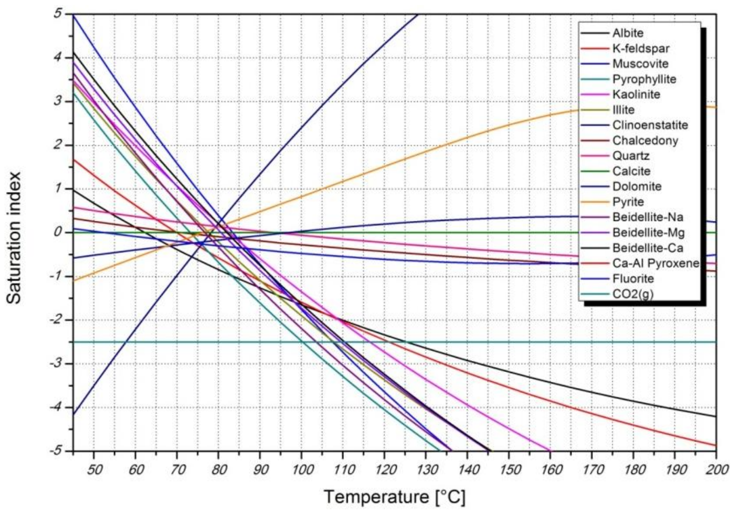

Figure 2. Saturation index for minerals vs. temperature for thermal water from well L-2 in Lądek Spa, equilibrated with calcite, at $\log PCO_2$= -2.50.

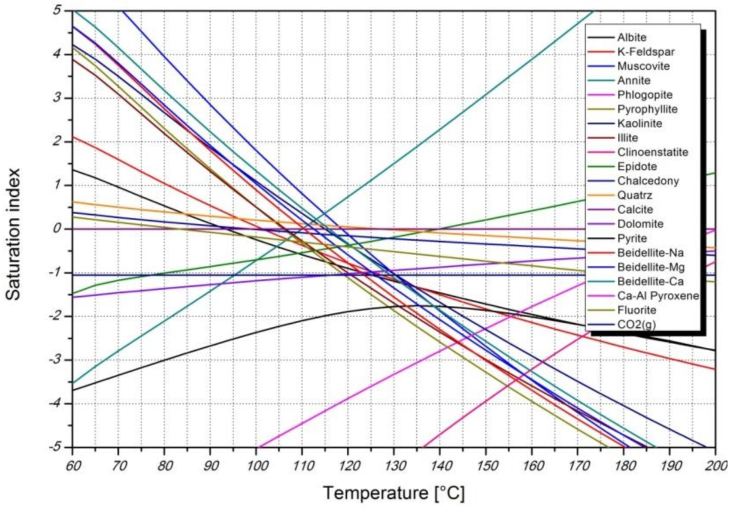

Figure 3. Saturation index for minerals vs. temperature for thermal water from well C-2 in Cieplice Spa, equilibrated with calcite, at logPCO2= -1.05.

In addition to the mineral saturation plots which provide a temperature at depth, a geochemical reaction paths revealing how the chemical composition is formed at a presence of a genuine mineral assemblage have been modelled. Geochemical reaction path modelling has been applied for identifying main chemical reactions which are responsible for formation the chemistry of thermal waters in both systems. Aquifer rocks in the Lądek geothermal system (mainly gneisses) and the Cieplice system (granites) are composed mainly of the same mineral set (plagioclases, K-feldspars, biotites, muscovites). These minerals, with genuine composition, were considered as a preliminary input of source mineral phases in the modelling. The apparent difference is that plagioclases in Lądek gneisses are more sodic (avg. $Ab_{85}An_{15}$) than plagioclases in Cieplice granite (avg. $Ab_{65}An_{35}$). Moreover, the formation of secondary clay minerals, calcite and silica were considered in the models. Fluorite was included in modelling as a source of fluoride, an important constituent of thermal waters. Hydrogen sulphide has been also added to the model of Lądek system because of its distinct presence (Tab. 1).

Logically, reaction path modelling were performed for the same CO_2 pressure and temperature as in the temperature estimation process, i.e., $logPCO_2$ = -2.50, T = 80°C and $logPCO_2$ = -1.05, T = 110°C for Lądek and Cieplice systems, respectively (Tab. 1). Reaction path models which fit the best the field data were found (Figs. 4, 5; Tab. 2) by the trial-and-error method. Species activities in thermal waters were assumed as an end-points of modelled reaction paths. The chemical reaction paths resulted from simulations in $[Na^+]/[H^+]$ vs. [Si], and $[Ca^{2+}]/[H^+]^2$ vs. [Si] scales, lead to the chemical compositions of the thermal waters of interest.

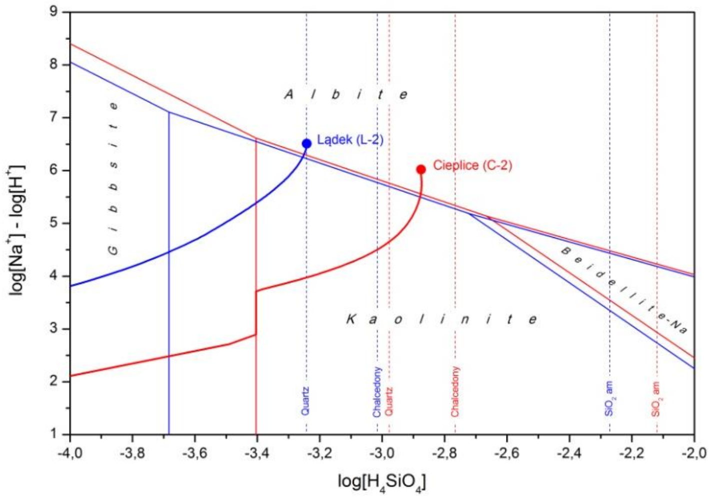

Figure 4. Reaction paths for thermal water from well L-2 (Lądek Spa) and well C-2 (Cieplice Spa) in the Na2O-SiO2-Al2O3-H2O system. Blue lines refer to the Lądek geothermal system, red ones to the Cieplice geothermal system.

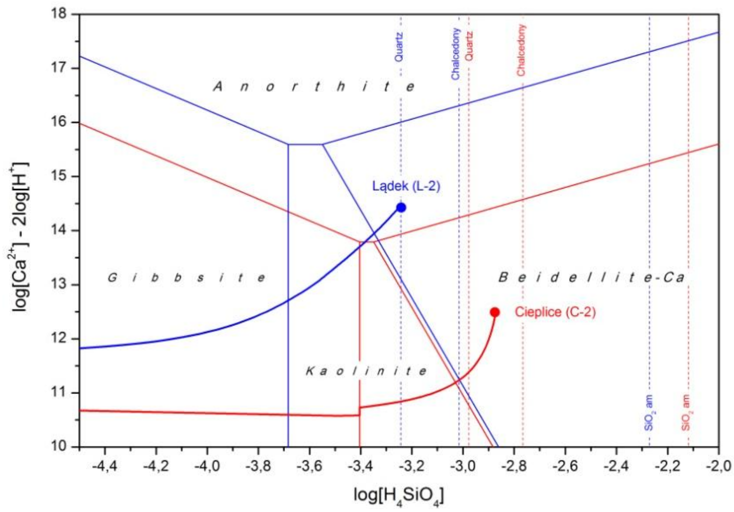

Figure 5. Reaction paths for thermal water from well L-2 (Lądek Spa) and well C-2 (Cieplice Spa) in the $CaO-SiO_2-Al_2O_3-H_2O$ system. Explanations as in Fig. 4.

It results, that the main features of the chemistry of the thermal waters in both geothermal systems are probably formed by a similar set of geochemical reactions: dissolution of plagioclases, biotites and fluorites, and formation of Ca-beidellite, calcite and silica. In the Lądek system, Na-beidellite is also forming. The details of the mass transfer of dissolving/precipitating phases can be found in Tab. 2.

Table 2. Phases considered in the geochemical reaction path models with mole transfers.

Lądek L-2			Cieplice C-2		
Phases	**Role in the model**	**Mole transfer ratio with respect to fluorite[1]**	**Phases**	**Role in the model**	**Mole transfer ratio with respect to fluorite[1]**
Plagioclase[2]	Diss	133.33	Plagioclase[3]	Diss	96.67
Biotite[4]	Diss	2.67	Biotite[5]	Diss	8.53
Fluorite	Diss	1	Fluorite	Diss	1
$H_2S(g)$	Diss	3.33			
Beidellite-Na	Prec	46.67			
Beidellite-Ca	Prec	20	Beidellite-Ca	Prec	11.52
Quartz	Prec	90	Quartz	Prec	103.6
Calcite	Prec	76	Calcite	Prec	100.53

Explanations: 1 – according to reaction path modelling fluorite mole transfer has been found to be the lowest one in both models. Average composition of genuine plagioclases and biotites assumed in the modelling:

2 – $Na_{0.85}Ca_{0.14987}Sr_{0.00013}Al_{1.15}Si_{2.85}O_8$; 3 – $Na_{0.65}Ca_{0.35}Al_{1.35}Si_{2.65}O_8$;

4 – $KFe_{1.495}Mg_{1.495}Mn_{0.007}Zn_{0.003}AlSi_3O_{10}(OH)_{1.629}F_{0.364}Cl_{0.007}$;

5 – $K_{0.8508}Na_{0.0847}Li_{0.0479}Rb_{0.0044}Fe_{1.9874}Mn_{0.0135}Mg_{1.1410}Ca_{0.2441}Th_{0.0002}U_{0.0003}Cu_{0.0008}Zn_{0.0080}Be_{0.0016}Sr_{0.0018}Ba_{0.0274}Sn_{0.0013}Al_{1.2128}Zr_{0.0015}Hf_{0.0001}Si_{2.9544}O_{11.29975}(OH)_{0.7041}F_{0.0050}$.

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abstract id: **386**

topic: **4**
Mineral and thermal water

4.3
Hydrogeochemical characteristics of mineral and thermal waters

title: # Thermomineral groundwaters of Mataruska banja spa, Central Serbia

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keywords: thermomineral waters, hydrogen sulphide

The Mataruska Banja Spa is situated in central part of Serbia, 180 km south of Belgrade at the foot of Stolovi Mountain, on the right bank of the Ibar River. The spa is situated at an altitude of 215 m and is characterised by moderate continental climate. The mean annual temperature amounts 12°C, while the mean sum of precipitation for many years amounts 761 mm.

Thermo mineral springs at the territory of the spa were discovered by chance after the big flood in the spring of 1898. The Ibar River turned from its watercourse right and made a new bed, closer to the mountains. Hot water smelling of sulphur occurred at the place where the Ibar River had made a new temporary bed. The increased percentage of sulphur hydrogen presence is one of the basic reasons of healing properties of Mataruške Banja thermo mineral waters.

Serpentinite and hydro thermally altered serpentinite of the Palaeozoic age represent the basic rock mass of which the terrain is constituted .Hydro thermally altered serpentinite represent a water-bearing formation of thermo mineral water where a fissure aquifer has been formed. A fissure aquifer within hydro thermally altered serpentinite is recharged predominantly by infiltration from precipitation. The circulation of thermo mineral water formed in deeper zones of the fissure aquifer takes place in fissure systems of younger faults and along fault zones within both kinds of serpentinite. It is supposed that there is a primary collector of thermo mineral water within limestones of Triassic age or marble of Palaeozoic age in the floor of serpentinite. By means of ^{3}H (tritium) and carbon ^{14}C isotope, the estimated age of Mataruska Banja Spa waters amounts about 16 700±350 years.

The existence of the collector within the serpentinite and hydro thermally altered serpentinite has been stated while working the MB-1/79 (355m), MB-2/81 (130m) and MB-3/83 (733m) exploratory-abstraction wells on the territory of the Mataruska Banja Spa (Tab. 1). The fault zone in hydro thermally altered serpentinite along which the circulation of groundwater takes place was discovered by working the MB-1/79 drillhole in the interv al of 6–56 m, while at the MB-2/81 drillhole that zone is caught by the whole interval to 130 m. The younger fault zone is not drilled by the MB-3/83 well, although its depth is 733m.

Table 1. General data on exploratory-abstraction wells on the territory of Mataruška Banja Spa.

Well	Well depth(m)	Groundwater table	Q (l/s)	S (m)	K (cm/s)	T (m²/s)
MB-1/79	355	2.6	6.54	22.7	1.28×10^{-2}	5.29×10^{-3}
MB-2/81	130	2.34	21	2.7	5.69×10^{-2}	2.27×10^{-2}
MB-3/83	733	5.72	6	23.5	—	—

The thermo mineral water from the MB-2/81 well belongs to the category of sodium, magnesium, hydro carbonate, fluorine, sulphureous, hyper thermal water (Tab. 2).

Table 2. Comparative survey of chemical composition of Mataruška Banja Spa thermomineral water.

Well	Depth (m)	T (°C)	pH	M (mg/l)	Na^{+} (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	HCO_3^{-} (mg/l)	Cl^{-} (mg/l)	SO_4^{2-} (mg/l)	H_2S (mg/l)
MB-1/79	355	32	6.9	1466	188	45	85	952	71	10	0.12
MB-2/81	130	52	6.95	1293	221	14	46	730	6	112	19
MB-3/83	733	25	—	958	18	70	113	385	35	304	0.22

By a chemical analysis, significant quantities of H_2S of 19mg/l, were measured in thermo mineral water of the MB-2/81 well, which makes this water a healing one. Hydrogen sulphide in the thermo mineral water of the Mataruska Banja Spa is probably of igneous origin. The mineralization ranges from 1 to 1.5 g/l. The temperature scope is in the interval of 25–52°C. The tempereature at the main well amounts 52°C and ,besides the increased concentration of H_2S, represents the main therapeutic value. The water is mildly radioactive.

The therapeutic effect of healing thermo mineral water of the Mataruska Banja Spa is realised best by bathing in hot sulphurous water and by muddy compresses. The increased temperature of 52°C, the concentration of hydrogen sulphide (to 19 mg/l) and the presence of meta silicon acid (about 100 mg/l) represent the basic balneologic properties of this water.

Rheumatic diseases, gynaecological diseases, post traumatic conditions and all their consequences, neurological diseases, damages of central and peripheral nervous system, as well as the diseases of peripheral blood vessels are cured in the Mataruska Banja Spa.

abstract id: **395**

topic: **4**
Mineral and thermal water

4.3
Hydrogeochemical characteristics of mineral and thermal waters

title: **Mercury concentrations assessment in bottled and spring waters (N Portugal): hydrochemical approach**

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keywords: hydromineral systems, hydrochemistry, mercury, fault zones, N Portugal

This work is strongly related to one of the essential water research issues of this millennium, "Water Dependencies: Systems under Stress and Societal Responses" under the scope of the main theme "adapting to the impacts of global changes in river basins and aquifer systems" (see UNESCO IHP VII Programme (2008–2013): http://www.unesco.org).

The full effect of the increased mercury (Hg) loading, for both industrial and agriculture use, results in a significant enhance in environmental contamination, especially on water. The main goal of this work was to assess the potential mercury concentrations in some Portuguese bottled waters and springs. Special emphasis was dedicated to quantify mercury concentrations in the several hydromineral systems spring waters issuing along the Verín-Régua-Penacova fault zone and surrounding area. The geological framework is characterised mainly by granitic and metasedimentary rocks, as well as metavulcanites and doleritic veins. The main regional structure is the Verín-Régua-Penacova fault zone (North Portugal, Iberian Peninsula), trending NNE-SSW along more than 200 km, which controls thermomineral water occurrences. This megastructure is part of a late-Variscan deep fault system that was reactivated by the Alpine tectonics.

Water samples for mercury analysis were collected from 19 bottled water and springs. Temperature, pH, and electrical conductivity of the waters were determined in situ. The mercury was determined by a cold vapour generation atomic absorption spectrometry (ContrAA 700 Analytik Jena) at Instituto Superior de Engenharia do Porto|ISEP, which uses an innovated technology that combines a continuum source, with a high resolution double echelle monochromator and a CCD detector. The limit of detection of the method was about 0,059 μg/L. Data analysis from bottled and spring water samples showed very-low and slightly variations (c. 0,28 μg/L to 0,17 μg/L) of mercury level that is probably close related with the Verín-Régua-Penacova fault zone system. The preliminary results suggested that mercury concentrations in groundwater are related to the regional deep fault zone with neotectonic activity. The water samples collected away from the main regional fault zone indicated very-low mercury levels. Some samples showed values close to the limit of detection of the method. Apparently, there are no anthropogenic interferences neither old mine tailing deposits near the springs.

abstract id: **416**

topic: **4**
Mineral and thermal water

4.3
Hydrogeochemical characteristics of mineral and thermal waters

title: **Mineral waters in the southern part of the Upper Silesian Coal Basin (Poland) and the possibility of using the mine waters from abandoned coal mines for therapeutic purposes**

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keywords: mineral water, mine water, abandoned coal mine

ABSTRACT

Some groundwaters from the Miocene (Badenian), the Carboniferous and the Devonian formations in the southern part of the Upper Silesian Coal Basin in Poland are used as mineral waters. The paper presents pharmacodynamic coefficients of the brines from the Korona well in Zabłocie and in Ustroń and of the mine waters from the abandoned coal mines "Żory" and "Rymer" in the southern part of the Upper Silesian Coal Basin, which show the possibility to be utilized in medical therapy.

INTRODUCTION

Groundwaters of the Upper Silesian Coal Basin (USCB) is characterised by different chemical composition, e.g. their mineralization degree ranges from several hundred mg/dm^3 to more than 200 g/dm^3 (Różkowski et al., 2004; Pluta, 2005). Some of them have been used for hydrotherapeutic purposed since the XIX century. This concerns several mineral waters that are taken from the Miocene (Badenian), the Carboniferous and the Devonian formations, located in the southern part of the USCB (Paczyński, Płochniewski, 1996).

It is also possible to use the mine waters from the Carboniferous formations of the USCB for therapeutic purposes. Studies of the pharmacodynamic coefficients of mine waters from the abandoned coal mines have been performed in order to evaluate the possibility of their use in medical therapy.

MINERAL WATERS IN THE SOUTHERN PART OF THE USCB

The mineral waters from the wells in Zabłocie and Ustroń are characterised by the pharmacodynamic coefficients in compliance with the Polish law. Selected these coefficients in mineral water from the "Korona" well in Zabłocie in the period 1950–2010 are presented in Table 1. Concentrations of iodides and iron ion (II) and values of the mineralization have been almost constant during more than last sixty years.

Table 1. The pharmacodynamic coefficients in mineral water from the Korona well in Zabłocie in 1950–2010.

Pharmacodynamic coefficient	Korona well					
	1950–1975	1976	2001	2007	2008	2010
Mineralization [g/dm^3]	42.2–44.2	43.4	43.1	46.5	46.4	41.0
Fe^{2+} [mg/dm^3]	8.6–59.5	15.8	14.9	10.5	14.0	12.8
F^- [mg/dm^3]				1.8		2.1
I^- [mg/dm^3]	121.0–140.7	128.7	130.0	134.0	138.0	126.0

MINE WATERS FROM ABANDONED COAL MINES IN THE SOUTHERN PART OF THE USCB

In the USCB in Poland many coal mines have been closed during the last twenty years. In the southern part of USCB "1 Maja", "Morcinek", "Moszczenica", "Rymer" and "Żory" coal mines have been abandoned. Selected pharmacodynamic coefficients in the mine water flowing from the abandoned "Żory" coal mine in the period 1997–2010 are presented in Table 2. Results of the iodide and iron ion (II) and the mineralization are in quantities exceeding the values of mineral waters therefore can be used for hydrotherapeutics.

Table 2. The pharmacodynamic coefficients in the mine water from the abandoned "Żory" coal mine in 1997–2010.

Pharmacodynamic coefficient	Mine water from the abandoned "Żory" coal mine					
	1997–1998	**1999**	**2000**	**2001–2002**	**2002–2008**	**2010**
Mineralization [g/dm^3]	71.0–74.2	75.8–85.5	87.1–93.6	95.2–106.5	101.3–109.7	101.8
Fe^{2+} [mg/dm^3]			40–60			37.2
F^- [mg/dm^3]				1.1		1.3
I^- [mg/dm^3]			20–57			18.2

CONCLUSIONS

Some groundwaters from the Miocene (Badenian), the Carboniferous and Devonian formations in the southern part of the USCB are used as the mineral waters. Studies show that mine waters flowing from the abandoned coal mines, in this region, have mineralization and the iron (II) ion and iodides concentration as required to classified as therapeutic waters.

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abstract id: **431**

topic: **4**
Mineral and thermal water

4.3
Hydrogeochemical characteristics of mineral and thermal waters

title: **Hydrogeochemical characteristics and their basic types thermomineral waters in Serbia**

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keywords: geological composition, hydrogeology, hydrogeochemical, thermomineral waters, basic type

ABSTRACT

The title of this paper sufficiently points out the essential presentation as a whole. Together with the state of research and exploitation of the thermomineral water in Serbia, the paper presents the categorization of these waters in accordance with the anion end cation contents, basic types i.e. the way and extend of the utilization, the origin and the processes occurring in the Earth's crust, zone in the relation to the environment where they ere formed, as well as the assessment of these waters in Serbia. The paper especially emphasizes the fact that geological composition and certain conditions and processes occurring in the Earth's crust represent the decisive factors for the genesis of these waters, well as the differences rep resenting the essence of these waters as a natural mineral resource. Serbia, in its whole territory, is country rich with mineral waters representing a natural treasure that should be appreciated. According to the registered natural occurrences (spring) up-to-now established by the research drilling, there are 272 locations in Serbia (as per recent data probably more than 300), out of which 230 locations have been tested in details. As far as the form and content are concerned, this paper represents a new conceptual approach to the treatment of thermo mineral waters – not only in classifying basic types of these waters, but in separating and defining hydro geochemical conditions of geological environment in which occurrences are noticed as well. There have been data about the depth of drilling, the kind of collector and its depth, for most boreholes. It is more important, however, that research work so far shows that thermomineral occurrences and their spread within the territory of Serbia depend very much on neotectonic movements reflecting in transformation of older structures, by activating existing dislocations, general relief raising, depression formation and horsts. The effect of neotectonic movements is followed by volcanic activity, namely geothermal anomaly formation in particular regions, of which contemporary manifestations on the surface of the terrain are, among the others, thermo mineral water occurrences as well. Tertiary igneous activity is another important factor for thermomineral water occurrences. Masses of vulcanite following faulting contributed to geothermal anomalies formation considerably. With regard to that, practically, it is very difficult, almost impossible, to draw a boundary among particular mineral water types in natural conditions, for different types of mineral waters are present on the terrain, it is very difficult to make an entire mineral water classification. Systematizing the presented results of former researches according to ion composition, mineralization, gas composition and radioactivity, the following types of thermo mineral waters in Serbia can be singled out by specific components: HCO_3-Ca, Mg-Ca, Mg-Ca-Na with M to 5 g/l, HCO_3-Na with M to 15 g/l, Complex anion composition Na or Ca-Na, raised t with M to 10 g/l, SO_4-HCO_3, Mg-Ca and Na-Mg-Ca with M to 5 g/l, SO_4-Cl-Na, Ca-Na with M to 15 g/l, SO_4-Cl and HCO_3-SO_4-Cl-Na, SO_4-Na and Mg-Na, HCO_3-Cl-Na rarely Cl-Na-Ca, Cl-Na and Ca-Na, in the last three types M is raised. The pH values of mineral and thermomineral water varies from 2.5 (hyperacid) up to 12 (hyperalcaline). Values of TDS vary from 0.2 gr/kg to 20 gr/kg. Maximal temperature of the natural springs is 96°C . Maximal temperature of thermal water from wells is 111°C.

INTRODUCTION

Serbia is situated in western part of Balkan Peninsula. The Balkan Peninsula is located in the South Eastern Europe and geographically it represents its largest section. Serbia covers relatively small area (about 88 000 km^2) but its geology is quite complex. Upper part of the earth crust at the territory of Serbia, 250 natural springs are situated. This paper shows main characteristics of thermomineral water of Serbia such as: yield, temperature, chemical content, and utilization.

REGIONAL GEOTHECTONICS AND GEOLOGICAL OVERVIEW

The most of the thermal springs are locatedin the Inner Dinarides their is situated in the southern periphery of the Pannonian Basin. It ranges from Belgrade at the east to Sisak at the west and from the Sava River at the north towards the cities of Banja Luka and Sarajevo (Fig. 1). Inner Dinarides represents the nothen branch of the Dinaric Formations, which are the largest geotectonic unit of thr Balkan Peninsula. According to conventional tectonics concepts the Dinaric Formations represen the central part of the former large geosinklyne inside Alpine Orogeny, wich also encompass the following large geotectonic units: Serbian-Macedonian Massif, Carpatho-Balkanides and Pannonian Basin and a small part of Mesian Platform (Grubić, 1980). According to the lates interpretations of the tectonics of Balkan Peninsula, which, are the result of the applied „global tectonic“ theory, the Eart"s crust in the teritory „Yugoslavia“ consists of terranes (Keppie & Dallmeyer, 1990). The terranes in the central and western parts of the Balkan Peninsula are the consequence of subduction that occurred during the Jurassic Period(Karamata & Krstić, 1996). According to these authors the hydrogeothermal system of Inner Dinarides is situated in the extreme southern section of the Pannonian Basin and the following Dinaric terranes: The dinaric Ophiolite Belt terrane (DOBT), The Central Bosnian Mts.terrane (CMBT), The Jadar Block terrane (JBT), The Vardar Zone composite terrane (VZCT). The Pannoniana Basin, or its south part in Serbia and Bosnia and Herzegovina, consists of Paleogene, Nogene and Quaternary sediments with a total maximum thicness of about 4 000 meters.

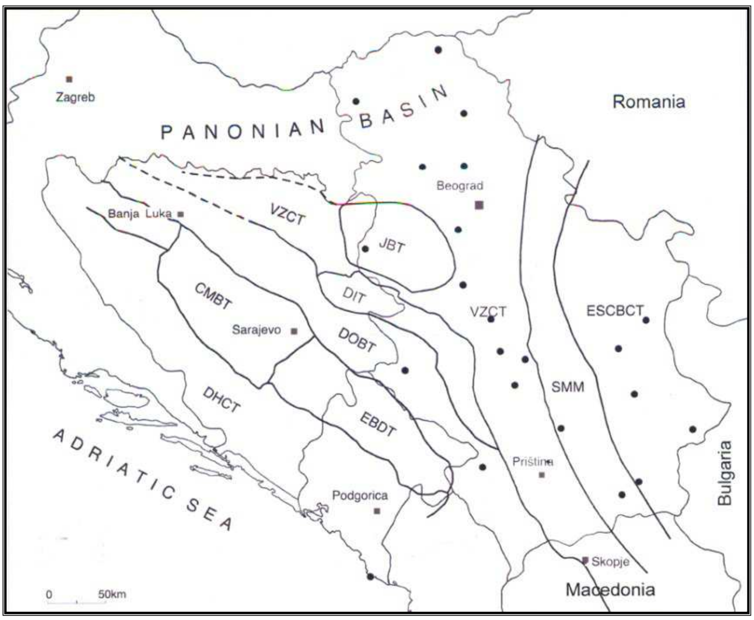

Figure 1. Geotectonic map.

HYDROGEOCHEMICAL CHARACTHERISTICS OF THERMOMINERAL WATERS IN SERBIA

Pannonian Basin. Within this geotectonik unit comprising a complex hydrogeothermel conductive system with a number of separate reservoirs, four groups of reservoirs are individualized by depth. First group of reservoirs have a maximum depth of 2000 m. The highest water temperature in the reservoirs is 120°C. The average flowing well yields are 1-13 kg/s. Total mineralization of thermal water is 1-9 g/kg, mostly 3-5 g/kg. Chemically, thermal waters are of HCO_3-Na type. Water temperature at well-heads are mostly 40-55°C, maximum 82°C (Tonic et al, 1989). The second group of reservoirs are in Lower Pliocen and Pannonian sediments, composed of sandstones of a lower porosity than the aquifers of the first group. Thermal waters in this reservoir are of HCO_3-Cl-Na typa and of mineralization rate 4-20 g/kg, mostly 5-12 g/kg. The maximum expected water temperature in this reservoir group is up to 160°C. Average yields of flowing wells are 2.5 to 5 g/kg, and the well-head water temperatures are 50-65°C on average. The third group of reservoirs are those at the base of Neogene or Paleogene sediments. These are Miocene limestones, sandstones, basal conglomerates, and basal breccias. Thermal water contained in these rocks is higly mineralized (to 50 g/kg), and its chemical composition is of the HCO_3-Na type. Average well yields are 5-10 kg/s and water temperature at well-heads are 40-50°C. The fourth group of reservoirs are in Mesozoic and Paleozoic rocks under Paleogene end Neogene sediments. The most important reservoirs of this group and of the entire Pannonian hydrogeothermal system and Republic Srpska are Triassic karstifield and fractured limestones and dolomites. Similar reservoirs extend beyod the border, in the Pannonian basin, in Hungary, Romania and Slovakia. Far from the basin's margin, at depths exceeding 1500 m, thermal waters in Triassic limestones are of Cl-Na type. In the marginal zone of the basin, where Neogene sediments are 1000 m deep over Triassic limesstones and where water-exchange is active thermal waters are of HCO_3-Na type and have mineral contents of up to 1 g/kg. Average well-yields is 12 kg/s, or 40 kg/s from reservoirs near the basin"s margin. The water temperatures at well-heads are mostly 40-60°C.

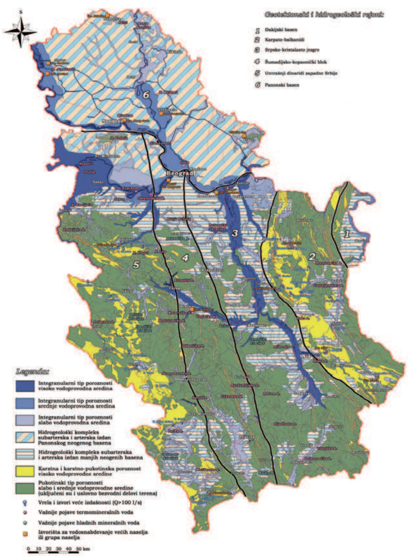

Figure 2. Hydrogeological map of Serbia.

Dinarides. Hydrogeothermal system in this geothermal province differ in their types, kinds of reservoirs and their extend,etc., as a result of varying geology. Rocks that have the largest distribution are Mesozoik in age (1), karstifited Triassic limestones and dolomite, (2) ophiolitic melange including large Jurassic peridotite massifs (3), Cretaceous flysch (4) Paleozoik metamorphic rocks (5), Paleogene and Neogene granitoid and volcanic rocks, and (6) isolated Neogene sedimentation basins. Hydrogeotherml system have formed in terrains: (1) Neogene sedimentation basins with reservoirs in Triassic limestones under them, (2) peridotite massifs and ofhiolitic melange with reservoirs in Triassic limestones; (3) granitoid intrusions and respective volcanic rocks with reservoirs in the same rocks, and(4) Paleozoic metamorphic rocks with reservoirs in marbles and quartzites. The best aquifers are Triassic limestones, as the thermal water contained has low mineral content (<1 g/kg) of HCO_3-Ca-Mg type. Springflows are very high, up to 400 kg/s, and well yields are up to 60 kg/s. Maximum temperatures of water at well –heads are 80°C. The second important reservoirs are those in granitoid intrusions and their marginal thermometamorphosed fracture zones. The contained thermal waters are also low in total mineralization (>1g/kg) of HCO_3-Na type, and maximum yield to 15 kg/s.The highest temperature of waters at well-heads are 78°C.There are few occurences of thermal water in Paleozoik metamorphic rocks.Such springs have low flows (< 1 kg/s), low water temperatures (< 20°C), mineralizations rates 5-7 g/kg, HCO_3-Na in type, and high concentrations of free CO_2 gas.

Serbian-Macedonian Massif. There are two types of hydrogeothermal system in this geothermal province. One is the type formed in the Proterozoik matamorphic complex, with the reservoir in marbles and quartzites up to 1500 m in thickness.Thermomineral waters in the reservoir have total mineral content of 5-6 g/kg.Their chemical composition is HCO_3-Na –Cl type water with high concentration of free CO_2. This gas is formed by thermolysis of marble at temperatures above 100°C in the presence of water, as verified by isotopic studies (Milivojevic, 1989). Thermal water temperature at springs is 24-72°C and springflow is of gas-lift type due to the high CO_2 gas content. The second type hydrogeothermal system was formed in contact with and in the marginal zones of the Neogene granitoid intrusions. The reservoir rocks are granitoids, metamorphic and contact-methamorphic rocks, heavily fractured as a result of heating and cooling. The thermal springs of Vranjska spa belong to this system type and have the warmest water in Serbia, 80-96°C.Its mineral content varies from 0.1 to 1.2 g/kg. The water type is HCO_3-Na-SO_4-Cl. Springflows are up to 80 kg/s.

Carpatho-Balkanides. This geothermal province has many hydrogeothermal system, most of them formed in regions of isolated Neogene sedimentary lake basins. Reservoir rocks are karstified Triassic, Jurassic or Cretaceous limestones. Thermomineral karst springs have flows of 60 kg/s, with water temperatures to 38°C. Total mineralization is 0.7 g/kg and the water type is HCO_3-Ca. Another type of hidrogeothermal system in this geothermal province was formed in the Upper Cretaceous paleorift of Eastern Serbia, where Mesozoic limestones were penetrated and thickly covered with andesite lavas and pyroclastics. The mineralization of these contained water are up to 0.8 g/kg and the water is of SO_4-Na-Cl type, or HCO_3-Na-SO_4-Cl type where it is limestones.Water temperatures at thermomineral springs are up to 43°C, and springflows are up to 10 kg/s.

Table 1. Review of represented classes and subclasses of mineral water in Serbia in the selected regions.

Region	Subclass	Ca	Ca Mg	Ca Na	Ca Mg Na	Mg Na	Na	Ca Na Mg	Mg Ca	Mg Na Ca	Mg Ca Na	Na Ca	Na Mg	Na Ca Mg	Na Mg Ca	NH_4 +Na	H, Fe	Σ
	Class																	
Carpatho-Balkanides	HCO_3																	
	HCO_3-SO_4	5	13		1									1				20
	SO_4-HCO_3						2											2
	HCO_3-Cl-SO_4							1				1						2
Serbian-Macedonian Massif	HCO_3													1				1
	HCO_3-SO_4		7		1		15				1	1						25
	SO_4-HCO_3		2				3											5
	HCO_3-Cl						1											1
	Cl-SO_4						1						1					2
	SO_4																1	1
	Cl		1															1
Šumadija-kososvo-Kopaonik area	HCO_3						1											1
	HCO_3-Cl	4	7		1	5	30	1	6	1	1	6	4	1	7			74
	SO_4-HCO_3						3		1				2	1				7
	SO_4-Cl			1														1
	Cl																1	1
Dinarides	HCO_3						1											1
	HCO_3-SO_4	2	21	2	1		24		2	1		5		2				60
	HCO_3-Cl											1						1
	Cl						2						1					3
Pannonian Basin	HCO_3						1											1
	HCO_3-Cl						13					1						14
	Cl-HCO_3						3									1		4
	Cl						5											5
Total	10	11	51	3	4	5	113	2	9	2	2	17	8	6	7	1	2	243
u (%)		4,53	20,99	1,23	1,65	2,06	46,5	0,82	3,70	0,82	0,82	7,0	3,3	2,47	2,88	0,41	0,82	100

CONCLUSION

Researched and analyzed thermomineral water occurrences of Serbia, are differed by their chemical composition. The result of varying composition is different lithological rock masses and other physical and chemical conditions that influence on water in their underground movement from infiltration zone to discharge zone. Test results are presented in the form of macro components content (anions and cations) that are served to extract the basic types of mineral water.

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abstract id: **450**

topic: **4**
Mineral and thermal water

4.3
Hydrogeochemical characteristics of mineral and thermal waters

title: **Natural radioactivity of thermal waters of Podhale trough – preliminary results**

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keywords: thermal waters, Podhale Trough, natural radioactive nuclides

The Podhale Trough is situated between the Tatras in the south and the Pieniny Klippen Belt in the north, both geological units belonging to the Polish Inner Carpathians. The Trough consists of the Paleogen flysh (sandstones and shales) overlain by conglomerates, and mudstones. The flysch strata rest on the Eocene and Mesozoic carbonate rocks of the Tatra units. Thermal water with the temperature 20.4°C was discovered for the first time by Zejszner (1844) in Jaszczurówka. Currently, thermal water has been reported in 14 boreholes (Sokołowski, 1992; Kępińska, 1997; Chowaniec, 2003; Małecka, 2003). The rocks of the Tatra massif affect most the hydrological conditions of the Podhale Trough. The thermal waters of Podhale are associated with meteoric waters recharging in the Tatra Mts the fractured and karstified Mesozoic carbonate rocks, and as a result come into contact with the Palaeozoic crystalline basement of the Tatras. These rocks dip to the north under impermeable and weakly permeable sediments of the Podhale flysch. The Pieniny Klippen Belt rocks form an impermeable barrier that closes the Podhale Trough waters from the north.

Physical and chemical analyses of water and measurements of their natural radioactivity were carried out on samples collected from selected boreholes: PIG/PNiG-1 in Bukowina Tatrzańska, IG-1 and Szymoszkowa GT-1 in Zakopane and PGP-1 in Bańska Niżna. The temperature of the thermal waters in question ranges from 25.9 to 83°C and their mineralization (TDS) from 0.3 to 2.4 g/L (Tab. 1). They are currently used for heating purposes and in recreation.

The specific activities of radionuclides are as follows: 1–81 Bq/L for ^{222}Rn; 23–686 mBq/L for ^{226}Ra; 10–401 mBq/L for ^{228}Ra; 0.4–1050 mBq/L for ^{238}U and 2.6–1000 mBq/L for ^{234}U. They are the highest in the water from the borehole Szymoszkowa GT-1. The maximum activities of radium, uranium and radon contained in the mineral waters of the similar mineralization from the Outer Carpathians are lower and amount to 170 mBq/L, 56 mBq/L and 32 Bq/L, respectively (Chau et al., 2009). The significantly higher level of natural radioactivity of the thermal waters from the Podhale Trough must be associated with their contact during migration with the crystalline, igneous and metamorphic rocks of the Tatra Mts.

Table 1. The data concerning to the analyzed thermal waters.

Code of the borehole and its localization	Borehole depth [m]	Temperature [°C]	Type of water	TDS [g/L]	Radon [Bq/L]	Radium [mBq/L]		Uranium [mBq/L]	
						^{226}Ra	^{228}Ra	^{234}U	^{238}U
PIG/PNiG-1 Bukowina Tatrzańska	3780.0	44.3	SO_4–Ca–Na	1.4	2.7	480	170	2.6	0.4
IG-1 Zakopane	3073.2	31.0	HCO_3–Ca–Mg	0.3	1.0	23	≤10	6.1	2.9
Szymoszkowa GT-1 Zakopane	1737.0	25.9	HCO_3–Mg–Ca	0.4	81	686	401	1000	1050
PGP-1 Bańska Niżna	3242.0	83.0	Cl–SO_4–Na–Ca	2.4	1.3	522	395	148	205

ACKNOWLEDGEMENTS

This work was supported by the Ministry of Science and Higher Education (Project No. N521000631/1137) and through statutory funds of the AGH University of Science and Technology (Projects No. 11.11.220.01 and No. 11 11.140.890).

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abstract id: **453**

topic: **4**
Mineral and thermal water

4.3
Hydrogeochemical characteristics of mineral and thermal waters

title: **Variability of major parameters of water from the Main Spring (Zdrój Główny) in Krynica Zdrój**

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Krynica is one of the Carpathian spas located in the south-eastern part of the Beskid Sądecki Mts at the altitude 560–620 m a.s.l. in the valley of the Kryniczanka stream and in the valleys of its tributaries: the Palenica and the Czarny streams. The resort is situated within the tectonic Magura Unit, at the border of two subunits that differ in their facies development. These are the Sącz zone and the Krynica zone divided by an elongated tectonic discontinuity known as the Krynica dislocation. The area is built of flysch strata: sandstones, shales and marls. The history of Krynica is inseparably associated with the Main Spring (*Zdrój Główny*), which was examined and whose water was analysed for the first time in 1796 by Baltazar Hacquet, a professor of the Lwów University. Next water analyses were carried out in 1807 by I. Schultes, in 1857 by E Czyrniański and A. Aleksandrowicz, in 1905 by K. Marchlewski, in 1933 by S. Jurkowski and in 1944 by B. Wagner (Aleksandrowicz, 1858; Dominikiewicz, 1951). A continuous monitoring of the spring began in 1962.

The Main Spring is a natural spring known from the 15th century, flowing from the terrace of the left bank of the Kryniczanka stream at the feet of Parkowa Hill. It is a fracture, ascending spring, flowing into Quaternary strata from the underlying sandstone-shale series belonging to the Paleogenian Maszkowice Member of the Magura Formation at its contact with the shale-sandstone series of the Mniszek Shale Member. The spring intake was first constructed of a timbering made of unknown wood, replaced later by a larch wood timbering, whereas a granite, dish-shaped stonework was made in 1858 (Skórczewski, 1906). The current intake is a bell-like construction; its concrete stonework in the form of a bowl is lined with ceramic tiles and over-built with a conical cupola. Part of the spring water is piped into the Major Pipe Room (*Pijalnia Główna*) and used in crenotherapy, while most of the water flows gravitationally to the tank in the Old Bathroom House (*Stare Łazienki*) and is used for bottling of the natural drinking water with the trade name „Kryniczanka".

The analysis of the major water parameters: mineralization (TDS) and the contents of CO_2, Ca^{2+}, Mg^{2+} and HCO_3^-, was based on the results of 40 physical and chemical determinations carried out between 1796 and 2005 (Fig. 1).

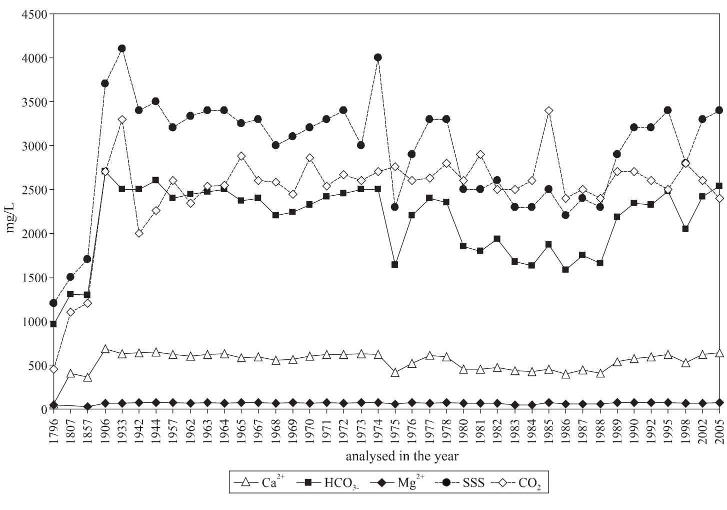

Figure 1. Variability of major parameters of water from the Main Spring (*Zdrój Główny*) in Krynica Zdrój (determined from a database assembled at the Chair of Economic and Mining Geology, AGH).

The first chemical analyses, as made at that time, should be considered accurate. Although their results differ from those of the current ones, it must be stressed that it was at the end of the 18^{th} century when Hacquet (1796) gave the first scientific description of the Krynica water properties and determined them as carbonated waters.

The therapeutic water of the Main Spring is a mineral carbonated water with the content of CO_2 from 2386 to 3448 mg/dm^3, whereas its hydrochemical type is HCO_3–Ca, Fe. Mineralization (TDS) varies between 3403 and 2166 mg/dm^3. The contents of the following ions in mg/dm^3 are: Ca^{2+} 630–399; Mg^{2+} 78–48; HCO_3^- 2501–1580; Fe^{2+} 24–3.1; Na^+ 106–40; Cl^- 13.3–5.2 and SO_4^{2-} 41–1.5. Mutual % milival ratios of individual, characteristic components remain stable.

ACKNOWLEDGEMENTS

This research has been supported by AGH University of Science and Technology, Kraków, grant no. 11.11.140.890 & 11.11.140.447.

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abstract id: **473**

topic: **4**
Mineral and thermal water

4.3
Hydrogeochemical characteristics of mineral and thermal waters

title: **Geochemistry of thermal waters of Sikhote-Alin ridge, Russia**

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keywords: thermal waters, hydrogeochemistry, nitric waters

INTRODUCTION

Low-temperature thermal waters of the continental margin of Russian Far East are widespread along the coast of Japan and Okhotsky Seas. All thermal water systems occur in Sikhote-Alin ridge (Fig. 1). Most of them were studied from the 1930s until 1960s (Makerov, 1938). Some are now balnearies: Annensky, Tumninsky ("warm spring"), Amgunsky and Chistovodny and others are used by locals for self-treatment: Khucin and St.Helen's springs at Amgunsky and "Hot spring" at Chistovodny thermal area. Latest investigations (Bragin et al., 2007) have shown geochemical properties of waters. However information about geochemistry and REE is limited. So this paper presents new data on geochemistry, isotopes, and REE of thermal springs of the Sikhote-Alin ridge.

Figure 1. Sikhote-Alin ridge. Situation plan.

SPRING CHARACTERISTICS

Annensky spa thermal area is located on the East of Khabarovsky krai, in the lowest part of the Amur river, 80 km from the Okhotsky sea shore. According the borehole data, thermal waters occur in the contact zone between effusive and tuffaceous sedimentary rocks of upper Cretaceous of Bolbinskaya and Tatarkinskaya suites. All over the area rocks are covered with eluvial-delluvial sediments (thickness up to 5-8 m) consisting of clay, poorly sorted sand and gravel. The water is low-temperature (49.5-54.5°C), low-mineralized (TDS 0.20-0.35 g/l), alkaline (pH 8.5-9.4) and the chemical classification of the groundwater is a $Na\text{-}HCO_3\text{-}SO_4$ type of water with high content of silica (25-35 mg/l) and fluorine (up to 7 mg/l).

Tumninsky spa thermal area is located on SouthEast of Khabarovsky krai, 9 km from the Tumnin River, and 40 km away from the Tatarsky channel (Japan sea). The geological structure is defined by the contact- zone of granites and andesitic basalts of the Eocene Kuznecskaya suite (Sidorenko, 1971). Waters from borehole № 9 (depth 460.0 m) are low-temperature (43.0-

46.0°C), alkaline (pH= 8.65-9.7), low-mineralized (TDS 0.15-0.25 g/l) and the chemical classification of the groundwater is a Na-HCO_3-SO_4 type.

The Chistovodny geothermal area is located in Lazo area of the Primorsky krai, 70 km away from the of Japan Sea shore and is known from a group of springs and boreholes (Chudaev, 2003). Host rocks consist of crumbling granites of upper Cretaceous age, broken by Paleocene dykes of aplites and diorite porphyries. Bedrock is covered by Quaternary alluvial deposits of 3 to 7 m thickness. The geothermal field is presented by several outlets, notably "Chistovodny spa" and "Hot Spring". Waters are low-temperature (30°C) low-mineralized (TDS= 0.14-0.16 g/l), low-alkaline (pH=7.0-8.4) of Na-HCO_3 type with high content of silica (up to 60mg/l) and fluorine (up to 4 mg/l).

The Amgunsky geothermal area is located in the Terney area of the Primorsky region, 10 km from the Japan sea shore. This geothermal field is presented by three well-known outlets: Banny, St.Helen's, and Khucin. The geological structure is defined by the contact of granite intrusions with rhyolites, tuffs and ignimbrites of Mesozoic and Cenozoic age (Chudaev, 2003). Waters are low-mineralized (TDS=0.1-0.2 g/l), alkaline (pH=8.5-9.0) of Na-HCO_3 type with content of silica (up to 22 mg/l).

ANALYTICAL RESULTS

Moving from southern to northern thermal areas of Sikhote-Alin we can find an increase of temperature of the waters that is reflected in quartz geothermometry (Bragin et al. 2007). The temperature increase is paralleled by increases in most dissolved species (Table 1). These trends may reflect enhanced reaction rates in higher temperature waters combined with likely longer flow paths as the higher temperature waters penetrate to greater depths than do lower temperature waters.

Table 1. Spring characteristics.

	Annensky	**Tumninsky**	**Amgunsky**	**Chistovodny**
pH	9.2	9.3	9.1	8.9
		mg/l		
TDS	235	195	183	167
Na^+	61.0	32	33.4	19.62
K^+	1.17	0.35	0.7	0.33
Ca^{2+}	2.0	2.11	2.0	5.42
Mg^{2+}	0.01	0.01	0.08	0.007
HCO_3^-	112.8	78.1	70.7	63.4
SO_4^{2-}	25.4	7.1	13.6	5.7
Cl^-	4.0	1.4	3.6	2.4
F^-	2.7	0.8	0.9	3.9
SiO_2	46.8	35.2	31.1	18.6
		°C		
T, °C (surface)	49.9	44.8	34.5	27.5
T, °C quartz geothermometer (Fournier, 1977)	98.7	86.1	80.9	60.7
T, °C Na/K geothermometer (Arnorsson et al. 1983)	123.7	95.9	128.7	116.8

Oxygen and hydrogen isotope ratios were measured in thermal waters from the whole Sikhote-Alin folded area. The δD and $\delta^{18}O$ values for thermal waters in Annensky and Tumninsky areas correlate well with data of Chudaev (Chudaev, 2003) on Chistovodny, Amgunsky and for precipitations in Primorye (Southern Sikhote-Alin). On a δD vs. $\delta^{18}O$ diagram the Sikhote-Alin thermal waters lie close to the global meteoric water line (Craig, 1961) as shown in Figure2.

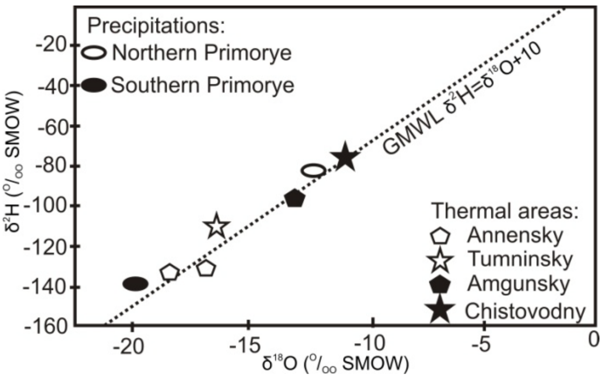

Figure 2. Deuterium and Oxygen-18 isotopes.

Rare earth elements were measured using an Agilent 7500C inductively-coupled plasma mass spectrometer (ICP MS). The REE data, normalized to North American Shale Composite (NASC), show the common rising trend caused by greater solubility of heavy REE (Figure 3).

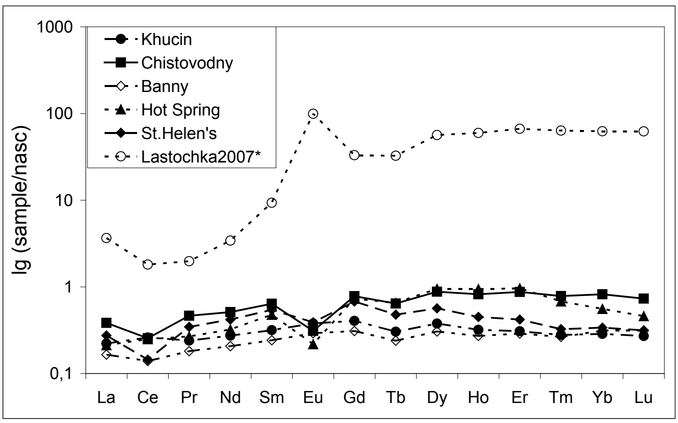

Figure 3. Concentration of REE in thermal and high pCO_2 waters (Lastochka) of Sikhote-Alin ridge normalized to NASC. * Lastochka data obtained by Tchepkaia (2007)

In contrast to the small REE concentrations in our waters ($0.02\text{-}20*10^{-9}$ g/l), the high pCO_2 Lastochka waters, also from the Sikhote-Alin region, have high REE concentrations, probably reflecting low alkalinity of studied thermal waters. Some water lines show negative anomalies on Ce and Eu. Eu anomaly may be caused by Eu-deficient plagioclase. Whereas Ce could be precipitated under oxidizing conditions.

Microprobe analyses of granite rock, which is host to the Tumninsky springs, showed the possible source of some REEs in monazite (Figure4) (La 12.49%, Ce 28.89%, Nd 12.9%, Sm 2.32%, Gd 2.14%). Other REEs are probably from plagioclase.

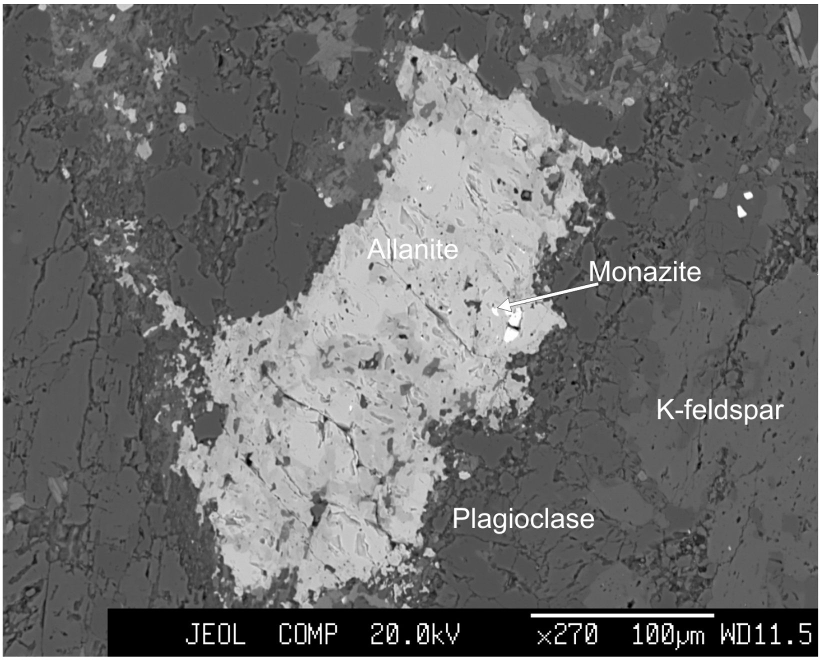

Figure 4. Monazite in granites of Tuminsky spring host rocks.

WATER-ROCK INTERATCTION MODELING

Calculations with computer code WATEQ4F (Ball & Nordstrom, 1991) show that all studied thermal waters are slightly supersaturated with calcite and chalcedony and strongly undersaturated with fluorite and albite (Bragin et al. 2007).

Temperatures calculated by quartz (Fournier, 1977) and Na-K (Arnorsson et al. 1983) geothermometers are shown in the Table 1. The Na-K geothermometer shows higher temperatures than quartz, possibly caused by admixing of fresh cold groundwater into reservoir, which lowers the quartz temperature but not Na-K geothermometer tempeature.

Based on all this data on geochemistry we propose a conceptual model (as an example) for a Tumninsky geothermal area (Figure 5) wherein meteoric groundwaters penetrate deep enough into the permeable rock to become heated to 90 to 120 C, and then rise through the contact zone or some other fissured zone. Rising water cools, and precipitates chalcedony and calcite, accounting for equilibrium with those two minerals, outflows at the surface.

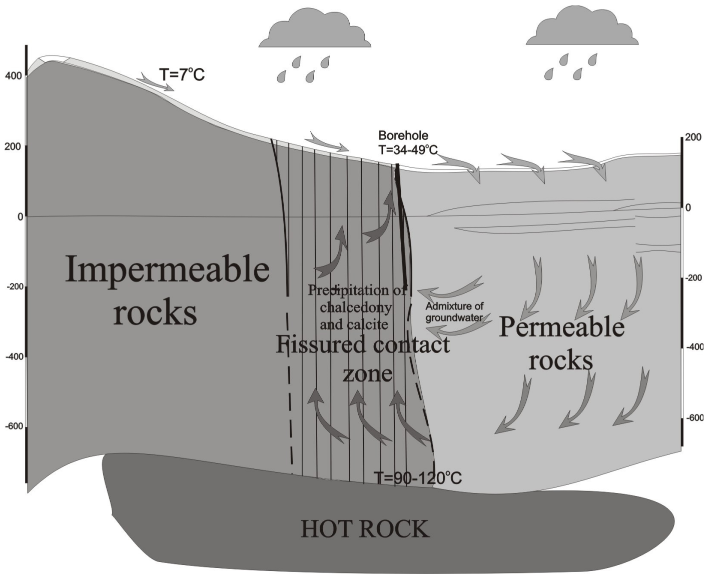

Figure 5. Conceptual model of evolution of thermal waters of Sikhote-Alin ridge.

CONCLUSIONS

The following summarizes the investigations of the thermal waters of Sikhote-Alin ridge:

- Data on stable isotope ratios ($\delta^{18}O$, $\delta^{2}H$) show that the waters are of meteoric origin (rain-water);
- REE measurement showed it's low concentrations caused by low alkalinity. Some water lines have Ce and Eu anomalies which should be studied further;
- Analytical results coupled with thermodynamic and geothermal modeling helped us to create a conceptual model of evolution of studied waters.

ACKNOWLEDGEMENT

This research is supported by grants of Far East Branch of Russian Academy of Sciences № 10-3-B-08-194.

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abstract id: **510**

topic: **4**
Mineral and thermal water

4.3
Hydrogeochemical characteristics of mineral and thermal waters

title: **Natural radionuclides and trace metals in thermal springs, Al-Lith Region, Saudi Arabia**

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keywords: thermal springs, natural radionuclides, Al-Lith

Some of the thermal water springs are widely popular for medical therapy, tourism, recreation and rehabilitation activities. Studies of geothermal resources in the Kingdom of Saudi Arabia started in 1980. Four thermal springs were identified in Al-Lith area (Ayn Al-Harra, Ayn Bani-Hilal, Ayn Markub and Ayn Darakah). The main aim of this study is to shed more light on the radio-ecological and chemical characterization of thermal springs in Al-Lith region, Saudi Arabia. Water and sediment samples were collected from the four thermal spring. Natural radionuclides (U, Th, K, ^{210}Po and Ra isotopes) concentration were determined in water samples using ICP-MS and, alpha- particle and liquid scintillation spectrometers. Chemical properties (pH, EC, total alkalinity, turbidity, bicarbonate, total hardness, major anion and major cations) of water samples were determined using standard methods. The correlation between natural radionuclides and chemical properties of water were discussed.

abstract id: **520**

topic: **4**
Mineral and thermal water

4.3
Hydrogeochemical characteristics of mineral and thermal waters

title: **Pesticides in mineral waters of the transcarpathian region**

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keywords: mineral waters, pesticides

The Transcarpathian region is the richest province of Ukraine, its main recreation resources being mineral waters, climate and landscape. About 50 fields with mineral waters of different types are known, among those the most widespread and valuable are carbonic waters. In 1989 and 1997 the Institute of Geological Sciences National Academy of Science of Ukraine (IGS NASU), carried out examinations of mineral water fields for the content of strong organochloric pesticides (DDT and its metabolites, HCCH and its isomers, aldrin, heptachlor, dilor); organo-phosphoric pesticides (methaphos, carbophos); fluorine-containing pesticide (trephlane). In 1989 sexteen fields were examined, and three fields in 1997. Analytical experiments were performed using two a gas chromatographs "Tsvet-500M" (Models 550 and 570). It was established that in the same sample there could be present up to eight substances and their metabolites, derivatives of chemical compounds of different groups in concentrations lower than MPC (maximal permissible concentration) for potable water. However, the total effect of their influence on human health has not been studied yet.

The Transcarpathian region is the richest natural province of Ukraine, its main recreation resources being mineral waters, climate and landscape. On a relatively small territory, mineral water fields of different types are concentrated. All over the territory of Union of Independent States variability of mineral waters in this region could be compared only with Caucasian mineral waters. About 50 fields with mineral water are known, among those the most widespread and valuable are carbonic waters. In the region 15 sanatoria and pensions with medication function as well as, several rest homes, 13 tourist centres and complexes, departmental health-improving organizations. Six enterprises for mineral water spillage function here.

The Transcarpathian region comprises a complex system of hydrogeological districts that differ in the conditions of groundwater formation.

The most widespread are carbonic waters of «Narzan» type. Large reserves of these waters are located near Uzhgorod. There are also springs near the settlements Uzhok, Krasny Ples, Belin, Kobyletzkaya Poljana. Chemical composition of the majority of Ukrainian narzans is hydrocarbon magnesium-calcium and sodium-calcium and dissolved carbon dioxide content is 0.8–2.9 g/L [1]. Carbonic waters of «Borzhomi» type are distributed mainly in Mukachevo and Svaljava districts of the Transcarpathian region. They are exploited by «Poljana» resort as well as by factories for spillage of mineral waters «Poljana Kvasova», «Luzhanskaya», «Plaskovskaya». The yield of wells comprises in average 1-2 and up to 10 l/sec. Mineralization of transcarpathian hydrocarbon sodium waters is 4.3–11 g/L. Increased content of such biologically active ions as fluorine and boron could be detected in the mineral waters.

Carbonic waters of «Essentuki» type are concentrated in the region of villages Dragovo, Sojmy, V. Bystraya. At the base of two large springs there operates a factory for spillage of mineral water «Dragovskaya». This water is of hydrocarbon-chloride- sodium composition with total dissolved solids (TDS) content of 5.9–10.5 g/L. Mineral waters near v. Sojmy are exploited by a sanatorium «Verchovina». They are of chloride-hydrocarbon sodium-calcium composition, mineralization equals 6–7 g/L. Out of biologically active ions only boron presents in the water.

Large reserves of «Essentuki» mineral waters were detected in the neighbourhood of the Vyshkovo settlement in Chustkovo district near «Shajan» sanatorium. A carbon dioxide content in water reaches 2.6 g/L. Their chemical composition is hydrocarbon and hydrocarbon-chloride sodium, sodium-calcium and magnesium-calcium. TDS content is equal to 4 - 6 g/L. Carbonic waters of «Arsni» type are often in the valleys of Uzh river and its tributaries near Kostrina and Sol villages. They consist of chloride sodium, 4.6–14.4 g/L. Besides carbon dioxide, mineral waters could also contain other medical components (iron — in the waters of the field Kelechenskoye, arsenic — in the field Gornotisenskoy).

The Transcarpathian region is one of the most successful in Ukraine from an ecological point of view. This is favoured by mountain relief, extensive forests and the absence of large industrial enterprises. However, anthropogenic pressure on the territory, such as environment pollution by oil products, heavy metals, agricultural chemicals and social wastes are associated with hydromineral resources of the region. One of the most widespread and dangerous types of pollution in mineral waters is pesticides that are widely used in agriculture and forestry in the Transcarpathian. Factors that worsen the danger of pesticide pollution of mineral waters are the high permeability of the gravel deposits in the river valleys Latoritza, Uzh, Tisa, Piniya and others, where both the main mineral water fields and settlements with adjoining agricultural lands are present. Moreover, in the geological section of these districts, the bedrock is highly fractured resulting in increased permeability.

Two cycles of sampling were conducted in the Transcarpathian mineral waters in 1989 and 1997. Strong organochloric pesticides (DDT and its metabolites: n,n'-DDT; n,n'-DDE, HCCH and its isomers: α-HCCH, β-HCCH, γ-HCCH, aldrin, heptachlor, dilor); organophosphoric pesticides (methaphos, carbophos); and fluorine-containing pesticides (trephlane) were detected (Tables 1 and 2).

Along with mineral waters, pesticides were also measured in surface stream-flows and soils. In 1989 sixteen fields that exploit mineral waters of different types were examined: Polyanskoye, Ploskovskoye, Novo-Polenskoye, Svalyavskoye, Golubinskoye, Nelipenskoye, Medvezhye, Shayanskoye (Borzhomi type); Soimenskoye, Kelechenskoye, Uzhgorodskoye, Dragovskoye, Gorno-Tisenskoye (Synegorskoye type), Pasikskoye (Krinitza type) (Table1). Dr. E.Molozhanova took part in expedition 1989 and the authors express their thanks for her contribution to this work. In 1997 there were performed determinations in three fields of mineral waters: Luzhanskoye, Poljanskoye, Uzhgorodskoye (Table 2).

Examined fields are intensively exploited by different resorts and sanatoria («Solnechnoe Zakarpatye», «Kwitka Poloniny», «Shajan», «Karpaty», «Verchovina»), as well as by factories for spillage of mineral waters «Luzhanskaya», «Dragovskaya», «Polyana Kwasova».

RESULTS

Analysis of mineral waters for pesticides content was carried out in the laboratory at the Department of Hydrogeological Problems, Institute of Geological Sciences, NAS of Ukraine, using a gas chromatographs «Tsvet» (Models 550, 570).

Total concentrations of the examined pesticides in the mineral waters vary in the range of 10^{-6}–10^{-4} mg/L; the same range of concentrations was typical for surface waters.

In the soils and water-bearing rocks, pesticides concentrations were considerably higher and reached decimal fractions of mg/kg. In the mineral waters ΣDDT was detected in 100 % of samples in the concentration range 10^{-7}–10^{-4} mg/L. **Σ**HCCH is present in 100 % of samples in the range of concentrations 10^{-7}–10^{-5} mg/L.

Table 1. The content of pesticides in hydromineral resources of Transcarpathian region (July, 1989).

Sampling sites	Object	Pesticides, mg/dm³, mg/kg					ΣD*
		Σ DDT	ΣHCCH	Dilor	Metaphos	Carbophos	
Svalyava district, village Golubinnoye, depression Lug, right bank of the river Piniya, well 4RE	Mineral water	$2.5\cdot10^{-4}$	$4.7\cdot10^{-7}$	$2.9\cdot10^{-5}$	$3.1\cdot10^{-6}$	$1.0\cdot10^{-6}$	$2.8\cdot10^{-4}$
River Piniya	Fresh water	$1.3\cdot10^{-4}$	$5.2\cdot10^{-7}$	$1.3\cdot10^{-5}$	$5.2\cdot10^{-6}$	Not detected	$1.5\cdot10^{-4}$
Depression Lug, 300 m to the west from well 4RE	Rock loam	$3.1\cdot10^{-1}$	$1.8\cdot10^{-3}$	$2.8\cdot10^{-1}$	Not detected	$1.0\cdot10^{-6}$	—
Depression Lug, 300 m to the west from well 4RE	Rock sandy loam	$8.9\cdot10^{-2}$	$7.0\cdot10^{-3}$	$2.5\cdot10^{-1}$	$2.4\cdot10^{-2}$	$5.0\cdot10^{-5}$	—
Depression Lug, 300 m to the west from well 4RE	Fresh water	$7.3\cdot10^{-5}$	$2.3\cdot10^{-7}$	$2.4\cdot10^{-5}$	$5.2\cdot10^{-6}$	Not detected	$1.0\cdot10^{-4}$
Village Polyana, well 3R	Mineral water	$1.1\cdot10^{-5}$	$3.0\cdot10^{-7}$	$3.0\cdot10^{-5}$	$4.1\cdot10^{-7}$	$1.0\cdot10^{-7}$	$4.1\cdot10^{-5}$
Sanatorium «Solnechnoye Zakarpatye», depression Nova Polyana, well 10-K	" "	$1.5\cdot10^{-5}$	$3.1\cdot10^{-7}$	$2.5\cdot10^{-5}$	$3.1\cdot10^{-6}$	$1.0\cdot10^{-7}$	$4.4\cdot10^{-5}$
Village Polyana, water intake Lug, spring 7 km from Polyana	Fresh water	$6.0\cdot10^{-6}$	$7.8\cdot10^{-8}$	$5.1\cdot10^{-6}$	Not detected	$1.0\cdot10^{-7}$	$1.1\cdot10^{-5}$
Sanatorium «Karpaty», stream Labij Potok	" "	$4.8\cdot10^{-5}$	$1.9\cdot10^{-7}$	$8.0\cdot10^{-6}$	$2.0\cdot10^{-7}$	Not detected	$5.6\cdot10^{-5}$
Mukachevo district, sanatorium «Karpaty» 4 km along the road Chinadievo-Svalyava, well 5.	Mineral water	$1.2\cdot10^{-4}$	$1.8\cdot10^{-7}$	$1.4\cdot10^{-6}$	$3.2\cdot10^{-7}$	$1.0\cdot10^{-7}$	$1.3\cdot10^{-4}$
Chust district, village Shayan, sanatorium «Shayan», well 242	" "	$2.2\cdot10^{-4}$	$2.0\cdot10^{-7}$	$3.5\cdot10^{-6}$	$1.0\cdot10^{-7}$	Not detected	$2.2\cdot10^{-4}$
Chust district, village Vyshkovo, well 713	Fresh water	$1.4\cdot10^{-6}$	$1.7\cdot10^{-7}$	$3.5\cdot10^{-6}$	$1.2\cdot10^{-6}$	$1.0\cdot10^{-7}$	$6.3\cdot10^{-6}$
Chust district, village Shayan, sanatorium «Shayan», well 9T	Mineral water	$2.2\cdot10^{-6}$	$5.8\cdot10^{-7}$	$1.8\cdot10^{-5}$	$2.4\cdot10^{-6}$	Not detected	$2.3\cdot10^{-5}$
Mezhgorskij district, village Soimy, sanatorium «Verchovina», well 4R	" "	$5.0\cdot10^{-7}$	$5.6\cdot10^{-5}$	$1.2\cdot10^{-6}$	$1.2\cdot10^{-6}$	$1.0\cdot10^{-7}$	$5.9\cdot10^{-5}$
Mezhgorskij district, village Soimy, stream Kwasovets (the place of falling into r. Rika)	Fresh water	$4.6\cdot10^{-6}$	$7.1\cdot10^{-8}$	$4.3\cdot10^{-6}$	$2.4\cdot10^{-7}$	$1.4\cdot10^{-7}$	$9.4\cdot10^{-6}$
Mezhgorskij district, village Soimy	Soil	$2.2\cdot10^{-2}$	$1.8\cdot10^{-2}$	$9.3\cdot10^{-1}$	$2.4\cdot10^{-2}$	Not detected.	—
Mezhgorskij distrikt, village Kelechin, well 359	Mineral Water	$1.5\cdot10^{-4}$	$6.5\cdot10^{-7}$	$8.6\cdot10^{-6}$	$4.8\cdot10^{-7}$	$1.0\cdot10^{-7}$	$1.6\cdot10^{-4}$
Factory "Polyana Kwasova", village Polyana Kwasova, well 7R3	" "	$2.0\cdot10^{-4}$	$5.1\cdot10^{-7}$	$5.2\cdot10^{-6}$	$1.2\cdot10^{-6}$	$1.0\cdot10^{-7}$	$2.1\cdot10^{-4}$
Village Polyana, Medvezhye, well 4P	Mineral Water	$1.5\cdot10^{-4}$	$6.5\cdot10^{-7}$	$8.6\cdot10^{-6}$	$4.8\cdot10^{-7}$	$1.0\cdot10^{-7}$	$1.6\cdot10^{-4}$
Factory «Lugy» (near Golubinnoe), well 3R3	" "	$2.0\cdot10^{-4}$	$5.1\cdot10^{-7}$	$5.2\cdot10^{-6}$	$1.2\cdot10^{-6}$	$1.0\cdot10^{-7}$	$2.1\cdot10^{-4}$
The city of Svalyava, factory «Svalyava», well 26K	" "	$8.0\cdot10^{-5}$	$2.6\cdot10^{-7}$	$6.3\cdot10^{-5}$	$2.1\cdot10^{-6}$	Not detected	$1.5\cdot10^{-4}$
Svalyava district, Nelipenskoe field, village Nelipeno, Svalyava food products factory, well 21	" "	$5.0\cdot10^{-7}$	$4.0\cdot10^{-7}$	$5.0\cdot10^{-6}$	$2.1\cdot10^{-6}$	$1.0\cdot10^{-7}$	$8.1\cdot10^{-6}$
The city of Uzhgorod, Gorkogo park, well 8	" "	$3.0\cdot10^{-7}$	$7.0\cdot10^{-7}$	$1.3\cdot10^{-5}$	Not detected	$2.0\cdot10^{-7}$	$1.4\cdot10^{-5}$
Mukachevo district, village Pasika, Pasikskoe field, well 1P	" "	$4.0\cdot10^{-7}$	$5.1\cdot10^{-7}$	$3.5\cdot10^{-6}$	" "	$2.0\cdot10^{-7}$	$4.6\cdot10^{-6}$
Dragovo field, well .51	" "	$5.0\cdot10^{-7}$	$2.2\cdot10^{-6}$	$1.8\cdot10^{-6}$	" "	Not detected	$4.5\cdot10^{-6}$
Gornaya Tisa, well 353R	" "	$6.3\cdot10^{-6}$	$5.8\cdot10^{-7}$	$5.2\cdot10^{-6}$	$2.4\cdot10^{-6}$	$2.0\cdot10^{-7}$	$1.5\cdot10^{-5}$
Gorno-Tisenskoe field, stream Trostinets	" "	$1.8\cdot10^{-6}$	$3.0\cdot10^{-6}$	$2.4\cdot10^{-5}$	$1.3\cdot10^{-5}$	$2.1\cdot10^{-6}$	$4.4\cdot10^{-5}$

Gorno-Tisenskoe field	" "	$1.3·10^{-5}$	$5.2·10^{-7}$	$2.8·10^{-5}$	$8.4·10^{-6}$	Not detected	$4.9·10^{-5}$
Svalyava district, village Golubinnoye, depression Lug, right bank of the river Piniya, well 4RE	Mineral water	$2.5·10^{-4}$	$4.7·10^{-7}$	$2.9·10^{-5}$	$3.1·10^{-6}$	$1.0·10^{-6}$	$2.8·10^{-4}$
River Piniya	Fresh water	$1.3·10^{-4}$	$5.2·10^{-7}$	$1.3·10^{-5}$	$5.2·10^{-6}$	Not detected	$1.5·10^{-4}$
Depression Lug, 300 m to the west from well 4RE	Rock loam	$3.1·10^{-1}$	$1.8·10^{-3}$	$2.8·10^{-1}$	Not detected	$1.0·10^{-6}$	—
Depression Lug, 300 m to the west from well 4RE	Rock sandy loam	$8.9·10^{-2}$	$7.0·10^{-3}$	$2.5·10^{-1}$	$2.4·10^{-2}$	$5.0·10^{-5}$	—
Depression Lug, 300 m to the west from well 4RE	Fresh water	$7.3·10^{-5}$	$2.3·10^{-7}$	$2.4·10^{-5}$	$5.2·10^{-6}$	Not detected	$1.0·10^{-4}$
Village Polyana, well 3R	Mineral water	$1.1·10^{-5}$	$3.0·10^{-7}$	$3.0·10^{-5}$	$4.1·10^{-7}$	$1.0·10^{-7}$	$4.1·10^{-5}$
Sanatorium «Solnechnoye Zakarpatye», depression Nova Polyana, well 10-K	" "	$1.5·10^{-5}$	$3.1·10^{-7}$	$2.5·10^{-5}$	$3.1·10^{-6}$	$1.0·10^{-7}$	$4.4·10^{-5}$
Village Polyana, water intake Lug, spring 7 km from Polyana	Fresh water	$6.0·10^{-6}$	$7.8·10^{-8}$	$5.1·10^{-6}$	Not detected	$1.0·10^{-7}$	$1.1·10^{-5}$
Sanatorium «Karpaty», stream Labij Potok	" "	$4.8·10^{-5}$	$1.9·10^{-7}$	$8.0·10^{-6}$	$2.0·10^{-7}$	Not detected	$5.6·10^{-5}$
Mukachevo district, sanatorium «Karpaty» 4 km along the road Chinadievo-Svalyava, well 5.	Mineral water	$1.2·10^{-4}$	$1.8·10^{-7}$	$1.4·10^{-6}$	$3.2·10^{-7}$	$1.0·10^{-7}$	$1.3·10^{-4}$
Chust district, village Shayan, sanatorium «Shayan», well 242	" "	$2.2·10^{-4}$	$2.0·10^{-7}$	$3.5·10^{-6}$	$1.0·10^{-7}$	Not detected	$2.2·10^{-4}$
Chust district, village Vyshkovo, well 713	Fresh water	$1.4·10^{-6}$	$1.7·10^{-7}$	$3.5·10^{-6}$	$1.2·10^{-6}$	$1.0·10^{-7}$	$6.3·10^{-6}$
Chust district, village Shayan, sanatorium «Shayan», well 9T	Mineral water	$2.2·10^{-6}$	$5.8·10^{-7}$	$1.8·10^{-5}$	$2.4·10^{-6}$	Not detected	$2.3·10^{-5}$
Mezhgorskij district, village Soimy, sanatorium «Verchovina», well 4R	" "	$5.0·10^{-7}$	$5.6·10^{-5}$	$1.2·10^{-6}$	$1.2·10^{-6}$	$1.0·10^{-7}$	$5.9·10^{-5}$
Mezhgorskij district, village Soimy, stream Kwasovets (the place of falling into r. Rika)	Fresh water	$4.6·10^{-6}$	$7.1·10^{-8}$	$4.3·10^{-6}$	$2.4·10^{-7}$	$1.4·10^{-7}$	$9.4·10^{-6}$
Mezhgorskij district, village Soimy	Soil	$2.2·10^{-2}$	$1.8·10^{-2}$	$9.3·10^{-1}$	$2.4·10^{-2}$	Not detected.	—
Mezhgorskij distrikt, village Kelechin, well 359	Mineral Water	$1.5·10^{-4}$	$6.5·10^{-7}$	$8.6·10^{-6}$	$4.8·10^{-7}$	$1.0·10^{-7}$	$1.6·10^{-4}$
Factory "Polyana Kwasova", village Polyana Kwasova, well 7R3	" "	$2.0·10^{-4}$	$5.1·10^{-7}$	$5.2·10^{-6}$	$1.2·10^{-6}$	$1.0·10^{-7}$	$2.1·10^{-4}$
Village Polyana, Medvezhye, well 4P	Mineral Water	$1.5·10^{-4}$	$6.5·10^{-7}$	$8.6·10^{-6}$	$4.8·10^{-7}$	$1.0·10^{-7}$	$1.6·10^{-4}$
Factory «Lugy» (near Golubinnoe), well 3R3	" "	$2.0·10^{-4}$	$5.1·10^{-7}$	$5.2·10^{-6}$	$1.2·10^{-6}$	$1.0·10^{-7}$	$2.1·10^{-4}$
The city of Svalyava, factory «Svalyava», well 26K	" "	$8.0·10^{-5}$	$2.6·10^{-7}$	$6.3·10^{-5}$	$2.1·10^{-6}$	Not detected	$1.5·10^{-4}$
Svalyava district, Nelipenskoe field, village Nelipeno, Svalyava food products factory, well 21	" "	$5.0·10^{-7}$	$4.0·10^{-7}$	$5.0·10^{-6}$	$2.1·10^{-6}$	$1.0·10^{-7}$	$8.1·10^{-6}$
The city of Uzhgorod, Gorkogo park, well 8	" "	$3.0·10^{-7}$	$7.0·10^{-7}$	$1.3·10^{-5}$	Not detected	$2.0·10^{-7}$	$1.4·10^{-5}$
Mukachevo district, village Pasika, Pasikskoe field, well 1P	" "	$4.0·10^{-7}$	$5.1·10^{-7}$	$3.5·10^{-6}$	" "	$2.0·10^{-7}$	$4.6·10^{-6}$
Dragovo field, well .51	" "	$5.0·10^{-7}$	$2.2·10^{-6}$	$1.8·10^{-6}$	" "	Not detected	$4.5·10^{-6}$
Gornaya Tisa, well 353R	" "	$6.3·10^{-6}$	$5.8·10^{-7}$	$5.2·10^{-6}$	$2.4·10^{-6}$	$2.0·10^{-7}$	$1.5·10^{-5}$
Gorno-Tisenskoe field, stream Trostinets	" "	$1.8·10^{-6}$	$3.0·10^{-6}$	$2.4·10^{-5}$	$1.3·10^{-5}$	$2.1·10^{-6}$	$4.4·10^{-5}$
Gorno-Tisenskoe field	" "	$1.3·10^{-5}$	$5.2·10^{-7}$	$2.8·10^{-5}$	$8.4·10^{-6}$	Not detected	$4.9·10^{-5}$

Table 2. The content of organochloric pesticides in mineral waters of Transcarpathian region (October, 1997).

Sampling sites	n,n-DDT	N,n-DDE	n,n-DDD	Σ DDT	α-HCCH	β-HCCH	γ-HCCH	Σ HCCH	Aldrin	Heptachlor	Trephlane	Σ D *
Kwitka Poloniny (Luzhanskaya type)	$8.4 \cdot 10^{-5}$	$1.2 \cdot 10^{-6}$	$2.7 \cdot 10^{-6}$	$8.7 \cdot 10^{-5}$	$1.2 \cdot 10^{-6}$	Not detected	$6.0 \cdot 10^{-7}$	$1.8 \cdot 10^{-6}$	Not Detected	$6.0 \cdot 10^{-8}$	$3.0 \cdot 10^{-8}$	$8.9 \cdot 10^{-5}$
Polyana Kwasova (carbonic Carbonate-chloride sodium)	$2.8 \cdot 10^{-5}$	$3.0 \cdot 10^{-6}$	$3.6 \cdot 10^{-6}$	$3.5 \cdot 10^{-5}$	$8.0 \cdot 10^{-7}$	" "	Not detected	$8.0 \cdot 10^{-7}$	$4.0 \cdot 10^{-7}$	Not detected	$4.0 \cdot 10^{-8}$	$3.6 \cdot 10^{-5}$
The city Uzhgorod Bozozhdokski park (Darasun type)	$5.4 \cdot 10^{-5}$	$4.6 \cdot 10^{-6}$	Not detected	$5.9 \cdot 10^{-5}$	$3.2 \cdot 10^{-6}$	" "	$8.0 \cdot 10^{-7}$	$4.0 \cdot 10^{-6}$	$1.0 \cdot 10^{-7}$	" "	Not detected	$6.3 \cdot 10^{-5}$

Note: Σ D* - total concentration of the pesticides, mg/dm^3 (all pesticides in one liter mineral water).

Dilor was detected in100% of samples in the concentration range 10^{-6} –10^{-5}mg/L. Metaphos is present in 82% of samples in the concentration range 10^{-7}– 10^{-6} mg/L. Carbophos is present in 71% of samples in the concentration range 10^{-7}– 10^{-6} mg/L. There were a total of nine pesticides and their derivatives detected in the mineral waters. In some samples, up to eight different substances were measured.

There is no clear correlation between pesticide content in the mineral waters and type, composition or location of mineral water. Both maximum and minimum total concentrations of the pesticides were detected in the hydrocarbon sodium waters of Polyana-Svalyava group (maximum equals $2.8 \cdot 10^{-4}$ mg/L in the well 4RE, v. Golubinnoye; minimum — $4.6 \cdot 10^{-6}$ mg/L, in the well 21 on the territory of food products factory, v. Nelipino).

In Ukraine, as well as in other countries of UIS, maximal permissible concentrations (MPC) standards were not established for the estimation of total influence of pesticides on a human body especialy (organochloric, organophosphoric, fluorine-containing pesticides), either for mineral waters nor for potable waters. Thus, it is not possible to estimate the danger of the detected quantities of pesticides in the examined mineral waters. Comparing the results obtained with the standards for industrial and potable water, we assume that none of the detected pesticides exceeds MPC.

However, the pesticide products listed above are among the most dangerous environmental pollutants, according to classification by the World Health Organization (WHO) and other international organizations. Particularly dangerous is the simultaneous presence of several substances and their metabolites in the same sample or water because their combined effect on the human body has not yet been studied.

CONCLUSIONS

Analysis of the situation at mineral water fields in the Transcarpathian region revealed the primary stages of contamination by pesticides, most likely due to agriculture and industry activities. If the situation is not controlled, this could cause irreversible negative consequences in the near future. Despite the variability of hydrogeological conditions in the Transcarpathian region there were no apparent regional correlations between pesticides concentrations in the mineral waters and either geological structure of the territory, type, or chemical content of the waters.

Pesticide content in the mineral waters was characterized by a mosaic character of distribution which relates to the quantity and assortment of pesticides that are utilized at agricultural lands and forests, permeability of aeration zone and filtration properties of the water-saturated zone, the technical state of wells and regime of their exploitation, permeability of the near-well surface and the confined and unconfined character of the aquifer.

During the last ten years (1987–1997), DDT content in water significantly decreased while HCCH concentrations remained practically the same. This suggests that HCCH was periodically used at the agricultural lands and forests. As far as DDT is concerned, there were no new input into the ecosystem, and pollution of DDT gradually decreased.

It's necessary to conduct systematic observations of pesticide content in hydromineral resources and to perform ecological studies of the territories in order to eliminate or diminish negative influence of the pesticides by changing the assortment of products used, decrease in concentration, and in some cases, prohibition of certain pesticides. Fundamental investigations are needed to reveal the transport mechanisms of these substances in the subsurface, to elaborate the criteria for the estimation of danger for the simultaneous presence of pesticides of different groups in the same mineral water.

To improve the ecological situation, modelling of DDT decomposition in mineral waters of the Transcarpathian region was established. As soon as DDT is concerned, there were no new income to natural ecosystems, and retrospective pollution gradually decreases ten years (for one order).

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abstract id: **521**

topic: **4**
Mineral and thermal water

4.3
Hydrogeochemical characteristics of mineral and thermal waters

title: **Stable isotopes of dissolved inorganic carbon and sulphur-bearing species in mineral and thermal waters from central Portugal**

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keywords: thermomineral waters, stable isotopes, carbon, sulphur

1. INTRODUCTION

There are many springs of mineral and thermal waters associated with the Hercynian Beiras Batholith granites of Central Portugal, which intruded meta-sedimentary rocks of Palaeozoic age. These low enthalpy thermomineral systems reflect the deep circulation of meteoric waters in fractured granites. All waters studied have similar chemical characteristics: pH varies be-tween 8 and 9.3; Na^+ is the dominant cation (representing over 90% of the total cations); HCO_3^- is the most representative anion, followed by Cl^- and/or F^- (always > 10 mg/L); and all of them are strongly reduced (as revealed by reduced sulphur (HS^-) and reduced nitrogen (NH_4^+)) and have very low Mg^{2+} contents (usually < 0.15 mg/L). Temperature ranges between 18 and 66°C, and total dissolved solids between ~200 and ~500 mg/L. Both natural springs and boreholes as deep as 500 meters were studied.

2. EXPERIMENTAL PROCEDURES

Samples for $^{13}C/^{12}C$ measurements were obtained by precipitation of the total dissolved inor-ganic carbon (DIC) as $SrCO_3$ by means of $SrCl_2$. The precipitate was filtered and dried without any contact with atmospheric air. Gas extraction was done by acidification with 103% H_3PO_4 and purification by criogenic distillation. Dissolved sulphide was collected as ZnS precipitated by addition of zinc acetate to the water, and later converted to Ag_2S by means of $AgNO_3$. Follow-ing filtration of the ZnS, the remaining water was acidified and treated with $BaCl_2$ to precipitate dissolved sulphate as $BaSO_4$. All isotopic analyses were done at the Stable Isotope Laboratory, University of Salamanca. The isotopic values are reported in the usual delta notation (δ‰) relative to V-PDB ($\delta^{13}C$) and CDT ($\delta^{34}S$).

3. RESULTS AND DISCUSSION

3.1. $\delta^{13}C$ of the dissolved inorganic carbon

The $\delta^{13}C_{VPDB}$ values of the total dissolved inorganic carbon (TDIC) in groundwaters range from –16.9 to –10.5‰. This range of $\delta^{13}C_{DIC}$ values is acompanied by a large variation of TDIC con-tents. The observed linear relation between TDIC and $\delta^{13}C$ (Fig. 1) suggest that inorganic carbon in the studied waters derives from more than one source: measured $\delta^{13}C$ values can not be at-tributed to isotope fraccionation between soil-CO_2 and DIC only.

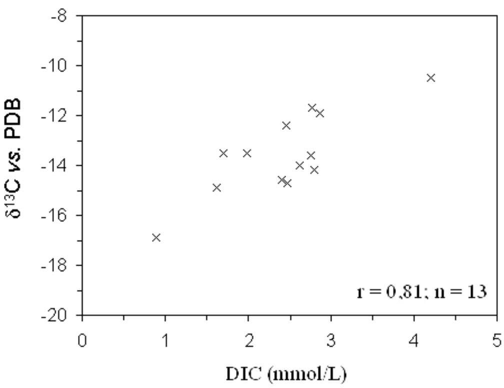

Figure 1. Relation between Total Dissolved Inorganic Carbon and $\delta^{13}C$.

A gaseous source, isotopically havier than the organic C of soil-CO_2 (such as regional deep mantle-derived or metamorphic flux of CO_2), must be invoked.

3.2. $\delta^{34}S$ of sulphur-bearing species (SO_4^{2-}; HS^-)

The $\delta^{34}S$ of sulphur-bearing species shows a remarkable variability: $\delta^{34}S_{CDT}$ (SO_4^{2-}) ranges from +6 to +44 ‰; $\delta^{34}S_{CDT}$ (HS^-) ranges from –25 to +2‰. Sulphate is always enriched in ^{34}S relative to reduced sulphur (HS^-). This isotopic difference ($\Delta^{34}S=\delta^{34}S$ (SO_4^{2-})–$\delta^{34}S$ (HS^-); mean value = 28.5‰) is interpreted as the result of biogenic reduction of sulphate occuring in these waters. An apparent reduction trend is seen on Figure 2.

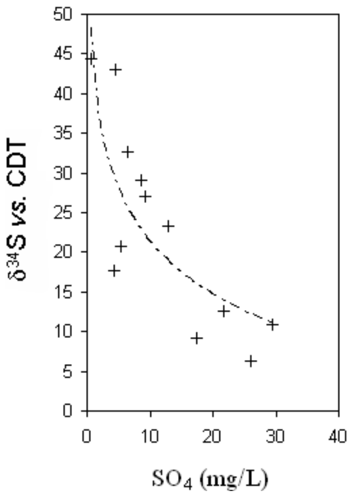

Figure 2. Comparison of sulphate concentrations and $\delta^{34}S$ values.

4.4 | Social, ecological and economic implications

IAH 2010
Krakow

abstract id: **180**

topic: **4**
Mineral and thermal water

4.4
Social, ecological and economic implications

title: **Healthy safety of natural mineral waters**

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keywords: mineral water, safety

INTRODUCTION

Modern firm manufacturing mineral water diligently protects its bore holes using cameras and security service. Water from water bearing deposit is poured into bottle in sterile conditions. Production lines belonging to the so called clean zone are computer controlled, workers supervising production are wearing protective clothes and have to have suitable health certificates. Bottles moulded in temperature 200°C are washed with a special stream of water before filling. Technological air used to pneumatic control of the production line is cleaned in three different types of filters which guarantees its sterility. The quality of water from the bore hole and the final product are examined by the factory laboratory.

The purpose of the work is to present the rules of natural mineral waters quality control from the health safety side connected with water consumption.

WATER IN HUMAN BODY

Water volume (V) in human body can be preliminarily estimated according to the Fris-Hansen formula (Hałat, 1998):

$$V = 0.55 \cdot \text{weight [kg]} + 0.5\ dm^3 \quad (1)$$

Proportional portion of water in human body depends on age and gender. At young women it is 50%, and at men 60%. At people over 60 the proportional portions are, respectively, 45% and 50%. Brain and muscles at adult person contain about 75% and blood about 87% of water. Twenty four hour's water requirement in human body is from 2.0 up to 3.5 dm^3, depending on the physical activity and ambient temperature. In twenty four hour's balance one should take into account the metabolism processes which produce 0.2 up to 0.6 dm^3 of water. For example, while 1 g of protein is burnt 0.41×10^{-3} dm^3 of water is produced, 1g of fat — 1.07×10^{-3} dm^3, and 1 g of carbohydrate — 0.6×10^{-3} dm^3 (Hałat, 1998).

With regard to consumers feelings the organoleptic properties of water, such as: taste, colour, transparency and smell are subject to estimation (Rak, Tchórzewska-Cieślak, 2005).

QUALITY SYSTEMS IN MINERAL WATERS PRODUCTION AND TRADE

Guarantees and safety of mineral waters consumers can be assured by the following quality systems (Głodkowski et al., 2004):

- management in order to achieve quality — Quality Management — QM,
- analysis of threats in critical control points — Hazard Analysis Critical Control Points — HACCP,
- risk analysis and biocontamination control — Risk Analysis Biocontamination Control — RABC,
- good hygienic practice — GHP,
- good manufacturing practice — GMP,
- early warning about dangerous food — Rapid Alert System for Food — RASF.

The rules of GHP and GMP are implemented before HACCP is introduced (Głodkowski et al., 2004).

Quality systems concerning mineral waters production and trade define the mentioned below terms in the following way:

- threat — biological, chemical or physical factors which can occur in mineral waters and cause the negative consequences for human health (Rybicki, 2004),
- monitoring — system of processed observations, measures and studies having a specified aim, performed on the representative samples,
- risk — danger that the negative severe consequences for human health will occur as a result of mineral waters drinking,
- risk analysis — procedure consisted of three interconnected elements including risk assessment, risk management and information about risk,
- risk estimate — scientifically aided process consisting of three stages containing threat identification, characteristic of danger, hazard assessment and risk characteristic,
- risk management — action undertaken by the suitable body supervising safety of using mineral waters that establishes the ways to prevent risk and to control risk, based on the risk estimate and binding requirements regarding sanitary and hygienic safety at production and trade of mineral waters,
- information about risk — it means to exchange information and opinions regarding threats and risk as well as factors connected with risk, during risk analysis, among those who estimate risk, manage risk, consumers, producers, traders and scientists,
- procedure — it is an established way of action — description of operations allowing to perform some task,
- instruction — it is an operational procedure of lower order — it gives detailed actions in logical sequence of execution, describes step by step the task connected with the given position, explains the way of carrying out.

THE HACCP SYSTEM METHODOLOGY

As results from the rules of the HACCP system, it is a proceedings which aim is to ensure mineral waters safety by the identification and the evaluation of a threat scale, from the point of view of a curative quality and risk of threats, during the course of all production stages and trade of mineral waters. The purpose of this system is also to determine the methods to reduce threats and to establish corrective actions.

The HACCP system regarding food control came to existence in the USA in the late 1960s, ordered by NASA (National Aeronautics and Space Administration). The origin of HACCP was related to the scientific research on production of food without pathogenic microorganisms for the astronauts (Głodkowski et al., 2004).

In 1971 Pollsburgy company presented this system at the American National Conference for Food Protection. The HACCP system has been accepted by World Health Organization (WHO) and International Commission on Microbiological Specifications for Foods (ICMSF).

As a result of the fact that Poland joined the European Union the sector dealing with mineral waters production and distribution has been obliged to use the HACCP system. It is regarded as the most efficient tool which guarantees that water as a foodstuff will not be polluted or contaminated and will be safe for consumers health. The HACCP system is created individually for every production line and distribution type, taking into account the specific character of the given activity.

The main rules are the following:

- the identification of the possible biological, chemical and physical threats and the methods of counteractions,
- the prevention, in form of a control of the particular phases of mineral waters production process and distribution, not the final product only,
- it is used in the whole production cycle: from water intake, then bottling plant, warehouse, distribution, delivery to consumers in stores and restaurants.

There are seven basic stages connected with the HACCP system implementation (Głodkowski et al., 2004).

Stage 1. Threats analysis.

It consists in:

- the identification of the potential threats in the categories of occurrence: biological, chemical, physical,
- the establishment of a source and a reason, as well as the preventive activities,
- the assessment of risk of threat (Rak, Tchórzewska-Cieślak, 2005).

Stage 2. The establishment of critical control points (CCP).

It enables to achieve the purpose of the system by being in control of mineral water sanitary safety. The condition of CCP determination is the possibility of their monitoring and the possibility of real threat controlling. To determine CCP one can use a decision tree method. It allows to determine CCP by the logical series of questions and answers concerning the possibility of eliminating the threat in a given point or reducing it to the acceptable level. An example of decision tree questions, according to Dutch procedures can be found in (Głodkowski et al., 2004).

Stage 3. The establishment of the critical limits for every control point.

After the CCP designation one should determine one or more indicators of contamination which will be controlled and the desirable values, the limits of tolerance and the unacceptable critical value (Dz.U. 2006 nr 171 poz. 1225). The criterion for the choice of the indicator should be speed and easiness of measurement and the possibility of monitoring. In case of difficulties one should use the visual and/or sensor assessment.

The microbiological examination and the examination of sanitary and hygienic state of water at its intake and in the consumer package are conducted to ascertain (Dz.U. 2004 nr 120 poz. 1256):

- lack of parasites and pathogenic microorganisms,
- lack of Escherichia coli and other forms of coli bacteria in 250 cm^3 in temperature 37°C and 44.5°C,
- lack of streptococcus faecalis in 250 cm^3,

- lack of Clostridium reducing sulphates in 50 cm^3,
- lack of Pseudomonas aeruginosa in 250 cm^3,
- total amount of bacterial colonies growing from 1 cm^3 of water:
  - in temperature 20–22°C during 72 hours in agar or in the mixture of agar and gelatine is not higher than 5,
  - in temperature 37°C during 24 hours in agar is not higher than 20.

Stage 4. The establishment of CCP monitoring procedures.

The CCP monitoring is a base of the HACCP operating. The results obtained from the monitoring have to be recorded. For monitoring procedures one should determine:

- a method of monitoring,
- a character, constant or periodical,
- a periodical monitoring frequency,
- a way of supervision,
- the rules of measuring device control and calibration.

In Table 1 the range of mineral waters quality examination within the framework of CCP monitoring during production is presented.

Table 1. The range of mineral waters quality examination within the framework of CCP monitoring.

Type of water quality rating	Range of monitoring
Organoleptic rating	smell, taste, turbidity, colour
Physical and chemical rating	conductivity, pH
Undesirable components in excessive concentration	nitrates, ammonia nitrogen, iron, COD
Basic components	characteristic components mentioned in water marking

The microbiological, physical and chemical determination of water quality in 5 bottles randomly taken from different production batches are performed within twenty four hours. The so called keeping quality examination that determines water quality before its consumption expiry date is also performed (Dz.U. 2006 nr 85, poz. 544).

Stage 5. The establishment of corrective actions.

Corrective activities have to be undertaken when monitoring shows the trend to exceed permissible values of cleanliness rating or such values are exceeded. The possibility of stop in mineral water production process should be predicted, in order to eliminate the causes of the necessity of the corrective actions.

In tab. 2 the maximum concentrations of chosen mineral waters components, when their quality is corrected by permissible process of water ozonization, are presented.

In order to regard water as curative the clinical and pharmacological examinations, according to the scientific methods, which estimate natural mineral water properties and its impact on human body, such as: diuresis, stomach and bowel functions, balance in mineral elements, should be carried out. In natural waters having components good for health the general water properties resulting from quantity proportions between macro and micro elements are essential. As an example one can give the desirable proportion of the contents of calcium to magnesium: 2:1.

Table 2. Maximum limits for components that remain or are created during aeration of natural mineral water and spring water by ozone enriched air.

Kind of component	Maximum limits (μg/dm³)
Dissolved ozone	50
Bromate	3
Bromoform	1

Stage 6. The establishment of system verification procedures.

Verifications are performed after the HACCP system is implemented as its first evaluation. Then a frequency of next verifications should be established, verification is always performed after the changes in the technological production process are made and also when the undesirable events occur.

Effectiveness of the HACCP system can be verify by means of external and internal audits. There is the possibility to achieve HACCP certificate which definitely increases confidence of the present and the future consumers of the given mineral water brand.

Stage7. The creation of documentation.

System documents should contain a plan of HACCP and the records testifying system operation. The way of documents drawing up, storage and supervision must be establish.

CONCLUSIONS

- The HACCP system is one of the systems to ensure mineral waters quality and curative values. The implementation of the system increases the confidence among the particular participants of mineral waters market. The beneficiaries of the effects of the HACCP system introduction are producers, sellers, supervisor service, and, most of all, mineral water consumers. The efficient HACCP system allows to avoid the groundless complains, protects against the loss of customers and credibility of the firm on the market.
- The external benefits of the HACCP introduction for mineral waters producer are the following:
  - the increase of consumers confidence,
  - the opportunity of sale in the European Union markets,
  - the improvement in product competitiveness,
  - the improvement in firm image,
  - the increase of confidence at official inspection units.
- The HACCP system means a change in the way of evaluation of mineral waters quality as a product. The evaluation of the conditions of high quality mineral waters production, instead of the control of the final product only, ensures the increase of health safety connected with their consumption.
- There are some possibilities to develop the method to assess the risk of threat, based on the three and four parameter matrix for risk analysis and evaluation (Rak et al., 2005).

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PN-Z-11001-1-3:1999: *Butelkowane naturalne wody mineralne i lecznicze — Wymagania jakościowe i badania butelkowanych naturalnych wód mineralnych.*

Rozporządzenie Ministra Zdrowia i Opieki Społecznej z dnia 8 lipca 1997r. w sprawie szczególnych warunków sanitarnych przy produkcji i obrocie naturalnych wód mineralnych, mineralnych wód mieszanych, naturalnych wód źródlanych oraz wód stołowych. Dz.U. 2006 nr 85, poz. 544.

abstract id: **475**

topic: **4**
Mineral and thermal water

4.4
Social, ecological and economic implications

title: **Geothermal water desalination project**

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keywords: geothermal water, water desalination, water balance

INTRODUCTION

The use of energy from alternative sources both in Poland and in the European Union is hampered by high investment costs, which are largely front-loaded (the cost of drilling the injection well, among other things), and are much higher than the financial outlay required in the case of conventional energy sources. Taking into account Poland's obligations to increase the share of energy from renewable sources, it is essential to intensify efforts aimed at reducing the aforementioned costs.

The specific nature of the problem and wide variation in the physico-chemical properties of geothermal waters (whose mineralisation ranges from a few to more than 120 g/dm^3) has given rise to a research programme designed to promote the comprehensive utilisation of geothermal waters in order to improve the water balance, stimulate the balneological sector and improve the operating conditions of existing systems.

Reducing the high investment expenditure, which is, inter alia, related to the need to drill the injection well, the cost of improving absorption capacity, etc., may be of key importance for the initiation of new investment and as a consequence for increasing the share of renewable energy in the domestic market.

This paper presents preliminary observations concerning the feasibility of desalinating geothermal waters, which would contribute to their utilisation in many areas, including:

- An improvement in the management of fresh water resources through the use of desalinated geothermal waters;
- Limiting corrosion processes and the precipitation of minerals that clog geothermal systems through an attempt to mix raw geothermal water cooled in heat exchangers with "pure water" in appropriate proportions following the treatment process;
- The development of the balneotherapy, tourism and leisure sectors;
- The recovery of mineral compounds with balneological and economic importance (the production of mineral resources).

In Poland, geothermal water resources are associated with the presence of large regional underground reservoirs. The proper examination and determination of the operating conditions in relevant facilities will not negatively affect the amount of resources, the possibility of sourcing renewable energy or the opportunities for sustainable operation.

THE SALINITY OF GEOTHERMAL WATERS EXTRACTED IN POLAND

The chemical composition of groundwater depends on several factors, including the lithology of the aquifer rocks, the circulation of groundwaters and the water-rock thermodynamic equilibrium. The geothermal water reservoirs that have been made available and are currently exploited in Poland exhibit varied physico-chemical properties. Fresh and weakly mineralised waters with an increased content of specific components are present here as well as brines.

In central Poland, in Mszczonów, weakly mineralised water (below 0.5 g/dm^3) with a temperature of 40.5^{o}C is being extracted from the Mszczonów IG-1 well, from a Lower Cretaceous horizon composed of sandstones interbedded with mudstone and claystone. This is high quality Cl-HCO_3-Na-Ca water. After the extraction of heat using an absorption pump and treatment, the water is used for consumption purposes in the municipal water supply system. Groundwater sourced from a Cenomanian reservoir in Słomniki (south-eastern Poland) is used for similar purposes. This is weakly mineralised (ca. 0.35 g/dm^3) HCO_3-Ca-Na-Mg water with a temperature of 16.5^{o}C at the well outlet.

In south-eastern Poland, in Podhale region, geothermal waters are extracted from carbonate formations of the Middle Eocene and from Middle Triassic limestones and dolomites. These exhibit relatively low mineralisation — from 2.358 g/dm^3 (Na-Ca-SO_4-Cl hydrogeochemical type) in the Bańska IG-1 well to 3.150 g/dm^3 (SO_4-Cl-Na-Ca) type in the Bańska PGP-1 well (Kępińska, 2006). Their temperature at the well outlet ranges from 69 to 86°C.

Geothermal water extracted from Mesozoic formations in the Polish Lowlands (e.g. in Pyrzyce, north-western Poland) has a different composition. Very hard (8,653 mg $CaCO_3$/dm^3) Cl-Na brines with a mineralisation of ca.123 g/dm^3 (Pyrzyce GT-1 well) and a temperature of 61°C are present here. The water has a high content of sulphates (1115 mg/dm^3), iron (16.4 mg/dm^3), manganese (1.5 mg/dm^3) and fluorides (1.2 mg/dm^3) (Kania, 2003).

WATER DESALINATION METHODS

Desalination processes can be classified as follows on the basis of changes in the phase, the type of energy used and the separation technique applied (Sadhukhan et al. 1999; El-Dessouky and Ettouney 2000; Bodzek et al. 1997):

1. On the basis of changes in the phase:

- without changing phase — reverse osmosis (RO) and electrodialysis (ED);
- involving changes in phase — distillation and freezing out.

2. On the basis of the type of energy used:

- heat-based processes — distillation processes;
- processes based on mechanical energy — reverse osmosis;
- processes based on electrical energy — electrodialysis.

3. On the basis of the separation technique applied:

- processes separating water from the solution: distillation processes and reverse osmosis;
- processes separating salt from the solution: electrodialysis and ion exchange.

The choice of the most appropriate water desalination process is dependent on the physicochemical properties of the water, its temperature, gas content and technical aspects related to the energy requirements of individual methods. The following factors are also significant: process efficiency (water recovery level), installation life (mechanical, thermal and chemical resistance of the membrane), the possibility of cleaning modules (membranes) and the need to implement extensive water pre-treatment processes as a result of, inter alia, raw water containing organic substances (macromolecular compounds, biological substances), inorganic compounds (metal hydroxides, calcium salts, silica), suspended particles, colloids (organic and inorganic) that may cause membrane efficiency problems — fouling and scaling.

Desalination processes based on thermal and membrane separation are the most important ones for drinking and domestic water production (Tsiourtrtis, 2001; El-Dessouky, Ettouney, 2000). Currently, membrane-based water desalination processes predominate due to their lower energy consumption compared to distillation techniques (Bodzek et al., 1997). Reverse osmosis (RO) enables pollutants to be separated at the molecular or ion level. In this process, pressure is applied to a water (solution) to force it through a semipermeable membrane, which separates two solutions with different concentrations. Under pressure, pure (permeate) water molecules pass through the membrane, while molecules of salts and other pollutants (e.g. colloids) and bacteria remain on the raw water side.

Hybrid installations combining thermal and membrane-based technologies are increasingly frequently used to treat salty water. These processes are, among others, the multi-stage flash process (MSF) and multi-effect distillation (MED). Their efficiency does not depend on the quality of the water supplied, which is the case with reverse osmosis (RO).

GEOTHERMAL WATER DESALINATION PROJECT

Water physico-chemical properties have to be determined in detail in order to assess whether it is possible to use geothermal water and to determine the most efficient treatment method. To this end, water has to be tested in situ at two locations: at the wellhead in order to determine the water parameters at the well outlet and in the geothermal installation, after it has been cooled in heat exchangers. During the geothermal water cooling process, several physico-chemical reactions take place, as a result of which the thermodynamic state of the water changes. This may cause the precipitation of the minerals dissolved in the water, which leads to many operational problems in the installation (Kępińska, 2006; Kania, 2003; Górecki (ed.) 2006). The analysis of the information obtained regarding the specific features of the heating system in question is a precondition for assessing the possibility of treating geothermal water by one of the methods available and using it in various applications other than the most common one.

In-situ studies at selected geothermal facilities in Poland that use water with varying salt content will make it possible to test the process on a semi-industrial scale (with a water desalination installation capacity of around 1 m^3/h). The study is to be implemented in two stages. In the first stage, the aim will be to obtain water that meets the requirements for safe drinking water, while at the same time recovering minerals that can be used in balneology or industry. In the second stage, attempts will be made to mix raw geothermal water cooled in heat exchangers with "pure water" following the treatment process in appropriate proportions. The final objective is to achieve a chemical composition of water that will reduce the mineral precipitation processes leading to the clogging of geothermal systems.

The results of studies on the treatment of geothermal waters following the heat recovery process, which often exhibit high salt content and do not constitute drinking water resources, will be used to assess the possibility of improving the local fresh water balance.

PILOT INSTALLATION

A pilot geothermal water desalination installation in Poland was commissioned at the Geothermal Laboratory of the Mineral and Energy Economy Research Institute of the Polish Academy of Sciences (PAS MEERI). Laboratory is localised in Podhale region, in south-eastern Poland. Geothermal waters are extracted from carbonate formations of the Middle Eocene and from Middle

Triassic limestones and dolomites. These exhibit relatively low mineralisation — from 2.358 g/dm^3 to 3.150 g/dm^3. Their temperature at the well outlet ranges from 69 to 86°C. After the cooling, in heat exchangers, water are used in the cascading system using geothermal energy. The first step of cascade is heating objects of PAS MEERI. In the next geothermal energy is used for drying wood, plant breeding greenhouses, thermophilic fish farming and heating of the land in plastic tunnels (Tomaszewska, 2009). The next step will be to research to the production of drinking water which is needed in the vicinity of the well. Installation is supplied with water at a temperature of about 35°C. The pilot installation must include typical industrial plant components because the pilot research must yield representative results which will constitute guidelines for industrial facilities (Fig. 1). For this reason, the minimum installation capacity has been set at 1 m^3/hour of desalinated water, which meets the above condition and will enable the extrapolation of results from the pilot installation to an industrial one. The study will take six to twelve months. The use of membrane-based methods is envisaged. The objective of geothermal water desalination will be to obtain water that meets the requirements stipulated in the Regulation of the Minister of Health of 29 March 2007 (Official Journal [Dz. U.] No. 61/2007 item 417) concerning the quality of water intended for human consumption.

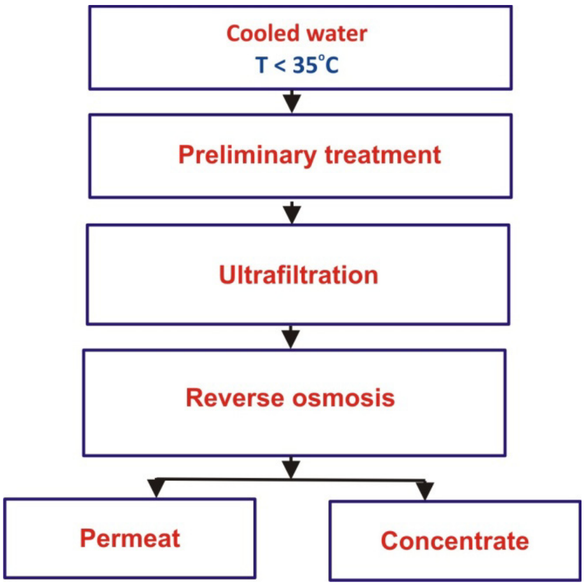

Figure 1. The concept design of the installation geothermal water desalination from the Bańska IG-1 well.

Primary criterion in selection of water desalination technology was <u>reliability</u> of installation in the presence of: silica — 62,5 mg/dm^3, hydrogen sulfide — 0,085 mg/dm^3, boron — 9,95 mg/dm^3, barium — 0,142 mg/dm^3, strontium — 7,19mg/dm^3, ammonium ion — 1,3 mg/dm^3, fluoride — 1,3 mg/dm^3, bromide — 1,75 mg/dm^3, sulfate — 872 mg/dm^3, mineralisation — 2482,59 mg/dm^3. After preliminary calculated there was selected the technology for the pilot installation, inclusive: preliminary filtration 1000 µm, ultrafiltration UF (for SDI < 4), activated carbon AC filtration double reverse osmosis (RO).

The successful implementation of the water desalination research programme presented in this paper would ultimately enable the development of best practices for geothermal water treatment in newly constructed installations and initiate proposals for improving the operation of existing facilities.

In particular, the application of water desalination methods at facilities which operate an open drain system (without reinjection) where the cooled water is released into a surface reservoir, would contribute to more effective use of the water released, including an improvement in the water balance of the area in question. Improvement of the economic parameters may be of key importance in the stimulation of new investment and as a consequence for increasing the share of renewable energy in the domestic market.

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abstract id: **482**

topic: **4**
Mineral and thermal water

4.4
Social, ecological and economic implications

title: **Legal and financial barriers for development of geothermal energy in Poland on the background of GTR-H project results**

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INTRODUCTION

In the period from December 2006 to October 2009, the Mineral and Energy Economy Research Institute Polish Academy of Sciences (PAS MEERI) was participated in the implementation of the EU Project: "GeoThermal Regulation — HEAT" (GTR-H, www.gtrh.eu), supported by Intelligent Energy Europe/Altener Programme. The GTR-H project was concerned with the regulation of geothermal energy for heat in the EU. It set out to review and establish the regulatory barriers and deficiencies in the geothermal sector through a process of discussion and consultation with key target actors and stakeholders at a national level in Hungary, Ireand, Northern Ireland and Poland. A review was carried out of best practice in geothermal regulatory frameworks in France, Germany and the Netherlands, to provide the necessary input to design a possible framework for the implementation of geothermal regulations (Goodman et al., 2007).

GEOTHERMAL REGULATORY FRAMEWORK

An analysis of the existing regulatory framework for geothermal energy in Member States has confirmed that the effective regulation of geothermal energy needs a sound legislative basis. This may be achieved through new policies, the modification of existing legislation, the introduction of new legislation or planning may cover aspects of geothermal energy exploration or development, or legislation specifically for geothermal energy may be made. The choice will depend on the scope of existing legislation or may be a matter of national policy.

The reviews and consultations carried out in the GTR-H project have identified factors that should be addressed in any regulatory system for geothermal energy and these essential elements was describe in the template for a geothermal energy regulatory framework.

The issues identified as requiring inclusion in "Geothermal Regulation Framework" have been grouped into the following categories in the template: legal, financial and other supporting or flanking measures (including education, training, standards and promotion strategy) (Goodman (ed.), 2009).

Below are selected excerpts from the text of "Geothermal Regulation Framework":

A. LEGAL GUIDELINES

A.1. DEFINITION AND CLASSIFICATION OF GEOTHERMAL ENERGY

"Geothermal Energy" — the energy stored in the form of heat beneath the surface of the solid Earth' (as defined by RES Directive, 2009/28/EC).

A.3. GEOTHERMAL ENERGY LICENSING SYSTEM

A. 3.2. Geothermal resouces definition and regulations under existing legislation (…) could be followed by a new Geothermal Act to address any shortfalls identified in the legislation once the licensing system has been in operation for several years.

A.3.9. There is an obvious potential for competition between onshore carbon storage and geothermal energy projects because they may target the same deep aquifer, or the same areas within sedimentary basins. Geothermal energy may also be produced from rocks below the depth range for potential carbon storage sites. Carbon capture and storage is essentially a bridging technology whereas geothermal energy is a sustainable energy resource. Areas of deep geothermal energy resources should be identified and priority given to geothermal energy over carbon storage exploration licenses.

A.3.11. Appropriate exemptions from the national planning and environmental impact assessment regulations should be considered for the exploration stage of geothermal projects in order to assist in the development of the sector.

A.3.12. Specific guidelines on the application procedure for deep geothermal exploration and exploitation should be developed. These need (…) to identify the relevant licensing authorities and outline the application process and guidelines for technical inputs, work programmes and reporting requirements. These should help streamline application submissions.

A.3.20. The costs of geothermal exploration licenses should be set lower than the petroleum and mineral exploration licensing costs to reflect comparatively lower economic return potential and to promote geothermal development as part of national RES' action plans (NREAPs, RES-Directive, 2009/28/EC).

A.4 SIMPLIFY REGULATIONS AND ADMINISTRATIVE PROCEDURES

A.4.3. It is recommended that small sized closed loop domestic systems should be registered through a simple information submission form to a nominated government agency. These systems should require no exploration licences or planning permission.

A.4.5. Deep geothermal energy production should comply with the Groundwater Framework Directive and national groundwater abstraction/exploitation legislation where implemented for the use of re-injection or closed circuit systems.

B. FINANCIAL INCENTIVES GUIDELINES

Financial Incentives Schemes (FIS) play an essential role in promoting the development of national shallow and deep geothermal energy sectors for heating and cooling (…) It is important that the FIS are adequately designed and implemented in the medium and long term.

Key positive effects of well designed and managed FIS:

- Reduction of the upfront investment costs,
- Changed perception of geothermal systems by consumers and local authorities and a resultant shift to increased uptake of these systems.

B.1 REGULATORY COSTS/LICENCE FEES/ROYALTIES

B.1.2. Fees or charges should not be applied on the production of energy by geothermal systems (shallow or deep) as the geothermal heat resource is continuously replenished (renewable) and therefore not "mined" in the conventional sense if used sustainably.

B.1.3. Royalty fees should not be applied to deep geothermal energy production plants especially where national legislation promotes the use of reinjection systems on the basis that geothermal system is renewable and contributes to fullfilling the RES targets set out in the national renewable energy action plants (NREAPs) to be defined in every EU state.

B.1.4. Groundwater abstraction/exploitation fees should be based only on the net water abstraction rate from shallow and deep systems and these should be waived where this is below a specified threshold. Where the re-injection of produced geothermal waters does not occur, national groundwater abstraction/exploitation and surface water regulations should apply.

B.2 DEVELOP FINANCIAL INCENTIVE SCHEMES

B.2.1. A Geothermal Risk Insurance Guarantee and Risk Fund for deep geothermal exploration and/or development drilling should be made available (…)

B.2.2. (…) Incentives for delivering heat from RES such as geothermal energy should be encouraged through low VAT rates and/or "Green Certificates" to geothermal and RES system heat producers (such as feed-in-tariffs) based on each unit of RES heat produced and installed geothermal capacity.

B.2.7. Administrative procedures for FIS should be as simple as possible.

B.2.8. National, regional, local government authorities should promote deep geothermal energy project development using financial incentives to reduce financial burden of such projects.

B.2.9. National research and development funding schemes should target geothermal energy research, with demonstration projects and spin-off activities amongst the priority fields.

B.3 NOTES ON FINANCIAL INCENTIVE PARAMETERS

B.3.2. Incentives could be based on the CO_2 emissions avoidance from operating geothermal plants and/or a set of agreed heat feed-in tariffs based on a national feed-in tariff strategy.

B.3.3.The development of CO_2 emissions credit system („green certificates") for the operation of geothermal energy projects should be encouraged at national level to incentivise sector investment. For small installations a simplified procedure should be established.

B.3.4. Geothermal energy should receive incentives similar to the support received by other RES in the form of financial assistance for initial feasibility studies, grants, low interest rate loans, risk insurance, preferential VAT rate, feed-in tariffs or certificates for geothermal heat units produced/installed.

B.3.5. Preferential VAT rates for heat sales from operating geothermal power plants should be below the higher rates of 19–21%. These should be designed to encourage fossil fuels substitution and provide a competitive price for geothermal based on national domestic and commercial energy rates.

B.3.6. A Geothermal Insurance and Risk Fund (particularly for deep exploratory and/or development drilling) is encouraged to be made available based on the substitution for fossil fuel use and on the potential for national CO_2 emission savings that can be achieved through the development of geothermal energy projects.

This type of Risk Fund typically covers the risk associated with the drilling for the exploration and assessment of the resource.

B.3.9. The cost of drilling permits for completion of geothermal energy boreholes should be waived or reduced. This should be considered for a period of 15–20 years until the sector is established.

B.3.10. Where applicable there should be a waiver/reduction on natural resource data acquisition costs to a licence applicant for review of geothermal energy data prior to application submission.

C. GENERAL GUIDELINES FOR FLANKING/SUPPORTING MEASURES

A number of indirect accompanying measures are important for the development of geothermal energy sector (in order to): provide comprehensive information, introduce the appropriate technologies to professional groups, meet existing national market demands, ensure the implementation of appriopriate quality standards.

C.1. TRAINING

C.1.1. Educational strategies about geothermal energy for students, academia, professional bodies and institutions involved in the implementation of projects should be devised by a national geothermal experts in consultation with NGOs and private sector companies (…)

C.1.3. A certification scheme must be proposed for shallow geothermal system installers and drillers (…)

C.2. PROMOTION OF GEOTHERMAL ENERGY

C.2.1. A national geothermal strategy (based on NREAPs) defining the goals and targets for geothermal as a contribution to the national RES mix is required to meet the EU-targets of 20% RES by 2020. (…)

The strategy will provide a stable implementation platform for geothermal regulation over a defined period of time.

C.2.4. The development of National Heat Markets and national strategies for future heating and cooling demand need to be addressed. (…) the heating and cooling markets in Europe are poorly defined. Geothermal energy deployment has potential to significantly contribute to the current status of the European Heat Market. In order for this to be achieved coherent European and national strategies for heat markets are required.

C.2.6. Information and economic benefits of RES-H need to be further disseminated to encourage changed investment behaviour of energy consumers.

C.3. STANDARDS AND CODES

Standards on the deployment of geothermal technologies need to be prioritised and implemented. Development and implementation of „Best Practice Guidelines" should be based on or linked to existing construction best practise guidelines and regulations in the different member states.

C.4. RESEARCH AND DEVELOPMENT

C.4.1. The general technological objectives of the sector are:

- increasing the knowledge about the usable geothermal potential amongs the various stake holders: end-users, advisers, authorities, etc.,
- for direct-uses: improving plant efficiency and decreasing installations and operational costs,
- for Geothermal Heat pumps: decreasing installation costs and increasing seasonal performance factor (SPF), optimization of the system (ground heat source/heat pumps/distribution),

C.4.2. The main research & development priorities for geothermal heating and cooling (several topics and issues) — several topics and areas of particular research interest (…)

LEGISLATION AND REGULATORY FRAMEWORK RELATED TO GEOTHERMAL HEATING SECTOR IN POLAND

In Poland, the activities related to geothermal energy sector are regulated by several legal acts (with Geological and Mining Act, Environmental Act, Energy Act as the basic ones):

Geological and Mining Law (new proposal under consultation and Parliamentary proceedings in 2009 and 2010); Energy Law; Building Law; Act on Spatial Planning and Land Development; Environmental Act; Act on Freedom of Business Activity; Water Law; Act on Proceedings in State Aid Cases; Act on the Amendment to the Act on the Conditions of Admissibility and Supervision over Public Aid. Taking into account management of geothermal energy, the above acts can be assigned to the following issues: 1) prospecting for, documentation and exploitation of geothermal energy, 2) production and distribution of energy by geothermal plants, 3) economical support for production of clean energy (Bujakowski et al., 2009).

THE ISSUES NEEDED TO BE CORRECTED IN POLAND, BY THE NEW/AMENDED LEGISLATION OR BY THE IN INTRODUCTION OF THE FRAMEWORK ELABORATED BY GTR-H

Several recommendations and proposals were suggested to be introduced in the new/amended legislation (if any) or by the introduction of the framework elaborated by the GTR-H works, following, among others, the GTR-best practice cases. i.e.: 1) transfer some procedures to lower administration level, 2) simplify and shorten the procedures concerning all stages of geothermal projects and investments, 3) cancel or limit several fees and royalties, 4) lower VAT for geothermal heat price (now 22% comparing with 5.5% in case of France), 5) introduction of the „green certificates" for geothermal heat, 6) establish a Risk Guarantee Fund (example of France), 7) establish a system /body to coordinate public support for geothermal on a basis of professional selection the best feasible projects (Kępińska, Tomaszewska, 2009).

Among import flanking measures one should listen the following: 1) comprehensive support and assistance for investors to gain the financing (state, international) and to create a quick and streamline path, 2) introducing geothermal research, R&D works in the area of financing by the Ministry of Science and Education; so far the financing by the Ministry of Science and Education is very limited (being mostly provided by the Ministry of Environment, National Fund for Environmental Protection and Water Management).

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5 | Data processing in hydrogeology

5.1 | Modelling as a tool of groundwater assessment

abstract id: **106**

topic: **5**
Data processing in hydrogeology

5.1
Modelling as a tool of groundwater assessment

title: **Modelling of water table fluctuations in the presence of canal seepage and pumping**

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keywords: modelling, water logging, cannal seepage, pumping

Agriculture is the main source of income to the Indian rural population which comprises almost 80 percent of the total population. The water logging problem due to rise of water table near to the ground surface resulting from seepage of water through beds of unlined canals has been reported from many heavily irrigated areas since the onset of green revolution in late sixties. Pumping of ground water using bore wells located in the vicinity of canals has been suggested as one of the effective measures to minimize the effect of water logging problems. The present paper deals with the development of a mathematical model to predict the dynamic behaviour of the water table in the presence of seepage owing to intermittently applied canal irrigation and groundwater pumping from any number of wells. Figure 1 presents a schematic diagram of a homogeneous anisotropic aquifer system of length A and width B. The aquifer system is characterized with the zero flux condition at all four boundaries. The aquifer is receiving recharge from a canal which is being represented by three strip recharge basins namely B1, B2 and B3, joined together. This figure also shows a well adjacent to the B3 segment of canal which is being used for ground water pumping to lower the level of the water table. For demonstration purpose only one well is shown, but in principle the model is developed to consider any number of wells with different pumping rates.

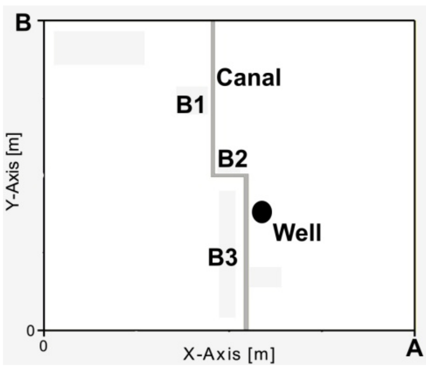

Figure1. Schematic diagram of aquifer with canal and well.

FORMULATION OF THE PROBLEM

Ground water flow in the aquifer system under consideration is represented by following 2-D linearized Boussinesq equation:

$$\frac{\partial^2 H}{\partial x^2} + \beta \frac{\partial^2 H}{\partial y^2} + \frac{2}{K_x} P(x, y, t) = \frac{1}{a} \frac{\partial H}{\partial t} \quad (1)$$

subject to the following initial and boundary conditions:

$$H(x, y, 0) = 0 \quad (2)$$

$$\frac{\partial H}{\partial x}(0, y, t) = \frac{\partial H}{\partial x}(A, y, t) = 0, \qquad 0 \le y \le B$$

(3 & 4)

$$\frac{\partial H}{\partial y}(x, 0, y) = \frac{\partial H}{\partial y}(x, B, t) = 0, \qquad 0 \le x \le A$$

in which $H = h^2 - h_0^2$, $a = K\bar{h}/S$, = Kx/Ky, and *P (x,y,t)* represent the sum of time varying recharge rate and pumping rates from multiple basins and wells. Intermittently applied time varying recharge and pumping rates have been approximated by using linear elements of different lengths and slopes depending on the nature of variation of recharge and pumping rates. *P (x,y,t)* is mathematically represented by

$$P(x,y,t) = \sum_{i=1}^{N} p_i(t)[H_a(x - x_{i1}) - H_a(x - x_{i2})].[H_a(y - y_{i1}) - H_a(y - y_{i2})] \qquad (5)$$

$p_i(t)$ = recharge rate of ith basin, N = Total number of basins,

$H_a(x)$ = unit step function,

$p_i(t)$ is approximated by a series of line elements given by:

$$p_i(t) = \begin{cases} r_{ij}t + c_{ij}, & t_{ij} \le t \le t_{i,j+1} \\ r_{ik}t + c_{ik}, & t \ge t_k \end{cases} \qquad (6)$$

r_{ij} and c_{ij} are the slope and intercept of the jth linear element of the ith basin.

Field examples of artificial recharge from basin suggest that the rate of recharge initially increases with time and after attaining a maximum value, it decreases due to clogging of pores canal's bed. When recharge operation is discontinued, the recharge rate tends to approach zero value (Zomorodi, 1991; Detay, 1995; Mousavi and Rezai, 199). Taking into account of such pattern of recharge variation, an example of the time varying recharge due to canal seepage resulting from one cycle of irrigation, as shown in Figure 2 is considered for demonstration purpose. In this case, with the onset of canal irrigation, rate of recharge increases from initial zero value to a maximum value of 0.7m/d at 5th day. Thereafter, irrigation is discontinued. As a result, the recharge rate decreases to 0.2 m/d at a faster rate till 15th day and thereafter with a relatively slow rate, it decreases to zero at 30th day. This time varying recharge rate is approximated by using linear elements of different length and slope. (Manglik et al., 1997, Manglik et al 2006, Rai et al. 2006).

SOLUTION

The above discussed initial and boundary value problem is solved by using Finite Fourier cosine transform. The solution is given as:

$$H(x,y,t) = \frac{1}{AB}\bar{H}(0,0,t) + \frac{2}{AB}\sum_{m=1}^{\infty}\bar{H}(m,0,t)\cos\left(\frac{m\pi x}{A}\right) + \frac{2}{AB}\sum_{n=1}^{\infty}\bar{H}(0,n,t)\cos\left(\frac{n\pi y}{B}\right) \qquad (7)$$
$$+ \frac{4}{AB}\sum_{m=1}^{\infty}\sum_{n=1}^{\infty}\bar{H}(m,n,t)\cos\left(\frac{m\pi x}{A}\right)\cos\left(\frac{n\pi y}{B}\right)$$

where:

$$\overline{H}(m,n,t)=\frac{2a}{K}\left[\sum_{i=1}^{N} g_i(m,n)\left\{\sum_{j=1}^{k-1} S_{ij}-S_{ik}\right\}\right]$$

$$g_i(m,n)=\left[x_{i2}\mathrm{sinc}\left(\frac{m\pi x_{i2}}{A}\right)-x_{i1}\mathrm{sinc}\left(\frac{\mathrm{m}\pi x_{i1}}{A}\right)\right].\left[y_{i2}\mathrm{sinc}\left(\frac{\mathrm{n}\pi \mathrm{y}_{i2}}{\mathrm{B}}\right)-y_{i1}\mathrm{sinc}\left(\frac{n\pi y_{i1}}{B}\right)\right]$$

$$\mathrm{sinc}(x)=\sin(x)/x$$

$$S_{ij}=\frac{r_{ij}}{\alpha}\left[t_{i,j+1}\exp\{-\alpha(t-t_{i,j+1})\}-t_{ij}\exp\{-\alpha(t-t_{ij})\}\right]$$
$$-\left(\frac{r_{ij}}{\alpha^2}-\frac{c_{ij}}{\alpha}\right)\left[\exp\{-\alpha(t-t_{i,j+1})\}-\exp\{-\alpha(t-t_{ij})\}\right]$$

$$S_{ik}=\frac{r_{ik}}{\alpha}\left[t-t_{ik}\exp\{-\alpha(t-t_{ik})\}\right]-\left(\frac{r_{ik}}{\alpha^2}-\frac{c_{ik}}{\alpha}\right)\left[1-\exp\{-\alpha(t-t_{ik})\}\right]$$

$$\alpha=a\pi^2\left[\left(\frac{m}{A}\right)^2+\beta\left(\frac{n}{B}\right)^2\right]$$

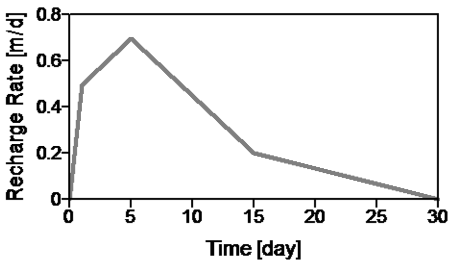

Figure2. The pattern of time varying recharge rate.

Application of this model (eq. 7) in the prediction of spatio-temporal variation of water table in the presence of seepage from canal and pumping would be demonstrated with the help of a synthetic numerical example with the time varying recharge rate shown in Figure 2. The model may be useful for appropriate planning of irrigation and pumping in order to prevent or at least minimize the effect of water logging and soil salinity. It can be also used to verify the results of a numerical model under developing stage.

ACKNOWLEDGEMENTS

Authors are grateful to the Director, NGRI (CSIR) for according permission to publish the extended abstract.

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abstract id: **124**

topic: **5**
Data processing in hydrogeology

5.1
Modelling as a tool of groundwater assessment

title: **Estimation of soil water retention curve parameters by Genetic Algorithm optimization technique**

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keywords: water retention curve, genetic algorithm

INTRODUCTION

Transport of fluids through porous media, is of interest to scientists and engineers. Before predicting transport phenomena in a porous medium, its hydraulic properties (i.e., the water retention and hydraulic conductivity relationships) must be determined. The relationship between the volumetric water content and the soil water pressure can be described with a soil water retention curve (soil moisture characteristic curve) that plots the soil water pressure as a function of the soil water content. Recording the pairs of suction and the corresponding water content of the soil sample the soil water retention curve can be constructed (Hunt, Ewing, 2009).

A genetic algorithm (GA), a popular evolutionary computational method, was used for the optimization process to estimate the soil water retention curve (SWRC) based on van Genuchten model (1980) of soils samples and will be discussed further below.

HYDRAULIC PROPERTIES OF SOILS

The soil water content can be expressed by (θ):

$$\theta = \frac{V_l}{V_t} \tag{1}$$

Where V_l, and V_t be the liquid volume and total volume, respectively. In most hydrologic applications, volumetric soil water content is used in no dimensional form:

$$\theta^* = \frac{\theta - \theta_r}{\theta_s - \theta_r} \tag{2}$$

Conventionally, θ_s is referred to as the volumetric soil water content at natural saturation and θ_r as the residual volumetric soil water content.

MOISTURE CONTENT VS. DEPTH

From the ground surface to the top of the capillary fringe, the saturation ratio increases from zero to unity and will remain so to the bottom of the aquifer. The functional relationship of the moisture content and hydraulic conductivity of the unsaturated profile can be demonstrated by the use of soil-water characteristic curve or retention curve. At very low (negative) values of the pressure head (h), both the moisture content and hydraulic conductivity are at minimal values for the system. With increasing values of h, they increase to become constant at the top of the capillary fringe where the saturation index is unity, indicating full saturation (Fig. 1).

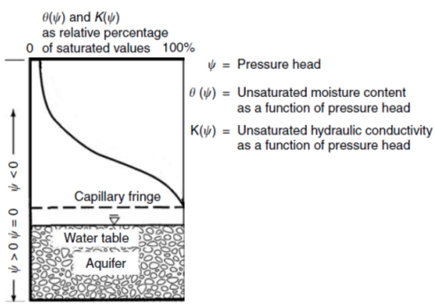

Figure 1. Soil moisture variation depending depth (Delleur, 2004).

SOIL WATER RETENTION MODELS

A SWRC is typically quantified by fitting experimental data to power law, hyperbolic, or polynomial functions (Brooks and Corey, 1946; van Genuchten, 1980). The van Genuchten (1980) model is most commonly used in numerical analyses because it is differentiable for the full range of suctions. Given the saturated, θs, and residual, θr, water contents, the effective saturation Se is defined by:

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} \qquad (3)$$

The following five-parameter van Genuchten function was used to the describe water retention data (van Genuchten, 1984):

$$\theta(h) = \theta_r + \frac{\theta_s - \theta_r}{\left[1 + (\alpha h)^n\right]^m} \qquad (4)$$

Where θ is the soil moisture content (cm^3/cm^3), h is the soil water tension (cm), α, n, m are water retention shape parameters. The water retention shape parameters m and n are frequently related according to:

$$m = 1 - \frac{1}{n} \qquad (5)$$

The α parameter controls capillary rising, while n and m parameters control shape and slope of the curve. Additionally, the van Genuchten SWRC is largely empirical and disconnected from basic soil properties, such as pore geometry and adsorption.

MATERIALS AND METHODS

Several techniques are available to determine the SWRC experimentally. A common test is the pressure plate test (Fig. 2), which involves placing a soil specimen on a high air-entry ceramic plate and applying air pressure to the specimen.

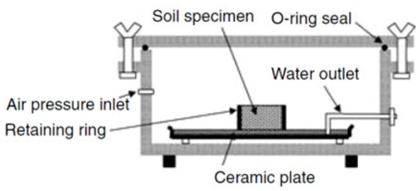

Figure 2. The pressure plate Conventional methods to determine the SWRC (Delleur, 2004).

Soils samples contain 6 soils from the Soil and Water Research Institute of Iran (SWRI) database according to the U.S. Department of Agriculture (USDA) soil textural classification were used to perfume the experimental part (Tab. 1). Retention data were obtained along the main drying curve at tensions of 1, 1.1, 1.33, 2, 3, 5, 10, 15 atm.

Table1. The soils samples used in our Analysis.

Soil type	% Clay	% Silt	% Sand
Loamy sand	6	10	84
Sandy loam	10	25	65
Silt loam	23	54	23
Loam	18	38	44
Sandy clay loam	30	18	52
Clay	57	21	22

GENETIC ALGORITHMS

Genetic algorithms (GAs) were invented by John Holland in the 1960s and were developed by Holland and his students and colleagues at the University of Michigan in the 1960s and the 1970s. Genetic algorithms use computational models of evolutionary processes as key elements in the design and implementation of computer based problem solving systems (Spears et al., 1993). GA has been shown to work well in noisy environments and in complex search spaces.

The GA begins, like any other optimization algorithm, by defining the optimization variables, the cost function. It ends like other optimization algorithms by testing for convergence. Genetic algorithms differ from more traditional search algorithms in that they work with a number of candidate solutions rather than just one or a partial solution (Mitchell, 1999).

A fitness function is designed such that fitness of individuals, or groups of individuals, moves toward an extremum if they carry some desirable traits. If the genes have only two alleles (0s and 1s), the chromosome is called a binary coded chromosome. If the genes are assigned real values, then the chromosome is called a real coded chromosome. Value encoding can be used in problems where values such as real numbers are used. Genetic algorithms start with randomly generating an initial population of possible solutions. The population size is the number of individuals that are allowed in the population maintained by a GA. If the population size is too large, the GA tends to take longer to converge on a solution.

The population is then operated by three basic operators in order to produce better offspring for the next generation. These operators are known as "reproduction", "crossover" and "mutation" (Randy, Haupt, 2004).

Reproduction is a process in which individual strings are copied according to their fitness (Goldberg, 1989). In a crossover operation, one child chromosome is produced from "mixing" two parent chromosomes. Crossover probability controls that how often crossover will be performed. Crossover is made in hope that new chromosomes will contain good parts of old chromosomes and therefore the new chromosomes will be better. This procedure of crossover, mutation and selection is repeated over many generations until some termination criterion is fulfilled.

The fitness function (f) was based on the minimization of differences between measured and calculated water content values ($\theta_{m,s}$) , and ($\theta_{c,s}$), respectively; that is,

$$Cost = Fitness = f = \frac{1}{N}\sum_{s=1}^{N}\left(\theta_{m,s} - \theta_{c,m}\right)^2 \qquad (6)$$

Where n is the number of water content measurements (n = 8).

The genetic algorithms parameters used in this study are listed in Table 2.

An interesting aspect of GA is that the initial population of individuals need not be very good. In fact, each individual of an initial population usually represents a randomly generated candidate solution. By repeatedly applying selection and reproduction, GA produces satisfactory solutions quickly and efficiently.

Table 2. GA parameters used in the model.

GA parameters	Value
Population size	1000
Number of generations	2000
Number of variables	4
Initial range	0–3
Type of genes/chromosomes	real coded
Crossover probability	0.5
Crossover procedure	heuristic
Type of selection	Roulette wheel
Minimum mutation rate	0.1
Maximum mutation rate	0.25

MATLAB MODELLING AND RESULTS

MATLAB is a commonly used program for computer modeling. The MATLAB Genetic Algorithm Toolbox is a collection of functions that extend the capabilities of the Optimization Toolbox. This Toolbox enables you to solve a variety of optimization problems that lie outside the scope of the standard Optimization technique. To use the Toolbox, you must first write an M-file that computes the function you want to optimize. The M-file should accept a row vector, whose length is the number of independent variables for the objective function, and return a scalar value. Our independent variables are van Genuchten model parameters (α, n, m, θ_s and θ_r). Matrix A represents these independent variables.

$$A = \begin{bmatrix} \alpha_{1,1} \ldots n_{1,2} \ldots \theta_{r,1,3} \ldots \theta_{s,1,4} \\ \alpha_{2,1} \ldots n_{2,2} \ldots \theta_{r,2,3} \ldots \theta_{s,2,4} \\ \ldots\ldots\ldots\ldots\ldots \\ \ldots\ldots\ldots\ldots\ldots \\ \ldots\ldots\ldots\ldots\ldots \\ \alpha_{n,1} \ldots n_{n,2} \ldots \theta_{r,n,3} \ldots \theta_{s,n,4} \end{bmatrix} \tag{7}$$

Where n in Matrix A is the number of Population size (n = 2000).

Evolution of the minimum cost of the genetic algorithm, which optimizes van Genuchten model parameters (α, n, m, θ_s and θ_r) appears in Figure 3. The algorithm found the best cost solution 0.007174 in 1000 generations.

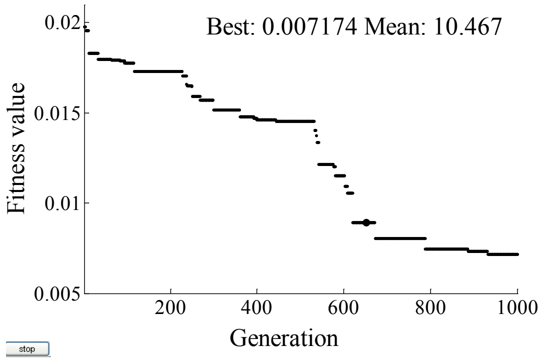

Figure 3. Convergence of the GA for the SWRC parameters optimizations.

On the basis of eqn. (4) we determined the Water retention curve and its parameters for soils samples of Tab. 1. The detailed description of van Genuchten model parameters (α, n, m, θ_s, θ_r) and regression coefficient (R^2) between measured and calculated volumetric water content (θ) values are showed in Table 2.

Table 2. Values of Parameters of water retention curve (α, n, m, θ_s, θ_r) and regression coefficient (R^2) obtained by GA model for soils samples of Table 1.

Soil type	**α**	**n**	**m**	**θ_r**	**θ_s**	**R^2**
Loamy sand	0.046	1.39	0.28	0.012	0.367	0.9966
Sandy loam	0.026	1.41	0.29	0.061	0.285	0.992
Silt loam	0.015	1.81	0.45	0.09	0.245	0.9988
Loam	0.01	1.53	0.342	0.056	0.308	0.9935
Sandy clay loam	0.0061	1.49	0.33	0.076	0.246	0.995
Clay	0.0057	1.81	0.447	0.146	0.546	0.9934

A sample of the experimental water retention curve and the predicted water retention curve for loamy sand sample based on the GA model are showed in Figure 4.

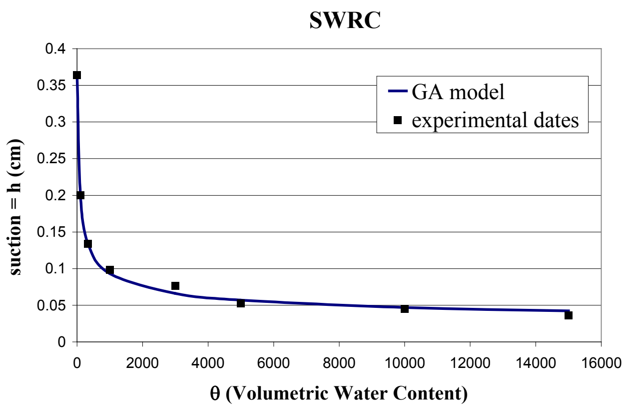

Figure 4. Predicted water retention curves for the Loamy sand soil Sample in Table 1. based on the van Genuchten model.

CONCLUSIONS

A Five-parameter van Genuchten type model was used to describe the water retention curves of our soils sample. In this study, the suitability of using the data driven GA for modeling the water retention curve process in six soils samples was studied. In all cases, GA was able to find the exact solution.

Analysis of the results shows that the increase of clay content in soils samples decreases the α parameter. Additionally, α parameter controls the capillarity phenomenon and n and m parameters controls steep of the SWRC. Results show an increasing value of n and m with increasing percent of fine grains nonlinearly and they have higher values in fine textured soil such as Clay and Sandy clay loam respect to coarser textured soil such as Loamy sand and Sandy loam soils samples. We also observed from the model results that it is not only the three shape parameters (α, n, m) are important, but also the θ_r and θ_s are significant.

ACKNOWLEDGMENTS

The authors wish to acknowledge Prof. A. Zuber for his support. This work was accomplished as part of grant No. N N525 348838 from the Ministry of Scientific Research and Information Technology.

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abstract id: **137**

topic: **5**
Data processing in hydrogeology

5.1
Modelling as a tool of groundwater assessment

title: **Estimating transmissivity from specific capacity for artesian aquifers in the middle Venetian alluvial plain (NE, Italy)**

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keywords: transmissivity, specific capacity, alluvial gravel aquifer, NE Italy

INTRODUCTION

In the northern high Venetian plain a single unconfined aquifer is present and its water table is located at depths of 50–100 m. Further south the water table intersects the topographic level, creating a series of plain springs called "fontanili" and marking the passage between the high and the middle Venetian plain. Downstream from the "fontanili" line the differentiation of the cover determines a multi-layered aquifer system resulting from depositional events of alluvial materials and marine transgressions.

The studied area is located in this middle Venetian plain in the provinces of Venice and Treviso covering an area of about 200 km^2.

Here we have identified 10 superimposed aquifers (from 15 to more 300 meters in depth), and except the first all the other aquifers are artesian with a spontaneous flow.

METHODOLOGY

In order to calculate hydrogeological parameters of these artesian aquifers, we have carried out some pumping tests on private wells (2 inches), both aquifer tests, using a well and a piezometer, and well tests (step drawdown test). In the site where was conducted the aquifer test was always carried out a step drawdown test. All the tests were made using digital manometers to monitoring the potentiometric levels.

During the aquifer tests the potentiometric level variation in time into a piezometer located near the pumping well was monitored, instead during a well test the pressure variation, changing the flow rate, was measured into the pumping well.

Empirical formulas Transmissivity vs Specific Capacity, derived from literature (Christensen, 1995; Razack and Huntley, 1991; Srivastav et al., 2007) and obtained in our similar stratigraphic zone, were considered processing well tests data. Results indicate underestimation of the transmissivities comparing them to the aquifer test results.

Considering the quicker well test respect to a classic aquifer test and the opportunity to execute a lot of well tests, we take into account the necessity to introduce a specific empirical relationship between aquifer and well test in presence of these 2 inches private wells and an essentially gravel composition reservoirs.

The obtained relationship (Fig. 1) come from a correlation on the same site between aquifer tests transmissivity (T) and Specific Capacity, considering only the aquifer loss (Δ) in the well performance equation, obtained by a well tests. It's a linear-type formula: $T = m\, Q/\Delta + b$, where m and b are respectively the angular coefficient and the intercept value, Q is the flow rate and Δ is only the aquifer loss. The regression was calculated by the R code (R Development Core Team, 2009), which is a free software environment for statistical computing and graphics.

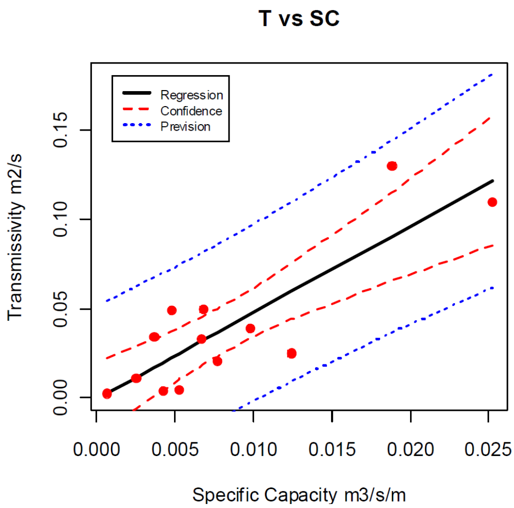

Figure 1. Linear regression Transmissivity vs Specific Capacity.

CONCLUSION

At present this relationships, still under development, presents a good regression coefficient $R^2 = 0.72$ and a residual median of –0.0001469. This experimental relationships is suitable for the hydrogeological characteristics of the middle Venetian plain, where gravel aquifers are present and for the well characteristics drilled in this area (artesian wells with a diameter of 2 inches).

The principal advantage in this relationship is to obtain a plausible transmissivity value performing only a well tests. Thus by a quick and relatively simple test, compared with a more precise but also more complex to execute aquifer test, the transmissivity distribution in a large area can be investigated.

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IAH 2010
Krakow

abstract id: **141**

topic: **5**
Data processing in hydrogeology

5.1
Modelling as a tool of groundwater assessment

title: **The use of numerical model in the Delta Llobregat Aquifer focused in planning and management**

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keywords: management, saline intrusion, simulation, prevention

INTRODUCTION

Llobregat's Delta Aquifers, near the city of Barcelona, are an important water source for urban, industrial and rural uses. Extraction above recharge in the 70's, and the proximity to sea, caused a significant saline intrusion. Increased awareness of the importance of conserving resources combined with worsening water quality lend to a progressive reduction of pumping and consequently an increase of piezometric heads and a decreased rate of seawater intrusion. Unfortunately at same time the recharge of the aquifer through infiltration has decreased due to urbanization and the construction of big infrastructures. Therefore the mass balance continues to be negative. For this reason a hydraulic barrier has been built to impede seawater intrusion, and two recharge basin systems have been built, with a third (the bigest) on the way, to compensate for the reduced infiltration. Presently the two basins systems aren't running yet, although they are ready. A first phase of the hydraulic barrier has been running for two years, at an injection rate less than a 30% of total planned injection, and a second phase is ready to start.

At present the total volume of extractions from these aquifers are approximately 60 hm^3 a year, of which more than 60 % corresponds to water supply companies.

A numerical model of flow and transport of low basin aquifers of Llobregat River was done in 2004 by Hidrogeology Group of Technical University of Catalonia (UPC). The model was built with their own code TRANSIN III (Galarza et al., 1995) at the request of the Catalan Water Agency (ACA) and covers the period of 1965–2005. The objective of this project was an accurate understanding of the hydraulic behaviour of the aquifers taking into consideration management and planning. The Llobregat Delta Community of Water Users (CUADLL) was given that model in order to examine it, update it and improve it as well as to take part in the aquifer's management and planning.

In this way CUADLL has the model ready to be used for different objectives, as needs come up. For example the model has been used to assess the impact of the artificial recharge measures on the aquifer and as a technical support for the Extractions Plan of Llobregat Delta and Low Valley Aquifers (Massana et al.). In this last work, a lineal relationship between recharge (natural and artificial) and extractions has been found, taking into account a sustainable condition to reduce salinity in the aquifer.

From the middle of 2007 through May 2008, the Llobregat basin suffered a serious drought. One of the measures taken against the drought was the recovery of some wells and the increase of pumping. CUADLL became concerned about the likely worsening of water quality from the aquifer. For that reason CUADLL used the numerical model to foresee the consequences of drought on the aquifer, and try to prevent possible problems.

DROUGHT SIMULATIONS

During the drought 2007–2008 of Llobregat basin, Water Agency of Catalonia ordered a set of exceptional emergency measures related to uses of hydraulic resources (Drought Order 84/2007 by Catalonian Administration). In this context and due to limited superficial resources, some of the measures were focussed on the necessity of increasing resources from aquifers. This exploitation had to be done according to the piezometric heads of aquifers. The indicator (N) is defined as the sum of the piezometric heads of five piezometers distributed along Low Valley until Prat de Llobregat (Fig. 1).

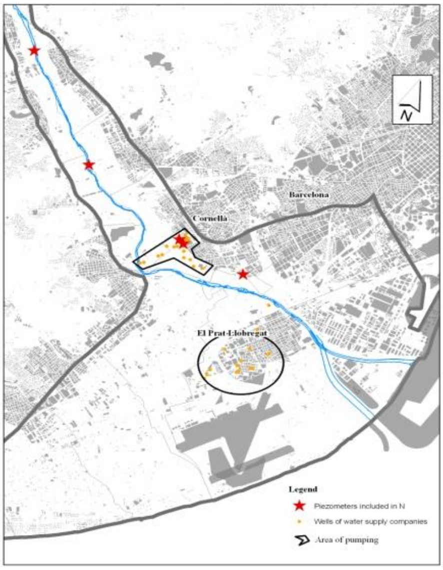

Figure 1. Situation of piezometers included in indicator N, and the water supply companies' pumping areas.

A piezometric state for every month is defined according the value of the indicator N by means of statistical methods, as shown in Table 1. On April 1 2008, N was equal to –20.4, and the aquifer was in State 1, very close to State 2

The Drought Order imposed a volume of extraction for Water Supply Company of Barcelona (SGAB) according to the piezometric state: 2 m^3/s if N corresponding to State 1, 1 m^3/s if N corresponding to State 2, and 0.5 m^3/s if N corresponding to State 3.

Table 1. Threshold values of piezometric state of aquifer by month.

	State 1	State 2	State 3
January	-17	-22	-32
February	-13	-22	-32
March	-12	-22	-34
April	-11	-21	-33
May	-12	-22	-30
June	-14	-24	-30
July	-11	-24	-30
August	-15	-23	-30
September	-12	-23	-29
October	-16	-22	-32
November	-11	-21	-30
December	-14	-19	-27

In this context Cuadll has carried out some simulations by means of the numerical model with the objective of bringing forward the piezometric evolutions.

An update of the model through February 2008 has been done. Figure 2 shows the calculated versus measured piezometric heads of two piezometers. It's important to note that the calculated values are simulated values, not calibrated values.

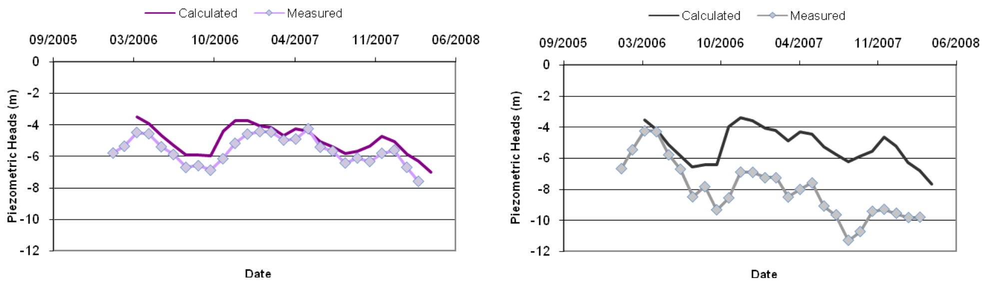

Figure 2. Calculated by simulation versus measured piezometric heads of piezometers Testimoni and Fives Lille. Note that there is a good relationship between simulated values and measures in piezometer Testimoni, and in piezometer Fives Lille only the form of evolution is well simulated.

A desirable relationship between simulated values and measures can be seen at some points. At other points only the form of evolution is simulated, and there are significant in values of piezometric heads. Despite the factor that the model has been shown to give relatively accurate results on a regional scale, on a local scale, its results aren't quite as accurate as we might hope. Furthermore, the model tends to produce results that are less dramatic than reality. Therefore in order to avoid an accumulation of errors some corrections have been carried out to better represent the evolution of simulated piezometric heads.

To continue the simulation from March 2008, the pumping has been changed according the Drought Order standards. The results are shown in Table 2 and Figure 3.

Table 2. Results of simulated indicator N, and the state of aquifer.

	N Simulated	State	Drought Order Pumping (m^3/s)
March	-18.28	1	2
April	-20.99	2	1
May	-23.14	2	1
June	-25.32	2	1
July	-28.28	2	1
August	-30.73	3	0.5
September	-29.74	3	0.5
October	-27.78	2	1
November	-30.15	3	0.5
December	-30.65	3	0.5

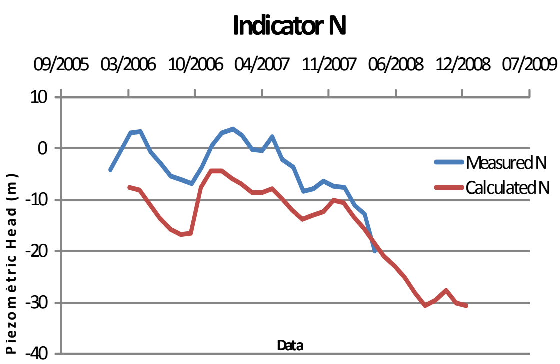

Figure 3. Simulated evolution of indicator N.

According to simulation results, indicator N enters into State 2 in April and, in spite of a reduction in pumping, N continues its fall until it enters into State 3. Then the reduction of pumping according Drougth Order allows ascension out of State 3, but of pumping increases again for just one month more because N enters into State 3 again. We have to be prudent with these conclusions. In fact, due to the model's tendency produces less dramatic results as was mentioned earlier, changes in N in piezometric state can be off by a month or so. This means: simulation results give us a superior temporal threshold of N value.

On the other hand it's important to note that while pumping is $1m^3/s$ N decreases, and while pumps are 0.5 m^3/s N increases. Thus N could be stabilized for pumping between 0.5 and 1 m^3/s. A similar conclusion was reached through other means in a separate project carried out for the Extraction Plan of Llobregat Delta and Low Valley Aquifers.

SUSTAINABLE EXTRACTIONS

The Drought Order is based in restricting pumping according to piezometric heads. In our aquifer, as has been discussed, the main problem is saline intrusion. Therefore the next step to take is the assessment of salinity evolution in application of Drought Order.

During work carried out by CUADLL as technical support for the Extraction Plan of Llobregat Delta and Low Valley Aquifers, a lineal relationship between recharge (natural and artificial) and extractions has been found, imposing a sustainable condition to reduce salinity in the aquifer (Massana et al.). At present, to satisfy this relationship with the current artificial recharge, supply companies pumping should be 50% less than pumps in a normal hydrological year, and much less than pumping of Drought Order for States 1 and 2.

In most of the simulations carried out by CUADLL, taking into account the currents conditions of artificial and natural recharge, and for any volume of supply companies extractions below $2m^3/s$, a division of the aquifer in two areas is possible: an area in which chloride concentration declines relative to initial concentrations, and another in which chloride concentration increases (Fig. 4).

Figure 4. The two areas in which aquifer can be divided due to its improving or worsening of chloride concentration relative to initial concentration.

The first area corresponds to where the most important industries, especially the supply companies, are located. The second area is located near the sea, and its initial concentrations in its control points are quite high yet. Note that there is a small zone in the middle of the second area that corresponds to the surrounding of current hydraulic barrier.

In this context, the idea is to change the sustainable condition to manage the aquifer in the short term while the artificial recharge isn't fully implemented.

So the question is: at what level should supply companies' pumping be set at in order to ensure that the final chloride concentration at the end of simulation is less than 400 mg/L (recommended chloride concentration in our aquifer)? Five simulations over forty years have been carried out to answer this question: supply companies pumping equal to 20 hm^3/year, 30 hm^3/year (the normal scenario), 40, 50 and 60 hm^3/year. Note that last simulation corresponds to maximum extractions as stipulated Drought Order. The results of these simulations are summarized in Figure 5 where three areas are defined:

- Blue zone: chloride concentrations are less than 400 mg/L for any volume extraction. In other words, this zone fulfills the recommended chloride concentration with pumping of State1.
- Red zone: chloride concentrations are over 400 mg/L for any volume extraction. This zone, at present conditions, never fulfills the recommended chloride concentration. Fortunately the second step of hydraulic barrier is coming soon, and the previsions are that the eastern area of delta will improve (as we have assessed by means of simulations as well, in other projects).
- Green zone: chloride concentrations are less than 400 mg/L when volume extraction is less than the indicate pumping beside the points in the figure. Note that there are maximum volumes that don't correspond to any simulation. That is because the final concentration is not exactly 400mg/L. Another division of blue zone is done: a subzone that fulfills the recommended chloride concentration with pumping of State 2 (pale green), and the other that fulfills the recommended chloride concentration only with pumping of State 3 (Dark green).

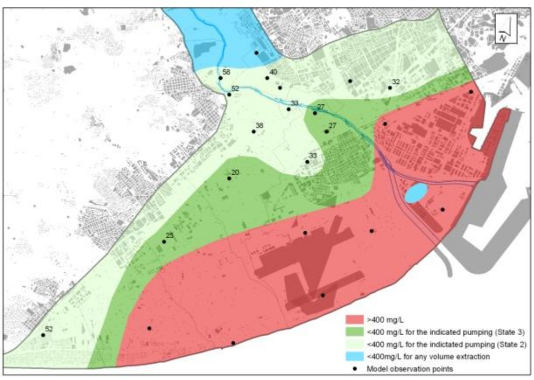

Figure 5. Aquifer can be divided according to the final chloride concentration: blue area in which chloride concentrations are less than 400 mg/L for any volume extraction; red zone in which chloride concentrations are over 400mg/L for any volume extraction; and green zone in which chloride concentrations are less than 400 mg/L when volume extraction is less than the indicate pumping beside the points.

Figure 5 gives us an idea of the consequences of variation of supply companies' pumping. In fact the indicate extraction beside the points shows the maximum extraction volume, that over this value, the quality water in each point tends to have values over the recommended value. The following conclusions could be deduced from Figure 5: only one area of Water Supply Companies fulfills the recommended chloride concentration for any pumping; and a huge area of Delta will be more than 400 mg/L with currents extraction (normal scenario, 30hm^3/year for supply companies pumping). Thus it's important to be conscientious of extractions in periods of drought as well.

CONCLUSIONS

According to simulation results, indicator N could be stabilized for pumping between 0.5 and 1 m^3/s. As earlier discussed, a similar conclusion was reached through other means in a separate project carried out for the Extraction Plan of Llobregat Delta and Low Valley Aquifers, where pumping, with a imposed sustainable condition to reduce salinity in the aquifer, is little higher than 0.5 m^3/s. Therefore the model would be use to correct or strengthen the method of N indicator and pumping according to the piezometric states, taking into account the evolution of salinity levels.

Due to the behaviour of the model in dramatic situations, simulation results give us a superior temporal threshold of N value.

With current artificial and natural recharge, only one area of water supplies companies pumping fulfills the recommended chloride concentration for any pumping. And with currents extraction (normal scenario) as well, it can observed that in some areas there is an improvement in chloride concentrations, but a huge area of Delta will have chloride concentrations above the recommended level (400 mg/L), or even a decline in water quality. Furthermore, the map of Figure 5 is an important management tool because it shows where water quality fulfills the recommended level and where not at a specific extraction volume.

Therefore at current extraction and artificial recharge, there is a huge area of delta whose quality water is not improving. Thus the European Water Framework Directive in this aquifer won't be fullfilled. Furthermore, as seen, in drought situations extractions may even increased. Fortunately, the second phase of hydraulic barrier is starting, and two of the three systems basins are ready to work. Thus it's very important to implement the planned artificial recharge as soon as possible.

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IAH 2010
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abstract id: **152**

topic: **5**
Data processing in hydrogeology

5.1
Modelling as a tool of groundwater assessment

title: **A novel approach to groundwater model development**

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keywords: modelling, mapping, uncertainty

INTRODUCTION

The hydrogeologic conceptual model is a key source of uncertainty in predictions of groundwater flow. This is however an area of uncertainty that is frequently unaddressed in model analysis, while say parameter uncertainty is explored. In part this has been due to the availability of tools, like PEST (Doherty, 2005), that ease parameter uncertainty analysis. Another problem that hinders the exploration of geological uncertainty is the time required to develop alternative conceptual models.

We present a method that addresses the key issues that hinder the development of multiple competing conceptual models: the methodology facilitates the creation of multiple conceptual models; and by accessing modern IT methods it facilitates the model building process by increasing transparency and speed of development.

We show how hydrogeological models can be created from the 3 and 4-dimensional data sets using Radial Basis Function (RBF) models. We develop RBF models for the components in a hydrogeological model: aquifers, aquitards, boundaries, drains, and rivers. This approach has significant advantages. Firstly, the models are consistent with the known data and can be automatically updated when new data comes to hand. Secondly, the models can be influenced by both the choice of high level parameters such as anisotropy while maintaining consistency with the data. Thirdly, the user can add manual interpretations (trends or a priori information) that are maintained separately from measurements, but are then merged in the model building process to produce a model consistent with both measured and interpreted data. Once created, the model can be isosurfaced or gridded at any resolution or fitted to any mesh, a process that provides a flexible interface to flow simulators.

RADIAL BASIS FUNCTIONS

The equations used to represent hydrogeological system elements are developed by fitting RBF's to the data set. RBF's are well established set of methods used in scattered data interpolation, signal processing and artificial intelligence methods. RBFs are real valued functions defined as:

$$y(x) = \sum_{i=1}^{N} w_i \, \phi(\|\boldsymbol{x} - \boldsymbol{c_i}\|)$$

Where, c is the ith center, $\boldsymbol{x}$ is locations in space (or space-time), w is a weight and function ϕ can be any one of a number of functions but typically is either, gaussian, quadratic, or a type of spline function. We apply a polyharmonic (thin-plate) splines function for ϕ. The key factor in the application of a RBF is the determining the weights w_i associated with centers $\boldsymbol{c_i}$, which is a straight forward optimization problem.

DATA MODEL

Today a huge amount and a wide variety of data are collected for hydrogeological problems. To develop a complete understanding of the system it is necessary to integrate all of these data into the analysis. Figure 1 shows a simplified example of the data that can be used in Hydro in the development of a conceptual model for a hydrogeological system.

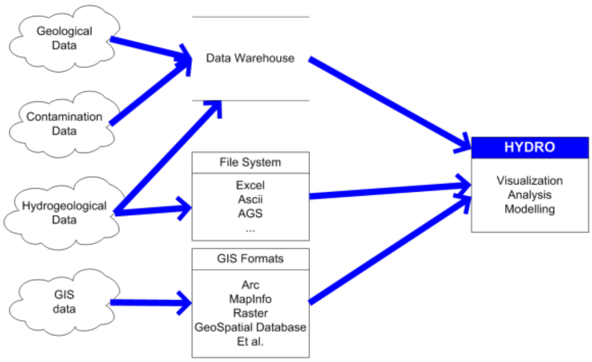

Figure 1. RBF's are used to describe geological units as bodies, the method ensures the entire subsurface is described.

An example of the type of analyses that Hydro can carry out is; geophysical data can be isosurfaced for a specific value (e.g. 20 ohm-m for a clay horizon) which can then be combined with well log data to define a contact surface.

CONSTRUCTING GEOLOGICAL MODELS

The data used to develop hydrogeologic conceptual models include geologic sample descriptions, interpretations of geophysical data, geochemical information et al. Frequently there is insufficient information to fully describe the hydrogeology without considerable interpretation from an expert. Existing methods for capturing this expert knowledge rely on solely manual interpretation of hydrogeological structures. This procedure is time consuming, difficult to update and also makes it difficult to maintain alternative interpretations of the hydrogeology. The methodology automatically captures data based geological contacts (Figure 2). Furthermore, the methodology documents in a clear manner the interaction of data versus manual interpretation.

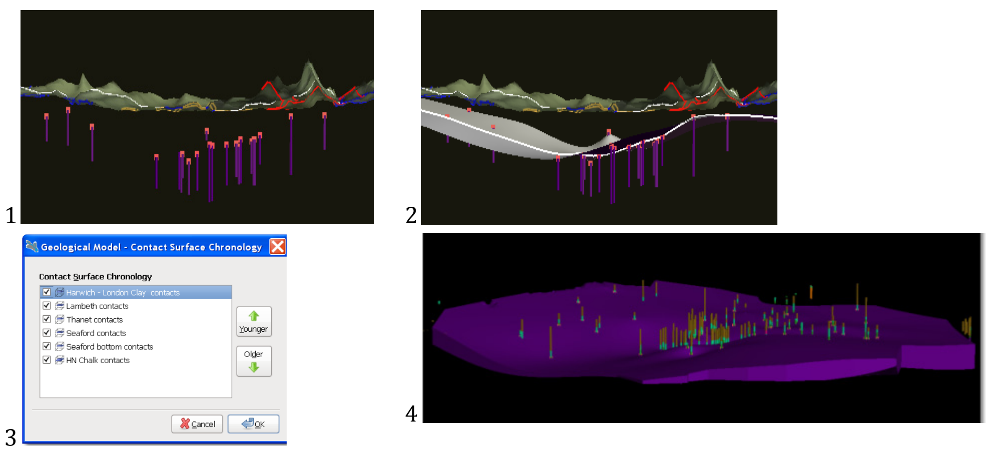

Figure 2. Process in developing a geological model (1→2→3→4). The user defines a set of contacts (Hydro can automatically extract these from well logs), a surface is fitted and put into a stratigraphic order, and finally a volume is created. The contact points are selected using database technology.

We show how hydrogeological models can be created directly from the 3 and 4-dimensional data sets using Radial Basis Function (RBF) models (Figure 3). We can develop RBF models for all the components in a hydrogeological model: aquifers, aquitards, boundaries, drains, and rivers. This approach has three significant advantages. Firstly, the models are consistent with the known data and can be automatically updated when new data comes to hand. Secondly, the models can be influenced by both the choice of high level parameters such as anisotropy while maintaining consistency with the data. Thirdly, the user can add manual interpretations (trends or a priori information) that are maintained separately from measurements, but are then merged in the model building process to produce a model consistent with both measured and interpreted data. The method is not restricted to simple layer based geological structures (Figure 5).

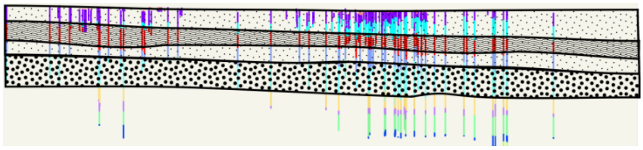

Figure 3. RBF's are used to describe geological units as bodies, the method ensures the entire subsurface is described.

DJURSLAND AQUIFER SYSTEM

In Djursland, Denmark a series of glacial and postglacial sediments lie on top of an erosion surface which consists of chalk. The glacial sediments have been partially reworked by subsequent glaciations and Quaternary sedimentation. The result is a far more complex geological setting than what is seen in the previous example. Here we have non-layered geology (till complex) resting on an erosion surface (Table 1). The main hydrogeologic issue in the region is quality degradation due to nitrates.

Table 1. Hydrogeology for the djursland aquifer system.

Formation	Environment	Type	Chronology
Postglacial sediments	***Various***	***mainly aquitards***	***youngest***
Till	***Glacial***	***Aquitard***	***same***
Sands and gravels	***Glacial***	***Aquifer***	***age***
	Erosion surface		
Chalk	***Marine***	***Aquifer***	***Oldest***

The data for the development of the hydrogeologic framework are 3851 well logs of varying depth. In addition to the well logs there is a digital elevation model and groundwater chemistry data. It is very time consuming if one is to group formations by hand for 3851 well logs, though one can learn by inspecting cross-sections and from experience, which formations are hydrogeologically similar. Our knowledge extraction process quickly resolves the hydrogeological formations at the site.

The hydrogeologic problem is to define sand and gravel aquifers and specifically identify where there is good groundwater protection, i.e. thick tills overlying sand and chalk. The upper 10–30 meters of the chalk is a fractured aquifer, regardless of the type of chalk. The geology is simplified into hydrogeological formations in the following manner: tills and silts and other fine grain sediments form one hydrogeologic formation; while sands and gravel form a second formation; finally chalk formations are placed into a 3rd formation. The surface between chalk and the other formations is defined as an erosion surface.

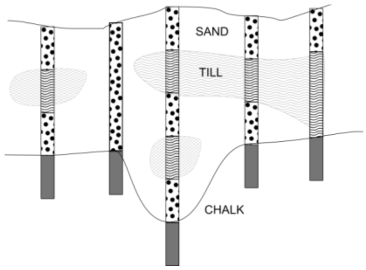

Figure 4. Conceptual problem in the Djurs hydrogeology.

Figure 4 shows the conceptual problem that is solved in the Djursland hydrogeology; that is we have a non-layered system overlying a layered system. The proposed method is ideal to addressing this type of problem because the RBF based model is not constrained to a layered system.

Another problem that needed to be addressed here is that as Djursland is a peninsula, there are no wells to the north and south. This causes a problem with the chalk surface as most interpolation routines will result in the chalk being exposed in the fjords north and south of Djursland. However, the addition of dip points just off shore for the erosion surface "forces" the chalk surface deeper, as we know is the case from wells north of the fjord.

Since an RBF is a function; once created, the model can be isosurfaced or gridded at any arbitrary resolution or fitted to any mesh or grid, a process that provides a flexible interface to flow simulators. This does not require re-fitting the data and interpretations, as opposed to say a Kriging approach that would require re-solving the Kriging equations if new grid resolution was chosen.

Hydrogeologic parameters are assigned to geological units and transferred to gridded models by the application of scaling relations. The long term goal is to develop models that can be more easily refined, either coarser or finer, without significant loss of simulation accuracy.

The method is implemented in a novel 3D user interface and is demonstrated on data from New Zealand and Europe.

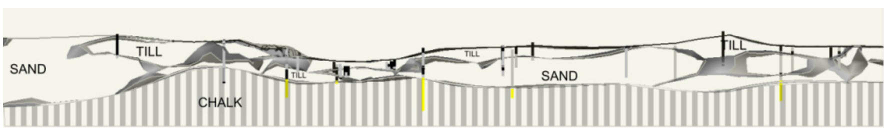

Figure 5. The method is not restricted to describing continuously layered systems.

CONCLUSIONS

We have presented a methodology that can be applied to develop hydrogeological models in complex hydrogeological systems. We believe the method shows advantages in extracting knowledge from the data and developing grid free hydrogeological models. The method also shows advantages in clearly indicating knowledge that comes from data versus expert opinion/a priori knowledge.

A significant part of the advantage with the method is how it is employed in the implementtation and is experienced carrying out the work flow in developing a hydrogeological model as well as in the collaboration between the geologist and hydrogeologist. This is difficult to demonstrate in a technical article.

The method was illustrated for an example one from Denmark. This example shows advantages in modeling non-layered aquifer systems.

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abstract id: **255**

topic: **5**
Data processing in hydrogeology

5.1
Modelling as a tool of groundwater assessment

title: **Stochastic simulation of geological heterogeneity for mapping catchment recharge**

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keywords: recharge, stochastic simulation, till

Quantifying recharge to aquifers that are overlain by glacial sediments presents two problems. First, detailed knowledge of the spatial pattern of the different glacial lithologies is not generally available. Second, recharge in these areas is not solely due to vertical flows from the soil zone to the underlying aquifer: lateral flow can occur within the subsurface above low permeability tills, producing significant recharge at the till edge. Where the low permeability till distribution is patchy, as observed across parts of the UK, it becomes more difficult to map the spatial distribution of lithologies and more important to estimate lateral flows. These two factors contribute to uncertainty in both the spatial and temporal distribution and magnitude of recharge. An approach based on stochastic modelling of the distribution of Quaternary glacial sediments is adopted to investigate uncertainty in recharge due to limited geological knowledge (Thatcher, 2008). This approach is tested for the Tern Catchment in Shropshire, UK for mapping catchment recharge to a till and outwash covered aquifer.

Stochastic simulation has been used to produce alternative maps of the Quaternary geology that overlies the regional sandstone aquifer in the Tern Catchment. In this catchment, the Quaternary geology comprises lodgement till and glacial outwash with limited areas of glaciolacustrine clays and, adjacent to the Tern river and its tributaries, fluvial deposits. Existing borehole and geophysical data that are available over the catchment were used to create a deterministic model of the Quaternary geology by the British Geological Survey. The same data were used to quantify the geostatistical model and condition the generated realisations of the outwash and till. An indicator simulation method was used to model the presence or absence of both till and outwash; catchment maps of both deposits are produced by overlaying an outwash realisation on top of a till realisation (Fig. 1).

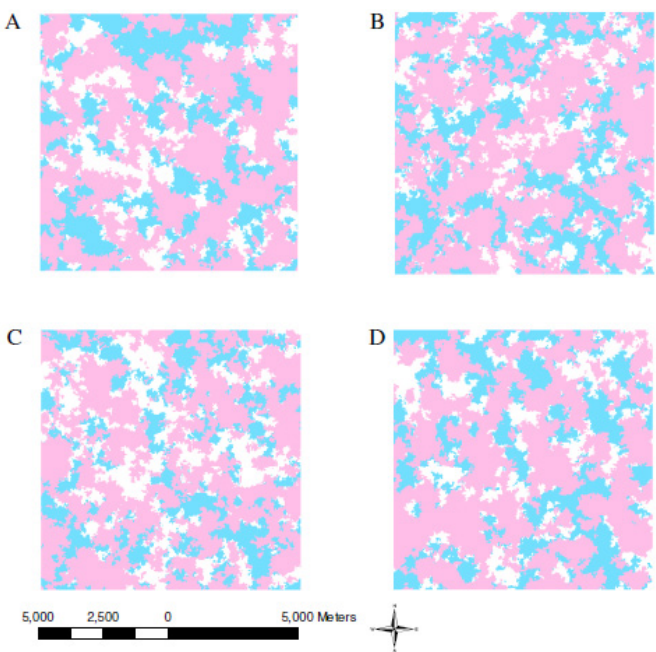

Figure 1. Four geostatistical realisations of till (blue) and outwash (pink) outcrop distribution in the Tern Catchment.

Areas of outwash overlying till are locations where sub-surface lateral flows above the buried till can occur. Lateral flows over buried till will impact aquifer recharge most significantly if the till is discontinuous, allowing lateral flow to become vertical at the till edge and contribute to the recharge of the underlying sandstone (Fig. 2). Such locations are termed "high recharge edges" in this work.

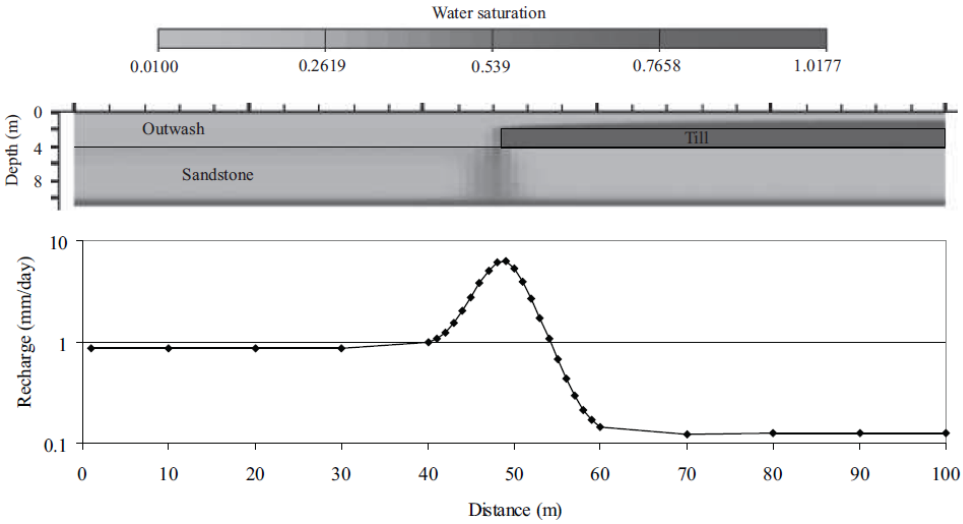

Figure 2. Moisture content for 2D profile orthogonal to the till edge and corresponding recharge to the sandstone aquifer.

The borehole data were also used to produce summary statistics on outwash thickness and the shape of the upper till surface across the catchment. Two-dimensional unsaturated zone flow simulations based on these summary statistics were used to estimate the magnitude of recharge along transects orthogonal to the till edge. Using a simple upscaling rule, these two-dimensional estimates were used to create maps of the spatial distribution of recharge to the aquifer for the distribution of glacial material generated in each realisation.

The resulting map of recharge distribution shows high spatial variability in recharge across the catchment and significant uncertainty in the location of "high recharge edges". "High recharge edges" are narrow zones, less than 20m wide and recharge is an order of magnitude higher than in adjacent areas not covered by till. The amount of recharge at the till edge is strongly dependent on exchanges of water at the soil/vegetation surface and on the thickness of outwash overlying the tills. As moisture content at the till edge is higher than surrounding areas throughout the year, relative permeability is higher in this location and recharge reaches the water table faster (Fig. 3). Around 25% of the recharge to the catchment arises at "high recharge edges", which account for less than 5% of the total catchment area.

The difference in recharge estimates for different geostatistical models is small (mean = 192mm/year, range 170-209mm/year), particularly in comparison with recharge estimated using the deterministic geological model (144 mm/year), which is not within the recharge limits defined by the stochastic models (Fig. 4).

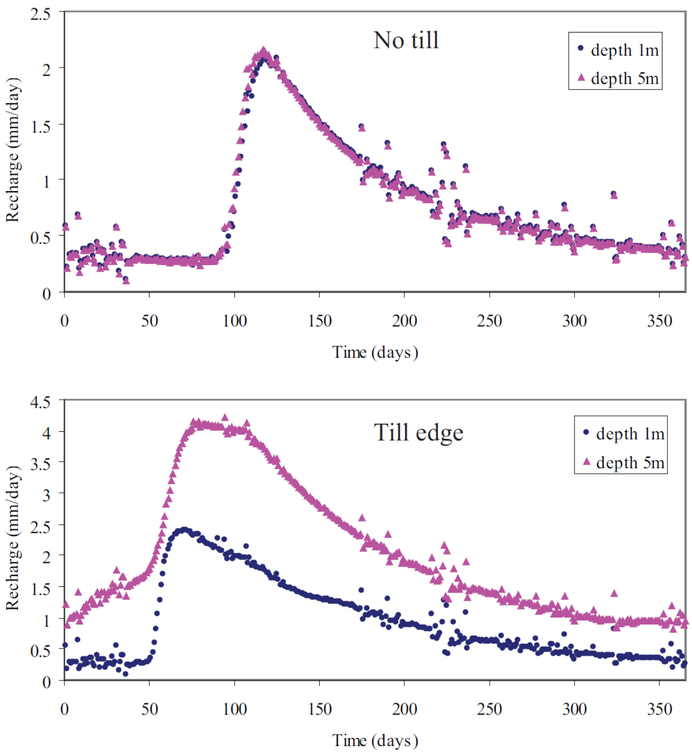

Figure 3. Timing of recharge for 2 till depths showing the early arrival of recharge signal at the recharge edge compared to locations away from till.

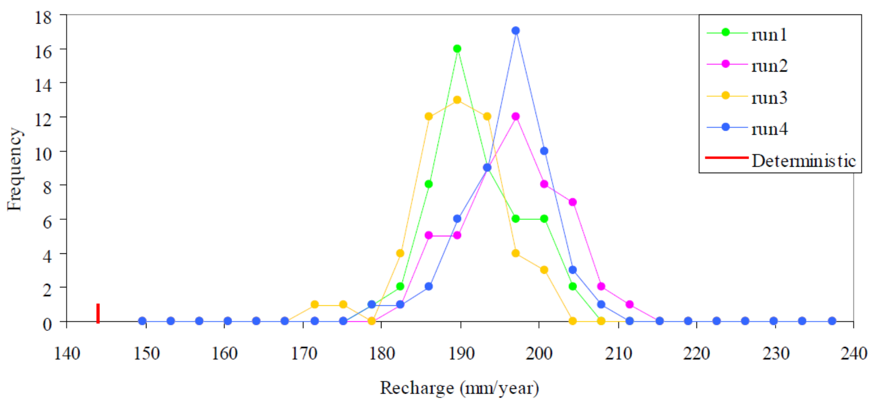

Figure 4. Total catchment recharge from 200 stochastic realisations and the deterministic model. Stochastic realisations are grouped into 4 runs according to slightly different variogram models used for both till and outwash distributions.

The geological realisation produced by deterministic modelling is much smoother than the stochastic realisations with fewer "high recharge edges" and only 5% of catchment recharge occurring in these zones. This implies that there is bias either in the deterministic model or the geostatistical model, but the available data do not allow us to determine which is more correct as both models fit the observations. The uncertainty in the spatial distribution of till and outwash leads to significant uncertainty in the predicted magnitude and spatial distribution of catchment recharge.

The relationship between catchment recharge and atmospheric variables, precipitation and evapotranspiration, is moderated by lateral flows within sediments above the groundwater table. These lateral flows are strongly dependent on the three-dimensional distribution of Quaternary deposits, resulting in a non linear relationship between recharge and atmospheric conditions. This is particularly significant for prediction of future recharge under climate change scenarios, where a simple scaling of catchment recharge with precipitation or evapotranspiration will not be appropriate.

By using stochastic simulation to produce possible conditional realisations of the Quaternary geology in the Tern Catchment, we have been able to build an understanding of the likely spatial distribution of recharge. The results confirm that geological knowledge is limiting accurate prediction of the location of "high recharge edges" but that these zones are crucial to the catchment water balance.

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abstract id: **257**

topic: **5**
Data processing in hydrogeology

5.1
Modelling as a tool of groundwater assessment

title: **Ljubljana polje aquifer heterogeneity, modelled with transition probability geostatistics**

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keywords: transition probability, geostatistics, hydrogeology, Markov chain, Slovenia

Heterogeneity of the aquifers is one of the key factors that control transport processes in groundwater. It is defined by the spatial distribution of hydofacies-sediments formed in characteristic depositional environments and have typical hydrogeological properties. Due to the (in time and space) changing sedimetological conditions, is the distribution of hydrofacies in nature often complex and difficult to define. The difficulty of this procedure most often limits reliability and consequently applicability of numerical transport models.

Ljubljana polje aquifer is highly productive intergranular aquifer which is the main water resource for supply of city Ljubljana with drinking water. In consists of up to 100 m alluvial sediments, deposited in Pleistocene. As a basis for improvement of reliability of hydrological model of the aquifer, hydrogeological model was constructed. It is based on the borehole logs, supplemented with geological conceptual information and geostatistical methods, combined with Markov chain models (Carle, Fogg, 1996, 1997; Carle, 1999). A set of 258 borehole logs (Fig. 1, 2) with 6,422 m of log description was used.

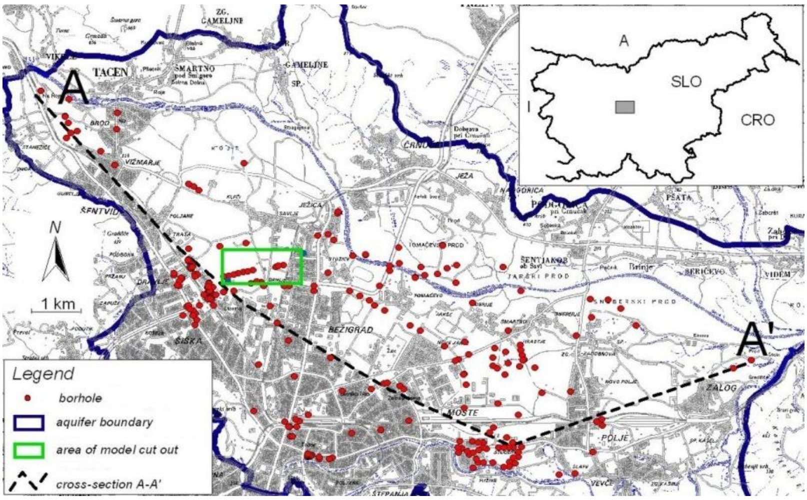

Figure 1. Study area with locations of the boreholes, area of presented model (Fig. 3) and cross-section (Fig. 2) (Janža, 2009).

Lithological descriptions were classified into four units — hydrofacies with different volumetric portions (Gravel 45%, Silt and clay with gravel 36%, Silt and clay 5% and Conglomerate 14%). Transition probability and Markov models were determined from the logs which were discretized into 1 m increments. With the procedure based on software TPROGS (Carle, 1999) a set of equally probable realisations of spatial distribution of hydrofacies that are conditioned to the borehole data and represent geologically plausible image of the heterogeneity of the aquifer were developed (Fig. 3).

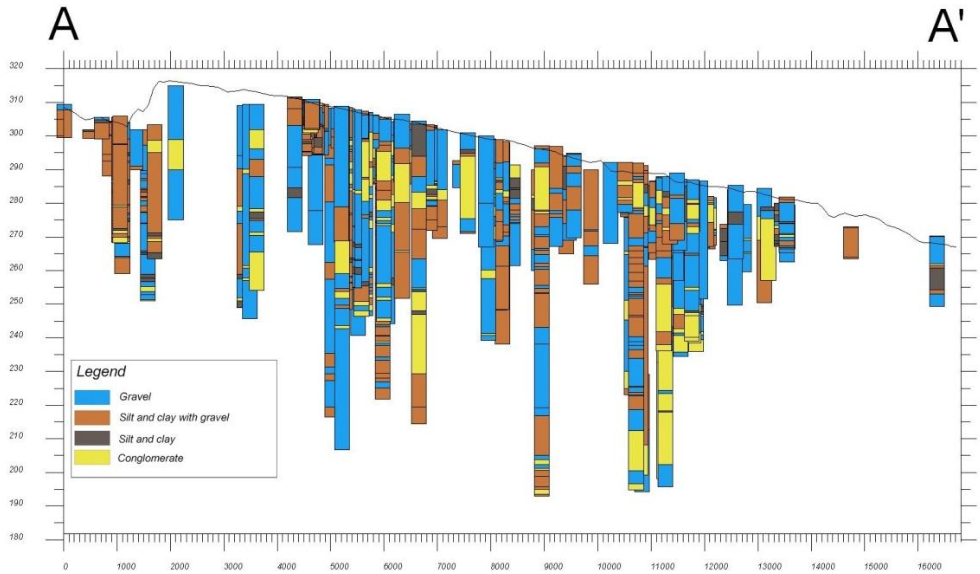

Figure 2. Boreholes in cross-section.

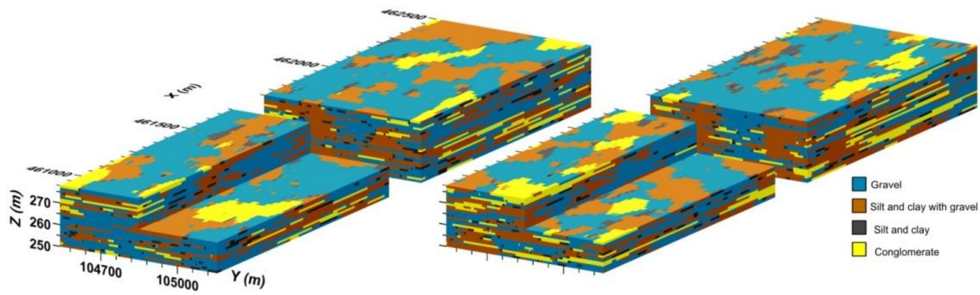

Figure 3. Parts (Fig. 1) of two realisations of geostatistical hydrogeological model of Ljubljana polje.

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abstract id: **282**

topic: **5**
Data processing in hydrogeology

5.1
Modelling as a tool of groundwater assessment

title: **New approach to characterize a contaminant area and to investigate about the source of pollution: a case study in Province of Treviso, Northeast Italy**

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keywords: unconfined aquifer, contamination, perchlorethylene, passive sampling, integral pumping test

In the Municipality of Arcade (Treviso Province), since 2002 (first monitoring year) there has been knowledge of a persistent contamination of perchlorethylene (PCE) in a private well. The concentration has been around 30–40 μg/L and the trend has been constant until now, without other evidence in nearby wells.

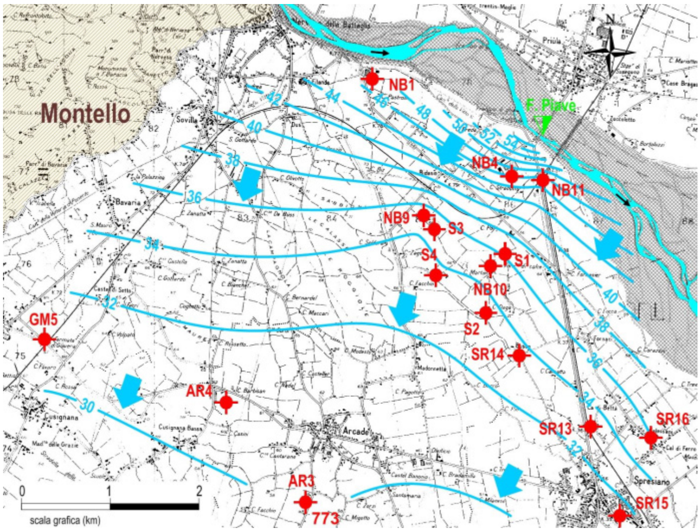

Figure 1. Hydrogeological map of the study area.

The study area is located in Veneto alluvial plain (Fig. 1) and is characterized by sandy gravel alluvium deposits with high values of hydraulic conductivity (10^{-1}–10^{-3} cm/s) where an unconfined aquifer exists (groundwater depth = 20–30 m below ground level). Locally there are some aquitards composed by silty–clay layers or cemented gravel.

In 2009 the site became a pilot site for the European project FOKS (Focus on Key Sources of Environmental Risks) and this paper focus on some new tools and strategies developed by recent researches here applied.

The project deals with the detection of the source of contamination that produced the groundwater pollution and with tries to determine priorities and investigative methods for remediation. The main objective of this initiative is finalizing a method of approach and characterization of remediation for the polluted freatic aquifer, which will allow to focus on main sources of contamination even through the use of new tools and a risk management system. In the study area the investigations consist of using innovative techniques like Integral Pumping Test (IPT) or Passive Sampling to elaborate a conceptual model of the site, by mean of the flow and transport modelling.

The integral groundwater method is used for the quantification of contaminant mass flow rates. In this approach, pumping wells is positioned along planes perpendicular to the groundwater flow direction and work for a certain interval of time and sampled for contaminants. The concentration time series of the contaminants measured during operation of the pumping wells are then used to determine contaminant mass flow rates, average concentrations and the plume shapes and positions at the control planes. The zones emitting the highest PCE mass flow rates could be determined, representing the areas where additional investigation and remediation activities will be needed.

In order to optimize the research planning , the proposed approach has been differentiated in three scale field which correspond to more exhaustive surveys: the underlying scheme (Fig. 2) shows the activities managed within the project.

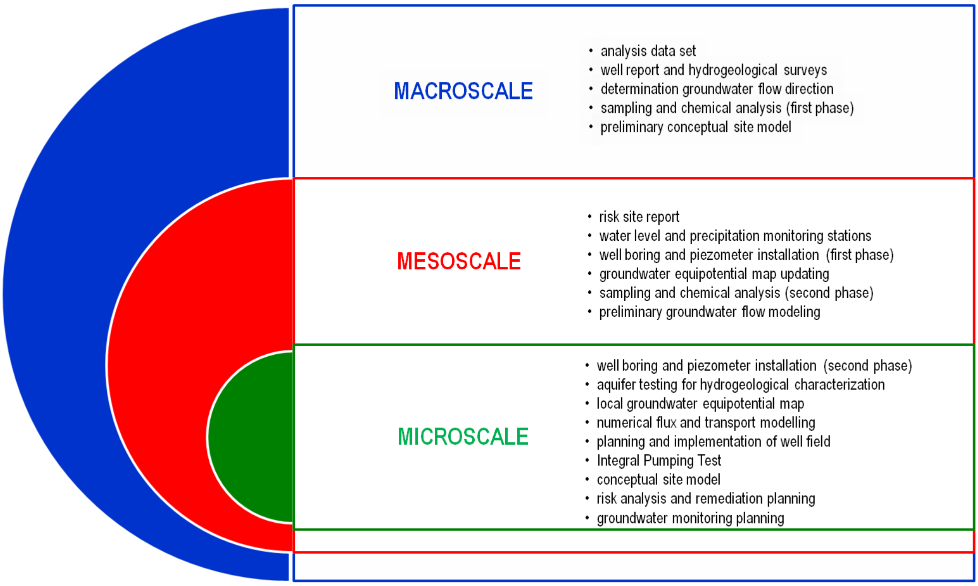

Figure 2. Survey preliminary schedule.

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abstract id: **302**

topic: **5**
Data processing in hydrogeology

5.1
Modelling as a tool of groundwater assessment

title: **Application of GIS techniques for determining suitable areas for managed aquifer recharge in the lower Ping-Yom river basin, Thailand**

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keywords: application of GIS, managed aquifer recharge, Lower Ping-Yom River Basin

ABSTRACT

Due to the year-round high water needs for growing rice in Thailand, farmers are drawing heavily upon the groundwater from the shallow aquifers located in the alluvium and alluvium fan deposits of the Ping - Yom River Basin. The average groundwater level has declined to about 7 to 10 meters below the ground surface; levels that are considered critical for pumping by farmers. The Department of Groundwater Resources, Thailand realizes that subsurface storage of some of the seasonally abundant surface water resource into the aquifers may be useful for the farmers and for restoring the water balance of the groundwater basin. Managed Aquifer Recharge (MAR) using ponding methods of recharge may be one of the cheapest method of recharge, and is proposed to be applied within this area. Therefore the objective of this study is to determine the suitable areas using MAR-based ponding systems. There are four significant groups of parameters to consider for selecting areas suitable for MAR, namely hydrogeology, geomorphology, soils, and slope. Thematic layers for all information were classified, weighted and analyzed by a Geographical Information System (GIS) using ArcGIS software. Weighted Index Overlay Analysis (WIOA) is used for the selection of potential MAR areas. Finally suitability of the integrated classes for artificial recharge is identified as (a) very suitable, (b) suitable, (c) moderately suitable, and (d) unsuitable. The result of the study indicates that about 1,900 km^2 (9%) of the study area is considered as very suitable for MAR. It is recommended that more detailed subsurface investigations be performed in order to validate the GIS approach.

INTRODUCTION

Extensive use of shallow groundwater for rice growing in the Lower North Region River Basin of Thailand has caused groundwater levels to decline from 1-2 m below ground surface in previous decades to 7-10 m at the present time. Artificial recharge is an effective technique for the restoration and augmentation of groundwater resources. Ponding systems may be one of the simplest and cheapest methods of artificial recharge, and is proposed to be applied to raise the groundwater levels within this area. The objective of the study is to identify the most suitable areas for managed aquifer recharge (MAR) using ponding system by application the Geographic Information Systems (GIS) techniques.

The study area is located in the Lower North Region River Basin, Thailand. It occupies three provinces, namely, Sukhothai, Pichit and Pitsanulok (Fig. 1) covering an area of about 21,312 km^2.

Geographically, the western part is located in the Yom river basin, whereas the eastern part is a part of the Nan River basin. Northern and northeastern part has high topography (up to 2,102 meters above sea level) at Phu Soi Dao, Amphoe Chat Trakan, Pitsanulok Province) and gradually flattening terrain in the central part with an average elevation of 33-46 m above MSL. The average temperature is about 28°C, the annual rainfall and potential evaporation are about 1,350 mm and 1,200 mm respectively.

The study area is underlain by thick sequences of unconsolidated rocks in the central part and igneous and sedimentary rocks in the north and northeastern sediments (Department of Mineral Resources, 1983, Figure 2).

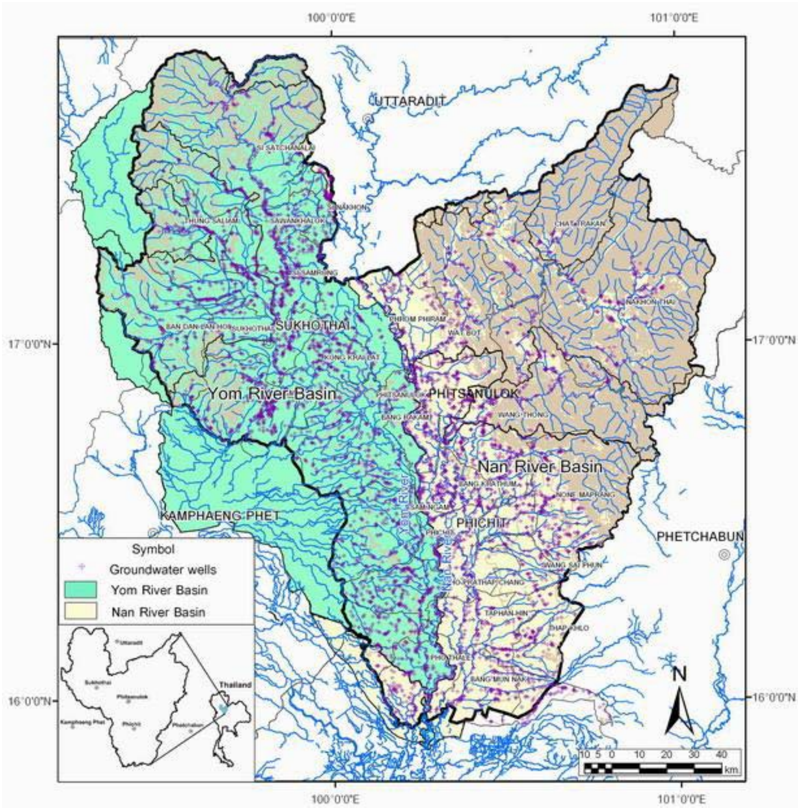

Figure 1. Location of the study area, the Lower North Region River Basin, Thailand (Department of Groundwater Resources, 2009).

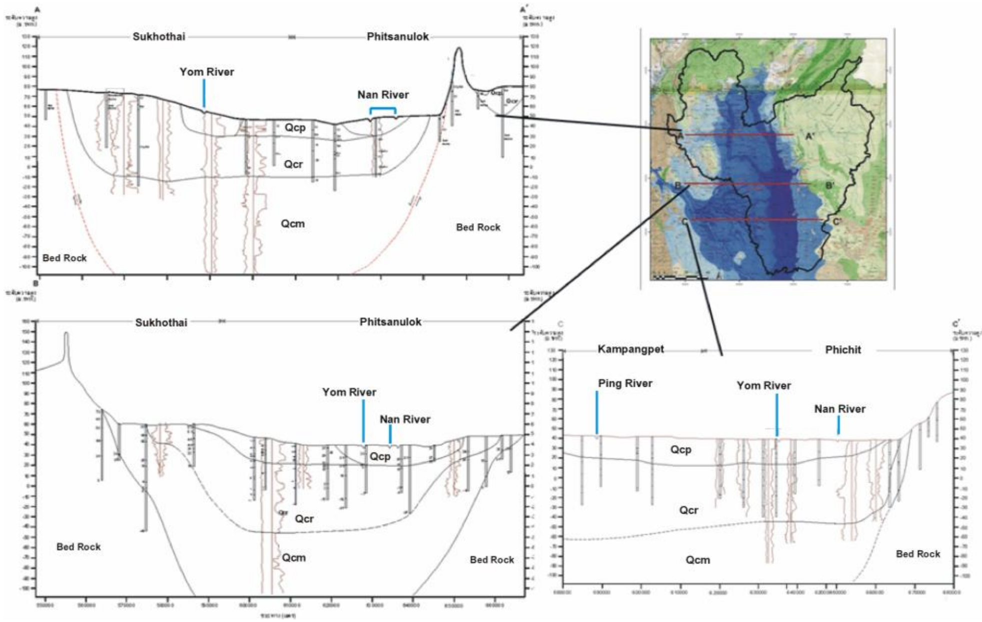

Figure 2. Hydrogeological map of the Lower North Region River Basin (modified from Department of Mineral Resources, 1983.

The unconsolidated sequence consists of (1) Recent flood plain deposits (Qfd) or Chao Phraya Aquifer (Qcp); consisting of sand and gravel interbeded with clay; with an average thickness of about 0- m and well yields ranging from 15-2 m^3 hr (2) Low terrace deposits (Qlt) or Chiang Rai Aquifer (Qcr) consisting of clay, silt, interbeded with sand and gravel (10-60 m thick) and well yields ranging from 15-20 m^3 hr , (3) High terrace deposits (Qht) or Chiang Mai Aquifer (Qcm) consisting of gravel, sand, and rock fragment with well yields ranging from 30-50 m^3/hr. The consolidated rocks are mainly limestone; interbeded with shale and sandstone with well yields ranging from 2-5 m^3/hr and metamorphic and Igneous rocks with well yields ranging from 1-5 m^3/hr.

METHODOLOGY

In determining the areas most suitable for MAR, there are four main groups of parameters to consider, namely geology, geomorphology, soil, and slope which are compiled and analyzed as a thematic derivative maps as shown in Figures 3 to 6.

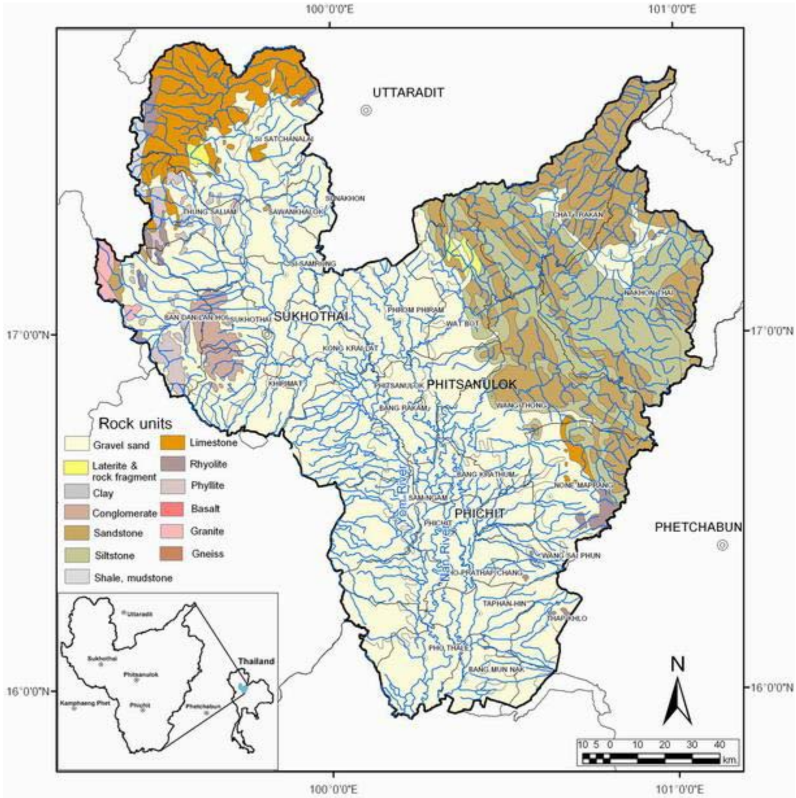

Figure 3. Geological map of the Lower North Region River Basin (modified from Department of Mineral Resources, 1976).

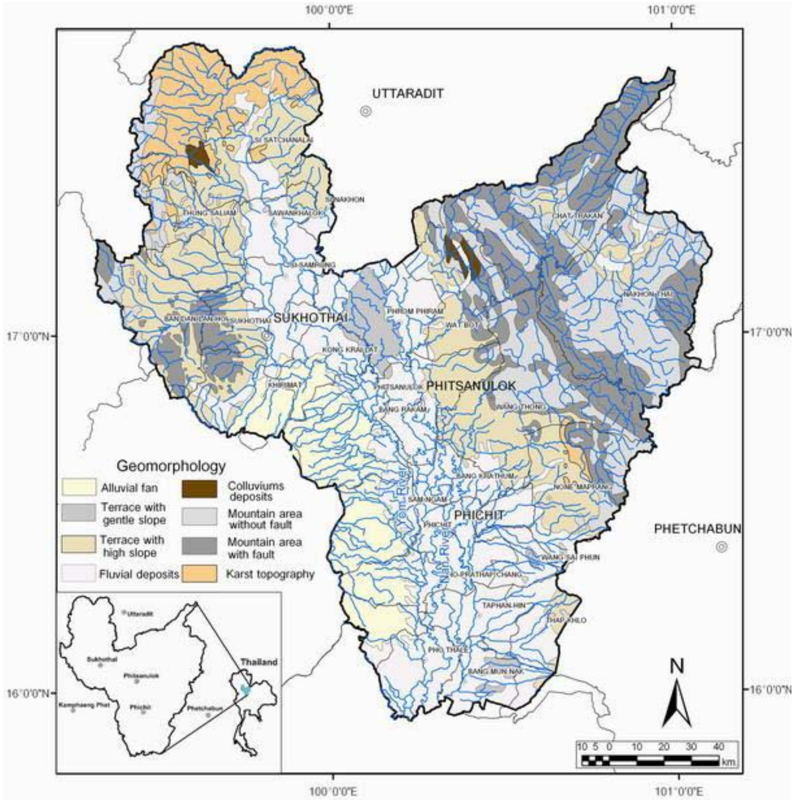

Figure 4. Geomorphological map of the Lower North Region River Basin.

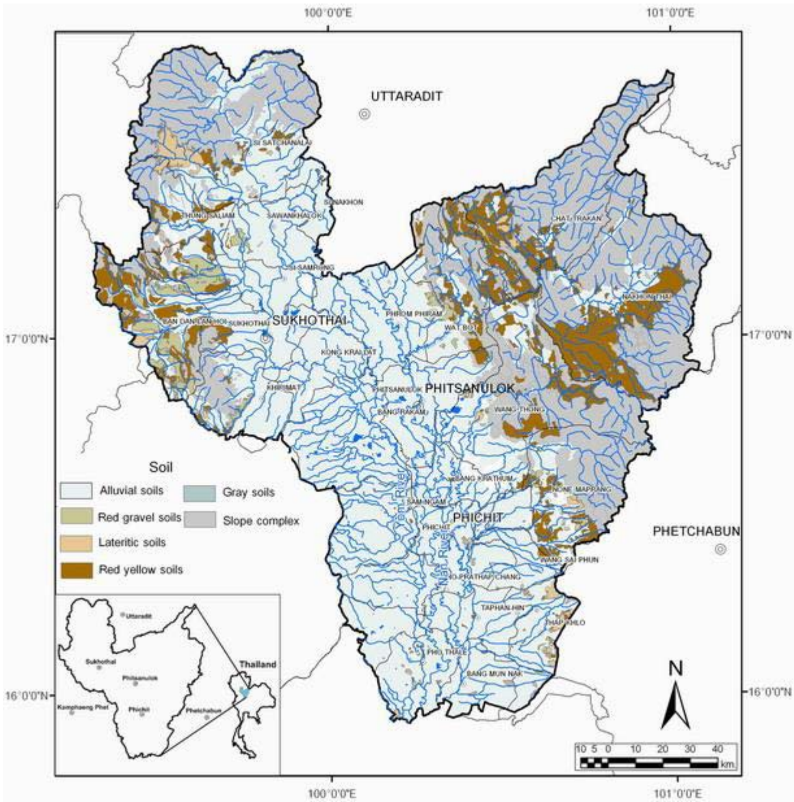

Figure 5. Soil map of the Lower North Region River Basin (modified from Land Development Department, 2000).

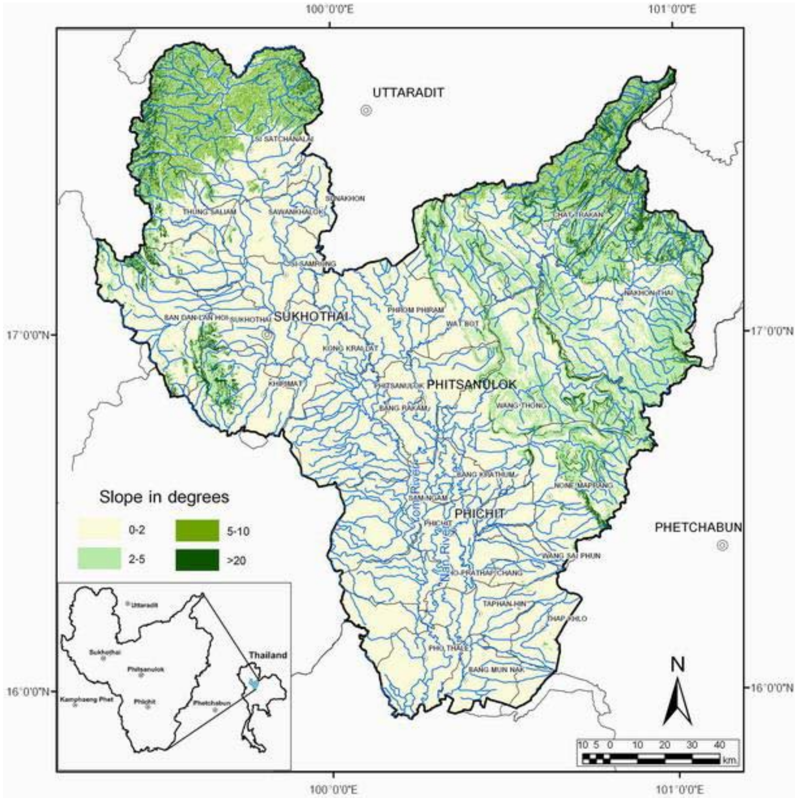

Figure 6. Slope map of the Lower North Region River Basin.

Geologic database is constructed using 1:250,000 scale geologic map (Department of Mineral Resources, 1976). Geomorphologic database is developed from topographical maps 1:250,000 scale (Royal Thai Survey Department, 2006) and hydrogeological map 1:100,000 scale (Department of Mineral Resources, 1983). Soil database is constructed using 1:50,000 scale provincial soil map (Land Development Department, 2000). Slope database is developed from topographical maps 1:50,000 scale (Royal Thai Survey Department, 2006). Classification, score and weight of each group of parameters were assigned for each thematic map based on the field evidence and previous works (Saraf, et. al, 2004) and shown in Table 1.

Table 1. Weighted indices for selecting potential MAR areas**.**

Thematic layers	Classes	Score	Weight
1. Geology	1.1 Gravel, sand	5.0	0.6
	1.2 Laterite & rock fragment	4.0	
	1.3 Clay	4.0	
	1.4 Conglomerate	1.5	
	1.5 Sandstone	1.5	
	1.6 Siltstone	1.5	
	1.7 Shale, Mudstone	1.5	
	1.8 Limestone	1.5	
	1.9 Rhyolite	1.5	
	1.10 Phyllite	1.0	
	1.11 Basalt	1.5	
	1.12 Gramite	0.5	
	1.13 Gneiss	0.5	
2. Geomorphology	2.1 Alluvial fan	5	0.7
	2.2 Terrace with gentle slope	3	
	2.3 Terrace with high slope	1	
2. Geomorphology (Cont.)	2.4 Fluvial deposits	1	0.7
	2.5 Colluviums deposits	1	
	2.6 Mountain area without fault	1	
	2.7 Mountain area with fault	2	
	2.8 Karst topography	5	
3. Soils	3.1 Red gravelly soils	5	0.5
	3.2 Alluvial soils	4	
	3.3 Lateritic soils	3	
	3.4 Red yellow soils	2	
	3.5 Gray soils	2	
	3.6 Slope complex	1	
4. Slopes	4.1 Range 0 - 2	4	0.4
	4.2 Range 2 - 5	5	
	4.3 Range 5 - 10	3	
	4.4 Range 10 - 20	2	

Suitable areas for managed aquifer recharge (MAR) were determined by an overlay technique with the Geographic Information System using ArcGIS software by the Weighted Index Overlay Analysis (WIOA) (Saraf, et. al, 2004). The overall methodologic framework is shown in Figure 7. All maps are presented at a resolution of 2.3 Mega pixels.

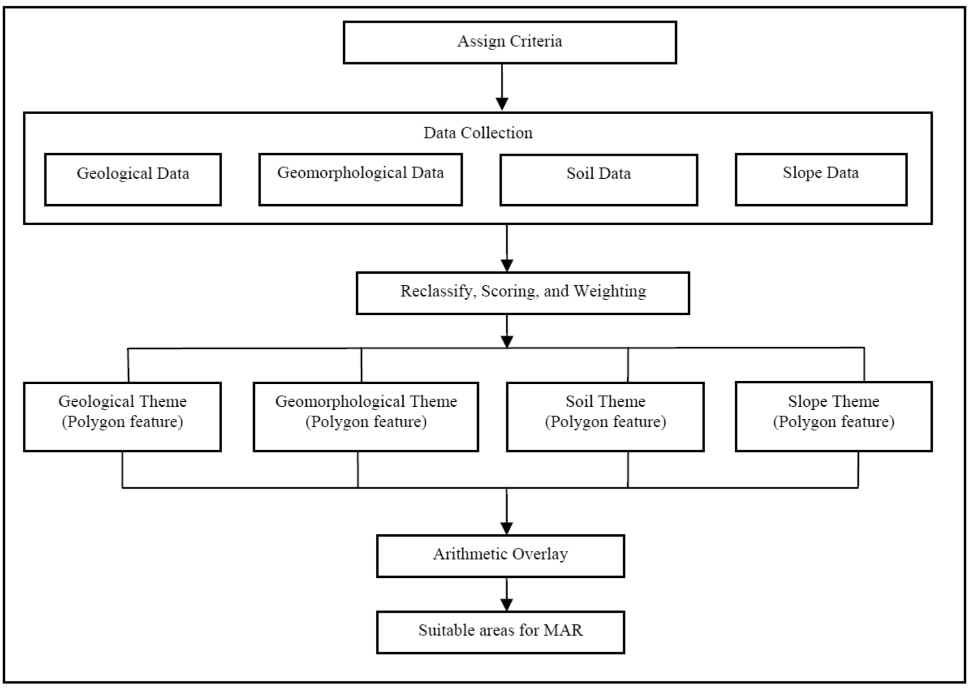

Figure 7. Flow chart illustrating the methodogy used in this study.

RESULTS

Suitable areas for managed aquifer recharge (MAR) can be determined and classified into 4 zones, (1) very suitable, (2) suitable, (3) moderately suitable, and (4) unsuitable as depicted in Figure 8.

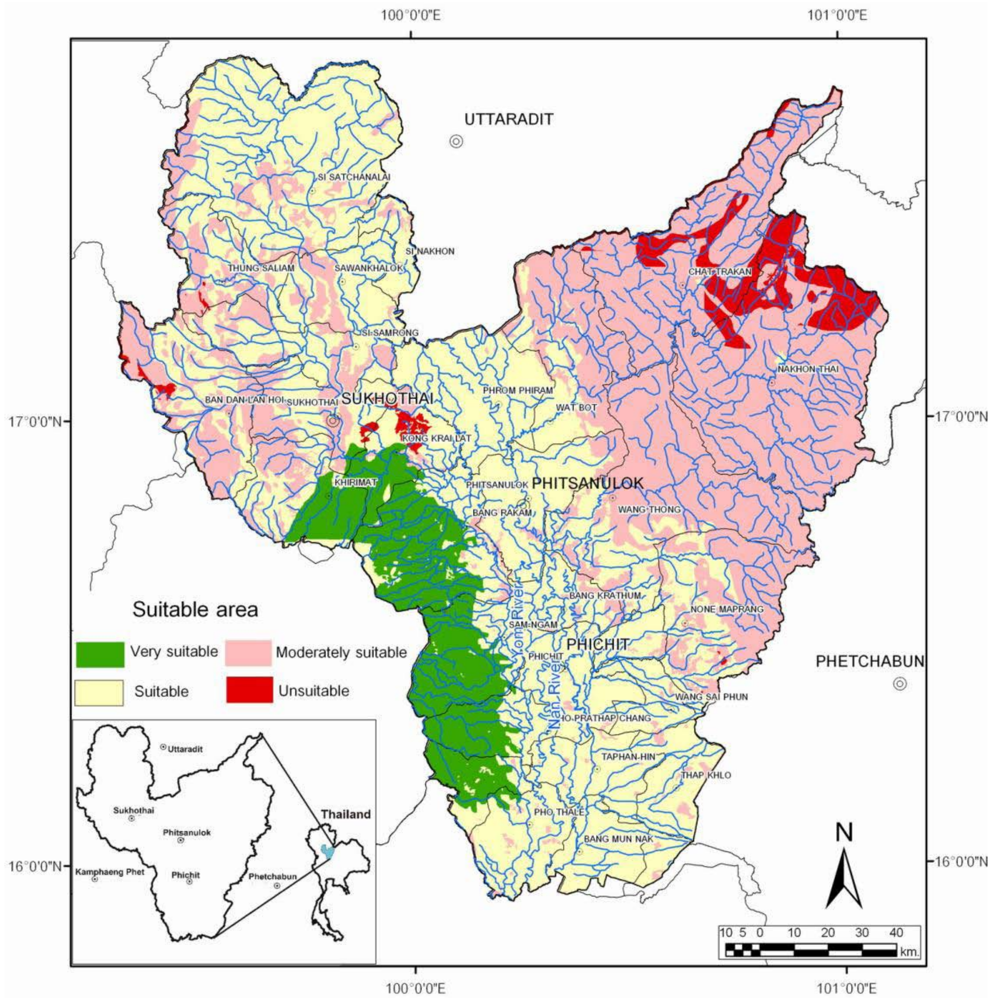

Figure 8. Suitable areas for MAR in the Lower North Region River Basin.

1. Very suitable area for MAR by using ponding methods is located in the southwest region of the Lower Region River Basin and covers area of about 1,900 km^2 (9% of the study area), in Amphoe Bangrakham, some part of Amphoe Kirimas and Kongkrilas, Pitsanulok Province, and Amphoe Samngam, Amphoe Vachira Baramee, Amphoe Popratapchang, Pichit Provinces. The most suitable areas are overlain by gravel and sand, alluvial fan, red gravelly soils, and have slopes of 2-5 degrees.

2. Suitable areas are located in the centre of the basin and cover an area of about 10,400 km^2 (48% of the study area), in Amphoe Sri Satchanalai, Amphoe Sri Samrong, Amphoe Sawankalok, Amphoe Phrom Phiram, Amphoe Wat Bot, Amphoe Muang, Amphoe Bang Kra tum, and parts of Amphoe Wangtong, Pitsanulok province, and parts of Amphoe Samngam, Amphoe Muang, Amphoe Taphanhin, Amphoe Bangmunnak, Amphoe Wangsaipoon, and Amphoe Tabkhlor, Pichit Province, respectively.

3. Moderately suitable areas cover an area of about 8,200 km^2 (39% of the study area) in the northwest and northeast regions where are the relatively high topographic terrain.

4. Unsuitable areas cover an area of about 800 km^2 (4% of the study area) and mainly situated in the high terrain regions in the north east as shown in Figures 8 and 9.

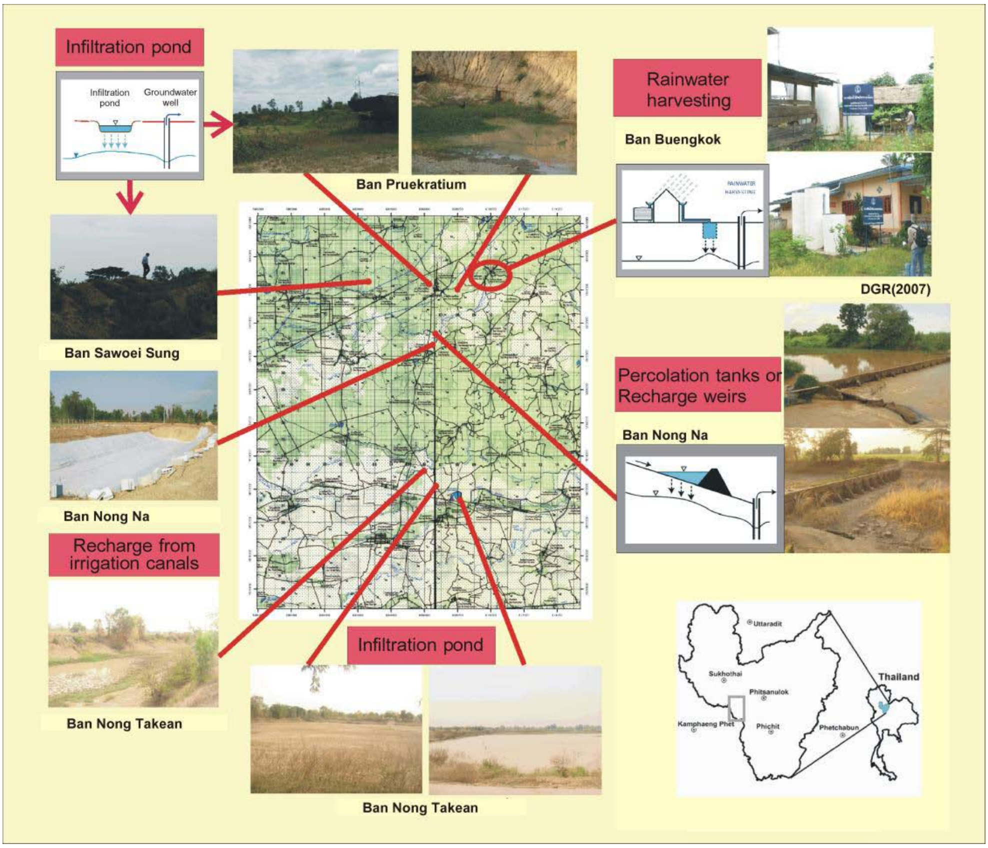

Figure 9. Topographic terrain of the suitable area, with the sand and gravel pits located in the Bangrakam area, Pitsanulok Provinces (Department of Groundwater Resources, 2009).

CONCLUSIONS AND RECOMMENDATIONS

A diverse and complex array of criteria determine the suitability areas for MAR. This study has demonstrated that GIS-based approaches can usefully delineate such areas. Verification of the approach is required by more in-depth site investigations for one or more suitability classes.

The technique described here can also be adapted and employed to determine the suitability other MAR techniques, such as trenching, rainwater harvesting, recharge weir, and Aquifer Storage and Recovery (ASR) in future studies (Figure 9).

ACKNOWLEDGEMENTS

We would like to thank you the Department of Groundwater Resources, Ministry of Natural Resources and Environment, Thailand for providing financial support to the project.

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abstract id: **358**

topic: **5**
Data processing in hydrogeology

5.1
Modelling as a tool of groundwater assessment

title: **Application of reactive solute transport models to groundwater risk assessment**

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keywords: risk assessment, models, contamination, reactive transport, pesticides

INTRODUCTION

Tiered risk assessment forms a key part of the UK guidance for environmental management and pollution prevention, as part of the implementation of European and national legislation. This risk based approach is applied to management of quantity and quality of water resources, including groundwater, complies with the Water Framework Directive (EU, 2000) and is accepted by the environmental regulators (Environment Agency of England and Wales, Northern Ireland Environment Agency and Scottish Environmental Protection Agency). This tiered approach follows the source-pathway-target approach and allows for a rapid initial risk screening, through application of simplified models with inherent conservatism and comparison of the results with guideline values such as drinking water standards. If no significant risk is predicted, then compliance is assumed. Otherwise, this initial tier is followed by progression to a more sophisticated assessment, which includes a more realistic representation of attenuation processes.

For groundwater risk assessment, the first model is invariably the Environment Agency's Remedial Targets worksheet, which simulates 1-D contaminant transport including degradation and sorption (Environment Agency, 2006). This method is extremely useful because it is simple to apply and provides a rapid assessment of risk. However, it tends to overestimate contaminant concentrations and hence risks, due to the assumptions that a continuous contaminant source with a constant concentration has reached the water table and is moving directly towards the receptor.

For complex problems and a less conservative assessment of risk, more sophisticated models are required, simulating 2-D or multi-layered flow and reactive transport of dissolved contaminants, using packages such as MODFLOW (McDonald and Harbaugh, 1988) with MT3D (Zheng, 1990). Although modelling of groundwater contamination requires a fine grid and appropriate vertical resolution, in more detail than those used for most groundwater flow models, the uncertainty in the flow pattern generally has less influence on the results than the transport parameters. Thus a steady state flow model is adequate for many contamination risk assessments, based on bulk hydraulic properties, average recharge and abstraction patterns, unless the main risk drivers are preferential pathways such as fracture zones.

The MT3D code simulates reactive transport, including dispersion, first order biodegradation and equilibrium controlled linear or nonlinear sorption. When rapid predictions are required for risk assessment, published data forms the most realistic source of contaminant properties, although scaling up from laboratory or small scale field experiments remains problematic for half lives and sorption rates, and most importantly for dispersion. However, in many applications, the greatest influence on the results comes from the poorly constrained source term, with uncertain timing and mass, and on rare occasions even the location is poorly defined.

Where contamination originates from the surface above a thick unsaturated zone, significant attenuation may occur above the water table, reducing contaminant concentrations entering the saturated zone. Few of the standard modelling packages simulate unsaturated zone processes, although PHREEQC (Parkhurst and Appelo, 1999) can be used successfully for inorganic contamination when transport is dominantly through a porous matrix (Butler et al., 2003).

Two examples of local contaminant transport models are used to illustrate the approach described above, with comment on the uncertainties and outcomes for groundwater risk assessment.

EXAMPLE 1, ATTENUATION IN UNSATURATED ZONE

Prediction of fluoride concentrations and pH in a thick Triassic Sandstone aquifer were required to assess the risks and requirements for remediation, following a large spill of fluorosilicic acid, which is used to add low concentrations of fluoride to drinking water (Mott MacDonald, 2008). The Triassic Sherwood Sandstone is the UK's second most important aquifer and an important resource in northern and central England. It comprises a thick sequence dominated by poorly cemented with calcite, fine to medium grained, red sandstones, with significant primary porosity and permeability, locally enhanced by fractures.

Initial assessment, using the Remedial Targets worksheet and assuming an ongoing source of contamination, indicated possible impacts on surface and groundwater resources, beyond an agreed compliance point at a distance of 50 m from the spill. As these results were considered to be unrealistic, additional investigation and modeling were undertaken.

PHREEQC was used to approximate the movement of the fluorosilicic acid spill through the unsaturated zone, 10.5 m thick, to determine the extent of spill attenuation before reaching the water table, simulating geochemical reactions between the mineral phases and pore water solution, as well as advection. Where site specific data were not available, typical parameters were based on literature (Butler et al, 2003; Tellam and Barker, 2006). The results predicted that pH would be rapidly buffered to pH 7 and that fluoride would take 5 to 7 years to reach the water table. The predicted slow release of fluoride into the saturated zone is illustrated by Figure 1.

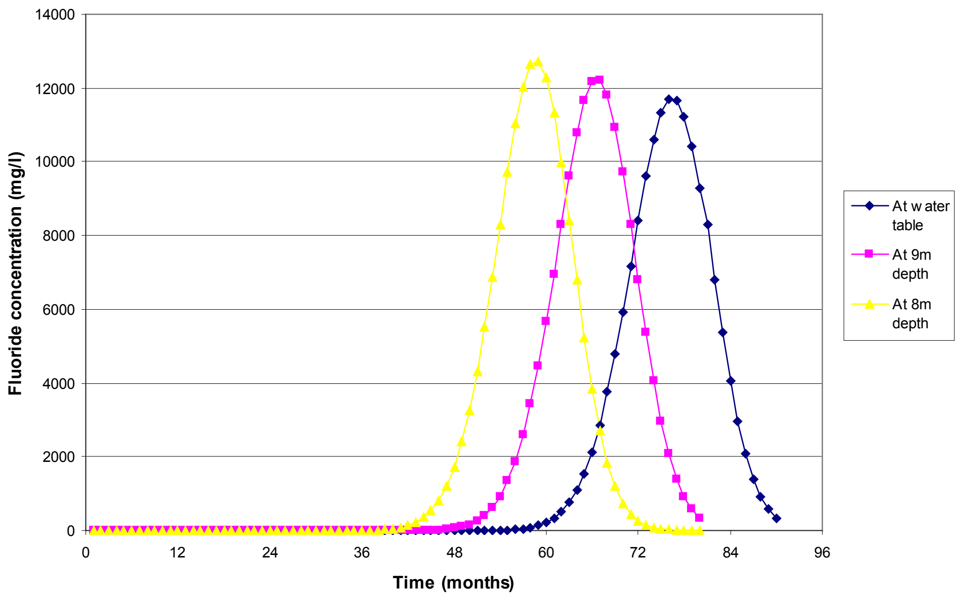

Figure 1. Simulated fluoride concentration at the water table.

The calculated concentrations were input as recharge to the MODFLOW and MT3D models, which simulated steady state flow and reactive transport using the nonlinear-Langmuir sorption isotherm, based on experimental data of average sorbed fluoride (Gresswell, 2005). The results showed that saturated zone transport of fluoride is extremely slow and that the predicted fluoride concentration exceeds the drinking water limit of 1.5 mg/l over only a small area downgradient of the site (Figure 2). Due to dispersion, a rise is concentrations at an existing monitoring well immediately upgradient of the spill is also predicted. The predictions indicate that no remediation is required to protect the aquifer beyond a distance of 150 m from the spill site.

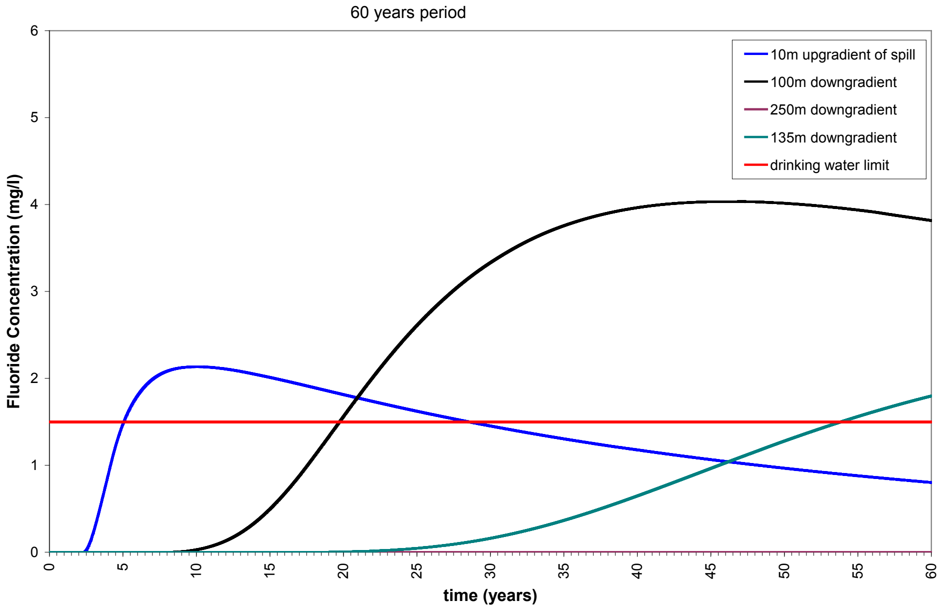

Figure 2. Simulated fluoride concentrations in the saturated aquifer.

EXAMPLE 2

The second illustration (Mott MacDonald, 2009) is an investigation into the causes of rising pesticide concentrations in an abstraction borehole, tapping the unconfined Chalk aquifer in a rural area, where both point and diffuse sources are possible but no definite sources have been identified. Thus there is uncertainty about the source's location, size and timing, as well as the thickness of the unsaturated zone. To allow for this, three alternative sources were modelled, two possible point sources (A and B) and a large area of diffuse pollution.

An initial risk assessment used the Environment Agency's Remedial Targets Methodology (Environment Agency, 2006) to simulate transport of five pesticides and identify three compounds of concern, trietazine, clopyralid and bentazone. Further modelling, using the MODFLOW and MT3D, was used to refine the risk assessment, including forecasting of the range of future concentrations. Useful data on pesticide use and properties was obtained from the European Pesticide Properties database (University of Hertfordshire, 2009). However as the location, size and concentration of the pollution sources are still uncertain and the only available data on concentrations is limited to time series at an abstraction borehole and sporadic measurements at two monitoring borehole, all models were calibrated to match modelled results to historical trends. This approach and the paucity of data result in significant model equivalence, particularly for the simple 1-D model as illustrated by Figure 3.

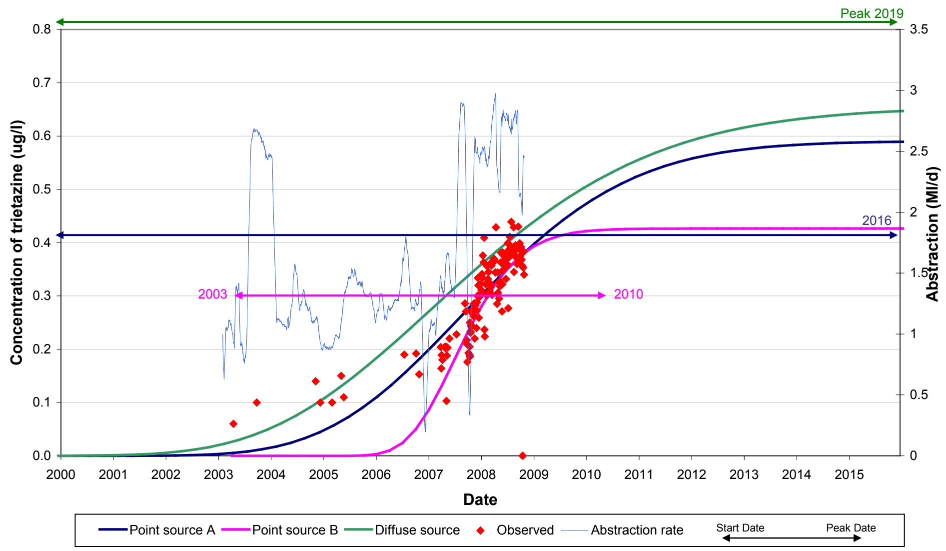

Figure 3. Simulated concentrations using simple 1-D model for 3 possible sources.

Although application of a more sophisticated approach brings a reduction in uncertainty, the inherent uncertainty in the data dominates the results. However, the results indicated that a point source is more likely than diffuse pollution, as illustrated by Figure 4, and provided a better understanding of the likely future risks even if the source is not located and remediated.

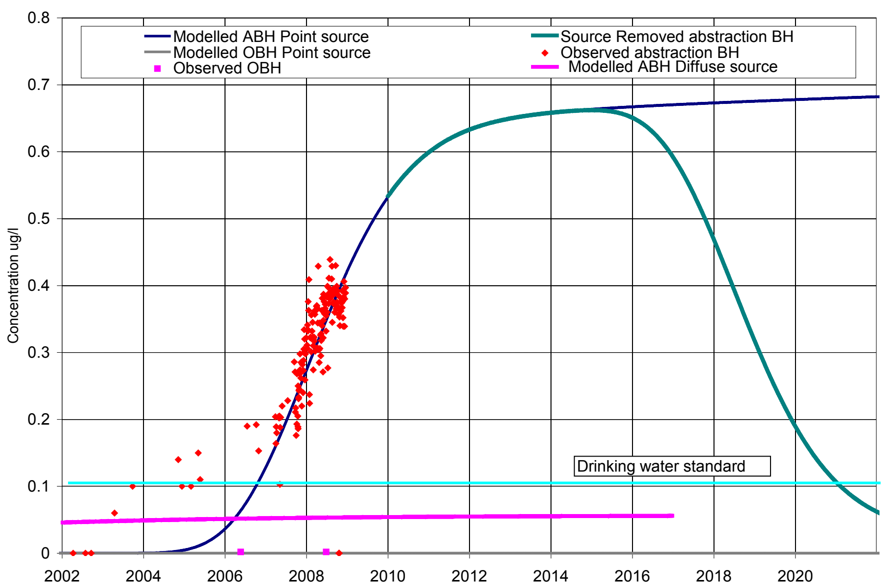

Figure 4. Simulated concentrations using 2-D model for point and diffuse sources.

CONCLUSIONS

The tiered risk assessment approach widely accepted by regulators in the UK provides a cost effective method of risk screening, but the emphasis on very simple models leads to highly conservative assumptions and overestimates of risk and impacts. In order to understand complex problems and derive a more realistic assessment, more sophisticated models are essential, including representation of reactive transport in both unsaturated and saturated zones. Results with sufficient accuracy for assessment of risks to water resources and requirement for remediation can be obtained using standard software packages, including MODFLOW, MT3D and PHREEQC, with input data based on published values to supplement site specific measurements. However, these predictions retain some uncertainty, notably when the source term is poorly understood, and would not be adequate for detailed design of remediation.

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abstract id: **434**

topic: **5**
Data processing in hydrogeology

5.1
Modelling as a tool of groundwater assessment

title: **Numerical model conceptualization utilizing advanced geoinformatic techniques in investigations of complex multi-aquifer systems of MGWB in Poland**

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keywords: conceptual model, groundwater flow modelling, MGWB, Poland

INTRODUCTION

The aim of the paper is to provide an overview of existing research studies and methodology of developing numerical models of the Major Groundwater Basins (MGWB) characterized by complex multi-layered conditions. The MGWBs were documented as regions with good groundwater quality and the most beneficial exploitation conditions in Poland and after the verification the quantity of 163 out of 190 MGWBs was finally accepted (Herbich et al., 2009). Model investigations for three different types of MGWBs: № 302, № 321 and № 326 (Fig. 1) were documented to show how important is GIS-based developing of the model structure including DTM creation and proper boundary conditions setting.

Figure 1. Location of models of the developed MGWBs.

Considering aspects of establishing a flow system, groundwater resources and protection zone identification a 3-D models were built using MODFLOW (McDonald, Harbaugh, 1988; Harbaugh et al., 2000) application in integration with other geoinformatic techniques especially advanced GIS tools (Gurwin, Lubczynski, 2005; Gurwin, Serafin, 2007, 2008). A highly complicated hydrogeological conditions are found as well within Quaternary/Neogene (Fig. 2) as Mesozoic MGWBs that were studied. The examples of different type and varying scale were selected to show crucial steps of conceptualization.

CONCEPTUALIZING MODELS OF COMPLEX QUATERNARY/NEOGENE AQUIFER SYSTEMS

Gathering appropriate data from hundreds of boreholes, utilizing GIS and advanced geostatistical analysis a 3-D representation of hydrostratigraphic unit interfaces is developed. Afterwards using fully GIS integrated modelling environments like GMS and VISTAS the structure of the aquifer system is transferred to the grid of numerical model. The boundary conditions of such a large-scale regional models should be consistent with natural hydraulic boundaries, that's why an extent of the entire model domain is usually far much wider than MGWB itself (Fig. 2).

Considering numerical models of deeper aquifers a special attention should be paid on semi-pervious layers, which determine distribution of recharge from above-lying shallow Quaternary aquifers. Then the parameters of thickness and vertical conductivity are crucial and GIS layers should be prepared utilizing geostatistically approved data analysis, as it is shown in map of the aquifer bottom in the Figure 3.

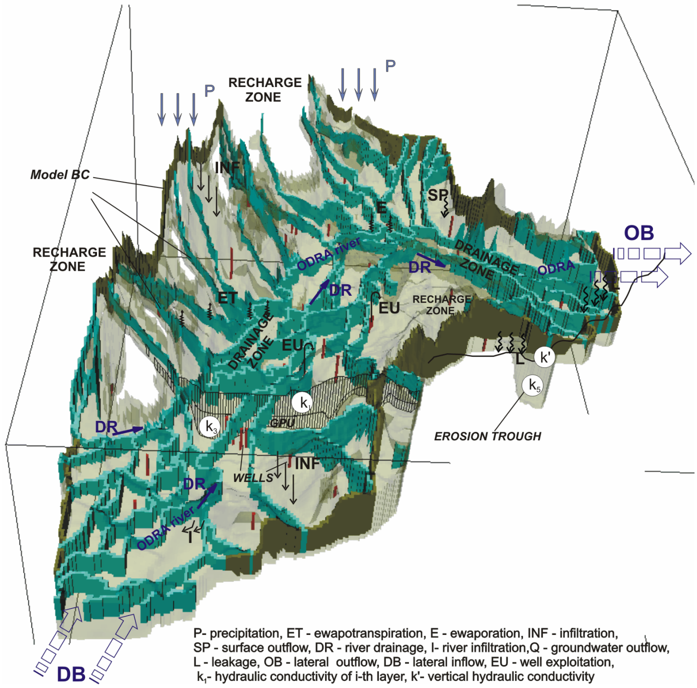

Figure 2. Conceptualisation of groundwater flow system within complex Quaternary MGWB No 302 on 3-D numerical model.

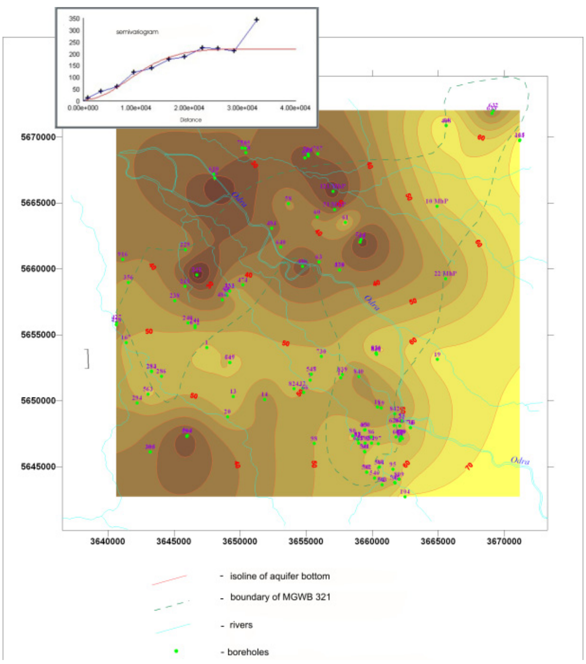

Figure 3. Contour map of bottom of the Neogene aquifer within the MGWB 321.

A composition of the top/bottom GIS layers together with hydrogeological parameters allowed to prepare a 3-D grid representation of the MGWB 321 in the GMS Modflow environment (Fig. 4).

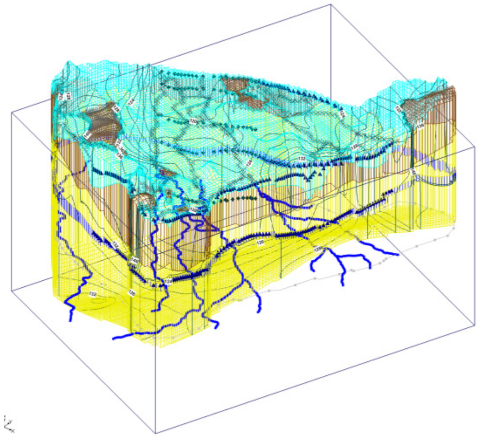

Figure 4. Scheme of the MODFLOW numerical model of groundwater flow system within the Neogene MGWB 321 with calculated hydroizohypses (Gurwin, 2008).

The results of the model are presented on the sets of numerical maps and diagrams, but full 3D model (Figure 2, Figure 4) gives also opportunity of pathlines analysis which is a basis for MGWB protection zone determination (Figure 5).

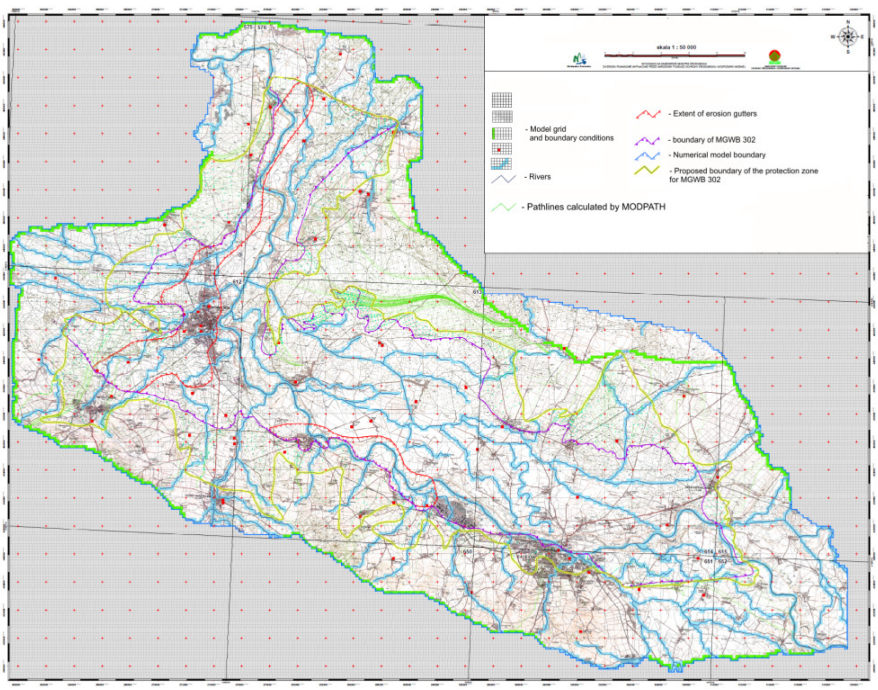

Figure 5. Results of protection zone evaluation for MGWB No 302 according to the numerical MODFLOW/MODPATH model.

A particle tracking method with forward advective pathline simulation is used to evaluate velocity vectors and to establish the isochrones of 25-year fluxes. But the final protection zone was delimited considering the time of seepage through an unsaturated zone as well (Gurwin, Serafin, 2010).

DEVELOPING OF A LARGE-SCALE MODEL OF MEZOZOIC AQUIFERS — MGWB Nº 326

As an example of extremely large-scale modelling can be taken a numerical model developed for MGWB Nº 326 which covers a big part of the central Poland (Fig. 1) — an active area of the model is 7 thousand of sq. km. A complicated structure of the Jurassic/Cretaceous fissured massif was evaluated with GIS support and next the nine-layer finite difference model was created (Fig. 6). Having finally calibrated model a water balance was calculated as a basis of groundwater resources analysis.

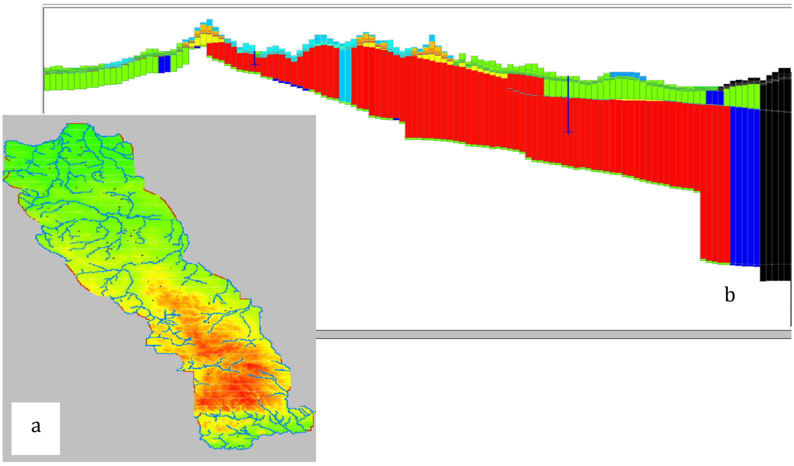

Figure 6. DTM in a finite difference projection (a) and spatial differentiation of the numerical model layers with respect to tectonics of the Mezozoic massif of MGWB No 326 (cross section W-E) (b).

CONCLUSIONS

So far investigations carried out for establishing water balance components, groundwater resources and protection zones in several MGWBs in Poland have proved that full model control from a GIS platform is necessary to fulfill all these tasks. Developing a 3-D numerical flow model gives opportunity of detailed analysis of complex Quaternary/Neogene aquifer systems. Setting of boundary conditions is much more credible using GIS, especially considering river BC and spatial recharge input data.

An extremely large-scale modeling within intensively tectonically engaged systems is also feasible to be done when thousands of records of data can be quickly analyzed in GIS tools including advanced geostatistical calculations.

ACKNOWLEDGEMENTS

Investigations are based on the projects being accomplished according to the Ministry of the Environment programme for the MGWB protection strategy in Poland.

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abstract id: **449**

topic: **5**
Data processing in hydrogeology

5.1
Modelling as a tool of groundwater assessment

title: **A complex flow system model of the Muszyna region (Beskid Sądecki Range, Polish Outer Carpathians)**

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keywords: conceptual model, numerical flow model, GIS, GMS

The studied area is located within an open hydrogeological structure in the Carpathian mountain basin. Regional model of the Muszyna area takes into account the presence of complex fold and fault structures as well as the interaction between groundwater, and surface water as well as fresh water with mineral water (Kania et al., 2010, submitted). The diagram (Fig. 1) showing the conditions of water flow system was used to construct the numerical model.

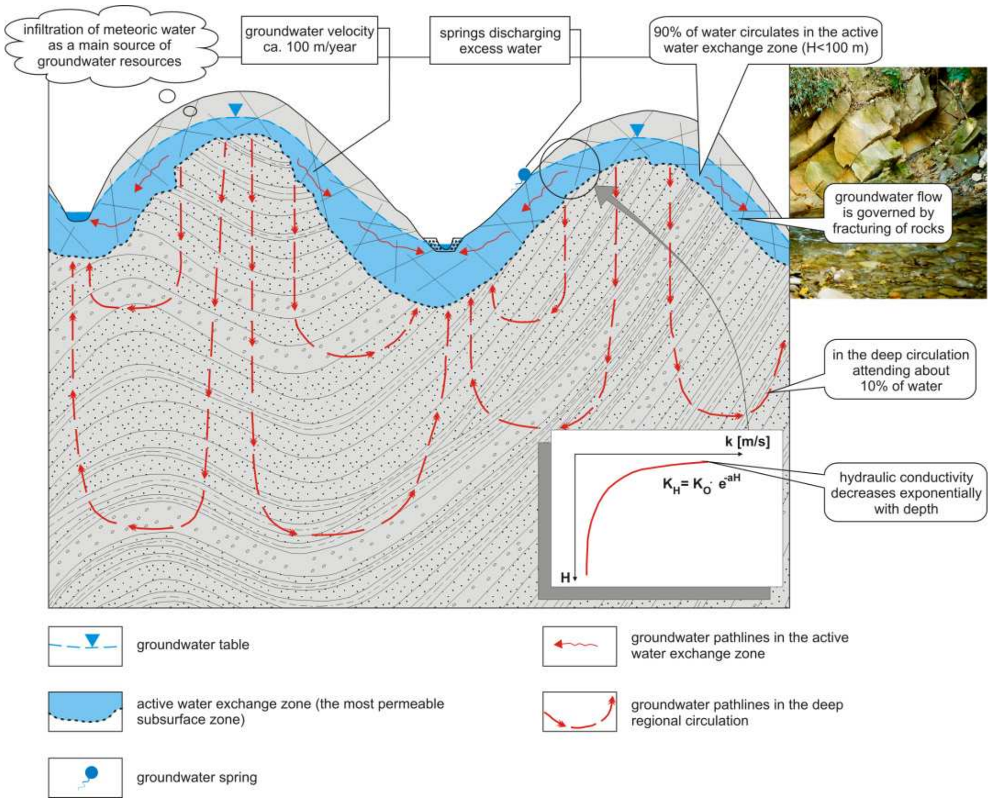

Figure. 1. Conceptual model of groundwater flow system in the studied area (Kania et al., 2010, submitted).

Within the model were separated 10 layers with different hydrogeological characteristics. The first layer includes Pleistocene-Holocene deposits. All other layers are built of fissured-porous flysch rocks. The hydraulic conductivities in studied flysch rocks decreases exponentially with depth (Oszczypko et al., 1981; Witczak et al., 2002). The most permeable subsurface zone is about 100 m thick. This is active water exchange zone recharged from the atmospheric precipitation. When the permeability of this zone is sufficient the groundwater supplies the main streams, as shown in the given diagram (Fig. 1). When the permeability is too low, the water table intersects the terrain surface and the flow of water from the spring, which usually initiates small stream. The varied morphology makes the elevated parts, where water table is much higher than in the valleys supplying the deeper water-bearing zone. Despite the decreasing fracturing and permeability of rocks the exchange of water can reach a depth of over 1000 m, although it is less intensive. The regional groundwater flow system also return to drainage areas, which are the river valleys.

Conceptual and numerical model of Muszyna hydrogeological region is based on the GMS software package — Groundwater Modeling System (Jones, 2005), working in close cooperation with the GIS environment, and using a software package ESRI ArcGIS (McCoy, 2004). Among the several methods for implementing the model in the GMS the LPF (Layer Property Flow) method was used to create a structure of the model. It involves the separation of the model space for many layers of varying thickness, within which zones of different hydraulic conductivities are separated.

The procedure of the model construction begins with the initial conceptual model of groundwater flow system. On completion of this, information about the structure of the model, hydrogeological properties and boundary conditions were included in the ArcGIS database. The data contained in the ArcGIS database is then transferred to the GMS conceptual model. The transfer process to GMS numerical model divided into blocks is done automatically. The model was therefore used, inter alia, to assess the disposable resources of medicinal and fresh waters of the studied area.

The experience gained from modeling for the Muszyna region show effectiveness of the principles of the creation of regional hydrogeological models. Such a quasi 3D model seems to be a good tool to carry out the rational exploitation of fresh and mineral water in a complex groundwater flow system (Kania et al., 2010, submitted).

ACKNOWLEDGEMENTS

This abstract was partly financed through statutory funds of the AGH University of Science and Technology (Project No. 11.11.140.139).

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5.2 Groundwater flow and solute transport modelling

IAH 2010
Krakow

abstract id: **131**

topic: **5**
Data processing in hydrogeology

5.2
Groundwater flow and solute transport modelling

title: **Flow and transport simulation models in a volcanic-sedimentary aquifer: La Aldea aquifer (Gran Canaria, Canary Islands)**

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keywords: chloride transport model, volcanic-sedimentary aquifer, Gran Canaria Island

INTRODUCTION

La Aldea Valley is located on the western side of Gran Canaria (Canary Islands, Spain) and covers an area of 44 km^2. In the lower part of the La Aldea-Tejeda basin (Fig. 1) the valley presents a flat bottom surrounded by high mountains to the north and south (heights from sea level to 1415 m). It is bounded to the east by the Atlantic Ocean and to the west by impermeable materials of the inner part of the island (intra-caldera border). The climate is dry subtropical. Rainfall and temperature mean values are 160 mm/year and 21°C, respectively. Intensive greenhouse horticulture (mainly tomatoes and cucumbers) is practised and irrigation water is mainly supplied by three dams situated upstream, although more than 370 large-diameter wells also provide crop water requirements in the dry seasons.

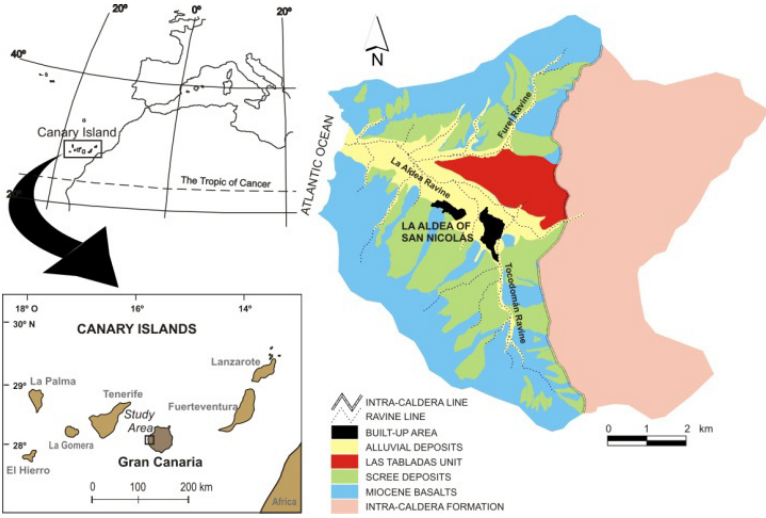

Figure 1. Localization of La Aldea aquifer in Gran Canaria (Canary Islands, Spain) and geological map showing the main geological units.

In this work, the hydrogeological functioning of this sedimentary-volcanic aquifer has been studied and contrasted from flow and solute transport modelling. Results obtained from a model of solute transport are shown in this article.

METHODOLOGY

A groundwater flow model in the area has been developed with previous and current data in steady-state for the average hydrologic year 1991/92 and in transient state for the period 1991/92-1998/99. Subsequently, hydrochemical and hydrogeochemical modelling techniques have been used to characterize and quantify the processes that lead to the chemical composition of the groundwater in the aquifer. Finally, a solute transport model for a saturated porous medium has been developed in steady-state for the average hydrologic year 1991/92, assuming an anisotropic and heterogeneous environment and constant density (Cruz, 2008). The solute selected for the transport model is the chloride ion which is an indicator of the mixing processes. This transport model will allow a comparison of the results obtained in the previous hydrochemical study and flow model.

FLOW AND HYDROCHEMICAL CONCEPTUAL MODEL

A conceptual model of the aquifer flow has been established within the framework of the insular aquifer, which has been conceptualized as a single, stratified, heterogeneous body of groundwater where recharge takes place mainly at the top of the island, with groundwater flowing towards the coast. The discharge flows towards the sea and towards groundwater works (Custodio, 2007). Within this framework, La Aldea Valley represents a discharge area from the aquifer to the sea.

Based on the geology, four hydrogeologic domains have been defined in the study area: Alluvial formation, scree deposits, Las Tabladas unit and Miocene basalts (Fig. 1), of which the alluvial formation and Miocene basalts are the most significant. The aquifer is unconfined and the alluvial deposits and the basalt rocks can be considered to be a single aquifer with two sub-layers: the upper alluvial deposits layer and the lower basalt layer. The flow has a main east to west direction in the La Aldea ravine, a south-north direction in Tocodomán ravine and a north-south direction in the Furel ravine. Recharge is a result of rainfall, irrigation returns, supply network leaks and inflow from the intra-caldera zone. Rainfall and irrigation returns are the main sources of groundwater recharge. Discharge takes place by pumping wells and seaward outflow. The maximum permeability values are located in the La Aldea alluvial area, 17–106 m/d. In the Tocodomán and Furel alluvial areas it is 5.5–22 m/d. The permeability for Miocene basalts is 0.0009–0.005 m/d and for scree deposits and secondary tributary alluvial areas permeabilities are 0.25–1.2 m/d and 6 m/d, respectively. Coefficient storage oscillates between 0.08 and 0.03 for alluvium and 0.0002–0.03 for Miocene basalts, depending on whether or not they are confined (Muñoz, 2005; Cruz, 2008).

The conceptual hydrochemical model proposes that water flows from the basalts to the alluvial deposits and therefore the extracted water is a mixture of both hydrogeological units and shows hydrogeochemical characteristics consistent with this mixture (Muñoz, 2005; Cruz, 2008). Most groundwater is of the sodium-chloride type, which has been attributed to the aridification of the recharge and airborne salinity. When the influence of marine aerosols is low (at higher altitudes and farther from the sea) the water is of the sodium-bicarbonate-chloride type. The exploitation of basalts produces an increase in the concentration of magnesium and occasionally high calcium concentrations show a geological mark produced by basalts. The geological mark of ignimbrites, trachytes and phonolites in well samples located in the scree deposits points to an increased concentration of sodium. The effect of the irrigation return flows (increased concentrations of nitrate and sulphate) is observed in almost the entire area. In general, there is agreement between the direction of groundwater flow and the increased chloride content, although deviations are observed in samples from wells close to the Las Tabladas area. In this area, a significant increase is observed in the concentrations of chloride, sodium and sulphate (reaching 8100, 3900 and 1800 $mg \cdot L^{-1}$, respectively) attributed to hydrothermal deposits ("Azulejos") located around the Las Tabladas area. Batch experiments run with these deposits have shown that they contribute a high Cl content to groundwater.

NUMERICAL MODEL

A three dimensional groundwater flow model has been developed with MODFLOW-2000 in Visual MODFLOW graphical environment in steady-state for the average hydrologic year 1991/92 and in transient state for the period of 1991/92-1998/99. A model of chloride transport has been realized with MT3DMS in Visual MODFLOW graphical environment in steady-state for the average hydrologic year 1991/92 (Cruz, 2008). Solute transport processes considered are advection and dispersion hydrodynamics.

The modelling area was tridimensionally discretized as cells of 50×50 m; 114,570 cells were divided into 190 rows and 201 columns and vertically into 3 layers. The superficial layer (layer 1) represents the sedimentary material (alluvial and scree deposits) and several metres of the underlying altered basalts, while the other two layers represent altered basalts (separated by an impermeable layer formed by lava flowing over previous soils named "almagre"). The bottom surface (the limit between the altered basalts and the unaltered basalts) has been located at 163 m depth by the previous drilled bore with a Miocene basalts slope between 3° and 5°.

The boundary conditions considered for the transport model were the constant concentration and recharge concentration. The limits of the mountain chains and the bottom surface have been defined as no-flow boundary conditions. The coastal line has been defined as a constant level and chloride concentration (elevation: 0 m and concentration: 20270 $mg{\cdot}L^{-1}$). The eastern limit has been considered to be a constant flow and chloride concentration along the contact line and by the alluvial deposits from the headwater of the ravine (concentration: 200 $mg{\cdot}L^{-1}$ and 270 $mg{\cdot}L^{-1}$, respectively). The upper surface boundary conditions correspond to the recharge. Different recharge origins have been calculated in each cell integrating the different sources: rainfall, irrigation return flows, supply network leaks (considered negligible compared to rainfall recharge in the model), inflow by the alluvial deposits from headwater of the ravine and inflow from the intra-caldera zone. Finally, concentration of water produced by the leaching of Azulejos deposits of the Las Tabladas area of 8500 $mg{\cdot}L^{-1}$ (obtained from water samples of oozes located in this area) has been imposed. The area was discretized in different areas where the recharge Cl concentration is the result of the different sources of Cl considered.

The hydraulic conductivities and storage coefficient have been divided into several zones based on the geology and were calibrated using the flow model. The considered dispersivity varies between 0.3 and 61 m for the alluvial and 0.6 m for the basalt. The estimated horizontal transverse dispersivity varies between 1.5 and 5.6 m and the vertical between 0.4 and 1.7 m. Effective porosity for alluvial deposits varies between 3% and 35% and for the basalt, 0.1% and 1% (Custodio, Llamas, 1996). These parameters have been calibrated in the steady state transport model. The molecular diffusion coefficient of water in porous medium is 10^{-9} m^2/d, which was not calibrated, because the model was insensitive to this parameter.

The groundwater chloride data consists of 41 chloride concentration measurements recorded in wells between July and August 1992 and distributed throughout the study zone. The comparison between the observed and the simulated chloride concentration is shown in Figure 3.

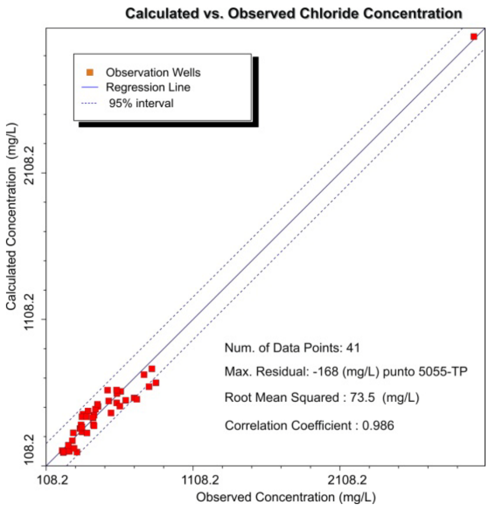

Figure 3. Comparison between observed (points) and simulated (solid lines) chloride concentration.

Longitudinal, transverse and vertical dispersity values obtained in the model calibration for all layers are 1 m, 0.33 m and 0.05 m, respectively.

Chloride map resulting (Fig. 4) fits satisfactorily to the conceptual hydrochemical model.

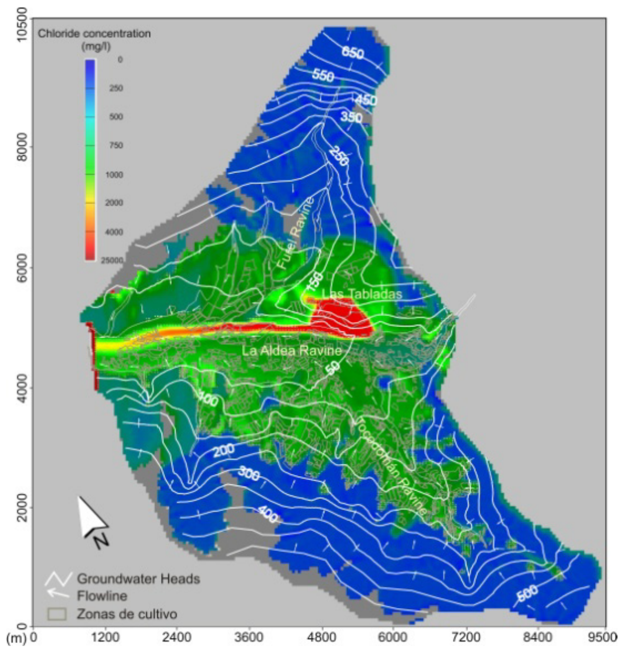

Figure 4. Steady-state water-table map and simulated chloride concentration distribution.

The necessity for groundwater protection is considered in the European Union in the context of its influence on the state of surface water and connected directly with terrestrial and water ecosystems as well in the context of its significance for the drinking water supply of the population. An estimation of ground and surface water quality includes among others the recognition of its biological elements of quality: plankton, macrophytes, phytobenthos and benthic invertebrates (Directive No 2000/60/EC, 2000).

The authors have carried out an investigative project on this topic. Investigations have carried out on the carbonate massif of the Cracow-Czestochowa Upland (the CCU). This is an area of upland karst not fully developed and differentiated in its inner structure. The Upper Jurrasic aquifer, which is the Major Ground Water Basin (MGWB No 326), is located in this area. In the southern part of the CCU it is a typical unconfined aquifer, which is closely connected with surface water. The Upper Jurassic aquifer is also closely connected with the surface water including living biocoenoses and other biocoenoses which depend on the state of water. With the aim of protecting the natural environment and groundwater resources, most of the area in the CCU is protected by law (Ojców National Park, Landscape Parks, Nature 2000 area). Therefore, this region with its unique karstic features, that is environment extensively managed and protected by law, is an excellent area for hydrogeological studies (Różkowski, 2006).

The presented project refers to hydrogeoecological studies. They include interdisciplinary studies of ecosystems of damp areas under the influence of ground and surface water as well marshes. Investigations have dealt with the water environment regime and also with the presence of subterranean microorganisms and invertebrates in it (Humphreys, 2009).

These habitats connected directly with groundwater outflow are treated in the so-called Habitat Directive of the European Union as very valuable and they have the rank of European cultural heritage. In the area of the CCU there are several hundred springs. They are not only the local groundwater drainage points but they also set composite hydrologic biotic ecosysytems (Springer, Stevens, 2009). The durability and stability of habitat conditions in springs results in the occurrence of a specific fauna (crenobionts) and some relic species, e.g. in the area of the CCU — Crenobia alpina and Bythinella austriaca. The composition of fauna living in springs is influenced by hydrogeological conditions, their surroundings, zonal differences eucrenal–hypocrenal and also by disturbances, especially in the form of anthropopression (Dumnicka et al, 2007). Existing faunistic and ecological studies on the springs located in the CCU indicate that they are highly diverse although the number of taxa found in individual springs was not substantial. However, there are no complex studies on fauna which take into account the presence and conditions of populations of crenobiontic and oligo-stenotermic species in individual springs.

Within the framework of this project in chosen study polygons the unconfined aquifer is investigated. The study is performed in spring drainage areas in zones of unconfined flow systems as well as in caves and outflows from caves, and in water-logged quarries. Such an approach to the natural environment will allow water and terrestrial esosystems connected with the water of the unconfined aquifer to be recognized. An assembly of benthic invertebrates, higher plants, bryophytes will be determined as the biomarkers of the environmental state and then they could be compared (on basis of literature) with porous environmental analogs. The study, done together with the recognition of regional management and pollution sources, will allow the influence of natural and antropogenic factors on water environment and its biotic elements within the karstic area of the CCU to be estimated. They will also show the current trends of this environment is development. In addition to the study aspect the project also has practical and methodological aims. For the purpose of providing the effective protection of karst water and its ecological environment in the area of the CCU, the further development of research procedures typical for the karstic areas is necessary.

DISCUSSION AND CONCLUSIONS

The concentration of irrigation return waters was calibrated during the modelling process. From an initial concentration of 350 mg·L^{-1} in samples of hydroponics crops returns a final concentration of 600 mg·L^{-1} was achieved with the better calibration. This shows that the pollution caused by irrigation returns is generally greater than that obtained from the hydroponics irrigation returns, so this fact may provide evidence that the irrigation return flows cause further contamination to the system. A constant concentration boundary condition (20 270 mg·L^{-1}) was imposed at the mouth of the ravine representing the seawater concentration. This points to the absence of seawater intrusion in the aquifer and confirms the hypothesis proposed in the conceptual model and verified in the flow model.

The simulated values of concentration of chloride have produced a good fit. The resulting map shows a representation of chloride consistent with the flow and transport conceptual models in the study area, reproducing them successfully. The most characteristic feature consisting in the input of chloride due to leaching of the Azulejos deposits located in the Las Tabladas area, with concentrations higher than 8000 mg·L^{-1} has been well simulated by the model. The transport model also shows the relevance of scree deposits in the hydrogeological system, as they are preferential flow pathways that accelerate and facilitate the recharge to the alluvial deposits providing chlorides from the irrigation return flows located thereon.

ACKNOWLEDGEMENTS

This work was carried out within a cooperation agreement between the Insular Water Council of Gran Canaria and the University of Las Palmas de Gran Canaria, CICYT 1FD97-0525, CONSOLIDER-TRAGUA (CSD2006-00044) and REDESAC (CGL2009-12910-C03-02) projects. This work is part of the doctoral thesis of the first author under the codirection of the other authors, funded by a Research Scholarship awarded by the Cabildo Insular de Gran Canaria.

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abstract id: **200**

topic: **5**
Data processing in hydrogeology

5.2
Groundwater flow and solute transport modelling

title: **Simulation of phosphorus transport in an unconfined aquifer: a case study**

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keywords: eutrophication, phosphorus, groundwater, MODFLOW

INTRODUCTION

Intensifying loading of nutrient into water reservoir such as pond and groundwater reservoir is an important environmental issue (Liu et al., 2008; Smil, 2000). Phosphorus is one of inorganic nutrients that is released widely by human through activities and may cause eutrophication with adverse effect on ocean water and fresh water (Hauer, 2006; Smil, 2000; Liu, 2008; Khan, Ansari, 2005). In Malaysia many plants, including oil palms, which are the primary crops in many areas, are notable to grow to maturity without application of phosphorus fertilizers due to deficiency of soil nutrients. Ninety percent of phosphorus in oil palm is derived from fertilizers (Zaharah et al., 1997).The Malaysian government imited the concentration of phosphorus in groundwater for class IIA/IIB and III as 0.1 mg/l and 0.2 mg/l respectively (DOE, 2004).

Since shallow lakes are almost always hydraulically connected to aquifer systems (Rahim et al., 2006), the interaction between surface subsurface water is a key feature in migration of pollutant from one to another. This interaction can be simulated by those computer softwares which are able to model either Navier-Stoks (de Lemos 2006) or the extended Darcy's (Todd and Mays 2005) equations. US Corps of Engineers recommended the later which is broadly used around the world with success (USCE 1999).

METHODOLOGY

In the present study, an area of 16.03 hectares inside the campus of University Putra Malaysia, Serdang, Selangor, Malaysia with annual average rainfall of 2990 millimeters, where a sludge pit and a pond are located at the same site, was chosen as the study area. The top layer of the aquifer, 10 meters thick Kajang formation, consists of clay loam while the lower layer is recognized as Kuala Lumpur limestone formation (Saghravani, 2009; Gobbett & Hutchiston, 1973; Huat et al., 2004). The soil was profiled as two layers, Layer 1 with less and underneath layer, Layer 2 with higher hydraulic conductivity. The required data and parameters for simulations were collected between January, 2007 and March, 2008 (Saghravani, 2009).Visual MODFLOW package which includes MODFLOW (Harbaugh, 2005) and MT3DMS (Zheng, 2006) was selected to find the patterns of groundwater flow for the case the groundwater level dropped two meters inside the pond was simulated. The model was run to simulate the flow in 3650 and 18250 days. These long periods were chosen due to low hydraulic conductivity of Layer No.1 and also slow phosphorus movement in soil.

RESULTS AND DISCUSSION

Transient regime was considered to simulate the transportation of contamination in the flow for both periods. The flow direction of groundwater was observed to be toward the pond due to the placement of boundary. In this case the water level dropped 2 meters in the pond. This causes change in groundwater flow direction and water from other parts of study area, including the sludge area. The simulation results show that the phosphorus does not spread in the first layer that is consisting of clay loam with low hydraulic conductivity. Figures 1, 2, 3 and 4 show the directions of phosphorus movement in 10 and 50 years respectively. In 18250-days, the maximum concentration of phosphorus in Layers No.1 and 2 were calculated at 0.55 mg/l and 0.35 mg/l respectively. One can conclude that vertical migration can be responsible for the occurrence of phosphorus within the second layer because the direct horizontal movement of pollutant through the first layer to the pond is limited due to its very low hydraulic conductivity.

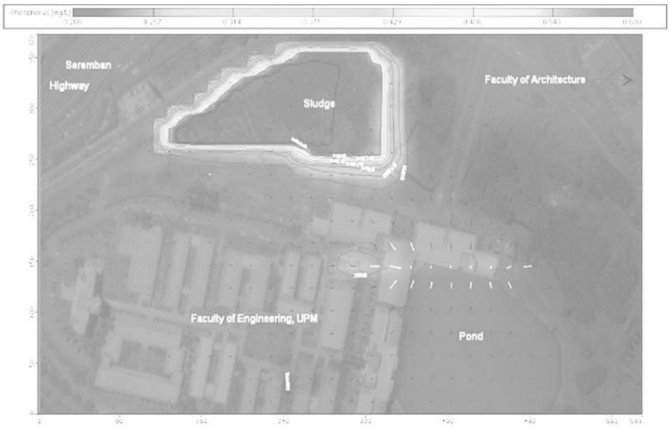

Figure 1. Phosphorus concentration in layer No.1 (3650 days).

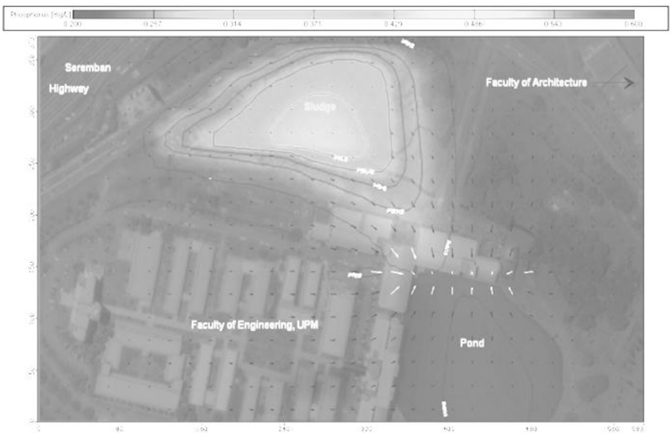

Figure 2. Phosphorus concentration in layer No.1 (3650 days).

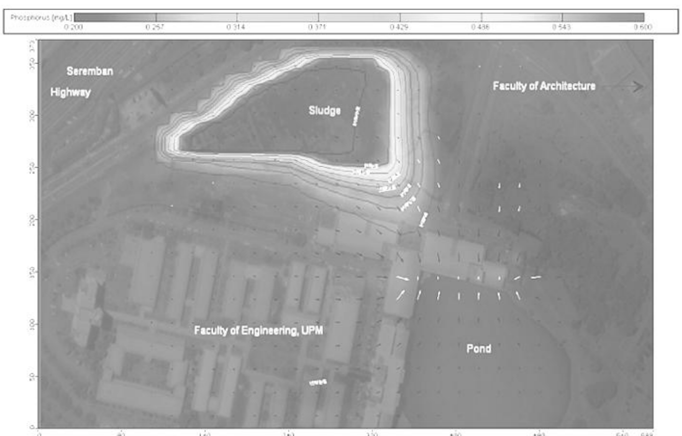

Figure 3. Phosphorus concentration in layer No.2 (18250 days).

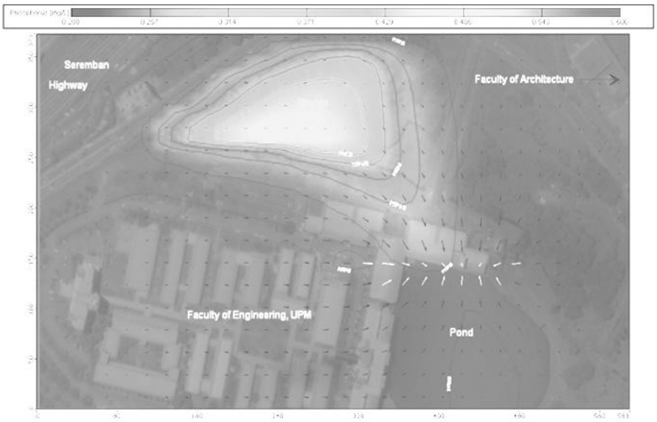

Figure 4. Phosphorus concentration in layer No.2 (18250 days).

CONCLUSION

Visual MODFLOW can be employed used to model groundwater movement and MT3DMS is able to find the fate of leached phosphorus from the sludge into the subsurface. The combination of these two was used to predict and estimate the conditions and concentration of contamination and assess water quality. The results show that along with the reduction of the water level in the pond, the direction of local groundwater can be changed from Northeast-Southwest to be toward the pond and increase in phosphorus concentration. As a result, the use of fertilizers should be reduced to control the concentration of phosphorus in groundwater. Further studies should be implemented to assess and control the source of contamination and water quality in future.

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abstract id: **231**

topic: **5**
Data processing in hydrogeology

5.2
Groundwater flow and solute transport modelling

title: **A semi-analytical model for estimating groundwater recharge through fractured till**

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keywords: groundwater recharge, till, fractures, semi-analytical modelling

The geology, material properties and hydraulics of a *c*. 6 m thick till deposit overlying a regional sandstone aquifer have been investigated at a field site in Shropshire, UK. The data have enabled a robust conceptual model of the processes contributing to groundwater recharge through till to be derived for the site. The hydraulic data indicate that water table responses to rainfall during the summer occur while large soil moisture tensions (suctions) are present higher up the profile. Given the very low permeability of the till at the core scale, these data are highly suggestive of the occurrence of preferential flow. Furthermore, near-vertical, hydraulically active fractures have been observed in a test pit extending to depths of greater than 2 m. The fracture intensity decreases with depth and they are commonly infilled with sediment (often fine grained calcareous material or sand) derived from weathered clasts within the till.

During the summer period, plants will draw moisture from both the fractures and the matrix in the soil zone leading to highly complex hydraulic interactions. However, for the winter period, we show how a simple semi-analytical model can adequately simulate the dynamics of the till water table, and suggest that this may be used to derive information to allow reasonable estimates of recharge to made for the whole year. The model assumes that, during the winter, flow predominantly occurs through the fracture network, that fracture apertures are constant but that the fracture spacing doubles with depth, consistent with our field observations. Since the fractures are infilled with sediment it is also assumed that flow is Darcian. Thus:

$$K(z) = \frac{aK_a}{z} \tag{1}$$

$$S(z) = \frac{aS_a}{z} \tag{2}$$

where z = depth below ground surface, and K_a and S_a are the hydraulic conductivity and specific yield respectively at a representative depth, a, at which values of K and S are defined.

Based on the assumptions above and the conceptual simplifications embedded in these assumptions, a model was constructed to simulate the position of the water table during the winter months (December 2004 to March 2005). If the mean vertical K in fractures is estimated as a harmonic mean between the water table and the base of the till then, using Darcy's Law:

$$Q_t = \frac{(WT_t - GWL_t)}{(WT_t - D)} \cdot \frac{(2aK_a)}{(WT_t + D)} \tag{3}$$

where Q_t = vertical flow (L/T) through the base of the till (i.e. recharge to the underlying sandstone) at time t, WT_t = water table elevation (bgl) at time t, GWL_t = groundwater level in the sandstone aquifer (bgl) at time t, D = total thickness of till.

Letting the unit time interval for model calculations be equal to Δt, the inflow-outflow imbalance for a given time step, ΔQ, is given by:

$$\Delta Q = P_t - AE_t - Q_t \tag{4}$$

where P_t and AE_t are the precipitation and evapotranspiration at time t.

If the mean vertical S in fractures is estimated as an arithmetic mean over the interval of head changes then it can be shown that:

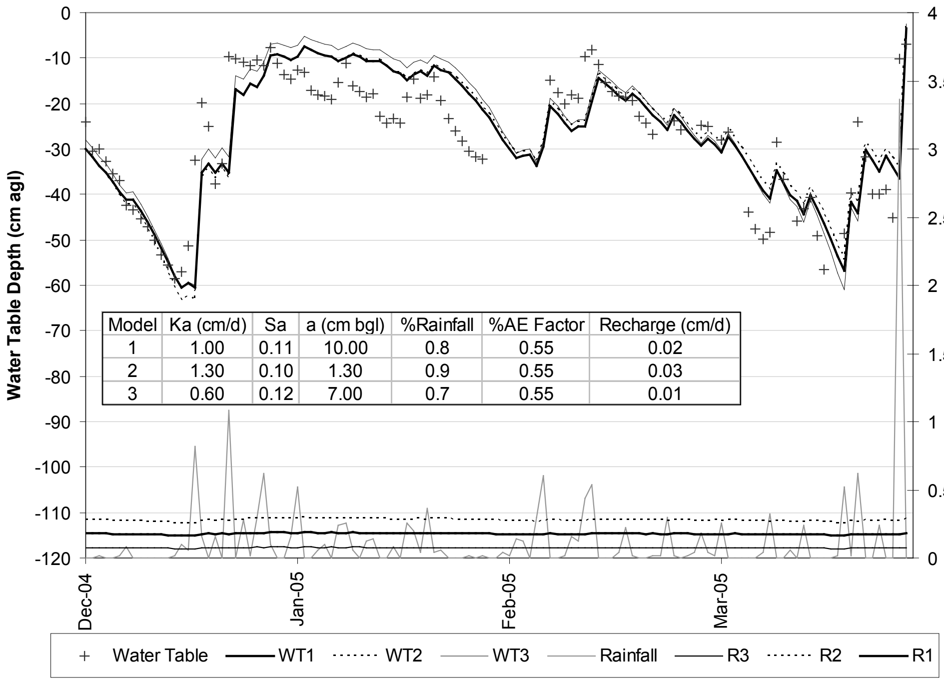
$$WT_{t+\Delta t} = \exp\left(\ln(WT_t) - \frac{\Delta Q}{aS_a} \right) \tag{5}$$

where $WT_{t+\Delta t}$ = water table elevation (bgl) at time $t+\Delta t$.

Combining equations (3), (4) and (5) gives:

$$WT_{t+\Delta t} = \exp\left(\ln(WT_t) + \frac{(WT_t - GWL_t).(2K_a)}{(WT_t - D).(WT_t + D).S_a} - \frac{(P_t - AE_t)}{aS_a} \right) \tag{6}$$

Equation (6) was implemented in a spreadsheet to generate a simulated water table for given time series inputs of P and AE using a daily timestep. A starting value for WT_t was assigned and then values of K_a, S_a and a were varied to refine the model. Three different scenarios were run based on rainfall values factored at 70, 80 and 90% of the observed values at Bowling Green. The model outputs are time series of water table elevation and groundwater recharge (Fig. 1).



Model	Ka (cm/d)	Sa	a (cm bgl)	%Rainfall	%AE Factor	Recharge (cm/d)
1	1.00	0.11	10.00	0.8	0.55	0.02
2	1.30	0.10	1.30	0.9	0.55	0.03
3	0.60	0.12	7.00	0.7	0.55	0.01

Figure 1. Model results.

While refining the models, it became apparent that with good fits to the data for the first three months of the modelled period the simulated water table values fall much too low during the month of March. Furthermore, fitting the March data produces poor fits to the first three months of observations. Warmer weather in March may have led to a change in the mode of evaporation at the near surface, most likely due to evapotranspiration gaining significance at the initiation of plant growth from this time on. Plants will thus draw moisture from both the fractures and the matrix in the soil zone whereas in the preceding months it has been assumed that evaporation is predominantly drawing water from the fracture network. Hence in March, even though the PE has increased, the proportion of the energy demand from the fracture system is still likely to be smaller than in the previous month because of the increased proportion of energy that will go towards transpiration. Therefore, for the month of March, a factor was applied to the AE input in order to reduce the evaporation from the fractured system resulting in much better model fits.

Model results indicate that the bulk hydraulic conductivity of the till at the field site is in the range 9×10^{-8} to 8×10^{-10} ms^{-1}, up to three orders of magnitude higher than the till matrix hydraulic conductivity measured in the laboratory. Fracture porosities of the till may be in the range 0.1 to 4% with groundwater velocities of a few cm/d (3×10^{-7} ms^{-1}). The recharge to the sandstone underlying the field site is likely to have been in the range 49 +/- 28 mm/a (1.5 +/- 0.9 × 10^{-9} ms^{-1}) during 2004 to 2005 and up to 50% lower during summer than winter.

The paper furthers understanding of the hydraulic processes contributing to recharge through till and makes the link between the detail of these processes and simplified models for recharge estimation, which may be needed for larger scale water resource studies. The results are relevant also to contaminant migration studies and aquifer vulnerability assessments.

abstract id: **251**

topic: **5**
Data processing in hydrogeology

5.2
Groundwater flow and solute transport modelling

title: **Identification of groundwater salinization sources using experimental, multivariate statistical analysis and numerical modelling tools: Case of Korba coastal aquifer (Tunisia)**

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keywords: salinization, multivariate statistics, numerical modelling, coastal aquifer, Tunisia

Groundwater quality degradation processes are threatening environmental and social sustainability in arid and semi-arid regions. Salinization is one of the most world spread forms of groundwater contamination (Custodio, Bruggeman, 1987). It mainly results from seawater intrusion due to over-pumping and loading of agricultural residual substances through irrigation return flow (Koh et al., 2007). This study aims to understand and predict groundwater and soil salinization processes in coastal irrigated areas using experimental and numerical tools. Field experiment was carried out in Korba coastal aquifer along two transects perpendicular to the sea (Fig. 1).

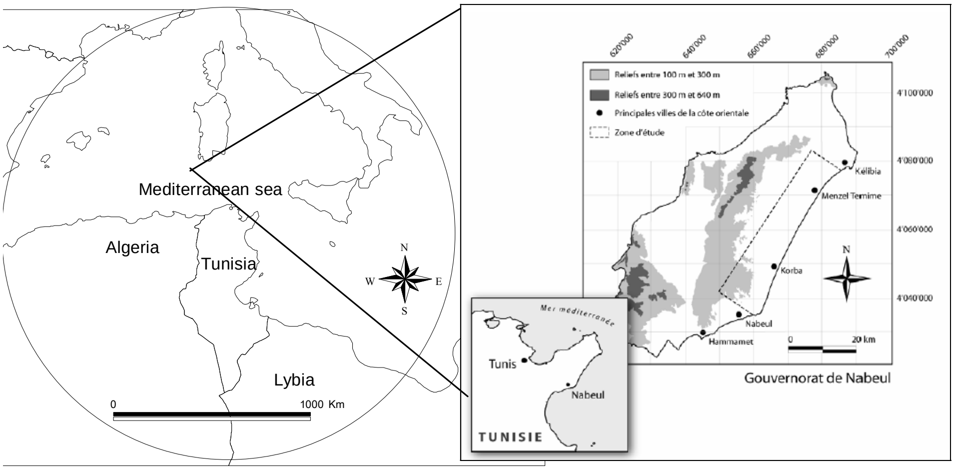

Figure 1. Location of Korba coastal aquifer.

The first transect is located in a piezometric depression and it is affected by seawater intrusion. In the second transect, the flow is still seaward. Experimentation involved soil and groundwater sampling as well as Electrical Resistivity Tomography Imaging (ERT). Irrigation water comes mainly from groundwater pumping. Groundwater was sampled at different periods from June 2006 to March 2008 in 50 observation wells along the two transects. Soil samples were used to determine vertical soil salinity, major ions and nitrate profiles on extractions from saturated soil paste. Major ions, nitrates and bromide were also determined for groundwater samples. Conventional geochemical methods and multivariate statistical analysis were performed to identify superimposed salinity sources. HYDRUS1D was used to simulate flow and solute transport in variably saturated profiles in order to predict soil and groundwater salinity. Simulations were first performed for a cycle corresponding to the irrigation season and second for some years. Results show that measured electrical conductivity in observation wells presents important values reaching 9 mS/cm. Principal Component Analysis as well as the geochemical study showed that salinity is originating from mixing with seawater and from irrigation return flow (Fig. 2).

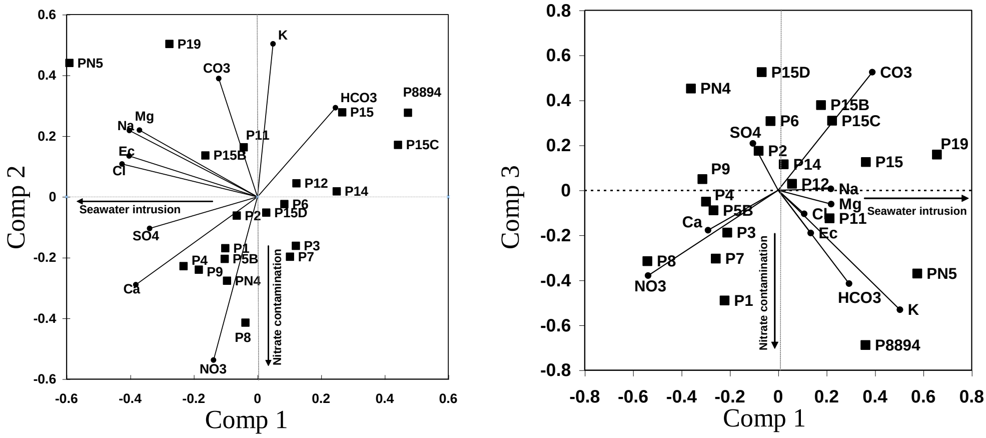

Figure 2. Principal Component Biplot of variables and observation points in the first transect for the dry sampling survey.

Electrical conductivity as well as major ions profiles, show salt accumulation in the soil surface reaching 17.5 mS/cm (Fig. 3).

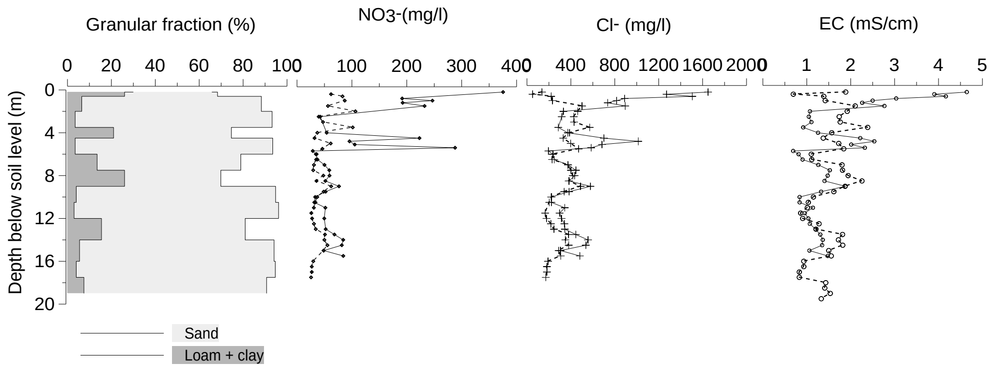

Figure 3. Distribution of granular fraction, chloride, nitrates, and electrical conductivity, along a 19 m soil profile. Variables (Cl, NO_3 and EC) were measured in August 2006 and April 2007 (dashed line).

This is essentially due to evapotranspiration processes and high irrigation water salinity. HYDRUS1D also simulated surface salinisation during the irrigation season. Impacts on groundwater quality are rather visible after some years of simulation.

ACKNOWLEDGEMENTS

This work was entirely funded by The Swiss National Science Foundation (SNSF).

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abstract id: **355**

topic: **5**
Data processing in hydrogeology

5.2
Groundwater flow and solute transport modelling

title: **Quantification of the water flux and transport processes in a heterogeneous aquifer model system with a multitracer approach**

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keywords: transport processes, experimental and mathematical methods, multi-tracer experiment

INTRODUCTION

Several studies have been performed to understand mass transport processes in porous groundwater systems. One common practice for the investigation of heterogeneous groundwater systems is the using of tracer techniques. Many field studies and laboratory experiments have been realised in the past to investigate transport parameters e.g.: main transport path, transport velocities, dispersivities, porosity (Einsiedl and Maloszewski, 2005; Ptak et al., 2004; Seifert and Engesgaard, 2007). To understand reactive transport of contaminants within an aquifer, tracer tests have also been used (Berkowitz, 2002; Cirpka and Kitanidis, 2000; Geyer et al., 2007; Ptak and Schmid, 1996; Reinhard et al., 1997).

To estimate how groundwater systems initially react to contamination, what controls biodegradation and how aquifers recover after contaminant removal, should be investigated in an indoor aquifer model established at the HMGU Institute of Groundwater Ecology in Munich. The aim of the present study in that aquifer model was to clarify how heterogeneous water flow caused by differently conductive porous layers can be quantified.

MATERIALS AND METHODS

Setup of the Indoor Aquifer Model

The experimental aquifer, shown in Fig. 1, has a length of 5 m and a height and width of 0.7 and 0.8 m, respectively. This aquifer model has been filled with quaternary sediment from the Bavarian Alpine Foreland, Germany (grain size between 0 and 4 mm). In addition to the natural sediment, in the middle of the model has been installed a horizontal layer with higher conductivity consisting of homogeneous quartz sand with a grain size of 0.5 to 1 mm. This artificial "heterogeneity" with a thickness of 0.12 m and a length of 0.5 m should focus the water fluxes. The groundwater flow through the model has been designed with a gradient of the water level (i=0.02). The model was fitted with in total 132 water-sampling points made of glass frits, which were connected to stainless steel capillaries and a multi-channel peristaltic pumps. To realise an injection of tracer, one vertical injection well has been installed in the centre of the model closed to inflow (Fig. 1).

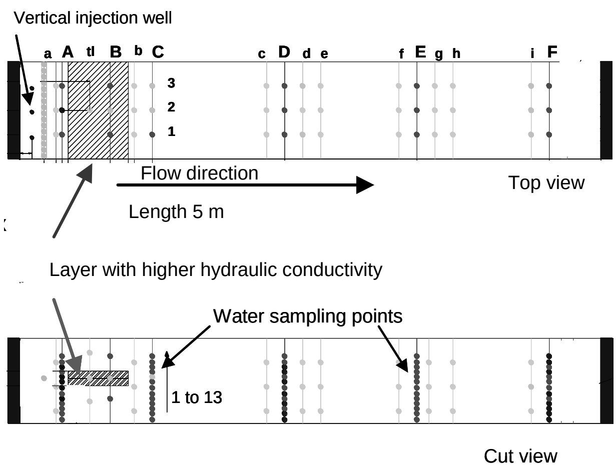

Figure 1. A schematic overview about the Indoor Aquifer Model.

Multi -Tracer Test

For a tracer test, a mixture of potassium bromide (4.4 g) tritium labelled water (activity 170 MBq) has been injected instantaneously as a Dirac-impulse in the vertical injection well. The first multi level well, evaluated in the present study, was installed in the middle of aquifer at the distance of 0.9 m from the injection well. At this vertical section, the water sampling proceeded along the main flow pathway, was performed to calculate the distribution of flow velocity and the longitudinal dispersivity. Further sampling perpendicular to the main flow pathway enabled us to calculate the transversal dispersivity.

Quantifying of tracer test using Multi-Flow-Dispersion-Model

The differences in hydraulic conductivity in vertical cross-section within the aquifer system are expected to cause multiple peaks in the concentrations curves, due to several flow paths with each having a different velocity. To describe the tracer transport in a multi-layered aquifer the multi-flow dispersion model (MFDM) was used. This model assumes that the tracer transport through the system can be approximated by a combination of 1D dispersion advection equations. Each flow path is characterized by a specific volumetric flow rate, mean transit time of water and dispersivity. It is assumed that the mass of tracer injected is divided into several flow paths proportional to the volumetric flow rates along those paths (Leibundgut et al., 2009; Maloszewski et al., 2006). The solution for a fully-penetrating observation well can be written in this case as follows (Maloszewski et al., 2006):

$$C(t) = \frac{\sum Q_i C_i(t)}{\sum Q_i} \qquad (1)$$

$$C_i(t) = \frac{M_i}{Q_i t_{oi} \sqrt{4\pi (P_D)_i (t/t_{oi})^3}} \exp\left[-\frac{(1 - t/t_{oi})^2}{4 (P_D)_i \, t/t_{oi}} \right] \qquad (2)$$

where Q_i [L^3] and M_i [M] are the volumetric flow rate and the mass of the tracer, P_{Di} [-] is the dispersion Parameter, t_{oi} [T] is the mean transit time of the water, for each i^{th} flow path, respectively.

The main assumption for the MFDM is that all i flow paths meet in one vertical observation well. However, the water sampling in the present aquifer-model was realised as a single observation over the depth. To overcome this difficulty each observed single tracer curve has been flux weighted and their sum was used as the outflow concentration curve C(t). The example of the calibration of the mathematical model (MFDM) to the tracer curve is shown in Fig. 2.

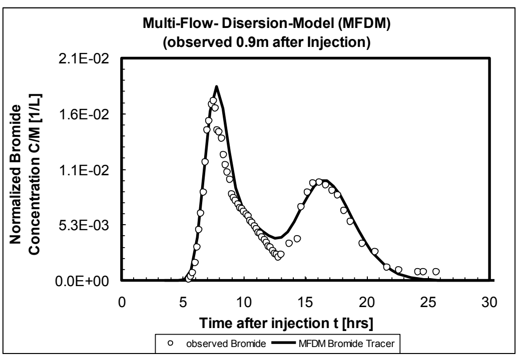

Figure 2. Bromide concentration curves observed (circle) and modelled using the MFDM (solid line).

RESULTS

The application of the MFDM has shown that there seem to be three layers with different velocities and longitudinal dispersivities, each (Table 1).

Table 1. Modelled transport parameters and calculated layer thickness for the different flow paths at a distance from the injection well of 0.9 m (model applied: MFDM).

	Flow path 1	Flow path 2	Flow path 3
Velocity [m/d]	2.72	1.88	1.27
Layer thickness [m]	0.16	0.11	0.39
Longitudinal Dispersivity [mm]	9.0	9.6	8.1

Further evaluation of the fitting parameters has produced the thickness of the layers characterized by different conductivities. The modelling of the flux weighted concentration curve showed that the local "heterogeneity", which was installed in the aquifer-model, could be found and quantified with the MFDM. The calculated thicknesses of the layers agree well with those installed in the indoor aquifer system model (Fig. 3), which validated the mathematical approach used. Modelling of both tracers produced practically the same values of system parameters, which can be considered as additional, indirect validation of the MFDM.

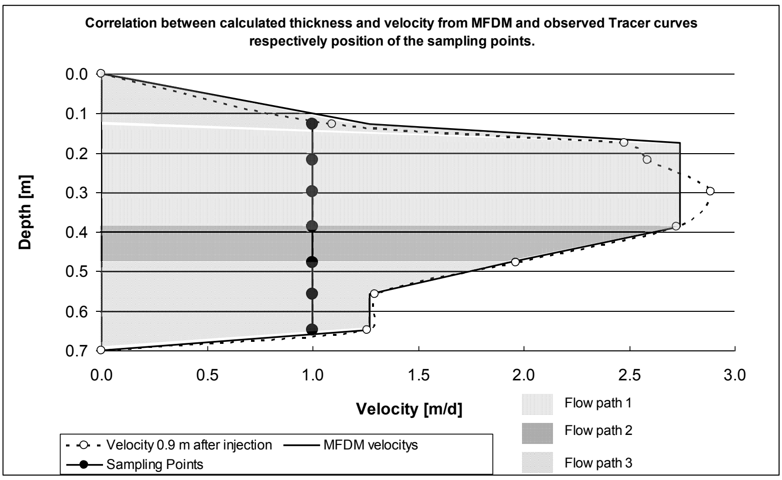

Figure 3. Velocities from the Multi-Flow-Dispersion Model; all three flow paths with the calculated thickness of each flow path.

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abstract id: **472**

topic: **5**
Data processing in hydrogeology

5.2
Groundwater flow and solute transport modelling

title: **The velocity oriented approach revisited**

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keywords: groundwater flow modeling, velocity oriented approach, continuity of water flux

INTRODUCTION

Many hydro-geological situations require an extremely accurate quantification of the 3-dimensional groundwater flow velocity in the subsoil. Examples are: hydrology of wetlands, water balances of aquatic ecosystems depending on groundwater recharge, river-groundwater interaction, advective transport of pollution underneath waste disposal sites, particle trajectories in aquifer-aquitard systems with contrasting heterogeneities, and many others. A notoriously difficult problem is the numerical determination of the *vertical* component of the groundwater velocity. This component may be two or three orders of magnitude smaller than the horizontal velocity components. Application of Darcy's law to numerically calculated hydraulic heads may lead to a relatively inaccurate vertical velocity component. In cases where the Dupuit approximation—negligible vertical head gradient—holds, numerical differentiation of hydraulic head yields zero vertical velocity.

THE VELOCITY ORIENTED APPROACH IN THREE DIMENSIONS: STREAM FUNCTION BASED

In the 1980s Nawalany and Zijl started to consider 3-dimensional groundwater flow in the context of what they called Flow Systems Analysis (also see Tóth, 2009). In Flow Systems the small vertical velocity component plays an important role (Nawalany, 1986a, 1986b; Zijl and Nawalany, 1987, 1990). Similar to what was accepted practice for 2-dimensional flow, it was proposed to invert the order of calculating 3-dimensional flow by eliminating the hydraulic head from Darcy's law. This 3D extension was called the velocity oriented approach (VOA). Indeed, Darcy's law $\underline{k}^{-1} \cdot \vec{q} = -\nabla \varphi$—in which the head occurs—is equivalent to $\nabla \times \underline{k}^{-1} \cdot \vec{q} = \vec{0}$— from which the head is eliminated. In addition, the continuity equation $\nabla \cdot \vec{q} = 0$ is equivalent to $\vec{q} = -\nabla \times \vec{\psi}$, where vector $\vec{\psi}$ is the 3-dimensional stream function. Substitution into the equivalent of Darcy's law yields $\nabla \times \underline{k}^{-1} \nabla \times \vec{\psi} = \vec{0}$. After having solved this equation the Darcy velocity $\vec{q}$ can be calculated. Finally, the head is calculated from the head equation $\nabla \cdot \underline{k} \cdot \nabla \varphi = 0$. The equation for the 3D stream function has not the same form as the equation for the head. This means that conventional finite element techniques for determination of the head cannot be applied to the stream function formulation.

THE VELOCITY ORIENTED APPROACH IN THREE DIMENSIONS: VELOCITY BASED

To overcome this disadvantage, not the three stream function components, but the two horizontal head gradients $e_x = q_x / k_h$, $e_y = q_y / k_h$ and the vertical Darcy velocity q_z have been chosen as the primary variables. For a perfectly layered aquifer-aquitard system in which the hydraulic conductivities $k_x = k_y = k_h(z)$ (horizontal) and $k_z(z)$ (vertical) vary only in the vertical z direction, the equations to be solved are

$$\nabla \cdot \underline{k} \cdot \nabla e_i = \frac{\partial}{\partial x} k_h \frac{\partial e_i}{\partial x} + \frac{\partial}{\partial y} k_h \frac{\partial e_i}{\partial y} + \frac{\partial}{\partial z} k_z \frac{\partial e_i}{\partial z} = 0, \; (i = x, y), \tag{1.1}$$

$$\nabla \cdot \underline{\kappa}^{-1} \cdot \nabla q_z = \frac{\partial}{\partial x} \frac{1}{k_z} \frac{\partial q_z}{\partial x} + \frac{\partial}{\partial y} \frac{1}{k_z} \frac{\partial q_z}{\partial y} + \frac{\partial}{\partial z} \frac{1}{k_h} \frac{\partial q_z}{\partial z} = 0 \tag{1.2}$$

Indeed, the above equations have the same form as the equation for the head

$$\nabla \cdot \underline{k} \cdot \nabla \varphi = \frac{\partial}{\partial x} k_h \frac{\partial \varphi}{\partial x} + \frac{\partial}{\partial y} k_h \frac{\partial \varphi}{\partial y} + \frac{\partial}{\partial z} k_z \frac{\partial \varphi}{\partial z} = 0 \tag{2}$$

which means that standard finite element techniques can be applied (Nawalany, 1987a, 1987b, 1990, 1992).

Good results have been obtained with this version of the velocity oriented approach (VOA) in combination with the conventional node-based finite element method. It has been proven to yield a high accuracy for all three components of the Darcy velocity, including the relatively small vertical component; see Figures 1a-b. In addition, this VOA version has successfully been used to analyze the Dupuit approximation in aquifer-aquitard systems (Zijl, Nawalany, 1993).

a)
b)

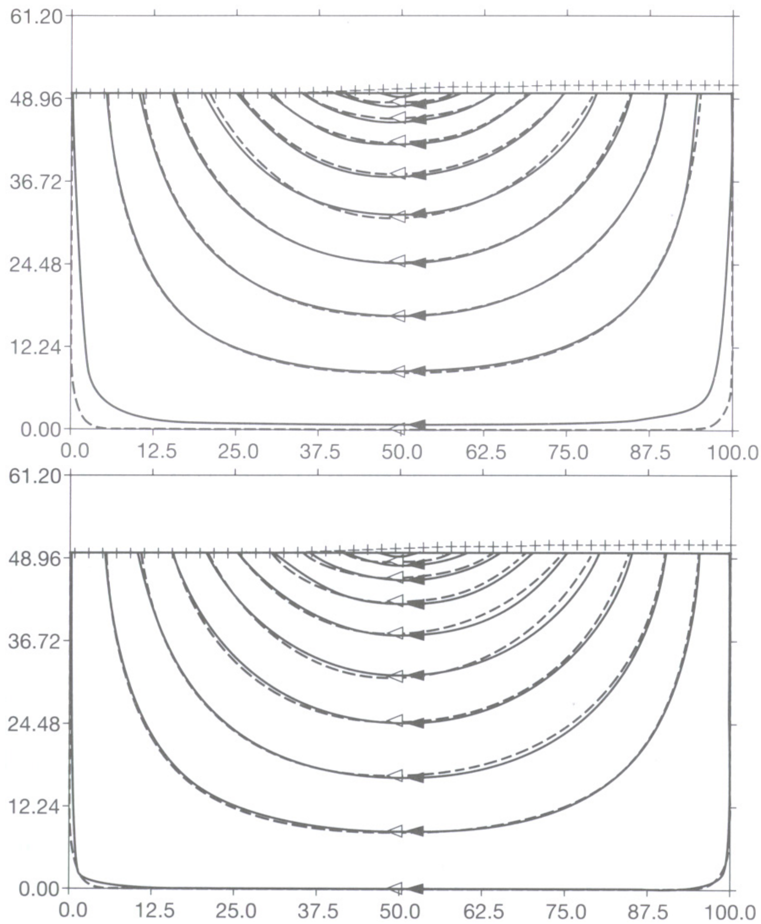

Figure 1. (a) Trajectories of water particles; (---) analytical solution, (—) finite element solution of velocity oriented approach; 605 nodes (121 horizontal × 5 vertical); (b) Trajectories of water particles; (---) analytical solution, (—) finite element solution of conventional head-based approach; 67240 nodes (1681 horizontal × 40 vertical).

It is important to note that equation (2) holds for all types of heterogeneity pattern of the hydraulic conductivity, while equations (1) hold only for perfectly layered patterns. To account for general heterogeneity additional terms can be added, but in these terms horizontal derivatives of the conductivities occur. This limits application of the velocity oriented approach to horizontally smoothly varying aquifer-aquitard systems. The remedy to overcome this disadvantage is the development of numerical techniques for the 3D stream function that differ from the techniques used for the head. In the 2000s Zijl and Nawalany (2004) found that a 3-dimensional stream function is feasible in the context of the finite volume method (FVM) and the mixed hybrid finite element method (MHFEM).

THE VELOCITY ORIENTED APPROACH IN THREE DIMENSIONS: STREAM FUNCTION BASED

Now we are in the right position to relate the velocity oriented approach (VOA) to the popular finite volume method (FVM) and its extension to non-rectangular grid volumes and general anisotropy, the mixed hybrid finite element method (MHFEM). In the velocity oriented approach the head is eliminated from Darcy's law. In addition stream functions $\Psi = (\Psi_1,\ldots,\Psi_{N_E})^T$ are introduced along the edges of the grid. The discretized system of algebraic equations for the stream function is $R^T \Gamma R \Psi = R^T \Pi$. Matrix R is the grid's incidence matrix relating faces to edges. Array Π contains the head boundary conditions. Impedance matrix Γ contains the metrics of the grid combined with the inverses of the grid block conductivities. Using the simplest form of impedance matrix Γ the stream function equation is equivalent to the FVM (Mohammed, 2009; Mohammed et al., 2009). With a Galerkin-based Γ this equation is equivalent to the MHFEM. For details see the original introduction by Zijl and Nawalany (2004), who used the Galerkin-based VOA for generally shaped grid volumes and general anisotropy.

As an example we show 2-dimensional flow to a fully penetrating well. The 3-dimensional flow domain has a thickness of only one edge length (1 m) in the vertical direction. The grid consists of 225 grid blocks, 15 rows and 15 columns. The grid spacing in the horizontal directions equals 10 m. A well with a flow rate of Q = 100 m^3/day is situated in the central grid block (see Figure 2). Half of this flow rate is abstracted from the top face and half of it is abstracted from the bottom face of the well grid block.

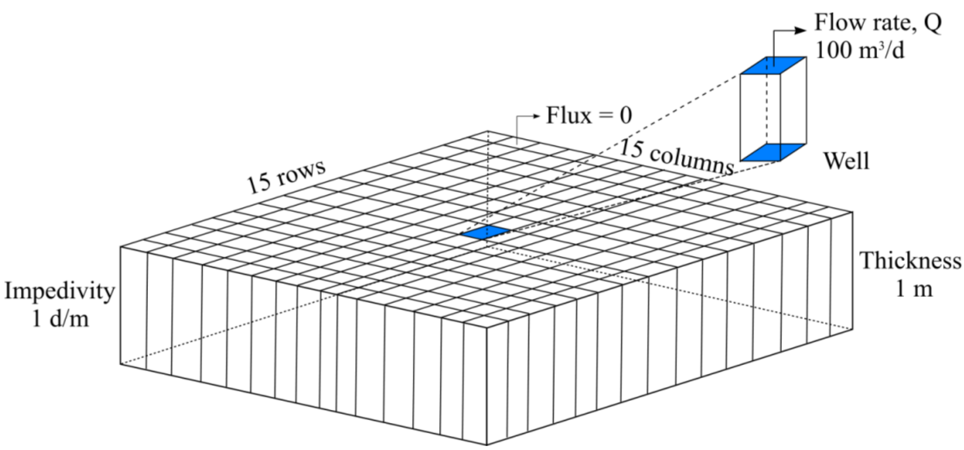

Figure 2. Illustration of the simulated system for the example.

Head boundary conditions were derived from the exact solution $\varphi = \gamma Q \ln r / 2\pi$, where $\gamma = k^{-1}$ is the impedivity (the inverse of the hydraulic conductivity), and $r = (x^2 + y^2)^{1/2}$. A stream function honors the continuity equation automatically, which means that for each internal grid block the inflow equals the outflow. Nevertheless, it is possible to apply a 2D stream function provided that the modeling domain is bounded by the positive *x* axis, with continuity of the Darcy velocity at $y = 0$ as boundary condition. Boundary conditions on such "cuts" in the modeling domain may be considered as a disadvantage of the stream function, especially if there are many wells in the modeling domain. This disadvantage is mitigated by introduction of the 3D stream function. In that case there is no need for cuts, because the nonzero flow into or out of the well grid block is arranged via the well grid block's top and bottom face. For more details of this particular example and of other examples see Mohammed (2009) and Mohammed et al. (2009).

SUMMARY, CONCLUSION AND FUTURE WORK

Although well developed, theoretically sound and applicable to complex subsoil conditions (3-dimensional heterogeneity and anisotropy of rocks), the VOA method still does not find its way in general practice, as it possibly deserves. On one hand it promises to keep continuity and sufficient accuracy of the Darcy velocity in all three dimensions once the equations for the 3D stream function are solved. Applications that require a very accurate numerical estimation of relatively small vertical velocities, or require that the continuity equation is honored exactly, are becoming more and more important. Subtle water fluxes that need to be estimated in eco-hydrological studies when assessing through-flows and mass transport within wetlands, or highly accurate calculations of inverse trajectories needed when trying to detect unknown sources of groundwater pollution are examples in which VOA might offer the expected solution. On the other hand, until recently the VOA, when applied to complex hydrogeological situations, has been considered "too complicated" even after (or, perhaps because of) adopting the existing (marketable) finite volume or finite difference software packages. It seems that, in order to get a breakthrough and to make VOA more popular, an appealing case study is needed (and financed). In this case study it can be clearly shown that that the accurate and continuous (exactly honoring the continuity equation) 3-dimensional estimate of the Darcy velocity is superior to the classical head-based approach. The superiority is to be well defined, either in terms of ultimate economics of the case, or just in terms of scientific accuracy of the physically estimated variables, or both.

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5.3 Groundwater mapping — approach and results

abstract id: **132**

topic: **5**
Data processing in hydrogeology

5.3
Groundwater mapping — approach and results

title: **Geostatistics tools for characterizing the spatial variability of groundwater temperature in Veneto region**

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keywords: geostatistics, kriging, indicator kriging, prediction, error variance

INTRODUCTION

The principal tool of most geostatistical analyses is the variogram, a function that relates the average squared difference between paired data values to the distance (and direction, where anisotropy is considered) by which they are separated. A theoretical variogram may be fitted to the experimental variogram. The model variogram obtained allows to assign the weights in the ordinary kriging prediction (Isaaks, Srivastava, 1989; Goovaerts, 1997). Kriging provides at every grid node the value prediction and the prediction error variance. In particular the use of indicator kriging in most earth science applications, and from the main reasons for its introduction, is both because is a non-parametric method and is a technique which allows to use together populations and qualitative data (Andrew et al., 2000).

METHODS

The dataset consists of 145 temperatures of groundwater measured in Veneto (NE, Italy) region until 100 m in depth. The software used in this geostatistical analysis is R (R Developed core team, 2009), and in particular its “gstat” package, which provides a flexible suite of prediction tools.

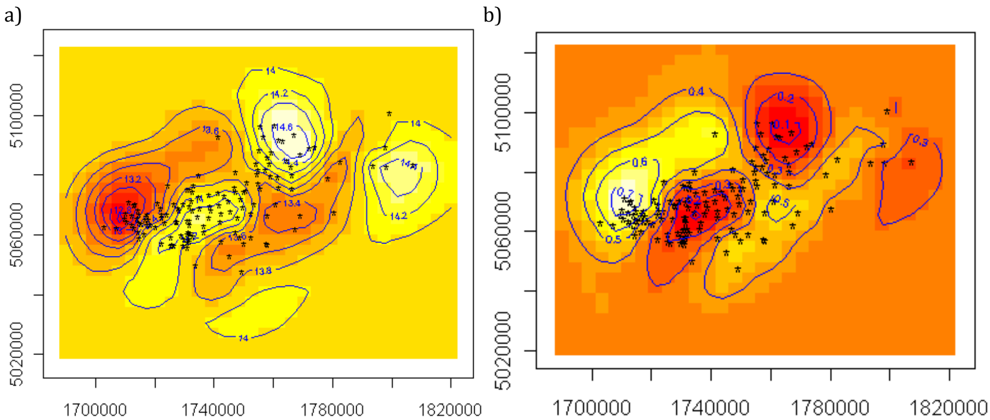

Figure 1. Prediction map of groundwater temperature distribution in Veneto region: a) Ordinary kriging; b) Indicator Kriging for the first quartile (< 13°C).

Using indicator kriging: three thresholds were selected as follow: (first quartile) is 13°C, (median) is 14°C and (third quartile) is 15°C, of the qualitative distribution function (c.d.f) of the temperature data. At every cutoff experimental variogram was calculated and then a theoretical variogram was fitted. Moreover the theoretical variogram of temperature was fitted based on the experimental one.

RESULTS

Figure (1a) shows the Ordinary Kriging results with a high groundwater temperatures concentrated in North eastern and in the middle part of the study region (14.1–14.5°C), but most of the highest values were found in the center of the region. The lowest values of temperature were found in the West part of the studied area (13–12.5°C). According to figure (1b) for indicator kriging, the groundwater temperature values are lower than 13°C in the North western Veneto, where the probability is close to 1.

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IAH 2010 Krakow

abstract id: **393**

topic: **5**
Data processing in hydrogeology

5.3
Groundwater mapping — approach and results

title: **Groundwater resource assessment in hard-rock systems (Central Portugal): coupling GIS mapping, hydrogeomorphology and hydrogeology aspects**

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keywords: groundwater, hydrogeomorphology, GIS mapping, central Portugal

Integrated studies were implemented for studying groundwater resources in Central Portugal. Understanding the role of geomorphology is essential to accurately assess hydrogeological systems and groundwater resources. Hard-rock watersheds provide a source of valuable water resources at a local level. They commonly exhibit complex geological bedrock and morphological features as well as distinctive gradients in rainfall and temperature. GIS tools provide an accurate way to improve the knowledge about groundwater and surface water circulation model and the overall functioning of the study aquifer system and can help the decision makers and managers to achieve a sustainable use of the groundwater resources of the a given area. This is particularly important regarding the existing hydromineral systems, a resource of high economical importance considering its utilization in the thermal spa and bottled water industry. Furthermore, groundwater from hard-rock aquifer systems is an important water source for several domestic, industrial and agricultural purposes, as well as for public supply for small communities.

A comprehensive integrated groundwater resources study has been carried out at *Cova da Beira* region (*Serra da Gardunha*) for some hydromineral systems in Central Portugal, coupling hydrogeomorphology, hydrogeology and GIS mapping techniques. Thematic maps were prepared from multi-source geodata namely satellite imagery, topographical and geological mapping and other hydrogeological field data. These maps were converted to GIS format and then integrated using GIS software with the purpose of elaborating a hydrogeomorphological map intended to delineate the infiltration and recharge potential areas.

This work highlights the importance of hydrogeomorphological cartography and groundwater GIS mapping as useful tools to support hydrogeological conceptualization, as well as for decision-making at a basin master plan level regarding land, water resources and sustainability.

IAH 2010
Krakow

abstract id: **522**

topic: **5**
Data processing in hydrogeology

5.3
Groundwater mapping — approach and results

title: **Groundwater resources and environmental geological map of Asia**

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keywords: Asia, groundwater resources, environmental geology, mapping

ABSTRACT

With the rapid economic development in Asia, water resources need more and more. Water shortages have taken place in many countries and become more and more serious. Human activities have impacted groundwater resources and made water supply security threatened in some areas. In order to strengthen international cooperation in Asia and make a better understanding of groundwater resources and environmental conditions, the China Geological Survey organized groundwater resources and environmental geological mapping of Asia. The map compilation mainly includes Map of Hydrogeology in Asia; Map of Groundwater Environment in Asia; Map of Groundwater Resources in Asia; Map of Geothermal Resources in Asia. The work on the compilation started from the comprehensive analysis of groundwater resources and environmental geology in Asia, meanwhile, the remote sensing, GIS and internet have to be used to establish the dynamic information platform of groundwater resources and environment for share. The final fruit is the compilation of Groundwater Resources and Environmental Geological Map in Asia. It is really an important job, which will fill the blank of the continental water resources and environmental geology maps, help to make more effective management of groundwater resources in Asia and build a harmonious international environment.

INTRODUCTION

With the social and economic development in Asia, human activities have become increasingly serious to damage groundwater environment and water resources and geological environment changes threat and impact the living environment and economic sustainable development in Asia. Compilation of groundwater resources and environmental geology in Asia taken as an international cooperative program is of great importance to develop the Asian economy and geological disciplines. Groundwater resources and environmental geology map series is a large multi-objective, multi-level, multi-dimensional and multi-factor system in Asia. This paper looks back and forward in recent decades the status, role and trends of the groundwater resources and environment-related research and proposes a new mapping resources, groundwater environment research levels, meanwhile, the international cooperation and the harmonious development between water resources and environment will be built up in Asia.

THE RECENT DECADES OF DYNAMIC GEOLOGICAL MAP IN ASIA

China started to work on the geological compilation in Asia in the duration of the late 1970s' and 1980s' when Prof. Ting-Dong Li in Chinese Academy of Geological Sciences made the edition of the "Geological Map of Asia" (1:5,000,000), which concluded a systematic summary of the regional geology in China and the development and characteristics of igneous rocks in Asia. It is divided into three geotectonic zones and five evolutional stages with magmatic activities of inheritance, differentiation, zoning and migration and the characteristics of evolution. In 1990s', a number of Chinese and Russian scientists cooperated together to compile "Map of Asia and Adjacent Area Land and Sea Topography" (1:8,000,000) edited by Prof. Chen Zhiming. This map is not only the contribution to the development of global geomorphology and plate movement, but the important practical value to the other Earth scientific applications, especially earthquakes and volcanoes and other endokinetic disasters and satellite positioning systems etc.

W.F. Struckmeter and W.H Gilbrich et al. made the map "Map of Global Groundwater Resources" (1:24,000,000) in 2006,which described the global distribution of groundwater resources and aquifers comparison to each other, while the term of trans-boundary aquifers was used firstly in the legend. China Environmental Monitoring Centre compiled "Geothermal Resources Map of Asia" (1:8,000,000), which systematically summarized the distribution of geothermal resources in Asia, and reflected the relations between geothermal water and the regional geological conditions. Prof. Zhang Zonghu edited "Hydrogeological map of Asia" (1:8,000,000) in view of the global water cycle, which described circulation between groundwater and surface water in Asia and reflected groundwater variation in different hydrogeological conditions.

Commission for the Geological Map of the World has organized and compiled a series of geological maps of the continent, the ocean and the world over years and the publication of the maps since 1999 includes Geological Maps of Asia in the following:

- Geological Map of the World (1:125,000,000 in 2000);
- Geological Map of the World (1:150,000,000 in 2001);
- Seismic Structure Map of the World (1:125,000,000 in 2001);
- Seismic Structure Map of the World (1:150,000,000 in 2002);
- Geological Hazards Map of the East Asia (1:177,000,000 in 2002).

The study on groundwater resources and environment exists in big difference in different countries in Asia. The compilation lies the same with big difference. The regional research results are not many and most of the maps are confined to one's country or region such as the Map of Hydrogeology of Soviet Union, Map of Hydrogeology of India, Map of Hydrogeology of Japan, Map of the Regional Distribution of Geothermal Resources occurrence. However, the previous studies still have some shortcomings. The compilation of groundwater resources and groundwater environment is still blank. Groundwater resources and environment compilation in Asia is reflecting the mapping status and summary of Asian countries for decades. The geological, tectonic, geomorphological conditions in the new compilation will conduct the geological research summary, analysis, preparation of water resources and environmental geology of Asia series map with great necessity and practicality.

BASIC PRINCIPLES OF THE COMPILATION

Groundwater resources and environment compilation in Asia has the basic principles as follows:

- Principle of unity for mapping technical specifications: work out the specific mapping method for groundwater resources and environment compilation with the Asian geological features as zoning compilation and summing up the zoning maps with unified principles;
- Principle of International mapping technology combined with groundwater resources and environmental characteristics in Asia to learn from the recent international publication combined with characteristics of groundwater resources and environment in Asia;
- Principles of both the traditional compilation and the technological innovation to apply the past geological mapping method, while the technological innovation of mapping content, concepts, methods and technical means for compilation should be reflected in the maps;
- Principles of the Asian countries and regions which co-ordinate the information of groundwater resources and environmental studies whether they have rich information or

poor information concerned with their research level, make an arrangement of compilation of both in high degree of information-rich countries and outline mapping technology, and at low levels of co-ordinating research, data compilations in the information-lacking regions;

- Principles of coordinating zoning compilation and summing-up the total results can be strengthening the international cooperation with the unified outline of compilation, organizing the full work through the unified mapping outline in the Asian region.

MAIN CONTENT OF THE ASIAN GROUNDWATER RESOURCES AND ENVIRONMENT

The map series include Hydrogeological map in Asia, Groundwater Resources Map in Asia, Groundwater environment map in Asia, Geothermal Resources Map in Asia and the content is expressed as follows:

- Hydrogeological Map in Asia: The main content of the map describes shallow groundwater distribution and migration, reflecting the different groundwater storage in the hydrological circulation alternating with water yield capacity. Mapping follows the three types of pore water, fissure water, karst water, and the hydrogeological conditions based on different water yield capacity will be divided into five grades. The recharge, runoff and discharge form of groundwater reflects the unique structure of the aquifer. There are special types (multi-layer structure porous aquifer, karst fissure water and pore water distribution basin). Natural outcrop of groundwater (big spring, underground rivers, hot springs, lagoons, etc.) is leading to the special characteristics of groundwater.
- Groundwater Resources Map in Asia: This map is to evaluate groundwater resources in various countries or regions based on the results of data. The basis comes from the ocean, large-scale hydrogeological control structure for the unit and the main river system. It also takes into account the large region's (country) results of groundwater resources evaluation. Zoning: groundwater resources, groundwater types and other boundaries. Mapping is based on the different groundwater types, natural groundwater recharge area for the modulus of the basic evaluation unit, in the map form to express groundwater and its exploitation, the spatial distribution of resources. Groundwater resources based on topography, climate, hydrology, aquifer recharge media can be divided into five grades. And the deep groundwater should be evaluated by the storage capacity of groundwater.
- Groundwater Environment Map in Asia: The map shows the appropriate spatial distribution of groundwater quality, original chemical components that threaten to human existing environment, unreasonable exploitation of groundwater induced environmental hazards. It includes the spatial distribution of groundwater quality status, chemical composition anomalies, hydrogeochemical zoning according to the main chemical types and groundwater quality to represent the sub-regional level. It can express the special vertical distribution.
- Geothermal Resource Map in Asia: The map shows the geological structure and features, and it is divided into three zones as volcanic geothermal areas, uplift fissured geothermal areas and sedimentary basin geothermal areas. The main features are thermal structure lines, typical hot springs, well outcrop and the point special chemical composition.

GEOLOGICAL FEATURES OF GROUNDWATER RESOURCES AND ENVIRONMENT MAP SERIES

This map series reflects guiding theory of the academic hydrogeologists in Asia, who consider the content of the maps. The maps show the recent study of groundwater resources and environment in the form of the map expressions in Asia. Groundwater resources and environment is of great importance of the research (Longrui et al., 1995).

Hydrogeologists use the map as a language to tell groundwater resources and environmental information in Asia to the planners, decision-makers how to use groundwater resources and to protect water environment. Symbols on the map are almost graphic. Map as an objective awareness and research results, may reflect a variety of natural and social phenomena of the spatial distribution. And it is objective awareness and research tool to gain new knowledge (Jun, 1986). Groundwater resources and environmental geology map series with the content of hydrogeology, groundwater resources, groundwater and geothermal resources in different colors, lines, symbols, digital etc. can guide the reader, and it has the following characteristics:

- A comprehensive range of services: It serves the entire Asian region, involving the whole Asia, water resource management to maintain the sustainable development of ecosystem services and to keep the steady development of the economy in Asia.
- To reveal the major issues of groundwater resources and environment: water is the basis of socio-economic development, environmental protection. However, poor management of water resources often exists, so people must manage it properly. Better management of water issues achieves better solutions (UNESCO, 2008). Groundwater resources and environmental geology maps for the country or between countries can develop sound water resources management policy.
- Water and ecological security: In recent decades, declining water quality, over-exploitation, hydrology and land deterioration and threats to river basin have negative impact on human health and the economic and social development. The map series can be a very good understanding of the human-environment systems to provide better ecosystem management. The lack of water can threat to social sustainability, especially in arid and semi-arid areas, coastal regions and small islands and the area with population density, industrial active regions. The maps will provide scientific support to achieve the minimum energy demand and ensure supply security.
- Informative and wide-ranging: Map covers the whole Asia groundwater resources and environmental geology. Compilation with full contents of the Asian continent groundwater and geological environment may reflect the conditions of groundwater storage, groundwater quality and environmental impact by human activities on groundwater situation. It also reflects the natural geological environment in Asia such as lithology, geological structure, hydrogeological conditions, groundwater resources, water chemistry and so on. Thematic content researches on the adjacent transboundary and transregional aquifers, analyzes regional groundwater resources and environmental geology related to current situation, problems and causes. During economic construction and development, the potential geological disasters, such as land subsidence, seawater intrusion, karst collapse, the soil saline and so on may occur.

- It demonstrates the characteristics of groundwater resources and environment in Asia. The mapping content and methods is fully based on the characteristics of topography and geological structure, groundwater media division, water resource amount, water environment, which display the comprehensive evaluation of resources and environmental features, especially for thick Quaternary aquifer, Mesozoic pore-fracture aquifer, water quality, and involves in the innovative characteristics.

MAPPING TECHNICAL METHOD

This compilation reveals the main characteristics of geological environment and groundwater on the Asian continent. The map will reflect the objective conditions of groundwater storage, groundwater resources, geothermal resources and so on. Collection of national data can keep the future international cooperation and organization and coordination.

The Asian continent can be divided into East Asia, Central Asia, West Asia, North Asia, South Asia and Southeast Asia by geographical location of which each region can select a lead country responsible for collecting the groundwater resources and environmental geology information. After the data collection, it should be classified into the national distribution of groundwater resources, groundwater type, chemical types and distribution of groundwater quality etc. In addition to geological phenomena, there are some special information, such as spring, land subsidence, volcanoes, lagoons and so on. The remote sensing can help the low study level country for more information what we need. Analysis of data and integrating with the same method, according to different regions of groundwater resources and environmental geology, can prepare for a working basis of the map series.

Use of existing mature technology, combined with Asian characteristics of groundwater resources and environmental data and requirements, can establish data processing and application system and the initial construction of groundwater resources and environment dynamic information platform. In the process of establishing the database, the formation of a database can be set up. Through its new database, using geographic information system (GIS) technology, a dynamic groundwater resources and environment information management system will be birthed for international sharing and updates in Asia.

Establishment of an international cooperation organization for mapping needs expert consultation to develop the outline, standard, uniform terminology and accuracy to harmonize map content and mapping method.

Mapping innovation should be on these points: 1) make full use of satellite remote sensing to address the low level research and the issue of lacking information areas to supplement the existing data in the compilations of the deficiency; 2) use of geographic information systems (GIS) and network set up groundwater resources and environment and dynamic information platform for data sharing and update; 3) analog technology should be used to balance the relevant information for intercontinental difference in regional compilations at scales; 4) Comparison of trans-border aquifers technology, research in the same river basin for water resources between countries can solve the development and utilization of environmental and geological problems; 5) In the hydrogeological map, some special types such as multi-structure of porous aquifers, fracture-pore groundwater may often be ignored or their definition of ambiguity can be expressed through symbols in the map.

APPLICATION OF THE MAP SERIES

Groundwater resources and environmental geology map series for the Asian countries can provide a scientific basis on groundwater development and utilization of natural resources, resource planning, environmental protection and disaster prevention to improve understanding of groundwater resources and environment.

Mapping by the advanced idea and methods can enrich the map content. The new set of the outline and the unified standard for the future small-scale maps may provide a useful reference value. The study on transboundary aquifer makes a proposal for settlement of groundwater pollution caused by human activities. On the international front, multi-national cooperation needs through the equality of sharing international cooperation.

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abstract id: **523**

topic: **5**
Data processing in hydrogeology

5.3
Groundwater mapping — approach and results

title: **A web map service of groundwater background values in Germany**

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keywords: EU Water Framework Directive, groundwater chemistry, background values, statistical evaluation

INTRODUCTION

One of the main objectives of the EU Water Framework Directive (WFD 2000) is to achieve a good chemical status of groundwater bodies. This requires the member states to determine the status of groundwater bodies and to define parameter specific threshold values that allow the identification of groundwater bodies at risk of failing to achieve good groundwater chemical status. Therefore intensive efforts were taken in Europe to identify suitable methods for the derivation of natural background levels and groundwater threshold values (Hinsby et al., 2008). As the natural composition of groundwater is mainly related to the rock type of aquifers, the geological surveys of Germany consequently started a joint project aimed at determining background levels of groundwater related to geology. The statistical analysis was based on hydrogeochemical rock units, derived from the Hydrogeological Map of Germany 1:200.000 (SGD 2009). A large number of naturally occurring major and trace elements were examined. The outcome is a nationwide map of the background levels of groundwater in Germany.

METHODS

The physical and chemical properties of groundwater are mainly determined by the composition of the seepage water, its alterations during passage through the unsaturated zone, the lithology of the aquifer and travel time of the groundwater. The natural geogenic properties of groundwater result from a dynamic equilibrium of groundwater and the rock surface, where complex chemical, physical and biological processes take place. Ancient groundwater in greater depth is mainly influenced geogenically, while younger and shallow waters tend to show more influences from the surface including anthropogenic indicators. In such groundwater pure geogenic properties often cannot be found anymore and in many cases the background values show a more or less prominent anthropogenic influence.

For the study presented here groundwater analyses from about 48,000 sampling points distributed over all of Germany measured between 1980 and 2005 were collected in a database. Samples with a known anthropogenic point influence such as from landfills were discarded from the dataset. As basis map the digitally available Hydrogeological Survey Map of Germany 1:200,000 (http://www.bgr.de/Service/grundwasser/huek200), which contains more than 1100 hydrogeological units, was aggregated into a map of nearly 200 hydro-geochemical units (HGU). The outcrops of this map represent the geology of the upper aquifer. A HGU represents a hydrogeological unit with a characteristic distribution of background values in its groundwater. Those distributions can be described statistically e.g. by box-whisker-plots. The statistical analysis was performed using probability plots, separating the anomalies of a data set from the underlying normal population. The 90th-percentiles of this population are defined as the parameter specific groundwater background values. The procedure is described in detail by Walter et al. (2010).

SPECIFICATIONS OF THE WEB MAP SERVICE

The results of the data analysis are available as a web map service (WMS) via the internet. At present the language is German but an English extension is in planning.

The WMS can be accessed via an internet address (URL with or without parameters):

http://www.bgr.de/Service/grundwasser/huek200/hgc_p90/

http://www.bgr.de/Service/grundwasser/huek200/hgc_p90/?REQUEST=GetCapabilities&VERSION=1.1.1&SERVICE=WMS

With this technology the background values of the units can be shown in maps and info queries can be launched. For visualisation WMS-capable programs like Google Earth, ESRI ArcGIS or an internet map-browser are necessary. At http://geoviewer.bgr.de/ the WMS has already been integrated and can be viewed.

The WMS contains 85 different data layers. A total of 40 parameters as listed in table 1 are shown in the WMS. Only naturally occurring inorganic parameters were taken into account, including relevant trace elements.

Table 1. Groundwater parameters shown in the web map service.

Major elements		Trace elements		Physico-chemical parameters
sodium (Na)	aluminium (Al)	strontium (Sr)	zinc (Zn)	total hardness
potassium (K)	ammonium (NH_4)	silver (Ag)	arsenic (As)	spec. electrical
calcium (Ca)	boron (B)	bismuth (Bi)	cadmium (Cd)	conductivity
magnesium (Mg)	barium (Ba)	cobalt (Co)	chrome (Cr)	pH-value
chloride (Cl)	bromine (Br)	copper (Cu)	mercury (Hg)	
sulfate (SO_4)	fluoride (F)	lithium (Li)	molybdenum (Mo)	
hydrogen carbonate	iron (Fe)	nickel (Ni)	lead (Pb)	
(HCO_3)	manganese (Mn)	antimony (Sb)	selenium (Se)	
	phosphate (PO_4)	tin (Sn)	thallium (Tl)	
	silicate (SIO_2)	uranium (U)	vanadium (V)	

For each parameter two layers are being provided: the parameter specific maps show the hydro-geochemical units in colours, shaded in 5 classes depending on the specific background values. The background values are represented by the 90th-percentiles of the statistical evaluation of the measurements within the areal extent of the respective HGU. Fig. 1 shows the map of background values of hydrogen carbonate for Germany. The northern part of Germany, which is depicted in a grey colour, is still in progress, because in this area the hydrogeological units showed distinct spatial variations of the hydro-geochemical properties. Therefore the HGUs cannot be determined by an aggregation of units but instead a subdivision of the units is necessary. Full coverage of Germany is expected until 2011. However, available point data are being provided for this area in the WMS.

After choosing a parameter of interest from the list, the WMS provides an overview map of Germany with the distribution of background values for this parameter. Zooming in is possible through the functionality of the browser.

Upon clicking on the polygon of a HGU an info menu is being activated and the window shown in figure 2 opens, presenting numerical values of the statistical data. The position of the HGU chosen is highlighted in an inserted map (Fig. 2, right bottom) in yellow. The following data are provided: name and size of the HGU and statistical parameters (percentiles) of the distribution of the geogenic basic population of the parameter in the respective unit. The percentiles are being illustrated by a box-whisker-plot (Fig. 2 right top).

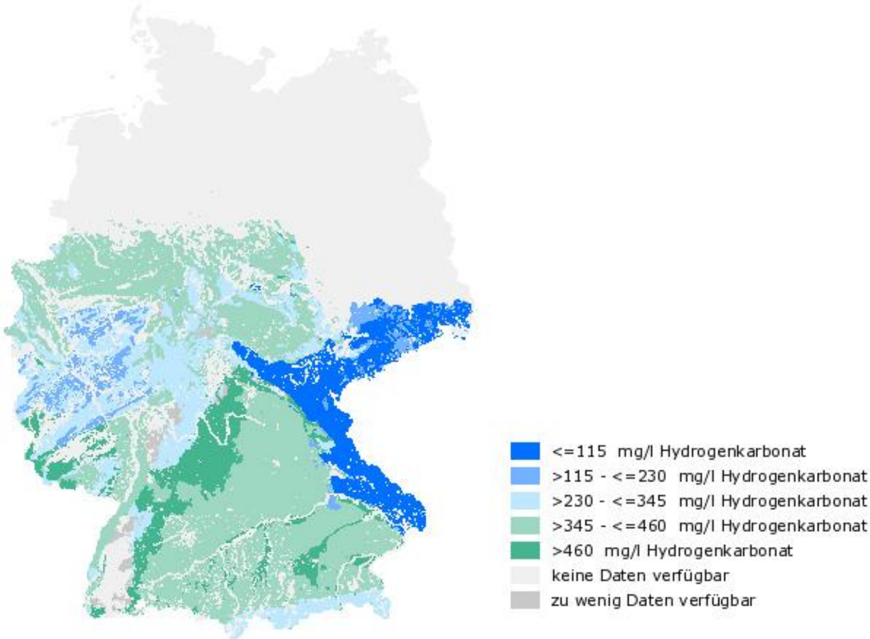
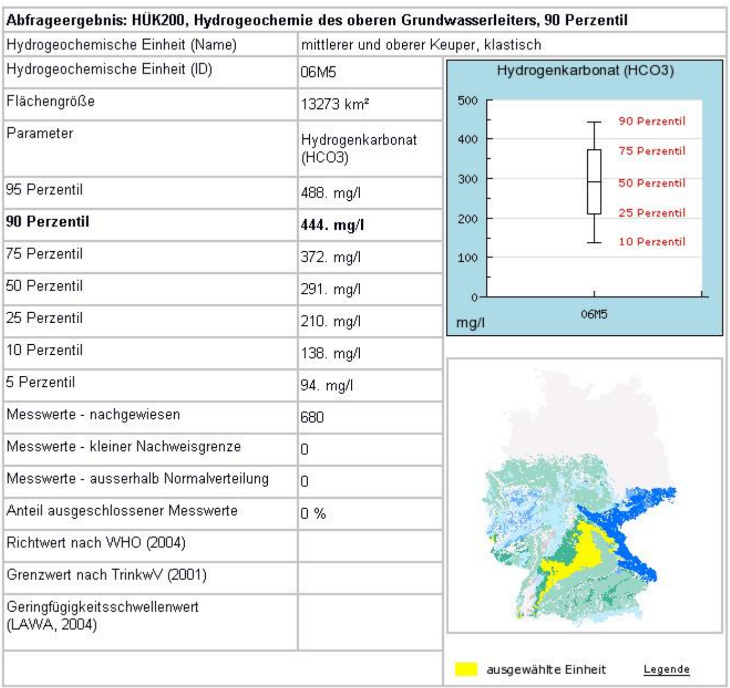


Figure 1. Map of the background values of groundwater in Germany for the parameter hydrogen carbonate.



Abfrageergebnis: HÜK200, Hydrogeochemie des oberen Grundwasserleiters, 90 Perzentil	
Hydrogeochemische Einheit (Name)	mittlerer und oberer Keuper, klastisch
Hydrogeochemische Einheit (ID)	06M5
Flächengröße	13273 km²
Parameter	Hydrogenkarbonat (HCO3)
95 Perzentil	488. mg/l
90 Perzentil	**444. mg/l**
75 Perzentil	372. mg/l
50 Perzentil	291. mg/l
25 Perzentil	210. mg/l
10 Perzentil	138. mg/l
5 Perzentil	94. mg/l
Messwerte - nachgewiesen	680
Messwerte - kleiner Nachweisgrenze	0
Messwerte - ausserhalb Normalverteilung	0
Anteil ausgeschlossener Messwerte	0 %
Richtwert nach WHO (2004)	
Grenzwert nach TrinkwV (2001)	
Geringfügigkeitsschwellenwert (LAWA, 2004)	

Figure 2. Result of an info query of a hydro-geochemical unit (depicted in yellow) for the parameter hydrogen carbonate, obtained upon clicking on a polygon of the unit.

Besides the spatial illustration of the background values, the measuring points used for the statistical evaluation are also shown in the WMS. In analogy to the polygons, the point data are coloured in 5 classes depending on the measured values of the parameters. Point data are depicted in circles, when they represent the HGU shown in the polygon where they are located, and in triangles, when they belong to a different HGU i.e. in most cases an underlying deeper HGU. An example is shown in figure 3. Again an info query is possible by clicking on one of the measuring points, which yields further information (name of allocated HGU, measured value of chosen parameter, filter depth). Depicting the point data enables the user to crosscheck local situations of measured parameter values and thus to relate the statistical data determined for the HGU to the actual situation in an area.

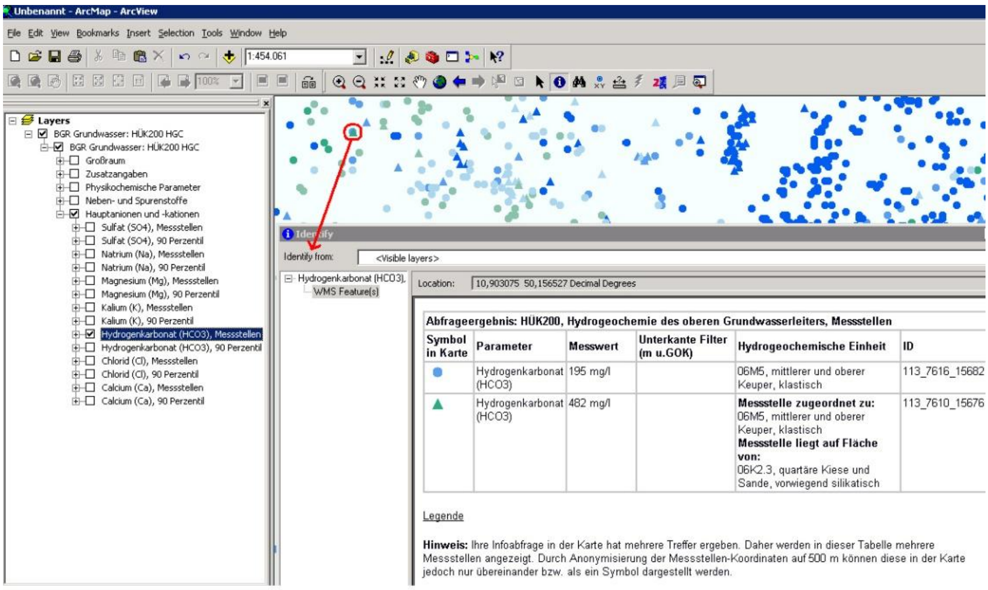


Figure 3. Detail of the point layer (top) and result of an info query of point data for the parameter hydrogen carbonate (bottom). The detailed information is obtained upon clicking on the point symbols.

Due to requirements of data protection laws, the point data are made anonymous by disguising the exact position of the points within a radius of 500 m and by hiding the object names. Thus the points shown in the map cannot be related to the real objects.

RESULTS AND CONCLUSIONS

Compared to previous studies, the statistical evaluation of groundwater quality in Germany presented here is the most detailed approach so far. However, this investigation has to be regarded as a macro-scale approach, giving an overview at a nationwide scale.

The maps of parameter-specific background values of the different hydro-geochemical units are an ideal basis to answer many questions related to groundwater quality. They can be used as a tool to evaluate groundwater analyses in their regional context. Through the knowledge of typical regional distributions of parameter values, exceedances of threshold values can be investigated and local geogenic or anthropogenic anomalies can be identified. Additionally, the data can be used for the evaluation of the qualitative status of groundwater bodies as required by the EU Water Framework Directive. The direct access to the data via internet offers great comfort for the users.

There are still gaps, especially concerning trace elements, which have not been measured systematically by all water authorities in Germany. Due to the requirements of the Water Framework Directive in some federal states trace element measurement programs of groundwater have been launched in the meantime. Therefore in the foreseeable future it will be possible to further extend the contents of the presented WMS.

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abstract id: **524**

topic: **5**
Data processing in hydrogeology

5.3
Groundwater mapping — approach and results

title: # Determining natural background values with probability plots

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keywords: natural background values, hydrochemistry groundwater, geo-statistical evaluation, probability plots

The implementation of the European Water Framework Directive requires knowledge of regional natural or normal background values of groundwater substances to assess correctly the chemical status of groundwater bodies. But the chemical composition of groundwater is always a mixture of different natural and anthropogenic influences, where the combination of natural influences — with the exception of geogenic ore mineralisation — normally leads to a more or less uniform and lognormally shaped distribution form, whereas anthropogenic influence predominantly acts on the higher range of concentrations. The first step to identify the anthropogenic load therefore has to be to separate the anomalies from the background population.

In exploration geochemistry, for anomaly identification the probability net has been used successfully since a long time (Lepeltier, 1969; Sinclair, 1976; Van den Boom, 1981). Its fundamental characteristic is the distorted representation of the axis with the sum percentage of the distribution in order to achieve a straight cumulative curve. This distortion can be achieved by a transformation of the values to standard distribution. A cumulative percentage value can then be attributed to every z-value.

If data are normally (or log-normally) distributed, they lie on a straight line when plotted against their z-values. Any deviation from the straight line leads to the conclusion that the data at least partly do not follow the chosen distribution. When in a sample populations with different means and/or standard deviations are mixed, they appear as two interconnected straight lines, whose particular intercept (z =0 or cumulative sum = 50%) is equivalent to the mean of the respective subpopulation and the slope to its standard deviation. Therefore, it is easy to derive the respective subpopulation's statistical distribution parameters and to identify normal and anomalous components.

An Excel-tool has been developed that iteratively fits a trend line to the bulk portion of the distribution, excluding anomalies on both sides of the distribution. Based on the resulting distribution parameters, the 90^{th} or the 95^{th} percentile is calculated as relevant background value. Goodness of fit is tested by comparing the correlation coefficient to the correspondent critical values (Ryan, Joyner, 1976). Additionally, a strong normality test, the d'Agostino-Pearson-Test, is also calculated.

Values below detection limit have to be taken into consideration proportionally, so that original slope and intercept of the trend line are preserved. Even for data sets with considerable proportions of values below detection limit (up to 40–50%), reasonable values for mean and standard deviation and therefore background values can be derived, as long as there is no reason to reject the basic assumption of (log)normality for the distribution of the data set.

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6 General hydrogeological problems

6.1 Hard rocks as specific media — methods and results

abstract id: **178**

topic: **6**
General hydrogeological problems

6.1
Hard rocks as specific media — methods and results

title: **Modelling of single-well injection-withdrawal (SWIW) tests in fractured carboniferous sandstone**

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keywords: SWIW-tracer test, parameter estimation

Tracer experiments have been used extensively for the investigation of flow and transport processes in fractured media. Often only a limited amount of observation wells is available and there is not always a verified hydraulic connection between the boreholes, so that it may not be possible to conduct cross-hole tracer tests. Single-well tests require only one borehole and are therefore an advantageous method for the hydraulic characterisation of fault and fracture zones. Push-pull tests, also known as single-well injection-withdrawal (SWIW) tests, consist of a controlled injection phase where a tracer solution is being forced out into the rock from a borehole section and a production phase in which the flow field is reversed and the tracer is pumped back into the same borehole. Frequently, the tests include a resting phase between injection and withdrawal to include time-dependent transport processes. (Nordqvist, Gustafsson, 2002). The breakthrough curve (BTC) obtained by measuring the solute concentration at the well during the extraction phase is used to determine the aquifer characteristics. This is typically done by fitting the BTC to a model by adjusting the parameters of the model until a best fit is obtained.

For the characterisation of a fractured carboniferous sandstone, single-well injection-withdrawal tests will be carried out in shallow observation wells in the vicinity of the city of Bochum (Germany). Preliminary studies focused on the acquisition of physicochemical tracer properties. In order to determine the sorption coefficients of different fluorescent tracers, batch tests were conducted. Measurements in diffusion cells provided diffusion coefficients. In order to obtain cumulative information about matrix diffusion, dispersion and sorption properties, comparative multi-tracer tests were carried out in a sandstone block containing a natural single fracture of defined aperture. In addition to the laboratory experiments, hydraulic field tests were conducted. Results from slug-and-bail and pumping tests show transmissivity values around 10^{-4} m^2/s for the investigation area (Bender et al., 2007).

The results of the laboratory and field tests as well as the stratigraphical data of the boreholes were used to build up a numerical model. Numerical simulations using this model indicated that many interaction mechanisms have a similar influence on the tracer recovery curve. Sensitivity studies were carried out on the basis of the model in order to determine a design of subsequent push-pull tests, which allows to distinguish the different mechanisms. Of special interest were the evaluation of appropriate experimental attributes such as injection and withdrawal flow rates, duration of the different experimental phases, tracer selection and input concentrations. Furthermore, the modelling helps to estimate the possibilities and constraints of parameter estimation via push-pull tests.

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abstract id: **303**

topic: **6**
General hydrogeological problems

6.1
Hard rocks as specific media — methods and results

title: **Study and correlation of hydrogeological, tectonic and hydrochemical conditions of fractured rocks in Tinos Island (Aegean Sea, Hellas)**

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keywords: fractured rocks, hydrogeology, hydrochemistry, Tinos Island, Aegean Sea, Hellas

The present paper is dealing with the analysis and characteristics of the discontinuous media, represented by the schist-gneiss sequences of the Tinos Island (Aegean Sea, Hellas). The encountered geologic formations belong to the Atticocycladic complex. According to Melidonis (1980), three groups or sequences of rocks participate in the geological structure of Tinos, the sequence of metamorphic rocks, the sequence of igneous rocks and the Quaternary sediments (Fig. 1a).

a) b)

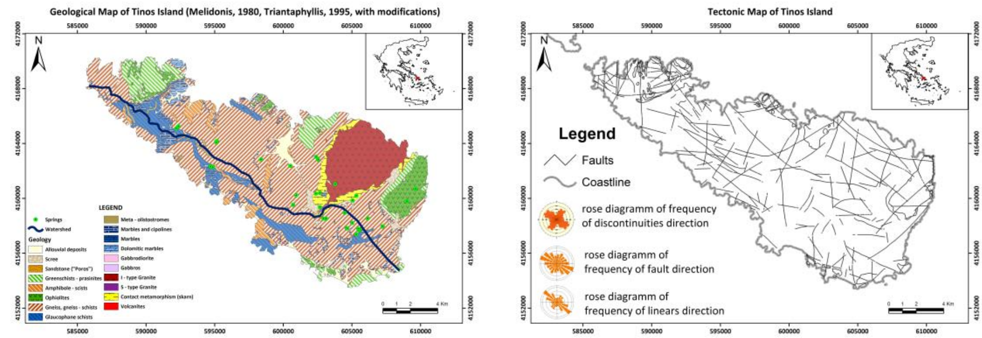

Figure 1. Geological (a) and Tectonic (b) map of Tinos Island (Melidonis, 1980; Triantafyllis, 1995; with modifications).

The existence of three main categories of folds (Stolz et al., 1997), with axes of NW-SE, NE-SW and N-S directions respectively and two groups of faults with SE-NW and NNE-SSW directions respectively, complete the geotectonic structure of the island (Fig. 1b). The basic factors which affect and form the hydrological and hydrogeological character of the island are the discontinuous media character (secondary porosity), due to the tectonic and microtectonic activity and the degree of weathering of the given formations (Stournaras et al., 2007; Leonidopoulou et al., 2005). The discontinuities of the rock mass are divided into different categories according their form and genetic cause and conditions. Special interest has been given in ruptures and diaclases, since they play the most important role for the groundwater circulation and accumulation. These discontinuities are classified by planning, geometry, and genetic point of view into shear, tension and hybridic discontinuities. In this frame, a correlation between the ruptures and the faults and plies has been attended. In the frame of the hydrogeological behavior, the hydraulic characters of the simple porosity, double porosity, and multiple porosity fractured media are examined and evaluated. In the field of the remote sensing, used in the tectonic approach, atmospheric and geometric correction, mosaic synthesis, and data integration led to the photo lineation-ruptures map of different groups, to the faults map and finally to the statistical analysis of the discontinuities (Botsialas, 2007).

The apparition of the main groups of springs of a schist aquifer in Tinos Island is described, related to the tectonic regime of the island and of the spring's environment (Stournaras et al., 2003). The springs mechanism and the lithologic behavior of the water bearing strata are connected and correlated to the above tectonic study, hence, a systematic regime. In order to estimate the groundwater flow due to the discontinuities, the Drogue equation has been applied. According the discharge rate of main springs, the values are of the order of 10^{-3} (1/t). Due to the fact that factor n represents the difference between the initial and the final flow, the Drogue's equation was applied for $n = Qo/Qt$. That rate, established for schist Tinos springs, approaches the value of 6/5. Regarding the role of the discontinuities, in the case of Tsiknias group (Lazaros and Glyko Nero springs), there is a coincidence of the springs orientations and the extended discontinuities, representing the main discharge flow paths.

In order to estimate the correlation of hydrochemical and hydraulic conditions, a sample collection (springs) was made. According to the chemical analyses, 5 main chemical types of ground water were identified. For the main springs, the beginning of springs' depletion is combined with an increase of the TDS concentration (Bourdakou, 2009).

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abstract id: **312**

topic: **6**
General hydrogeological problems

6.1
Hard rocks as specific media — methods and results

title: **Use of vertical head profiles to infer fractured zone properties above a Longwall Coal Mine**

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keywords: longwall mining, fractured zone

Longwall coal mining causes rocks to collapse into the void to form a caved zone. As mining proceeds, a fractured zone will develop above the caved zone with altered aquifer properties that will change with time (Fig. 1). The rocks in the fractured zone will have a higher vertical permeability from connected fractures and possibly higher horizontal permeability along dilated bedding planes. The fractured zone, considered as the extent of vertically-connected mining-induced fracturing, varies in height according to panel width, seam height and the competence of overburden strata. The depth of cover determines whether the effects of fracturing at depth might cause environmental disturbance to shallow aquifers or to aquifer-stream interactions. Constrained and surface zones will occur at higher altitude if the mine is deep (Fig. 1). The constrained zone in the overburden is likely to have competent sandstone/claystone lithologies that sag coherently rather than fracture extensively. This zone, by mediating the hydraulic connection between shallow and deep aquifers, will mitigate potential impacts at land surface.

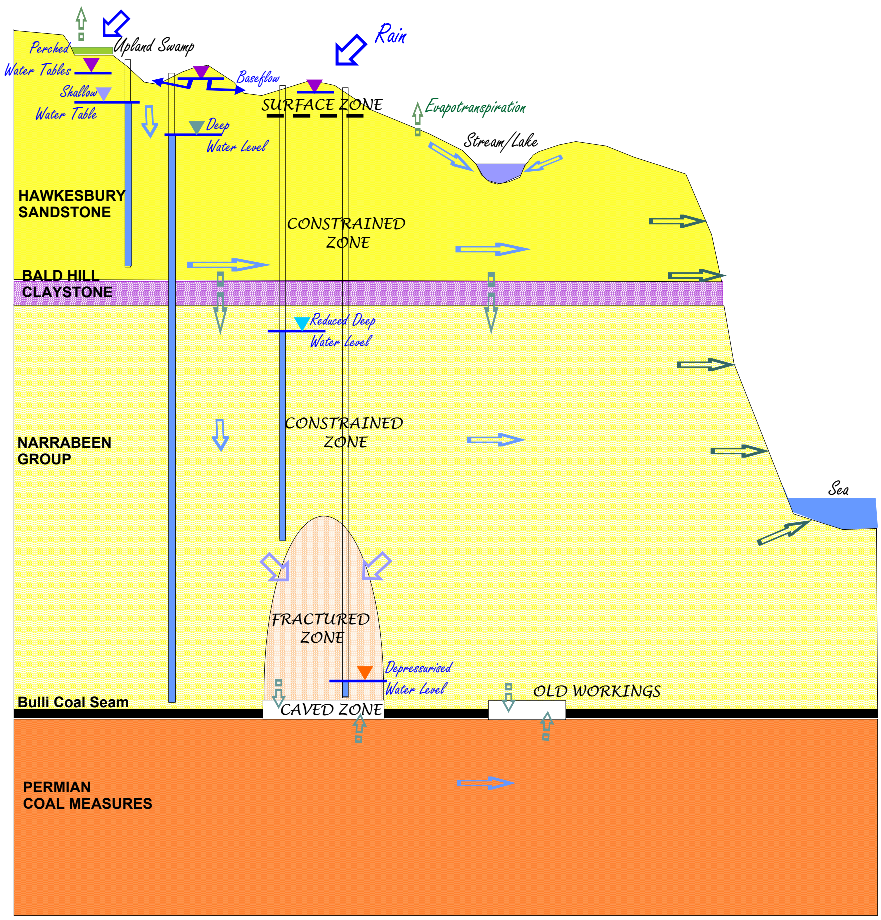

Figure 1. Conceptual hydrogeological model for a longwall coal mine in Australia.

This paper examines the response of an aquifer system at a particular coal mine in Australia where the depth of cover is 400–500 metres and the height of the fractured zone is about 130 metres. Given the difficulty of direct measurement of fractured zone properties, multiple vibrating-wire piezometers grouted in surface-to-seam boreholes can provide diagnostic data on vertical hydraulic head profiles at sites more or less affected by mining, with a facility for tracking head variations in time as mining approaches. Fractured zone hydraulic conductivities, at macro-scale, can be inferred from vertical head profiles through model calibration. An example of static head profiles is given in Figure 2 for a borehole drilled to the top of a fractured zone after mining had passed, and for another borehole about 4 km from current mining. Partial depressurisation is evident in the constrained zone above the area that has been mined.

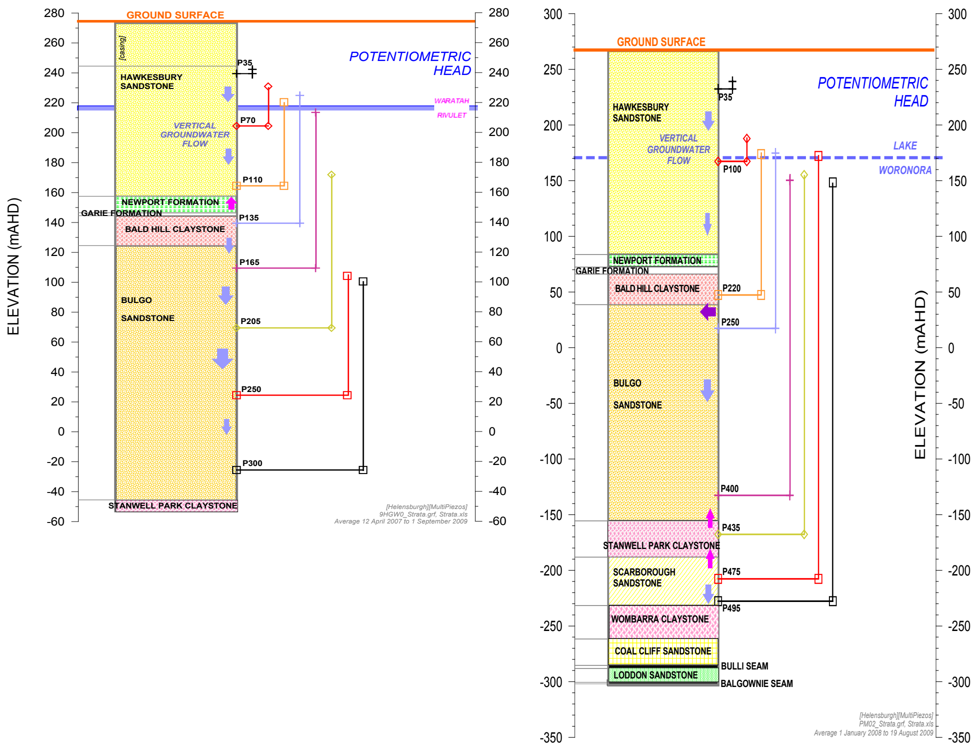

Figure 2. Vibrating-wire piezometer heads, vertical hydraulic gradients and inferred vertical flow directions at a mined area (left) and an unmined area (right).

Model calibration using PEST software has resulted in a median vertical permeability in the fractured zone that is higher than the host value by a factor of 8 to 14 for alternative models using different types and numbers of calibration targets. A model post-audit has provided verification of inferred hydraulic properties by successfully predicting the static vertical head profiles at three new surface-to-seam boreholes.

abstract id: **423**

topic: **6**
General hydrogeological problems

6.1
Hard rocks as specific media — methods and results

title: **Estimate of fractured aquifer thickness using multiple pumping tests analyses**

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keywords: weathering, hydraulic conductivity, storage, India, hydraulic test

A new method consisting in multiple pumping tests to estimate the aquifer thickness is applied on a shallow fractured crystalline aquifer. The methodology developed here requires short duration pumping cycles on an unconfined aquifer with significant seasonal water table fluctuations. The interpretation of 24 pumping tests under variable initial conditions provides information on the change of hydrodynamic parameters *T* and *S* according to the initial water table level (Fig. 1).

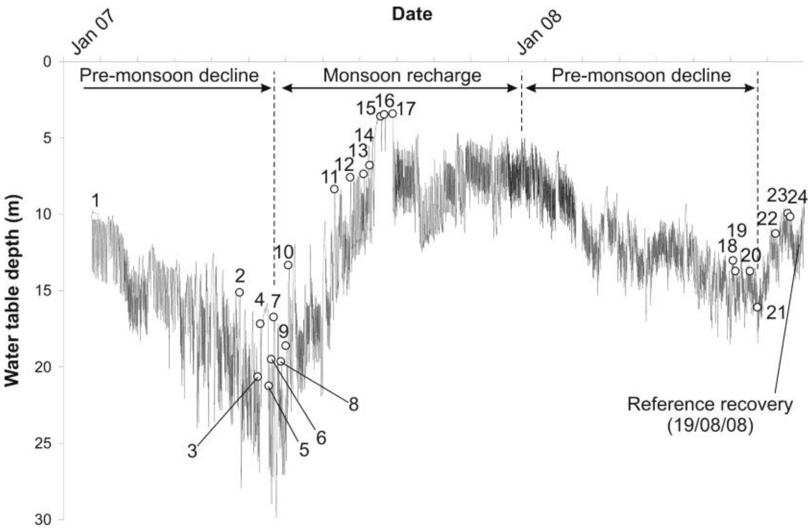

Figure 1. Water table depth fluctuations at observation well during the monitoring period (analyzed pumping cycles are numbered from 1 to 24).

The transmissivity is found to linearly decrease with the initial water level (Fig. 2), thus suggesting a homogeneous distribution of hydraulic conductivity (K = 2.4 × 10^{-6} m/s) with depth. The extrapolation of the relationship between transmissivity and water level (Fig. 2) provides an estimate of the aquifer thickness (35.6 ± 7.2 m) that is in good agreement with the thickness of weathered/fractured rocks estimated from geophysical investigations.

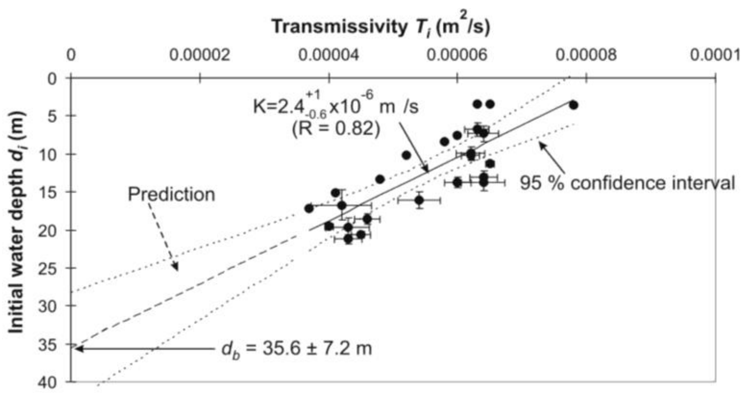

Figure 2. Transmissivity obtained from multiple pumping tests at CMP1 as a function of initial water table depth using unconfined aquifer model.

Our results suggest that the hydraulically active part of the aquifer is located in both the shallow weathered and the underlying densely fractured zones of the crystalline basement. However, no significant relationship is found between aquifer storativity and initial water level. This could be due to the fact that the estimated storage does not correspond to the specific yield but rather to the elastic storage.

This new method contributes to fill a part of the methodological gap between single pumping test and hydraulic tomography in providing information on the variation of the bulk transmissivity according to depth. It can be applied to any unconfined aquifer in the world experiencing large seasonal water table fluctuations and short pumping cycles.

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abstract id: **460**

topic: **6**
General hydrogeological problems

6.1
Hard rocks as specific media — methods and results

title: **Exploring groundwater in weathered crystalline basement areas: a method integrating geomorphologic, geologic and geophysic approach**

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keywords: hardrocks, weathering, fissured layer, weathering aquifers, Magnetic Resonance Sounding

In most of crystalline basement areas, aquifers are stratiform and linked to old weathering profiles (Wyns et al., 2004; Lachassagne et al., 2001, 2006; Maréchal et al., 2003, 2004; Cho et al., 2003; Dewandel et al., 2006). 80 to 90 % of groundwater reserve is located in a fissured layer (figure 1), the deepest horizon of weathering profiles, where porosity and permeability result from cracks related to inflation of some minerals (biotite, pyroxenes, olivine…) during weathering.

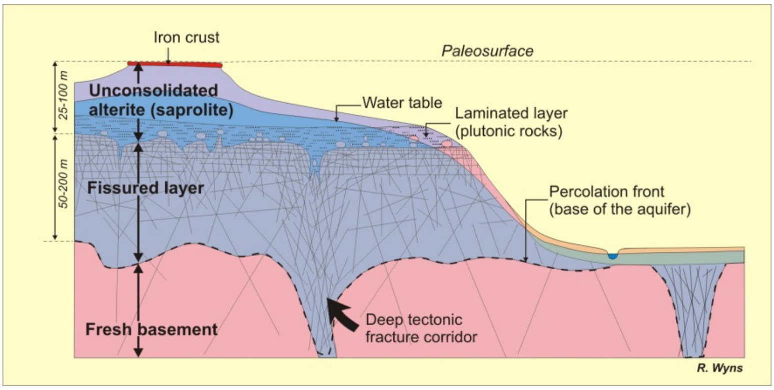

Figure 1. Conceptual cross-section of paleoweathering profile showing stratiform aquifer (after Wyns et al., 2004).

In French Massif Central, a survey is being carried out in order to establish a map of groundwater potentialities. The basement rocks, hercynian in age, are made up of granitoids, gneisses and micaschists.

The first stage of the study is to attribute a note of favourability to each geological formation, according to rock content in inflatable minerals, using 1/250,000 scale geological map. In Limousin area, the geological formations have been classified in 6 classes, according to their ability to develop a thick fissured layer (table 1):

Table1. Classification of the geological formations of Limousin areaaccording to their favourability to develop a weathering aquifer.

code	Legend
0	Formations that are not concerned by weathering aquifers (sedimentary formations, surficial deposits, veins)
1	Unfavourable (acidic volcanics, rocks without micas)
2	Low favourability (amphibolites, muscovite-bearing granites)
3	Favourable (2-micas granites, micaschists, leucocratic gneisses)
4	Very favourable (biotite-bearing granites, biotite gneisses)
5	Extremely favourable (diorites, granodiorites)

The second stage is to identify the age of the weathering through the realisation of a map of palaeosurfaces, in order to predict the evolution of the porosity resulting of geological evolution of the region.

Five weathering profiles, associated with palaeosurfaces, have been identified in the study area: an infra-Stephanian profile, an infra-Permian profile, an infra-Liassic profile, an Early Cretaceous profile, and an Eocene profile. In all profiles anterior to Liassic deposits, the porosity of the aquifers has been sealed by crystallisation of carbonates and sulphates, due to burying below a thick sedimentary cover and to additive weathering (calcrete, dolocrete) prior to Liassic transgression. Only Early Cretaceous and Tertiary weathering profiles are considered as favourable for the preservation of open porosity in the fissured layer.

The final map (figure 2) results from crossing the favourability map (stage 1) with geomorphologic map (stage 2). It gives the location of geologic formations where weathering aquifers, if preserved from recent erosion, have retained an open porosity up to now.

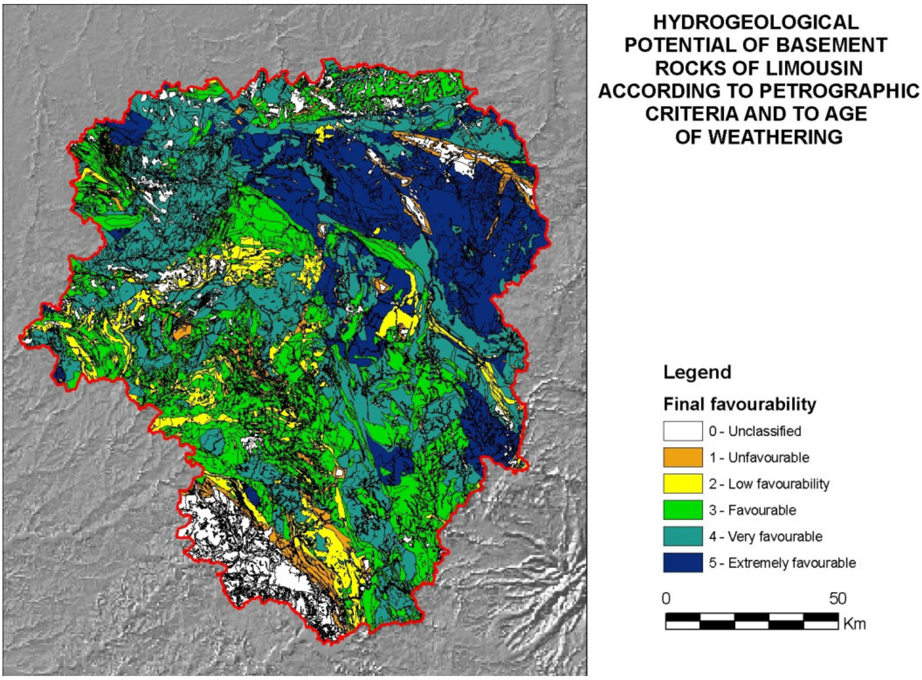

Figure 2. Final map of groundwater potential for Limousin region.

In a further stage, characterization and quantification of aquifers will be carried out in selected favourable zones: geometric modelling of the aquifers and water table, coupled with Proton Magnetic Resonance Sounding (Wyns et al., 2004; Baltassat et al., 2005), will conduct to groundwater reserve mapping (figure 3). These maps will be relevant for localisation of water reserves and for mean characteristics of aquifers (3D modelling of porosity and permeability at the scale of large zones (100 to 1000 km^2 and more), in order to better plan the management of groundwater and surface water.

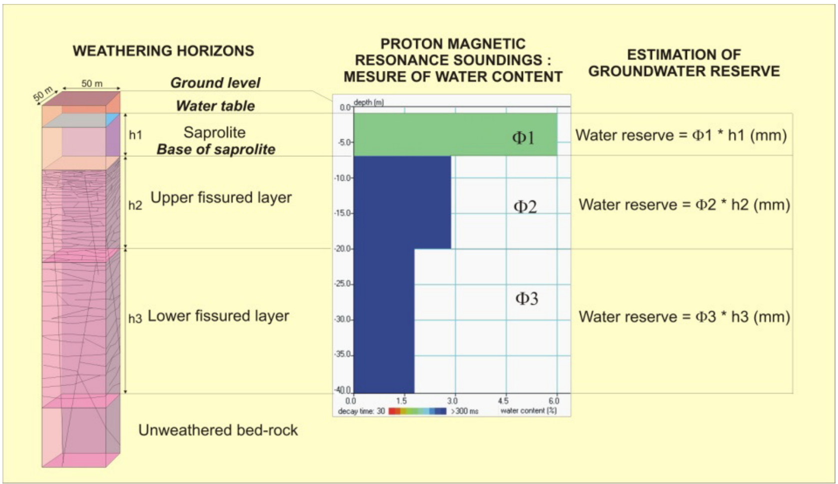

Figure 3. Principle of groundwater reserve mapping using geometric modelling of aquifer coupled with Proton Magnetic Resonance Soundings (From Wyns et al., 2004).

Groundwater reserve mapping has been carried out in numerous areas of western France since 1998. An example is shown in figure 4 (Chemillé 1:50,000 map, Maine et Loire).

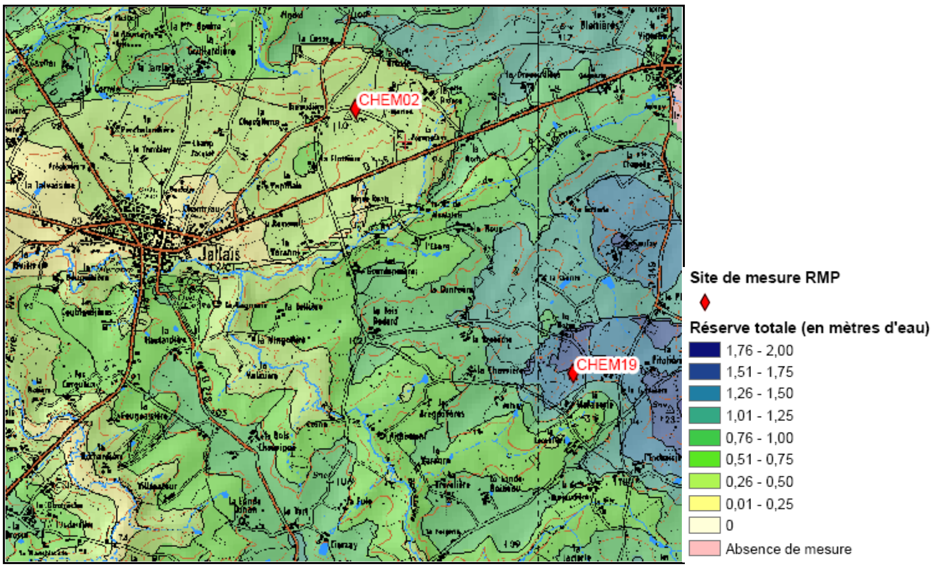

Figure 4. Example of groundwater reserve map in micaschists (East of Nantes, France).

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6.2 | Hydrogeology of karst

abstract id: **116**

topic: **6**
General hydrogeological problems

6.2
Hydrogeology of karst

title: **Evaluating the effect of lineaments on groundwater flow system in karstic aquifers**

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keywords: karst, flow system, lineament

One of the most important problems in karstic aquifers studies is to determine groundwater flow regime in such hard rock aquifers. Methods to determine whether flow system in an aquifer is diffuse, conduit or something in between, are in most cases expensive and time consuming. The major aim of this study is to reduce and optimize costs and time of flow system determination in karstic aquifers. To reach this goal two basins were selected and were chosen because of status of their karstic development. Cheshme Gilas basin is located NE of Iran and Dasht-e Bou basin is located N of Iran.

There is only one spring in each basin which is the only discharge point of them (Gilas spring in the Cheshme Gilas and Gholghol spring in the Dasht-e Bou basin). They have been used to determine the hydrogeological characteristics of study areas. Also, structural properties and lineaments geometrical characteristics of the two basins are measured concurrently.

Studies show that flow system in Dasht-e Bou aquifer is fully diffuse (Fig. 1a), while in Cheshme Gilas is mixed (Fig. 1b).

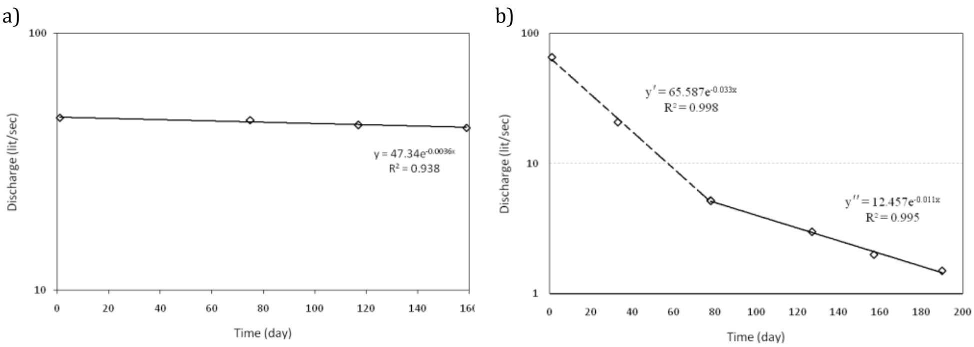

Figure 1. Recession curves in study areas: a) Gholghol spring recession curve (Dasht-Bou); b) Gilas spring recession curve (Cheshme Gilas).

Average fractures dip in Cheshme Gilas basin is less than that of in Dasht-e Bou (Tab. 1).

Table 1. Fracture geometry statistics (related rose diagrams will be inserted in the extended paper).

Basin	Fracture Type	Filling (%)	Ave. Dip	Dip SD.	Strike SD.
Cheshme Gilas	Relaxation	55	47	20	9.5
	Tensional	73	73	17	70
	Shear	44	77	15	78
Dasht-e Bou	Relaxation	74	73	11.5	48.5
	Tensional	52	74.4	5.6	96.9
	Shear	35	74.6	9.5	133.6

These show that in Cheshme Gilas less fractures filling, more relaxation fractures intensity (maps will be inserted in the extended paper) and less fractures dip in comparison with that of Dasht-e Bou are major reasons for more developed karstic features. Furthermore, fractures strike standard deviations (SD) in Cheshme Gilas basin are less than that of Dasht-e Bou. Moreover, in Cheshme Gilas fractures are concentrated in distinctive areas (Maps are available). So, these cause less fluid energy downfall and more concentrated karstification in Cheshme Gilas aquifer. Besides, fractures aperture size distributions in Dasht-e Bou are more homogenous than Cheshme Gilas which cause heterogeneity in karstification in Cheshme Gilas (Fig. 2).

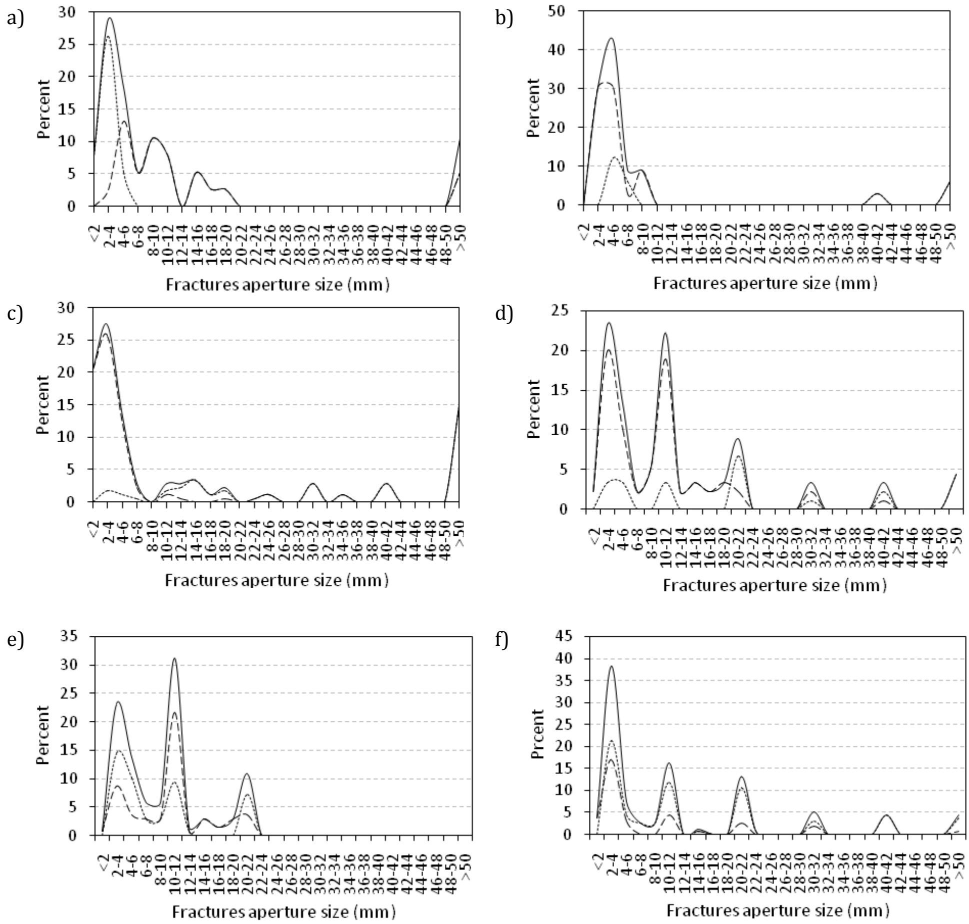

Figure 2. Fractures aperture size distributions for various types of joints in the both study areas. Dotted lines illustrate non-filled fractures; while, dashed ones are demonstrate those which are filled. Continues lines reveal overall percent of fractures: a) Cheshme Gilas relaxation fractures; b) Cheshme Gilas tensional fractures; c) Cheshme Gilas shear fractures; d) Dasht-Bou relaxation fractures; e) Dasht-Bou tensional fractures; f) Dasht-Bou shear fractures.

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abstract id: **139**

topic: **6**
General hydrogeological problems

6.2
Hydrogeology of karst

title: **Characteristic of ammonia nitrogen adsorption on karst underground river sediments**

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keywords: karst, underground river, sediment, adsorption, desorption

Karst aquifers are the most important aquifers in Southwest China. One of the characteristics of karst aquifers is that their enhanced permeability permits high flow velocities capable of transporting suspended and bedload sediments. The transport is episodic and occurs primarily during storm flow in the conduit system. As storm flow recedes, clastic sediments are deposited in the conduit system and at the spring mouths. Mobile sediment in karst may act as a vector for the transport of contaminates. A better understanding of sediment transport in karst is needed to protect these vulnerable systems. 14 sediment samples were collected from two underground rivers in typical peak-cluster and peak-forest karst areas in Liuzhou city, Guangxi Autonomous Region, China. According to simulated experiment methods, characteristic of adsorption of ammonia nitrogen on sediment was studied. The results of ammonia nitrogen adsorption dynamics on sediments showed that the maximum adsorption velocity was within 120 min. It reached balance after 120 min. The maximum adsorption quantity of ammonia nitrogen was 385.5 mg/kg, which was sediment from a cave in the middle areas of Guancun underground river system. The study of isotherm adsorption indicated adsorption quantity of NH_4^+ increase following by incremental balance concentration of NH_4^+ in the aquatic phase. Adsorption quantity of ammonia nitrogen in sediments has a relative linear relationship with adsorption balance concentrations. In the condition of low and high concentrations of ammonia nitrogen in overlying water, Langmuir and Tempkin couldn't simulate or simulate results couldn't reach remarkable level, while Linear and Freundlich models could do that, which has a little difference from rivers or lakes sediments. The maximum adsorption quantity in inlet of Longzhai cave was 0.0874 mg/l, while 0.0365 mg/l in the outlet, indicating the risk of ammonia nitrogen release was higher in the inlet than the outlet of the cave. Sediments from Zhonghudong cave and Nandong cave in Guancun underground river system showed adsorption and desorption balance concentrations were higher in summer than in spring, indicating adsorption and desorption balance concentrations were affected by seasonal variation. Risk of ammonia nitrogen release to aquatic phase was highest in summer.

abstract id: **147**

topic: **6**
General hydrogeological problems

6.2
Hydrogeology of karst

title: **Evaluation of climate change impact in pollution vulnerability of Mesozoic karst aquifers in Burgos province (Spain)**

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keywords: karst aquifers, pollution vulnerability, hydrogeochemistry, climate change

This study presents a methodological approach for the assessment of the Climate Change Impact in the vulnerability to chemical contamination of karst aquifers of Mesozoic age, located in Tierra de Lara (West of the Sierra de la Demanda, northeast of the Duero river basin) in the province of Burgos (Castilla y Leon, Spain). There are very different methodologies to assess vulnerability to contamination of an aquifer. The vulnerability of karst aquifers to contamination, both chemical and microbiological, is extreme, especially in high rainfall and a strong growth of the net movement of groundwater. Methods for determining the vulnerability to contamination of aquifers used different techniques, which are grouped into hydrogeologic methods, parametric or model-based simulation.

In this project we study the evaluation of climate change impact, below several hydrological hypotheses, on the quantity and quality of these groundwater. The results are presented in the form of thematic maps using a system Geographic information (GIS) in order to identify areas of greater or lesser susceptibility to contamination. It also identifies areas of highest risk of pollution from chemicals.

Hydrogeochemistry and Isotopes of Mesozoic Karst Aquifers are also studied, and different hydrochemistry zones are showed in relation to groundwater flow, recharge and discharge areas. Hypothetical evolution of their hydrochemistry is also studied.

abstract id: **155**

topic: **6**
General hydrogeological problems

6.2
Hydrogeology of karst

title: **Hydrogeological and geophysical research of the brackish groundwater lens on the small karst island of Ilovik in Croatia**

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keywords: island, karst, pumping test, geophysical research, salt/fresh water relations

The island of Ilovik is situated in Kvarner region, in the northern part of the eastern (Croatian) Adriatic Sea coast. It is one of the smallest inhabited islands in the Adriatic Sea (5.88 km^2), built of karstified Cretaceous and Paleogene limestones. It is a part of the well-known Dinaric karst region, with very deep and irregular tectonics and karstification, which causes the possibility of seawater intrusions under the freshwater lenses or aquifers, with very irregular shape and wide transition zone. This transition or mixing zone spreads practically within the whole island's aquifer, making its water brackish. In such an environment, establishment of an extraction site (with as low salinity as possible) would be quite a big success.

Although the island is very small, in the years 2002–2004, it was subjected to a bulk research program with the main aim of developing a groundwater extraction site with 1.0 L/s of the brackish groundwater (chloride concentration should not exceed 5000 mg/L). The number of permanent inhabitants is quite low — less than a 100, but during the summer season it is usually much higher (few hundreds, or even more). Every year, more and more people, especially nautical tourists, come to this beautiful island to enjoy their summer vacations.

The research program was carried out within three phases and it contained (and combined) many different methods, such as: geological and hydrogeological mapping, geophysical researches (electrical tomography and seismic refraction), investigatory core drilling, designing of the test wells construction, pumping tests, groundwater level monitoring, and hydrogeochemical researches (*in situ* and laboratory). Because of these researches, more than the needed water quantity and quality was found and could be extracted with three boreholes (BIL-1, BIL-2, and BIL-3).

Achieved results and conclusions showed that parametric estimation of hydrogeological properties is useful even in such heterogeneous karst environment. Numerous and very different parameters were proven as useful tools for the hydrogeological description of such a complex environment. Accomplished results have been scientifically analyzed and compared with the results of similar studies from other Adriatic islands (Terzić, 2006). A very similar research case study — the island of Dugi Otok, has already been published (Terzić et al., 2007). Numerous experiences from other carbonate islands were used in planning and executing our research (Vacher, Quinn, 2004). The island's karstified rock mass is very permeable, and using Thiem's method of pumping test interpretation, hydraulic conductivity in Eocene limestone was 5.2×10^{-6} m/s, and in Cretaceous limestone from 2.0×10^{-5} to 2.6×10^{-4} m/s. The most permeable is rock mass around the borehole BIL-2, where there was only negligible drawdown during the pumping with 0.9 L/s (maximal quantity for the borehole diameter).

Considering the scale of research, which is closest to the so-called subregional scale (Sauter, 1992), where pumping test calculations are applicable to a certain extent and considering the results of geological and hydrogeological mapping and geophysical research, the groundwater flow in the island of Ilovik's underground happens dominantly within the fractures, fracture zones, fissures, and small connected caverns, and not that much through big karst conduits. Tidal efficiency was also noted in the groundwater level (as well as in chemical) fluctuations. Around the BIL-2 borehole, electrical tomography showed some 4000 Ωm in a dry rock mass above the groundwater level. Around the first few meters of fresh/slightly brackish water saturated rock mass it immediately dropped from 1200 to bellow 300 Ωm, and deeper in the transition zone, it was bellow 100 Ωm. Hydraulic and geophysical parameters should be used just as an orientation or order of magnitude and not as exact values that could be used for modeling.

ACKNOWLEDGMENTS

The research was carried out in the framework of the research project of the Croatian Ministry of Education, Science and Sports: "Basic hydrogeological map of Croatia" (181-1811096-3165). We are grateful to "Croatian waters", the investors of a part of the presented research.

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abstract id: **221**

topic: **6**
General hydrogeological problems

6.2
Hydrogeology of karst

title: **Sinkhole distribution and density in the Istria County (Croatia)**

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keywords: sinkhole distribution, sinkhole density, Istria County

INTRODUCTION

The Istria region, with population of 206,344 persons and minimum twice as many tourists during the summer season, is supplied with potable water from karst aquifers. The karst aquifers are particularly prone to anthropogenic impacts because of short time of water retention in the underground and the fact that water generally flows through the underground using privileged paths – caverns, thus its self-purification capacity is minimal. Additionally, recharge of the groundwater is almost exclusively from precipitations that fall directly on the aquifer. This is autogenic recharge, as opposed to allogenic recharge encountered in more complex geological relations with surface inflow from neighboring non-karst areas which drain into the karst aquifer. While autogenic recharge is diffuse and happens through fissures along the entire surface, allogenic recharge is marked by concentrated (point) sinking. These two patterns of recharge result in different water chemistry and recharged volume per surface area, with significant consequences for dissolution porosity development rate and distribution. Concentrated recharge in autogenic system is encountered only in areas with well developed karst sinkholes, since they reflect presence of non-uniform spatial vertical hydraulic conductivity resulting in preferential paths or seepage zones. Karst sinkholes act as small catchments by collecting and directing the precipitation towards the aquifer, and it is exactly the same path by which contamination enters into the underground.

The present paper describes spatial distribution and density of sinkholes in the Istria County, and it was prepared using topographic maps in scale 1:25.000. The sinkhole density maps are useful for preparation of urban development plans, groundwater protection, and in water resources management. The sinkhole density maps could point to potential hazardous geological zones and/or areas where groundwater contamination potential is higher.

METHODOLOGY

Sinkhole density is a number of sinkholes per surface area. This study uses a surface area of one square kilometer, and sinkholes distribution in the Istria County is determined from 30 topographic maps in scale 1:25.000. Geomorphologic analysis of the topographic maps has singled out 29,889 sinkholes. Fig. 1 clearly shows that there are zones with densely arranged sinkholes and those with no developed topographic depressions, which is due to the lithological structure of the area under consideration. Areas with carbonate rocks can be singled out, which occupy about 60% of the surface area, with dominant autogenic recharge of the underground, while areas built of flysch and Quaternary alluvial deposits with dominant surface runoff cover 40% of the surface area. Concentrated allogenic recharge of the underground occurs at the contact of carbonate and flysch deposits.

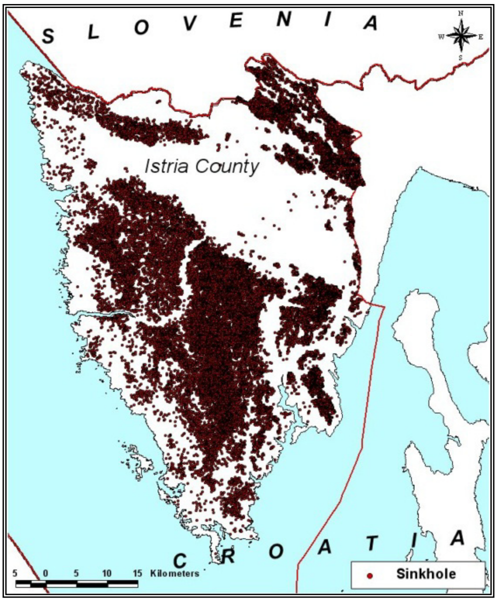

Figure 1. Sinkholes distribution at the Istria County territory.

Once the sinkhole distribution has been determined, sinkhole density mapping started so that the Istria County was plotted in a 1000 × 1000 m grid. The area was divided into 2974 squares, and sinkholes in each square were counted. The sinkhole density map for the Istria County was generated using the data on number of sinkholes in each square (Fig. 2).

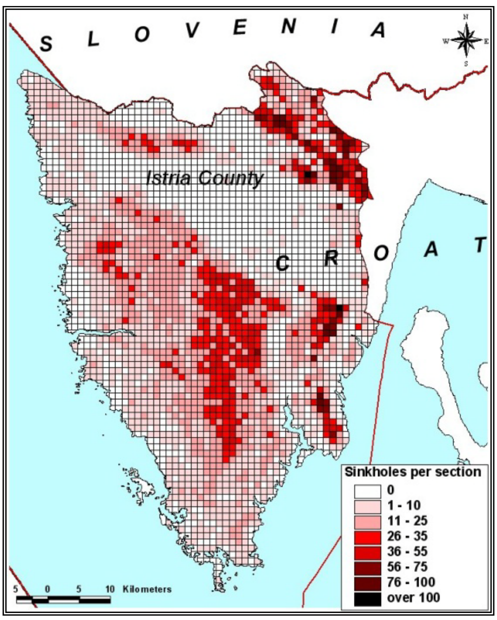

Figure 2. Sinkhole density map.

The sinkhole density per square kilometer ranges from 0 to 123. A comparison of the sinkhole density map, which shows areas of different karstification intensities, with the geological map shows a relation between different lithological units and karstification intensity. The areas where sinkhole density is more than 25 sinkholes per km^2 are related directly with the karstified Upper Cretaceous and Paleogene limestones with numerous and well developed morphological karst forms in the underground.

CONCLUSION

The sinkhole density is an important factor in determination of areas prone to development of sinkholes. It is known that the areas with larger number of registered sinkholes have higher number of unstable cavities in the underground, and probably a well developed system of caverns. The Istria County area stands our for higher karstification intensity of Upper Cretaceous and Paleogene limestones which are more prone to development of different karst forms, unlike Jurassic and Lower Cretaceous limestones. Therefore, it could be concluded that the areas with high number of sinkholes have similar geological and topographic characteristics, and the areas with high density of sinkholes per surface area intensify erosion processes and stimulate further generation of new sinkholes increasing in that way the geological hazard. Generation of new sinkholes is a slow natural process which cannot be stopped, but can be accelerated by in impact of human activities, such as overpumping of groundwater and phreatic line drawdown, boring and excavations, creation of reservoirs, etc.

Further, since the sinkholes are a direct link between the surface and the underground, they are potentially very dangerous points for propagation of accident-related contamination directly into the underground causing contamination of the groundwater. The groundwater in karst aquifers generally streams through underground karst conduits, its flow rates are much higher than in other aquifers, thus any ingress of contaminant into the underground water bearing system could result in contaminant transportation to large distances in a very short period of time. This makes them exceptionally vulnerable and endangered systems.

abstract id: **225**

topic: **6**
General hydrogeological problems

6.2
Hydrogeology of karst

title: **Chemical composition of spring water in the northern boundary zone of the Tatra Mountains (East-Central Europe)**

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keywords: carbonate Eocene, springs, karst springs, Tatra Mts.

Springs located in the northern boundary zone of the Tatra Mts. were investigated in the past according to their potentiality in water management (Małecka 1993, 1997; Małecka, Roniewicz 1997; Małecka, Małecki 2005). Water intakes are located at some of them. Springs have drained carbonate Eocene rocks, which neighboring from north the Podhale flysch rocks (Figure 1). Differences between hydrogeological properties of carbonate Eocene rocks and Podhale flysch rocks are conducive for occurrence of springs in this zone. The aim of researches is to investigate physical and chemical characteristics of springs with varied discharge.

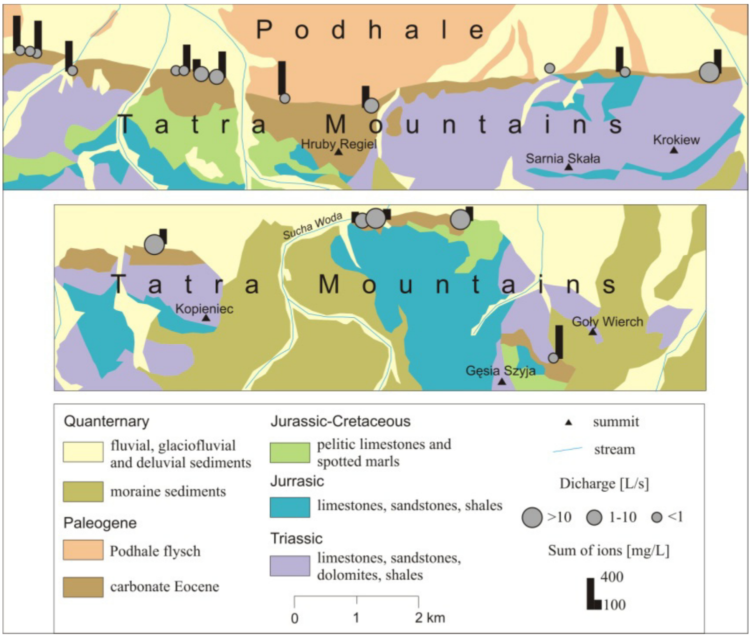

Figure 1. Discharge and mean sum of ions in investigated springs at the background of geology (after Geologicka Mapa Tatier, 1986).

Carbonate Eocene rocks have an important role in hydrogeology of the north part of the Tatra and the Podhale. Precipitation witch infiltrate in carbonate Eocene outcrops in Tatra recharge groundwater aquifer lying under flysh in Podhale artesian basin (Małecka, Małecki, 2005). A karst phenomena is developed in some parts of the carbonate Eocene, especially in the Sucha Woda basin, in the east part of the Tatra (Głazek, Wójcik, 1963). Springs witch have drained carbonate eocene are recharged by rainwater which is infiltrated and inflowed within all Tatras (Małecka, Małecki, 2005).

18 springs were investigated. Field works were conducted in April, June and October 2007. Water temperature, electrical conductivity and pH were measured in terrain (Elmetron CX-401) and water samples (from 15 springs) were taken in June and October. Chemical analyses were done in the laboratory at the Institute of Geography and Spatial Management, Jagiellonian Univeristy using ion chromatography (DIONEX ICS-2000). Mineralization was counted as sum of all measured ions. Based on measurments from three or two months mean values of physical and chemical characteristis were calculeated.

Among investigated, nine are debris springs and the rest are rocky ones. There are vaucluse springs: Koziarczyska (mean discharge 87.1 L/s) and Przyporniak (mean discharge 60.0 L/s) (Małecka, Roniewicz, 1997). Discharge of rest of springs varied from 0.01 L/s to 20 L/s (Figure 1). Discharge of debris springs were a little bit higher in June when there was rainfall before and during field works. In June also one periodic spring was noticed in the west part of area (Figure 1). Water temperature of most springs amounted between 5.0–7.5 °C and was stable during all investigations period. Temperature higher than 7.5°C was noticed only after a fresh rainfall.

Mean sum of ions varied from 126 to 418 mg/L. Values lower than 200 mg/L was noticed in vaucluse springs and in two karst-fissure springs, which also have drained karst rocks in the west part of area. The highest values of sum of ions were noticed in two debris springs located at most west and east part of investigated area (Figure 1). Mean electrical conductivity were from 151 to 452 μS/cm. The highest and lowest values occurred in the same sites that maximum and minimum of sum of ions. Electrical conductivity and sum of ions are statistically correlated. Reaction was typical for carbonate rocks and not very divers. Mean values were form pH=7.29 to pH=8.45.

The type of springs water was HCO_3-Ca-Mg or HCO_3-Ca. Among kations the highest concentration had Ca^{2+} (Table 1). Sum of Ca^{2+} and Mg^{2+} in each spring made more than 90% of all kations in mval/L. Another kations are Na^+ with had concentration approximately 1 mg/L and K^+ and NH_4^+, with concentration lower than 1 mg/L. Among anions considerable higher concentration had HCO_3^-, and it dominated also in structure of chemical composition. It constituted 86.1-98.4% of sum of all anions in mval/L (Table 1). Next anion with the highest concentration was SO_4^{2-}, but it constituted only about 5% of anions. Other anions were Cl^- (concentration 0.1-0.9 mg/L) and NO_3^- (concentration 0.2-2.0 mg/L).

The lowest values and participation of HCO_3^- occurred in vaucluse springs and in karst-fissure spring in Sucha Woda basin. The highest concentration of SO_4^{2-} were also observed in them.

Table 1. Mean values of concentration [mg/L] and percent of sum of kations or anions [%] in spring water (n=15).

		Main kations		**Main anions**	
		Ca^{2+}	**Mg^{2+}**	**HCO_3^-**	**SO_4^{2-}**
Concentration [mg/L]	minimum	25.03	3.47	84.18	2.75
	maximum	84.78	21.41	316.95	13.85
	mean	52.35	12.09	214.34	7.80
Percent of sum of kations or anions [%]	minimum	60.7	12.8	86.1	1.1
	maximum	85.4	38.3	98.4	11.1
	mean	71.4	26.4	93.0	5.2

Physical and chemical characteristics were stable during researches. That confirm deep recharge aquifer. Chemical composition of waters indicates draining carbonate rocks. Similar structure of chemical composition of debris and rocky springs concessived that debris springs also are draining the carbonate Eocene rocks. It may be stated, that these types of water are representative for water circulating in carbonate eocen rocks.

ACKNOWLEDGEMENTS

The Project was supported by the Ministry of Science and Higher Education (Grant N305 081 32/2824, Factors determining spatial variability and dynamics of water chemical composition in the Tatra National Park).

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abstract id: **288**

topic: **6**
General hydrogeological problems

6.2
Hydrogeology of karst

title: **Effect of land use/land cover change on karst hydrogeochemistry: A paired catchment study of Chenqi and Dengzhanhe, Puding, Guizhou, SW China**

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keywords: karst hydrogeochemistry, carbon isotope, karst spring, land use and land cover change, paired catchment study

INTRODUCTION

Land use and land cover change is an important anthropogenic factor that shows the influence on the surface of the earth. It directly impacts biological diversities, contributes to the local and regional climate changes as well as to global warming, and may cause land degradation by altering ecosystem services and livelihood support systems. The primary objective of this study is to understand how the karst processes and karst hydrogeochemistry respond to different land use and land cover change, which is essential to assessing the karst-related carbon cycle (Yuan, 1997; Liu et al., 2010).

METHODS

Rainfall, spring stage, water temperature, pH and conductivity (EC) in the paired karst spring catchments of Chenqi and Dengzhanhe, which shared the same climatic condition but different land use/land cover changes at Puding, Guizhou Province, SW China (Fig. 1), were monitored by two high resolution multi-parameter auto-recordable instrument of CTDP300 during the hydrological year of September, 2007-September, 2008.

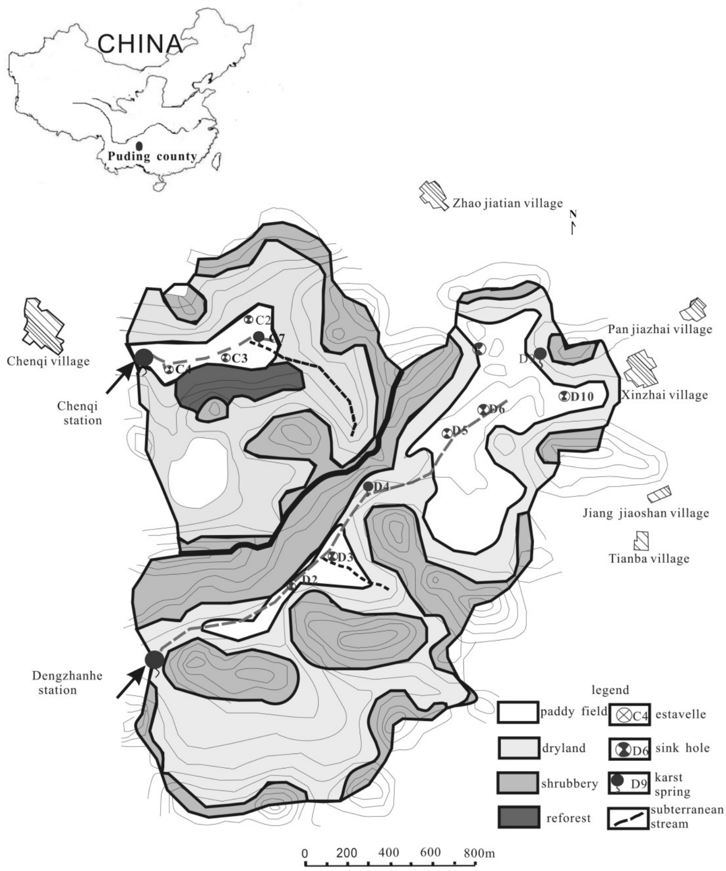

Figure 1. Comparison of distribution of various land use types between Chenqi and Dengzhanhe spring catchments [Modified after Zeng (2009)].

Other monthly hydrogeochemical (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^-, SO_4^{2-}, Cl^-, NO_3^-) and carbon isotopic ($\delta^{13}C$) variations in the paired karst catchments during the same hydrological year were also investigated. A thermodynamic model was used to link the continuous data to monthly hydrogeochemical data allowing the calculation of CO_2 partial pressure (pCO_2) and calcite saturation index (SIc) on a continuous basis (Liu et al., 2007).

RESULTS

Marked seasonal variations were found for pH, conductivity, pCO_2, SIc and $\delta^{13}C$ of the two springs (Figs. 2 and 3), indicating that both springs were dynamic and variable systems. However, there were differences in the magnitude of the variations of these features between the two springs. The higher pCO_2 and HCO_3^- concentration and lower pH, SI_C and $\delta^{13}C$ in Chenqi Spring than those in Dengzhanhe Spring tend to be related to the difference in land use and land cover change between Chenqi and Dengzhanhe spring catchments: in the Chenqi Spring catchment, there was larger soil cover and the paddy land was located in the discharge area, both of which produced and kept more CO_2 (a major driving agent for the karst processes) and lower $\delta^{13}C$ in the soil-aquifer system, while in the Dengzhanhe Spring catchment area, there was larger bare carbonate rock occurrence and the paddy land was located mainly in the recharge area (Fig. 1).

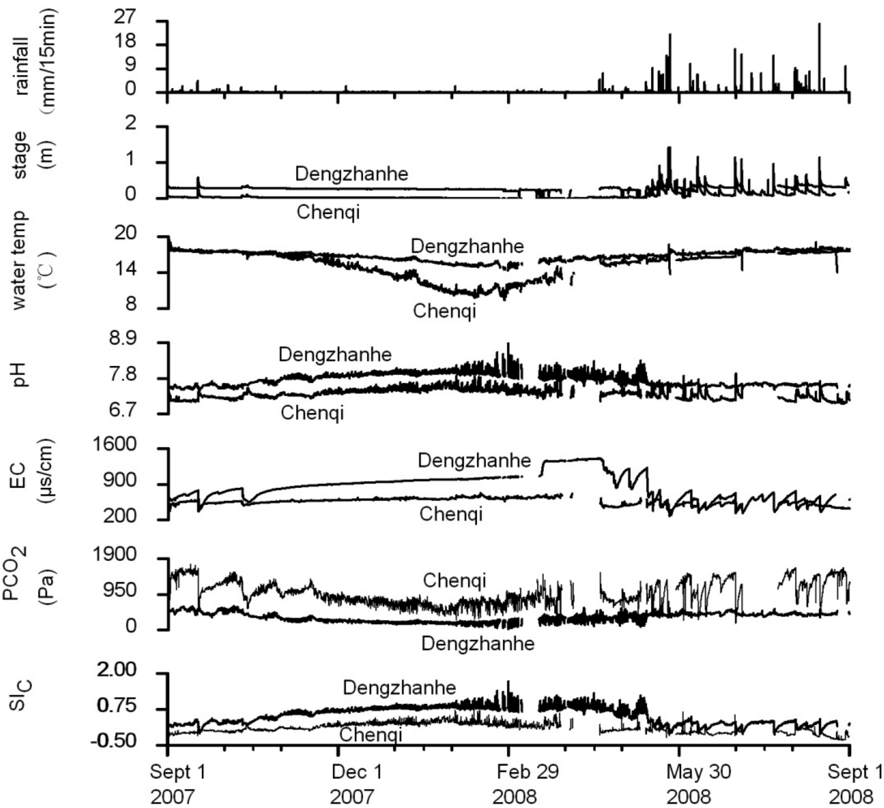

Figure 2. Comparison of continuous hydrochemical variations between Chenqi spring Dengzhanhe spring in relation with rainfall (The discontinuities in the curves are due to human disturbance).

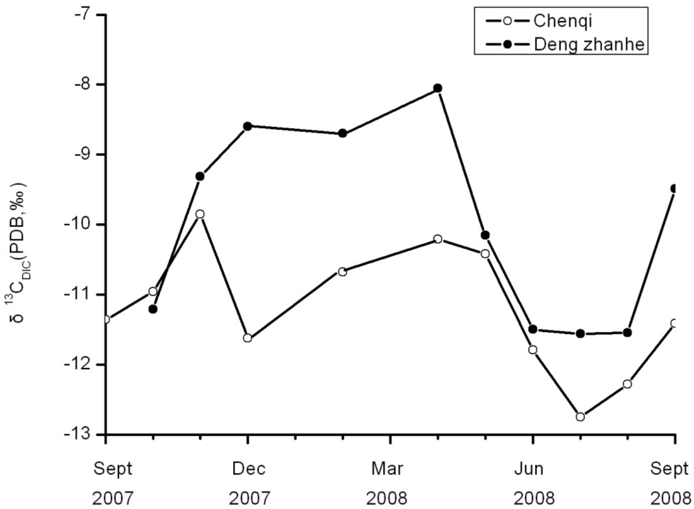

Figure 3. Comparison of seasonal variations of $\delta^{13}C_{DIC}$ between Chenqi and Dengzhanhe springs during the hydrological year period of 2007–2008.

In addition, the pH increased and pCO_2 decreased generally in Chenqi Spring after rainfall, possibly due to more carbonate dissolution in the larger soil cover rich in limestone fragments in the spring catchment, while the pH decreased and pCO_2 increased generally in Dengzhanhe Spring after rainfall (Fig. 4).

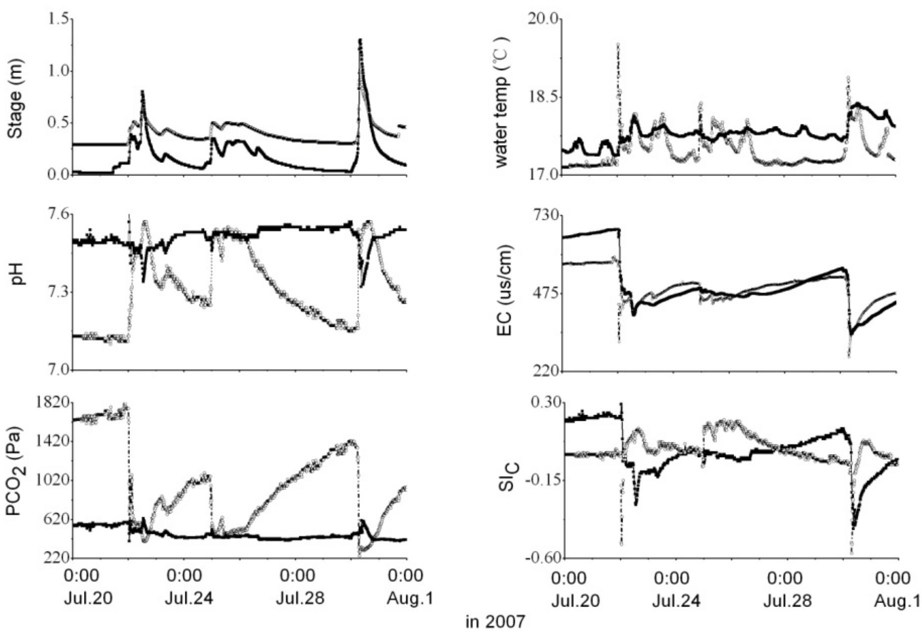

Figure 4. Comparison of storm-scale hydrochemical variations during July 20-Aug.1, 2007 between Chenqi Spring (dotted line) and Dengzhanhe Spring (solid line).

CONCLUSIONS

All these differences show that soil cover played a key important role in the karst processes. In other words, the karst hydrogeochemistry and the karst-related carbon cycle could be regulated effectively by different land use and land cover changes.

Therefore, the karst hydrogeochemical parameters, including pH, conductivity, HCO_3^-, Ca^{2+}, Mg^{2+}, pCO_2, SIc, and $\delta^{13}C_{DIC}$, could serve as good indicators of different land use and land cover changes and the other environmental changes.

ACKNOWLEDGEMENTS

This work was supported by the Hundred Talents Program of Chinese Academy of Sciences, the foundation of the Chinese Academy of Sciences for Innovation (Grant No.kzcx2-yw-306), National Natural Science Foundation of China (Grant No. 40872168), and Ministry of Science and Technology of China (Grant No. 2005DIB3J067).

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abstract id: **345**

topic: **6**
General hydrogeological problems

6.2
Hydrogeology of karst

title: **Characteristics of water flow in the karst catchment of the Unica River (SW Slovenia)**

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keywords: karst hydrology, discharge, electrical conductivity, temperature, tracer test

INTRODUCTION

Karst aquifers are important sources of water supply, but due to their specific characteristics they are very vulnerable to various human activities. For the efficient planning of protection measures it is essential to understand and consider the characteristics of groundwater flow and the processes of its exchange with surface waters. This is especially difficult for karst springs with a large extent and complex structure of their recharge areas. One of such examples is the Malenscica karst spring in south-western Slovenia, which is captured for the regional water supply. Based on hydrogeological researches, its protection zones were set in 1987, but they have not been properly implemented in praxis. Since then the understanding of the functioning of this karst system has improved and the proposed protection measures should be adjusted adequately. In order to do this the relations between different parts of the recharge area and the changes in the shares of their contribution at different hydrological conditions were studied in more detail. The physical and chemical parameters of water at different locations within the catchment were monitored in the total period of two hydrological years. The elaboration of data is still going on and in this article the first results of the general comparison of data on a time scale of hydrological years are presented.

CHARACTERISTICS OF THE STUDY AREA

Several karst springs are located at the southern border of the Planina karst polje in south-western Slovenia (Fig. 1).

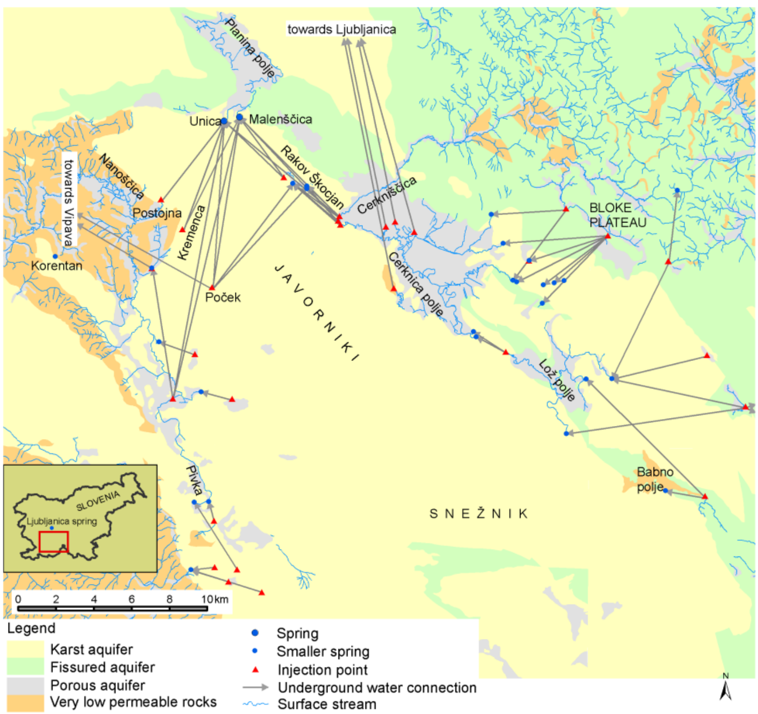

Figure 1. Hydrogeological map of the recharge area of the Unica and Malenscica springs with proved underground water connections.

The most important are the Unica and Malenscica springs. The latter is an important source of water supply for approximately 21,000 inhabitants. Relatively high discharge of the spring at low waters is an important advantage, but due to a large extent of the recharge area it is difficult to plan the protection and control the water quality. Based on the known geological and hydrogeological conditions, and the results of tracer tests, the recharge area of the springs was defined. It can be divided into three separate but hydrologically connected parts (Fig. 1). The central part is the karst massif of Javorniki and Sneznik. It borders at the western side on the valley of the Pivka river and its tributaries, and on the eastern and northern side on a string of karst poljes (the biggest among them is the Cerknica polje), which are distributed gradually in the SE-NW direction. These three areas can be named as Javorniki, Pivka and Cerknica parts of the catchment. In the Javorniki part the underground flow is dominant, and in other two parts surface streams are present also. They are mainly recharged by karst waters, and after a certain distance of surface flow they sink again underground. The underground water connections between various parts of the catchment (Fig. 1) were defined by several tracer tests (Petric, 2010).

The area of Javorniki and Sneznik is composed of Cretaceous carbonate rock, mostly limestone (Fig. 2).

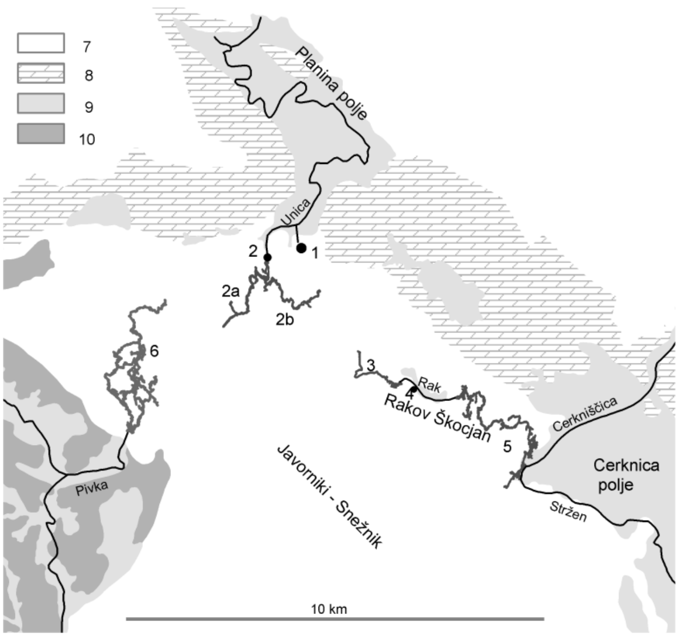

Figure 2. Hydrogeological map of the study area (Legend: 1. Malenscica spring, 2. Unica spring, 2a. Planina Cave-Pivka branch, 2b. Planina Cave-Rak branch, 3. Tkalca Cave (ponor of the Rak River), 4. Kotlici spring, 5. Cave system Zelse (spring of the Rak river)–Karlovica (ponor on the Cerknica polje), 6. Postojna Cave, 7. Karst aquifer, 8. Fissured aquifer, 9. Porous aquifer, 10. Very low permeable rocks).

On very low permeable Eocene flysch in the Pivka valley a surface drainage net is developed. Quaternary alluvial sediments are deposited along the surface streams. The oldest rock in the Cerknica part is Upper Triassic dolomite between the Planina and Cerknica poljes. Jurassic limestone and locally dolomite build the north-eastern border of the sequence of karst poljes.

Quaternary alluvial sediments are deposited on karst poljes. At high waters these are flooded and the intermittent lakes are formed. At the north-western border of the Cerknica polje, the Cerkniscica and Strzen surface streams, which flow along the polje, sink and flow underground mostly toward the Rak and Kotlici springs in Rakov Skocjan. Both springs recharge the Rak River, which flows on the surface for 2 km. The Rakov Skocjan area is composed of Cretaceous limestone, which is covered along the stream with Holocene sediments. Rak sinks again underground in the Tkalca Cave and flows toward the Malenscica and Unica springs at Planina polje. The Unica spring emerges from the Planina Cave, in which the underground waters from the Pivka area (along the Pivka branch) and from the area of Rakov Skocjan and Cerknica polje (along the Rak branch) flow together and form a unique underground confluence.

METHODS

The monitoring net was installed within the catchment of the Malenscica and Unica springs in 2007. Three rain-gauges were set in the three contribution areas (Onset RG-M at Postojna and Javorniki, and Eijkelkamp e+ diver at Bloke plateau). The sondes for measuring of discharge, temperature and electrical conductivity were installed at 2 karst springs (ISCO 6700-Sonde YSI 600 and 750 Area-Velocity Module at Malenscica spring, and Gealog S Logotronic at Unica spring) and 5 water streams within their catchment (Eijkelkamp CTD divers at Kotlici spring, Rak branch, and Pivka sinking stream, and Eijkelkamp TD diver at the Cerknica polje and in the Rak spring). In this way we gathered data on precipitation, water levels, discharges, electrical conductivity and temperature in 30-minute intervals from the autumn 2007 to the autumn 2009 (at some locations only data for one hydrological year are available due to later instalment or technical troubles).

RESULTS

Days with detected precipitation are distributed similarly at all three precipitation stations, and the differences are mainly in recorded daily amounts. Therefore for further comparison only the data for the Postojna station were used. To assess the daily values of effective infiltration (assessment based upon the soil water balance, methods used described in Petric, 2002), meteorological data were obtained at the Environmental Agency (Tab. 1).

Due to different duration of the hydrological years, the average daily values are compared. In the second hydrological year the average daily precipitation was slightly higher, but the difference is more significant for the effective infiltration. The main reason is in the distribution of precipitation, which is in the first year more uneven, with shorter precipitation events and larger amount during the summer when the share of effective infiltration is lower. More intensive precipitation events in the second hydrological year, when several days of consecutive rain were often recorded, are reflected in hydrographs with intervals of very high discharges.

The lowest oscillations of discharges were observed in the Malenscica spring with the ratio Q_{min} : Q_{max} = 1 : 9.1. Also the difference in average discharges between the two hydrological years is not significant for this spring. Its discharge is mostly closer to Q_{max} than to Q_{min}, which indicates that during the high waters the discharges of this spring are limited with the permeability of the inflow channels and the surplus water flows toward the nearby Unica spring. At other monitoring points the differences between the minimum and maximum discharges are much larger, and their average discharges are significantly higher in wetter hydrological year 2008-2009.

Table 1. Characteristic values of measured parameters for two hydrological years.

	Precipitation P and effective infiltration I_{ef} (mm)								
	2007–2008 (413 days)			**2008–2009 (334 days)**			**2 hydrological years (747 days)**		
	Max	**Sum**	**Avg**	**Max**	**Sum**	**Avg**	**Max**	**Sum**	**Avg**
P (mm)	49.8	1,410	3.4	113.4	1,279	3.8	113.4	2,689	3.6
I_{ef} (mm)	39.1	598	1.4	100.6	758	2.3	100.6	1,255	1.7
I_{ef}/P (%)		42			59			47	
	Discharge (m^3/s)								
	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max
Malenscica	1.45	5.92	9.50	1.09	5.94	9.91	1.09	5.93	9.91
Unica	0.05	5.58	56.89	0.04	14.43	69.34	0.04	11.20	69.34
Rak branch	0	9.00	26.46			36.10	0		36.10
Pivka	0.05	3.20	31.83			91.42	0.05		91.42
	Water level (in cm above the minimal measured value)								
Kotlici	15	174	696	0	472	1308	0	219	1308
Cerknica L.	0	743	924						
	Temperature (ºC)								
Malenscica	5.0	9.8	17.7	1.7	7.9	13.8	1.7	8.9	17.7
Unica	4.0	9.6	14.6	3.0	8.7	12.6	3.0	9.2	14.6
Rak branch	5.5	10.8	15.0	2.6	7.6	12.8	2.6	9.4	15.0
Kotlici	2.6	10.7	22.7	2.0	9.4	15.3	2.0	10.1	22.7
Cerknica L.	2.0	12.2	25.1						
Pivka	0.1	8.3	21.9						
	Electrical conductivity (μS/cm)								
Malenscica	338	378	428	278	359	440	278	369	440
Unica	288	381	479	221	373	479	221	377	479
Rak branch	290	362	398	267	362	451	267	362	451
Kotlici	205	378	452	162	392	460	162	384	460
Pivka	204	394	574						

Interesting results were obtained by the comparison of hydrological conditions and temperature of water (Figs. 3 and 4). The Cerknica Lake and the Pivka sinking stream are surface water bodies which represent the sources of recharge of the Malenscica and Unica springs from two different parts of the catchment. In both the oscillations of temperature are high due to the adaptation to the changes of air temperature. In the underground path of water from the ponors to the springs, its temperature changes according to the residence time, discharge and geometry of the karst system (Dogwiler, Wicks 2005). But also the mixing of waters due to the inflows from different parts of the recharge area should be considered.

The comparison of characteristic values of water temperature at all observed springs shows high oscillations. This confirms a significant share of secondary recharge from the surface water bodies. This is the most evident in the Kotlici spring, which is the closest to the ponors of the Cerknica Lake. In the Malenscica spring the oscillations are lower as the residence time of the water in the underground is longer. The reactions of temperature of the Unica spring are often very similar, but a more detail comparison shows an important influence of the recharge from the Pivka sinking stream, which is not characteristic for the Malenscica spring. This difference between the two springs is additionally confirmed by the comparison of measured values of electrical conductivities. Namely, a significant influence of the Pivka stream on the Unica spring can be detected.

Figure 3. Effective infiltration and discharges or water levels (presented relatively to the maximum value for the two hydrological years) at selected monitoring points in the first hydrological year 2007-2008.

Figure 4. Effective infiltration and discharges or water levels (presented relatively to the maximum value for the two hydrological years) at selected monitoring points in the second hydrological year 2008-2009.

During high waters the temperatures of the springs approaches to the temperatures of the surface waters in the recharge area. The reason is very fast groundwater flow from the ponors to the springs, but it also indicates an important share of secondary recharge of the springs. Only at such conditions the lowest and highest temperatures of springs are detected. On the other hand, during low waters the extreme temperatures of the surface water bodies in the recharge area are not significantly reflected on the temperatures of the springs. In these periods the recharge is slower and the retention time of water in the karst underground longer, but the comparison also indicates larger share of primary recharge from the Javorniki-Sneznik karst aquifer.

CONCLUSIONS

The characteristics of groundwater flow in the catchment of the two observed springs are strongly dependent on meteorological and hydrological conditions and are changing very fast. Different shares of recharge from various parts of the catchment were indicated by the described analysis, but for a more detailed assessment we continue with the study in which we will compare all measured parameters in selected flood events at different hydrological conditions.

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abstract id: **394**

topic: **6**
General hydrogeological problems

6.2
Hydrogeology of karst

title: **Hydrochemical contrasts between vadose and shallow/deep saturated environments in a carbonate aquifer (Nerja Cave experimental site, S. Spain)**

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keywords: karst, hydrochemistry, vadose zone, groundwater, Nerja Cave experimental site

INTRODUCTION

This work is based mostly on hydrochemical data obtained in the Nerja Cave experimental site, situated at less than 1 km from the Mediterranean Sea (Fig. 1A). It is located over a regional aquifer made up of fissured and karstified Triassic dolomite marbles which host an important show cave: the Nerja Cave (Malaga province, Andalusia, S. Spain), visited by some 500,000 people each year mostly during summer months.

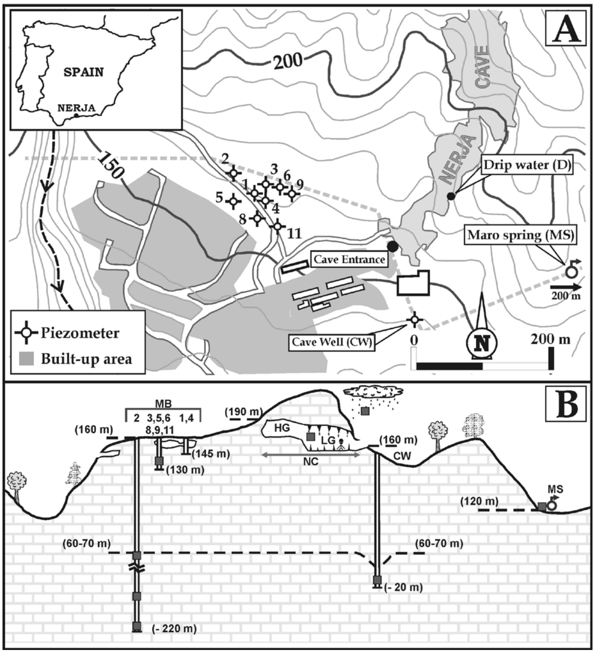

Figure 1. Hydrogeological map of the Nerja experimental site area (A), and idealized cross-section (B) sketching the main characteristics of the monitoring and sampling points. NC: Nerja Cave, LG: Lower Galleries, HG: Higher Galleries, MB: Monitoring Boreholes. Numbers between brackets in part B indicate approximate altitudes in m a.s.l. Discontinuous lines indicate groundwater levels. Grey squares represent the location of the samples considered.

The study site is equipped with 10 boreholes (Fig. 1A). Nine of then –designed by numbers in Figure 1- are small-diameter (90–120 mm) monitoring boreholes (piezometers); other (CW) is a production well which was built to supply the cave facilities. Recently, a new pumping well was drilled nearby, and the CW point — which is 160 m deep — is used for monitoring purposes. With the exception of piezometer 2 (P-2), which is 380 m deep, all the small-diameter boreholes have depths between 15 m and 30 m, and are drilled in the vadose zone of the aquifer (Fig. 1B).

The main discharge from the carbonate aquifer in the study area is the Maro spring (MS, Fig. 1). Its approximate altitude is 120 m a.s.l., and it has an average outflow of 250 L/s, with a range between 20 and 1600 L/s, suggesting relatively well developed karstic conditions (Liñán et al., 2000).

The saturated zone is reached in two boreholes: CW and P-2. The altitude of the groundwater level at these two points is roughly 60–70 m a.s.l. This value does not match with that of the nearby Maro spring altitude (Fig. 1B), suggesting some kind of low permeable boundary between them. The thickness of the saturated zone is thus of approximately 80–90 m in point CW, and 280–290 m in point P-2.

Differences in fissure connectivity probably favour the presence of a sporadic perched groundwater level in the vadose zone which sometimes is found in the lowest meter of piezometer 6 (P-6).

The estimated void volume of the Nerja Cave is 300,000 m^3. Only one third of the cave — the part labelled as LG in Figure 1B — is open to large-scale visitation along an adapted pathway tour. The average CO_2 content inside this part ranges between approximately 250 ppm in the winter and 2,000 ppm in the summer (Carrasco et al., 1999; Liñán et al., 2008a). Access of visitors to the rest of the cave (HG in Fig. 1B) is restricted.

In previous works (Benavente et al., 2010; Vadillo et al., 2010) we have focused on the interpretation of systematic measurements of the air CO_2 contents in the vadose zone, mostly through logs inside the boreholes. Air temperature and relative humidity values were also registered. These data were compared with those coming from the routine monitoring of the same variables inside the part of the cave that is open to visitors. Such works allow identifying CO_2 concentrations that are frequently in the range of 20,000 to 40,000 ppm in the vadose zone, with maximum values near 60,000 ppm. These values have been validated using a hydrogeochemical simulation model that reproduces the processes affecting the evolution of rain water through the epikarst and vadose zones until its appearance as drip water in the cave. Associated with the dripping, there is an intense CO_2 degassing effect induced by strong cave ventilation. The cave itself appears as an environment relatively depleted in CO_2 within the vadose zone that surrounds it.

The aim of the present work is to present preliminary results concerning hydrochemical data in the saturated zone of the Nerja cave experimental site, and compare them with the information of the nearby vadose environment.

METHODS

Rainwater samples are routinely taken after precipitation events from a rain gauge collector at the meteorological station (Fig. 1A). Another collector was used to sample the drip water inside the cave (Fig. 1A). These two types of samples have been routinely collected by the cave's scientific staff since 1991, and provide hundreds of samples of both types of waters (Carrasco et al., 2002; Liñán et al., 2008). Measurements of pH, electrical conductivity (EC) and major constituents were carried out within 24 hours of sampling. Both types of samples can thus stay some hours in the collector devices before their analysis. So, for the rainwater samples an equilibration process with the carbonate dust in atmosphere is likely to occur. For the drip water samples the equilibrium is mainly imposed by the CO_2 content inside the cave.

All samples were stored at 4°C and analysed using ion chromatography (Dionex DX-100) at the Nerja Cave Research Centre laboratory.

Sampling in boreholes was carried out with a 0.5 L HDPE bailer. This device allows to sample at different depths in P-6 (100 m, 200 m and 300 m: Fig. 1B). Electrical conductivity (EC), temperature (Tª), redox potential (Eh), pH and dissolved oxygen (DO) measurements were performed in the field with a HACH-LANGE HQ40D device. Major ions were analysed by ionic chromatography with a METROHM 792 Basic IC equipment. A SHIMADZU TOC-VCSN analyser provided the inorganic carbon (HCO_3^-) and total organic carbon (NPOC). Isotopic measurements of dissolved sulphate (^{34}S and ^{18}O) were performed with Elemental Analysers (Carlo Erba 1108 for sulphur and TC/EA Thermo-Quest Finnigan for oxygen) coupled with an IRMS (Delta C Finningan Mat). Notation is expressed in terms of delta (‰) units relative to the Vienna Standard Mean Ocean Water (V-SMOW) and Vienna Canyon Diablo Troilite (V-CDT) standards.

Analytical results providing an ionic-balance error of more than 5% have not been taken into account in further interpretation.

RESULTS, DISCUSSION AND CONCLUSIONS

Table 1 summarizes the main physical-chemical characteristics of the waters studied, which have also been plotted in a Piper diagram (Fig. 2).

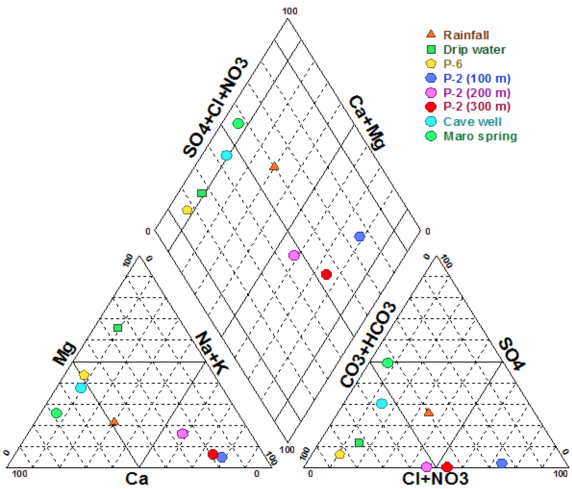

Figure 2. Piper diagram for the samples of Table 1.

Rainfall (P) and drip water (D) in Table 1 corresponds to average values from hundreds of samples since 1991. The rest are averages of two sampling campaigns in May 2007 and 2008. Data of points P-2 and P-6 are presented here for the first time. Data of points CW and MS can be compared with those of a previous monthly record during 1991 and 1992 (Andreo y Carrasco, 1993). These authors calculate average equilibrium PCO_2 values in the range of 4,000 ppm (MS) and 14,000 ppm (CW). The comparison between their data and those of Table 1 indicates a slight increase in the concentrations in CW, which can derive from the fact that in the previous study the samples were obtained when the well was currently operating. The MS values show a fair similarity.

Previous studies (Liñán et al., 2008b) show that rainwater composition changes with episodes. Its anomalous average pH is determined by the sampling procedure, as explained before. Drip waters are quite homogeneous in their composition, due to the effect of the residence time in the vadose zone. The bicarbonate, calcium and magnesium contents are due to the high CO_2 partial pressure in the vadose zone (30,000–60,000 ppm: Benavente et al., 2010). This has been validated by the composition of the water sampled in point P-6. The drip water shows the effects of the intense CO_2 degassing and calcite precipitation. The vadose water has a pH near 7.4, but inside the cave it rises up to 8.3 (Table 1).

Table 1. Hydrochemical average values of samples. GWL: Groundwater level depth, EC: Electrical Conductivity (microS/cm), TOC: Total Organic Carbon. Concentrations in mg/L.

Name	Reference	GWL	EC	T^a	pH	Eh	O_2	TOC	Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	SO_4^{2-}	Cl^-	NO_3^-	F^-
Rain Water	P	-	49	-	7.8	-	-	-	8.9	2.35	4.6	2.8	23.6	12.0	10.7	1.8	-
Vadose Water	P-6	28	800	21.9	7.4	+122	6.8	2.5	102.1	55.3	16.4	1.9	521.7	30.9	27.8	18.5	0.1
Drip Water	D	-	459	-	8.3	-	-	2.2	28.6	45.3	9.6	3.7	274.3	34.3	30.5	3.3	-
Piezometer 2	P-2 (100 m)	98	190	20.6	10.3	-41	2.0	17.9	5.8	1.1	22.9	15.5	24.6	1.6	43.3	0.1	0.7
	P-2 (200 m)	-	165	19.5	10.2	-53	2.1	3.4	7.6	2.9	15.3	7.6	46.1	0.2	23.1	0.1	0.5
	P-2 (300 m)	-	170	19.6	10.2	-15	1.7	2.6	5.2	1.0	17.1	10.7	37.1	0.2	25.4	0.1	0.6
Maro Spring	MS	-	666	19.0	7.6	+224	9.2	0.3	119.2	27.2	11.0	1.9	228.6	204.5	20.7	0.8	0.6
Cave Well	CW	62	878	-	7.1	-	-	0.8	112.4	48.3	20.7	2.9	326.5	139.5	34.6	25.2	0.2

Analytical data in the saturated zone (points MS, CW and P-2) show –when compared with the vadose values- a decrease in the Mg/Ca ratio, and an important increase in the sulphate contents. The origin of this ion is from gypsum hosted in the carbonate formation, as suggested by sulphate isotopic values ($\delta^{34}S_{SO4}$ = 15.4 ‰, $\delta^{18}O_{SO4}$ = 12.3 ‰).

The composition of P-2 samples is anomalous. There are not significant differences in ion contents with depth. Only TOC shows high values (18 mg/L) related to the proximity of the groundwater level and less than 3 mg/L in the rest. The saturation indices in calcite and dolomite for the two deepest samples indicate oversaturation conditions with respect to both minerals. The sample near the groundwater level approach saturation conditions. Bicarbonate contents (< 50 mg/L), calcium and magnesium (< 10 mg/L) and pH (~ 10.0) in this point suggest an aqueous carbonate environment nearly depleted in CO_2. This can indicate a groundwater flow in closed conditions with respect to that gas (Appelo, Postma, 2005), which is in sharp contrast with the measured, calculated and modelled values of CO_2 contents in the nearby vadose zone. It seems difficult to admit such differences in the same groundwater flow system, provided the short distances involved. Maybe the P-2 is drilled in a block of the carbonate matrix which is not connected to the CO_2-rich vadose atmosphere through the karst conduit network where the other points penetrate. Hydraulic testing in this borehole is necessary to check this. Another possibility to check is, provided that the P-2 is hydraulically connected with adjacent sectors, what kind of processes can contribute to the CO_2 depletion. Perhaps most of the gas is lost to the atmosphere due to the ventilation of cavities and big karst conduits in the vadose zone above the groundwater level in P-2.

ACKNOWLEDGEMENTS

Research funded by the Nerja Cave Scientific Foundation. This research is also a contribution to the project CGL2008-04938BTE of the Spanish Ministry of Science and Innovation.

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abstract id: **411**

topic: **6**
General hydrogeological problems

6.2
Hydrogeology of karst

title: **Is the main karst reservoir situated above the regional water table level?**

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keywords: unsaturated zone, residence time, epikarst, tracer test, environmental tracer

Flow pattern and residence time in karst unsaturated zone was studied. Study area is situated in The Moravian Karst in The Ochoz, The Rudice and The Amaterska Cave (Czech Republic). Limestone is of Devonian age, high grade, folded and well lithified but not metamorphosed. There are numerous caves and sinkholes present in the area. Karst unsaturated zone is several tens to more than 100 m thick, saturated zone of karst aquifer is up to 500 m thick.

Main aim of the study was to find out: 1) the character of flow and 2) mean residence times of various flow components via unsaturated zone and 3) to compare the residence time in unsaturated zone with residence time of karst springs draining saturated zone.

Wide spectra of environmental tracers — ^{18}O, ^{3}H, CFC 11, 12, 113 and SF_6 were used, some of them repeatedly in period 2001 to 2008 in water draining from 70 m thick karst unsaturated zone of The Ochoz Cave to estimate mean residence time by means of modeling using FLOW code (Maloszewski and Zuber, 1996). Water was drained via sealed tubes to preclude the contact with cave air. To get information about fast flow components the tracer test using fluorescent dyes via unsaturated zone was launched and monitored by automatic sampler for 700 days. Conductivity and discharge were monitored on base of unsaturated zone for several years in 20 minutes intervals to record and quantify any direct recharge from soil zone. Five springs draining the karst aquifer were studied by environmental tracers mentioned above to estimate the residence time in whole karst aquifer. No-tension lysimeters were placed into soil zone to separate the residence in soil from residence in limestone body. Collection tank of lysimeter situated in 15 cm depth was equipped by pressure transducer to observe the inflow with high time-resolution and to study the hydraulic response propagation from soil zone to cave.

Mean residence time in 70 m thick unsaturated zone is 10–20 years, while hydraulic response after heavy rain or snowmelt propagates through it in few days. Based on monitoring the O isotopes, the direct fast flow via unsaturated zone did not exceed 15% in cave seepage even during largest recharge events. Residence time in several decimeters thick soil zone is few months only. Karst springs show similar mean residence times as seepage from unsaturated zone alone. Studied karst unsaturated zone thus probably presents dominant reservoir of mobile water in whole karst aquifer. In fact, based on water table levels in monitoring boreholes in close quarry, the "unsaturated zone" (part of the karst aquifer above the regional water table level) contains in many cases perched water table levels, which have small spatial extends. The results agree with study of Perrin et al. (2003) who found that epikarst host important part of whole water stored in the karst aquifer.

ACKNOWLEDGEMENTS

Research was supported by projects No. 80509 of the Grant Agency of the Charles University, research project MSM00216220855 and Ceskomoravsky Cement a.s.

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abstract id: **419**

topic: **6**
General hydrogeological problems

6.2
Hydrogeology of karst

title: **Interpretation of pumping tests in a mixed flow karst system**

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keywords: modelling, France, double continuum approach, matrix, spring

INTRODUCTION

Mixed flow karst systems (MFKS) can be conceptualized as dual or triple flow systems comprising localized and often turbulent flow in solution conduits and Darcian flow in the fractures and in the porous rock (Atkinson, 1977). Pumping tests carried out in wells intercepting the solution conduits of a MFKS are difficult to interpret because the geometry of cave networks and connections to the matrix are very often unknown. The present paper describes such a long-duration pumping test. The response of the system is analyzed into the solution conduit and the surrounding carbonate rocks (matrix). An approach using a double-continuum model is developed for the interpretation of drawdown into both the conduit and the matrix. The exchange of flow between the two reservoirs is explicitly modeled using a physically-based approach (varying difference in hydraulic heads) through the application of the superposition principle. The method is applied to a real case study (Maréchal et al. 2008), the Cent-Fonts karst system in the Hérault region of Southern France (Fig. 1).

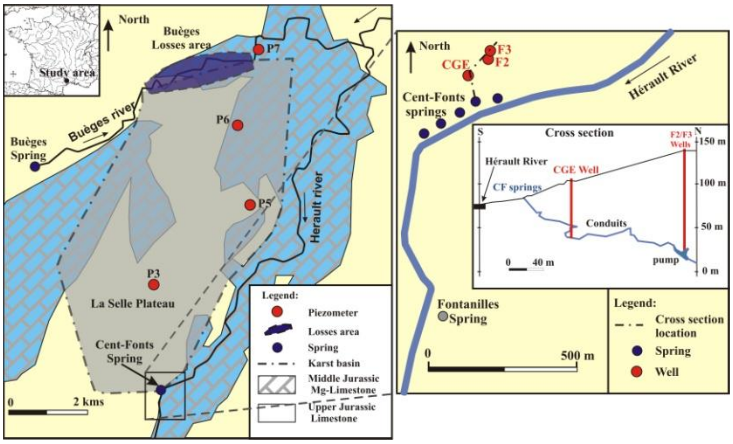

Figure 1. (a) Geological and location map of the Cent-Fonts karst system. (b) Location of pumping well (F3); cross section showing the wells intersecting the conduit network.

STUDY AREA AND DATA

The Cent-Fonts karst (Figure 1) is a MFKS located north of Montpellier (Hérault region, Southern France) in a thick limestone and dolomite series. The Cent-Fonts spring, located on the right bank of the Hérault River, is the only outlet of the karst system (Figure 1a). Its discharge ranges from Q_S = 0.220 m^3/s to more than 12 m^3/s (Q_{Smoy} = 1 m^3/s). The Cent-Fonts spring is the outlet of a water-saturated karst conduit network that has been partially explored and mapped by divers to a depth of 95 m in the vicinity of the spring (Figure 1b). Three wells intercept the karst network near the spring (Figure 1b): CGE is about 60 m deep, F3 is located about 100 meters upstream from CGE and reaches the largest part of the conduit at a depth of 128 m, and F2 is located 3 meters from F3 in the same conduit. The observation wells located within the karst basin (P3, P5, P6 and P7, Figure 1a) do not intersect the karst conduit.

The plateau, called "Causse de la Selle", is deeply cut by the Hérault River, which flows near the spring and constitutes the present-day base level of the karst system. Sinkholes in the Buèges

River (Figure 1a) provide 50 % of the annual mean recharge of the Cent-Fonts karst aquifer system, the rest being diffuse recharge on the karst catchment area.

Pumping tests were done on the Cent-Fonts karst system (well F3) in 2005 (Maréchal et al., 2008). The main objectives of the pumping tests were to evaluate the capacity of the tapped conduit to mobilize the reserves of the karst aquifer and to identify the potential impact of the pumping on adjacent groundwater systems. The long duration pumping test began with a 0.4 m^3/s flow rate on August 1, 2005. During this pumping test, which lasted more than one month (01/08/2005–06/09/2005), pumping was halted twice on-purpose (09/08/2005 and 02/09/2005) and stopped once due to electrical problems (22/08/2005 less than one hour).

The Buèges river losses contribution was constant at L = 0.015 m3/s during the entire test. Infiltration of Hérault River water to the conduits occurs only in the immediate vicinity of the spring and reaches QR = 0.030 m3/s after August 1 when the hydraulic head in the karst conduit drops below 75 m [Ladouche et al, 2005]. The initial discharge rate at the spring before pumping (July 27, 2005) was measured at QS(0) = 0.255 m3/s with a recession coefficient ⍰ = 0.0021 d-1 (Fig. 2).

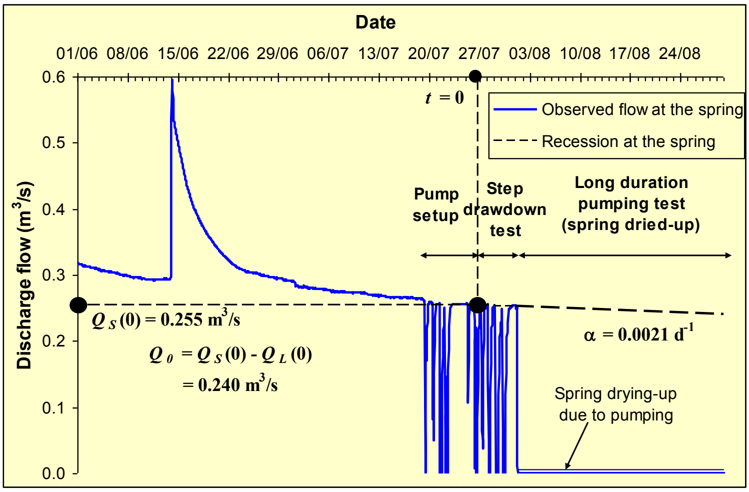

Figure 2. Discharge at the spring before and during the pumping test.

During the pumping test, the drawdown in the matrix is low ($s_{m\,max}$ ≈ 5.1 m as an average on P5, P6 and P7 at the end of the long-duration pumping test, Fig. 3) and depends on the location of the observation wells to karst heterogeneities and pumped conduit network. Measured water level decline in the matrix includes the natural recession of the karst system and is therefore not only induced by the pumping test. Based on the average natural water level recession before pumping tests, the water level decline observed in P5 during the long-duration step is due to both natural recession (25%) and pumping (75%). In P6 and P7, natural recession represents approximately 50% of the observed water level decline.

The final drawdown in the karst conduit is high ($s_{c\,max}$ = 52.17 m; Fig. 3) and does not show any sign of stabilization after one month of pumping. These results show that both matrix (several kilometers away from the pumping well) and conduits are affected by the test but the matrix is much less affected by pumping than the karst conduit. Therefore, the interpretation of the pumping test was focused on the drawdown in the main karst conduit.

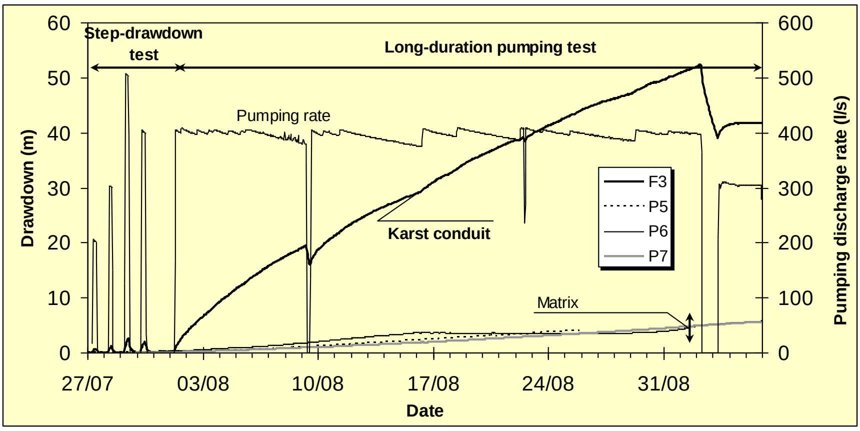

Figure 3. Drawdown during the pumping test. Drawdown is high in the karst conduits (well F3) and low in matrix (P5, P6 and P7).

INTERPRETATION AND MODELLING

Karst water hydraulics is strongly governed by the interaction between a highly conductive conduit network and a low-conductive rock matrix under variable boundary conditions (Liedl et al., 2003). Fig. 4 shows a conceptual model of the Cent-Fonts MFKS with well F3 intersecting the conduit.

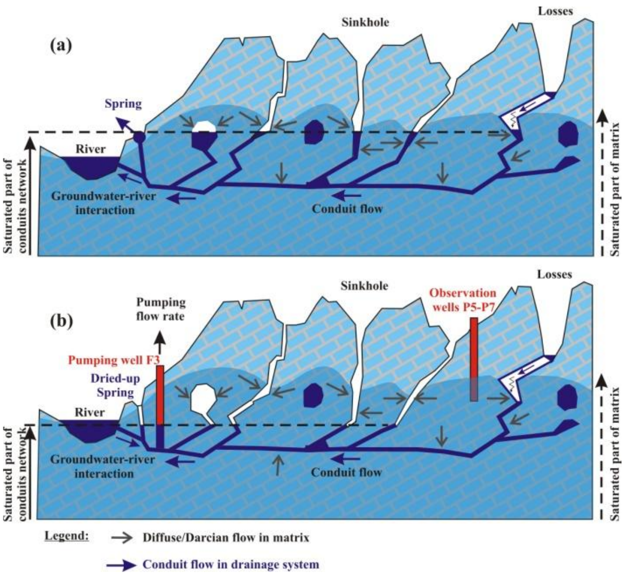

Figure 4. Conceptual model of the Cent-Fonts karst system (a) under natural low flow conditions and (b) when pumping is done in a well intersecting the solution conduit of the same karst system (dark blue: Water in solution voids and conduits; light blue: Water in matrix).

The karst system (Fig. 4a) comprises a main spring connected to a conduit network recharged by surface water losses in a sinkhole system and by flow from the matrix to the conduits. During the pumping tests (Fig. 4b), the highly permeable solution conduits act collectively as the initial source of the water being pumped. Consequently, the hydraulic head in the solution conduits decreases (high drawdown in the conduit network), resulting in an increase in the hydraulic gradient between the matrix and karst conduits. This causes water in the fractures and/or in the porosity of the matrix to flow toward the larger solution conduits at a higher rate than before pumping. At the karst basin scale, since the matrix has a much higher storage capacity than the conduits, the hydraulic head fluctuates much less in the matrix than in karst conduits during the pumping test (very low drawdown in the matrix, Fig. 3).

A modelling approach is proposed for this interpretation. The developed double continuum model consists of two reservoirs-karst conduits and the surrounding carbonate rocks - between which exchange flow rate is modeled (Fig. 5). The total exchange flow β is divided into two components: the natural contribution Q_{α} (recession flow at the spring, Fig. 2) and the induced contribution Q_{IND} (modelled using the superposition principle and the hypothesis of Darcian flow in the matrix considered as an equivalent porous media with transmissivity T_m and storage ϕ_m, Maréchal et al., 2008). The karst conduits are assumed to have an infinite hydraulic conductivity and a finite length.

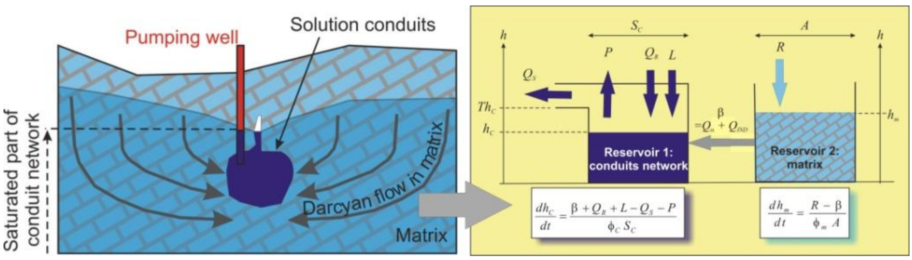

Figure 5. Interaction between matrix and conduit (a) Vertical section of a MFKS (b) sketch of the double reservoir model and volume conservation equations.

Model calibration results (Fig. 6) in a very good match (relative root mean square [rRMS] = 2.3 %) with drawdown measured at the pumping well (karst conduit). It shows that the matrix hydrodynamic parameters (transmissivity T_m=1.6 x 10^{-5} m^2/s and drainage porosity ϕ_m = 0.007) have a greater influence on the drawdown than the storage capacity of the conduit network (ϕ_c = 6 x 10^{-5} at the basin scale). The accuracy of the model relies mostly on a very good knowledge of both pumping rate P and natural discharge at the spring Q_S (with and without pumping).

The sum of the pumping rate and the spring discharge results from the natural contribution of the matrix (Qα), the additional flow from the matrix due to the pumping (QIND), the Hérault river contribution (QR), the Buèges river losses contribution (L) and the dewatering of the karst conduit network. According to the recession function incorporated in the model (Fig. 2), the natural flow from the matrix decreases exponentially from Q_0 = 0.240 m^3/s at the beginning of the pumping down to about 0.219 m^3/s at the end of the test. The additional flow from the matrix induced by pumping increases with time along with the drawdown from Q_{IND} = 0 m^3/s at the beginning of pumping (no induced flow) and up to 0.105 m^3/s (maximum induced flow) at the end of the 0.4 m^3/s pumping step.

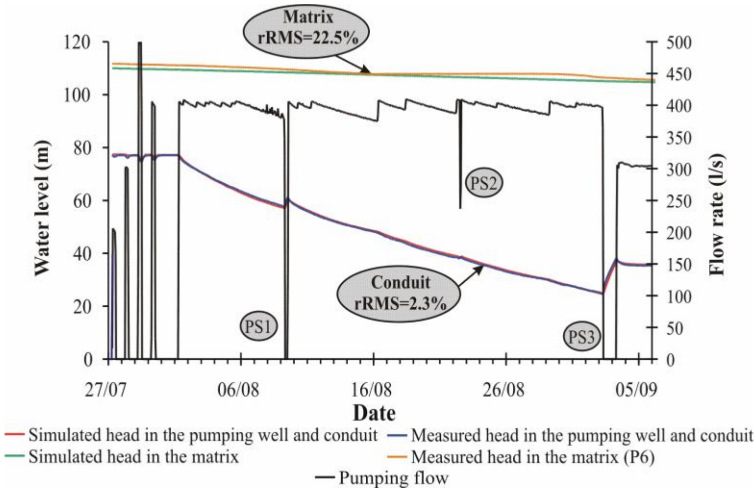

Figure 6. Temporal evolution of simulated and measured drawdown in the conduit and in the matrix using the model (rRMS is computed on drawdown referred to initial water level; PS: pump stop).

The diffuse flow decreases rather quickly after each pumping stop due to recovery in the conduits, and becomes negative when the hydraulic head in the conduit rapidly increases and inverts the hydraulic gradient between matrix and conduits. In that case, the karst conduits recharge the matrix ($Q_{IND} < 0$), similar to what happens during recharge of the aquifer during high-flow periods. The dewatering of the conduit network is the lowest flow component (Fig. 7).

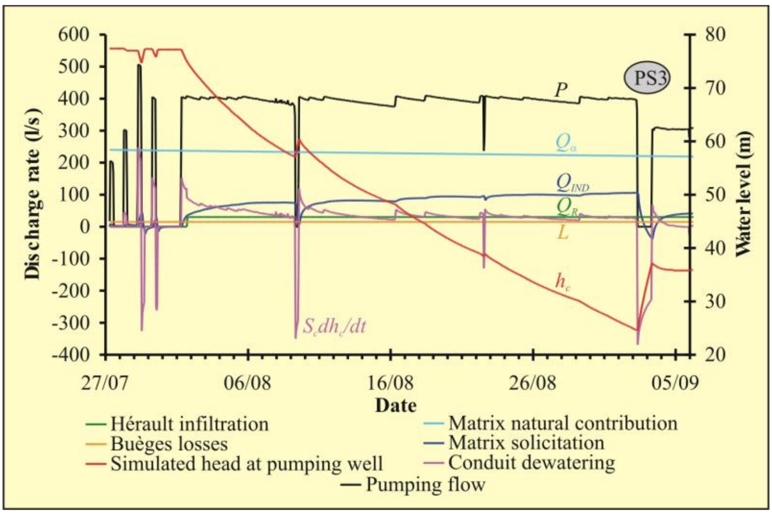

Figure 7. Temporal evolution of the flow contributions simulated by the model during the pumping test.

It decreases with time, proportionally to the decreasing rate of depletion in the conduits. Obviously, the dewatering is proportional to the drawdown in the conduit network, whatever the value of drawdown. The dewatering fluctuates between 0.150 m^3/s at the beginning of the test and about 0.020 m^3/s at the end of the pumping test at 0.400 m^3/s. It suddenly increases after each increase in the pumping rate due to the associated increase in the drawdown rate. It becomes negative during pumping stops, when the hydraulic head in the conduit increases and water from the matrix (and other contributions) is stored in the conduit network (dewatering flow is negative).

CONCLUSION

The hydrodynamics of a mixed flow karst system (MFKS) in which a long-duration pumping test has been done on the main karst conduit was analyzed and modeled. These results show that both the matrix (several kilometers away from the pumping well) and the conduit network are affected by the test. Nevertheless, the conduits are much more affected by pumping than the matrix (drawdown in the conduits ten times higher than drawdown in the matrix) due to their better connection to the pumping well and their low storage capacity at the basin scale (ϕ_c = 6 x 10^{-5}).

The double continuum model composed of two reservoirs (conduit network and matrix) well reproduces the transient response in the pumping well. The sensitivity analysis shows that it is the low-permeability matrix that dictates the pumping test response. The conduits induce a moderate capacitive effect (dewatering of vertical shafts and variably saturated conduits).

Free of deterministic finite-difference/elements modeling, it is simpler than hybrid models and constitutes an advance in double continuum modeling of karst systems notably by an improvement in the calculation of the flow exchange rate between matrix and conduits.

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abstract id: **462**

topic: **6**
General hydrogeological problems

6.2
Hydrogeology of karst

title: **Management of karst water of Albania**

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keywords: karst water, Albania

Albania is situated in the southwester part of Balkan Peninsula, with a territory of 28,749 km^2.

Karst rocks outcrop on about 25% of the territory of the country and on about 50% of the territory the karst rocks are covered by other sedimentary non karstic rocks. Karst aquifer is most important aquifer of Albania. Carbonate karst rocks form 25 significant hydrogeological structures; there are also two structures of sulphate rocks. In Albania, karst is more developed in wide and relatively plain carbonate structures consisting of Triassic and Cretaceous limestone formations, and is less developed in narrow longish carbonate structures.

As karstified rocks in Albania mostly form high elevation massifs extending down to the valleys, high hydraulic gradients tends to drive linear conduits forming generally karst networks quite different from the fractured pattern. The surface hydrography practically is missing or is poorly developed, but in contrary the subsurface hydrography is very active and is finalised with formation of big karst springs. Disappearing and reappearing rivers in karst could be observed in karst areas of Albania. On special hydraulic situations, often is observed the "karst piracy"; a karstic area having lower hydraulic head is recharged by another one having higher hydraulic head.

At a regional scale the permeability of karstic rocks is very high but at a local scale it could be even not relevant. The results of many groundwater wells testify that the hydraulic parameters of karst rocks vary at very large limits. Usually efficency wells could be located close to springs or at least at valley bottom sites.

The efficient infiltration, which represents the part of the precipitation recharging the karstic groundwater, consists about 50% of the mean yearly precipitation. It is varying from about 500–600 mm/year in southeaster Albania to about 3000 mm/year in North Albanian Alps zone. In Albania about 110 karst springs have mean yearly discharge bigger than 100 l/s, and among them 17 have mean yearly discharge more than 1000 l/s, while the mean discharge of Blue Eye Spring, the biggest Albania's spring, is 18.5 m^3/s.

Karstic water has significant differences in physic-chemical characteristics. The main factors controlling the formation of chemical composition of karst water are the lithology of the karst rocks, the solution of carbonates and the calcite and dolomite saturation conditions. Most of karst springs are undersaturated with respect to calcite and dolomite, but being much more undersaturated with respect to dolomite than with respect to calcite.

Environmental isotope and hydrochemical studies are applied in order to better understand the karst water circulation patterns. Applying these methods is established that Prespa Lake intensively recharges the Ohrid Lake through the Mali Thate karstic massive; with the same methods have been established that Poçemi karst spring at about 80% is replenished by Vjosa River, as well as that Blue Eye Spring at about 35% is replenished by the Drinos River gravely aquifer. The average total karst water resources of Albania consist about 227 m^3/s.

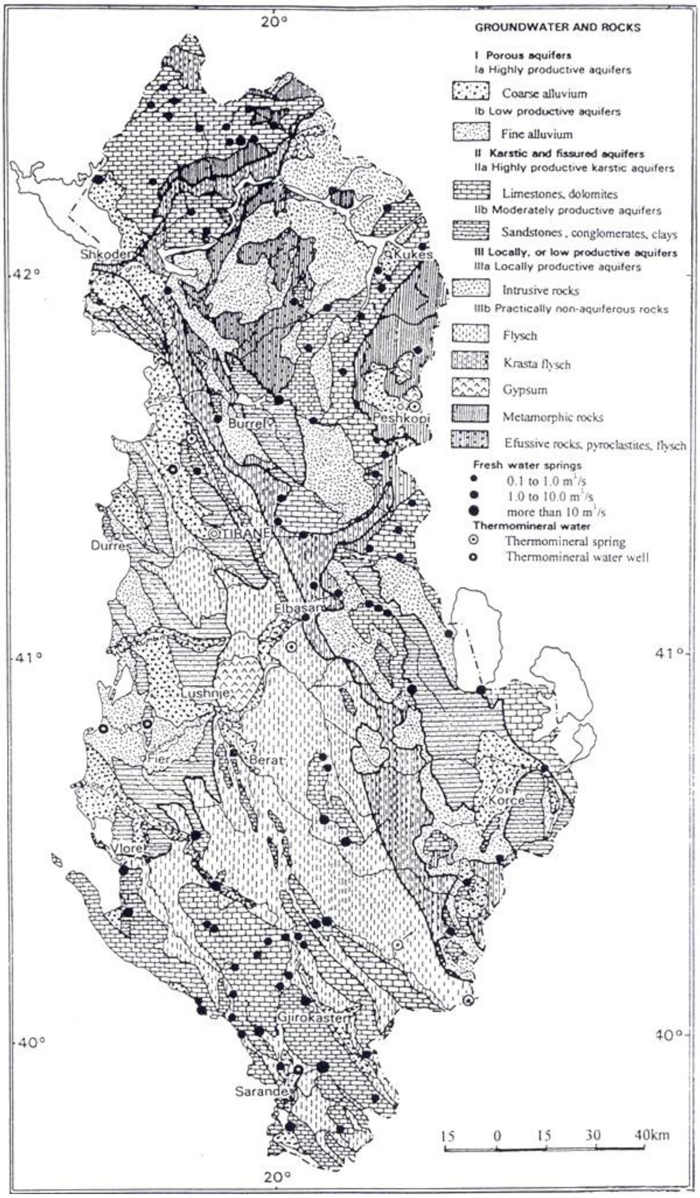

Figure 1. Simplified Hydrogeological Map of Albania.

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abstract id: **491**

topic: **6**
General hydrogeological problems

6.2
Hydrogeology of karst

title: **Characterizing aquifer behaviour of two karst systems from S Spain by hydrodynamic and hydrochemical data**

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keywords: karst aquifers, hydrochemistry, hydrodynamic

ABSTRACT

The monitoring of karst springs provides data about hydrogeological functioning, water resources and their vulnerability to contamination, information that is essential for the appropriate management and exploitation of karst aquifers. Hydrochemical and hydrodynamic studies of the karst waters at the springs of El Burgo and Fuensanta (Málaga province, southern Spain), carried out during an 18-month sampling period, reveal the main hydrochemical processes and flow conditions within the Sierra Blanquilla and Sierra Hidalga aquifers.

Electrical conductivity (EC) time series and hydrochemical monitoring suggest that the karst aquifer network drained by the Fuensanta spring is more developed than that of El Burgo.

Discharge variations at La Fuensanta are faster, but less marked than at El Burgo (average discharge rates of 0.068 m^3/s and 1 m^3/s, respectively). The hydrochemical characteristics recorded at the two springs indicate different degrees of functional karstification: thus, the chemical components dissolved in the spring water at El Burgo present a lower variation than at Fuensanta. At El Burgo, EC varies in accordance with TAC, Ca^{2+}, Cl^- and TOC contents, while NO_3^-, SO_4^{2-} and Mg^{2+} vary inversely.

The Fuensanta spring water presents large variations in most chemical parameters, such as Ca^{2+}, TAC, SO_4^{2-}, Mg^{2+}, NO_3^- Cl^- and TOC. This spring presents a typical pattern of karstic functioning, with predominantly conduit flow during high water conditions.

INTRODUCTION

The growing demand for high-quality water, together with the scarcity of water resources, in an area such as the Mediterranean, characterised by considerable climatic variability, accounts for our interest in determining the hydrogeological functioning of carbonate aquifers, the volume of resources available and their vulnerability to contamination, all these factors being relevant to the appropriate management and exploitation of such aquifers. The present study presents two examples of karst springs in southern Spain, located within an area classified as a UNESCO Biosphere Reserve.

Karstic aquifers are differentiated from other types of aquifer by the development of secondary porosity through conduits and fissures that are enlarged by dissolution processes, thus enabling rapid groundwater flow (White, 2002; Ford, Williams, 2007). In karstic aquifers, infiltration takes place in diffuse form via fissures, and in a more concentrated way through karstic sinkholes.

In the absence of direct information (from prospective boreholes, speleological exploration, etc.), karst studies normally focus on the natural responses apparent at discharge points. Thus, the joint analysis of hydrodynamic responses (Mangin, 1975) and hydrothermic and hydrochemical responses (Bakalowicz, 1979; Mudry, 1987) enables us to characterise the functioning of a karstic aquifer.

The main aim of the present study is to characterise the hydrogeological functioning of the two most important springs draining the carbonate aquifers beneath Sierra Blanquilla and Sierra Hidalga (Fig. 1), in the eastern part of the Ronda mountains (Serranía de Ronda), in the province of Málaga (southern Spain).

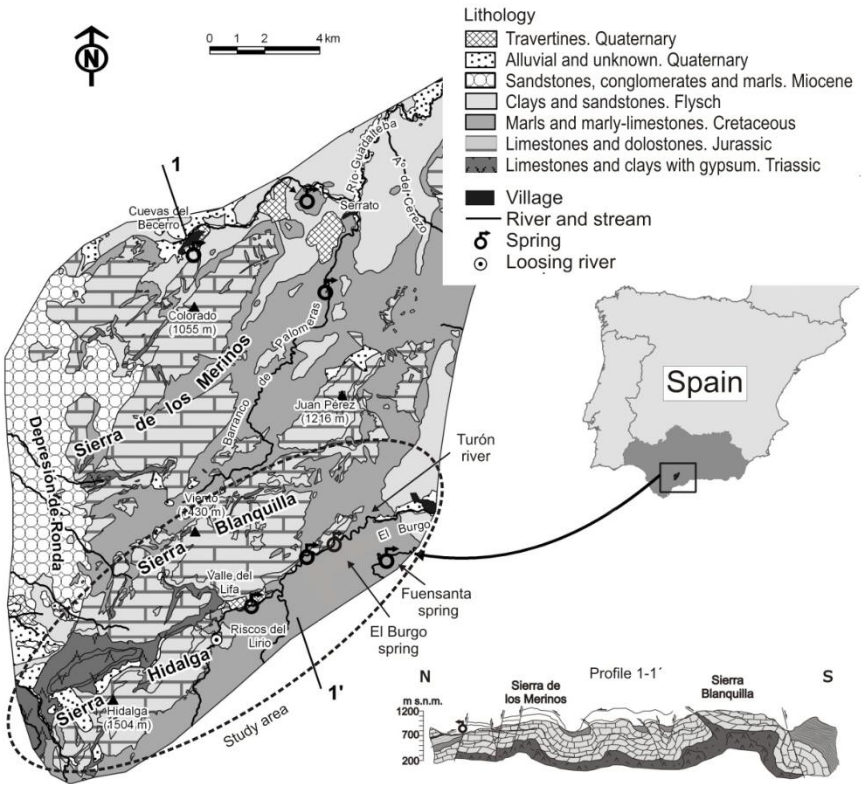

Figure 1. Location of the study site (dotted line ellipse). Geological and hydrogeological settings and geological structure (Profile 1-1´).

SITUATION

The study area is shown in figure 1 and it is located in NW of Málaga province. It has a surface area of approximately 90 km^2, and presents a varied, rugged relief, rising to altitudes exceeding 1500 m (the Hidalga summit is at 1505 m), although the upper parts of the massifs are rounded. The most important river in the area is the Turón, which receives both groundwater and surfacewater flows from the adjacent heights. The climate is of the Continental Mediterranean type, strongly influenced by Atlantic winds. There are two significant rainy periods, in winter and spring. Average precipitation values and mean annual temperatures in this part of Serranía de Ronda are 650 mm and 15ºC (Jiménez et al., 2007), respectively. During the study period (August 2007 – February 2009), the average annual precipitation was over 800 mm, and the mean air temperature was 14°C. Therefore, the study period was both wetter and colder than the historical average.

From a geological standpoint, three main lithological groups have been identified (Cruz Sanjulián, 1974; Martín Algarra, 1987): limestones, dolostones and clays with evaporites (Triassic age)at the bottom; these are overlain by a thickness of several hundred metres of carbonate rocks (Jurassic limestones and dolostones); and finally, a top formation constituted of Cretaceous-Paleogene marls and marly-limestones.

The geological structure is constituted of NE-SW oriented folds, tilting towards the NE (Martín Algarra, 1987). The folds are box-type, with flat hinges and subvertical flanks (Fig. 1; cross section 1-1´). All the fold structures are affected by fractures, which are preferentially oriented N50-70E and N150E (Fernández, 1980).

Sierra Hidalga and Sierra Blanquilla present significant karstic modelling in the Jurassic formations, with large extensions of karrenfields, dolines, uvalas and karstic sinkholes.

METHODOLOGY

Hydrodynamic, hydrothermic and hydrochemical parameters at the El Burgo and Fuensanta springs were monitored during the period August 2007 – February 2009. Water samples were taken at the two springs for chemical analysis, and in situ measurements obtained of electrical conductivity (EC), temperature, pH and water discharge. In addition, continuous (hourly) monitoring was taken of EC and temperature at both springs.

All the hydrochemical parameters considered were analysed at the Hydrogeological Centre at Málaga University. Total alkalinity (TAC) was determined by volumetry, the majority ions (Ca^{+2}, Mg^{+2}, Na^{+}, Cl^{-}, SO_4^{-2} and NO_3^{-}) by ionic chromatography, and total organic carbon (TOC) using a carbon analyser.

RESULTS AND DISCUSSION

In an initial consideration of the hydrochemical characterisation of the carbonate aquifers of Sierra Hidalga and Sierra Blanquilla, we examined the water mineralisation at the springs of El Burgo and Fuensanta, determined from measurements of electrical conductivity (EC) and the continuous records provided by the dataloggers installed at these springs (Fig. 2).

At El Burgo, the electrical conductivity ranged from 288-383 µS/cm. The shape of the frequency curve obtained reveals a distribution with a single clearly-defined mode value, around 320 µS/cm, and a frequency of 26%.

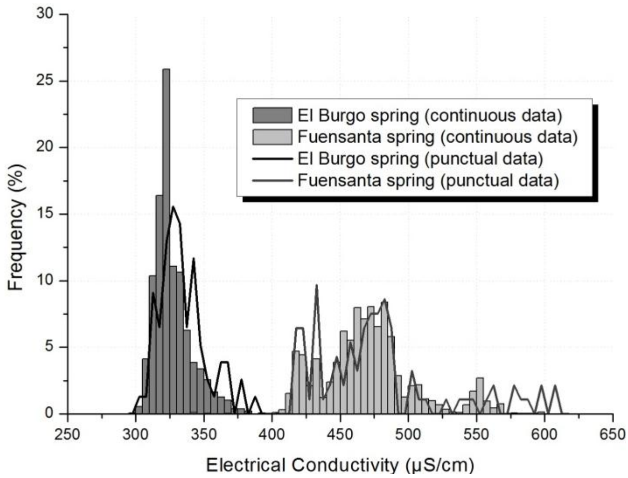

Figure 2. Frequency analysis of electrical conductivity (EC) at El Burgo and Fuensanta karstic springs (EC intervals are 5 µS/cm).

At the Fuensanta spring, EC ranged from 336-600 µS/cm. The frequency distribution presented a wide range, with low frequency values (in no case exceeding 10%). Multiple modes were visible; the curve, thus, was plurimodal.

The distribution of frequencies for the EC values at the two springs studied shows that water mineralisation presents greater variability at Fuensanta, due to the higher degree of development of the karstic conduits there.

The temporal evolution of the hydrochemical parameters registered at El Burgo (Fig. 3A) is shown together with the series of punctual discharge values recorded to the river Turón, which is the main drainage axis for Sierra Blanquilla. The mean net annual discharge from Sierra Blanquilla to the river Turón exceeds 1 m^3/s, with maximum values exceeding 5 m^3/s and minimum values of about 50 L/s during the summer.

The lag affecting the discharge from the spring at El Burgo, with respect to rainfall, is less than one day (Fig. 3A). The continuous recording equipment revealed short-term increases in EC of up to 50 µS/cm (Fig. 3A) during most high-water periods, followed by dilutions in which EC values returned to their initial levels. These episodes provide clear examples of the "piston" effect, by which each increase in discharge provokes a parallel increase in water mineralisation. The EC, temperature and all the chemical components dissolved in the aquifer water presented significant decreases in response to the inflow of less highly mineralised recharge water. In summer, once depletion is established, the increase in water mineralisation is slow but continuous.

The water temperature recorded at El Burgo spring ranged from 12 to 16°C, with a mean annual value of 14.4°C. Temperature variations occurred practically simultaneously with changes in EC, with slight increases, of just a few tenths of a degree, per point increase in EC. After each recharge event, the water temperature fell gradually. An average water temperature of 15.5°C was recorded during the summer and approximately 13°C during periods of heavy rainfall. Thus, the temporal evolution of the water temperature is equivalent to a seasonal curve, with higher values in the summer and lower ones in the winter.

Alkalinity is the main factor responsible for the mineralisation of the spring water at El Burgo, together with the content of Ca^{2+} (calcium bicarbonate facies). Increases in spring water discharge during recharge periods provoke the drainage of more highly mineralised water, with higher TAC values (Fig. 3A). This variation in concentration also affects the Ca^{2+} ion and, moreover, coincides with an increase in calcite saturation. Contents of the Mg^{2+} ion are low (mean value: 6.7 mg/L), and this concentration decreases during high water periods; nevertheless, these variations are of less magnitude than are those of alkalinity and of the Ca^{2+} ion.

Total organic carbon (TOC) responds rapidly to rainfall, with significant increases during spikes in spring water discharge. This is also the case with the ions NO_3^- and Cl^-, which present important increases following the first autumn rainfall. This was particularly so following the heavy rain of October 2008, when maximum levels of concentration of these ions were recorded.

These temporal evolution findings reflect the existence of rapid flows, with the participation of the soil and the unsaturated zone, especially during the recharge events at the beginning of the hydrologic year, because rapid infiltration tracers such as TOC and Cl^- are mobilised, and these become more highly concentrated with the arrival of the recharge water. This effect is in addition to the dilution of other parameters that are characteristic of the saturated zone, such as

SO_4^{2-} and Mg^{2+}, which suggests that the water stored in the saturated zone is becoming mixed with the recharge water, which contains a lower concentration of these components.

On the other hand, the Fuensanta spring (Fig. 3B) presented a mean discharge of 68 L/s during the study period, with maximum values of 325 L/s. During the summer, the discharge fell to barely 10 L/s, but the spring never became completely dry. The response time to rainfall, measured by spring water discharge and hydrochemical parameters, was minimal, at less than one day.

The evolution of EC at the Fuensanta spring presented rapid, important variations in response to the entry of rain water. Recharge events produced punctual increases in mineralisation, followed by reductions proportional to the intensity of the precipitation. The heavy rainfall in the spring and autumn of 2008 provoked a considerable decrease in EC, and this value remained low throughout practically the entire winter (Fig. 3B).

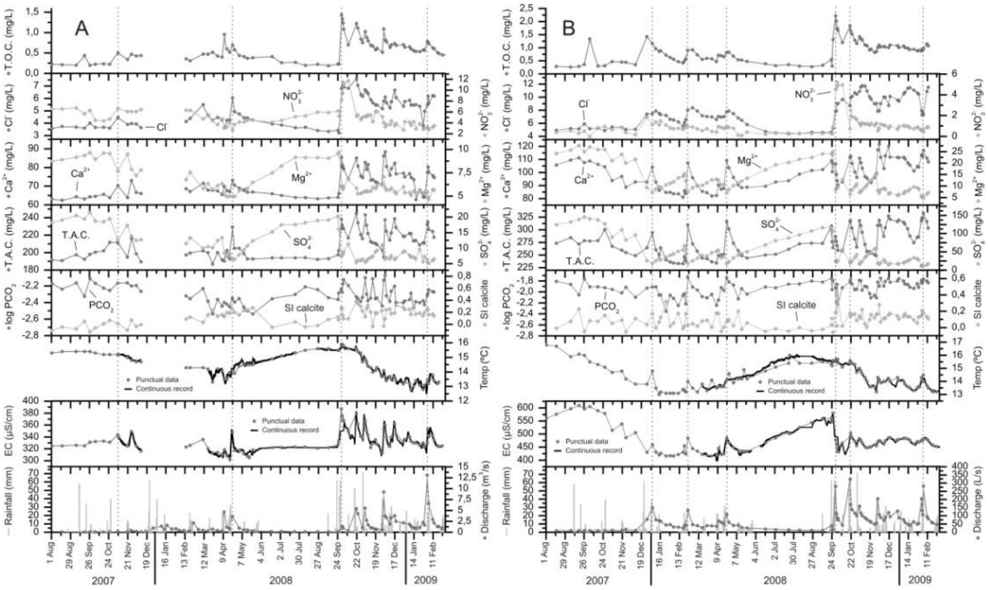

Figure 3. Temporal evolution of dissolved chemical parameters and discharge values at El Burgo (A) and Fuensanta (B) springs.

Water temperature at the spring ranged from 13-16.8°C, with an average value of 14.4°C. The temperature pattern corresponded to a sinusoidal curve, such that during high water periods, colder waters were drained, while during the summer, water temperatures were higher. The general evolution was interrupted by each recharge event, when the spring water underwent slight increases in temperature and in EC, related to increases in water discharge, and decreases in the values of chemical components such as SO_4^{2-} and Mg^{2+}.

The alkalinity and Ca^{2+} and SO_4^{2-} contents influenced the mineralisation of the water at Fuensanta spring. A significant finding was the considerable variability of certain hydrochemical parameters, such as TAC (233-332 mg/L), SO_4^{2-} (11-146 mg/L), and Ca^{2+} (81-122 mg/L). The content of Ca^{2+} and alkalinity varied in parallel, although the responses in the latter case presented greater magnitude. In both cases, the concentrations rose rapidly with higher discharge values (the "piston" effect). On the other hand, during low water periods, the increase in concentration was continuous but slow, due to the greater contact time with the rock and the kinetics of calcite dissolution.

The contents of SO_4^{2-} and Mg^{2+} varied following a similar pattern, with maximum values in summer, and lower concentrations during rainy periods.

In general, the values for NO_3^- and TOC behaved in a similar way (Fig. 3B), unlike EC and water temperature. The former values tended to be higher at the beginning of the hydrologic year (in the autumn), when the first rains fell, and decreased as less water reached the spring. During high water periods, the two parameters responded rapidly with slight increases, almost always associated with increases in discharge from the spring.

CONCLUSIONS

The application of different hydrogeological techniques to the data obtained in this study has enabled us to obtain a hydrochemical characterisation of the two springs, El Burgo and Fuensanta, that drain the carbonate aquifers beneath Sierra Blanquilla and Sierra Hidalga, respectively.

The discharge variations were found to be more rapid at Fuensanta, although of lesser magnitude (68 L/s versus 1 m^3/s).

The EC values recorded at the two springs reflected different degrees of functional karstification. Thus, the Fuensanta spring presented a high level of differentiation of flow types through the aquifer, a pattern that is typical of karstic springs, while El Burgo presented a less variable discharge pattern.

The hydrochemical variations at the two springs also differed significantly, indicating different degrees of functional karstification. El Burgo was characterised by a lower development of functional karstification (less hydrochemical variability with respect to Ca^{2+}, SO_4^{2-}, Mg^{2+} and TOC, although higher variability for NO_3^-), with rapid flows, sometimes reflecting a piston effect, in which each increase in discharge rate was reflected by a punctual increase in water mineralisation, involving some of the chemical components (TAC, Ca^{2+}, Cl^- and TOC). The remaining parameters (NO_3^-, SO_4^{2-} and Mg^{2+}) varied inversely, in accordance with the dilution of the volume of water stored in the aquifer.

Fuensanta is a typically karstic spring, with a well developed network of internal drainage, which is reflected in the considerable variation recorded for most of its chemical components (TAC, Ca^{2+}, SO_4^{2-}, Mg^{2+}, NO_3^- Cl^- and TOC).

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6.3 Groundwater contamination — monitoring, risk assessment and restoration

abstract id: **101**

topic: **6**
General hydrogeological problems

6.3
Groundwater contamination — monitoring, risk assessment and restoration

title: **Human risk assessment of arsenic contaminated groundwater in India**

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keywords: arsenic, groundwater, contamination, risk assesment, environment

ABSTRACT

The profound impact of our environment on the human body is apparent in understanding the cause of disease. Human survival is dependent on the environment and therefore, environmental protection should be a major issue in modern society. Additionally, the significance of acclimatizing to the surrounding environment is crucial for human health and survival. Arsenic contamination in water is a major human health concern worldwide. The greatest threat to human health arises from arsenic in drinking water because millions of people are at risk of drinking water contaminated with the metalloid. In India arsenic human exposure is mainly by ingestion of drinking water naturally contaminated with inorganic arsenic from geogenic sources. Presently public attention is focused in many states e.g. New Delhi, West – Bengal, Uttar Pradesh, Bihar, Jharkhand and Chhattisgarh where level of arsenic in drinking water are often higher than W.H.O. permissible limits. Many persons of either sex died of cancer and millions are suffering from arsenicosis, melanosis, keratosis, and gangrene and skin cancer which is believed to have been triggered by their prolonged use of arsenic laced drinking water. The arseniferous belt is mainly characterized by complete or truncated cycles of fining upward sequences dominated by course of medium sands, silt and clay sediment. A geochemical and hydrogeological characteristic of this alluvial sediment influences the mobility of arsenic in groundwater. Arsenic poisoning or arsenicosis is emerging as the world's biggest environmental health disaster. So far about a 60 million people spread over an area of about 85,000 Sq. Km. have been found to be affected by poisoning. Finally, we have to evaluate and identify potential prevention and mitigation strategies to reduce arsenic exposure and its fatal and non-fatal consequences. These findings have important public health, socio-economic and policy implication for large number of arsenic exposed population of the world.

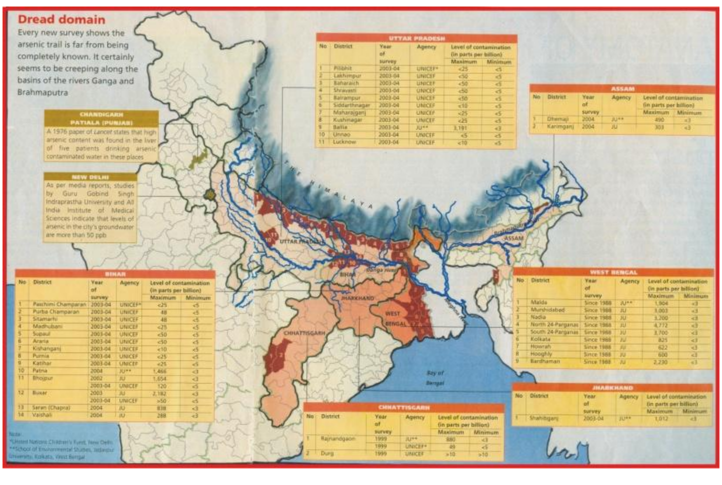


Figure 1. Location map No. 1.

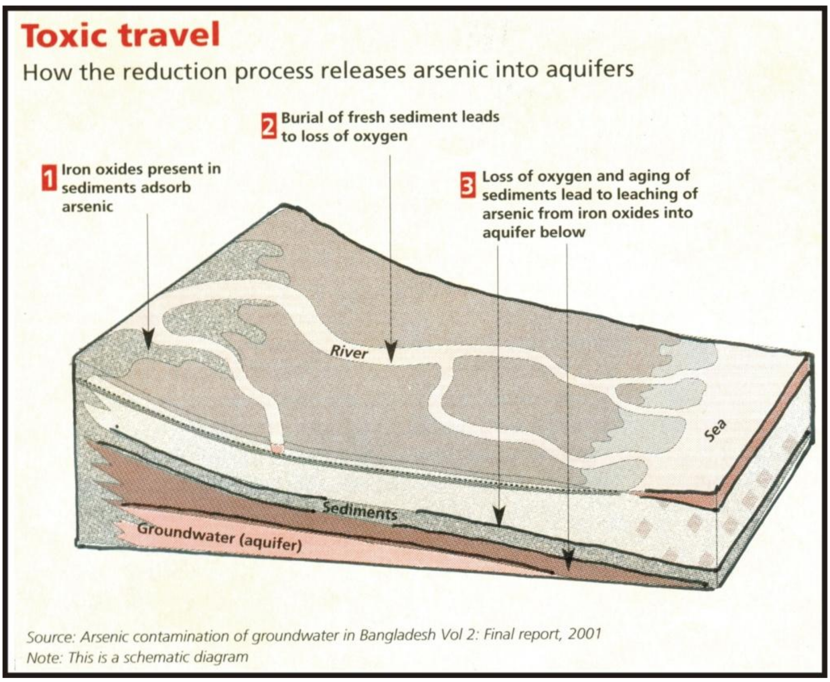
METHODS AND MATERIALS

The Reduction Theory

According to the reduction theory, arsenic is adsorbed by iron oxides, which form a part of fine-grained sediments. These sediments are rapidly "reducing" (losing oxygen) because the rich organic matter. When the sediments reduced (lose oxygen), a series of geochemical reactions occur leading to the release of arsenic into the groundwater. The exact processes involved are not yet well understood. But as per BGS researchers, they are likely to involve one or more of the following processes:

- reduction of strongly adsorbed arsenic to less strongly bound arsenic, which leads to the release of arsenic from iron oxides;
- iron oxides partially dissolve and release iron as well as the adsorbed arsenic;
- the iron oxides undergo changes leading to the desorption (release) of arsenic.

Acharya (2001) explains that "arsenic gets preferentially entrapped in the organic-rich clayey floodplain and delta sediments and therefore any delta or floodplain that developed into marsh-land or swamp is prone to contain arsenic contaminated groundwater". A 2004 paper in the British journal Nature supports this theory, arguing that anaerobic-metal reducing bacteria can play a key role in the mobilization of arsenic in the sediments. According to this research, arsenic release takes place after iron reduction – release of iron in anaerobic conditions –rather than occurring simultaneously with changes in the iron oxides.



The oxidation theory

The other set of researchers believes that the oxidation of iron releases the arsenic in the sediments. These researchers hold that arsenic is present in pyrites – iron-containing rocks – that are deposited in the aquifer sediments. When the iron is exposed to oxygen, its capacity to adsorb arsenic reduces, and therefore the toxic chemical starts leaching into the aquifers,. This hypothesis is called the pyrite oxidation thesis. Chakraborti (2003) propose that oxygen enters the aquifer because of heavy groundwater withdrawal, favoring the oxidation of arsenic-rich iron sulphide, which in turn mobilizes the toxic element into the water. The oxidation theory fails to explain arsenic contamination in deep aquifers, where oxygen cannot reach. The organic carbon reduction theory explain contamination in these aquifers: dissolved carbon in the waters of some regions combines with iron hydroxides rich in arsenic. When these oxides embrace carbon, they simultaneously liberate arsenic, which in turn contaminates the aquifers.

RESULTS AND DISCUSSION

One of the highest arsenic concentrations in the world appears to be in the bengal deltaic alluvial aquifers generally at depth 20–50 m. A working hypothesis for the release of the arsenic has been oxidation of pyrite/arsenopyrite in clay or peat interbeds. However, the deltaic alluvial aquifers hold reducing iron rich in alkaline low sulphate groundwater and the reduction of arsenic bearing iron-oxyhydroxides may be the cause ascribed to reductive dissolution reaction is mediated by anaerobic heterotopic Fe (III) reducing bacteria. It may occur due to some geochemical changes. These alluvial tracks contain high contents of pyrites which are rich in arsenic. Due to increased population and their need to meet their food requirements, three or more crops are harvested each year. As a result, excessive groundwater is used. Million of bore holes are installed for agriculture and drinking purposes and due to the fluctuation of water table from pre-monsoon to post-monsoon; the ground water aquifers are aerated. Thus, the pyrites are decomposed and As (arsenic) acids ($H_3 ASO_4$, $H_3 ASO_3$) are released from sediments.

Evidences suggest that the ingestion of arsenic can cause several different types of cancers. The clinical representation of arsenicosis is initially dermatological, including melanosis, leukomelanosis, keratosis, hyperkeratosis and progresses to gangrene or skin cancer. Prognoses for people exhibiting these symptoms are poor. There is no cure of arseniocosis as yet. Patients are advised to drink arsenic free water, and to maintain a diet of nutritious foods, which is often not possible because the inhabitants are neither health conscious nor can afford the suggested line of treatment because of extreme poverty. The gravity of the problem may be ascertained with the report that only a small fraction of groundwater of the affected area was tested and reported to have more than 0.05 ppm arsenic. The WHO specifies a limit of 0.05 ppm arsenic and less than 0.01 ppm is desirable in drinking water (WHO Guidelines for Drinking Water, 1993).

CONCLUSION

There is no doubt that arsenic content of groundwater situation in India is very grave. Patients are suffering, relatives are desperate and physicians are frustrated. We are optimistic that with joint efforts with national and international agencies and scientific communities, some solution will be obtained which will bring smile on the faced of the distressed. To mobilize and organized efforts of the international community toward this goal is the prime target of this work.

Figure 2. Lesions on the Face of baby, caused by drinking contaminated water.

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abstract id: **109**

topic: **6**
General hydrogeological problems

6.3
Groundwater contamination — monitoring, risk assessment and restoration

title: **Classification of groundwater pollution index by using fuzzy set theory**

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keywords: groundwater quality index, fuzzy inference system, fuzzy index

In recent years fuzzy set theory has emerged as a transcendental tool to deal with environmental engineering application having uncertainty, ambiguity and subjectivity. Analysis of ground water quality plays significant role in environmental impact assessment studies. For qualitative description of ground water quality, number of physical, chemical and biological parameters are taken into consideration, allotted a weightage factor and calculated into an index called water quality index (WQI). Water quality index uses crisp set to analyze water contaminants and hence deals with standing boundary conditions. This paper illustrates use of fuzzy inference system for analyzing physical and chemical parameters to assess ground water pollution. A ground water pollution index calculated with fuzzy inference system has been developed and discussed. Various physical, chemical parameters of ground water are divided into three groups and are finally clubbed with to get a single index of ground water pollution by using fuzzy set theory.

abstract id: **222**

topic: **6**
General hydrogeological problems

6.3
Groundwater contamination — monitoring, risk assessment and restoration

title: **Contamination of a regional confined aquifer by leaky boreholes. Campo de Cartagena case study (SE Spain)**

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keywords: aquifer interconnection, leaky borehole, nitrate, mixing rate, Campo de Cartagena

ABSTRACT

The present work provides a methodological approach to evaluate the impact of poorly constructed (leaky or without a gravel pack) and abandoned wells for facilitating the transfer of contaminants between aquifers at different depths. The approach was based on the use of nitrate as a tracer and the MIX_PROGRAM code for mixing calculations. Proposed methodology was applied to the Campo de Cartagena (SE Spain), where intensive irrigated agriculture takes place. The hydrogeologic unit consists of a multi-layer system constituted by an upper unconfined aquifer and a deep confined aquifer with a high density of wells exploitation (1.18 wells/km^2). Results show the increase of the unconfined aquifer impact on the confined aquifer along the groundwater flow direction toward the coast, although this general pattern is controlled by local factors (pumping, intensity of agricultural practices, density of wells and groundwater residence time).

INTRODUCTION

Abandoned, leaky and poorly constructed wells (leaky or without a gravel pack) may act as conduits transferring contaminants to underlying aquifers and are common features at many polluted groundwater sites. In a multi-layer aquifer, abandoned or poorly constructed wells penetrate through geological strata otherwise considered impermeable (aquitard) that supposes open conduits for pollutant migration. Aquifer interconnection may also occur via flow through aquitards in areas of reduced aquitard thickness which could be enhanced by water pumping in the underlying confined aquifer.

The present study was carried out in the Campo de Cartagena (SE Spain) (Fig. 1a), where the land is intensively irrigated for agriculture and groundwater pollution exists. The agricultural activities are practised over the unconfined aquifer, with an intensive mineral fertiliser application (0.9-1.6 t ha^{-1} yr^{-1}) which constitutes a source of contamination and is separated from the lower confined aquifer by a thick aquitard (Fig. 1b). The objective of the research is to evaluate the significance that abandoned and poorly constructed wells have on cross-formational groundwater flow and contaminant transport between the shallow unconfined and deep confined aquifers. The work provides a methodological approach based on the geochemical tools application and water mixing calculations from a numerical model. The state of saturation of groundwater samples for relevant minerals, and ionic speciation were calculated using the PHREEQC code (Parkhurst, Appelo, 1999). Water mixing calculations were carried out using the MIX_PROGRAM numerical code (Carrera et al., 2004), which provides theoretical estimates of the end-member concentrations, thereby reducing the uncertainty due to spatio-temporal variability and thus improving the reliability of the output mixing calculations.

METHODOLOGY

The regional groundwater flow direction for both aquifers is toward the coastal, from northwest to southeast. The aquitard between the two aquifers is composed of marls in regions 2 and 3, and mainly of evaporites in region 1 (Fig. 1b). Groundwater records for the 1974–2008 monitoring surveys were provided by the Quality Network of Water Authority (CHS-IGME). The chemical data set includes physico-chemical parameters (pH, temperature and electrical conductivity); major ion content (Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, SO_4^{2-}, and NO_3^-); and CO_3^{2-}, NO_2^-, NH_4^+, and SiO_2. Some specific surveys in situ analysed dissolved oxygen (DO) and heavy metals.

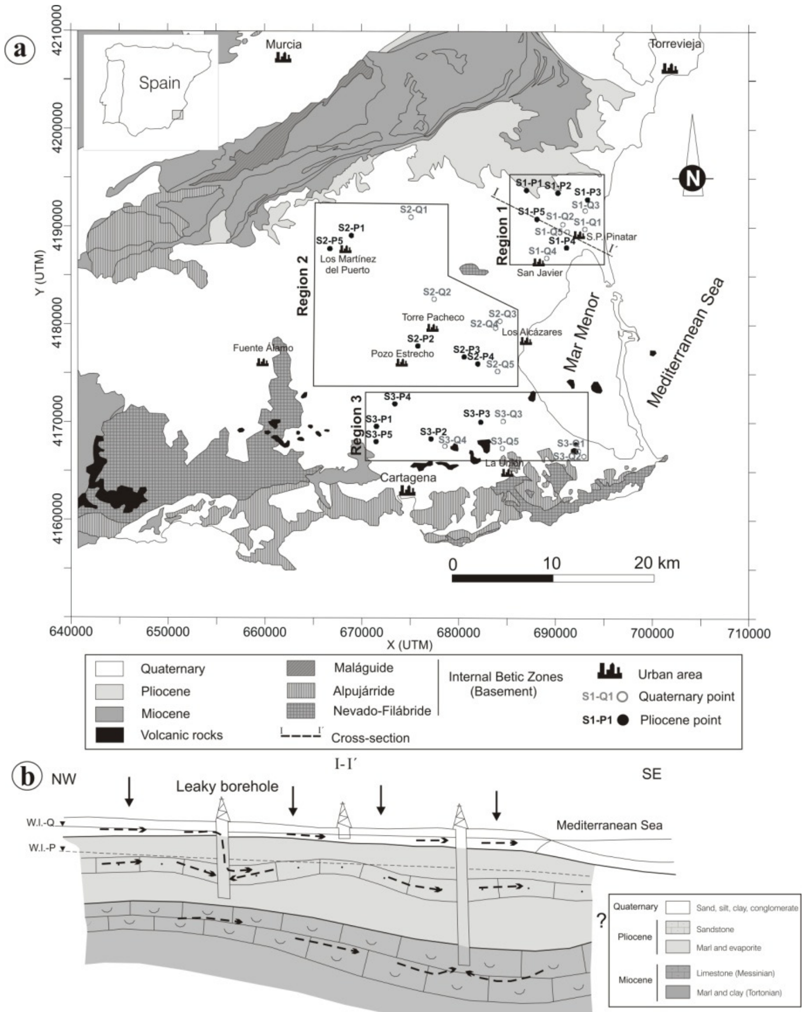

Figure 1. a) Study area and geological sketch. Location of the defined regions and sample points (S1 to S3 region; P: Pliocene aquifer; Q: Quaternary aquifer; 1 to n sample point). b) Geological cross section and conceptual model.

Due to the broad extension of the study area, three regions were defined based on land use and regional geology (Fig. 1a). A subset of five water sample points within the surveyed period for each aquifer and defined region was selected. Selection was based on the geographic location, aquifer sampled and length of available records.

Nitrate as an indicator of interconnected aquifers

In regional groundwater flow systems, which are shaped by the geology, the attenuation processes regulate nitrate transport and control its distribution in aquifers. Nitrate attenuation may occur by dilution, through mixing of groundwater in the aquifer (Altman, Parizek, 1995), or by denitrification. In reducing environments it is the only geochemical process that permanently removes nitrate from aquifers. Nitrate reduction can be mediated by oxidation of organic matter, pyrite and iron under anaerobic conditions (Korom, 1992).

For the three defined regions, nitrate constitutes a good indicator for assessing the Quaternary and Pliocene interconnection. Homogeneity in the spatial distribution of land covered by crops (source of nitrate), along with the long term records of nitrate concentration and dissolved oxygen values (oxidation-reduction potential), support this assumption.

Geochemical and mixing models

To calculate ionic speciation and state of saturation (saturation-index) for relevant minerals, PHREEQC was applied. This preliminary step is necessary to evaluate the potential geochemical reactions occurring in the aquifer, since deviations from mixing lines could be attributed to chemical reactions.

Concentrations of mixed samples, mainly affected by analytical errors, are likely to be more accurate than end-members, commonly with high spatial and temporal variability. This fact can be used to impose constraints on valid end-member concentration since taking mixing constraints into account may significantly reduce uncertainty in end-member concentration by imposing consistency. Consistency is dealt with in two ways: first, end-members should fall on the mixing line and second, mixed waters should fall within the interval defined by end-members. The MIX_PROGRAM code permits the mixing ratios in mixed samples to be derived, allows for redefinition of mixing lines.

The Cl/Br ratio (R), used as an indicator of seawater intrusion (R = 655±4) or evaporite dissolution (R = 1200–5400), was calculated in all available water samples in order to assess the importance of a third member for mixing calculations (Custodio, Herrera, 2000).

RESULTS AND DISCUSSION

Hydraulic conductivity of the aquitard ranges over several orders of magnitude, marls (10^{-5}–10^{-6} m d^{-1}) and evaporites (10^{-10} m d^{-1}). Considering the highest hydraulic conductivity value and vertical head difference through the aquitard, flow rate q ranges between 0–10^{-5} m d^{-1}. Flow through the aquitard was excluded as a major contribution to the pollution process.

Nitrate as an indicator

Average concentration in wells located toward the coast show a generally increasing trend (Fig. 2a), except for region 3, where nitrate average concentration is approximately constant, being controlled by the low hydraulic gradient of the Pliocene aquifer in this region. Nitrate presence in the unconfined aquifer clearly originates from the intensive agricultural practices; however, with regard to the confined aquifer much lower concentrations, even nil, should be expected since no agricultural development or anthropogenic activities take place in the recharge area (NW part of the basin, Fig. 1a and b). Moreover, the thick aquitard separating both aquifers should act as an impervious barrier, contributing to the attenuation of nitrate (Roberston et al., 1996) and related species (NO_2^- and NH_4^+) concentration if cross-formational flow occurs. DO content in both aquifers ranges between 1 and 9.8 mg l^{-1}; therefore, nitrate attenuation in both aquifers mediated by denitrification processes is unlikely.

The high variability of nitrate content observed in the lower confined aquifer (Pliocene) reflects the presence of pumping wells in the vicinity of a sampled point. Groundwater stratification due to water chemical composition (Guimerà, 1998) may also exist.

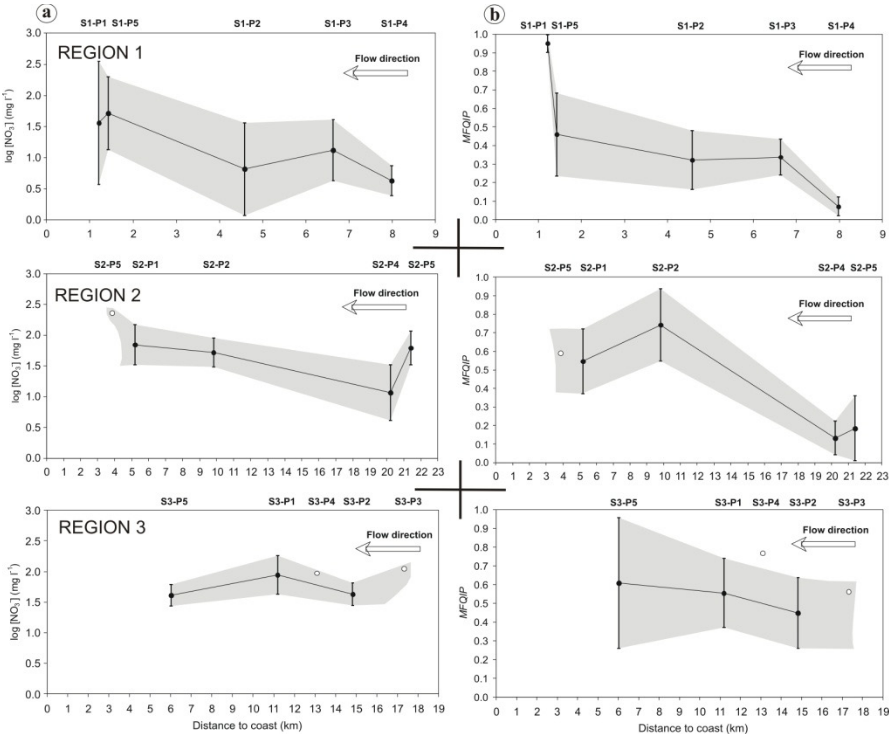

Figure 2. a) Average nitrate concentration of Pliocene aquifer for selected sample points versus distance to coast for each region. b) Quaternary aquifer water mass fraction (computed mixing ratios-MFQIP) introduced into the Pliocene aquifer versus distance to coast. Solid dots: average computed mixing ratios. Vertical bars: standard deviation. Empty circles: only one data available. Arrows: groundwater flow direction.

MIXING MODELS

The two end-members are the Quaternary (from 1980 to the present time) and Pliocene (natural background concentration 1970's, data set non-affected by agricultural pollution) aquifer water samples, and the two chemical species selected were chloride (Cl^-) and sulphate (SO_4^{2-}) (Table 1). Cl^- is a conservative compound but SO_4^{2-} can be affected by several processes. Sulphate reduction, pyrite oxidation and nitrate, instead of oxygen as the electron acceptor, control the SO_4^{2-} concentration in groundwater (Massmann et al., 2003). The decision for SO_4^{2-} selection was due to several reasons: (i) presence of oxic conditions, similar HCO_3^- concentration and non-existent H_2S in both aquifers; (ii) lack of pyrite in this geologic context (very low concentration of iron in groundwater); and (iii) higher NO_3^- concentrations in the unconfined aquifer than in the confined aquifer, indicating that NO_3^- as electron acceptor is not possible in the confined aquifer. Obtained values of the R = rCl/rBr ratio for both aquifers indicating the absence of saline intrusion and dilution of the middle aquitard evaporitic rocks (gypsum and halite). End-member data computed using the MIX_PROGRAM code for each of the regions are shown in

Tab. 1. The model runs not only allowed for obtaining more reliable mixing lines than those obtained through measured end- members, it also allowed for assessment of important existing differences between measured and computed end-members, mainly for the Quaternary aquifer and for the three regions.

Table 1. Measured end-member concentrations for the three defined regions (*m*: mean; *σ*: standard deviation). Computed end-member (e-m) concentrations from the MIX_PROGRAM (Carrera et al., 2004) are also shown.

Aquifer	Species	Region 1				Region 2				Region 3			
		Number samples (period)	*m* (mg l^{-1})	*σ* (mg l^{-1})	Computed e-m	Number samples (period)	*m* (mg l^{-1})	*σ* (mg l^{-1})	Computed e-m	Number samples (period)	*m* (mg l^{-1})	*σ* (mg l^{-1})	Computed e-m
Quaternary	Cl^-	129 (1980-2008)	1372.4	374.8	1214.7	91 (1980-2008)	1794.2	651.3	2559.2	37 (1980-2008)	1305.3	395.5	1418.4
	SO_4^{-2}		624.9	201.7	1082.2		1270.4	437.1	1871.3		766.2	430.4	1122.6
Pliocene	Cl^-	3 (1970´s)	493.7	17.6	457.4	4 (1970´s)	1121.3	141.9	974.9	3 (70´s)	1053.0	20.8	1041.1
	SO_4^{-2}		238.7	143.6	62.4		949.8	225.5	946.3		679.0	84.9	273.1

If the computed water mixing ratio Quaternary/Pliocene aquifers (mass fraction-*MFQIP*) is plotted versus distance to coast and flow direction (Fig. 2b), an increasing trend of the *MFQIP* average value and its variability toward the coast is observed, although local factors surrounding each sample point can disturb it. This result agrees with the important number of wells reaching the Pliocene aquifer according to the groundwater flow direction. For region 1, which presents the greatest density of wells, computed *MFQIP* values are the lowest (between 0.07 and 0.46) due to the short travel distance between recharge (upland) and discharge area (toward the coast). In region 2, high *MFQIP* values reaching 0.74 are observed due to high concentrations of Cl^- and SO_4^{2-} species in the Quaternary end-member along with the longer groundwater travel distance across the Pliocene aquifer. Finally, for region 3, sample points present similar average values of *MFQIP* (~0.53), although agricultural activity and the density of wells is lower than the other regions; this pattern appears to be controlled by the low hydraulic gradient of the Pliocene aquifer in this region.

CONCLUSIONS

Results proved the validity of the applied methodology to assess aquifer interconnection, primarily based on the presence of nitrate in groundwater and numerical mixing calculations, in areas highly impacted by agricultural activities as the Campo de Cartagena area.

The study shows that the upper unconfined aquifer (Quaternary), which is polluted by nitrate due to intensive agricultural activities, also constitutes the source of pollution of the lower confined aquifer (Pliocene). Contamination was caused by leaky wells in areas with high density of production wells and the induced leakage allowed for the downward flow of contaminated water from the upper aquifer into the unpolluted lower confined aquifer.

Water mixing fractions were estimated using the numerical code, which provides more accurate estimates of not only the end-member concentrations but also of the output mixing ratios. The mixing ratios approach showed that the Quaternary aquifer average mass fraction leaking into the Pliocene aquifer ranges between 0.07 and 0.74 and tends to increase toward the coast following the increase of well density.

ACKNOWLEDGEMENTS

CGL-2004-05963-C04-01 and CGL-2007-66861-C04-03 research projects, Ministry of Science and Innovation (Spain). 08225/PI/08 research project, "Programa de Generación del Conocimiento Científico de Excelencia" of Fundación Seneca, Región de Murcia (II PCTRM 2007-10).

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abstract id: **240**

topic: **6**
General hydrogeological problems

6.3
Groundwater contamination — monitoring, risk assessment and restoration

title: **Study of soil contaminated by vinasse applying leach test methods**

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keywords: vinasse, Guarani aquifer system, leach test, groundwater contamination

INTRODUCTION

Vinasse is an effluent result from ethanol, buthanol and white rum production (Rezende, 1984). It is produced from sugar cane distillation and fermentation processes along the alcohol and sugar production.

Silva and Orlando Filho (1981) presents a range of vinasse composition (C, pH, N, P, K, Ca, Mg, S, Fe, Cu, Zn and Mn) based on samples collected from several Brazilian sugarcane industries (Table 1). High concentrations in macronutrients and micronutrients, and acidic pH are found in Brazilian vinasses.

Table 1. Range of vinasse composition based on samples from sugarcane industries in Brazil.

Elements	Range	Elements	Range
C	7.53–49.74 g/L	S	0.04–3.42
Macronutrients	g/L	pH	2.8–5.4
N	0.10–1.55	Micronutrients	mg/L
P	0.02–0.77	Fe	15–359
K	0.55–13.00	Cu	0.5–137
Ca	0.09–3.98	Zn	0.62–119
Mg	0.10–1.34	Mn	1.2–16

From: Silva and Orlando Filho (1981).

Thus, vinasse is extremely pollutant due to high values of organic material, low pH, high corrosivity and high rates of biochemical oxygen demand, despite the high temperature (Da Silva et al., 2007).

Brazil is the world largest producer of sugar cane, and the state of São Paulo is responsible for 75% of the national production (UNICA, 2009). In 2009 Brazil produced about 17 billion liters of ethanol. Cortez et al. (1998) reported that vinasse production varies from 10 to 15 liters of vinasse per liter of ethanol produced.

The focus of this work is to apply the leach test and nitric acid lixiviation methods to know different chemical signatures from the behavior of vinasse soil contamination in an old effluent lagoon without impermeable layer.

The study area is situated in Serra Azul municipality, 300 km from São Paulo city. In that area, the Guarani Aquifer System occurs and has from moderate to high indices of vulnerability for groundwater. The vinasse disposal in effluent lagoon happened since the 80's to 2004, where the main land use of the study area was sugar cane plantation. This plantation finished due to the agrarian reform, that originated Sepe Tiaraju rural settlement, the study area.

MATERIALS AND METHODS

A borehole was drilled into this old vinasse disposal lagoon, and 27 samples of soil were collected until 24 meter of depth. Eight samples were selected to analyze soil texture and consistence indexes in the following intervals of depth: 2–3, 6–7, 9.5–10, 12–13, 15–16, 18–19, 20–21 and 23–24 meters. Particle size distribution (ASTM, 1998) tests were carried out; however particle size distribution was also measured without using a soil dispersant so as to highlight some features of the tropical soil tested, as aggregation of the particles.

The percentage of ignition loss (Potts, 1992) was determined in 27 samples according to Potts (1992). The trace elements were determined using x-ray fluorescence spectrometry (XRF) in 27 samples.

Leach tests (Hageman 2007) were executed in 27 soils samples, and cations (Ca^{2+}, Na^{+}, Mg^{2+}, K^{+}) and anions (SO_4^{2-}, NO_3^{-}, NO_2 and F^{-}) were analyzed by ion chromatography (IC). pH, Eh (mV) and electric conductivity (μS/cm) had also measured by portable equipments.

RESULTS AND DISCUSSION

Figure 1 shows granulometric curves of soil samples, with dispersant (WD) and without dispersant (ND) in the tests. These curves presented sand fractions in over than 50%, silt fractions from 16 to 29%, and clay fractions from 8 to 25 % of all depths, indicating that soil profile belongs to Botucatu Formation (a Guarani Aquifer System formation). It can be seen in Figure 1 that clay fractions decrease a long of the depth while the silt and sand fractions increase. From 15-16 m of depth, the curves, with and without dispersant, presented more differences between silt and clay fractions, due to aggregation of these fine particles. Average particle unit weight values were 27.9 kN/m^3.

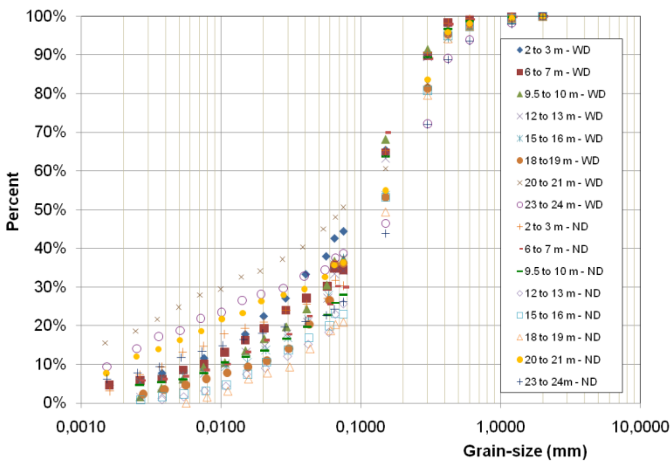

Figure 1. Particle distribution curves obtained using a dispersant (labeled WD) and without using a dispersant (labeled ND).

The results of x-ray fluorescence spectrometry in the soil samples indicate that the percentage of SiO_2 and K_2O is higher in the deepest samples, while the percentage of TiO_2, Al_2O_3, Fe_2O_3, MnO and CaO is higher in the superficial samples. Analyses results also indicated higher concentrations of Zn, V, Zr and Ga in lower depths, decreasing in concentration in deeper profile, and concentrations of Ba, Sr and Pb increasing in concentration along the profile.

Others analyzed elements had presented distribution not related directly to depth. However, all the substances had high concentrations in soil samples, and their excessive amounts could be related to vinasse disposal for years. Detailed studies have been elaborated.

Table 1 presents average, median values of parameters determined by XRF in soils samples.

Table 1. Average, Median, Maximum and Minimum values for elements determined by XRF in soils samples (27 samples collected from 0 to 27 meters depth).

Element/Substance	Average	Median	Max	Min	Element/Substance	Average	Median	Max	Min
SiO_2 (%)	53.97	52.10	70.10	40.60	Ga(μg/g)	17.55	18.50	21.30	10.70
TiO_2(%)	2.96	3.12	3.84	1.73	Mo(μg/g)	3.45	3.30	4.30	2.40
Al_2O_3(%)	23.88	24.40	29.30	17.80	Nb(μg/g)	33.13	33.00	37.00	25.00
Fe_2O_3(%)	11.04	11.70	15.00	5.20	Ni(μg/g)	8.93	9.00	12.00	5.80
MnO(%)	0.05	0.06	0.06	0.03	Pb(μg/g)	13.92	14.10	18.20	8.30
MgO(%)	0.06	0.06	0.07	0.04	Rb(μg/g)	4.65	4.15	7.30	2.10
CaO(%)	0.08	0.08	0.15	0.05	*S(μg/g)	173.04	122.00	365.00	61.00
Na_2O(%)	0.06	0.06	0.06	0.05	Sn(μg/g)	4.97	4.00	6.90	4.00
K_2O(%)	0.08	0.10	0.12	0.02	Sr(μg/g)	42.16	40.00	63.00	23.80
P_2O_5(%)	0.16	0.15	0.24	0.13	Th(μg/g)	12.56	12.40	15.10	8.80
%Loss Ignition	6.74	6.98	9.52	4.29	V(μg/g)	200.19	203.00	264.00	139.00
As(μg/g)	5.24	5.40	5.80	2.50	Y(μg/g)	7.75	7.60	11.40	5.40
Ba(μg/g)	76.05	75.00	120.00	26.30	Zn(μg/g)	35.08	34.00	50.00	22.90
Cr(μg/g)	46.81	46.00	63.00	37.00	Zr(μg/g)	563.96	563.00	637.00	495.00
Cu(μg/g)	35.91	38.00	46.00	19.10					

*S – amount informed

The percentage of loss on ignition indicates the quantity of volatile elements in the sample, mostly CO_2 and water. It could be related to some volatilization of alkaline metals, fluoride and sulfur dioxide. The quantity of volatile elements in the superficial samples is higher than the amount in the deepest samples. The values of ignition loss indicated a percentage decrease along the profile (from 15% to 11%) (Fig. 2).

Leach tests results showed that lower values of electric conductivity (11 μS/cm) in leached solution were found in shallower and deeper samples (0–2 and 22 to 24 m, respectively), and higher values from 2 to 22 meters depth (varying from 18 to 37 μS/cm) (Fig. 2).

Regard to physical-chemical parameters from leached solutions, pH results indicated acidity in the surface (average pH 5.2) and neutral to slightly alkaline in deeper soils (average pH 7.0).

The acidity in soils samples (pH 4.0–4.5) had close association with vinasse disposal (pH 2.8–5.4) (Fig. 3). Eh results (from +105 to -45 mV) indicated oxidant environment in surface samples becoming reduced in deeper samples (Fig. 3).

Higher concentrations of SO_4^{2-} (Fig. 4), NO_3^- (Fig. 5), Ca^{2+} (Fig. 6), Na^+ and Mg^+ (Fig. 7) were found in lower depths (mainly the interval 6 to 9 meter), in oxidant environment, and they decreased in concentration in deeper profile (reduced environment). Fluorine concentrations

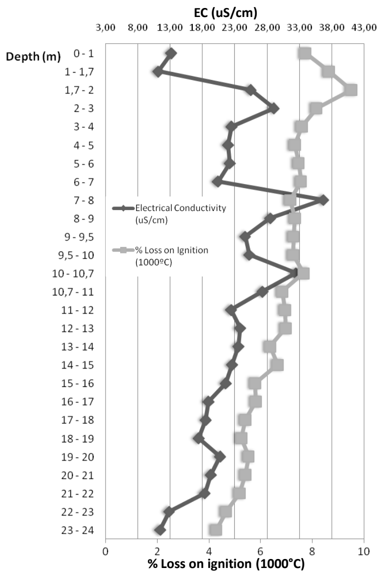

Figure 2. Electric Conductivity (μS/cm) and % Loss on ignition results — leached solutions in depth intervals (m).

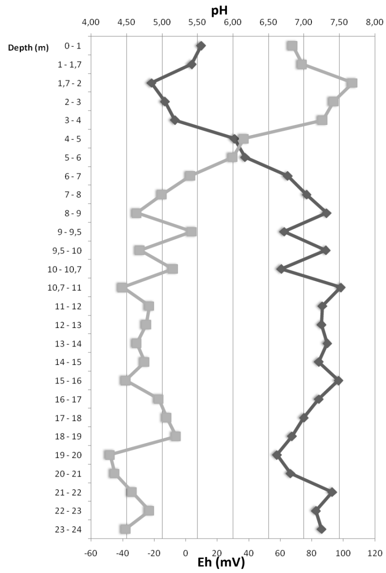

Figure 3. pH and Eh (mV) results — leached solutions in depth intervals (m).

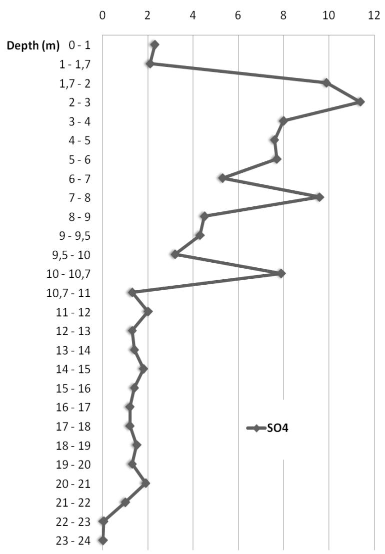

Figure 4. Sulfate concentration distribution — leached solution in depth intervals (m).

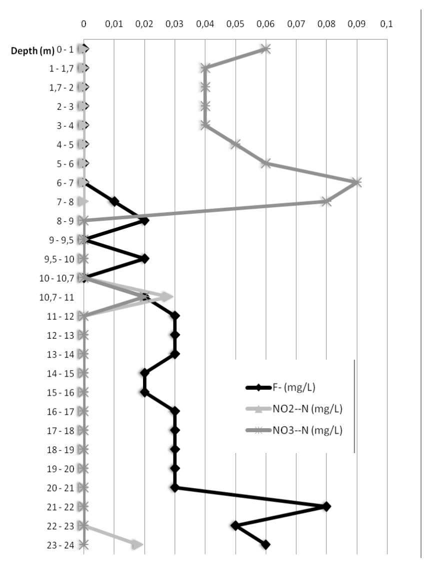

Figure 5. Fluorine, Nitrite and Nitrate concentration distribution in leached solution in depth intervals (m).

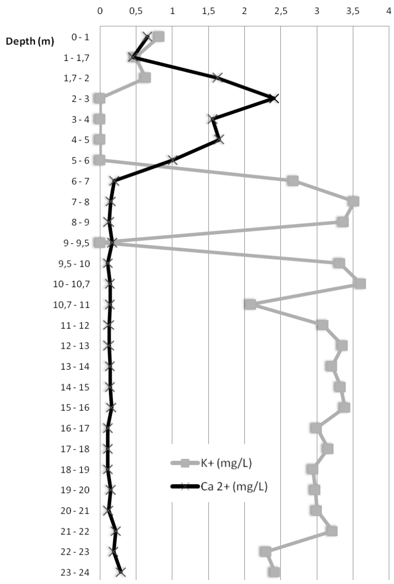

Figure 6. Concentrations of potassium and calcium — leached solutions in depth intervals (m).

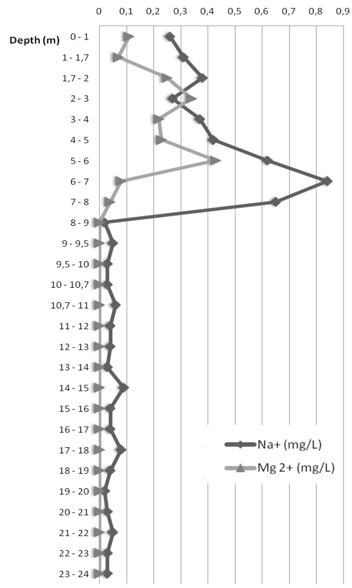

Figure 7. Concentrations of sodium and magnesium — leached solutions in depth intervals (m).

The occurrence of high concentrations of Ca^{2+} (Fig.6), Na^{+} and Mg^{2+} (Fig. 7), from 1.7 to 9.5 m, could indicate the mass of vinasse in soil releasing theses ions to percolation solutions. Concentrations in soils (determined by XRF analysis) had similar distribution in depth

K^{+} distribution had augmentation in deeper samples (Fig. 6). Analysis results by XRF indicated that potassium concentration also increase in deeper samples. According to Da Silva et al. (2007), mineral and organics elements, mainly potassium and nitrate, could be leached when disposed vinasse volume is higher than the soil capacity of ion retention. Bebe et al. (2009) reported that potassium had increased in all soils depth when they were fertirrigated by vinasse, regardless periods and time of applications.

CONCLUSION

The behavior of solutions leached from soil samples indicated that the soil had been presented vinasse (or its altered product) along the profile (24 meters depth). Silty-clayey sands were defined for all depth and were weathering material from Guarani Aquifer sandstones.

The high concentrations of all elements analyzed in soils by XRF indicated vinasse presence in all depth of the borehole studied.

The leach test method showed elements distribution tendencies along the profile. This method defined two distinct oxi-reduction zones: one oxidized zone from 0–7 meters, acid pH and positive Eh leached solutions, grading to reduced zone (from 8 to 24 meters), with neutral pH and negative Eh leached solutions. $SO_4{}^{2-}$ presence in shallower depth and others oxidized elements could be reduced in deeper profile and then, its concentrations decreased. Na^{+}, Mg^{2+} and Ca^{2+} in shallow depth could indicate presence of specific clays or organic material, which hold theses ions in first meters of depth, or presence of vinasse.

ACKNOWLEDGEMENTS

We are thankful to FAPESP (Sao Paulo Research Foundation), process 2007/05323-1, for the financial support and INCRA (National Institute of Colonization and Land Reform) for the logistical support provided.

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abstract id: **243**

topic: **6**
General hydrogeological problems

6.3
Groundwater contamination — monitoring, risk assessment and restoration

title: **Combining tracer hydrology and isotopic analysis to assess in situ natural transformation of chlorinated ethenes in groundwater**

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keywords: natural transformation, groundwater dating, isotopic methods, environmental tracers, chlorinated ethenes

Tracer hydrology (mainly groundwater dating methods) and compound-specific stable (^{13}C) isotope analysis (CSIA) were combined to assess the natural transformation of chlorinated ethenes (CEs) in groundwater at the field scale. Two field sites representing different natural hydrogeological settings were selected to verify the usefulness of the suggested approach in the determination of timescales of *in situ* degradation processes. The selected study sites differed mainly in the groundwater residence times, groundwater redox conditions and on the level of contamination and were chosen to represent situations of favorable and unfavorable conditions for the CE natural transformation. Site I was a confined two-aquifer system, where CE transformation is taking place under the highly anoxic conditions and groundwater residence times of up to 40 years of the upper aquifer. This aquifer overlays an oxic aquifer only slightly contaminated and with water ages of up to 17 years, where no CE transformation occurs. Site II, an aerobic aquifer with short water residence time of about 2 years showed no evidence of CEs transformation, before and after remediation measures. Moreover, evidences based on the environmental tracers suggest the presence of bedrock fractures to act as a long lasting CEs "reservoir", implying that will take many decades, or even centuries, for the contamination to reach acceptable levels.

It is shown that even under unfavorable conditions for transformation, our methodological approach adds valuable information to the understanding of the evolution of the organic contamination, to the location of contaminant source zones and to the estimation of time-scales for the decrease of contamination levels to acceptable levels.

abstract id: **265**

topic: **6**
General hydrogeological problems

6.3
Groundwater contamination — monitoring, risk assessment and restoration

title: **Innovative solutions in using reactive barriers**

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keywords: PRB, heavy metal contaminated groundwater, natural reactive material, laboratory testing, modeling aided design

BACKGROUND

The most common technique widely applied for groundwater remediation is „pump and treat", where production wells lift the contaminated water onto the surface where the water is treated and the clean water is injected back to the aquifer. There is always an uncertainty in this process concerning the capturing of the whole contaminated plume, if there are no untreated sources or separated plumes left behind. This treatment process always require a long-term (several months or years long) attended and quite expensive operation. During the time of remediation the real estate development is hindered by the presence of onsite equipments and installations. It is often observed that several months after the remediation method is finished, the groundwater monitoring data show repeatedly high levels of the contamination due to the secondary contamination of groundwater from soil. The average cost level of these remediation techniques varies between 4–7 Euro/m^2 and the operation costs can go even beyond that.

With ongoing activities and operating facilities on site, or when the contaminated site has buildings and infrastructure elements, usually there is no real chance to eliminate the contamination source with these traditional techniques. In such cases the realistic goal of the intervention can only be to eliminate the spreading of the contaminant plume to (1) uncontaminated areas or (2) unaffected environmental media. This is often accomplished by a barrier installed in the way of the moving dissolved contamination. Since the 90s there is a widespread technology for such passive remediation alternatives that is called Permeable Reactive Barriers (PRBs). The remediation is based on a carefully designed permeable barrier installed in the path of the moving dissolved plume that is capable to treat the groundwater. While groundwater moves through the permeable wall the pollutants are precipitated, adsorbed or decomposed and water with acceptable quality leaves the safe side of the wall. The traditional reactive materials applied in such installations are iron and active carbon granulate.

The appropriately selected barriers are capable of cleansing organic and inorganic dissolved contaminants (e.g. hydrocarbons, chlorinated hydrocarbons, pesticides, chromium and other toxic metals, nitrate, sulfate contaminations, and acid mine drainage (AMD). Beyond the above applications there are remarkable technical and business opportunities in the development of new reactive material packs. There are open questions related to the design and planning of complex and transient hydraulic systems and related innovative solutions, such as relative barriers.

The University of Miskolc, Faculty of Earth Science and Engineering has been involved in the research of Permeable Reactive Barriers for more then a decade. The European Commissions Framework Five program supported the EVK'-1999-00186 PEREBAR research program, which was titled as „Long-term Performance of Permeable Reactive Barriers used for the Remediation of Contaminated Groundwater". The Faculty of Earth Science has been involved in this research project as a research partner and its role was to evaluate the aging mechanisms of the reactive materials, and their impact on the hydraulic permeability and design of the reactive materials (Bőhm et al., 2003). Parallel to that the three institutions of this proposal (Institute of Chemistry, Institute of Process Engineering and Department of Hydrogeology and Engineering Geology) jointly with the University of Nottingham launched an innovative research on using high humin-acid containing natural materials, such as lignite or peat as reactive material (OTKA T-031959) (Laktos et al., 2007). During the last year a new multidisciplinary research team was formulated by the same institutions of the University of Miskolc to start the preliminary investigation and innovation on the design of a *new generation of PRBs.*

RESEARCH GOALS

Our goal is to lay the technical foundations of an innovative, passive remediation system, which is a considerably cheaper, and offers faster option for Brownfield rehabilitation and real estate development than the traditional PRBs, while cost-effectively secures the protection of (1) human receptors, (2) ecosystem and (3) environmental media. Our research toolbox contains: laboratory tests, modeling and technical design tools.

The set of innovative technical solutions consist of: the development a new natural reactive material, with high humin-acid content (e.g. lignite or peat), which can be installed and operated cost effectively; a modular design, which enables the operator to easily replace the exhausted reactive module pack with new ones; PRB designed for its full life cycle, incorporating the demands of reclaiming exhausted reactive modules and the energy recovery from its material; full compliance with the latest European and domestic technical standards and legal regulations.

The core of the research contains the (1) development, (2) material processing of the reactive material, its (3) chemical and (4) hydrological analysis and (5) investigation of energy recovery alternatives of the same material. At the end of the three year project we shall provide the technical documentation of a set of innovative solutions that can be applied in a new generation of PRB applications. The technical documentation and design can be the basis of a test operation of such an installation.

RATIONALE AND BENEFITS

PRBs has a demanding and complex design preparation phase which is followed by a rather simple installation and an almost unattended operation with minimum energy demand. The reactive wall utilizes the natural groundwater gradient to clean the moving dissolved plume.

Our new and innovative PRB goes beyond its traditional type in several aspect. Traditionally the active carbon reactive pack has excellent absorption capacity and can be regenerated with good efficiency. The natural materials tested in this research project are significantly cheaper than the active carbon, and even though its contaminant retention capacity (CRC) is by far below that of the active carbon but it can reach as much as its 30%. Once exhausted there is no need for the expensive regeneration but rather it can be co-incinerated in coal power plants with energy recovery, and can be replaced by a new reactive pack. In many of our countries there is a significant volume of mining wastes available (e.g. coal dust, and silt) as cheap resources (often with disposal problems) that can be tested for such applications too. In its readily available form or with certain modifications those can be used due to their high ion exchange capacity and complex forming, reducing capacity. The new generation of PRBs is estimated to offer 20–50% cheaper alternatives to the traditional active carbon packs.

Another innovative element of the design is that the reactive packs can be reclaimed after being exhausted. The technical framework and viable design of such an underground installation is a major task of the development project. The exhausted reactive packs must be reclaimed and replaced with new ones if needed. The reclaimed reactive packs can be co-incinerated in traditional coal power plants, which require a “cradle-to-grave” approach right from the first steps of design and material selection. This idea is unique among the PRB applications.

One reactive pack applied in a wide, universal sense for more contaminants is an idealistic plan, which has no any technical and financial legitimacy. The reactive material must be selected by matching it to the investigated dissolved plume and considering the environment of its transport. In case of mixed chemical plumes there is always a demand for compromise in operating the reactive barrier bellow its contaminant specific optimum. The modular design of the PRB can serve for the benefit of this problem too, by coupling several, different material packs optimized for different chemicals within one wall.

There are considerable capacities available from humin-acid rich materials (e.g. lignite, and brown coal), that are potentially applicable as reactive matrixes. Several Hungarian raw material sources (e.g. Bükkábrány) and foreign coals shall be evaluated and compared. These materials and their raw material processing techniques are routinely applied when they are used in coal power plants. There is a considerably different processing technology need when the material is used as a reactive barrier. The required process engineering tasks demanded vary on a wide range, mainly because the reactive material must provide activity on a relatively long timescale. This requires primarily high reactive surface of the lignite grains, which means a relatively small grain size of lignite. The decrease of grain size has an effect on permeability, and other physical conditions within the barrier. In order to reach our goals, for all development modules we must determine the specific parameters of the reactive material, in terms of reaction kinetics, hydrodynamics and energy utilization.

RESEARCH TASKS

The research efforts are grouped into four modules:

Reactive material development — chemical compatibility

The research project will focus on the treating of dissolved heavy metal plumes. There are three available principles in removing metal ions, such as cementing, precipitation and sorption. Iron is the primary option for cementing, which does not cause environmental threat when dissolved in groundwater. There is a limit in its application though, because this method is only effective for those metals to the left side of irons electrode potential rank. As precipitating materials the basic oxides can be considered or the sulfide generation. Such biological barriers with sulfate reducing bacteria have been applied already. The third option: sorption offers much greater variability than the previous two, because there are various known sorbents among organic and inorganic materials. The (1) selectivity of the material, its (2) compatibility with the environment and its (3) price are the three main parameters in determining applicability and competitiveness. The price of the sorbent has a major impact on the treatment of the exhausted pack. When using expensive sorbents regeneration is recommended, but it further raises the price of the operation. When using cheaper sorbent material, regeneration is avoidable and the exhausted reactive pack can be integrated to an appropriate waste stream and its management. The selectivity of the sorbents to contaminants is a very important factor when choosing the material. The PRB must operate in a geochemical environment where dissolved plume in balance with the geological environment. The elements of the geological environment are represented in the groundwater according to the solubility balance.

The low quality mineral coals such as lignite forms may very well comply with all three criteria listed above, so primarily this material shall be investigated in detail as potential sorbent. Preliminary tests on model barriers show promising contaminant retention capacity under various concentrations and flow rate. Parallel to that, several other parameters must be determined to support the modeling task, such as sorption capacity as a function of pH and ion composition, and sorbtion rate. Beyond these, also as a part of reactive material development, research shall cover the efficiency check of simple surface alteration methods too, such as: modification of quantity and type of functional groups, modification of pore structure, and finally the effect of ion exchange on the reactive material. For this later one pH control and anion removal might be needed.

Reactive barrier and its environment — hydrodynamic compatibility

Although the good material composition of the reactive barrier is necessary, the fulfillments of other conditions are also required to achieve effective remediation of underground contaminants. The hydrodynamic design and the environmental settings of the elaborated reactive barrier materials are inevitable for effective applications. Complex hydrogeological modeling can play a significant role to design the permeable reactive barrier properly involving all information concerning the contamination properties of the geological environment. As a first step, it is important to investigate the influence of the applied reactive barrier on the groundwater flow system at the targeted site. In order to achieve hydrodynamic compatibility, changes in geometry and permeability conditions of the barrier system, based on the modeling simulation results can help to avoid any unfavorable effects, like flooding the shallow groundwater system or the movement of the contamination plume beside the barrier.

As a second step, the underground contamination transport, and the change of physical and chemical processes in space and time between the plume and the reactive barrier material can be described with the help of reactive transport modeling. These transport simulations can also explain how the effectiveness of barrier material changes in time concerning the actual physical, chemical and possible biological processes. Based on the proposed complex hydrodynamic and transport modeling activity, the appropriate design of reactive barrier systems can be realized more effectively than by the earlier practice. The simulations can determine whether the contact time inside the reactive barrier is long enough to absorb the contaminants or not. The simulations can also predict how frequently it is necessary to replace the barrier material.

One of the key issues is to determine the hydraulic conductivity of the elaborated reactive barrier material. To support the hydrogeological modeling activity, laboratory hydraulic conductivity and permeability tests will be implemented to derive reliable information about the hydrodynamic properties of the different barrier materials. Then, based on the modeling simulation results, new laboratory investigations can help to set the required hydraulic conductivity parameters for given environmental problem.

Technical design — compatibility of the individual modules

One major research task of the innovative PRBs is the framework development of the modular design which facilitates the reclaiming of exhausted packs. The modular design enables the operator to construct the barrier from different reactive packs, without mixing their material streams. This arrangement of the packs has a major role in designing the order of chemical processes taking place in the barrier. This technical feature guarantees clean material streams to make the utilization of exhausted reactive packs much easier. The reclaiming the exhausted packs for this purpose is a new concept in the PRB remediation, which requires a more complex installation than the traditional slurry wall technique. The technical framework of accommodating and reclaiming reactive modules requires a new innovative technical solution, to be described in this module.

The harmonization of the individual design modules and investigation of their impact on each other is also a major task in this module. Each single step of the design has its impact on the technical feasibility of the PRB, in fact there are interactions among each modules. Within this module we shall develop a harmonized set of technical parameters in terms of chemistry, hydrogeology and technical design.

Utilization

One of the great advantages of carbon based reactive matrix materials over against other type of reactive materials is the relatively easy feeding into carbon based plant processes for energetic utilization after the end of their lifetime. However it must be determined which properties of the reactive material are going to be altered during the groundwater remediation process (heavy metal concentration, humidity, heating value,...). It is also important to determine the method, the altered matrix material can be modified for implementation into carbon based energetic operations. It is known, that application of gasification or incineration of coal requires different raw material quality. The required coal quality can be produce from the used matrix material using process engineering methods, however the technology has to be determined and the costs of the technology and regeneration process as well as the financial feasibility have to be investigated too.

The alteration of the reactive media and the appearance of the bounded contaminants are going to be estimated by the "accelerated model" carried out in module 1 and using reaction – kinetic models. Using the estimated data, regeneration, utilization and disposal methods, the applied technology and its cost can be determined.

Focusing on thermal utilization, it has to analyze how the heating value of the carbon material is changing during groundwater remediation process. It is also very important to determine the phase in which the pollutants are concentrating as the effect of thermal processes or gasification. Next to calorific properties, thermo–analytic and selective extractive techniques are going to be used to track the bound metal ions and their alteration, their stabilization process during recycling and disposal practice. These analyses support the evaluation of the alternatives and the selection of the least risky one. It is important to compare the costs of the promising methods to clear weather they are cost effective and competitive against conventional and feasible solutions (e.g. disposal).

ACKNOWLEDGEMENT

This research is being supported by the INNOCsekk Plus funding program.

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abstract id: **286**

topic: **6**
General hydrogeological problems

6.3
Groundwater contamination — monitoring, risk assessment and restoration

title: **Water and solute transport in unsaturated zone of the Sava River, Croatia**

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keywords: Zagreb aquifer, unsaturated zone, trace elements, pollution, modelling

The object of this study is unsaturated zone of unconfined Quaternary aquifer (Fig.1), located below Zagreb, capital of Croatia. Unsaturated zone consists of Pleistocene aeolian sediments and alluvial and proluvial Holocene sediments. Hydromorphic soils of different hydromorphic regime prevail in the Sava River valley. Sediments along the Sava River form the recent fluvial terrace, while Molic Fluvisols, Calcaric Fluvisols, Eutric Cambisols on Holocene deposits, and Eutric and Calcic Gleysols (FAO 1990), are developed on the Holocene terrace Romić and Romić (2003).

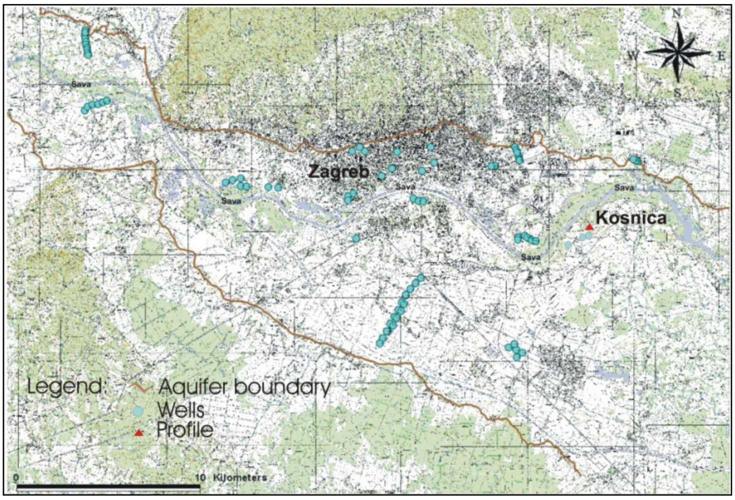

Figure 1. Simplified map of Zagreb aquifer boundaries and wells. Source: Croatian Water Resources Management.

Romić and Romić (2003) already showed that the distribution of trace elements in soils of investigated area is primarily controlled by: (a) geology, (b) industrial impact—traffic, heating plants, chemical industry and airports and (c) external factors—some trace elements are brought by the Sava River, which has been exposed to intensive pollution by mining, industries and towns in its upper course recently. A portion of trace elements is wind-blown from the industrial region of north Italy Antonić and Legović, (1999). The goal of this study is detail sedimentological and pedological description of complete vertical profile through unsaturated zone and 1D modeling of water flow and solute transport.

Investigated profile is located in (45°76' N; 16°08' E) second zone of sanitary protection of the water abstraction site Kosnica (Fig. 1), about eight hundred meters from Sava river. This profile consists of two parts (Fig. 2).

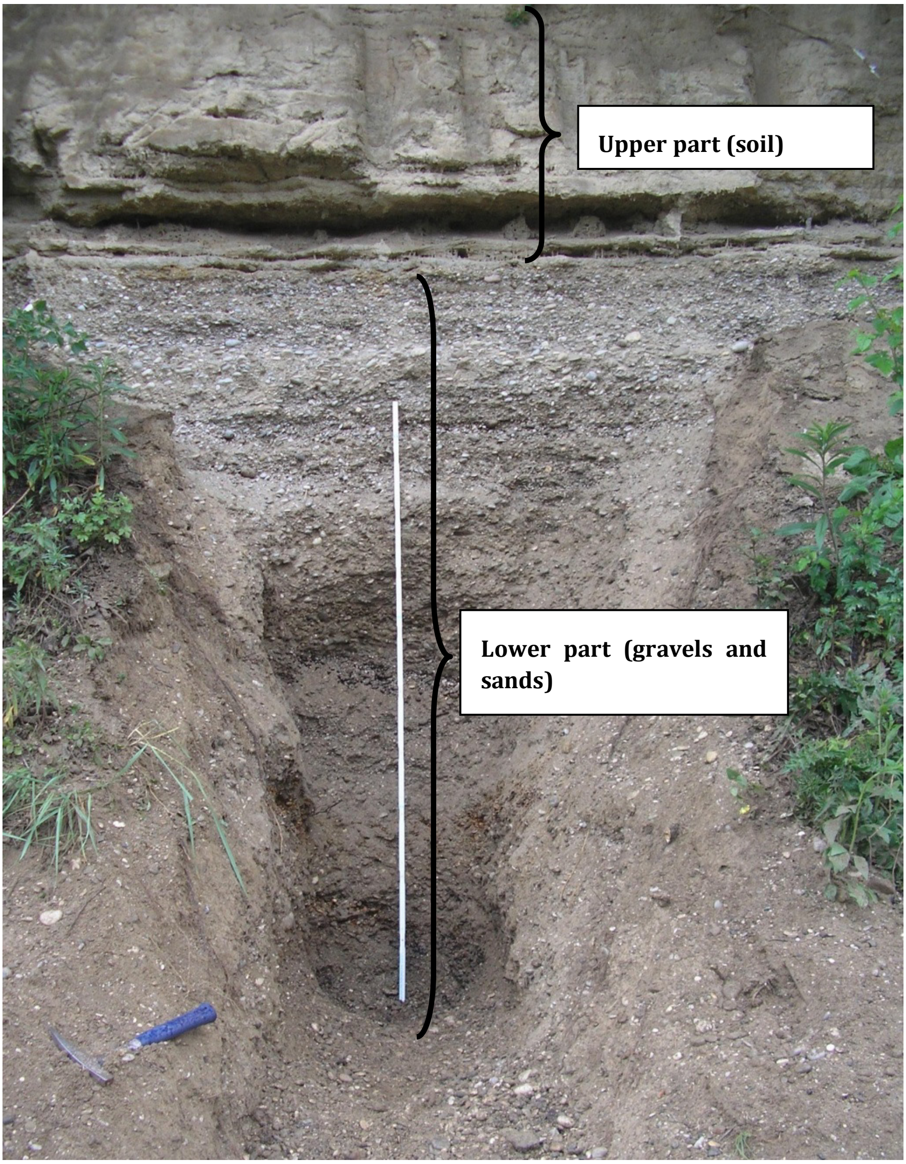

Figure 2. Unsaturated zone profile (upper part - soil; lower part - gravels and sands). White label presents scale of two meters. Photo: Stanko Ružičić.

First part (upper 2.5 meters) is hydromorphic soil, which is developed on alluvial sediments. These types of soils emerge in river valleys on alluvial deposits after flooding. Structure of this type of soils is mainly loamy, in some parts clayey with loam. Second part (lower 2.7 meters) are unsorted alluvial sediments, which consist of gravels and sands, mainly unstratified. Pebbles are mainly rounded and oval in shape. Sands reveal different granulation, from gravely to silty sands. In some places, these sediments are red to black in colour.

Laboratory work, which is in progress, includes mineralogical (XRD, CEC), chemical (trace elements using AAS) and sedimentological (grain size analysis) analyses of samples from investigated profile.

Modelling will be performed using Hydrus 1D software (Šimůnek et al., 1998).

With current study, we are trying to establish procedure for description, sampling, analysis and modelling of unsaturated zone profile of unconfined Quaternary aquifer. Future investigations will be expanded to more profiles in Zagreb aquifer area.

ACKNOWLEDGEMENTS

This work was supported by European Union through seventh Framework Program Project *"Groundwater and Dependent Ecosystems: New Scientific and Technical Basis for Assessing Climate Change and Land-use Impacts on Groundwater Systems"* (Grant No. 226536).

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abstract id: **348**

topic: **6**
General hydrogeological problems

6.3
Groundwater contamination — monitoring, risk assessment and restoration

title: **Heavy metals removal from contaminated groundwater using PRB with immobilized membranes — the feasibility study**

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keywords: sorption, heavy metals, permeable reactive barrier (PRB), polymer inclusion membrane (PIM), enhanced natural attenuation (ENA)

INTRODUCTION

Groundwater contamination with heavy metals caused by industrial waste storage and current and/or abandon mining activities is a widespread ecological problem in many industrialized countries worldwide. In Poland, especially in the Upper Silesia region, heavy metals (Cd(II), Co(II), Cu(II), Ni(II), Pb(II), Zn(II), Cr (VI)) have been discharged into the environment causing soil and groundwater contamination, which is currently of great concern due to the threat it poses to drinking water and/or adjacent ecosystems (Lutyński, Suponik, 2008; Malina, Kwiatkowska, 2003; Suponik, 2009). Soil and groundwater remediation technologies have to deal with the reduction of this risk. Groundwater contaminated with heavy metals is typically treated by “pump and treat” that is neither cost-effective nor sustainable approach. Permeable reactive barriers (PRBs) (Fig. 1) seem to provide an effective and sustainable alternative for the *in situ* treatment of groundwater contaminated with heavy metals (Diels et al., 2002; Szewczyk et al., 2009; USEPA, 1998).

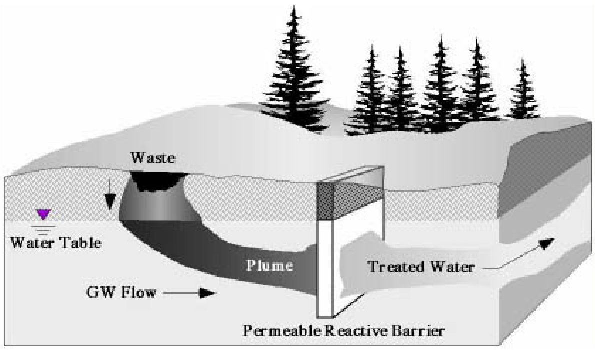

Figure 1. The concept of a permeable reactive barrier (PRB).

The PRB technology is considered as a part of the Enhanced Natural Attenuation (ENA) strategy, which is intensively developing in the EU countries. This strategy is based on the removal of heavy metals from the groundwater flow by enhancing natural geochemical processes, such as: adsorption, ion-exchange, chemical binding, redox reactions, precipitation etc (Fronczyk, 2006).

APPROACH

Our study evaluates the potentials of immobilized polymer inclusion membranes (PIMs) application within a PRB. The tubular modules formed from immobilized membranes provide rapid metal ions transport with high selectivity, as well as easy setup and operation (Nghiem et al., 2006). PIMs can be used for: (i) treatment of landfill leachates to minimize the risk of groundwater contamination, and (i) reduction of heavy metals concentrations in the groundwater flow (Malina, 2007). The PIMs are formed by casting cellulose triacetate (CTA) from an organic solution to form a thin, stable film. This solution contains also an ion carrier and a membrane plasticizer (mostly o-nitrophenyl alkyl ethers). The resulting membrane is used to separate source and receiving phases; it does not contain, however, an organic solvent to maintain the transport of ionic species through PIM (Kozłowski, Walkowiak, 2002).

The presented feasibility study concerns the studies of chromium(VI) removal from groundwater through PIMs containing: CTA as a support, o-nitrophenyl pentyl ether as a plasticizer, and Aliquat 336 as an ion carrier.

MATERIALS AND METHODS

The PIMs were prepared according to following procedure. First, a solution of CTA as a support, ONPPE as a plasticizer, and Aliquat 336 as an ionic carrier in dichloromethane as an organic solvent was prepared. Then, a specified portion of this solution was poured into a membrane mold comprised of a 9.0 cm glass ring attached to a plate glass with CTA—dichloromethane glue. Dichloromethane was evaporated overnight and the resulting membrane was separated from the glass plate by immersion in cold water.

The experiments were carried out in a permeation cell, in which the membrane film (4.9 cm^2 effective surface) was tightly clamped between a source and receiving phase. The source phase was a synthetic groundwater contaminated with chromium(VI). Samples of the aqueous receiving phase were removed periodically via a sampling port with a syringe, and analyzed directly afterwards with plasma atomic emission spectroscopy (ICP-AES) to determine chromium(VI) concentration.

PRELIMINARY RESULTS

The concentration of ion carrier plays an important role in the metal ions transport through PIMs. The influence of ion carrier (Aliquat 336) concentration on chromium(VI) transport is presented in Fig. 2. The optimal Aliquat 336 concentration was 1.0 M.

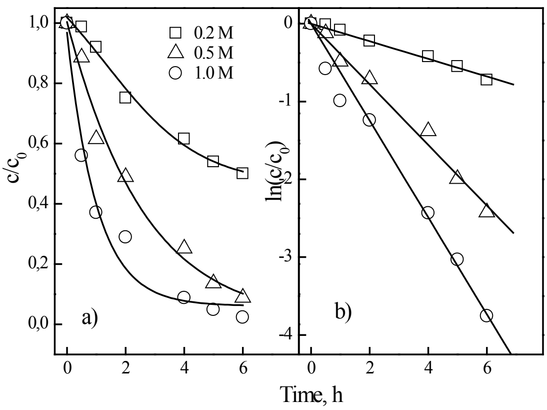

Figure 2. Chromium(VI) concentration in the source phase vs. time of transport through PIMs at different Aliquat 336 concentrations.

The results (Table 1) indicate that the rate of transferred mass of chromium(VI) through PIM depends on the equilibrium of Cr(VI)-Aliquat 336 in the aqueous phase/membrane boundary layer, and the source/receiving phase volume ratio.

Table 1. Chromium(VI) removal from synthetic groundwater using PIM with Aliquat 336.

Number of run	Initial concentration of Cr(VI) in source phase (ppm)	Volume of source phase (cm^3)	Volume ratio of source/receiving phase	Time of process (h)	Residual Cr(VI) concentration in source phase (ppm)
1	54.0	50	1:1	6	1.0
2	1.0	1500	30:1	3	0.001

With the source/receiving phase volume ratio equal to 1.0, it was possible to reduce the Cr(VI) concentration from 54.0 to 1.0 ppm in 6 h. Results of run no. 2, where the source/receiving phase volume ratio was of 30:1, showed the possibility to reduce the Cr(VI) concentration 1000 times, i.e. from 1.0 to 0.001 ppm already after 3 h (Fig. 3).

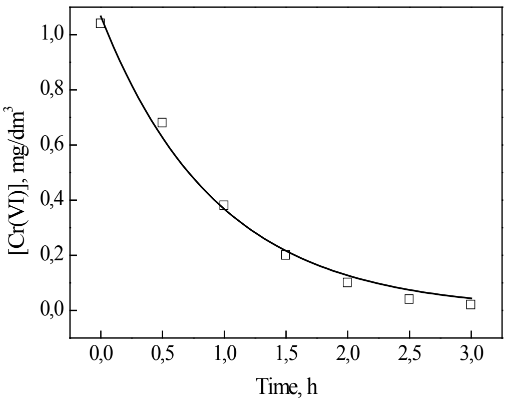

Figure 3. The changes of Cr(VI) concentration in groundwater.

CONCLUSION

This feasibility study showed that the groundwater transport through PIM allows for reducing chromium(VI) concentration in the source aqueous phase to 0.001 ppm, which is below the permissible limit for drinking water in Poland. Thus, the application of PIMs can be effective for heavy metals removal from contaminated groundwater, and the immobilization of specific ion carriers on the reactive material within PRB — a novel approach in groundwater remediation at contaminated sites.

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IAH 2010
Krakow

abstract id: **354**

topic: **6**
General hydrogeological problems

6.3
Groundwater contamination — monitoring, risk assessment and restoration

title: **Quality of groundwater in the shallow and deep aquifers of the Gefara Plain, Tripoli region, Libya**

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The Libya as North African Arabic country is located in North Africa, and covers a big surface area. Groundwater is the main source of Drinkwater supply in main regions in Libya.

The study area is located in Gefara Plain between the Mediterranean coast and the Jebel Nafusa Mountain in the south; it is also an agricultural and industrials center with high population and farms activities. Large increases in water demand with very little recharge have affecting the water levels and water quality.

The GMMR project the world's largest engineering venture is intended to transport about 6 Million m^3 per day of drink water from these aquifers in deep Sahara to the northern coastal belt, to provide for the country's 6 million inhabitants and for irrigation.

The groundwater resource in the coastal region of Gefara Plain in the south west of Tripoli city has extreme contaminated by seawater intrusion. Different groundwater samples were collected and analysed for hydrochemical investigations. The chemical analyses of groundwater samples indicate high ions concentrations. Some water samples are characterized by high chloride, sodium, sulphate, total dissolved solids and nitrate. Some water samples were analysed for isotopes techniques. The isotopic analysis aimed to determine the age, recharge and origin of the groundwater bodies and to offer support for the hydrochemical analysis.

abstract id: **373**

topic: **6**
General hydrogeological problems

6.3
Groundwater contamination — monitoring, risk assessment and restoration

title: **Selection of models for hydrogeological risk assessment of landfills**

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keywords: risk assessment, landfill, models, dual porosity

INTRODUCTION

In the UK, environmental regulators require Hydrogeological Risk Assessments for landfills as part of the permitting process, to demonstrate compliance with both the Landfill Directive (EU, 1999) and Environmental Permitting Regulations. In April 2010, the Environmental Permitting Regulations for England and Wales (UK government, 2010) were extended to include some of the provisions of the Groundwater Daughter Directive (EU, 2006), with emphasis on pollution prevention. Under the regulations, Hydrogeological Risk Assessments form part of the "prior examination" of a discharge from a landfill to groundwater (Environment Agency, 2003).

Although both operational and closed landfills with environmental permits must now comply with the regulations, many sites have a long history and include older phases, which were constructed to "dilute and disperse", alongside modern engineered cells with liner, control and management of leachate and gas, cap and drainage. In addition, many of the older sites started as infill of a void created by sand and gravel extraction, in hydrogeological environments which would be considered too vulnerable for landfill by modern standards. Although infiltration into the older cells can be reduced by capping, the inevitable loss of leachate to ground results in a complex interaction between historical and ongoing contaminant sources. This makes it difficult to distinguish the impacts of different phases and complicates compliance with regulations.

The standard approach to Hydrogeological Risk Assessment for landfills (Environment Agency, 2003) includes justification of the risk assessment method, consideration of the potential impacts over the entire lifecycle of the landfill, selection of priority contaminants to be modelled, creation of a conceptual model of the site, numerical modelling, completion criteria and a monitoring scheme. LandSim v 2.5 (Golder Associates, 2003) is most frequently used to model the potential contamination impacts, because it is considered to be the regulator's preferred tool. LandSim uses a probabilistic approach to simulate leachate production and chemistry in the landfill, followed by migration and leakage through the base of the landfill and the unsaturated zone.

In order to represent uncertainty and provide the regulators with a precautionary evaluation of potential risks to groundwater, input parameters are represented by the use of conservative probability distribution functions to describe site specific characteristics and model results are usually considered at the 90th percentile, over a prolonged time period. Although the model is comprehensive, it is inevitably simplified, thus for sites with a long and complex operational history, simulation of contaminant breakthrough and concentrations may not fit with monitoring data. These issues are illustrated with data and modeling results for a closed and capped landfill in eastern England.

LANDFILL SITE

The site was a sand and gravel pit until the early 1970s when it began to accept non-hazardous domestic, commercial and industrial waste. The landfill remained operational for over 30 years, with five main phases of disposal (Mott MacDonald, 2010). Each phase incorporated different design details, as the technology or current practice progressed. This lack of consistency in engineering is typical of the UK's older landfill sites.

As the overlying Neogene and recent sediments were mostly removed by quarrying, the landfill site lies directly on the Cretaceous Upper Chalk, a fractured white limestone with a fine grained, porous matrix, which forms the major aquifer in Eastern and Southern England. A simplified conceptual model is illustrated in Figure 1.

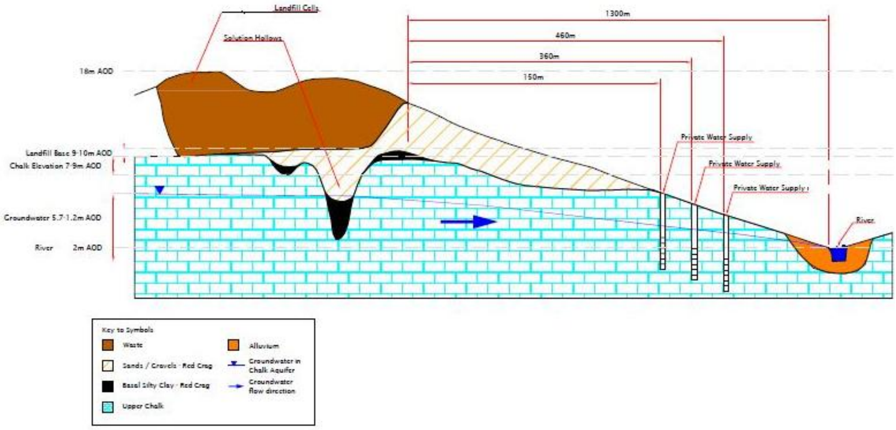

Figure 1. Schematic Cross section and Conceptual Site Model.

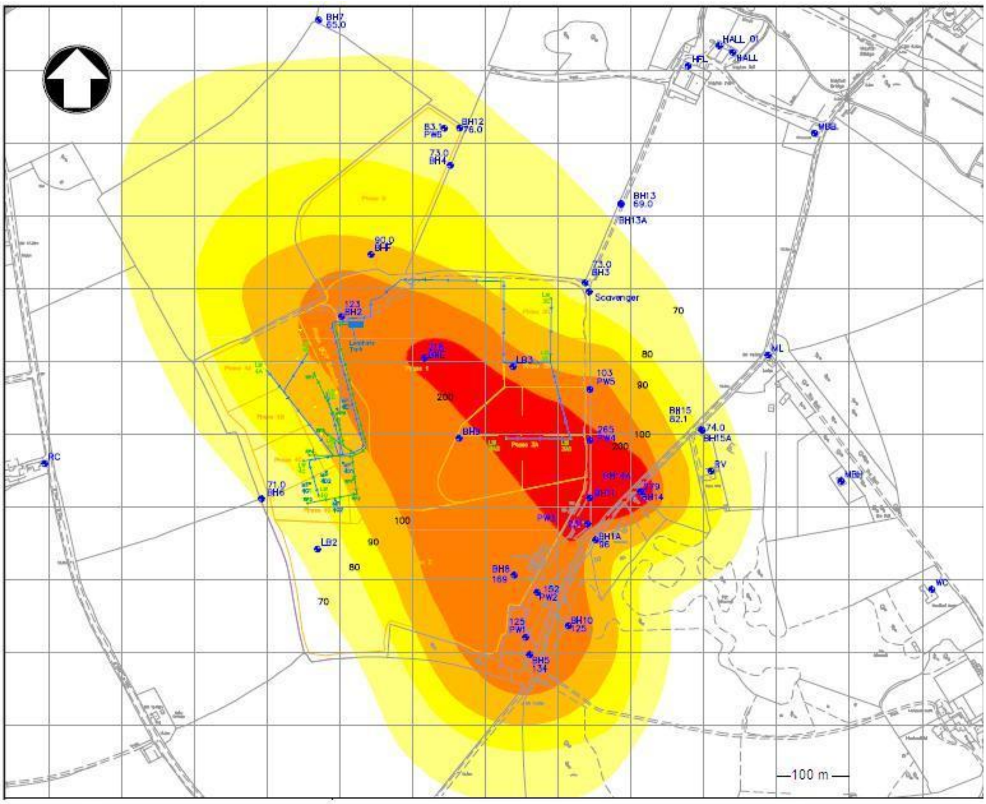

Figure 2. Observed Chloride concentrations (mg/l) in 2009.

Over 20 years of monitoring data indicates that groundwater flow is dominantly to the south east. The distribution of landfill derived substances, especially ammonia and chloride (Fig. 2), is consistent with this inferred flow direction but shows considerable lateral dispersion, although this is partly due to the large source area. The distribution also implies that preferential flow pathways may be active, and that the older, unlined phases are the main source areas. The time series data (Fig. 3 and 4) also shows that retardation is occurring, even for conservative species.

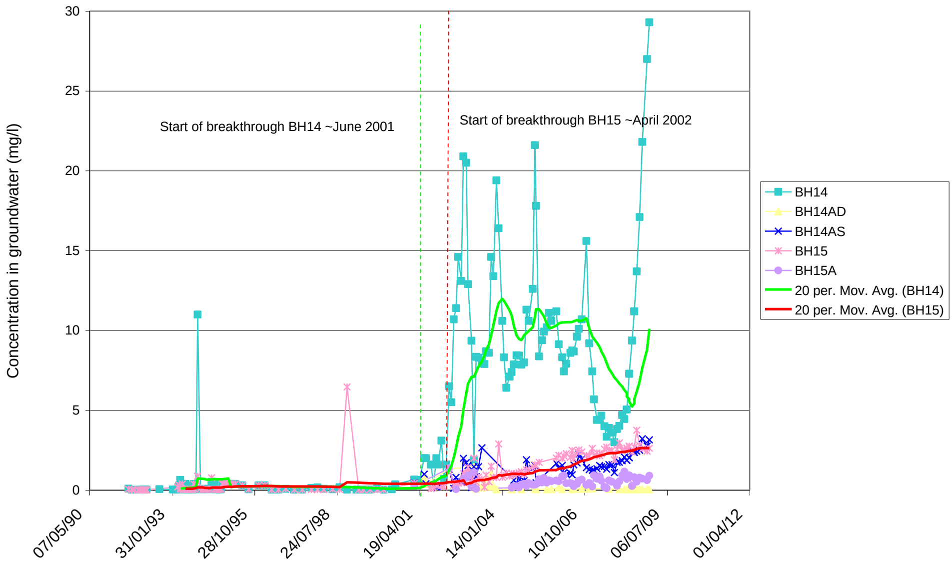

Figure 3. Observed concentrations of Ammonia with time in Chalk aquifer.

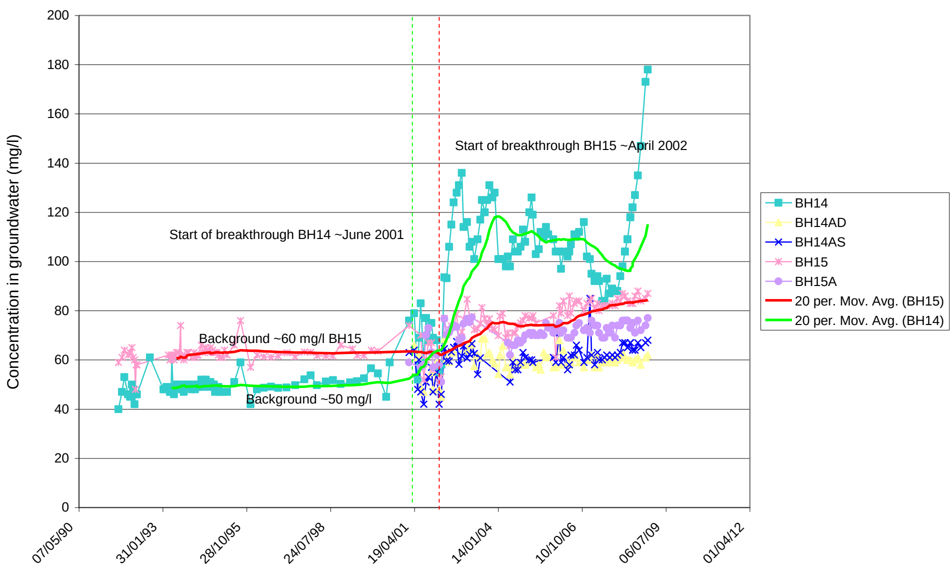

Figure 4. Observed concentrations of Chloride with time in Chalk aquifer.

APPROACH TO MODELLING

Based on the initial conceptual model, the saturated zone of the Chalk was represented in LandSim with high permeability, a low effective porosity and dispersion, thus representing rapid flow and contaminant transport in the fissure network only. Using these data, the simulated breakthrough of inorganic species was extremely rapid, with a sharp rise in concentrations, and quite different to the observed trends.

As the initial results were unrealistic, concerns about potential groundwater contamination required an alternative approach to risk assessment and predictive modelling of contaminant concentrations hydraulically downgradient of the landfill. A rapid assessment was essential, so the Remedial Targets Worksheet (Environment Agency, 2006) was used to simulate the 1-D migration of dissolved contaminants in the aquifer along several flow lines, with the source based on measured groundwater concentrations at the landfill boundary. Although this is a simplified model, it includes attenuation by dispersion, retardation and biodegradation. A good fit to observed breakthrough times and concentrations was achieved, using an effective porosity of 0.3 and hydraulic conductivity of 2 m/d for the Chalk aquifer. These values are consistent with local measurements, but differ from the accepted understanding of properties of the solution enlarged fractures in the aquifer's main flow zone. The interpretation is that the apparent retardation is due to diffusion from fractures into the matrix blocks, which have a total porosity of 0.35, and that transport is occurring through a network of small fractures in the upper part of the saturated zone. It was also apparent that ammonia is only slightly retarded, relative to chloride, close to the landfill, as demonstrated by Figures 3 and 4. This may be due to the heavy loading of ammonia and is consistent with the observations of Erskine (2000).

The results from the sensitivity analyses were used as the input to Landsim for the groundwater pathway through the Upper Chalk. This allowed a more realistic prediction of future risks to local abstractions and a baseflow fed river.

CONCLUSIONS

Although the LandSim model is capable of simulating a wide range of processes in and around a landfill and is the standard UK model for hydrogeological risk assessment, it is essential to check the results against observations and adjust input values to improve the agreement between model and observations. When the results do not fit well, a simpler model can be extremely useful for rapid sensitivity analysis and testing of the conceptual model. In this case, a simple 1-D model showed that the accepted model of a dominantly fractured aquifer, with high permeability and low effective porosity, is not realistic for a 30 year period with significant contaminant loading from the landfill. Diffusion into the matrix the upper part of the saturated zone is significant and results in an effective porosity which is close to the total porosity of the aquifer. The insights gained from the simplified model can then be used to constrain the data input to the more sophisticated LandSim model, thus generating greater confidence in the predictions.

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abstract id: **403**

topic: **6**
General hydrogeological problems

6.3
Groundwater contamination — monitoring, risk assessment and restoration

title: **Hydrogeological study of contamination in the Aquifer System of Sines, South Portugal**

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keywords: contamination, karst and porous aquifer

INTRODUCTION

The Aquifer System of Sines is located in the western coast of South Portugal (Figure 1), and it is formed by sedimentary rocks overlying the Paleozoic metamorphic rocks of the South Portuguese Zone. It is a complex aquifer system, mainly composed by two aquifers, the top one phreatic, porous, built by tertiary sands interbeded with more clayish formations, and the second one confined, composed mainly by limestones, with mixed karstic and porous characteristics. In the south part of the system the geology is more complex, influenced by the intrusion of an igneous batholith south of the aquifer, accompanied by radial dykes, which disrupt and disturbed this part of the aquifer. In this area the upper and the second aquifer are sometimes linked, sometimes interrupted by tectonics, with an extreme variance not so easy to understand.

In the nineteen seventies, some industries based in oil products were installed and have started activity in the south part of the system (Fig. 1).

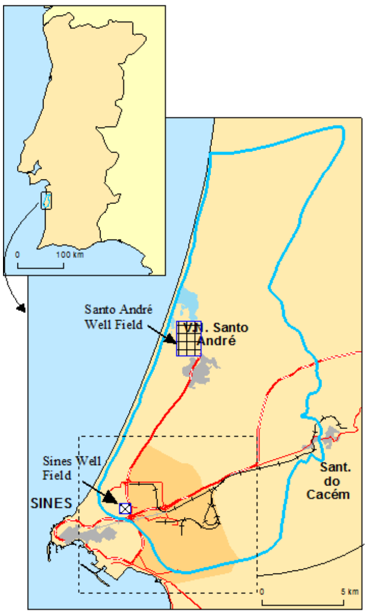

Figure 1. The Aquifer System of Sines (inside the blue line), in the western cost of South Portugal. All groundwater in this aquifer system flows essentially from east to west, in direction to the sea. In the shaded area of the south part of the system (east of Sines) an industrial area was installed in the seventies, including a refinery and other industries based in oil resources. Two main well fields guarantee the supply of potable water to the population and the industrial area, being the south one immediately downstream of the industrial area (ICCE 2009).

The expansion of some urban areas (in the city of Sines) and the creation of an entire new city (Santo André) to accommodate the workers for the new industrial area, led to an increase on the demand of quality water for the public supply system, including potable water for the industrial area. This supply has been based in groundwater from this aquifer system. The water for industrial processing was based in an artificial lake created by the construction of a dam nearby the city of Sines, using water transference from another river east of Sines, the Sado River. Two abstraction areas were created. The northern one is based in the confined aquifer, near the city of Santo André (Santo André Well Field in Figure 1), where this aquifer is protected by impermeable clay and limestone compact layers, at about 60 to 80 m deep. Here the wells are artesian and can have more than 100 l/s of flow as natural discharge at surface. Most part of these wells allows the abstraction without the need of pumping, using only the natural discharge. These wells supply the city of Santo André, the industrial area of Sines, and Sines municipality in summer, when a high quantity of tourists come to this coast on vacations and there is the need to strengthen the Sines supply system in drinkable water. In the south part of the aquifer, northeast of the city of Sines, other group of wells (Sines Well Field in Figure 1) supplies water to this city, with exception to the industrial area, supported by the first set of wells. These non artesian wells were drilled in the border of the industrial area, downstream the aquifer flow, and, in 2009, some analysis showed the presence of hydrocarbons in groundwater. At the same time, contaminated soils were identified inside the industrial perimeter.

GEOLOGY AND HYDROGEOLOGY

The sedimentary infill of the Meso-Cenozoic intracratonic Sines basin (Figure 2), supporting the multilayer Sines Aquifer, reaches a thickness of more than 1,000 m.

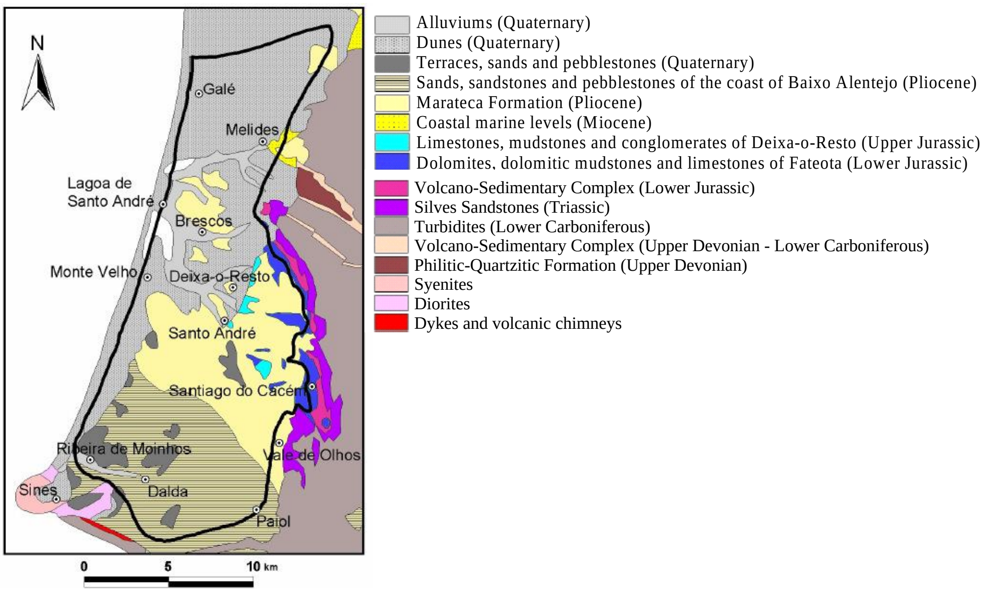

Figure 2. Schematic approach to the geology of the area of the Aquifer System of Sines. The aquifer system is delimited by the black line. East of Deixa-o-Resto and Santo André a fault (Deixa-o-Resto Fault) marks the recharge area of the confined karstic aquifer. West of this fault, the limestones that outcrop in contact with the fault on its eastern border are at 60 to 80 m deep, defining the eastern border on the confined aquifer, which extends to the coast and, probably, by some hundred meters under the sea.

The basin contacts with low permeability Carboniferous flysch turbidites to the South and to the East and with the sub-volcanic Sines massif to Southwest. The Grândola Fault defines the northern boundary of the sedimentary basin. The oldest sediments in the Sines Basin consist mainly of red continental sandstones and mudstones (Silves Formation). Above this Triassic siliciclastic rocks, with an average thickness from 80 to 120 m, a sequence of Hettangian-

Rhaetian evaporites, clay and marls (80 m) and dolomites (15–40 m) were deposited. Sinemurian-Hettangian deposits (130 m) are dominated by marls, clays, dolostones and limestones intruded by basaltic and doleritic dikes and are followed by the Jurassic carbonate rocks, supporting the most important and deeper regional aquifer of the basin, which is artesian in an important part of its area. The sequence of these carbonate rocks starts by Early Jurassic (Toarcian-Sinemurian) limestones, dolostones and marls (100 m). It is followed by Middle Jurassic (Callovian-Bathonian) limestones (250 m) and finishes with 600 m of Late Jurassic limestones, marls and conglomerates (Oxfordian-Kimmeridgian). Due to the absence of Cretaceous rocks (except for the off-shore part of the basin, where sediments of this age were identified) the Miocene deposits follow the Jurassic rocks in the sedimentary sequence (Inverno et al., 1993). Outcrops of Miocene lithologies are scarce in the Sines Basin and are represented by sands, silts, sandstones and biocalcarenites. The thickness of the Miocene deposits is in the order of 30 m and was identified in boreholes under Plio-Pleistocene and Holocene deposits, at a depth varying between 8 m and 40 m (Oliveira et al., 1984). The Plio-Pleistocene silt and clay sands, together with beach and dune sands are the most important deposits covering the Jurassic rocks. These detritic rocks are present in the western coastal plain, which is limited by the ocean to the West and by the Santiago do Cacém Hills (with an altitude between 50 and 200 masl) to the East. These hills, built by early and middle Jurassic carbonate rocks outcrops, define the limit of the Mesozoic formations of the Sines Basin and form the main recharge area of the deep carbonate aquifer. The area with outcrops of late Jurassic carbonate rocks is very limited. These rocks occur in the coastal plain, covered in most of its area by the Miocene, Plio-Pleistocene and Holocene sediments. The Holocene deposits, associated with lowlands at the Melides (0.4 km^2), Santo André (2.5 km^2) and Sancha (0.2 km^2) lagoons were deposited in the terminal reaches of the Melides, Ponte, Badoca and Sancha creeks. These deposits consist essentially of detritic, minerogenic and organic sediments arranged in several units with a maximum thickness of about 40 m (Freitas et al., 2002). These deposits limit the hydraulic connection between the lagoons and the shallow detritic aquifer, due to the fine fraction of the sediments in the lagoons. However, as the rivers associated with the shallow lagoons aquifer are effluent in the terminal reaches, where sediments are coarser than in the bottom of the lagoons, the water balance of the lagoons is controlled by the hydraulic connection of the stream network with the shallow aquifer. Figure 3 shows the geological and hydrogeological profile of this aquifer.

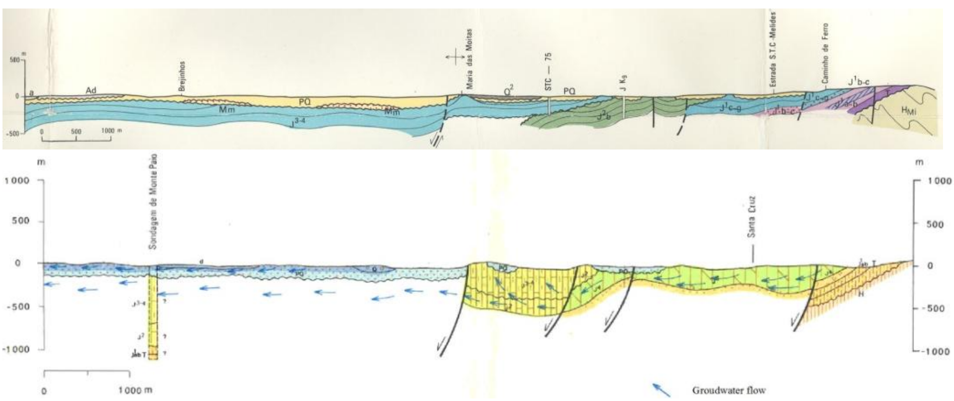

Figure 3. Geologic and hydrogeologic west-east profiles of the area of the aquifer system of Sines, in the area of Santo André (Oliveira 1984, Esteves Costa 1994, respectively).

ACTUAL GROUNDWATER USES IN THE AQUIFER SYSTEM OF SINES

The aquifer system of Sines is mainly composed by two aquifers, a porous phreatic one on the top, in the first 60 m, and a karstic one, confined, under 70–80 m deep in the western part of the fault of Deixa-o-Resto. The bottom of the second one is unknown, but the limestones are known to be on the order of several hundreds of meters. Recent drillings in this aquifer showed what seems to be a karstic system filled with sand and a great quantity of fossils.

As it can be seen in Figure 1, this aquifer system presents two main pumping fields, one responsibility of the private company Águas de Santo André, SA (the northern one) and the other responsibility of the Municipality of Sines (the south one). The first field is supported by wells in the karstic confined aquifer, varying between 100 and more than 200 m deep, and all the supply wells are artesian, with natural flow at surface varying between 30 and 110 l/s. The second field is situated in the south part of the system, where the aquifer is not so well defined, due to the intrusion of the magmatic rocks in the area of Sines during the Alpine Orogeny; in this area both the phreatic and the confined aquifers are surely linked in some areas, but they can also be independent on others, and there is no more signs of artesian flow in the area. One strong possibility, due to the deficient construction of the wells of the Sines Well Field (for example there are no signs in some of the wells of any vertical protection, the tubes were just inserted into the well, but the flow cross all the layers outside the casing), is that the wells can be responsible by the flow by-pass between the two aquifers.

Recent studies (Chambel, Monteiro 2007; Monteiro et al., 2008) showed that the abstraction rates in the confined aquifer must be about 50% of the infiltration rates. From this 50%, 5% are supposed to be abstracted from the infiltration area of the confined aquifer and used mainly in agriculture, and 45% are justified by these two well fields and some private wells used inside the industrial park. So, from a total average infiltration of 12×10^6 m^3year^{-1}, a calculated value of 6×10^6 m^3year^{-1} is abstracted in the confined aquifer.

CONTAMINATION

In the southern well field (Sines Well Field) some hydrocarbon contamination had begun to be detected in analysis since 2009. The wells are down flow the industrial area, involving at least two oil industries in its vicinity, one at south-east, and other north-east of the well field. The global analysis of data shows that the presence of hydrocarbons is increasing along the months, namely the naphthalene and total oil hydrocarbons. From all the detected polycyclic aromatic hydrocarbons (PAH's), the presence of naphthalene is the only one which clearly results from industrial synthesis; all the others are present in bitumen as well in other organic materials. So, the naphthalene can clearly help to identify industrial origins, opposing natural origins. Even so, the PAH's are present in concentrations less than admitted by the Portuguese law and international directives, so the contamination levels are not yet dangerous, but of high concern, due to the fact that the place is just outside an industrial area. Also the presence of xylene, with quantities that had passed 25 times the levels defined by the 'Dutch List' (VROM, 2000) in some analysis, are compatible with contamination based in oil derivates. The presence of naphthalene, BTEX (in this case only the case of xylene) and hydrocarbons of oil clearly indicate the presence of anthropogenic contamination.

The substances originated from human activities can accommodate in the following origins:

- Migration from industrial origins nearby,
- Groundwater migration from landfills of chemical substances nearby,
- Groundwater migration coming from pipelines with chemical products,
- Nearby wells with deficient protection permitting the contamination between aquifers,
- Contamination through surface in wells without upper protection against vandalism or accidental spreading of substances.

CONCLUSIONS

The detection of hydrocarbon contamination in the aquifer system of Sines had led to three basic actions: the decontamination of contaminated soils, a deep study of the aquifer contamination (flow patterns, attenuation, degradation, diffusion or miscibility processes of pollutants), and a geophysical study to implement new supply wells for the city of Sines. A new inventory of wells and contamination points was developed and a new piezometric map was defined for the aquifer system. The evolution of contaminants has been followed and remediation measures will be proposed if it shows essential for the protection of the groundwater resources. Isotopic studies are planned, in order to help understand the water time travel from recharge to discharge areas.

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abstract id: **404**

topic: **6**
General hydrogeological problems

6.3
Groundwater contamination — monitoring, risk assessment and restoration

title: **The changes of groundwater chemistry of a semi-confined buried valley aquifer during one decade of water exploitation**

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keywords: groundwater quality deterioration, groundwater contamination, Wielkopolska Buried Valley aquifer, Poland

INTRODUCTION

The buried valleys are the most attractive sources of groundwater in many parts of Poland. As a result of low vulnerability (large thickness of the aquitard) these aquifers usually accumulate unpolluted groundwater. However, more and more often the symptoms of water quality deterioration become visible also in this type of aquifers (Gorski, 1989). The additional factor that increases vulnerability to pollution is groundwater exploitation that causes high downward gradient (Jeong, 2001; Lawrence et al., 2000). This gradient activates or intensifies the migration of contaminants from land surface and shallow (usually polluted) aquifers to deeper water systems.

The investigation of groundwater chemistry of the semi-confined buried valley aquifer (Wielkopolska Buried Valley aquifer -WBV, Poland) was performed in 2000 year. The classification of hydrochemical zones was performed and used for identification of groundwater flow pattern within the aquifer (Dragon and Gorski, 2009). Also the zones of groundwater anthropogenic contamination were identified even though the semi-confined conditions occur (Dragon, 2008). For identification of temporal groundwater chemistry changes wells tapping WBV aquifer were resampled in 2009 year.

The main objective of this paper is the identification of the temporal variability of groundwater chemistry. Special emphasis is being places on the hydrogeochemical processes initiated or intensified by anthropogenic contamination.

STUDY AREA

WBV aquifer is very important for drinking water supply of many towns and villages in Wielkopolska region (Fig. 1).

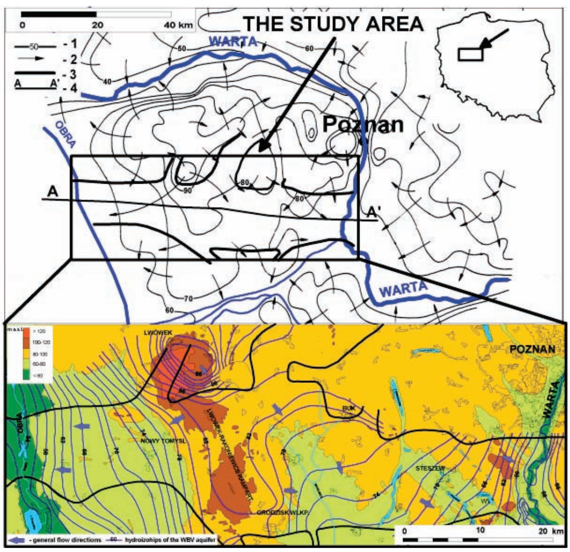

Figure 1. Location map of the study area on the background of the groundwater flow system of the Quaternary aquifers (after Dragon, Gorski, 2009). 1 – hydroizohips of the Quaternary aquifers; 2 – general groundwater flow directions; 3 – boundary of the Wielkopolska Buried Valley aquifer; 4 – line of cross-section (Fig. 2).

The thickness of the aquifer (composed mainly by sand and gravel) ranges from 20 to 50 meters (Fig. 2). The confining layer has thickness between 20 and 50 m and is composed of glacial tills. The main recharge area is located in the region of the Lwówek-Rakoniewice Rampart. The principal source of the recharge is the percolation of groundwater through glacial tills and upper intertill aquifers (Fig. 2). The recharge by the inflow from the intertill aquifers, located to the north of the WBV aquifer, also takes place. It was documented with use of hydrochemical data (Dragon and Gorski, 2009).

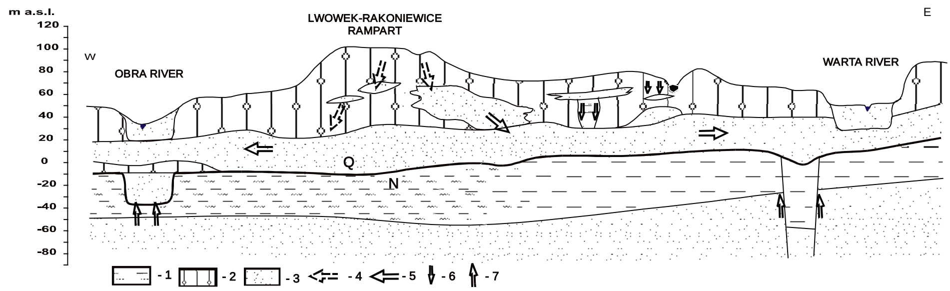

Figure 2. Schematic cross-section and conceptual model of the aquifer recharge (after Dragon, Gorski, 2009, simplified) 1 and 2 – confining layers (1 – clays, muds and silts; 2 – glacial tills); 3 - water bearing sediments (sands and gravels); 4 – preferential flow through glacial tills; 5 – groundwater flow direction in the aquifer; 6 – leakage of contaminated water from surface and shallow aquifers; 7 – upward flow from deeper flow system; Q – Quaternary; N – Neogene.

Sources of pollution typical for the Wielkopolska region are present in the study area. The most significant source of pollution is the untreated sewage from both rural and urban lands – a long-lasting problem that has not been solved since the last centuries. It should be underlined that very long time of influence is characteristic for this type of contaminant sources, dating back to the beginning of the settlement. Another most important source of contamination, connected with agriculture, are livestock farms. Livestock manure is in most cases spread on the fields. The other risk concerning a cultivated land is an excessive usage of fertilisers.

MATERIALS AND METHODS

The study of temporary hydrogeochemical evolution of groundwater accumulating within WBV aquifer has been made based on a comparative analysis of data obtained in two surveys performed in 2000 and 2009. The sampling survey performed in 2000 consists of 61 sampling sites (Dragon, 2006, 2008). In the 2009 sampling program, water samples were taken from 41 wells from among of 61 wells sampled in 2000. Unfortunately some of wells sampled in 2000 were closed down before 2009. Water samples were taken from productive, continuously pumped wells. For quality control measures the ionic error balance was calculated and does not exceed 3%. Moreover, archival physico-chemical analyses from the period of wells construction and performed during wells exploitation were use.

RESULTS AND DISCUSSION

The results of chemical analysis show relative small water chemistry variation over time. Nonetheless in case of some parameters increase of concentrations over time is observed. The most intensive increase is visible in case of chloride and sulphate (and is reflected by electrical conductivity – Fig. 3), thus the parameters reflecting water anthropogenic contamination (Dragon, 2008).

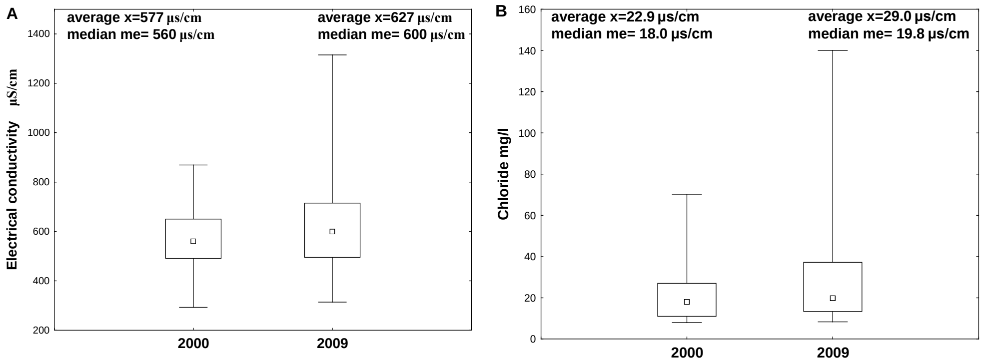

Figure 3. Variability of groundwater chemistry (example parameters) during period between 2000 and 2009 years (whole data set, number of samples n=41). Explanations: □ Median ⎕ 25%-75% ⊥ Min-Max.

The typical changes of groundwater chemistry in the zones of anthropogenic input and in the remaining parts of the aquifer are presented on Fig. 4. The most intensive increase of concentrations is visible in the zones identified using factor analysis as the most vulnerable parts of the aquifer (Fig. 4A) (Dragon and Gorski, 2009). The increase of concentrations of chloride, sulphate and total hardness is clear visible while in the remaining parts of the aquifer concentrations of these parameters are stable during wells exploitation (Fig. 4B). These groundwater components were identified as the most sensitive indicators of anthropogenic input (Dragon, 2008). Their concentrations are incomparably higher than in whole data set (compare Fig. 3 and 5), moreover the steady increase of its concentrations over time was documented.

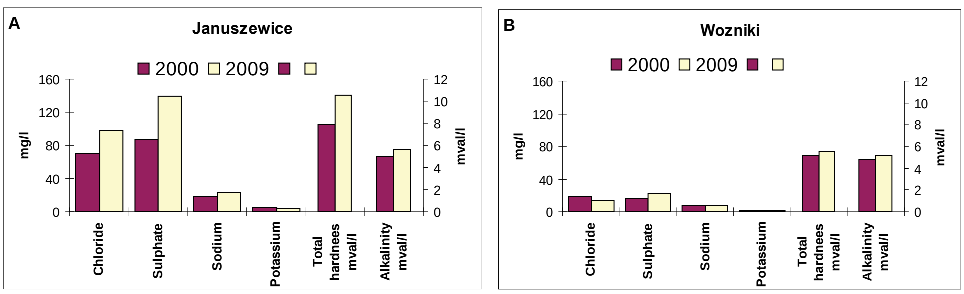

Figure 4. The typical variation of groundwater chemistry in period between 2000 and 2009. A — example well located in zone of anthropogenic input; B — example well located in zone of lack of anthropogenic input.

It is clear visible in case of some wells. Fig. 6 presents water chemistry changes in well located in the Grodzisk Wielkopolski town during period of water extraction between year 1960 (well construction) and year 2002 (well liquidation). At the period of well construction all groundwater components (include indicators of water pollution) were at level of natural hydrogeochemical background. The systematic increase of chloride (from the range of the natural hydrogeochemical background - 10 mg/l to more than 80 mg/l) and sulphate (increase to more than 175 mg/l) as well as total hardness is visible during wells exploitation. It should be underlined that at the beginning of water exploitation the contamination was not observed and appear with stable tendency later.

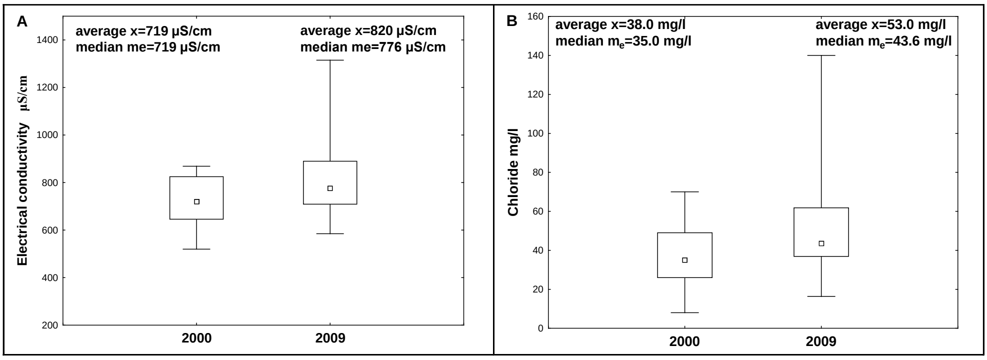

Figure 5. Variability of groundwater chemistry (example parameters) during period between 2000 and 2009 years (zone of anthropogenic input, number of samples n=14). Explanations: ▫ Median ☐ 25%-75% ⌶ Min-Max.

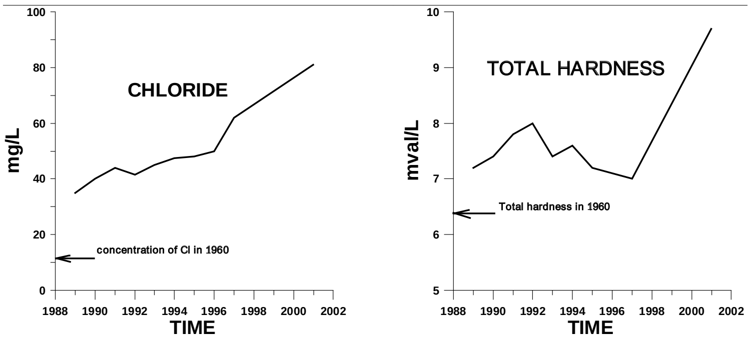

Figure 6. The variations of the contamination indicators concentrations with time in well located in Grodzisk Wielkoposlski town.

This is characteristic also for other wells tapping WBV aquifer. It should be suspected that the mechanism, which activate or increase effectively migration of contaminants from surface, is water exploitation that can create high downward gradient. If the exploitation is performed during long period of time (like in case of Grodzisk Wielkopolski town) it can cause the shift of the groundwater divide. On the map (Fig. 1) the characteristic bent of the hydroisohips in direction of the town is visible. The original location of the water divide was probably in the central part of the Lwowek-Rakoniewice Rampart.

The influence of anthropogenic contamination on groundwater chemistry confirms results of the factor analysis. The analysis was performed using methodology presented in previous work (Dragon, 2006). The results obtained are consistent with previous and moreover shed a new light on groundwater chemistry changes due to contamination. The comparing of the FA results for 2000 and 2009 sampling surveys is presented on Table 1. Three factors were calculated for both data sets. The calculation for 2000 and 2009 sampling surveys explain 72 % and 77 % of variance (respectively). For both data sets Factor 1 was identified as “anthropogenic” because describing variation of parameters identified as contamination indicators, while Factor 2 is recognized as "geogenic" because reflect natural hydrogeochemical processes (Dragon, 2006). The interpretation of factor 3 is difficult because is different in both data sets, but it has relative small importance (explain 15 and 11 % of variance respectively). The comparison of the factor loadings of factor 1 point out that indicators of pollution (Cl, SO_4, TH and TDS) have significantly higher factor loadings in 2009 data set. Moreover, shift of the TDS and TH in direction to "anthropogenic" factor is visible (comparing years 2000 and 2009).

These findings indicate that contamination identified in year 2000 is still effective regardless of enforce of the groundwater protection activities (e.g. building of new sewage systems, rationalization of the fertilizers use, etc.), very effective in Poland after political democratic changes. These findings show the travails connecting with groundwater quality protection of the confined or semi-confined aquifers. It shows that for the visible effects of the water quality protection activities in this type of aquifers we must wait long period of time.

Table 2. Comparing of the results of the factor analysis (after *varimax* rotation) performed for data sets from 2000 and 2009 sampling surveys.

	2000 sampling survey			**2009 sampling survey**		
	Factor 1	**Factor 2**	**Factor 3**	**Factor 1**	**Factor 2**	**Factor 3**
Colour	-0.17	0.00	**0.87**	-0.36	0.54	0.47
pH	-0.38	**-0.82**	-0.01	-0.42	**-0.74**	-0.15
Oxygen consumption	-0.12	0.40	0.55	-0.12	**0.80**	0.14
Total hardness (TH)	**0.70**	0.63	-0.07	**0.91**	0.35	0.07
Alkalinity (HCO_3)	0.27	**0.91**	0.12	0.41	**0.83**	0.09
Cl	**0.90**	0.02	0.17	**0.94**	0.03	0.04
SO_4	**0.77**	-0.13	-0.28	**0.93**	-0.20	0.04
N-NH_4	0.07	**0.77**	0.18	0.17	**0.79**	-0.17
Fe	-0.11	0.69	-0.14	0.12	0.66	0.10
Mn	0.55	0.16	-0.48	0.14	-0.01	**0.88**
Na	0.55	-0.07	0.67	0.73	0.41	0.15
K	0.65	0.36	-0.18	0.56	0.29	0.60
Total dissolved solids (TDS)	**0.84**	0.52	0.02	**0.90**	0.30	0.09
Percent of variance	30	27	15	37	29	11

Factor loadings >0.7 are marked by bold font

CONCLUSIONS

The research presented in the article show that influence of contamination on groundwater chemistry of the Wielkopolska Buried Valley aquifer identified in previous work is still effective. Groundwater contamination lead to deterioration of water quality mainly in case of the parameters identified as the most sensitive to anthropogenic impact (ie chloride, sulphate, total hardness and TDS) The contamination is the most effective in the regions identified in previous work as the most vulnerable parts of the aquifer The observations presented confirm earlier findings that the intensity of anthropogenic contamination of the WBV aquifer is visible even though the semi-confined conditions occur there. The nature of anthropogenic changes of water chemistry of the WBV aquifer indicates that these water are still at early stages of chemistry transformations (the concentrations usually do not exceed Polish national limits for drinking water and WHO recommendations). However, a distinct and constant increase of water components concentrations over time creates serious hazard for groundwater quality deterioration and its utilities for use in the future This fact should be taken into consideration if we thing about water resources for the next generations. It is very important particularly in case of confined or semi-confined aquifers.

ACKNOWLEDGMENT

The author would like to thank Prof Dr Jozef Gorski for his valuable contribution to the topic and important discussions.

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IAH 2010 Krakow

abstract id: **417**

topic: **6**
General hydrogeological problems

6.3
Groundwater contamination — monitoring, risk assessment and restoration

title: **Groundwater contamination at landfill sites in Selangor**

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INTRODUCTION

A study was performed to determine the total number of landfill sites and their operating status in Selangor. It was also conducted to evaluate the impact of landfills into groundwater and surface water systems. This paper presents some of the study findings related to the impact of landfills on water resources especially on groundwater. Evaluation of the extent of pollution at landfills was made and immediate remedial measures to be taken were suggested.

Sanitary landfills are generally classified into 5 levels (Department of Local Government, 2006). They are:

- Level 0: open dumping
- Level 1: controlled tipping
- Level 2: sanitary landfill with a bund and daily soil cover
- Level 3: sanitary landfill with leachate recirculation system
- Level 4: sanitary landfill with leachate treatment facilities.

OBJECTIVES OF THE STUDY

The study was carried out to assess and evaluate the extent of pollution at landfills and to select the most critical site especially in term of groundwater as well as surface water quality which would require immediate remedial measure to be taken. The 3 main objectives of the study are:

- To carry out desktop study on operational and close landfills (rehabilitated of abandoned)
- To assess the impact of leachate into the surface and groundwater systems, and
- To recommend remedial measures for the protection of surface and groundwater systems.

OVERVIEW OF THE LANDFILLS

There are 20 landfill sites in the state in which 7 of them are still operating and 13 are closed. Most of the landfills could be classified as Level 0 or 1. The engineered landfills (Level 4) are very few but one more would be built in Tanjung Dua Belas, Banting. Figure 1 shows the location of all the landfills in Selangor.

The landfills are either sited on alluvial deposits comprising of unconsolidated coarse grain sand, clays and peat, or metasedimentary deposits of Devonian to Carboniferous age, or granitic rocks of Triassic age. The alluvial deposits are regarded as one of the promising aquifers in Selangor.

The landfills are located in 5 major river basins; Sg. Selangor (7), Sg. Klang (5), Sg. Langat (6), Sg. Bernam (1), Sg. Buloh (1). None is located in the Tengi River Basin. Most of the landfills are sited very close (<100m) to river/stream.

Most of the landfills in Selangor are built and operated without proper monitoring facilities and pollution controls such as liner materials, groundwater monitoring wells, leachate collection and leachate treatment ponds, and methane gas ventilation pipes. They are not subjected to the requirement of EIA because they were built prior to 1989 (in which EIA requirement was enacted).

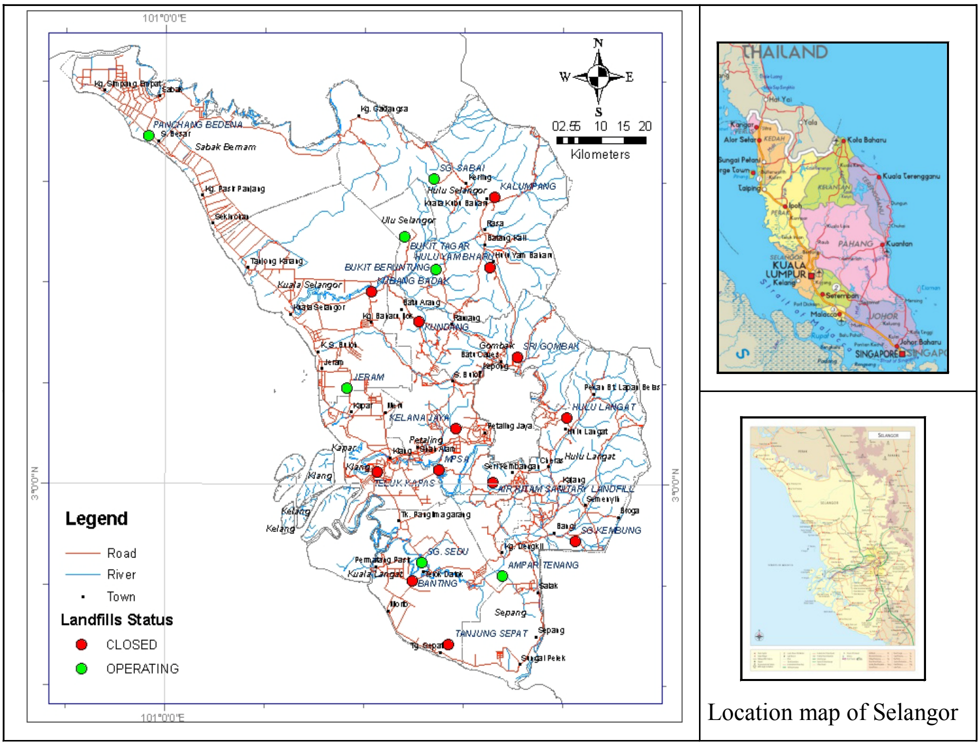

Figure 1. Operational status of identified landfill sites in Selangor.

They are not properly managed, wherein the leachate produced by the landfill is allowed to seep into the ground (no liner materials) as well as flowing to the nearby drainage or river (Figure 2) without any treatment. Only 25% are equipped with monitoring wells to monitor groundwater quality.

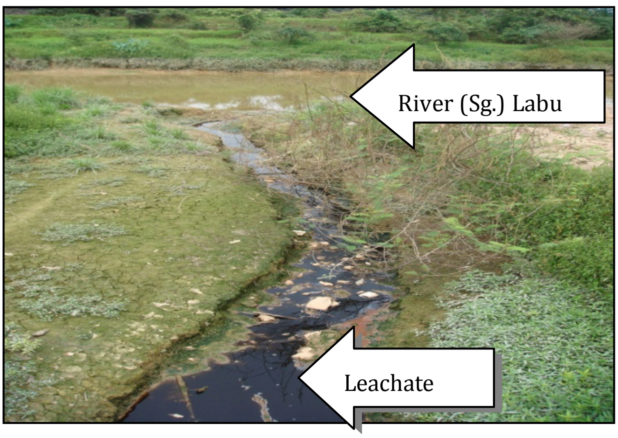

Figure 2. Leachate from Ampar Tenang landfill flows directly to River (Sg.) Labu.

Table 1. List of landfills in Selangor.

No	Local Authorities*	Site name	Locations	Level	Status	Landfill Liner	Distance to river/ stream (m)	Location of water intake
1	MB Shah Alam	MPSA	3°1'39.40"N; 101°33'3.64"E	0	Closed (waste removed)	Natural clay	10	Downstream
2	MP Ampang Jaya	Hulu Langat	3° 7'58.87"N; 101°48'20.68"E	0	Closed	None	20	Upstream
3	MP Kajang	Sg Kembong	2°53'15.49"N; 101°49'34.99"E	0	Closed	None	5	Upstream and downstream
4	MP Klang	Teluk Kapas	3°02'47.27"N; 101°23'33.70"E	I	Closed	None	20	None
5	MB Petaling Jaya	Kelana Jaya	3° 6'34.26"N; 101°35'29.96"E	0	Closed & developed	Natural clay	20	None
6	MP Selayang	Kundang	3°18'43.91"N; 101°30'24.48"E	0	Closed	None	10	None
7	MP Subang Jaya	Air Hitam Sanitary Landfill	3°00'07.44"N; 101°39'46.22"E	IV	Closed (post closure)	Various	5	None
8	MP Sepang	Ampar Tenang	2°49'07.69"N; 101°40'47.68"E	I	Operating	None	25	Downstream
9	MD Hulu Selangor	Sg Sabai	3°36'21.00"N; 101°32'25.80"E	0	Operating	None	2 km	None
10	MD Hulu Selangor	Bukit Beruntung	3°25'32.14"N; 101°32'56.6"E	0	Operating	None	5	None
11	MD Hulu Selangor	Hulu Yam Bharu	3°25'48.70"N; 101°39'14.71"E	0	Closed	None	No river nearby	None
12	MD Hulu Selangor	Kalumpang	3°34'07.08"N; 101°34'20.60"E	0	Closed (waste removed)	Not known	No river nearby	None
13	MD Selayang	Seri Gombak	3°15'07.72"N; 101°42'26.08"E	0	Closed	None	No river nearby	None
14	MD Kuala Langat	Tanjung Sepat	2°40'23.41"N; 101°31'33.91"E	0	Closed	Not known	No river nearby	None
15	MD Kuala Langat	Sg Sedu	2°50'38.77"N; 101°30'59.63"E	I	Operating	Natural clay	20	None
16	MD Kuala Selangor	Kubang Badak/ Kg. Hang Tuah	3°22'59.59"N; 101°24'52.38"E	II	Closed (post closure)	Natural clay	20	None
17	MD Kuala Selangor	Jeram	3°11'27.63"N; 101°22'02.54"E	IV	Operating	Various	70	None
18	MD Sabak Bernam	Panchang Bedena	3°41'26.36"N; 100°57'50.06"E	I	Operating	Natural clay	>1 km	None
19	MD Hulu Selangor	Bukit Tagar	3°29'46.64"N; 101°28'50.35"E	IV	Operating	Various	100	Downstream
20	MD Kuala Langat	Banting	2°48'24.98"N; 101°30'10.19"E	I	Closed	Natural clay	20	None

* MD=Majlis Daerah (District Council), MP=Majlis Perbandaran (Town Council), MB=Majlis Bandaraya (City Council)

METHODOLOGY

Information regarding landfill sites such as construction, operational status, geological characteristics and water quality data collected and reviewed were obtained from reports, technical papers, manuals, guidelines and research thesis from various government agencies, universities and private organisations. Site reconnaissances were carried out to verify and update the existing information and data. During the field investigation, landfill inventories and sampling of surface water, groundwater and leachate were carried out within the vicinity of selected landfills depending on availability of facilities. A number of landfills are not equipped with monitoring wells and as a result groundwater samples could not be collected.

The sampling technique, sample preservation and analytical procedures followed the standard methods recommended by APHA (1995 & 2005). The data on the composition of leachate is important in determining its potential impacts on the quality of nearby surface water and groundwater. This leachate often contains high concentration of organic matter and inorganic ions including heavy metals (Chian and DeWalle, 1976). In carrying out the landfill inventories, questionnaires were also distributed to landfill operators to update information on the current condition of landfills, environmental impact conditions, land utilisation after closure, and landfill closure and monitoring. Interviews with a small number of residents relatively near the landfills were also conducted. *In-situ* analysis was performed for DO, pH, temperature, salinity and conductivity using YSI multi parameter to evaluate the current status of water and leachate quality. Heavy metals were analysed using Inductively Coupled Plasma Mass Spectrophotometry (ICPMS). Ammoniacal nitrogen (NH_3-N), phosphate, nitrate and sulphate were analysed using spectrophotometry HACH DR 2800.

Out of 20 landfills, only 5 sites are equipped with groundwater monitoring wells and hence sampling activities for groundwater were done only at these landfill sites. Surface water from the nearby streams/rivers and leachate were also collected for chemical analysis to determine the effect of leachate to water resources. Table 2 shows the quality of leachate and the effect of landfill (leachate) on the groundwater and surface water quality from selected landfill.

Table 2. Leachate quality and effect of landfill (leachate) on the groundwater and surface water quality from selected landfill (equipped with groundwater monitoring wells) in Selangor.

Landfills	Groundwater	Surface Water	Leachate
Kelana Jaya	Slightly contaminated. Cr, Ba, Pb, Fe, As and Hg are slightly higher than the standard.	Class III Coliform exceeds the INWQS Class III limit.	Most parameters are less than the Effluents of Standard B except for BOD, COD and TSS.
Air Hitam	Slightly contaminated. Nitrate, Cr, Cd, Pb, Fe and Se are slightly higher than the standard.	BOD, COD, TSS, Sulphide, Cd, Cr, Pb, Fe, oil and grease are higher than the Effluents of Standard B.	BOD, COD, TSS, Sulphide, Cd, Cr, Pb, Fe, oil and grease are higher than the Effluents of Standard B.
Ampar Tenang	Contaminated. TDS, nitrate, Cr, Cd, Pb, Fe and Se exceeded the standard.	Contaminated (Class III). Increase in BOD, nitrate, As, Mn, Pb, Fe, Cu and Zn.	Most parameters are less than the Effluents of Standard B except for BOD, COD, As, Cr, Fe and Zn.
Jeram	Very slightly contaminated. BOD, COD, Fe, Pb, Cr, Zn, Hg and Ba are above background data.	Not available	Not available
Bukit Tagar	Not contaminated. All parameters below the standard except Fe (natural condition)	Class III	Not available

Results from the chemical analysis of groundwater, surface water and leachate quality were analysed and evaluated by comparing them with [Leachate] - Effluent Quality (Sewage and Industrial Effluents) Regulations, 1979 in Environmental Quality Act, 1974; [Surface water] - Interim National Water Quality Standards for Malaysia (INWQS), Department of Environment (DOE) (1995a); [Groundwater] - Guidelines for Raw Drinking Water Quality Benchmark for Groundwater Quality, Ministry of Health (2000), and Malaysian Environmental Impact Assessment Guidelines for Groundwater and/or surface water Supply Project, Department of Environment (1995b). Chemical analysis results from Jeram and Bukit Tagar landfills were referred to standard and background data obtained from EIA reports of these landfills.

Results from chemical analysis showed the leachate from Kelana Jaya, Air Hitam and Ampar Tenang exceeded the Parameter Limits of Standard B of Effluent Quality (Sewage and Industrial Effluents) Regulations, 1979 in Environmental Quality Act, 1974. Groundwater quality from selected landfills equipped with monitoring well indicates COD, BOD, TDS, Cd, Cr, Cu, Pb, Fe, As and Hg slightly higher than the standards for the Raw Drinking Water Quality Benchmark for Groundwater Quality and background data except the Bukit Tagar landfill. Data from surface water quality for samples taken from streams/rivers adjacent to landfill sites showed certain parameters are higher than standards and classified polluted according to INWQS except Bukit Tagar landfill which adopts a zero discharge target.

CONCLUSION

Groundwater quality from the groundwater monitoring wells of five landfill sites showed the value for various parameters are higher than standards. This indicates that the groundwater within and surrounding the landfills are contaminated by the leachate. More than 70% of the landfills are located within 100m from the stream/river. Most of the water quality of the rivers adjacent to landfill sites is slightly polluted and classified into Class III of INWQS classification. The leachate quality from most of the landfills exceeded the Standard B of Effluents Limits by the DOE.

The clean-up measures are recommended to prevent further movement of contaminant into the groundwater and surface water system as well as to ensure environmental sustainability. Action such as waste removal, construction of containment wall and pumping of contaminated groundwater may need to be considered. It is also recommended that specific guidelines and standards to address issues related to landfill be established. Several landfill sites such as Sg. Kembong, Ampar Tenang, Sg. Sedu, and Bukit Beruntung are recommended for safe closure since they have had surpassed the operation capacity. The Sg. Kembong, Ampar Tenang, Sg. Sedu landfills are also located in areas with high groundwater development potential. Further study on the closed Kelana Jaya landfill is required as the site is already developed into a residential area, in order to determine the extent of risk to human health posed by the landfill knowing the degree of the contamination.

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abstract id: **421**

topic: **6**
General hydrogeological problems

6.3
Groundwater contamination — monitoring, risk assessment and restoration

title: **Geophysical investigation (electromagnetical induction method) as a useful tool for monitoring the remediation of groundwater and soil pollution**

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Geophysical methods (geo-electrical and electromagnetical investigations) have since a long time been used in environmental studies to delineate groundwater and soil pollution. A condition for their usefulness is that the pollution must have caused a significant change in ground conductivity or resistivity. This approach is very effective when being applied in combination with the traditional method of investigation of soil and groundwater pollution, consisting in the installation of piezometers followed by soil and groundwater sampling for chemical analysis. Yet, the integration of both investigation methods is unfortunately not common practice, even if a new application of extended integration has recently been proposed: the monitoring of remediation, as ground conductivity will change throughout the remediation process. This innovative approach is illustrated by an example. At a food processing factory, groundwater pollution is caused by rinsing out the delivered vegetables in pickle in the open field before they were processed for consumption. The water loaded with salt infiltrated into the soil with a salt water intrusion as a result. Although the procedure of uncontrolled rinsing has been stopped, the pollution is still present. The groundwater reservoir has a total thickness of approximately 18 m and, based on the results of borehole logging, consists of 2 aquifers separated by a continuous clay layer of around 5 m. The pumping wells are placed above the clay layer, where the pollution is situated.

The groundwater will be pumped and cleaned before being discharged into surface water. To evaluate the progress of the remediation, monitoring is performed: electromagnetical profiling with the EM34-3 instrument and EM induction well logging have been carried out. Before the start of the remediation, the horizontal and vertical extent of the pollution have been defined. Also a reference profile has been set up, to detect possible influences due to changes of depth of groundwater level. During the remediation, the investigations are carried along the same profiles and in the same wells to evaluate the changes in conductivity due to the remediation. Groundwater analyses are used to validate the results. The first results show that the measured conductivity decreases in the vicinity of the pumping wells. So far, it can be concluded that EM induction method is a reliable tool for monitoring of remediation.

IAH 2010
Krakow

abstract id: **508**

topic: **6**
General hydrogeological problems

6.3
Groundwater contamination — monitoring, risk assessment and restoration

title: **Development of a methodology to characterize the reactive transport of organic contaminants in groundwater impacted by a Chemical Complex**

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keywords: contamination, organic compounds, methodology

Estarreja Chemical Complex (CQE) is an industrial complex located on NW Portugal, near Ria de Aveiro, an environmentally and economically important coastal lagoon. The CQE was constructed in the early 30's on top of high permeable dune and beach sand formations, which are part of the Aveiro Quaternary groundwater body (AQGWB) classified as "at risk" under the implementation of Water Framework Directive. The upper unconfined AQGWB aquifer is regarded as particularly vulnerable to contamination due to: (1) the high permeabilities of the sediments; (2) the small thickness of the unsaturated zone; (3) the plain topography; and, (4) the high groundwater recharge rates. Moreover, the Portuguese Environmental Agency (APA) classified the CQE surrounding area as at high risk due to social, environmental and economical impacts, which makes it a priority remediation area under the Environmental Liabilities Recover Program.

CQE surrounding area has been subjected to several research and technical studies, focusing on different aspects of the natural surrounding ecosystem: geology; hydrogeology; groundwater recharge; soil, surface and groundwater contamination. These studies also refer the CQE past practices regarding the rejection of solid and liquid effluents. For decades, the different CQE industries disposed solid wastes directly on the permeable sands without any kind of containment or impermeabilization, and discharged liquid effluents directly on streams connected to the coastal lagoon, without any previous treatment. Nowadays, and although waste management practices improved significantly, there are still signs of long term soil and groundwater contamination.

Recent work developed in the study area (Ordens, 2007) characterized the groundwater contamination (both inorganic and organic) and identified the processes responsible for the hydrochemical evolution of groundwater, including interactions with surface water. This study used geophysical methods to identify electromagnetic anomalies that can be related to different origins of contaminants and to surface and groundwater interactions. It also delimitates the extension and the magnitude of the contaminant plume.

The hydrochemical studies characterized the spatial evolution of groundwater quality due to both natural and antropogenic influences. The identified background properties give evidence to groundwaters with sodium-chloride facies, low mineralization (SEC $\leq$ 300 μS/cm), Eh ~ 300 mV, dissolved O_2 ranging from 2.4 to 5.5 mg/L, and pH ~ 5.4. Hydrochemical data also indicate that groundwater is mainly originated by rainfall infiltration; rainwater in the study region is basically diluted seawater.

In the contaminated sites, groundwater SEC is often over 20,000 μS cm^{-1}; pH presents either very low values (<5.0) or very high (>8.5), depending on the origin of contamination; Cl reaches values of 10 300 mg l^{-1}; NO_3 and SO_4 are well above 100 and 2000 mg l^{-1}, respectively; the concentrations of most heavy metals in groundwater are often well above background concentrations and in close relation to pH and Eh values.

Different types of groundwater contamination have been identified, depending on the type of rejected effluent, interaction between contaminants and on the natural hydrochemical characteristics of the aquifer. The main types of groundwater inorganic contamination identified in the study area are: (1) acid mine drainage or metallic sulphide tailings drainage — low pH with high levels of sulphates and pyrites associated metals; (2) halite dissolution — high concentration of chloride and sodium, and low [Br]/[Cl] rates; (3) agricultural activities — typically with high levels of nitrates, sulphates and potassium; (4) mercury sludges: high concentrations of mercury.

Generally the hydrochemical data shows groundwater contamination levels that compare well with the electromagnetic survey data (Figure 1).

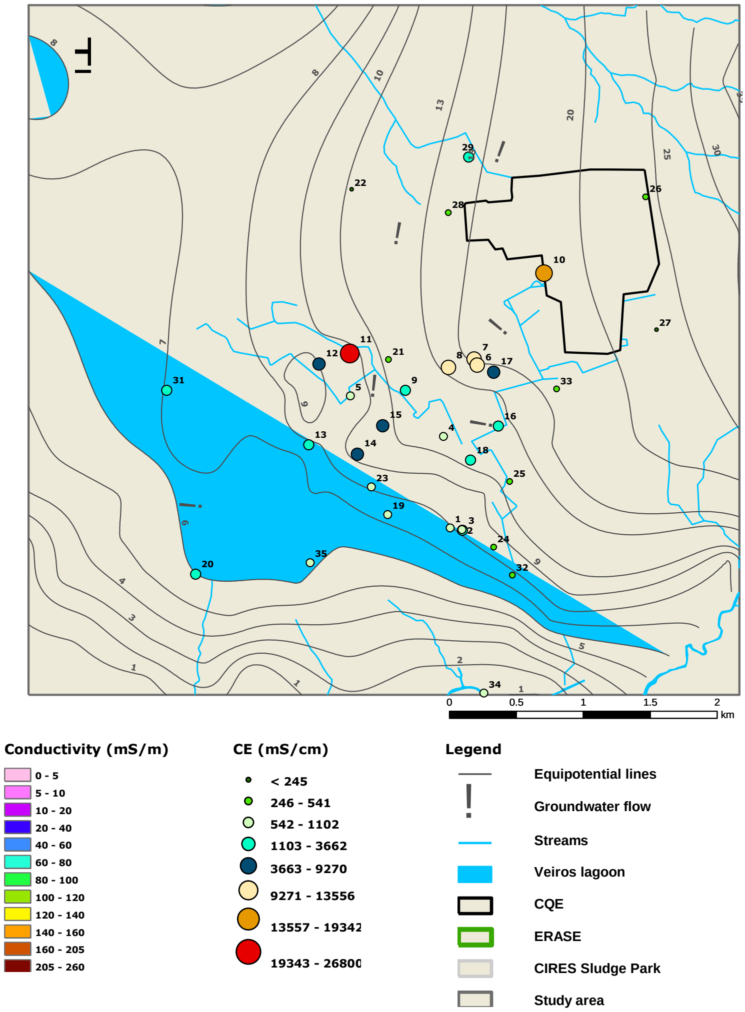

Figure 1. Correspondence between electromagnetic survey data and hydrochemical data (source: Ordens, 2007).

Previous investigations also identified the main organic contaminants present in the groundwater of the study area. These include chloroform, benzene, trichlorethylene, tetrachlorethylene, chlorobenzene, phenanthrene, naphthalene, aniline, vinyl chloride, 2-chlorofenol and mononitrobenzene (Figure 2). Five of these compounds are classified as priority substances according with the Directive 2008/105/EC (directive on priority substances), being two of them classified as priority hazardous substances according with the same directive.

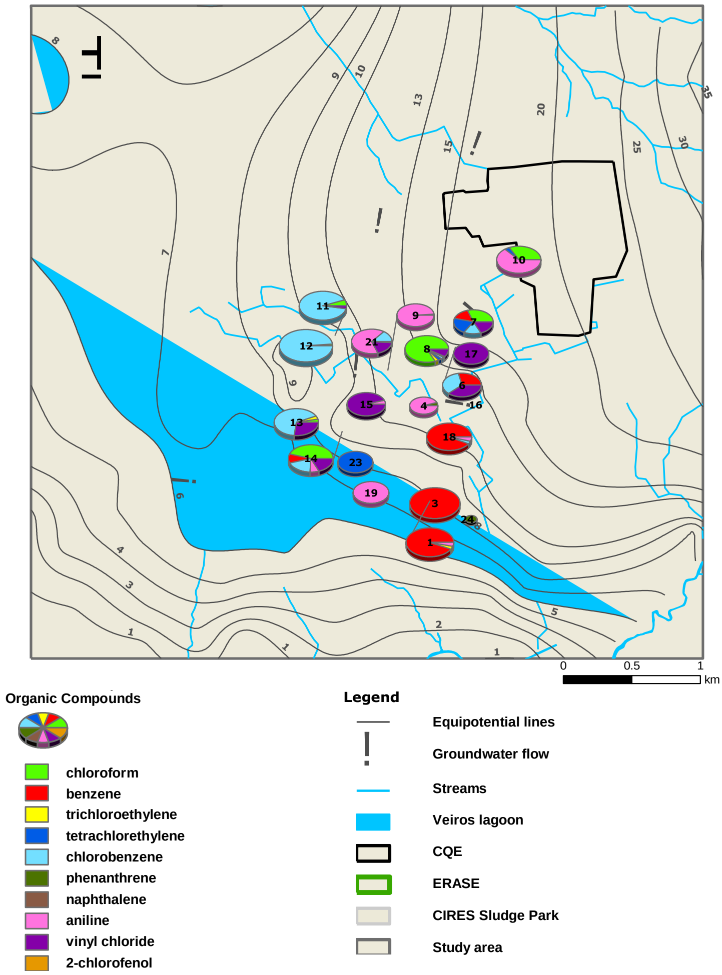

Figure 2. Spatial distribution of the main organic compounds identified on groundwater (source: Ordens, 2007).

Organic contamination is a major contamination issue worldwide and there is an increasing interest and necessity of study organic compounds transport and degradation mechanisms. The main objective of this research, which is part of CRUDE research project (PTDC/CTE-GEX/72959/2006), is to delineate and test a new methodology for deriving coherent and broad understanding of the reactive transport mechanisms of organic compounds in soil-vadose zone-aquifer media, using the surroundings of CQE as a case study.

The development of a coherent multidisciplinary investigation protocol (integrating geology, hydrogeology, geochemistry, geophysics, geostatistics, modeling, GIS) for soil/groundwater contaminated sites will contribute for the selection of the most appropriate technologies for the mitigation and remediation of contaminated sites.

ACKNOWLEDGMENTS

The authors would like to thank Fundação Ciência e Tecnologia (FCT) for funding Project CRUDE (PTDC/CTE-GEX/72959/2006); a Post Doctoral Research Position (Ciência 2007) and two PhD grants (SFRH/BD/47778/2008 and SFRH/BD/43625/2008).

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Project CRUDE, 2009: *Internal Report.*

abstract id: **531**

topic: **6**
General hydrogeological problems

6.3
Groundwater contamination — monitoring, risk assessment and restoration

title: **Radium in discharge waters from coal mines in Poland – effects of mitigation**

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keywords: Mine waters, radium balance, mitigation methods

INTRODUCTION

Very often human activity, connected with the exploitation of mineral resources, leads to the contamination of the natural environment. Sometimes natural radionuclides are released or concentrated as waste material. In Poland the main source of waste and by-products with enhanced concentration of natural radionuclides is power industry, based on the coal exploitation and combustion. In hard coal mining industry 50 million tons of different waste materials are produced annually. As a result of coal combustion in power plants, the area of fly ash and sludge piles is increased by several km^2 per year (Michalik et al., 1995).

Upper Silesian Coal Basin (USCB) is located in the Southern-West part of Poland. Presently underground coal mines there extracting approximately 90 mln tons of coal per year. The depth of mine workings is from 350 to 1100 m. Upper Silesia is characterized by a very complicated and differentiated geological structure with numerous faults and other tectonic dislocations. Additionally, the area is very affected by mining. Two hydrological regions of the Coal Basin have been distinguished. First region is located in southern and western Silesia with thick strata of sediments covering carboniferous formation. This overlay is built mainly by Miocene clays and silts. The thickness of this rocks is up to 700 m. Such strata make almost impossible migration of water an gases. In the second region Miocene clays do not occur. Carboniferous strata are covered by and Quaternary sediments, slightly compacted. The oldest formations of this area form isolated sediments of Permian or Triassic limestone strongly fissured. There are numerous outcrops of coal seams. These formations enable very easy migration of water and gases.

An additional and unexpected component of the radioactive contamination of the natural environment, and different from that usually associated with this kind of industry, is caused by underground coal exploitation. In many of coal mines, located in Upper Silesian Coal Basin waters with enhanced radium content occur (Lebecka et al., 1986). Sometimes in radium-bearing brines barium ions are also present, in concentrations up to 2 g/l. Such waters were classified as radium-bearing type A waters. On the other hand, in the second kind of waters, which have been called type B, no barium can be found but radium and sulphate ions are present. The presence of barium in waters is the most important factor for the further behaviour of radium isotopes in mine galleries or on the surface. From type A waters radium and barium always co-precipitate as sulphates, when such waters are mixed with any water containing sulphate ions. As a result of the precipitation, barium sulphate deposits with highly enhanced radium concentrations are formed (Lebecka et al., 1986; Michalik et al., 1999). The total activity of radium isotopes in these sediments may sometimes reach 400 kBq/kg. In comparison, average radium content in soil is 25 Bq/kg (UNSCEAR, 1982). In case of radium-bearing type B waters, no precipitation occurs due to the lack of the barium carrier, and that is why the increase of radium content in sediments is much lower than ones originated from type A waters.

APPLIED METHODS AND INSTRUMENTATION

Radioactivity of waters from coal mines is mostly from radium isotopes — ^{226}Ra from the uranium series and ^{228}Ra from the thorium. A method of chemical separation of radium, developed by Goldin (Goldin, 1961), has been modified for liquid scintillation counting (Chałupnik, Lebecka, 1990; Chałupnik, Lebecka, 1993). Radium is co-precipitated with barium in form of sulphates and this precipitate is mixed with liquid gelling scintillator. The prepared samples were measured by a low background liquid scintillation spectrometer (QUANTULUS, PerkinElmer). This counter is equipped in alpha/beta separation and anti-coincidence shield, which enables measurements of ^{226}Ra concentration above 3 Bq/m^3 with simultaneous measurements of ^{228}Ra (LLD = 30 Bq/m^3) and ^{224}Ra (LLD = 50 Bq/m^3). In addition, the procedure enables the simultaneous preparation of ^{210}Pb, which can separated from radium isotopes at the last stage of analysis and also measured in the LS spectrometer with a detection limit of 20 Bq/m^3.

SYSTEM OF MONITORING IN THE VICINITY OF COAL MINES

In the mining industry in Poland, monitoring of the radioactivity of mine waters, precipitates as well as gamma doses was obligatory since 1989.

Monitoring of radioactive contamination caused by effluents and tailings from coal mines must be done since 1986 (Guidelines, 1986). Due to these regulations the following measurements must be done in mine's vicinity:

1. The concentration of ^{226}Ra and ^{228}Ra in effluent from the settlement pond, in river above and below the discharge point, in water supplies nearby discharge point.
2. The concentrations of natural radionuclides in solid samples, dumped onto the piles.

Such complex monitoring system gives an opportunity to obtain a complete picture of the influence of a certain mine on the underground and surface employees as well as on inhabitants of adjoining areas.

Concentration of radium isotopes in original water samples from different coal mines varies in a very wide range — from 0 to 110 kBq/m^3 for ^{226}Ra and from 0 to 70 kBq/m^3 for ^{228}Ra (Report, 2004). In 80's waters with radium concentration above 1.0 kBq/m^3 were found in 43 out of 65 coal mines in Upper Silesian Coal Basin. The highest concentrations of radium were measured in highly mineralised waters from deeper levels in radium-bearing waters type A. The ratio of ^{226}Ra to ^{228}Ra in radium-bearing waters type A was in average of about 2:1. Contrary in radium-bearing waters type B there were more ^{228}Ra than ^{226}Ra, the ratio ^{226}Ra: ^{228}Ra was from 1:2 up to 1:3. Concentration of ^{226}Ra in these waters reached 20 kBq/m^3, while maximum concentration of ^{228}Ra was as high as 32 kBq/m^3. These values justify the statement that Upper Silesian radium-bearing waters belong to the waters with highest known radium concentration. Original waters flowing into mine workings from the rocks from different aquifers are collected in gutters in underground galleries, brought together from different parts of the mine, clarified and pumped out to the surface. Radium concentration in these mixed waters was lower than in original water and did not exceed 25 kBq/m^3 of ^{226}Ra and 14 kBq/m^3 of ^{228}Ra (Report, 2004). Basing on the results of measurements of radium concentration in the original waters inflows into the mine workings and on data on the flow rates of water provided by the mine hydrologists, the total activities of both radioisotopes of radium flowing with water to different parts of mines and to different mines were calculated. This results were compared with values obtained using radium concentrations in mixed waters taken from the drainage system (from gutters) from different parts of mines and corresponding flow rates obtained from the mines. The difference is indicating the activity of radium remaining in underground mine workings due to spontaneous precipitation of radium and barium sulphates or due to applied purification of water. The calculated activity of radium remaining in underground mine workings as deposits in all Upper Silesian coal mines is 580 MBq/day of ^{226}Ra and 530 MBq/day of ^{228}Ra. These values can not be considered as very accurate, since the uncertainty of measurements of flow rates of small inflows is rather large. The approximate amount of ^{226}Ra in water inflows in coal mines in USCB have been calculated as high as 650 MBq/day (i.e. 230 GBq per year) while for ^{228}Ra this value is of about 700 MBq/day or 255 GBq per year. Although radium concentrations in waters type B were usually lower than in waters type A the total inflows to mines where radium-bearing waters type B occur were much higher. As a result the total activity of radium carried with water type B was higher. The highest values for a single mine (with waters type B) were: 78 MBq per day of ^{226}Ra and 145 MBq per day of ^{228}Ra.

In comparison corresponding values of inflows of radium with saline waters in 4 copper mines in Poland were: 31 MBq of ^{226}Ra and 3 MBq of ^{228}Ra per day.

ASSESSMENT OF RADIUM BALANCE IN DISCHARGE WATERS

One of the biggest advantages of the monitoring system in Upper Silesia region is a possibility to make an assessment of radium balance in discharge waters periodically. For instance in years 1987, 1995, 2003 and 2006 such assessments have been prepared. For the calculations of about 300 results of mine waters have been taken as well as 40 analyses of river waters have been done. The term „mine waters" means not only mine waters but also river waters close to the discharge points. Term "river waters" is used for the samples taken at the sampling points of regional monitoring system of water quality. All the data are included in the mine waters database in the Laboratory of Radiometry as the element of the radiation hazard monitoring and environmental monitoring. A comparison of assessment results in chosen periods is shown in table 1.

Table 1. Radium balance assessment in rivers from Upper Silesia region

Catchment area	**Total activity 1995 [MBq/day]**		**Total activity 2003 [MBq/day]**		**Total activity 2006 [MBq/day]**	
	^{226}Ra	**^{228}Ra**	**^{226}Ra**	**^{228}Ra**	**^{226}Ra**	**^{228}Ra**
Inflows into "OLZA" pipeline from 11 mines	*9.8*	*6.7*	*6.8*	*6.8*	*6.5*	*6.5*
Olza River – discharge of „Olza" pipeline	1.6	1.4	2.5	1.8	2.3	1.6
Ruda-Nacyna Rivers (3 mines)	2.2	1.4	0.7	0.7	1.2	1.1
Bierawka River (5 mines)	1.6	1.2	2.7	3.2	1.8	1.4
Bytomka River (5 mines)	0.4	0.5	1.5	3.0	1.2	1.9
Kłodnica River (7 mines)	2.6	2.9	2.6	3.7	2.8	2.9
Rawa River (4 mines)	0.2	0.2	1.2	2.7	0.6	2.1
Black Przemsza River (4 mines)	1.6	3.1	1.3	2.3	1.5	2.8
Gostynka River (3 mines)	133.9	248.1	61.1	147.6	52.4	128.5
Mleczna River (2 mines)	1.3	2.4	1.5	3.3	1.5	3.3

The assessment of the total activity of radium released from coal mines in Upper Silesia with waste water is based on:

- results of determination of radium isotopes in waters released by collieries;
- data on amount of water released by individual mines.

We have also made an estimation of total activity of radium which remains in underground workings in a form of deposit precipitated out of radium-bearing waters either due to unintended mixing of natural waters of different chemical composition or due to the purification of radium-bearing waters. This estimation has been done basing on:

- results of determination of radium isotopes in original waters inflowing to the underground mine workings from the rocks;
- rough estimation of the amounts of water inflows from different sources or parts of mines;
- calculated value of the total activity of radium pumped out from underground mine workings with waste waters by individual mines.

Much more accurate were the results of calculations of the total activities of radium present in water pumped out from individual mines. These values were calculated basing on the radium concentration determined in these waters and on data of amount of water provided by mines. Samples of discharged waters were taken from settling ponds. In outflows from these ponds in 87% mines ^{226}Ra concentration exceeded 0.008 kBq/m^3, in 25% ^{226}Ra concentration was higher than 0.1 kBq/m^3 and in 8 % exceeded 0.7 kBq/m^3 (Decree, 1989). In rivers enhanced concentrations of radium can be observed many kilometres down from the discharge points. This is mainly true for radium-bearing waters type B, because out of these waters radium is not easily precipitated. The highest value of ^{226}Ra concentration was as high as 1.3 kBq/m^3 — it was found in a small stream near it's conjunction with Vistula river.

The significant decrease of daily discharge of radium was observed in the period 1987 -1995. Very first assessment of radium ^{226}Ra in mine effluents has been done in 1987, giving the value of the daily release at level 400 MBq. At that time no results of ^{228}Ra measurements were available. Results of another assessment, prepared in 1995 showed a significant decrease of radium activity in mine waters, released into natural environment, roughly by factor 2. There were two reason of this effect. Firstly, the purification of A type mine waters has been started in several coal mines in catchment areas of Olza river and Upper Vistula.

The another reason was due to economical changes in the mining industry – dewatering of deep mines was more and more expensive and hydro-technical solutions have been applied in numerous mines to reduce water inflows into underground galleries, with special emphasis on brines. In the last decade the decrease of radium activity in discharge waters is mainly due to the purification of B type brines in Piast Colliery (started in 1999) and construction of another treatment station in the year 2006 in Ziemowit Mine. In Piast Mine the implementation of the treatment technology on deeper of the horizons in the mine caused the decrease of radium release from the mine at level 150 MBq/day – 60 MBq/day of ^{226}Ra and 90 MBq/day of ^{228}Ra. Additionally, purification system for second horizon of Piast mine is under designing, and it will solve most of the problems with radium contamination of river waters in Upper Silesia region.

The process of water treatment is based on the dissolutionof barium chloride and immediate co-precipitation of barium and radium ions sulphates. This reaction is possible due to the surplus of sulphate ions in brines (30-50 times more than required for steichiometric reaction). This reaction is shown below:

$BaCl_2 \rightarrow Ba^{2+} + 2Cl^-$

(dissolution of barium chloride)

$Ba^{2+} + Ra^{2+} + 2SO_4^{2-} \rightarrow BaRa(SO_4)_2$

(co-precititation)

$Ba^{2+} + SO_4^{2-} \rightarrow BaSO_4\downarrow$

The solubility of barium sulphate is roughly 0.002 g/l, and presence of sulphate ions in the water makes the dissolution of barium sulphate impossible. Moreover, the solubility of radium sulphate is two orders of magnit ude lower, therefore sediments are stable, and no back leaching is predicted.

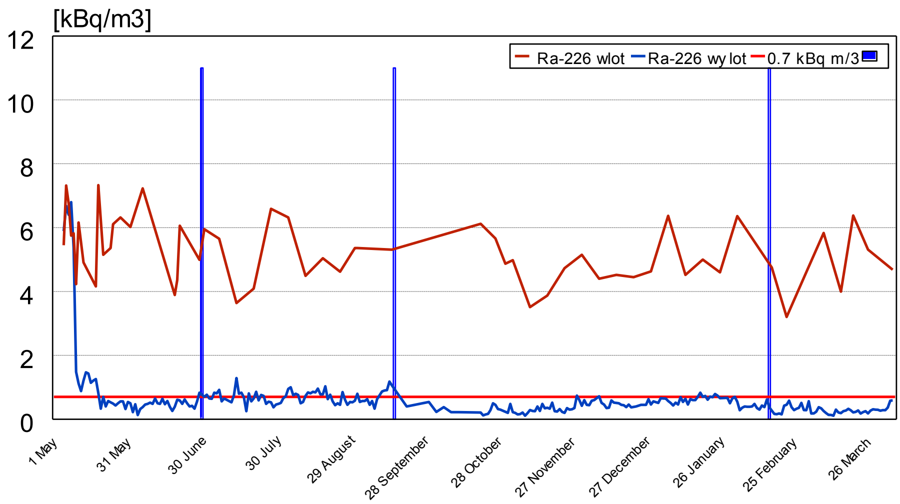

Figure1. Results of water treatment in Piast Mine in years 1999–2000.

In 90's enhanced radium concentrations were mainly observed in the Vistula river, into which most of the radium is discharged with B type waters — approximately 200 MBq of ^{226}Ra and 350 MBq of ^{228}Ra per day. Concentration of ^{226}Ra (0.035 kBq/m^3) was observed in Vistula in Cracow — 70 km downstream from Upper Silesia. Some of these waters were not discharged directly to Vistula river, but to it's tributaries. The influences of singular inflows were very clearly. Moreover, waters from first mine were A type and the difference of radium behaviour (fast precipitation) in comparison with other 3 mines (waters B type) was very evident. Different situation was observed in the vicinity of Oder river, where in coal mines occur mainly waters type A. The amount of radium discharged into this river was much lower - 20 MBq per day of ^{226}Ra and 25 MBg/day of ^{228}Ra. As a result concentrations of radium in Oder were below 0.01 kBq/m^3. At the beginning of new century a treatment of mine waters (type B – without barium) has been started in underground galleries of Piast mine (1999). The total activity of radium isotopes in discharge waters decreased significantly, but still concentrations of radium isotopes in some rivers in Upper Silesia were clearly enhanced as compared with natural levels. In comparison with data from other locations, concentrations of radium isotopes in rivers in USCB are significantly higher. Enhanced concentrations of radium in river waters in Upper Silesia are caused solely by the influence of mine waters.

One of the collieries, releasing radium isotopes into surface settling pond and finally into Vistula River was Ziemowit Mine. In this mine saline brines are very common, and the total inflow into mine galleries exceeds 20 m^3/min. Radium concentration in these brines is as high as 12 kBq/m^3 for ^{226}Ra and 20 kBq/m^3 for ^{228}Ra. Due to the lack of barium in brines (type B waters) from Ziemowit Mine the spontaneous coprecipitation of radium was negligible and only small part of radium remained underground as a result of adsorption on bottom sediments in underground water galleries. Therefore Ziemowit Colliery was the main source of the contamination of small brook, called Potok Golawiecki, a tributary of Vistula River and Vistula itself. In 2003 almost 50% of total activity released from all mines in USCB was dumped into surface waters from Ziemowit. Of about 60 MBq of ^{226}Ra and 100 MBq of ^{228}Ra was released daily, despite the fact, that concentrations of radium isotopes in effluents from Ziemowit Mine weren't very high, reaching 1.3 kBq/m^3 in case of ^{226}Ra and for ^{228}Ra - 2.5 kBq/m^3.

The ecological effect of the purification is the most important issue. At the outflow from the purification system, at the level -650 m the removal efficiency is above 95%. On the surface the efficiency is lower, due to mixing with untreated waters from level -500m, But at the inflow of saline waters into the settling pond, as well as at the outflow from that pond, concentrations of radium isotopes are approximately 80–85% lower than before purification. It corresponds to the decrease of about 40 MBq for ^{226}Ra and 60 MBq for isotope ^{228}Ra of daily release from the Ziemowit Mine. It means, that the total amount of radium, discharged into the Potok Golawiecki and Vistula rivers is much lower, by a value 100 MBq/day. Due to release of radium-bearing mine waters from coal mines there is a contamination of river waters. As a result radium concentration in some small rivers exceeds permissible level for radioactive wastes. Therefore development and application of purification methods is justified and further efforts should be done to reduce the contamination of rivers, particularly of Vistula River and it's tributaries. On the other hand we must take into account, the exploitation of deeper coal seams will cause more problems with inflows of radium-bearing brines into underground workings, even in these mines where no radium problems exist right now. Therefore periodical monitoring of discharge waters is necessary. Another legal problem must be also solved - responsibility for monitoring of waters, released from abandoned mines.

SUMMARY

Coal mining may cause significant pollution of the natural environment due to release of waste waters with enhanced concentrations of natural radionuclides (mainly radium isotopes. This phenomenon is well known not only in Upper Silesian Coal Basin but also in other regions of underground exploitation of coal (Ruhr Basin), oil and gas or other resources.

Due to mitigation measures, undertaken by mines, the significant improvement can be observed during last two decades. In most cases radium concentrations in discharge waters are low and surface waters are not contaminated. Moreover, further decrease of radium release is predicted as a result of underground mine water purification in two collieries.

Monitoring system of natural radionuclides in waste waters and river waters is an important element of the prevention against the pollution of the natural environment. Moreover, it is a source of data for optimization of ground reclamation of previously contaminated areas (mainly settling ponds) of abandoned coal mines.

Of course, further improvement of the system is required as well as solution of important legal problems, related with liquidation of coal mines, harmonization with EU regulations etc.

ACKNOWLEDGEMENTS

Investigations have been made with use of the instrumentation, received within the frame of the project, supported by European Fund of Regional Development, entitled “Development of the research capabilities for revitalisation of the post-industrial areas” Nr: OIG.02.01.00-24-045/08, This project is allocated at the Central Mining Institute within Operational Programme “Innovative Economy”, period 2007-2013, Priority 2. Infrastructure of R+D sphere, Activity 2.1. Development of institutions of high research potential.

INNOWACYJNA GOSPODARKA NARODOWA STRATEGIA SPÓJNOŚCI
GŁÓWNY INSTYTUT GÓRNICTWA
UNIA EUROPEJSKA EUROPEJSKI FUNDUSZ ROZWOJU REGIONALNEGO

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abstract id: **533**

topic: **6**
General hydrogeological problems

6.3
Groundwater contamination — monitoring, risk assessment and restoration

title: # Current problems of mine dewatering in Upper Silesian Coal Basin (Poland)

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keywords: mine water, coal mines, Poland

Since 1990 there have been substantial changes in the organization of Polish coal mining sector. All coal mines in the Lower Silesian Coal Basin, and almost a half of the mines in the Upper Silesian Coal Basin (USCB) have been closed down. This had a major impact on the range of drainage zone due to mining activity. Concentration of mining works (Dubiński ed., 1999), constant increase in the average depth of mine exploitation (Bukowska ed. 2009) and changes in the range and intensity of the drainage enforce the changes in the system of mine water reception and surface disposal. Therefore mining activity impacts both the resources and the perspectives of groundwater and surface water management. This impact for surface water means the need of disposal of huge amounts of water of various quality into, whereas for groundwater means mainly depletion of the amounts and the quality of the resources. On the other hand there is more and more water of various chemistry filling the mine voids. This water may in turn be a source of water hazard for the adjacent mines, as well as for the fresh water resources and even for the land surface. On the other hand, this water may be a chance for a new recoverable energy sources or may be used for industrial needs (Bukowski, 2009).

There is significant vertical and lateral variability in the floodable void volume as well as in the quality of mine water in the mines of USCB (Różkowski ed., 2004; Kropka, 2009; Janson et al., 2008). On the other hand there are substantial changes in the structure of mining enterprises, which enforces the changes in mine water management and the disposal ino surface water. Quite often the changes are also enforced by the changes in EU legislation and the subsequent changes in Polish law.

For 1991, which was the year of the start of major structural changes, the total daily inflow to whole USCB mines was about 843 000 m^3. The sum of the load of chloride and sulfate ions was 8 000 tones (Rogoż et al., 1992). According to classification of mine water by Central Mining Institute (vide: Rogoż, 2004), the majority of this inflow was the fresh water, with total dissolved solids (TDS) less than 1g/dm^3 (36%) and the mere salty water, with TDS from 3 to 70 g/dm^3 (33%). So called "industrial water" (TDS from 1 to 3 g/dm^3) had a lower share (25%) and salty water (TDS >70 g/dm^3) had a minor share (6%).

For 2008 the total daily inflow to whole USCB mines was about 649 000 m^3 (23% decrease). The sum of the load of chloride and sulfate ions in 2008 was 5 000 tones (37% decrease) while average concentration of chlorides and sulfates decreased from 9,7 g/dm^3 in 1991 r. to 7,3 g/dm^3 in 2008 (Augustyniak & Bukowski 2009). The majority of the mine water was merely salty (53%). The water has been pumped by mining systems and disposed into surface water – mainly small rivers and creeks, tributaries of two main Polish rivers: Wisła and Odra.

Until 1990 in Polish coal mines the one- or multi-level stationary pumping system dominated. It was important for the selective pumping and rational management of mine water. There have been four quality groups of mine water (Rogoż 2004), with regard to the possibility of its use as drinking water or for the industrial needs. However, as regards water hazard, stationary system is vulnerable for each unexpected change (increase) in mine water inflow and requires lots of maintenance and operational efforts. The cost of operation of such system is usually a significant part of mine maintenance, of course depending on specific conditions like inflow rate, and dispersion of water collection points.

Therefore, since many mines have been closed down, the pumping systems have been simplified and a shift from stationary pumping system into submersible pump system occurred. Currently there are 9 areas with submersible pump dewatering systems in USCB created on the base of the shafts of 9 coal mines that have been closed down. Submersible pump dewatering system is usually in operation in the mines which major part is already flooded, up to the level that is safe with regard to adjacent mine, taking into consideration the water flow and the resistance of safety measures. As regards the operation costs the submersible pump dewatering system is cheap. However, from a perspective of an adjacent active mine, such system is vulnerable for the water hazard resulting from large volumes of water stored in the mine voids (Bukowski 2009). In such system the water inflowing into the mine are usually contaminated and mixed and the outflow from the system in the first stage is limited due to storage in the mine voids (Banks, Gzyl, 2007). The quality is usually suitable rather for industrial use than for drinking water purposes and the possibility of selective collection of water having different quality is usually very limited.

Lately, there is a trend to close down the mines through their inclusion into adjacent active mines; the mine voids of the part that is closed down are either flooded or included into dewatering system of an active mine. The practice to close down a mine through joining the adjacent mines is driven by the social acceptance. People somehow tend more to accept the closure, when at first two mines are joined together and then a part of one big mine is undergoing closure. However, for technical and economical reasons such practice brings a burden for the active mine, as it has to take over the dewatering of the closed mine, including investment costs, the efforts to protect the deposit and the costs of closure process, as well as refund for any damages caused by a closed mine during its operation.

In the perspective of implementation of EU Water Framework Directive (WFD) and related regulations in Polish water management and environmental laws, the organization of mine dewatering and the related environmental costs may in future be the key factors for the economy of mining industry (Ney ed. 2006). In order to reach the WFD aims it is often necessary to reconsider substantially the mine water management system. Some measures like the controlled redirection of mine water to specific parts of the mines would have to be applied. This is going to enforce huge amounts of costs for investment, maintenance as well as for the safety both down the mines, as well as on the surface. Mine dewatering systems would now need in many cases a new complicated network of pipelines, pumping stations and water galleries.

In general, the situation of current mining industry is going to change soon with the implementation of WFD. It is expected that the mine water management would become more and more important and that the significant increase in investment for surface water protection is going to be enforced.

ACKNOWLEDGEMENTS

This paper have been prepared during the realization of scientific investigation in the frame of the project N R09 0035 06/2009 (2009-2012) funded from the Polish National Centre for Science and Development.

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6.4 Cost-effective measures to control and contain groundwater contamination

IAH 2010
Krakow

abstract id: **108**

topic: **6**
General hydrogeological problems

6.4
Cost-effective measures to control and contain groundwater contamination

title: **Cost-effective remediation of high fluoride rich groundwater in parts of India**

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keywords: fluoride, endemic fluorosis, tooth decay, defluorination, sodicity

Fluoride problems are wide spread in India especially in nine States covering almost the entire country. In order to assess the water quality and the related health problems due to high fluoride content, water samples from nine States across India have been collected and analyzed. Analyses from surface, subsurface and thermal water samples had fluoride concentration that range from < 0.2 to 13.2 ppm. The probable source of high fluoride relates to the water-rock interaction within the sedimentary basins. During rock weathering and subsequent circulation of pore water through the soil and rock matrix, fluorine is leached out, mainly from the mineral fluorite (CaF_2) and calcium difluoride, and dissolved in the ground water. Human health affects of high fluoride content in water are manifested in the form of 'endemic fluorosis' causing tooth mottling and inducing the prevalence of osteoporosis and collapsed vertebrae. Fluorosis has no known treatment other than early detection and limiting the amount of fluoride ingested. The concentration of fluoride below 1.5 ppm according to World Health Organization (WHO) is helpful in the prevention of tooth decay, and such level of fluoride also assists in the development of perfect bone structure in human and animals but long term ingestion of drinking water having fluoride concentration above 1.5 ppm leads to dental and skeletal fluorosis as well as non skeletal manifestations. High fluoride consumption leads to the fluorosis of the bones which is generally found in Asian region but it is particularly acute in India. Reducing the high fluorine content of groundwater is done by dilution or by defluorination process. Dilution with the surface water is one very simple technique but not very practical in water scarce India. In-situ treatment is now receiving more attention. Alkaline soils can be remedied through the application of gypsum, pyrite and sulfuric acid. Gypsum treatment is the classical method of alleviating the soil alkalinity but makes the water harder. However, this may be an advantage of getting a higher intake of Ca^{2+} which can mitigate the effect of F^-. Encouraging results have been obtained for lowering fluoride content in water using turmeric and planting the popular trees (*populus deltoids)* trees in affected to alleviate sodicity in soils. But the addition of Ca^{2+} ions to the fluoride rich groundwater causes an appreciable decrease in fluoride concentration which appears to be the potential cost effective solution to high fluoride problem in an otherwise water scarce India.

abstract id: **161**

topic: **6**
General hydrogeological problems

6.4
Cost-effective measures to control and contain groundwater contamination

title: # Fertilizer standards vs fertilizer taxes to control groundwater nitrate pollution from agriculture

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keywords: groundwater nitrate pollution, hydro-economic modeling, nonpoint source pollution control

Economic theory mentions different control mechanisms of environmental externalities. Policy mechanisms used for agricultural non-point pollution control are direct regulations (emission standards), economic instruments (as pricing schemes or as incentives via subsidies) applied either directly to the emissions or based on some emission proxies (like polluting inputs or certain agricultural practices), and tradable emission or pollution permits.

In this paper we compare the cost-effectiveness of direct regulation (fertilizer application standards) and fertilizer taxes as policies to control groundwater nitrate pollution. A hydro-economic model is used to determine the most cost-efficient distribution of fertilizer standards constrained by the groundwater quality requirements at various control sites. These results are compared with farmer's response to an increase in fertilizer price. The modelling framework relates the fertilizer loads with the nitrate concentration at the control sites, i.e., the ambient standards (Peña-Haro et al., 2009). Agronomic simulations are used to obtain the nitrate leached, while numerical groundwater flow and solute transport simulation models are applied to develop unit source solutions assembled into a pollutant concentration response matrix. The benefits in agriculture were determined through crop prices and crop production functions. The methodology was applied to the El Salobral-Los Llanos aquifer in Spain, where nitrate concentrations in some water supply wells has reached values of 54.1 mg/l (Moratalla et al., 2009). This research aims to contribute to the ongoing policy process in the Europe Union (the Water Framework Directive) providing a tool for analyzing the cost of measures for reducing nitrogen loadings and assessing their effectiveness for maintaining groundwater nitrate concentration within the target levels.

1. FERTILIZER STANDARDS

The fertilizer standards to control GW nitrate pollution from agriculture are analyzed by means of different scenarios:

Scenario 1: Business-as-usual scenario, where nitrate concentrations are simulated considering the fertilizer application rates of 2005.

Scenario 2: Fertilizer application was optimized in order to maximize the total net benefits, without groundwater quality restrictions

Scenario 3: Maximum nitrate fertilizer application to control nitrate pollution (reference values) as defined by Castilla La Mancha regional government

Scenario 4: The optimal spatial distribution of fertilizer application over 50 years of planning horizon is determined by using the hydro-economic model (Peña-Haro et al., 2009). A recovery time in 2015 is defined based on the environmental objectives of the EU WFD.

Table 1. Results for the different scenarios.

	Average fertilizer application (kg/ha)	Is max nitrate concentration at control sites below WFD standards?	Total net benefits (M€/year)
Scenario 1. Business as usual	240.4	NO	96.6
Scenario 2. Maximum benefits	218.7	NO	96.7
Scenario 3. Reference values	157.8	NO	80.9
Scenario 4. Optimal fertilizer 2015	201.1	YES (after 2015)	95.4

2. FERTILIZER TAXES

Several optimizations were performed to obtain the fertilizer tax that would reduce its use to the WFD standards. The fertilizer price is increased until nitrate concentration in groundwater was below 50 mg/l. It seems that farmers are not sensitive to fertilizer tax until it reaches a very high level.

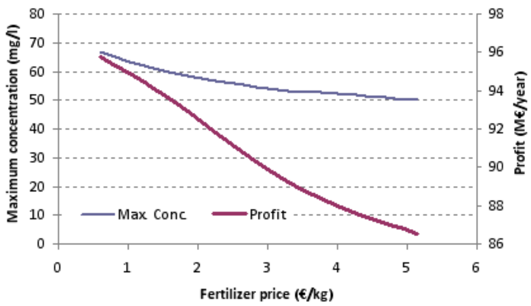

Figure 1. Maximum nitrate concentration forh different fertilizer price and total benefits.

CONCLUSIONS

The results obtained for the BAU or baseline scenario (scenario 1) show that following the current fertilizer application rates does not guarantee to comply with the "good groundwater chemical status" required by the WFD, since the standard of 50 mg/l of nitrates would be overpassed.). The fertilizer application that generates the maximum net benefits (scenario 2) are lower than those obtained by calibration of the nitrate transport model in order to reproduce the observed nitrate concentrations in scenario 1 (which are also a bit higher than those reported in the official surveys). The reference values requested by the authorities because of the definition as "nitrate vulnerable zone" maintain groundwater nitrate concentrations stable; however, the maximum nitrate concentrations are still over 50 mg/l, since the initial values (year 2005 concentrations) were already above the target value. The total net benefits of this scenario is lower than for the scenario 4 (optimal fertilizer application constrained by the quality standards) because the reduction was applied to all crops without taking into consideration the influence of the spatial distribution of the crops upon nitrate concentrations in the control sites. The scenario 4 showed the fertilizer application rates that will yield the maximum total net benefit while complying with the quality standards for two different horizons: year 2015 and year 2021. Therefore, these values can be interpreted as the "fertilizer standards" that should be imposed in order to meet the standards at the least cost. Even though the policy of fertilizer standards has appeared as more cost-efficient, in real applications it can be difficult to implement and to control. hen applying fertilizer taxes the fertilizer price has to be increased up to 5.15 €/kg to obtain nitrate concentrations below 50 mg/l in all control sites (Fig. 1). Therefore a tax of 858 % would be required, thus leading to a lower profit of 86.6 M€/year. The benefits obtained by increasing the fertilizer price are 8.9 M€/year, lower than those obtained from the fertilizer standards corresponding to scenario 4. Fertilizer taxes are a promising policy option, easier to apply and control. Some countries are now discussing its practical implementation.

ACKNOWLEDGMENTS

The study was supported by the European Community 7th FP GENESIS (226536) on groundwater systems.

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IAH 2010
Krakow

abstract id: **192**

topic: **6**
General hydrogeological problems

6.4
Cost-effective measures to control and contain groundwater contamination

title: # The natural attenuation concept, a cost-effective measure to control and contain groundwater contamination

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keywords: landfills, hydrogeochemistry, natural attenuation concept, groundwater contamination, geomicrobiology

ABSTRACT

The “NA-Screening” is a tool to distinguish between those contaminated sites, were Natural Attenuation (NA) is sufficiently effective to contain and minimize the groundwater contamination, and those sites, were it can’t be used because of neighboring sensitive environment or insufficient NA effectiveness. The “NA-Screening” has a hierarchical structure with three steps. During the first step (A) site-specific data is acquired and collected and the surrounding is checked for sensitive protective goods. During the second step (B), which will be discussed a bit more detailed in this paper, the effectiveness of the retention and degradation processes (NA) is investigated and the possible endangerment of protective goods is checked. Only when the first two steps have a positive result the third step (C), the monitored natural attenuation (MNA) can commence. Even as these investigative tools are cheap, the method is scientifically sound and a cost effective-measure to control and contain groundwater contamination.

INSTANCE OF THE RESEARCH

In Germany more than 300.000 contaminated sites (LABO 2009) are registered. Most of them are to some extend investigated but only the most prominent polluted sites (23.500) were until now remediated with “technical” methods. Many are left as they are, such already indirectly using NA. To provide a scientific base for NA the Federal Ministry for Education and Research (BMBF) funding priority KORA (Acronym for the German — Kontrollierter Rückhalt und Abbau) (Michels et al. 2005) was brought into action. During this research program, natural attenuation processes in groundwater affected by of contaminated sites in Germany were identified, characterized and quantified. The aim of this research was to explore the extent to which natural attenuation (NA) can be used for remedial purposes of groundwater contamination and to generalize the results for a guideline, the “NA-Screening”. As active remediation measures are for most of the groundwater contaminations too expensive, this concept provides a basis for planning, granting permission by public authorities and remediation measures for acceptable costs for the public. It has a hierarchical structure and was successfully evaluated in Germany under the guidance of the German environmental agency (UBA).

THE THREE STEPS OF THE “NA-SCREENING” CONCEPT

During **step A** an extended investigation about and around the site is conducted, to sample information about the size, the content, the age and the geological siting. Secondly the emissions into the groundwater should be thoroughly explored using the “groundwater screening” (Kühn 2009) and the distribution of the pollution downstream should be known. Furthermore data about the hydrogeological situation, the use of the surrounding area and the sensitive protective goods (e.g. potable water production wells, deep founded constructions) in the area should be collected. The aim of part A is to install a data basis on that could be decided whether the damage of the groundwater could be improved, as well as a damage or danger for sensitive protective goods downstream of the site has to be excluded.

Step B has the aim to prove, that NA is effective enough to contain the contamination in the already damaged groundwater area. The polluted groundwater should not progress; NA should achieve a steady state or reduction of the emission. To prove this effectiveness three lines of evidence were developed.

In **part B1** (Kühn et al. 2009) the reduction of the emission along a centre-line is measured geochemically and the results are summarized by the main ions, the trace elements, DOC and the AOX (tab.1). These parameters are compared to the regional baseline values and the evidence of retention is positive, when the baseline values are approached within an appropriate distance. Table 1 illustrates the variation of the contamination over time (for example from 1983 to 2003) and decrease in space, from very high values (violet) close to the source to near baseline values (green) in 250 m distance.

The appropriate distance depends on multiple factors as groundwater velocity and the distance to the next sensitive protective good. As the depletion should not only be achieved by dilution, it is necessary to use a method to prove that NA is as well achieved by mineralisation and metabolisation.

Table 1. Reduction of emissions as global prove for NA effectiveness.

Geochemical parameter	Year of sampling	Monitoring well downstream of the contaminated site			
		50 m	100 m	150 m	250 m
Σ main ion	1983	violet			
	2003	violet	red	yellow	green
Σ trace elements	1983	violet			
	2003	red	yellow	yellow	green
DOC	1983	yellow			
	2003	red	yellow	green	green
AOX	1983	yellow			
	2003	red	yellow	yellow	yellow

Color	Colour	Collor	Colour
Very high	high	increased	baseline

The Theta-method ($\Theta t/\Theta$) (Holzbecher et al., 2010) is used in **part B2** as a second check for effects of NA in the groundwater emissions. This method is based on the comparison of concentrations for a tracer and the attenuation substance.

Examinations of the mathematical analytical solutions show that the ratio of normalised concentrations $\theta t/\theta$ is expected to increase in space and time in the presence of NA, but to remain constant in case of dilution and diffusion only or of no degradation. Figure 1 is a screenshot of the Theta-software developed for the "NA-Screening". This facilitates the calculation of the tracer versus the attenuation component and the results are displayed at the window at the right bottom. The increase of the ratio is obvious until the attenuation component has been depleted and the ratio near zero.

In **Part B 3** the contamination reduction by microbiological organisms is demonstrated, as NA effects should not solely attributable to physico-chemical factors, but also to microorganisms.

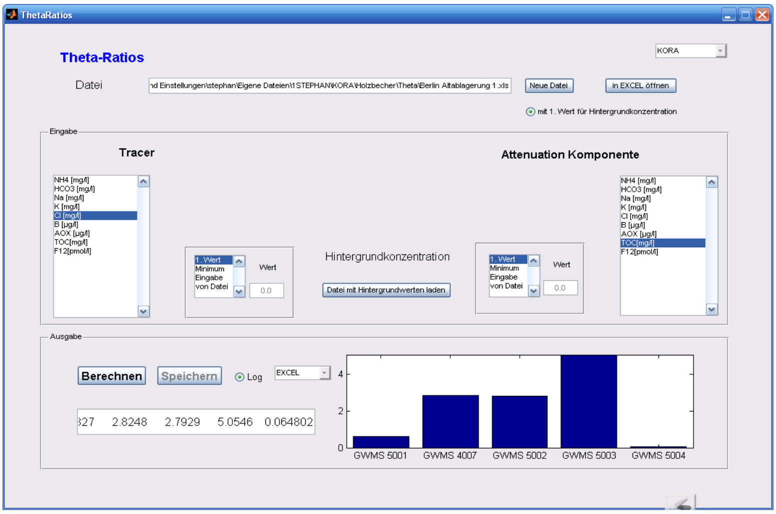

Figure 1. Screen-Shot of the Theta-Value software-program.

The contribution by groundwater microfauna can be checked with the PCR-DGGE method (Kilb 1999, Struppe et al. 2006, Struppe et al. 2010) or more reliable with the newly developed DNA-microarrays (Kühn et al. 2009 and Charlé et al. this issue). This method can be used to differentiate bacteria and archea as well as their activity (Fig. 2). Only when all three methods are positive NA can be legally, based on scientific evidence, used for the reduction of the groundwater contamination.

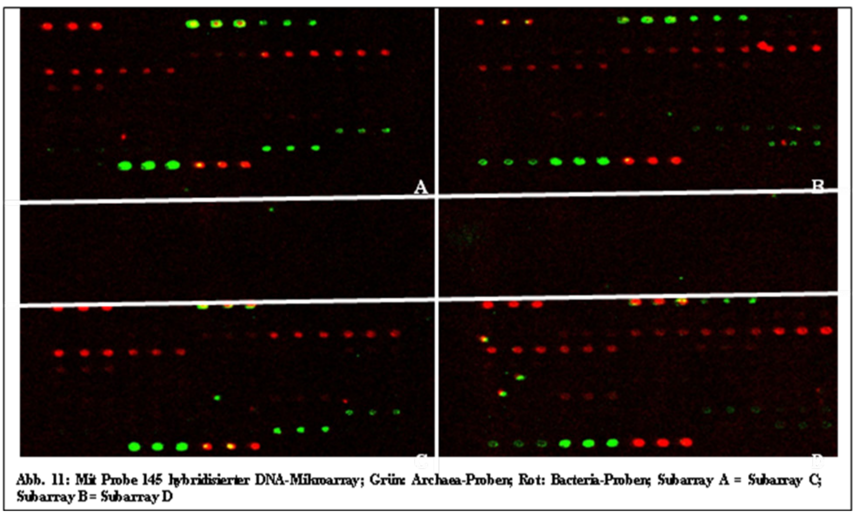

Figure 2. Photo of a DNA-arrays with Archae (green) and Bacteria (red). Their colour intensity equals their activity.

To control this effectively **step C** proposes a monitored natural attention concept (MNA). Based on the results of the investigation indicator-parameters and sampling sites are derived and together with the environmental authorities a target should be defined over which time and to what extend the groundwater quality has to be improved. The MNA is then used to control the reduction of the pollution for as many years as necessary until the agreed target is reached. This NA-concept provides a cost-effective scientifically proved measure to control and contain groundwater contamination.

PREREQUISITES FOR THE "NA-SCREENING"

To use the "NA-Screening" effectively there are some prerequisite, some of these are useful but some are "conditio sine qua non". To the last category belong the thorough investigation of the groundwater downstream of the pollution. This means sufficient and rightly sited monitoring wells along flowlines, either via direct push or conventionally drilled and a complete analysis of the groundwater samples, using preferably the "groundwater screening". Other sine qua non conditions are that the contaminated site should not be too small and too young, as the NA processes need substance and time to develop.

ACKNOWLEDGEMENTS

The authors wish to thank the BMBF for funding KORA TV 4.1 (FKZ.:0330501) and the PRONA-BAC-project (FKZ: 033 R040 A)

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abstract id: **426**

topic: **6**
General hydrogeological problems

6.4
Cost-effective measures to control and contain groundwater contamination

title: **Low-cost permeable barriers for acid rock drainage prevention and control**

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keywords: sulfidic extractive wastes, leachate, contaminant loads, protective barriers, waste materials reuse

Sulfidic waste rock or tailings from coal and metalliferrous ore mining and enrichment processes, which constitutes the largest waste stream in the world, is an environmentally problematic material due to acid generation potential resulting from sulfide oxidation and formation of sulfate- and metal-rich leachate called Acid Rock Drainage (ARD). In accordance with Directive 2000/60/EC and legislation of other countries with developed extractive industries, the operator of a waste facility is obliged to prevent or minimize leachate generation and groundwater from being contaminated. The basis of preventive measures might be either minimization of the oxygen transport to sulfide minerals, or treating contaminated water and leachate to the appropriate standard, or applying both these measures to efficiently mitigate groundwater deterioration. The biggest problem with environmentally safe management of ARD generating waste rock is the scale of extractive waste facilities, which involves the need of large amounts of a material to be applied as oxygen transport barrier (in covers or intrinsic layers) or as a material preventing contaminant transport (e.g. metal sorbent). Such materials, besides efficiency in long-term applications, are thus to be abundant, easily available and cost-effective. These requirements may be fulfilled, if appropriate waste materials are used in an effective and environmentally safe way.

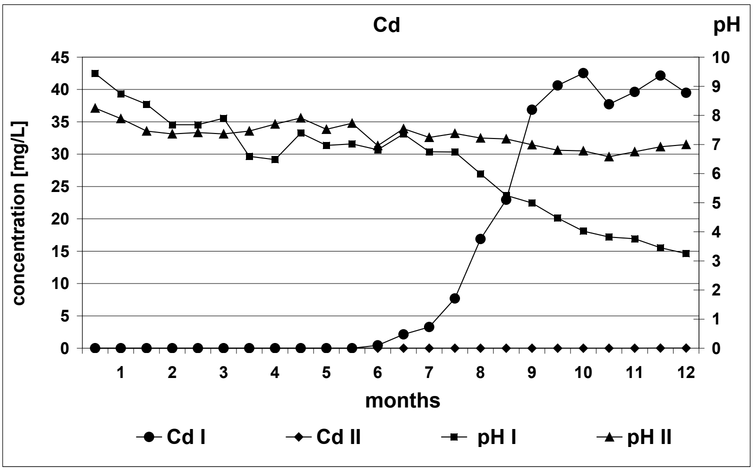
Considering the availability, abundance and required properties, two kinds of waste materials were selected as potentially applicable in barriers: (A) dense mixture of low-quality water with fly ash from coal combustion (FA); (B) sewage sludge (SS) from municipal sewage treatment facilities (MSTF). Both studied materials originated from the Upper Silesia coal basin (USCB) in Poland, the coalfields of the highest hard coal output and the highest concentration of sulfidic wastes in the EU. A series of laboratory batch experiments confirmed high penetration resistance of solidified FA dense mixtures (I) ranging from 1100 to 1990 kPa, high hydraulic conductivity and low permeability to air; SS showed high binding capacity for metals comparable to natural sorbents such as peat, which for Me–SO_4 systems ranged from 24600 mg/kg (Ni) through 49 200 mg/kg (Cr), up to 181 450 mg/kg (Pb).

Further long-term bench experiments in columns φ 0.30 m and H =1.5 m simulated high-metal ARD (Tab. 1) migration through a layer of sulfidic waste with protective layers of FA dense mixtures and stabilized SS in different configurations. A composition of input solution reflected environmentally relevant contents of metals reported in different ARD, while infiltration rate was computed for local weather conditions with use of WHI UnSat Suite Plus v. 2.2.0.3 program.

Table 1. Mean concentrations of ions [mg/L] in the simulated ARD applied to columns.

pH	Fe	Mn	Cd	Cr(III)	Cu	Ni	Pb	Zn	SO_4	NO_3
1.5	680	242	48.3	179	221	241	1.094	230	18276	620

Comparative results of simulated ARD application in 1-year's infiltration cycle onto sulfidic coal mining waste layer 1.0 m high without (I) and with protective barriers (II) showed high efficiency of trace metal binding onto barriers (example — Fig. 1).



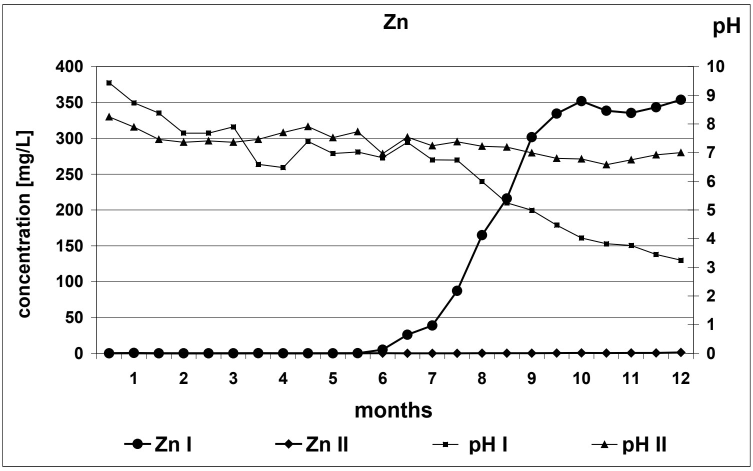


Figure 1. Concentrations of metals (Cd and Zn) in leachate from ARD infiltration through coal mining waste layer 1 m thick: (I) reference column without protective barriers; (II) column with protective barriers.

Besides trace metals, a significant reduction of sulfate (for about 30%) and Fe loads (for almost 100%) released in leachate from the column with barriers (II) compared to the reference column (I) due to attenuation of pyrite oxidation in coal mining waste was observed.

The studies confirmed high efficiency of studied abundant and inexpensive waste materials application in permeable barriers for groundwater protection against contaminant release from sulfidic waste, in particular against deterioration of groundwater resources by Acid Rock Drainage.

ACKNOWLEDGEMENTS

This study was carried out within an R&D Project No R0902802 funded by the Ministry of Science and Higher Education of Poland.

abstract id: **461**

topic: **6**
General hydrogeological problems

6.4
Cost-effective measures to control and contain groundwater contamination

title: **Groundwater extraction control for protecting the water works in Lobodno (SW Poland) against contamination with nitrates**

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keywords: hydraulic control, groundwater intake protection, extraction regime, nitrates, resources management

INTRODUCTION

The water works in Lobodno (5 deep wells with the total admissible discharge rate of 820 m^3/h) is extracting potable water for the population of the city of Czestochowa and neighbouring communes (S-W Poland) from the fracture-karst upper Jurassic Major Groundwater Basin (MGWB 326). The yield of the MGWB 326 is sufficient to meet all needs, so no licensing conflicts arise on amounts of water available for safe exploitation. However, the recharge areas of deeper and shallow phreatic aquifers are vulnerable to contamination from industrial emissions, point sources (landfills and farms) and the contaminated Warta River. Stationary monitoring of groundwater quality in 1996-1997 showed a constant increase of nitrate ions (NO_3^-) concentrations in the recharge areas of this water works, and their abrupt increase in the extracted groundwater from 28.8 to 38.8 mg NO_3/dm^3 (well no. 3), and from 18.5 to 38.9 mg NO_3/dm^3 (well no. 8). Already in 2001, these concentrations exceeded the permissible value for potable water of 50 mg NO_3/dm^3 (Dz.U.2007.61.417), and in 2008 the mean annual concentrations in the extracted water were as high as 61.42 and 60.7 mg NO_3/dm^3, respectively. Keeping up this trend, which is predicted by mathematical modeling, may lead in the worst case to exclusion of wells from operation and/or the need for applying groundwater treatment, as it is already the case in another water works operated by the Water Supply and Sewerage Company (PWiK) in Czestochowa (Malina - submitted).

The main goal of this research was to reverse, or at least stop this trend in order to protect the water works in Lobodno using a specifically designed water extraction regime. Such a hydraulic control of groundwater flow conditions should not only protect the wells against contamination with NO_3^- but reduce the contamination loads in the aquifer as well.

HYDROGEOLOGY

Groundwater in this area is connected to rock formations varying in age that compose the Quaternary, Jurassic, Cretaceous and Triassic multi-aquifer formations (Malina *et al*. 2007). The Warta River, which cuts outcrops of the upper Jurassic formations, often changes its character from draining to infiltrating. The Jurassic multi-aquifer formation consists of upper, middle and lower Jurassic water-bearing horizons. The upper Jurassic horizon is built of fissured and karst limestone, with preferential groundwater flow paths and good recharge conditions. It is drained by watercourses, with a part of underground runoff crossing Cretaceous outcrops and recharging this formation. Under natural conditions, groundwater quality is high, fully corresponding to drinking water standards, thus the upper Jurassic horizon (MGWB 326) is the main source of potable water. However, considering the zones of hydraulic contacts with surface and watercourses, the water is particularly vulnerable to contamination. The middle Jurassic horizon includes three formations of sandy and sandy-gravel deposits. Silt and clayey rocks isolate the aquifers, and groundwater table is confined except the outcrops. The recharge is via outcrops and groundwater flow is in the northeast direction. The lower Jurassic horizon is built of a number of sandy-sandstone strata, separated by silt-shale deposits. Groundwater table outside outcrops is confined, and preferable hydrogeological parameters are in the bottom passages of the horizon.

The MGWB 326 is symbolically divided (with the Warta River as a natural border) into two subbasins: MGWB 326 (S) - with the area of 170 km^2 and documented and approved disposable water resources of 4,220 m^3/h (additional 30,000 m^3/d documented for a perspective water intake in Julianka) (Malina *et al*. 2007), and MGWB 326 (N) - with the area of 570 km^2 and documented and approved disposable water resources of 8,900 m^3/h. In the studied area two groundwater bodies (GWB) no. 94 and 95 were distinguished. The former encompasses lower and middle, while the latter – upper Jurassic groundwater horizons (Paczyński, Sadurski, 2007).

METHODS

The operation strategy of the water works in Lobodno was developed in such a way that, by creating appropriate hydrogeological conditions (required groundwater flow directions forced by controlled well discharge rates), water resources could be protected, as well as NO_3^- concentrations in water delivered to clients kept below the permissible level (Mizera, 2010).

The continuous groundwater exploitation with high rates was assumed to decrease the NO_3^- concentrations in the extracted water. To find an effective extraction regime for the water works, 15 operation variants with diverse overall and specific wells discharge rates were designed based on specific water demands. The admissible discharge rates of wells no. 3 and 8 were set within the range of 200-245 m^3/h, with their suggested periodic reduction to ca. 100 m^3/h, due to current low water demands. Moreover, other factors were taken into account, such as: current admissible discharge rates of wells, NO_3^- concentrations in the extracted water and water delivered to clients, NO_3^- loads leached out the aquifer, operation time and technical conditions of wells, location of contamination sources within the recharge areas.

Based on existing geological and hydrogeological documentation, numerical groundwater and contaminant transport models for MGWB 326N were developed using the Visual Modflow package. Calculations of groundwater transport were done and verified with the Modflow software (Malina *et al.,* 2007). Numerical modeling using MT3D software allowed for calculating NO_3^- concentrations in MGWB 326N, in the vicinity of the water works in Lobodno at diverse water extraction regimes. The NO_3^- transport model was validated for selected solutions of groundwater flow and prognoses of NO_3^- migration. The validated model was then used for prognoses of NO_3^- distributions at diverse groundwater extraction regimes.

The NO_3^- migration in the unsaturated zone was evaluated based on infiltration rates and average values of soil volumetric humidity. The lateral migration time was obtained from analytical calculations and modeling, while loads of NO_3^- discharged to groundwater – based on empirical studies. The same NO_3^- loads discharged to groundwater and constant quantities of water extracted by the water works (which reflects current water demands) were used in all variants. The NO_3^- loads leached out the aquifer were calculated as a sum of products of a NO_3^- concentration in a block with a well and a discharge rate of a well. The average NO_3^- concentration in the extracted water was calculated as a quotient of the total NO_3^- load leached out and the total discharge of the water works.

Water for analysis (ca. 1 dm^3) was sampled from the wells and piezometers using the Kemmerer sampler that allows to sample water at discrete depths within a body of water, and transported to the laboratory according to the standards (PN-88/C-04632/04, ISO 5667/3). Concentrations of NO_3^- in groundwater as nitrate nitrogen (NNO_3) were analyzed in the licensed laboratory of PWiK using the spectrofotometric method (UV-VIS CINTRA) according to the Polish standards (PN-82/C-04576/08).

RESULTS AND DISCUSSION

The results show that the permissible NO_3^- concentration for potable water (50 mg NO_3/dm^3) was not exceeded in any of studied variants. The water works operation assured the lowest possible concentrations in the delivered water, or the highest loads of NO_3^- leached out the aquifer, keeping concentrations in the extracted water below the permissible value. The periodic reduction of the admissible discharge rates of wells no. 3 and 8 to ca. 100 m^3/h allowed for their more frequent operation (significantly limited due to reduced water extraction resulting from low water demands) and, consequently for more flexible operations of the water works.

An increase of NO_3^- concentrations (from 22.11 to 48.29 mg/dm^3) was observed in variants 1-8, along with an increase of leached loads from the aquifer (from 1,677 to 70,564 tons NO_3/a), with increasing total discharge rates of the water works from 100 to 820 m^3/h, respectively. The lowest NO_3^- concentrations (22.11-40.50 mg/dm^3) in the extracted water at discharge rates of 100-500 m^3/h, were in variants (1-5), in which wells no. 3 and 8 were not operated. On the other hand, operation of wells no. 3 and 8 led to increased loads of NO_3^- leached out the aquifer (variants 6-8). The highest NO_3^- concentrations (43.94-49.30 mg/dm^3) in the extracted water were in variants 6-12, in which wells no. 3 and 8 were in operation. The highest loads (70,564 tons NO_3/a) were leached out the aquifer in variant 8, in which wells no 3 and 8 operated with the admissible discharge rates.

Under actual conditions of low water demands, variants 13 and 14 are the most effective operation mode for the waterworks in Lobodno as they allow for fulfilling the requirements regarding permissible concentrations of NO_3^- in water provided to clients (40.29 and 40.98 mg/dm^3, respectively). They also lead to the reduction of NO_3^- accumulation in the adjacent zones of wells no. 3 (variant 13) and 8 (variant 14) screens.

The selection of efficient extraction variants has to be, however, determined not only by actual water demands, but also by operation conditions of each well and their effects on groundwater dynamics and the chemical status. From this point of view, continuous operation of well no. 7 may assure water supply with NO_3^- concentration at a safe level, i.e. far below the standards. On the other hand, continuous operations of wells no. 3 and/or 8 at the admissible discharge rates may lead to significant reduction of NO_3^- contamination, and consequently to groundwater remediation due to high NO_3^- loads leached out the aquifer.

CONCLUSIONS

- The permissible NO_3^- concentration for potable water (50 mg/dm^3) was not exceeded in any of studied variants.
- Under actual conditions of low water demands, variants 13 and 14 are the most effective operation modes of the water works in Lobodno to protect the extracted water against contamination. These operation modes, along with the substantial reduction of current NO_3^- loads discharged from the surface to the aquifer, should result in a gradual decrease of NO_3^- concentrations in the groundwater.
- Effective control of the extraction regime of each well should allow for reduction of groundwater contamination with NO_3^- within the recharge areas, and consequently for delaying or eliminating the need for treatment (a NO_3^- removal installation) to be applied at the water works in Lobodno.

- The most attractive extraction regime of the water works in Lobodno should lead to fulfilling demands in terms of water quality and quantity on one hand, and to enhanced removal of NO_3^- loads from the aquifer (i.e. to fasten aquifer remediation), on the other. In such a case more frequent operation of wells no. 3 and 8 with higher discharge rates should be favored.

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6.5 Risk-based groundwater management (brownfields, industrial/postindustrial and urban areas)

abstract id: **456**

topic: **6**
General hydrogeological problems

6.5
Risk-based groundwater management (brownfields, industrial/ postindustrial and urban areas)

title: **The best location for a public supply well – an analysis using a GIS**

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keywords: public water supply, aquifer, GIS

INTRODUCTION

In order to determine a site within the regional aquifer for a location of a new water supply well, the detailed study of severe pumping and recharge conditions has to be performed. The geological and hydrogeological parameters, such as: the depth, thickness, permeability and conductivity of the aquifer; as well as the economic factors, such as: the distance from the water supply network, electric lines, roads; and the environmental features, such as: protected areas or sources of water pollution, have to be taken into account. To maintain such an amount of spatial and descriptive data, the computer procedure basing on the geographical information system (GIS) is the best approach. The results of the study searching for the best location of the public water supply for Jaworzno town are presented in this paper.

Jaworzno (population 97 000; area 152 square km) is located in the southern Poland, near Katowice. The distinctive for this town is that 32 % of its area is covered by forests and 50% are the rural areas, but 10% are dense urban and 5% industrial areas.

Three major aquifers identified beneath Jaworzno are: the Quaternary sands and gravels which fill the Przemsza river valley, the Triassic karstic-fissured dolomites and limestones, and the Carboniferous sandstones. The long-term mining of coal, zinc and lead ores and sand, along with the other industries connected with mining, caused many changes in the natural environment in Jaworzno, among them the development of the extensive cones of depression and groundwater pollution. Whilst the Carboniferous aquifer is influenced by a coal mine drainage and the Quaternary aquifer is shallow and vulnerable to water pollution, the main source of drinking water is the Triassic aquifer. The resources of three wells (Dobra, Galmany and Bielany) abstracting water from the Triassic aquifer are not sufficient for the water supply of the town and the Jaworzno Waterworks must purchase water for the public supply. For this reason they decided to enquire a study searching for a new source of drinking water.

Figure 1. A map of Jaworzno town.

METHODS

The study was conducted in the Upper Silesian Branch of the Polish Geological Institute. It was divided into 5 steps:

- 1 - the analysis groundwater resources basing on the published and archival materials,

- 2 - the field investigations (measurements of depth of water table and water sampling for the chemical and bacteriological analyses),
- 3 - the verification and the updating of geological and hydrogeological data,
- 4 - the construction of a GIS (using Geomedia software), which consists of 26 data layers,
- 5 - the series of a computer analyses. The following factors were analysed: land surface, climate, surface waters, the land use, sources of groundwater pollution, geology, hydrogeology (recharge, discharge, water level, wells), the water-supply network, quality of groundwaters, aquifer vulnerability as well as the mining of coal, zinc and lead ores and sand, industrial and urban activities.

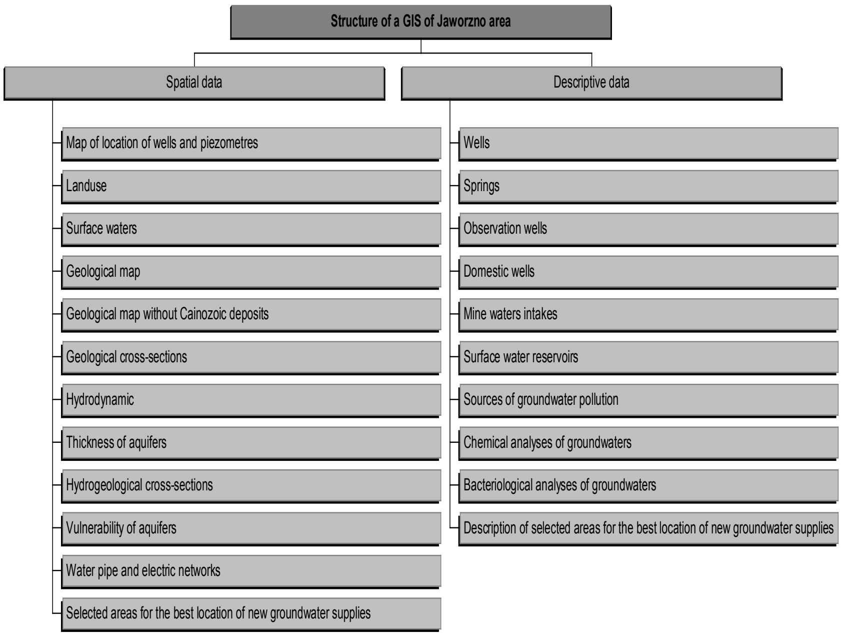

Figure 2. A structure of a GIS of Jaworzno area designed for this study.

The series of the topological operations such as: overlying, buffering and extraction of these data layers were performed. The figure 1 presents the structure of a GIS with the descriptive data and spatial features.

Initially, all the collected data were entered into this system, and 26 data layers have been created. The data layer which was analyzed firstly was the "land use". The first topological operation was the extraction of the forests, dense urban and industrial areas. Then the surface water reservoirs, as well as wetlands were extracted (Fig. 3). Following that the resulting map was overlain by the map of the Triassic aquifer in order to leave only the areas with the Triassic aquifer of the thickness more than 40 m (Fig. 4). Then the intersection operation removed the areas under groundwater drainage including mine drainage (Fig 5). The operation of negative buffering around the roads and rivers removed areas located too close to them. The operation of positive buffering around water supply network and electric line network left the areas located close enough to this network due to the economical reason (Fig. 6).

Figure 3. Areas in the town (blue) after the extraction of forests, urban and industrial areas and surface water reservoirs.

Figure 4. Areas in the town (blue) after the intersection of the areas in the figure 3 with the Triassic aquifer of a thickness more than 40 m.

Figure 5. Areas in the town (blue) after the extraction from the areas in the figure 4 of the areas of groundwater drainage by mining and the operating wells.

RESULTS

The analysis resulted in the selection of the sites with the best hydrogeological conditions. A final map (Fig. 6) contains 8 small areas suitable for the location of public water supply wells in Jaworzno. Within each of them the location of water abstraction well may be considered with the depth of 20-80 m and the discharge of 70-120 m^3/h. All determined areas are located within the Middle Triassic aquifer. Before the drilling of a public supply well, the further detailed study have to be performed in order to determine the depth and the potential groundwater resources of the Triassic aquifer within each of the selected site.

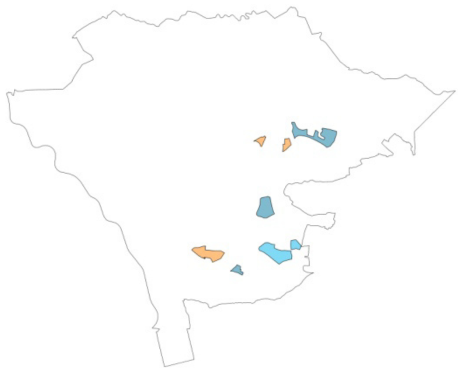

Figure 6. A final product — areas suitable for the location of public water supply wells in Jaworzno town. Orange colour depicts the best sites.

CONCLUSIONS

Although beneath the total area of Jaworzno lie the Quaternary, Triassic and Carboniferous aquifers of high water resources; due to a forestation, urban and industrial development and mine drainage, the sites suitable for the location of public water supply wells occupy only 3% of the town area.

All of these sites are located within the Middle Triassic aquifer of high resources and good water quality, which is built of the fissured-porous dolomites and limestones.

A GIS analysis is very useful for this kind of study, but it requires a high computer proficiency and a wide geological and hydrogeological experience. The results of this analysis may be furthermore used by the waterworks and the local and regional administration.

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6.6 | Coastal zone management

abstract id: **267**

topic: **6**
General hydrogeological problems

6.6
Coastal zone management

title: **Seawater intrusion control by means of an injection barrier in the Llobregat delta, near Barcelona, Catalonia, Spain**

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keywords: seawater intrusion, injection barrier, groundwater, mixing, Llobregat Delta

INTRODUCTION

The aquifers of the lower valley and delta of the Llobregat

The geological make-up of the Llobregat delta has been well known since the middle of the 20th century (Marqués, 1984; Simó et al., 2005; Gámez, 2007). There is a silt and clay wedge that separates two sand and gravel aquifers: an upper one with thicknesses of 15 meters below current surface, and another aquifer with thicknesses of 10 to 20 meters approximately, which is the main and most important aquifer (Fig. 1). It is confined and very transmissive (1,000 to 5,000 m^2/day). The main aquifer of the Llobregat Delta is primarily used for urban and industrial supply, linked to the Lower valley aquifer that is a strategic resource for supplying Barcelona and its metropolitan area.

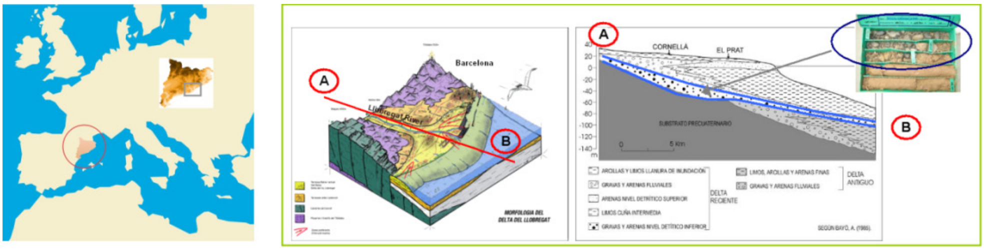

Figure 1. Location and geological configuration of the Llobregat main aquifer.

The seawater intrusion

Seawater intrusion processes have affected the main delta aquifer since the 1960s. The intensive exploitation over time of groundwater resources, along with the excavation of part of the confining layer, has led to the progressive deterioration of groundwater quality (Custodio, 1987; Custodio et al. 1976; Custodio et al. 1989; Iríbar, 1992; Iríbar et al., 1997). The seawater intrusion fronts are advancing along the dock of the port of Zona Franca and along La Ricarda, currently occupying a third of the area of the delta (Fig. 2). Water abstraction counts currently for approximately 54 hm^3/year, but it exceeded 100 hm^3/year the 1970's. The sustainable value to avoid groundwater deterioration is around 40 hm^3/year.

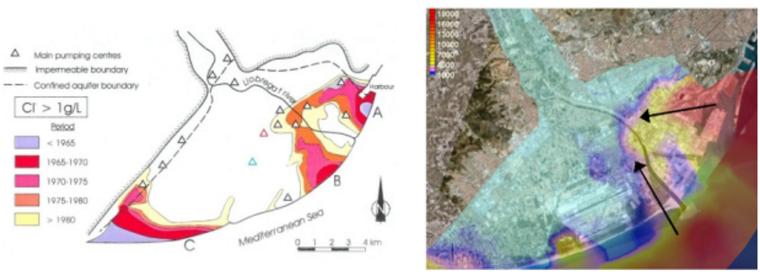

Figure 2. Progress of seawater intrusion (left) and 2007 chloride concentration (right) in the main Llobregat delta aquifer (Catalan Water Agency data). Seawater intrusion currently occupying a third of the area of the delta, and is moving inland from the sea in the direction indicated by the arrows.

Artificial recharge in the Llobregat aquifers

To mitigate the water deficit, the Catalan Water Agency, along with government agencies operating in the same area, Agbar S.A. and the Users' Community, are carrying out various artificial recharge actions and an Extractions Distribution Plan. In the lower valley of the Llobregat, recharge ponds are being constructed in three areas, which will provide a total additional recharge of 6 to 10 hm^3/year, and Agbar is traditionally performing scarification activities in the Llobregat river bed to enhance recharge, as well as direct recharge through injection wells.

THE LLOBREGAT HYDRAULIC BARRIER

The hydraulic barrier project

The most emblematic project to improve the quality of the aquifer is the construction of the positive hydraulic barrier using reclaimed water (Ortuño et al., 2008). The objective is to halt the advance of seawater intrusion. The barrier has being implemented in two phases (Fig. 3). Phase one has been in operation since March 2007 with an injection flow of 2,400 m^3/day in four injection wells. The second phase has a total injection flow of 15,000 m^3/day to 11 injection wells operating since April 2010. There are 17 specific monitoring piezometers with remote-control data systems for water temperature, head and water electrical conductivity. The aquifer monitoring network also includes 13 wells and 7 existing piezometers, covering more than 30 km^2, in order to follow the impact of the barrier.

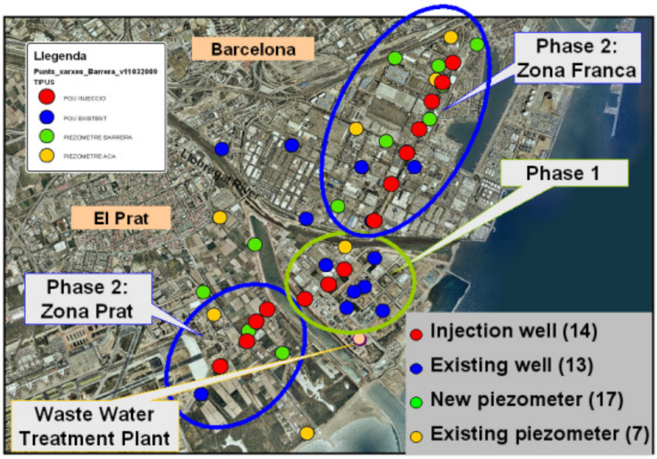

Figure 3. Hydraulic barrier network configuration: injection wells (red) and monitoring points (blue, green and orange). The project has been performed in two phases.

Injection water

The injection is reclaimed water from the El Prat Waste Water Treatment Plant, near Barcelona, and undergoes several treatments. Water is subjected to secondary and tertiary treatment, the latter consisting in ballasted coagulation-flocculation, lamellar decantation, filtration and disinfection. Tertiary treatment is used for the environmental uses: Llobregat river flow increase and wetlands (Cazurra 2008), and to feed the treatment plant of the hydraulic barrier. At the Hydraulic Barrier Plant, ultrafiltration, reverse osmosis (50% of the water) and UV disinfection are performed, prior to the distribution to the injection wells (Fig. 4). The water quality control is carried out in compliance with the requirements of the Sanitation Authority.

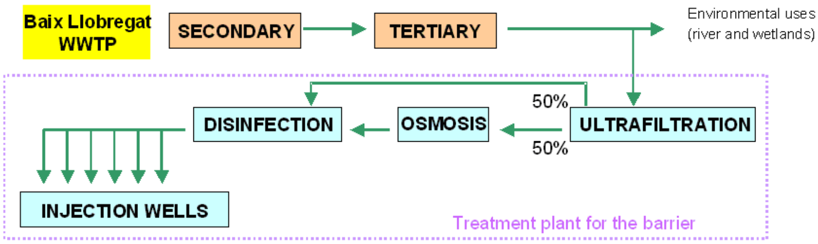

Figure 4. Water treatments prior to its injection in the aquifer. The injection is reclaimed water from the tertiary effluent of the El Baix Llobregat WWTP (Barcelona) and, after being subjected to ultrafiltration, reverse osmosis and disinfection, is sent to the wells.

Investment and exploitation costs

The total investment for the construction of the Llobregat hydraulic barrier amounts to €23M contributed by the Catalan Water Agency, the Spanish Ministry of the Environment and Rural and Marine Affairs, and the European Commission. The total cost of exploitation is €0.28/$m^3$of injected water.

PHASE 1 EVALUATION AND RESULTS

Injected water

Injection of the phase one began on 26 March 2007, and since then around 1,800,000 m^3 of reclaimed water have been injected in 4 injection wells. Some parameters (electrical conductivity, pH and temperature) of the injection water are logged automatically, and bacteriological and physicochemical parameters (BOD, COD, P, N, Cl, NO_3 and TOC) are monitored weekly. Monthly monitoring of major elements, metals, and volatile organohalogenated compounds is performed. The average chloride content of injected water is 347 mg/l, which is similar to that found in aquifers in areas that have not been affected by seawater intrusion. The electrical conductivity of the water is around 1500 mS/cm, and turbidity is less than 0.09 NTU. To date, the presence of coliforms, escherichia coli and nematodes has not been detected in any of the samples. Injection water accomplishes the Drinking Water Quality Regulation requirements.

Well clogging

No change has been noted in the specific flow (flow/head increase) of the four injection wells over the last three years of operation, which would imply that no clogging incidents have been detected. This is attributed in part to the high quality of the water, as reverse osmosis and ultrafiltration prevent physical clogging, and disinfection prevents bacteriological clogging, and in part to the strict cleaning program. The wells are cleaned through the use of electropumps or compressed air once a week.

Aquifer improvement

The analyses and field monitoring of the aquifer show a progressive decrease in the amount of chlorides (Fig. 5), sodium, calcium, magnesium, iron and ammonium, and a slight increase in nitrates, which are present in the injected water. The barrier clearly has an oxidizing effect on the otherwise highly reducing medium; as a result, different hydrochemical and reactive-transport studies are being carried out to determine if mobilization of metals or another processes taking place. Until now, sodium for calcium ion exchange has been identified, and the injected water is slightly oversaturated with respect calcite. These hydrochemical studies, as well as those carried out to identify clogging processes, are important factors to understand the behavior of the barrier and for a correct management for the complete barrier.

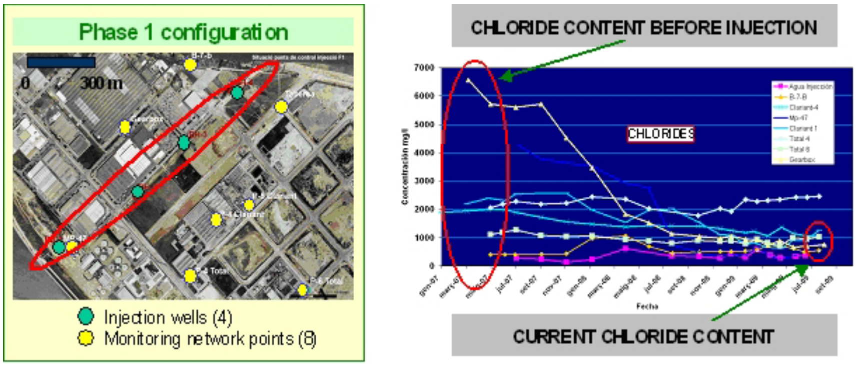

Figure 5. Pilot phase configuration of the hydraulic barrier project and chloride evolution in the monitoring control points between January 2007 and September 2009. Water injection started March 2007.

DISCUSSION AND CONCLUSIONS

A positive hydraulic barrier injecting highly treated reclaimed water into the aquifer has been constructed in order to stop the advance of the seawater intrusion in the main Llobregat delta aquifer. The pilot phase of the project has been working during the last 3 years, showing highly positive results. No clogging has been appeared in the 4 injection wells, and it is attributed to the high water quality, with ultrafiltration, reverse osmosis and disinfection, and to the strict cleaning program. Substantial improvement of the groundwater quality has been also observed in wells surrounding the injection points. This shows that the concept and technology of the hydraulic barrier are able to contain the advance of the saline water fronts. Currently, hydro-chemical studies and modelling are carried out to identify ion exchange, mixing processes or mobilization of metals in the aquifer. These hydrochemical studies, as well as those carried out to identify clogging processes, are important to understand the behavior of the barrier and implement the appropriate management. The results from the two-phase development of this project has been extremely positive in terms of learning from mistakes, calling the different teams, government agencies and business involved to action, thus achieving and improved a better guarantee of success for the future of the entire project.

ACKNOWLEDGEMENTS

Special thanks to Josep Maria Niñerola and Gabriel Borràs (Catalan Water Agency) for their support to the project. The authors acknowledge all the companies, universities, organizations and city councils involved in the hydraulic barrier project, special to AREMA and the Water Users' Community of the Llobregat Delta (CUADLL). Financial support has been provided by the

Catalan Water Agency, the Spanish Ministry of the Environment and Rural and Marine Affairs, and the European Commission.

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abstract id: **299**

topic: **6**
General hydrogeological problems

6.6
Coastal zone management

title: **Coastal aquifers management in the Caribbean case studies — Jamaica**

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keywords: coastal aquifers, Caribbean area, aquifer management

Freshwater resources are finite and vulnerable in the Caribbean Islands. The location of major developments close to the coast and the fact that these islands are heavily dependent on tourism, services, industry and agriculture makes the management of water resources critical to future economic growth and sustainable development of Caribbean economies. Under the WAP-II programme, two Caribbean coastal aquifers studies (located in Jamaica and Trinidad) are being conducted to assess existing problems dimension, management actions and recommendations for sustainable management. This presentation only focuses in the Yallahs aquifer (Fig. 1), located in the Yallahs Watershed Management Unit-WMU of the Blue Mountains South Hydrologic Basin (south-eastern of Jamaica).

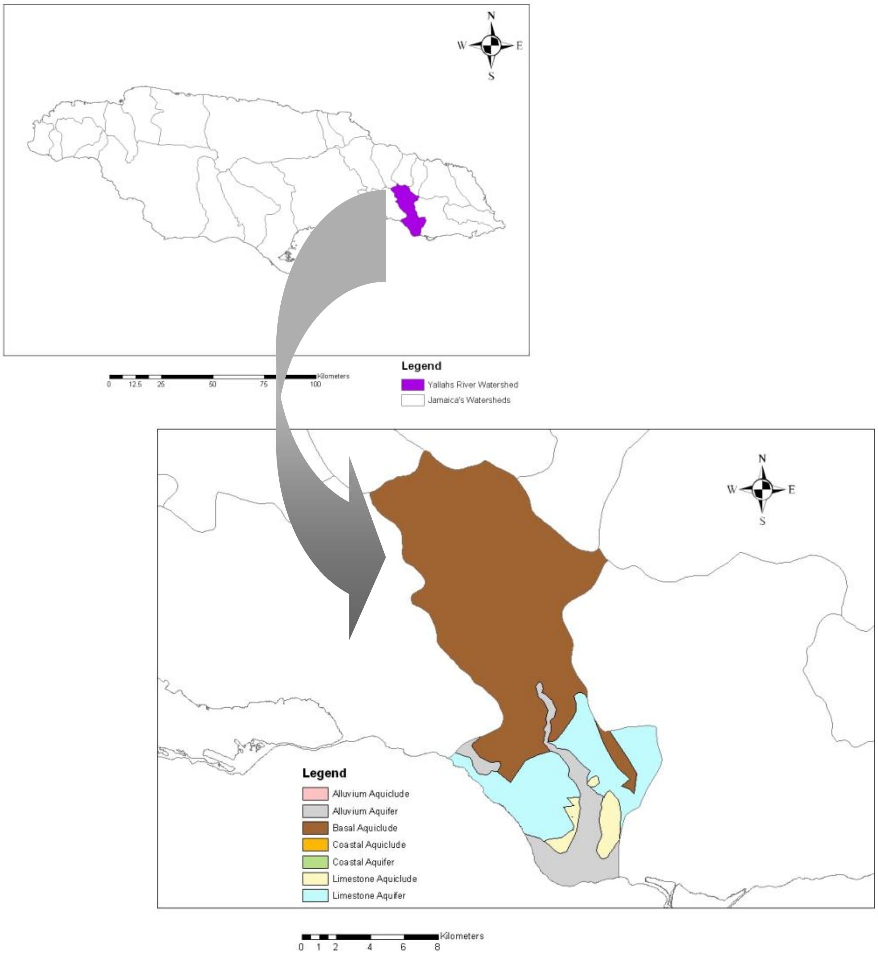

Figure 1. The Yallahs Watershed Management Unit (Jamaica). Geographic location of the Yallah alluvial aquifer and delta (medium grey).

The Yallah alluvial aquifer is composed by successive formations of river terraces of sands and bolders with thin layers of clay and silt, and extending over 10.9 km^2 (Baptiste, 1996). Thickness ranges from few tens of meters to an undetermined thickness in the main area of the aquifer. The mean annual rainfall is 2085 mm, 80–95% is produced during the wet season, being regularly influenced by tropical storms. This fact makes water resources greatly dependent on the existing coastal aquifer. Its main recharge is from precipitation and river infiltration. Aquifer discharge is to the sea and through existing pumping wells.

Main water demand is for water supply, and diversion of water from the Yallahs river has resulted in significant reduction in downstream flow, increasing reliance on groundwater in the lower part of the WMU. Groundwater over pumping has led to saline upconing in the western part of the aquifer. This situation maybe aggravated as a consequence of expected impacts from climate change.

Responses to the water resources threats in the study area mainly focusses on the application of legislative management tools (policies, standards and guidelines), establishment of action plans for water resources assessment, monitoring and management, water management strategies to increase water availability and protect water quality, participation in regional and international treaties and conventions, water resources act and adaptative measures to climate change impacts.

ACKNOWLEDGEMENTS

This project is being developed under the UNESCO-Italy *Water Programme for Environmental Sustainability (WPA-II)* framework and its financial support is greatly acknowledged.

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abstract id: **334**

topic: **6**
General hydrogeological problems

6.6
Coastal zone management

title: **A conceptual model of the coastal aquifer of the Andarax Delta (SE Spain)**

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keywords: conceptual model, delta aquifer, coastal aquifer, aquifer management

GEOLOGICAL AND HYDROGEOLOGICAL FEATURES

The coastal detritic aquifer of the Andarax delta is quite small (16 km^2 in area, with an average thickness of 80 m). Like many other Mediterranean aquifers, it dates from the Plioquaternary and comprises alternating sands, gravels and lutites, making a highly heterogeneous aquifer with intergranular porosity. In the vertical plane, this type of aquifer can correspond to a number of theoretical models (Custodio, 2002). As an initial approximation, the delta can be considered as a partially leaky aquifer, with a thin water table aquifer overlying a much thicker, confined aquifer (Jorreto et al., 2009).

There is a wealth of data available from various sources for this aquifer. In terms of its geology, the surface of the delta has been mapped, and there are borehole logs as well as local stratigraphic analyses. All these have contributed to establishing the type of aquifer materials, the boundaries of the aquifer, its geometry and stratigraphic architecture, all of which are determining factors for defining its hydrogeology (Clarke, 2004). Also, we used electrical resistivity tomography from the ground surface (Ogilvy et al., 2009) as well as several logs of gamma ray, water temperature and electrical conductivity in boreholes already existing in the area. All these data have enabled a better understanding of the geological detail of the delta deposits.

The hydrogeological database was derived from a detailed inventory of water points and from the analyses of water sample. Also available were time series of piezometric level, as well as water temperature and electrical conductivity in various boreholes at different depths through the aquifer. Other data of interest were also considered, including climate data, river flow and groundwater flow in the detritic aquifer of the Lower Andarax as sources of recharge; historical piezometric data, cycles and magnitude of marine tides and pumped extractions of fresh and saline water. Other analytical tools were applied to represent the data graphically, such as spatial interpolation and geostatistics (maps of piezometry, isocontents and geometry of the freshwater-saltwater contact).

By integrating all of the geological, geophysical, hydrogeological and hydrochemical data a conceptual model is proposed for the Andarax coastal detritic aquifer. This clear model considers all the elements that influence the evolution of the groundwater, which is highly dependent on the type and disposition of the strata, on recharge, extractions and marine phenomena.

FINAL COMMENTS

The definition of a conceptual model of the Andarax deltaic aquifer is of great relevance in both the short and medium term. In the short term, it represents the actual scenario of intensive saltwater extractions (1200 L/s) from close to the coastline to supply a desalination plant. The model indicates marked impacts on the dynamics and geochemistry of the aquifer, particularly on the freshwater-saltwater contact, with diverse consequences on the quality and the quantity of the resource ("freshwater" intrusion, possible repercussions on freshwater users of the aquifer, subsidence, and others). Careful spatial and temporal planning of the extractions will largely abate these drawbacks. The hypothetical scenario in the medium to long term concerns the rise in sea level due to global warming, and the particular impacts that this could have in this coastal aquifer, which management strategies must attempt to minimise.

ACKNOWLEDGEMENTS

This work was undertaken within the framework of project CGL2007-63450/HID funded by the Spanish Ministry of Science.

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abstract id: **414**

topic: **6**
General hydrogeological problems

6.6
Coastal zone management

title: **Identification of groundwater salinization at the Suyeong county in the Busan city, Korea**

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keywords: salinization, groundwater quality, groundwater level, groundwater discharge from subway, geostatistics

INTRODUCTION

The Busan Metropolitan City is the 2nd large city in Korea and is located at the coast. Generally, groundwater use is restricted by seawater intrusion at the coastal area. Groundwater is contaminated by seawater intrusion at the coastal area in Busan. The population of Busan is 3.7 million. The city has many tunnels for three subway lines, for communication cables and for electrical cables under the ground. Groundwater discharge from the tunnels is very serious. The groundwater level is drawdowned especially around the subway lines, and the groundwater quality is deteriorated by the inflow of seawater or river water derived from the groundwater discharge. So many groundwater wells around subway tunnels have been abandoned because of the reduction of quantity or the contamination of quality.

In this study, the cause for the deterioration of groundwater quality is identified by several investigations and analyses at a coastal area at the Suyeong District in the Busan Metropolitan City. Research methods include the investigations of groundwater level and quality of wells, quantity and quality of groundwater discharged from subway, quality of river water, and geostatistical analysis of groundwater level and quality data.

MATERIALS AND METHODS

Hydrogeological settings

The study area includes the Suyeong District in the Busan Metropolitan City. The Kwanganri Beach is located at the southeastern side of the Suyeong District (Figure 1). The Suyeong River is located at the eastern side, and is connected to the sea. The geology of the study area is composed of andesitic volcanic breccias, tuffaceous sedimentary rocks, rhyolitic rocks, and intrusive granodiorites and granite porphyries (Chang et al., 1983; Son et al., 1978). The geologic time belongs to the Cretaceous Period in the Mesozoic Era.

Alluvial deposit is developed around the Kwanganri Beach, and groundwater is relatively vulnerable to seawater intrusion. However, the coastal area of crystalline rocks is not highly influenced by seawater intrusion.

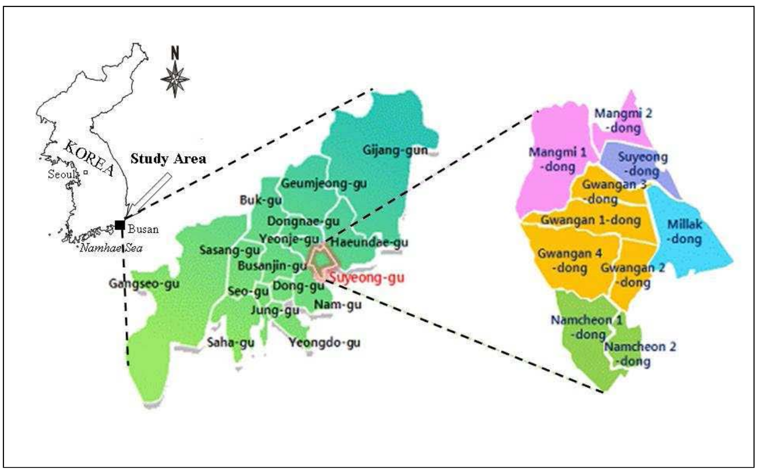

Figure 1. Administrative districts of the study area.

Groundwater samples and analysis

Groundwater was sampled at 135 wells developed in shallow and deep aquifers, and the samples were relatively uniformly distributed at the study area. However, many groundwater samples couldn't be collected at the west side of the study area because there is no groundwater wells at Mt. Kumryeon. Temperature, pH, Electrical Conductivity (EC), Oxidation-Reduction Potential (Eh), Dissolved Oxygen (DO) and Alkalinity were measured in the field. Seven major elements, five minor and trace elements were analyzed in the laboratory using Atomic Absorption Spectrometer (AAS), Ion Chromatography (IC) and Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES). Piper's trilinear diagram was used for the classification of groundwater quality type.

Geostatistical analysis

For geostatistical analysis, ordinary kriging was used to produce distribution maps for groundwater level and groundwater quality in this study. Kriging is a local estimation technique of the best linear unbiased estimator (BLUE) for the unknown values of spatial and temporal variables (Journel and Huijbregts, 1978). Kriging is expresses as

$$Z_K^* = \sum_{i=1}^{n} \lambda_i Z_i \tag{1}$$

where Z_K^* is an estimated value by kriging, λ_i is a weight for Z_i, and Z_i is a variable value. The weight is determined to ensure that the estimator is unbiased and that the estimation variance is minimal.

The unbiased condition of kriging is

$$E\{Z_V - Z_K^*\} = 0 \tag{2}$$

where Z_V is an actual value and Z_K^* is an estimated value.

The sum of weights is

$$\sum_{i=1}^{n} \lambda_i = 1.0 \tag{3}$$

The estimation variance of kriging variance is

$$\sigma_K^2 = E\left\{\left[Z_V - Z_K^*\right]^2\right\} = \overline{C}(V,V) + \mu - \sum_{i=1}^{n} \lambda_i \overline{C}(v_i,V) \tag{4}$$

where $\overline{C}(V,V)$ is covariances between sample variables, μ is Langrange parameter and $\overline{C}(v_i,V)$ is covariances between sample variable and estimates.

RESULTS AND DISCUSSIONS

Groundwater use

The number of groundwater well is 377 at the study area. The quantity of groundwater use could not be examined at 71 wells. The total uses of groundwater are 1,531,000 m^3/year (4,243 m^3/day) at the study area. The quantity for living use is 1,356,684 m^3/year (3,760 m^3/day), and 89% of total uses.

Groundwater discharge from subway tunnels

2,057 m^3/day (751,000 m^3/year) of groundwater is discharged from the subway at the study area. 67 m^3/day (24,500 m^3/year) of discharged groundwater is used for living and washing uses, the rest is sent directly to the river. Table 1 shows that the sustainable development yield of groundwater is 951,000 m^3/year, and total quantity of discharged groundwater from the subway and used groundwater is 2,282,000 m^3/year at the study area. So the total quantity of discharged groundwater from the ground is 2.4 times the sustainable development yield of groundwater. So the groundwater level is decreased at the study area.

Table 1. Groundwater use and discharge at the study area (unit: m^3/year).

Sustainable development yield	Groundwater use	Groundwater discharge from the subway	(Groundwater use + Groundwater discharge)/(Sustainable development yield)
951,000	1,531,000	751,000	240 (%)

Source: MLTM and KWRC (2007, 2008), BTC (2007).

Groundwater level distributions

The groundwater levels of 135 wells were measured on December, 2007 and July, 2008. The average groundwater level is 7.81 m above the mean sea level in dry season, and 9.11 m above the mean sea level in wet season. The difference between dry season and wet season is about 1.3 m.

The distribution maps of groundwater level were produced using a geostatistical method (Robertson, 2004). Figure 2 and 3 shows groundwater level distributions in dry and wet seasons, respectively. The groundwater levels are located below the average sea level. The minimum groundwater levels in dry and wet seasons are -32.32 m and -30.37 m below the mean sea level, respectively.

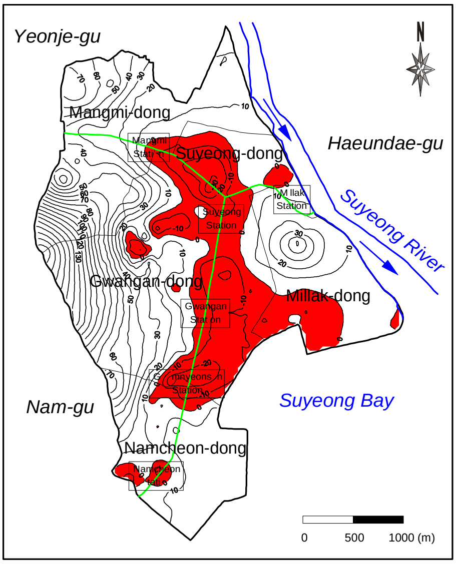

Figure 2. Distribution map of groundwater level (Dry season).

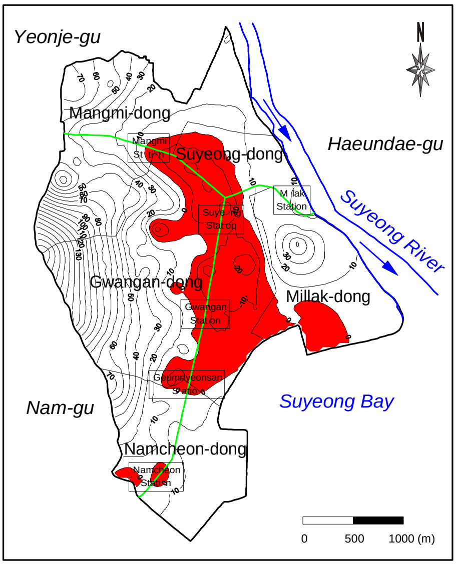

Figure 3. Distribution map of groundwater level (Wet season).

Groundwater quality distributions

The average water temperature of wet season is 5.5°C higher than that of dry season. The average of pH is 0.4 higher, and the average of DO is 0.6 mg/L lower in wet season. The average of EC is 136 μS/cm higher in wet season.

Figure 4 and 5 show the distributions of EC in dry and wet seasons, respectively. The higher EC over 800 μS/cm (red color zones of Figure 4 and 5) is formed around the subway lines and the

Suyeong Bay. It is the result of seawater intrusion derived from the drawdown of groundwater level around the subway lines. The water of the Suyeong River also comes into the Millak subway station because of the groundwater discharge from the subway. By the way, the Suyeong River is salinized by the seawater. The salinized river water contaminates the original groundwater around the Millak subway station.

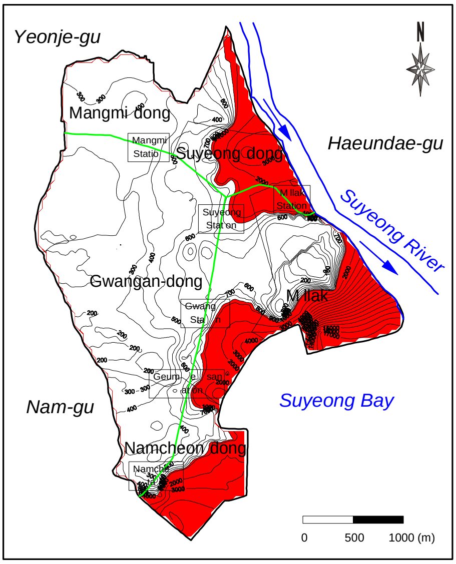

Figure 4. Distribution map of EC (Dry season).

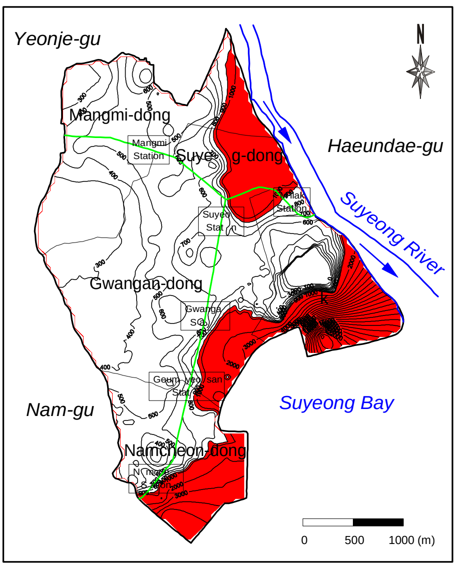

Figure 5. Distribution map of EC (Wet season).

Seawater impact to the Suyeoyng ang Oncheon rivers

The Suyeong River is the largest river in Busan, and is connected to the sea. It is affected by tide, and is salinized by seawater. The EC of the Suyeong River reaches to 32,000 μS/cm in dry season, and to 15,000 μS/cm in wet season. The influence of seawater is to 5.5 km distance from the Suyeong Bridge. The EC of the Oncheon Stream reaches to 23,000 μS/cm in dry season, and to 12,000 μS/cm in wet season . The influence of seawater is to 1.5 km distance from the cross point of two rivers.

Quality and quantity of groundwater discharged from subway

The quantity of discharged groundwater is measured using a TLC meter, and ranges from 232 to 545 m^3/day during 7 months. The quality of discharged groundwater belongs to NaCl type (Table 2). It proves that the water of the Suyeong River infiltrates the Millak subway station.

Table 2. Quality of groundwater discharged from the Millak subway station.

Cations	Concentration (mg/L)	Anions	Concentration (mg/L)
Ca^{2+}	157.70	HCO_3^-	578.30
Mg^{2+}	101.50	Cl^-	1,878.00
Na^+	682.20	SO_4^{2-}	312.00
K^+	52.30	CO_3^{2-}	0.00
NH_4^+	1.43	NO_3^-	7.50

CONCLUSIONS

The total quantity of discharged groundwater from the ground is 2,282,000 m^3/year at the study area. It is 2.4 times the sustainable development yield of groundwater. So the groundwater level is seriously decreased at the study area. The groundwater level around the subway is located at 30 ~ 32 m below the mean sea level. The deep drawdown of groundwater level brought about the inflow of seawater and river water. By the way, the Suyeong River is salinized by seawater, because it is connected to the sea. Therefore, the groundwater around the subway lines is contaminated by seawater and salinized river water. The quality of groundwater doesn't reach to the standard of potable, domestic, agricultural and industrial uses.

The distribution maps of groundwater level and quality were produced using a geostatistical method, i.e., kriging. The maps were very useful to find out the problems of groundwater at the study area. The maps identified that the sea water and river water infiltrated the inland groundwater and contaminated the groundwater around the subway lines.

ACKNOWLEDGEMENTS

This research was supported by a grant (code# 3-3-4) from Sustainable Water Resources Research Center of 21st Century Frontier Research Program (Korea).

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abstract id: **516**

topic: **6**
General hydrogeological problems

6.6
Coastal zone management

title: **The threat of groundwater resources in the Polish Baltic coast area**

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keywords: hydrogeology of Polish Baltic coast, salt water intrusion, salt water ascension, origin of groundwater

Salt and brackish waters occurring along the Baltic lowland in Poland originated by the sea water encroachment (intrusion) or by brines' ascension from deep Mesozoic strata (Dowgiałło, 1988; Kleczkowski, Nguyen-Manh-Ha, 1977; Zuber et al., 1990; Zuber, Grabczak 1991; Burzyński, Sadurski, 1990b, 1991; Burzyński et al., 2005). The recharge area of regional groundwater flow systems is the moraine plateau of the Lakeland where the land surface exceeds 200 m a.s.l. The fresh groundwater of 0.7 g/dm^3 in total mineralization was stated in Połczyn Spa at depth of 767 m in Jurassic aquifer. The values of $\delta^{18}O$ and δD where –9.25‰ and –62.5‰ respectively. The residence time of these waters, established by ^{14}C, was calculated as 5500 yrs (Krawiec 1999; Krawiec, Dulski, 2004).

The saline springs of total mineralization 34 g/dm^3 have been known in Kołobrzeg Spa since the VIIth century. The therapeutic salt waters exploited in: Kamień Pomorski Spa, Świnoujście Spa, Międzyzdroje Spa and Sopot Spa belong to the Cl^-–Na^+ hydrogeochemical type and are enriched in iodine and bromine compounds. The lowest values of $\delta^{18}O$ and δD up to –10‰ and –69‰ respectively were marked in water samples from Quaternary aquifers in this area (d'Obryn et al., 1997).

Groundwater flows in these aquifers were analysed using a mathematical model based on Boussinesq's equation. The equation resulting from adoption of the continuum hypothesis and the law of continuity and the momentum conservation law — Darcy's law, for steady-state flow conditions, is evaluated for a vertical, two dimension flow system (Burzyński, Sadurski, 1990a).

Noble gas temperature (NGT) and ^4He excess were measured in groundwater samples taken from drilled wells situated in the spas. Waters, that were supposed to be of Holocene ages, have NGT distinctly higher than the present mean air temperature (7°C) in this area. Results of the groundwater flow modelling suggest, that salt waters in the sluggish zone of circulation have different origins (Krawiec et al., 2000).

Clarification of the genesis of saline groundwater along the Polish Baltic coast is required for water resource protection and safe yield calculation of water intakes, including the salt water in the Spas.

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6.7 | Managing aquifer recharge

abstract id: **125**

topic: **6**
General hydrogeological problems

6.7
Managing aquifer recharge

title: **Recharge management in Delta Llobregat Aquifers**

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keywords: artificial recharge, management, users

INTRODUCTION

The Llobregat river lower valley and delta are in the Barcelona's Metropolitan Area, consisting of about 30 km^2 of alluvial valley, up to 1 km wide, and 80 km^2 of delta. The importance of the aquifer system cannot be understated as it is an strategic source of water for the city supply, the industries and the agriculture in Barcelona's surrounding areas. The big development of this area in the 1970's involved intensive pumping that caused both a piezometric depletion and a penetrating seawater intrusion body in the deep aquifer. Aware of the importance of these aquifers, local factories, suppliers and farmers founded the Water Users Community of Low Valley and Delta Llobregat (CUADLL) in the mid 1970's with the objective of protecting and self-managing the groundwater resources (Queralt, 2007).

The final stretch of Llobregat's river is divided in three hydrolgeological units which form three different water users' communities: Abrera's basin aquifer, Castellbisbal's basin aquifer and the Low Valley and Delta aquifers (the administrative limits of each community are shown in Fig. 1).

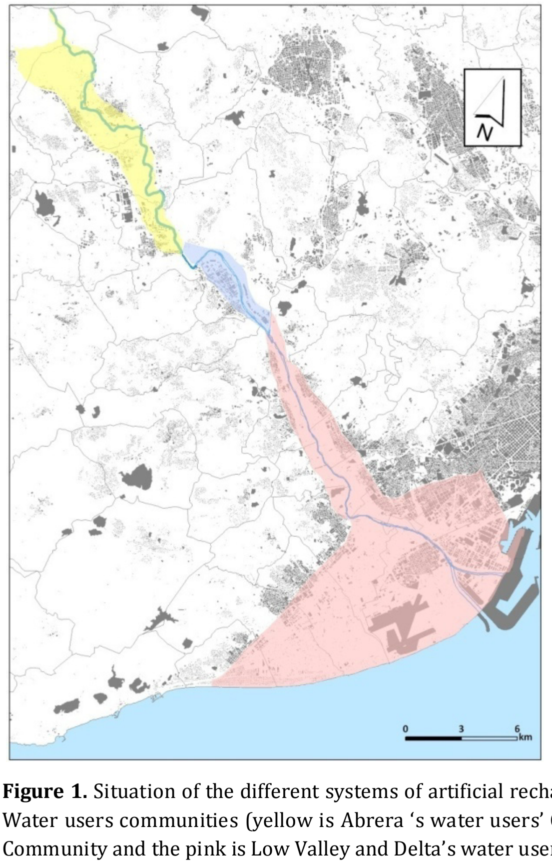

Figure 1. Situation of the different systems of artificial recharge. Different colours show the three different Water users communities (yellow is Abrera 's water users' Community, blue is Castellbisbal's water users' Community and the pink is Low Valley and Delta's water users' Community).

Geologically the delta is formed by a sedimentary package of sands, gravels and clays ranging from Pliocene to Quaternary in age. In the low valley, the aquifer is unconfined while in the delta there are two: the upper one which is unconfined and the deep one which is confined.

Both aquifers are separated by a silty wedge which appears at Cornellà and gets thicker towards the sea (Gàmez, 2008). The low valley and deep delta aquifer is the important one for drinking water and industrial supply in the metropolitan area.

In the last decades, this area has experienced a huge development. With the aim of becoming the main Southern European distribution centre, many infrastructures have been enlarged (the harbour, the airport, metro lines etc…) or constructed (highways, railroads etc...). Furthermore Barcelona and its metropolitan area have increased in size as well as its services areas. All this growth affected the aquifer recharge and led to increase in extraction. Therefore, artificial recharge needs to be done to improve the quality and quantity of water in the Llobregat's aquifers.

CUADLL has assessed the artificial recharge measures' impact by means of numerical models as well (Massana et al., 2007).

Moreover a recharge protocol is being written. This protocol contains quality and quantity variables, economical cost, and the joint viability of the different recharge systems.

ARTIFICIAL RECHARGE SYSTEMS

Due to the strategic value of these aquifers some corrective measures to improve the water's quality and quantity have been projected in the Llobregat's low valley and delta. One example is the hydraulic barrier which has been designed against the seawater intrusion. Others are recharging ponds, scarification and deep injection to compensate the reduced infiltration (Fig. 1).

All the artificial recharge methods will raise the groundwater resources leading to compensate the soil impermeabilization, avoiding the clogging of the river bed, stopping the seawater penetration and achieving the environmental objectives of the European Water Framework Directive.

Scarification

Scarification is a process which induces the aquifer recharge directly through the river bed. It is done upstream, in the upper part of the low valley. This method consists in removing the silty sediments of the river bed with a tractor so that the water can easily be infiltrated through sands and gravels.

This system of recharge has been used since the 1940's by Barcelona's Water Supply Company (SGAB). It is usually done in spring and autumn when the river flow is between 10 and 35 m3/s and the turbidity lower than 150 N.T.U.

Deep injection (aquifer storage and recovery)

Late in the 1960's Barcelona's Water Supply Company (SGAB) built a treatment plant whose surpluses were used to be deeply injected into the aquifer through seven wells of 40 m depth that were designed for collecting. In a second stage, five more wells were drilled specifically for recharging purposes. Nowadays, these thirteen wells are still in use. They pump when it's needed and inject when treated water surpluses exist. The amount of recharged water by deep injection ranges from 0 to 14 hm^3/year, it varies to such extremes because it depends on the availability of the resources.

Recharge ponds

In order to increase the infiltration upstream, there are 3 projects of infiltration ponds in different stages of development along the Llobregat's low valley with the goal of recharging about 15 hm^3/year.

Castellbisbal recharge ponds

The Catalan Water Authority (ACA) and the water users' community of Castellbisbal (CUACSA) signed an agreement in 2002 to rebuild some old basins existing from the mid 1980's, and to transfer the exploitation and the maintenance of them from the former to the latter.

These ponds were inaugurated in April 2010, and consist of 14.000 m^2 of wetland surface and 6.000 m^2 of infiltration pond. Total amount of recharge predicted is 1.8 hm^3/year. The recharged water is collected from the river and in the interconnection of the two basins there's a control station which has been programmed to automatically take water samples at a pre-set frequency to check the water quality (amount of ammonia, conductivity and turbidity). When the water sample isn't up to set standard, the station is programmed to automatically close the interconnection floodgate by itself.

Another agreement was signed between CUACSA and the Spanish Geological and Mining Survey (called IGME) for a research and development project related to these ponds.

Sant vicenç dels horts recharge ponds

As a compensatory measure for impermeabilizing the area during the building of the Baix Llobregat's highway a recharge ponds of 1 Ha were constructed in Pallejà. Shortly after that, those same ponds were taken out of commission due to the fact that they lay directly where the high speed train railway (AVE) was to be built. So, Spanish railway infrastructures administrator (ADIF) was required to build the Sant Vicenç dels Horts basins on the right river bank in 2004.

The sedimentation pond is upstream with a surface of 4.000 m^2 and the infiltration pond is downstream and has 5.000 m^2. There are three possibilities for the sources of the recharged water. It can come directly from the river or when due to a draught or bad quality, there are 2 sources of regenerated water: from Reversible Electrodialysis Plant in St Boi or from El Prat's Waste Water Regeneration Plant. When coming from a plant, the water can be poured directly into the infiltration pond as the sedimentation process becomes unnecessary.

In March 2009, CUADLL made an infiltration test in these ponds. During the test the water recharged was diverted from the river through a pipe. The volume provided was 422,568 m^3 in 78 days, which results in a calculated infiltration rate of 1.08 m/day (1.98 hm^3/year). One conclusion of this test is that due to sedimentation while in the pipe, most of the turbidity of the water disappears by the time it gets to the sedimentation pond. Another finding in the test is that in order to obtain a constant rate of infiltration, a higher water column in the infiltration pond is needed over time. That is to say, the infiltration pond is affected by a clogging process. Figure 2 shows how the infiltration (divided by the water column height in order to see it properly) decreases over time, by more than half in three months.

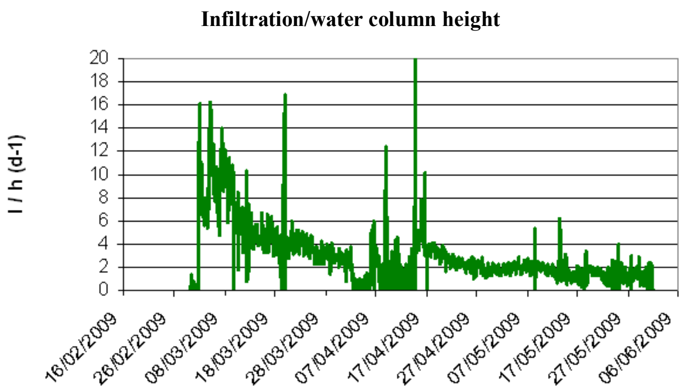

Figure 2. Infiltration rate observed during the test. It decreases by more than half in during the test due to a clogging process.

Santa coloma de cervelló recharge ponds

CUADLL signed an agreement signed with the Catalan Water Authority (ACA), the Environmental department of the Catalan government (DMAiH), Environmental Entity of the Metropolitan Area of Barcelona (EMSHTR) and Barcelona's Water Company (AGBAR) to build the recharge ponds in the Santa Coloma de Cervelló area. All the preliminary studies needed to create the project have been completed and the ponds will go into construction in 2011.

The geologic and geophysical characterization is one of these aforementioned preliminary studies. It was done by means of tomographies and test drillings interpretation. More than 30 test drillings were done, and 22 of these tests drillings were preserved as piezometers, configuring the monitoring network for the test and for the future recharge system. As a result of these studies, a geological interpretation of the media was obtained concluding that the clay and silt layer present in Santa Coloma area is thicker in the downstream direction (Figure 3).

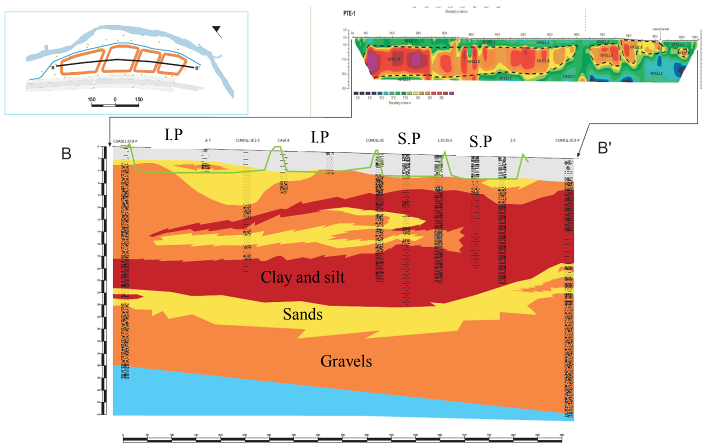

Figure 3. Tomography and geological cross section with the basins profile overlapped. The 2 sedimentation ponds (S.P) are located downstream. This is because of the type of dirt, which is more impermeable downstream than upstream. Clay and silt layer is thicker in that direction, for that reason the basins are projected upside down.

For that reason the basins are projected upside down: infiltration ponds will be located upstream of the area, and the sedimentation ponds downstream where the vertical hydraulic conductivity is smaller.

Two different kinds of infiltration tests were done. The first one was by means of infiltration rings at 2 or 3-meter depth aimed to learn the behaviour of superficial layers (seven tests in different locations).

The second kind of infiltration test was by means of pilot ponds at the depth of projected ponds. Two small ponds of 150 m^2 were dug in different places. These tests' results were used by the hydrogeologic model to calibrate hydraulic parameters of the vadose zone, especially vertical hydraulic conductivity. The infiltration rate deduced from these tests ranged from 1 m/d (in the fist pilot pond) to 10 m/d (in the second). The big difference is due to the location of each pilot pond, thus exactly where the future infiltration ponds will be located is very important.

We built a hydrogeologic model of the area and modelled 2 sections: transversal and longitudinal related to the river. The most important conclusion drawn from this model is the minimum infiltration rate, which would be around 8 hm^3/year (Luna et al., 2009). This rate is between the two values obtained from the pilot ponds. The model also foresees that only a 5% of the infiltrated water would flow towards the river.

As the model, the pilot ponds and the geologic characterization all indicate, the local flow induced by the infiltration is in the upstream direction, due to the clay layer's shape: water flow doesn't infiltrate vertically through clays, but it flows over the clay layer until its end, where it infiltrates through sands and gravels.

HYDRAULIC BARRIER

The seawater intrusion appeared in Llobregat's delta in the 1970's. While constructing Barcelona's harbour, the impermeable layer that separates the aquifer and the sea was excavated, so the seawater moved inland. The hydraulic barrier was created to raise the groundwater head near the coast to avoid seawater penetration.

The first stage of the hydraulic barrier consists of 4 wells in the delta's area that inject water into the aquifer. It started in March 2007 with an injection flow of 2.500m^3/day. Injection water comes from El Prat's Waste Water Treatment Plant after several advanced treatments: ultrafiltration, UV disinfection and reverse osmose (50%). This pilot stage has 8 points of monitoring network that have shown an improvement of the groundwater quality (Ortuño et al., 2009).

Nowadays, a second stage of this hydraulic barrier is in trial. It consists of 14 wells with a total injection flow of 15.000 m^3/day.

CONCLUSIONS

Water management is quite complex due to the urban and industrial development of the Llobregat's area and the resulting large number of infrastructures built (roads, railroads, airport, large harbour and its service areas...). This development has a negative affect on the aquifer recharge, since they increase surface runoff, modify groundwater flow, and discharge contaminants. Artificial recharge done by SGAB since the 1970's (scarification and deep injection) is not enough and needs to be increased.

For all these reasons and in order to increase available water resources, three artificial recharge ponds are planned in the low valley and delta area. These 3 ponds each are in a different stage: Castellbisbal's recharge ponds were inaugurated in April 2010; Sant Vicenç dels Horts ponds are ready to recharge and in Santa Coloma de Cervelló recharge system all the preliminary studies have been completed and the ponds will be constructed soon. Moreover the brand new hydraulic barrier against seawater intrusion is presently in trial and will contribute 5.5 hm^3/year to the aquifer. In fact, Llobregat's area is probably one of the places in the world with more variety of recharging methodologies.

In order to regulate all the technical specifications of the artificial recharge, ACA and CUADLL are writing a recharge protocol for the different recharge systems. The quality parameters of the recharged water will also be considered in this protocol.

By 2012, all these measures working together will mean a total volume recharged of 24 hm^3/year, which is almost half of the annual extraction in the low valley and delta. This volume artificially recharged will guarantee the quality and the quantity of the Llobregat's aquifers and will achieve the environmental objectives of the European Water Framework Directive.

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abstract id: **209**

topic: **6**
General hydrogeological problems

6.7
Managing aquifer recharge

title: **The impact of regulated river-flow on the travel-time and flow-path of bank filtrate in Haridwar, India**

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keywords: riverbank filtration, sustainability, groundwater flow modelling, travel-time, Upper Ganga Canal

INTRODUCTION

In Haridwar, riverbank filtration (RBF) accounts for more than 35% of the total drinking water production of around 64,000 m^3/day for 200,000 permanent residents and an additional approximate 330,000 pilgrims visiting the city daily (Dash et al., 2010). Even when the demand for drinking water peaks to supply up to 8 million additional pilgrims in a single day, such as during religious festivals like the Kumbh and Kanwar Melas, the abstracted water only requires disinfection. Throughout the year the flow in the Ganga River and Upper Ganga Canal (UGC) is controlled by the Bhimgoda Barrage (or weir) on the river, and an intricate system of smaller weirs and escape channels on the UGC to the south, to ensure sufficient discharge in the canal for irrigation and religious rituals of bathing and worship. However, for a 20-day period annually in Haridwar (October–November), the UGC receives no flow in order to permit dredging and levelling of the fluvial sediments, especially at the bathing sites which are located between the RBF wells and the canal. During this period, the production of these wells decreases significantly.

This study investigates the impact of the three-month monsoon (July–September), the canal closure and the normal surface water levels (November–June) in the UGC and Ganga River on the travel time and flowpaths of bank filtrate.

WATER SUPPLY AND HYDROGEOLOGY OF HARIDWAR

Until the end of 2009, the total 64,000 m^3/day drinking water production of the city of Haridwar was obtained from 16 large-diameter partially penetrating bottom-entry (caisson) wells abstracting bank filtrate (Fig. 1) and 31 vertical wells abstracting mainly groundwater. Out of these, twelve caisson wells are situated along a 3.3-km-long and 190-310–m-wide stretch of land between the UGC and the Ganga River, at a distance of 3–115 m from the canal and its escape and feeder channels. These wells receive a high proportion of bank filtrate (>70%) because of a significant natural gradient between the UGC and the Ganga River. Four more wells are situated approximately 10–50 m from the Upper Ganga Canal to the north of Pant Dweep Island and further upstream within 70 m of the Ganga River. In preparation to meet the large increase in drinking water demand during the huge religious gathering of the Kumbh Mela in January–April 2010, six more new caisson bank filtrate wells of a similar design to the existing wells (Fig. 1) and 19 new vertical wells became operational in January 2010 and will be permanently integrated into the water supply network (Sandhu et al., 2010). The depth of the caisson wells is 7–10 m below ground level and their discharge ranges from 0.01–0.047 m^3/s. The abstracted water is chlorinated at the wells and then routed directly into the distribution network. Previous studies on the quality of the abstracted bank filtrate by the caisson wells have demonstrated that the RBF scheme in Haridwar is a sustainable source of clean drinking water (Thakur et al., 2009; Dash et al., 2010).

On Pant Dweep Island and the area immediately to the island's north (Fig. 1; enlarged area), nine caisson wells (wells 16, 18, 26, 40 and the 2010-built wells of Bhopatwala 1, 2 & 3, Pant Dweep New and Kangra Dweep new) operated by Uttarakhand Jal Sansthan (UJS; Uttarakhand state water supply company) abstract around 518–2,530 m^3/day of raw drinking water per well. The operation of the wells (that use air-cooled centrifugal pumps) is discontinuous depending on the yield and water demand. For instance, while well 40 operates for at least 19 hours/day and is shut down for 5 hours to allow the pumps to cool during periods of low water demand, well 18 operates for around 8-10 hours/day due to insufficient yield (Dash et al., 2010).

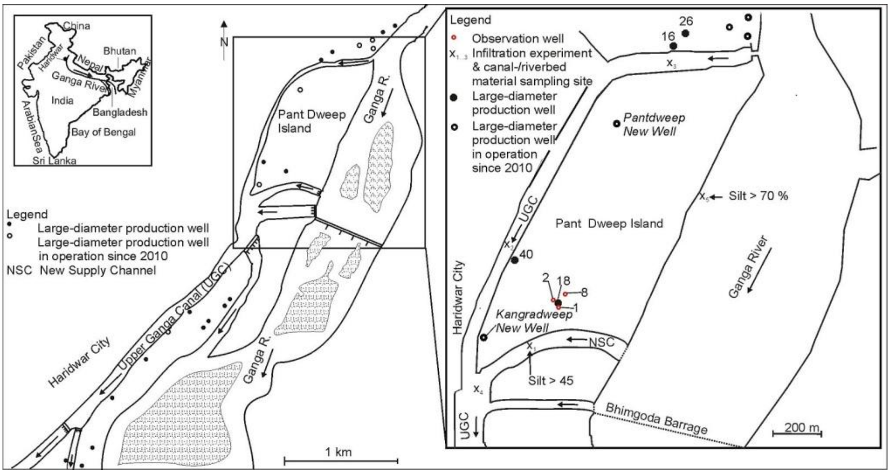

Figure 1. Study area in Haridwar and location of large diameter (caisson) bank filtrate production wells

The Pant Dweep Island was originally influenced solely by the seasonal variation in the flow of the Ganga before the Bhimgoda Barrage was built and thus was also inundated at times by the river resulting in varying rates of sediment deposition. The deposits are overlain by Holocene fluvial boulders (Dash et al., 2010). Grain size distribution analyses of borehole material from two monitoring wells (Fig. 1; 1 & 2 in enlarged area) constructed in 2005 revealed a 21-m-thick unconfined aquifer comprising fluvial deposits of fine to coarse sand and gravel in the upper 12 m followed by finer material comprising mainly silty sand (Sandhu et al., 2006). According to Dash et al. (2010), the hydraulic conductivity (K) calculated after Beyer (1964) for borehole material up to a depth of 14 m below ground level varies from 1.9×10^{-4} to 4.7×10^{-4} $m\cdot s^{-1}$. On the other hand, pumping tests conducted on wells 8, 18 and 40 (Fig. 1) resulted in K values of 2.3×10^{-4}, 7.1×10^{-5} and 1.2×10^{-4} $m\cdot s^{-1}$ respectively. In comparison to well 8 and 40, the very low K value for well 18 is attributed to well clogging and is not a representative value for the aquifer as a whole.

Dash et al. (2010) describe the aquifer as being in direct hydraulic contact with the UGC, New Supply Channel (Fig. 1; NSC) and Ganga River. Results from infiltration experiments in the UGC (Fig 1; locations x_1...x_3, in March 2007), using a piezometer inserted into fine sand lodged between fluvial boulders in the bed of the UGC, gave K values ranging from 0.4×10^{-5} to 8×10^{-5} $m\cdot s^{-1}$. Grain size distribution analyses of superficial UGC bed material (Fig 1; location x_4, in October 2009) resulted in K values of 1.2×10^{-4} to 7.4×10^{-3} $m\cdot s^{-1}$ (after Hazen, 1893). Considering that the UGC has a gradient of around 3‰ along the northern and western boundary of Pant Dweep, and that its bed exhibits a K value nearly equivalent in magnitude to the adjacent aquifer, the clogging of the UGC can also be considered negligible. The removal of the upper UGC bed material by dredging, when the canal is closed for 20 days annually (usually in October–November), and high flow velocity (>1 $m\cdot s^{-1}$) especially during monsoon (July–September) also limit clogging in the UGC. However, the beds of the Ganga River in the reservoir of the Bhimgoda Barrage along Pant Dweep's eastern boundary and the NSC along the island's southern boundary have a high silt content of 40–70% (Fig. 1; sites x_1 & x_5), which likely limits the hydraulic connection with the aquifer to a certain degree. Additionally, the K value of the bed material of the NSC (Fig. 1; site x_1), determined from infiltration experiments, ranges from 0.2×10^{-6} to 9×10^{-6} m·s^{-1}. This is representative of fine sediment material deposited by the barrage outflow as a result of the lower flow velocity (<1 m·s^{-1}) and gradient compared to the UGC.

TRANSIENT-STATE GROUNDWATER FLOW MODELLING

Description of groundwater flow model

To get an improved understanding of the boundary conditions and the travel time and flow-paths of the bank filtrate abstracted by the drinking water production wells, a three-layered groundwater flow model was constructed from the field observations described in section 2 using Processing MODFLOW version 5.3.0 (Chiang, Kinzelbach, 2001) for the existing as well as new caisson wells on Pant Dweep Island and to its north on the bank of the UGC and Ganga River (Tab. 1).

Table 1. Main features of the groundwater flow model for Pant Dweep Island, Haridwar.

Parameter	Characteristics				
Geometry	Area: 2400 m × 2800 m; 37 rows, 46 columns. Cell-size: 5 m × 5 m to 100 m × 100 m				
Boundary conditions	River stage: Field water level measurements on 01.03.2008 Kriver bed: UGC = 1×10^{-4} ... 2×10^{-3} m s^{-1} NSC = 5×10^{-5} ... 4×10^{-4} m s^{-1} Ganga River: = 1×10^{-6} ... 8.3×10^{-5} m s^{-1} Actual production well discharges = 0.019–0.037 m^3 s^{-1} Discharges normalised for 24 hours for model (QAbstraction) = 0.013–0.029 m^{3}s^{-1}				
Time	Stress period	Time step (Length = 30 days/time step)	Month	Remarks	Change in boundary conditions
	1	3	July–September	Monsoon: Increase in surface water levels compared to 01.03.2008	UGC +0.6 m NSC +0.9 m Ganga + 1.7 m
	2	1	October	UGC closed (deactivated)	QAbstraction decreased by 50% (all wells)
	3	8	November–June	Normal post- & pre-monsoon	Normal post- & pre-monsoon conditions
	4	3	July–September	As in stress period 1	As in stress period 1
Initial heads	Interpolation of surface and groundwater level measurements of 01.03.2008				
Aquifer parameters	Kx = Ky = 3.7×10^{-4} ... 5.0×10^{-4} m s^{-1}; Kz = 2.6×10^{-5} m s^{-1} (upper & middle layer) Kx = Ky = 2.7×10^{-4} m s^{-1}; Kz = 2.6×10^{-5} m s^{-1} (lower layer) Specific storage = 0.001; specific yield = 0.25; effective porosity = 0.30				

The cell sizes of the nine production wells in the model domain were refined to a finer resolution having a range of 5 m × 5 m to 50 m × 50 m. The surface and groundwater levels measured on and around Pant Dweep Island on 01.03.2008 were interpolated and assigned as initial hydraulic heads and used for the river stage elevation of the Ganga, UGC and NSC. To account for the partial penetration of the caisson wells, the bottom elevation of the upper layer of the model corresponds to the bottom of the productions wells. The bottom elevation of the middle (second) and lower (third) layers corresponds to the stratigraphy interpreted from the borehole logs of the two monitoring wells on Pant Dweep Island.

All surface water levels were simulated using the river boundary condition. A uniform river bed conductance of 0.5 $m^2 s^{-1}$ was assigned to the cells of the UGC. Depending on the variation of the cell dimensions, this conductance value corresponds to a hydraulic conductivity of 1×10^{-4} m s^{-1} to 2×10^{-3} m s^{-1} (Tab. 1) that closely reflects the hydraulic conductivity determined from the grain size distribution analyses of the UGC bed material and infiltration experiments (Sec. 2.2). The conductance of the bed of the NSC to the south corresponds to a lower hydraulic conductivity of 5×10^{-5} m s^{-1} to 4×10^{-4} m s^{-1}, thereby accounting for the higher silt content lodged between the fluvial boulders as a result of the NSC's low gradient. A hydraulic conductivity of 1×10^{-6} m s^{-1} to 8.3×10^{-5} m s^{-1} was used to calculate the riverbed conductance of the Ganga in the reservoir of the Bhimgoda barrage to the east of Pant Dweep Island to account for clogging and the high deposition of silt. Due to the variation in the discharge and the duration of daily operation between the wells, the actual discharges and pumping hours of the nine production wells were normalised for twenty-four hours, causing the model discharge values to range from 0.013 to 0.029 $m^3 s^{-1}$ (Tab. 1).

Simulation of scenarios

The transient groundwater flow model was run for one complete continuous cycle to simulate a 15-month period that starts with the monsoon at the beginning of July in the current year (stress period 1, time step 1) and ends at the end of the monsoon in the following year (stress period 4, time step 15) as shown in Tab. 1. During this cycle the Upper Ganga Canal closes for 20 days (usually October-November) after the monsoon in the current year ends (stress period 2, time step 4). After the UGC reopens, whose flow s regulated throughout the year, no major changes occur in the water level of the canal till the onset of the monsoon in July of the following year (stress period 4, time step 13). The inclusion of two monsoon phases was necessary in order for the model to attain the starting groundwater levels (that were simulated in stress period 1, time step 1) again after a one year cycle.

TRAVEL TIMES AND FLOWPATHS OF BANK FILTRATE

For the production wells located close to the UGC, the travel time of the bank filtrate from the canal to the wells is less than a month when the simulation starts at the beginning of the monsoon in the current year (Fig. 2A). Towards the end of the monsoon in September, an increase in the groundwater levels on Pant Dweep Island of more than 0.5 m can be observed, as depicted by the general southward movement of the groundwater contours (Fig. 2B). The wells close to the UGC also begin to receive a higher proportion of bank filtrate at this stage. Then, the groundwater levels and flow velocity decrease around the wells close to the UGC during its closure (Fig. 2C) and in the period of resumption of operation (Fig. 2D). However, within one year of operation, all wells receive bank filtrate (Fig. 2E) whose proportion is sustained by the second monsoon season accompanied by higher groundwater levels on Pant Dweep Island (Fig. 2F).

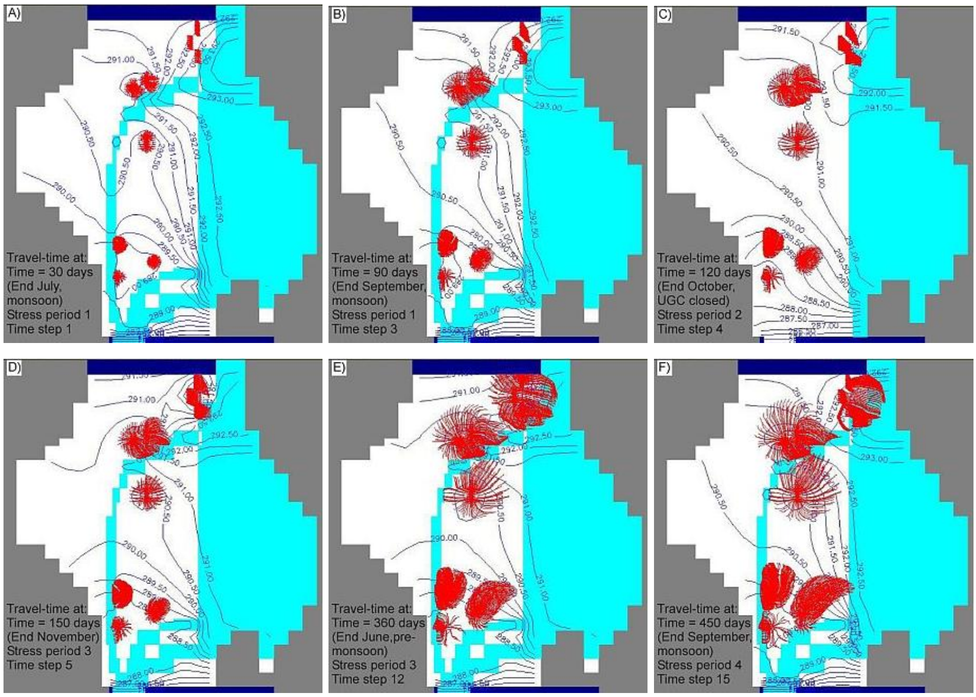

Figure 2. Travel times and flowpaths of bank filtrate to production wells on and to the north of Pant Dweep Island, Haridwar, under different surface water flow scenarios.

CONCLUSION

The closure of the UGC has no long-term adverse impacts on the volume and quality of bank filtrate. But during the 20-day closure, the operating hours of all wells decrease and thereby the production rates normalised for 24 hours also decrease (all pumps operate at a single frequency). The increased groundwater abstraction to compensate for the reduced bank filtrate production is sustainable because the parent groundwater is originally bank filtrate infiltrated more than 2 years prior along the river upstream of the Bhimgoda Barrage where the flow remains significant throughout the year. The annual UGC maintenance closure also disturbs the clogging layer of the canal in places where the dredging occurs. While this could increase the yield of the wells, it could also permit greater and more rapid entry of contaminants into the groundwater ultimately abstracted by the drinking water wells. As the level of dissolved organic carbon and coliform bacteria is comparatively low in the Ganga upstream of the Bhimgoda Barrage, one of the main risks of the dredging of the UGC bed could be from shock loads of organic compounds that may accidentally enter the river.

ACKNOWLEDGEMENTS

The authors are grateful to the financial support of the German Federal Ministry of Education and Research (BMBF) to the project Riverbank Filtration Network (BMBF IND 08/156) funded within the BMBF's programme "India and Germany — Strategic Partners for Innovation". The financial and logistic support of the water companies Stadtwerke Düsseldorf AG in Germany and Uttarakhand Jal Sansthan in India towards the Cooperation Centre for Riverbank Filtration in Haridwar to help conduct this study is also gratefully acknowledged.

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IAH 2010
Krakow

abstract id: **246**

topic: **6**
General hydrogeological problems

6.7
Managing aquifer recharge

title: **Effect of vegetation cover on infiltration rates in artificial basins**

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keywords: infiltration, vegetation, infiltration basin

INTRODUCTION

The area of impervious cover in urban environments, including roads, paved surfaces and railways, is continuously increasing. To limit the resulting impact on the water balance and groundwater levels, surface water runoff is often collected and transported to artificial infiltration basins or natural infiltration areas. The infiltration capacity of infiltration basins, ponds and constructed wetlands often decreases after several months or years. Small sediment particles and organic material is retained in the pore space which results in clogging and reduced infiltration rates. Removal of the clogging layer in order to achieve the initial infiltration capacity is costly.

There is a dispute over the advantages or disadvantages of vegetation cover in infiltration basins among practitioners and researchers. Some researchers found that the infiltration rates are higher with vegetation cover compared to bare soils (Gajic et al., 2008; Orradottir et al., 2008; Hatt et al., 2009; Martinez-Zavala, Jordán-Lopéz, 2008). Vegetation cover may change as a result of climate change, e.g. long dry periods during summer. This affects the rate of infiltration during storm events. Lange and Scheufele (1987) illustrated that grassland has a positive effect on infiltration rates. Infiltration increases due to higher soil humidity (shadowing effect) and roots of vegetation in the upper soil layer. However, the infiltration capacity can decrease if a biofilm is created. This may occur when a reservoir is filled over a long time and the vegetation is not suitable for the site conditions.

The objectives of this study were to: (1) analyse the infiltration rate at storm water infiltration basins beside motorways and (2) to investigate the impact of typical wetland plants and their effect on infiltrations rates in artificial basins.

MATERIALS AND METHODS

Site description

The study includes investigations at four sites in Saxony, Germany between 2009 and 2010: (1) a storm water infiltration basin beside a motorway near Dresden, (2) a newly constructed wetland for wastewater treatment in Reichenbach, (3) a fallow field near Meissen and (4) a rain water infiltration trench in Dresden-Pillnitz. The main focus of this article is on the motorway storm water infiltration basin. Results from investigations at the other three sites will be discussed in other papers.

The study site at the motorway in Dresden includes three storm water infiltration basins with areas of (B1) 845 m^2, (B2) 1213 m^2 and (B3) 2520 m^2. The basins were constructed in 2000 and partially reconstructed in 2005. Each basin consists of three main parts: (1) a settling basin, to remove small particles like dirt and dust to prevent clogging of the infiltration basin and to capture floating solids like heavy metals (e.g. lead, cadmium, nickel, copper, zinc) (2) a down-flow baffle and (3) an infiltration basin. The infiltration basin at B2 is 4.5 times larger than the settling basin (Figs. 1 & 2). The upper soil in the infiltration basin was sampled by digging a hole to a depth of 50 cm. The soil can be characterized as sand and consists of 1.7 % silt, 86.4 % sand and 11.9 % gravel.

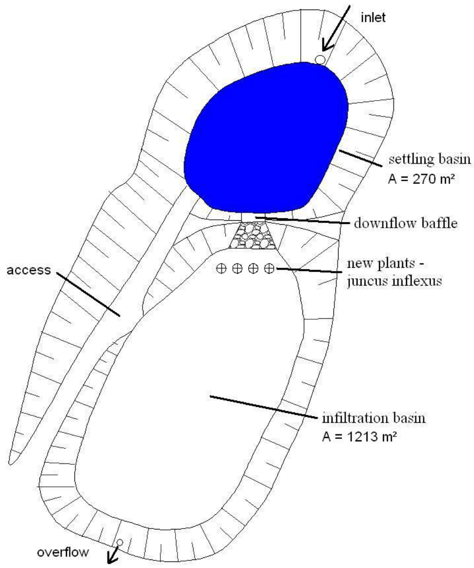

Figure 1. Layout of the storm water infiltration basin B2.

Figure 2. Cross section of the storm water infiltration basin B2.

Dresden has a cold-moderate to continental climate with hotter summers and colder winters than the German average. The average value of selected climate parameters of the Dresden-Klotzsche climate station is shown in Tab. 1 for the period from 1961 to 1990. The average temperature in January is 0.8°C and in July 17.9°C. The driest months are February and March, with precipitation of 39 mm and 42 mm per month. The wettest months are June and August, with 75 mm and 76 mm per month.

Table 1. Average values of climate parameters — Location Dresden-Klotzsche (222 m above sea level), 1961–1990.

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
Air Temperature in °C	0.8	0.3	3.7	7.9	13.0	16.3	17.9	17.6	14.1	9.7	4.4	0.9	8.8
Precipitation (P) in mm	45	39	42	53	63	75	69	76	51	46	51	58	668
Days with P ≥ 0.1 mm	17.6	15.3	15.5	15.4	15.2	15.4	14.1	13.7	13.2	13.0	16.3	18.7	183.4
Days with P ≥ 10 mm	0.5	0.5	0.7	1.3	1.7	2.3	2.1	2.2	1.4	1.2	0.9	1.1	15.9

Planting of a test area

Artificial basins are ecosystems with seasonally flooded or waterlogged conditions. The selected plants have to grow under these changing conditions with strong root growth. Lesser pond-sedge *carex acutiformis* and European meadow rush *juncus inflexus* are plants typical of wet areas. Grass is a typical plant in dry areas and the reed *phragmites austral* is a typical plant in flooded areas. These kinds of marsh plants can be found in nature all over the world and are suitable for a range of applications.

The species *Juncus inflexus* was planted over an area of more than 10 m^2 in November 2009 at each storm water infiltration basin, to determine the effect of roots on infiltration rates. The remaining area of the infiltration basins is overgrown by grass.

Methods for measuring hydraulic conductivity

The first measurements were made in summer 2006. The infiltration rates were measured using two different methods: double ring infiltrometer tests and laboratory column experiments. The measurements were repeated in summer 2009 using the same methods at the same places in the basin as in the year 2006.

The inner and outer rings of the double ring infiltrometer have a diameter of 30 cm and 60 cm, respectively. The rings were driven 20 cm into the ground and a constant water level in the inner ring was maintained by using a Mariotte's bottle (Fig. 3). Darcy's equation was applied for the calculation of hydraulic conductivity (*K*).

The soil column experiment is another method to determine hydraulic conductivity. Metal columns with 10 cm diameter and a length of 55–100 cm were driven into the ground using a hammer (Cobra, Atlas Copco). The columns were extracted using a hydraulic system, closed with special fittings, placed in a special box and transported to the geohydraulic laboratory of the University of Applied Sciences Dresden. Figure 4 shows the experimental setup to measure the flow passing through the soil column. The soil columns are fixed at the ground (1) and the water flows through the columns under an adjustable head difference (3). The volumetric flow rate can be measured per time using overflow buckets (2). The soil columns must be saturated before starting the experiment.

Figure 3. Double ring infiltrometer.

Figure 4. Soil column experiments.

The temperature of the infiltrated water is measured to normalize the hydraulic conductivity for 10 °C using a formula of Poiseuille:

$$K_{10^\circ C} = \frac{1.359}{1 + 0.0337 \cdot T + 0.00022 \cdot T^2} \cdot K = \alpha \cdot K \quad [m/s]$$

where:

T — water temperature [°C],

K — hydraulic conductivity without temperature standardization [m/s].

Table 2. Factor α including the viscosity of water.

Temperature in °C	5	10	15	20	25
α	1.158	1.000	0.874	0.771	0.686

Before measuring the infiltration using double ring infiltrometers each point was flooded over several minutes to achieve saturation. The measurements were repeated at least once for each measuring location and the mean value was recorded.

RESULTS

The comparison of the measurements from the years 2006 and 2009 revealed some significant changes in the infiltration rate. Figure 5 shows the measured infiltration rates in basin B1 and basin B2 using a double ring infiltrometer. In basin B1 the infiltration rate decreased at 5 of 8 locations by 80 % and remained constant at the other 3 locations.

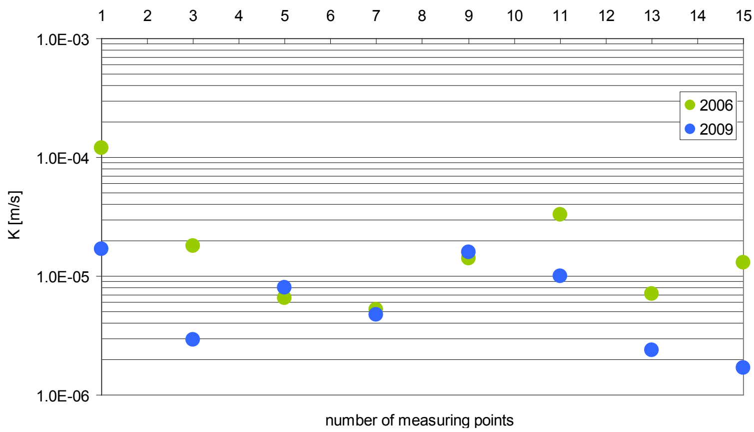

Figure 5. Hydraulic conductivities determined using a double ring infiltrometer in basin B1 (measuring locations 1–7) and basin B2 (measuring locations 9–15).

Figure 6 shows the infiltration rates in basins B1 and B2 determined using the soil column experiments. The infiltration rate decreased at 4 of 8 measuring locations, was constant at 2 locations and increased at 2 locations. The changes in the infiltration rate indicate increased clogging of the basin. Of course, the local infiltration rate depends on the soil structure and the pore system of the soil. Results can be substantially skewed by preferential flowpaths, wormholes or even large pebbles in the subsoil. Compaction and different saturation of the soil could be other reasons for differences, thus demanding a high number of measuring points to achieve reliable results.

The K-values determined in the column experiments were higher than those from the double ring infiltrometer. By hammering the columns into the ground, the upper millimetres of a potential clogging layer might be disturbed. Furthermore, the side effects at the column wall may have greater impact because the area is smaller than in the double ring infiltrometer. The differences between the results from the infiltrometer measurements and the column experiments warrant further research, as well as into the influence of compaction and saturation.

The results of the measured K-values or infiltration rates at the newly planted section in storm water infiltration basin B1 are shown in Figure 7.

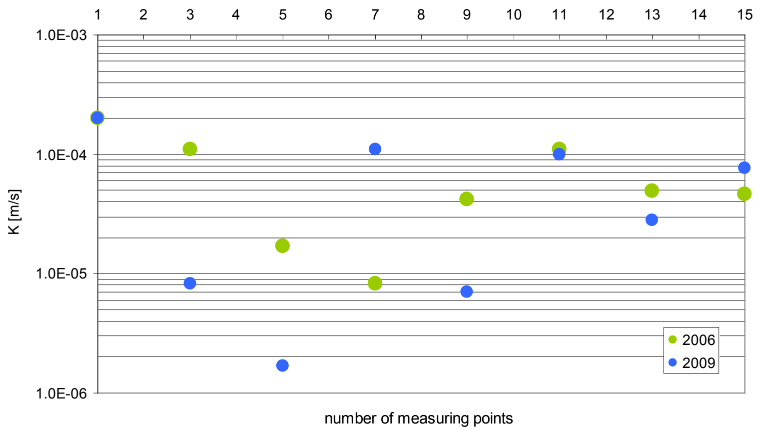

Figure 6. Hydraulic conductivities determined using soil column experiments for basin B1 (measuring locations 1–7) and basin B2 (measuring locations 9–15).

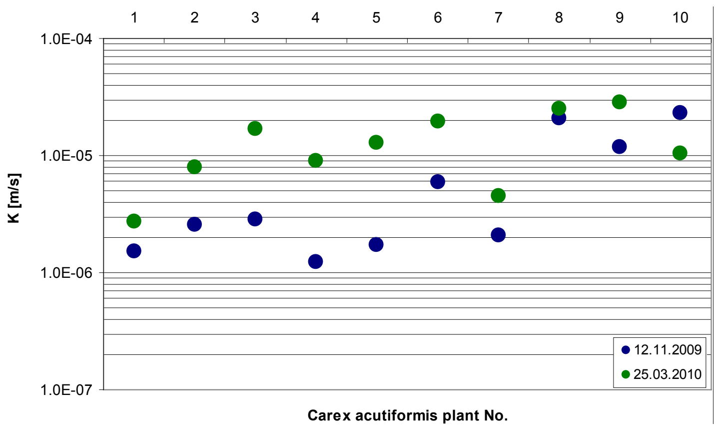

Figure 7. Changes in the infiltration rate of the storm water infiltration basin B1.

The infiltration rate increased an average of 63% at 9 of 10 locations over 4.5 months from November 2009 to March 2010, which might be a result of the long winter in 2009/2010 with severe frost and the loosening of the ground during planting. The (promising) changes in the infiltration rate do not yet allow a clear statement about the effect of vegetation cover. A complete growing season is essential to properly analyse the effect of vegetation and to obtain significant results, which will be shown after September 2010.

CONCLUSION

It is assumed that the infiltration rate in artificial basins can be maintained or even improved by the introduction of suitable plants. Based on the present results and literature studies, an increase of hydraulic conductivity by an order of magnitude is expected. It should be possible to make more precise suggestions regarding the design and planting of artificial basins after analysing the results from the 2010 growing season.

ACKNOWLEDGEMENTS

This project was supported by a grant from the Ministry of Science and Art, Saxony (SMWK 475316002512009/3).

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IAH 2010
Krakow

abstract id: **269**

topic: **6**
General hydrogeological problems

6.7
Managing aquifer recharge

title: **Extensive aquifer recharge through atmospheric chloride deposition on the land by means of groundwater from penetrating wells**

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keywords: chloride deposition, recharge, aquifers, mixed samples

INTRODUCTORY REMARKS

Aquifer recharge is the water arriving at the water table as a result of precipitation and occasionally surface water infiltration, including excess irrigation water and possible leakages. The transit from the soil root zone to the water table means a delay and also a smoothing out of precipitation irregularity. Most of rainfall infiltration is temporarily stored in the root some and partly evaporated, although a fraction may penetrate below the root zone through soil discontinuities, thus avoiding evapotranspiration. When the water table is shallow groundwater may be up–taken by permanent or alternative phreatophytes or evaporated. Net recharge is then diffuse recharge arriving to the water table (total recharge) less groundwater evapotranspiration and the possible vadose zone lateral recharge. What follows refers mostly to diffuse rainfall recharge under Mediterranean climates, especially in areas with a remarkable topographical relief and relatively deep water table.

Aquifer recharge is essential to evaluate aquifer renewable water resources for water studies and management. However this is one of the most difficult issues in hydrogeology. In order to get reasonable results, as many different appropriate techniques as possible should be used. The most used ones for total diffuse recharge are those relying on soil water balance. In order to check the evaluations, the use of other independent methods is advisable, even if they are simple ones. The chloride mass balance method is one of them and the subject of this paper. It is not a novel method (Eriksson, 1960; Prych, 1998; Custodio, 2009) and is has been used widely, but some caution is needed. Commonly the results are long–term recharge values.

ATMOSPHERIC CHLORIDE BALANCE IN THE SOIL

Precipitation is a source of chloride, a conservative and non complexed ion under most natural circumstances. It falls dissolved in rain water (wet deposition) and contained in dust (dry fallout or dry deposition). The main chloride source is the sea, but there are also chlorinated volatile compounds in the air, and continental and lithologic sources. Deposition values are obtained by means of sampling stations operated along some time. Anthropogenic sources are a disturbance to be avoided.

In a given parcel and time interval, the water and chloride mass balances in the vadose zone column, assuming only rainfall input and that there is no significant lateral outflow from the vadose zone, is:

$$P = R + ES + \Delta S + E \qquad \text{water balance} \qquad (1)$$

$$A = R \bullet C_R + ES \bullet C_{ES} + \Delta SC + F \qquad \text{chloride mass balance} \qquad (2)$$

where:

P = water precipitation on the land

R = net diffuse recharge to the water table

ES = surface runoff from the area

ΔS = increase in root zone soil water

E = total evapotranspiration (vadose zone + water table), which is chloride–free water vapour

A = atmospheric bulk chloride deposition

C_R = average chloride concentration in recharge water

C_{ES} = average chloride concentration in runoff

ΔSC = change (increase) of root zone soil chloride mass storage

F = other sources of chloride

The long–term balances are obtained by adding the successive time intervals:

$$\sum P_i = \sum R_i + \sum ES_i + \sum E_i \;;$$

$$\sum A_i = \sum\left(R_i \bullet C_{Ri}\right) + \sum\left(ES_i \bullet C_{ESi}\right) + \sum\left(F_i\right) \qquad (3)$$

in which the storage changes cancel out.

$\sum A_i \equiv \sum\left(P_i \bullet C_{Pi}\right)$ in which C_{Pi} is the rain sample concentration (including dry deposition) for a precipitation P_i in a given sampling interval. In developed soils F can be safely neglected except when evaporites and recent unleached saline sediments are present.

If $\overline{C}_R$ is the average chloride concentration at the water–table top, for a simple case and a series of n complete years, the average recharge value $\overline{R}$ is:

$$\overline{R} = \frac{1}{n}\left[\sum^{n} A_i - \sum^{n}\left(ES_i \bullet C_{ESi}\right)\right]\frac{1}{\overline{C}_R}$$

whose estimation uncertainty can be evaluated by error propagation. A calculated negative value of $\overline{R}$ may be due to errors in the estimation of $\overline{A}$, $\overline{ES}$, $\overline{C}_{ES}$, or non–representative $\overline{C}_R$ values. For a permeable soil in flatland ES is small, provided the ground does not become water logged or frozen. When ES and ES•C_{ES} are not negligible and are not considered, $\overline{R}$ results too high. In thick unsaturated zones in dry climates –small recharge– the effect of past climate changes may still be moving down, so water entering the water table is not current recharge but recharge under past conditions.

UPSLOPE RECHARGE CONTRIBUTION

Groundwater mixing is a common fact for springs, long–screened wells, and stream base–flow. Therefore, samples do not yield the local C_R value. The chloride content of these samples, C_M, corresponds to a weighed mixture of water recharged at other sites and altitudes. The C_M value can be used to yield lumped aquifer recharge rates over the aquifer catchment by assuming an exponential mixing model.

In the situation depicted in Figure 1A, H is land elevation, and h the water–table elevation, all of them above the discharge base, such as a major river, the coast, a large lake, or a highly pervious aquifer. P is the average precipitation and R the average recharge, with respective average chloride contents C_P and C_R, which vary with location. Steady state is assumed and runoff is taken as negligible, or its effect is previously discounted from rainfall contribution.

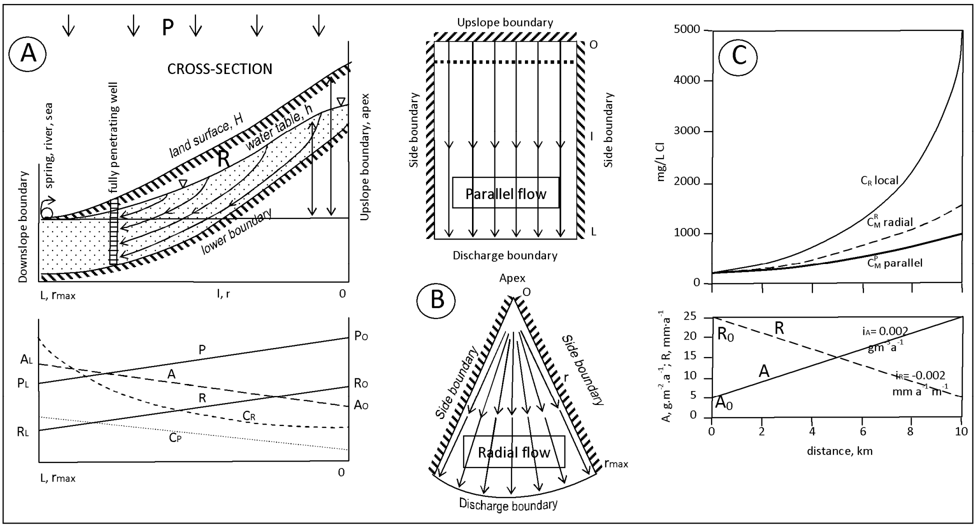

Figure 1. Behaviour of a slopping aquifer. A.– Cross–section and assumed evolution with altitude of P, R, A, C_P and C_R. B.– Parallel and radial flow aquifers along which recharge and chloride mass are integrated, C.– Results for linear variations of R and A along slope and the resulting differences between C_M^P (parallel flow), C_M^R (radial flow) and local recharge chloride concentration (after Custodio, 2009).

For parallel flow lines (Figure 1B), the water and mass (chloride) balances per unit width at distance l from the divide can be computed:

Flow per unit width at l (x is an intermediate distance dummy integration variable).

Water balance $q_l = \int_o^l R(x)dx$; Mass balance $q_l^c = \int_o^l R(x)C_R(x)dx$ (5)

For divergent flow lines (flow in a wedge–shaped aquifer) the same reasoning can be applied (Figure 1B), in which case r is the distance to the apex and ρ the dummy integration radius. Flows are total flows through the section, per unit angle (radians):

Water balance $Q_r = \int_o^r r\, R(\rho)d\rho$; Mass balance $Q_r^c = \int_o^r \rho\, R(\rho)C_R(\rho)d\rho$ (6)

Then, the average chloride content C_M^P for parallel flow at l and C_M^R for radial flow at r are:

$$C_M^P = \frac{q_l^c}{q_l} = \frac{\int_o^l R(x)C_R(x)dx}{\int_o^l R(x)dx} \quad \text{and} \quad C_M^R = \frac{Q_r^c}{Q_r} = \frac{\int_o^r \rho\, R(\rho)C_R(\rho)d\rho}{\int_o^r \rho\, R(\rho)d\rho} \qquad (7)$$

Chloride concentration in the top of the water table at distance l is $C_R(l)=A(l)/R(l)$ and at radius r is $C_R(r)=A(r)/R(r)$. They may be very different from C_M measured at the same place (see Figure 1C).

Since C_R may vary remarkably and non linearly from top down, it is more convenient to refer it to the smoother variable A, being $A \equiv R(l) \bullet C_R(l)$, or $A \equiv R(r) \bullet C_R(r)$. Then equations [6] transform into:

$$C_M^P = \frac{\int_o^l A(x)dx}{\int_o^l R(x)dx} \text{ for parallel flow ; } C_M^R = \frac{\int_o^r \rho\, A(\rho)d\rho}{\int_o^r \rho\, R(\rho)d\rho} \text{ for radial flow} \qquad (8)$$

If R and A vary lineally, with top–down slopes (negative for decreasing values), designed as i_R and i_A, respectively, the linear variations are:

$$R(x) = R_O + i_R x \quad ; \quad R(\rho) = R_O + i_R \rho \qquad (9)$$

$$A(x) = A_O + i_A x \quad ; \quad A(\rho) = A_O + i_A \rho \qquad (10)$$

where R_0 and A_0 are respectively the recharge rate and the atmospheric bulk chloride deposition at the upper boundary or apex. Results are:

$$\frac{1}{C_M^P} = \frac{2R_O/A_O + (i_R/A_O)l}{2+(i_A/A_O)l} \quad ; \quad \frac{1}{C_M^R} = \frac{3R_O/A_O + 2(i_R/A_O)r}{3+2(i_A/A_O)r} \qquad (11)$$

Plotting $1/C_M$ versus l or r allows drawing a curve (about a straight when i_A is small). The coordinates of three points distributed along it can be used to solve for the unknowns.

In the cases in which A is almost constant ($i_A \approx 0$):

$$\frac{1}{C_M^P} = \frac{R_O}{A} + \frac{i_R}{2A} l \quad ; \quad \frac{1}{C_M^R} = \frac{R_O}{A} + \frac{2}{3}\frac{i_R}{A} r \qquad (12)$$

In a plot $1/C_M$ vs. l or r, they are straight lines with intersects R_0/A and respective slopes $\frac{i_R}{2A}$ and $\frac{2}{3}\frac{i_R}{A}$.

SIMPLE APPLICATION EXAMPLES

Several application to slopping and varied topography aquifers have been considered in Custodio (2009) and the method has been applied to the whole Spanish territory in the Iberian Peninsula (Alcala, 2006) and the estimation errors are been analysed and refined in two papers under review. Figure 2 shows the results from a well–recharge sandy area and variable rainfall and arid basins from a volcanic island. Figure 3 considers results for the Iberian Peninsula, with a rough estimation of uncertainty.

ACKNOWLEDGEMENTS

The authors acknowledge the support received by the Geological Survey of Spain (IGME) and the Spanish Committee for Science and Technology (CICYT, HID–99–205), and currently through CICYT project REDESAC (CGL2009–12910–C03–01).

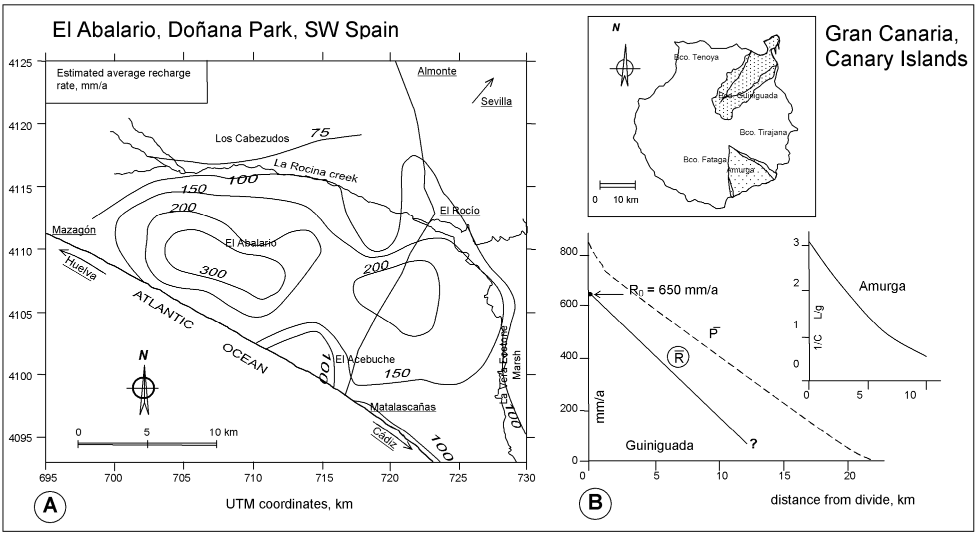

Figure 2. Two local examples of recharge estimation (mm/a) through atmospheric chloride mass balance. A.– The eolian sand covered area of El Abalario, Doñana, SW Spain, B.– altitudinal variations of recharge in Gran Canaria volcanic island, for the Guiniguada basin (wet to semi–arid) and Amurga massif (arid: $\overline{\mathbf{R}}$ is 10 mm/a, R_o=30 mm/a (after Custodio, 2009).

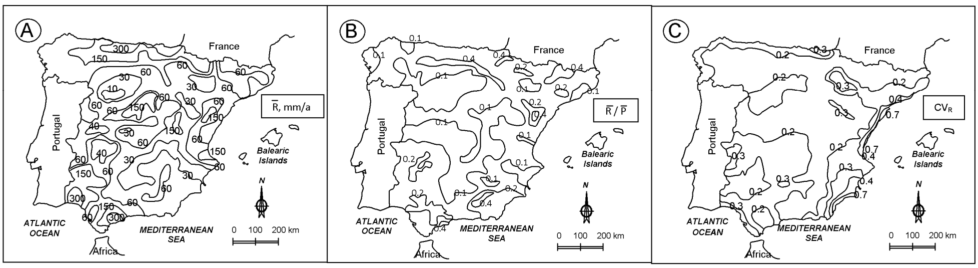

Figure 3. Average recharge in Peninsular Spain after Alcalá (2006). A.– Average recharge in mm/a. B.– Ratio of average recharge to average precipitation. C.– Preliminary coefficient of variation (standard deviation/mean value, as a fraction) of recharge; upgraded data series treatment reduces the higher values by a factor about 2.

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abstract id: **294**

topic: **6**
General hydrogeological problems

6.7
Managing aquifer recharge

title: **A coupled groundwater flow, solute and heat transport model to facilitate operation of an aquifer storage transfer and recovery system in a brackish aquifer**

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keywords: managed aquifer recharge, Feflow, groundwater modelling

INTRODUCTION

Groundwater recharge, retention and reuse are recognised as adaptive strategies to increase security of water supply (van Steenbergen, Tuinhof, 2009). An example using reedbed-treated urban stormwater in an Aquifer Storage Transfer and Recovery (ASTR) system has been tested in the city of Salisbury, South Australia (Dillon, 2005; Rinck-Pfeiffer et al., 2005). Similar to Aquifer Storage and Recovery (ASR) systems that operate throughout the world, ASTR is a method of utilising subsurface storage to provide a reliable buffer against seasonal variation in water demands and supplies while also providing natural treatment to take place within the aquifer. While ASR uses the same well for both injection and extraction, the ASTR system uses separate injection and extraction wells to provide a longer and more uniform residence time in the aquifer (Dillon, 2005). This residence time ensures that the degradation of potential contaminants is more efficient but can also increase the potential for mixing between the injectant and the ambient groundwater. In Salisbury, the brackish aquifer had to be efficiently flushed to recover freshwater suitable for urban reuse.

Eventually, the aquifer is intended to be a reliable source of potable quality water.

A finite element groundwater code FEFLOW (Diersch, 2009) was used to simulate injection and extraction operations in well fields of various designs (Pavelic et al., 2005), and following site construction and initial operation, the model was subsequently calibrated with data from pumping tests, hydraulic head variations and solute breakthrough to wells (Kremer et al., 2010) and subsequently also using water temperature.

The objective of the research is to combine the use of solute and heat transport to reduce uncertainty in groundwater modelling of the ASTR system.

STUDY SITE

The bore field consists of 6 wells positioned within a rhombic domain (4 outer wells and 2 central wells), with a uniform 50 m separation between the wells. The captured stormwater is injected to the confined T2 carbonate aquifer between depths of 160–220 m (Fig. 1).

Regional groundwater flow gradient is 0.0015. The transmissivity of the aquifer is 120 m^2/d. The ASTR wells are however screened only in the upper part of the profile (T2a, T2b) where permeability of the aquifer is lower (T = 50 m^2/d). The reason for this was to avoid short residence times of injected water before recovery.

In the initial phase of the site operation (i.e. flushing period) the stormwater was injected using the two wells located in the central part of the bore field. Once the salinity had declined in the four outer wells, these were used as the injection wells for ongoing operation, and water was extracted from the two inner wells. As a result, 377 × 10^3 m^3 of stormwater was injected from September 2006 to June 2008 (Table 1).

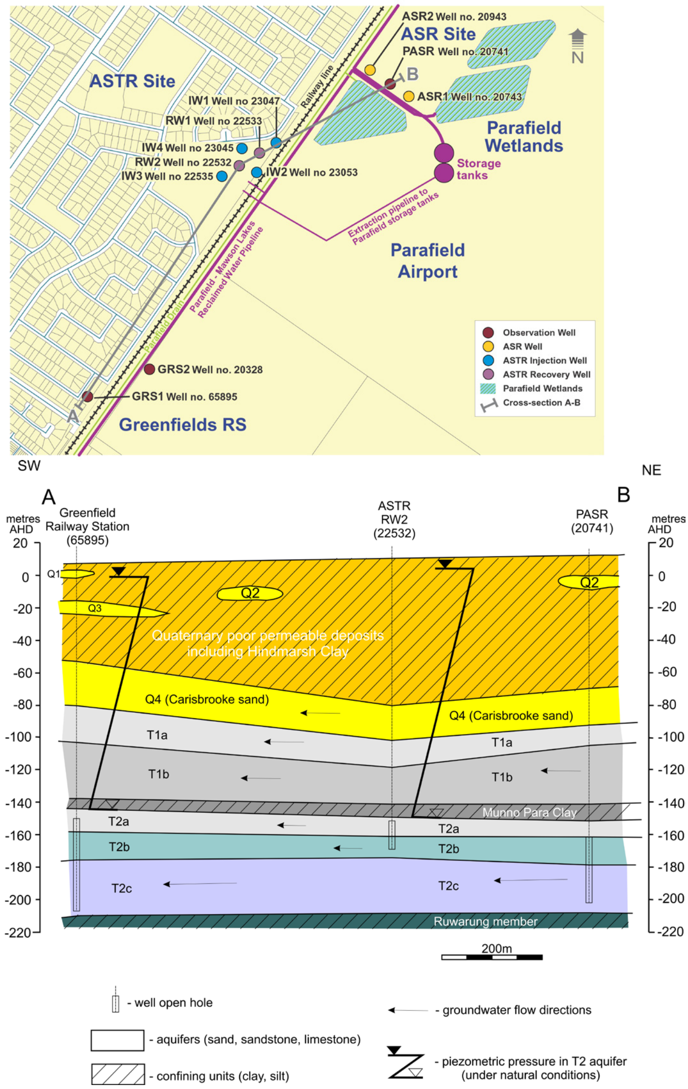

Figure 1. Map of the site and hydrogeological cross-section through Cenozoic deposits.

Table 1. Quantities of water (in 103 m^3) injected (+) and extracted (-) at ASTR system from September 2006 to March 2009.

	IW1	IW2	IW3	IW4	RW1	RW2	TOTAL	
							injected	extracted
Sept 2006 June 2008	0.0	0.0	0.0	0.0	+197.3	+179.8	+377.1	0.0
Sept 2008 Jan 2009	+9.1	+9.0	+3.0	+8.8	+0.1 –0.3	0.0 –0.7	+30.0	–1.0
Feb 2009 Mar 2009	0.0	0.0	0.0	0.0	–44.8	–44.8	0.0	–89.6

METHODS

Salinity (Electrical Conductivity, EC) and temperature of water was monitored using periodic profiling. Electrical conductivity is considered to be a conservative tracer here, although dissolution of calcite due to injection of stormwater is feasible. Thermal properties of limestone are known from the literature (Clauser, Huenges, 1995). The FEFLOW (Diersch, 2009) finite element code was applied to simulate groundwater flow as well as transport of solute and heat in the aquifer. The three-dimensional solute and heat transport model was calibrated using a trial-and-error method on the basis of breakthrough curves for the outer wells during the initial flushing phase.

RESULTS AND DISCUSSION

The ambient groundwater was brackish (3650 μS/cm on average) with a temperature of 27°C, whereas the injected stormwater was fresh (250 μS/cm on average) and exhibited temperature variations in the range of 8-15°C in winter, when most water was injected.

Injection of stormwater over 857 days of aquifer flushing resulted in the decrease in EC of groundwater from 3650 μS/cm to 700 μS/cm at the outer wells and a decline in temperature from 27 to 20.5°C at the outer wells (shown for IW3, Fig. 2). The temperature breakthrough curve is retarded (R≈2) compared with EC (Fig. 2), which is consistent with the theory of heat transport in aquifers (Anderson, 2005). The modelled values fit the observed data well during the flushing period.

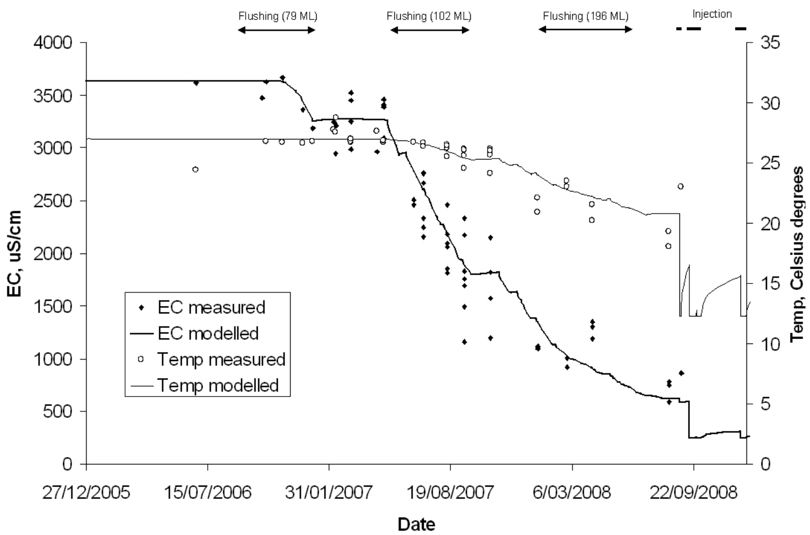

Figure 2. Observed and modelled breakthrough values of EC and temperature of water in the outer well IW3 (This well was first used as an injection well in Sept 2008, which caused step changes in EC and temperature).

Given the variable nature of rainfall and subsequently the volume of stormwater available for recharge, the numerical model was used to simulate a range of operating scenarios in dry, typical and wet sequences of rainfall years. This enabled an operating rule to be defined to allow operators to predict the volume of water recoverable at suitable quality for the following summer based on the volume of winter recharge, while also ensuring the storage zone remains fresh and sustains ongoing operation as a drinking water supply. The results suggest that at this site ASTR can be an effective means of improving quality of recharged water while meeting salinity constraints (Kremer et al., 2010).

The coupled model of groundwater flow, solute and heat transport is a powerful tool to analyse the interactions among the wells in the ASTR system. We showed that groundwater flow and solute transport model can be constrained by using temperature data which can be measured easily and rapidly during a typical groundwater survey. FEFLOW has the capability of simulating both solute and heat transport concurrently, which is a big advantage of this code. Nevertheless, further evaluation of the presented model against data taken from a prolonged storage and extraction periods is required. Other environmental tracers (SF_6) will be helpful in the examination of the heterogeneity of the aquifer and in the improvement of the model.

ACKNOWLEDGEMENTS

The ASTR project is supported by the Australian Government Department of Innovation, Industry, Science and Research through its International Science Linkages Programme. The project is also supported by the South Australian Premier's Science and Research Foundation and the Australian Government National Water

Commission through the Water Smart Australia Programme commitment to Water Proofing Northern Adelaide Project. Project partners include CSIRO Land and Water, City of Salisbury, United Water, SA Water Corporation and the SA Department of Water, Land and Biodiversity Conservation (DWLBC).

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IAH 2010
Krakow

abstract id: **343**

topic: **6**
General hydrogeological problems

6.7
Managing aquifer recharge

title: **Artificial recharge in the office yard of Jakarta, Indonesia: An optimization effort**

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keywords: artificial recharge, pond, well, gallery, groundwater

High rainfall intensity combined with the densely populated area are making the greater area of Jakarta is almost always experiencing flood disaster every rainy season.

Average annual rainfall of Jakarta is between 2500 mm and the rainy season is lasting from October to April. On the other hand groundwater shortage problem occurs during dry season. To resolve the situation an experiment to artificially recharge the runoff water from an office area have been done using combination method of pond, gallery and well. Roof top water from an office building is diverted into the pond that has been completed with several recharge wells and gallery. Recharge into the aquifer is made through the well and gallery. After 4 months no flooding took place in the office area.

The groundwater level in the monitoring well increases from –6 m to –3.8 m below the surface. This artificial recharge also resulted in the improvement of water chemical properties of Fe^{2+} and Mn^{2+}. One problem in this experiment is the clogging of the recharge well. Run off water used for recharge contains too much suspended solid. Surging and flushing was carried out to solve the problem. This paper elaborates some efforts and results which have been carried out to increase the recharge capacity in the study area.

abstract id: **420**

topic: **6**
General hydrogeological problems

6.7
Managing aquifer recharge

title: **Groundwater recharge — evaluation, methods and results**

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Groundwater recharge is an important issue considering water management and water quality protection from land surface. Groundwater recharge assessment methods could be divide into several groups: water balance, lysimeter, isotopic techniques, numerical modeling, heat transport or water level fluctuations or hydrograph separation method. Water balance methods despite knowledge on precipitation distribution require assessment of evapotranspiration what creates difficulties. Lysimeter measurements are expensive point field experiment and allow precise calculations in shallow zones. Isotopic techniques like heat transport provide good results in local scale and does not include regional variations. Method of water level fluctuation despite having long series of observation needs assumption the constancy of parameters aquifers. For regional evaluation of special important are numerical modeling methods, based on the flow system analysis, as well as the method of hydrograph separation what illustrating the final effect of the effective infiltration and covering the whole study area (Brodie, Hostetler, 2005). An overview of process and techniques could be found in many papers summarized for example in Pleczyński (1981), Pazdro and Kozerski (1990), de Vries and Simmers (2002), and Scanlon et al (2002).

In Poland, most of these methods are applied and especially water balance (for example Pleczyński, 1981). In groundwater resources documenting process the most appropriate and recommended are method of water balance and effective infiltrate based mainly on permeability of surface rocks (Paczyński, 1995, Instruction) associated with methods of long-term pumping tests results and more popular numerical modeling.

Poland, located in moderate climatic condition, receives low annual amount of atmospheric precipitation as average equals 600 mm. Only in southern part within Carpathian and Sudeten Mountains rainfall up to 1200-1400 mm is reported. According to normal evaluated value of the effective infiltration only 18.2 % of this amount renew country groundwater resources (Pazdro, Kozerski, 1990). However a significant spatial and temporal variability is observed.

Evaluation of groundwater recharge has been calculated during Groundwater vulnerability map of Poland elaboration (Duda et al., 2007). Considering the amount of water entering shallow groundwater system two methods of recharge has been tested. Effective infiltration method has been selected and next base flow analysis used as a verification method. In first method infiltration coefficient of annual rainfall has been assigned for different soil types based on moisture capacity and permeability of top soil detailed maps.

EFFECTIVE INFILTRATION METHOD

One of the basic methods of assessing renewable groundwater resources (equals groundwater recharge) is the designation of the amount of water to the top soil through a effective infiltrate. This method assumes that part of precipitation infiltrating actually to aquifers, and finally flow to the rivers, lakes or the sea. The quantity of water entering into the aquifers called effective infiltration is expressed as water column height in relation to average annual rainfall in long term condition. Calculation of recharge in the area can be performed based on geological maps. On such map class of infiltration area is designed in first stage. There are several classification of top soils on the basis of which such division is made. They include proposal by: Pazdro and Kozerski (1990), Paczyński (1995), Schneidera i Züschang'a (vide Załuski 1973), Singh (2003), Wright et al. (1982) and Daly (1994).

In Pazdro and Kozerski (1990) approach effective infiltration in range 0.05–0.3 has been assumed as permeability (or stsrativity) for different types of rock. Similar approach adopts Wright et al. (1982) but value indicators are higher. For example it 0.2 for poorly permeable clay rocks, 0.5 to 0.8 for sand clay soils and high permeable sand and gravel. In turn, Daly (1994) proposes infiltration 0.3 for thick clay sediments, and 0.6 for thin clay layers and 0.9 for thin permeable soils developed on carbonate karstic rocks. Both of these examples use values infiltrate concern areas of Ireland, where high average precipitation (from 750 mm for areas area to 1600 mm) and evaporation (500–575 mm) are reported.

In Poland in general this method has been used to lowland terrains and was adopted by Pazdro and Paczyński (poz. cit). However, it was also adapted this method for foreland of mountain (Tarka, 2001) or mountainous terrains (Duda et al., 2006).

For example, for the purposes of modeling research in the catchment of the River Raba in Carpathian flisch sandstone series 0.11 effective infiltration and 0.165 and flisch series of mudstone shale. (Duda et al., 2006).

To design value of infiltration, also map of top soil could be applied, because soil type and genesis is function of geological build up and climatic conditions. Hence there is a direct relationship between rock properties development and granular soil types. This relationship was applied when creating an elaborate layers of information to the Groundwater vulnerability map on pollution from land surface in scale 1: 500,000 (Table 1).

Table 1. Characteristic protection properties of soil (Witczak et al., 2003; Duda et al., 2004) modified.

Protection ability of soil	Soil category	Granular group (according to soil classification)	Infiltration coefficient [%]	Field water capacity as volume [a)]	t_{g1m} Mean residence time in 1m soil profile [years]
Very low	Very light	Sand: loose, loose dusty, poorly loam and dusty	30 (27*)	0.12	1.2
Low	Light	Sand: loam light, strong, dusty and dusty sand	20	0.17	1.7
Medium	Medium	Clay light and dust loam	13(20*)	0.24	2.4
Good	Heavy	Clay: average and dusty, heavy and silt particles	8	0.36	3.6

(27*) modified value.

Application of soil or geological maps, as the experience is very similar to its assessment of renewable groundwater resources (Tarka, 2001). For example, for the eastern and central parts of North Sudetes Syncline, where Cretaceous rocks are the main the main geological formation, comparison of renewable groundwater resources has been discussed based on an analysis of geological maps 1: 50 000 (Szałamacha, Milewicz, 1988) and soil maps 1:300 000 (Musierowicz et al., 1960) i 1:500 000 (Pawlak et al., 1997).

Obtained results indicated effective infiltration as 134.7 and 116.8 mm respectively despite application of different layers of land cover (Tarka, 2010).

Evaluation of groundwater recharge with effective infiltration method required assessment of the average annual precipitation for calculated fields. Then designated surfaces area of the classes representing different infiltration values is calculated in the precipitation region. On this basis calculated weighted value of infiltration is designed for each precipitation area as follow:

$$\alpha_r = \frac{\sum_{i=1}^{n} \alpha_i \cdot A_i}{\sum_{i=1}^{n} A_i} \quad (1)$$

where: α_r — average effeective infiltration for selected area of precipitation r, α_i — infiltration coefficient for i — selected soil region in precipiatation area, A_i — surface area i-soil type [L^2] in precipitation arrea r.

The total infifltaration is the sum of the recharge evaluated for individual regions:

$$R = \frac{\sum_{r=1}^{m} \alpha_r \cdot P_r \cdot A_r}{A} \quad (2)$$

where : P_r — average precipiatation amount in precipitation region r [L], A — surface area of study region [L^2], m — number of selected precipiataion regions.

At the construction of the map of groundwater recharge, for Lower Silesia region, in order to select clases of infiltartion the numerical map of soil in the scale 1:500 000 performed by the Institute of Soil Sciences and Plant Cultivation in Puławy (Musierowicz et al., 1960) has been used. In the first stage we accepted clases of the infiltration for individual soil types in compliance with Table 1 and with orders to the Map of the groundwaters vulnerability to pollution in the scale 1:500 000 (Witczak et al., 2003; Duda et al., 2004). Calculations were performed for 15 catchments (basin) with different surface area and the height of the position and the geological buil-up (Fig. 1). Tested area covers surface almost 17000 km^2.

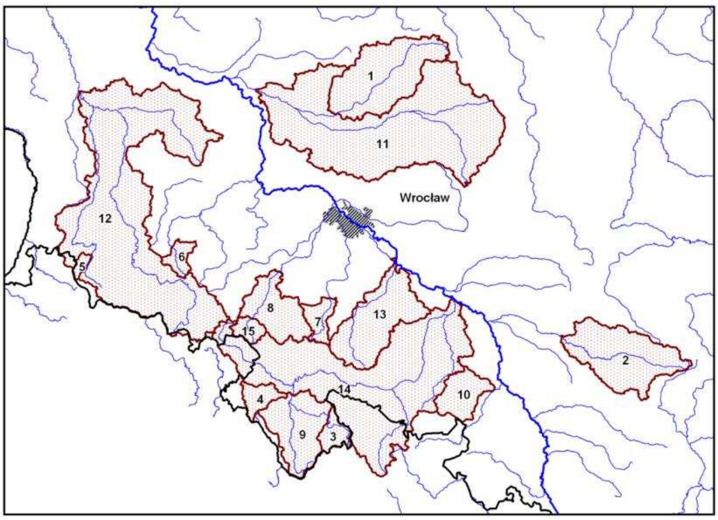

Figure 1. Localization of tested catchmentt areas in Lower Silesia region (number according Table 2.).

Precipitation were accepted on the basis of the Atlas of the climate of Poland (Lorenc, 2005). The estimated value of infiltartion has been verified based on measuerd values of groundwater base flow in basins.

The groundwater run-off from the catchment was evalualted by means of methods Wundt method (Jokiel, 1994) for periods 1976–2005, based on low monthly flows rates in selected rivers. In several cases were analysed smaller basins. In the first stage of calculations obtained results was not directly corresponding to the basin areas. In next the steppe values of effective infiltration has been corrected that change of categories of selected soil properties in the order are obtain the conformity with evaluated values of the groundwater base flow. As a result modification of the category of soil „very light" with 30% on 27% and to change classifying of forest-(Ls) areas from the category of average soil on light what provide effective infiltration value the change from 13% to 20%.

Received close results with both methods for 9 catchment. The difference among the appointed groundwater base flow and magnitudes of recharge amounts from 13% to almost 117%. Greater divergences appear in small mountainous basins (Fig. 1). It could be explained by under estiamation of rainfalls which in top-parties of Sudeten are higher than accepted to calculations. The difference appears in the Baryczy river basin (No. 11) are connected with the considerable degree of the transformation of the basin (the fishery pond). For remaining basins (No. 1, No. 7 and No. 10) it could be explain with the divergence among properties of soils and rocks represented in this scale and inter basin water exchange. Nevertheless for the all test-area the difference among the evaluated recharge with the method of the effective infiltration and the ground run-off method amounts only 0.7%.

With the method of the effective infiltration obtained results for whole region the average recharge in the amount of 109 mms for average annual precipitation equals 587 mms while the method of the groundwater base flow showed 108 mms. Recharge states so as average 18.5% of precipitation. It allows quite good conformity of results what permits this to accept obtained the map of effective infiltration as reliable in the regional scale.

Another example is groundwater modeling technique, as a recommended method when water resources are evaluated in regional scale. Results of such research showed low values in range 52-84 mm/year for Quaternary aquifer system (Gurwin, 2000). In central part of Poland where the lowest values of rainfall are recorded groundwater recharge values 11-80 mm has been reported by Dąbrowski et all (2007) for deeper Tertiary aquifer.

Special case is recharge in mountainous region of the Sudety Mountains (Staśko et al 2010). Recent study on recharge in small and medium mountainous hard rock catchment (7-160 km^2) in Sudeten Mountains in SW Poland characterized by moderate to cold mountainous climate with mean precipitation 1360 mm/y showed interesting results.

Table 2. Comparison of evaluated effective recharge and base flow in selected river basins of Lower Silesia.

Watershead number	River	Measuring point	Surface areas of subbasins	Surface area	Flow as average	Base flow	Groundwater run-off	Infiltration in subbasins	Infiltration in basin	Difference	Base flow IMGW*
			[km²]	[km²]	[m³/s]	[m³/s]	[m³/s]	[m³/s]	[m³/s]	[%]	[m³/s]
						Wundt's method	Effective infiltration method				
1	Orla	Korzeńsko	1143.7	1143.7	4.42	1.76	—	3.08	3.08	75.0	1,25
11	Barycz	Osetno	3438.5	4582.2	12.22	7.52	7.52	12.46	15.54	106.6	8,19
2	Mała Panew	Staniszcze Wlk.	1066.6	1066.6	6.90	4.03	4.03	4.78	4.78	18.6	4,61
10	Biała	Dobra	357.6	357.6	1.13	0.68	0.68	1.16	1.16	70.6	—
3	Biała Lądecka	Lądek Zdrój	161.2	161.2	3.37	2.03	—	0.67	0.67	–67.0	3,06
4	Bystrzyca Dusznicka	Szalejów Dln.	173.9	173.9	2.26	1.30	—	0.67	0.67	–48.5	1,21
9	Nysa Kłodzka	Kłodzko	722.1	1057.2	12.93	6.82	—	2.44	3.78	–44.6	10,59
14		Skorogoszcz	3497.0	4554.2	33.89	17.31	17.31	11.22	15.00	–13.3	28,21
13	Oława	Oława	959.2	959.2	3.88	2.51	2.51	2.09	2.09	–16.7	2,65
7	Ślęza	Białobierze	186.1	186.1	0.48	0.24	0.24	0.52	0.52	116.7	0,30
15	Bystrzyca	Jugowice	120.6	120.6	1.33	0.52	—	0.46	0.46	–11.5	0,77
8		Krasków	555.4	676.1	4.32	1.61	1.61	1.71	2.17	34.8	2,83
6	Kaczawa	Świerzawa	136.2	136.2	1.18	0.60	0.60	0.40	0.40	–33.3	0,52
5	Czarny Potok	Mirsk	51.1	51.1	0.90	0.35	—	0.24	0.24	–31.4	0,35
12	Bóbr	Żagań	4192.3	4243.4	37.93	23.14	23.14	16.17	16.41	–29.1	30,55
		Sum	16761.5				57.64	58.06		0.7	
					Recharge [mm]		108.4	109.2			153.6

* Dubicki (ed.) 2002

Four recharge assessment methods were applied: (1) lysimeter infiltration; (2) groundwater drainage by gallery; (3) river baseflow; (4) groundwater table fluctuation method. The obtained results showed that: (i) the recharge had an impulse character and was largely temporally variable; (ii) different methods of recharge assessment resulted in different recharge estimates mainly due to different spatial scales of assessment and different rainfall contributing areas; (iii) except of lysimetric method, the recharge-to-rainfall ratio was consistent and was estimated as ~50% of precipitation; such large recharge–to–rainfall ratio, was mainly due to high all year round soil moisture status and low 1–3 m thickness of weathered deposits implying relatively low soil retention capacity; (iv) the groundwater residence time was approximately 7–10 years as defined by tritium isotopic sampling and model simulation; (v) the investigated aquifer of this study, as many other mountainous hard rock aquifers, receives large quantity of recharge that results in significant groundwater flow; despite relatively low transmissivity that groundwater flow is efficiently transferred through the aquifer system to drainage lines (rivers and streams) and drainage points (springs) mainly thanks to large hydraulic gradients, typical for mountainous catchments (Staśko et al., 2010).

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IAH 2010
Krakow

abstract id: **433**

topic: **6**
General hydrogeological problems

6.7
Managing aquifer recharge

title: **A new method to measure the unsaturated properties of soils**

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keywords: unsaturated soil, hydraulic conductivity, soil moisture characteristic curve

Water movement in the underground is a matter of great importance for water resource management as well as stability estimations for embankments, dams and slopes among others. Water movement is generally estimated by utilizing numerical models, which require knowledge of certain hydraulic parameters, the most important one being hydraulic conductivity.

In this work, a new steady state method to determine hydraulic properties of unsaturated soils is proposed. In comparison to existing approaches, it is simpler and cheaper. The proposed constant-head system does not utilize tensiometers and moisture content measuring devices, as shown in Fig.1.

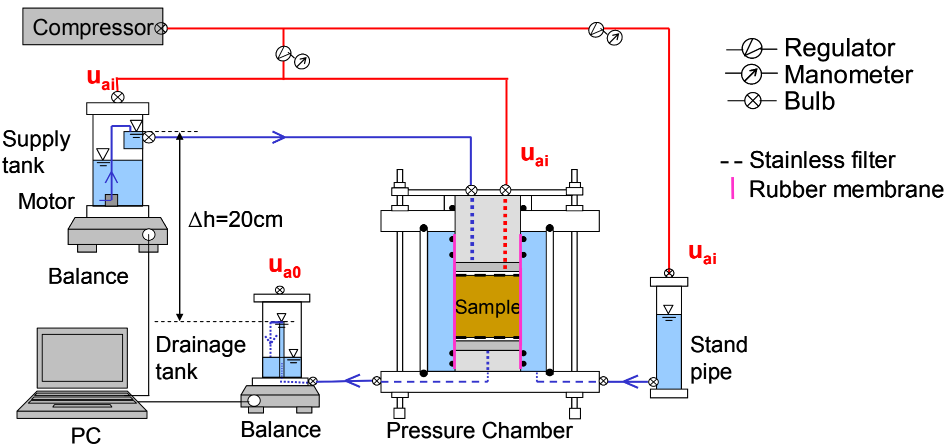

Figure 1. Configuration of the proposed measurement method for unsaturated soil properties.

In order to determine hydraulic conductivity and soil water characteristic curve, a soil sample is set into a compression test cell, which is connected to a supply tank, a drainage tank, a stand pipe and a compressor. The stand pipe, which is connected to the compressor, is used to control confining stress on the test piece within the pressure chamber. The compressor is also used to regulate pore air pressure and pressure within the supply tank. Weight of the supply tank and the drainage tank is continuously measured with electric balances and a PC. In the beginning of a test, water is absorbed in the soil sample until the saturation degree which belongs to the given air pressure is reached. Once this point is passed, the masses of supplied and drained water are equal and allow calculation of hydraulic conductivity belonging to the applied suction (air pressure in the test piece). By variation of applied air pressure the soil water characteristic curve may be obtained.

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6.8 Understanding and communication on groundwater — education and public involvement

abstract id: **167**

topic: **6**
General hydrogeological problems

6.8
Understanding and communication on groundwater — education and public involvement

title: **Environmental education and the Guarani Aquifer in a documentary: An approach to a broader educational process**

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INTRODUCTION

The Guarani Aquifer has continental dimensions, extending over some 1.2 million km^2 within the Paraná sedimentary basin, South America. Their waters are extensively utilized for four countries (Brazil, Argentina, Uruguay and Paraguay) for several purposes like in water supply systems, industries, recreation and irrigation. More than 1,000 wells are expected to exploit the aquifer, according to public and private interests, but the right number is unknown due to the existence of a lot of clandestine ones. The over-exploitation without any criteria and support affect the quantitative and qualitative potential of their waters.

Such problem is an example pointing out the need to educate the society to face the challenges inherent in the relations among the human beings themselves and with nature that involves interests and fights among different groups concerning to the environmental goods. This paper focuses this question, discussing the educational task and presenting a proposal of an educational work about the Guarani aquifer.

Since the 1970s, the educational field has been requested to contribute with the reflections and actions to deal with the environmental question, as demonstrate the several international meetings already organized, which indicated objectives and general guidelines for the Environmental Education (EE). The First Intergovernmental Meeting on Environmental Education was held in 1977 and it was organized by UNESCO in Tbilisi, Georgia. General guidelines for environmental education were established in that meeting.

However, despite those recommendations, EE projects have shown great variations concerning their theoretical-methodological benchmarks, since they reflect the varied conceptions about the causes and proposals for action when facing environmental problems. Moreover, they also reflect different understanding of education itself. Although the socio-political-economical aspects were highlighted in the guidelines proposed in Tbilisi, breaking up with a view of ecological reductionism, EE still has a great tradition as a way of studying nature and promoting individual behavioral change.

Breiting and Mogensen (1999) point out that all environmental issues involve conflicting interests, that appear at least at three levels: individual (the conflict exists between incompatible needs and wishes, often expressed as personal dilemmas); social (the conflicting interests exist between various groups and/or individuals) and the structural level of society (the conflicting interests regarded as conflicts between political decisions and market forces or economical mechanisms). For these authors, if the EE is to deal with the real environmental issues, it has to face these three levels of conflicting interests.

From this approach, I consider that the projects on EE must deal with three dimensions (Carvalho, 2006):

- knowledge: to deal with facts and concepts from the natural/social sciences, as well as with the process of production of the knowledge itself, that help us to understand the process of construction of our conflicting relation patterns among human beings organized in the societies and among societies and nature;
- values: ethics and aesthetics, for reviewing the basis of present relation and constructing new standards of relation with the natural environment;

- political participation: for the development of the citizenship and construction of a democratic society, giving voice to all citizens in order to participate of the decisions affecting everybody.

Under these views, I present an educational proposal to deal with the questions related to Guarani aquifer from a documentary focusing it.

THE FILM GUARANI: CAMINHOS DAS ÁGUAS

The film presents an "encounter" with the Guarani Aquifer, starting with the conduction of a scientific research, in which samples of its waters in different Brazilian cities were collected. Parallel to the initial exposure of some basic information of techno-scientific nature, the esthetic look makes colors stand out, shapes and sounds pop out of the images of natural elements linked with the aquifer — just like the ones in technological devices and human constructions geared to its water collection, treatment and distribution.

Aspects of the society-water relation emerge from different situations found in field work, revealing the problematic issue related to the exploration of those waters to the spectator through a set of information and the situations presented. The relation among Science, Technology and Society, present in the Guarani watercourse, and important for reflections on the present environmental crisis, can be stated through this production.

When the over-exploitation and contamination problems are presented to the spectator, some tracks are provided in order he or she not makes a commitment only in an individual level relating to the water care. The spectator must perceive how the problem involves interests of several segments, i.e. public and private interests that are behind these risks. So, initiatives to take care of the environmental resources extrapolate the individual action of each citizen, but need them in a collective action in order to demand measures from decision makers for attending the collective interests of the population.

By this way, considering Guarani Aquifer, it is clear for all the need to establish norms and regulations for avoiding its indiscriminate use, contamination and other harmful problems to public interests, reason by which it is necessary focus on interest conflicts that this thematic includes. The educational process must reach this level of political participation instead of only giving "conclusive" (many times not really conclusive) information and training on the acquisition of desirable behavior.

Considering the knowledge dimension linked to Guarani aquifer, it is necessary as well to display the process of its construction, with the subjacent conflicts and interests involved in it. Sarewitz (2004), discussing the nature of science and its influence on the environmental issue, argues that political controversies with technical underpinnings are not resolved by technical means.

Drawing from examples of some environmental issues, he explores the idea that scientific inquiry is inherently and unavoidably subject to becoming politicized in environmental controversies. He presents three reasons for this:

- first, science supplies contesting parties with their own bodies of relevant, legitimate facts about nature, chosen in part because they help make sense of, and are made sensible by, particular interests and normative frameworks;

- second, competing disciplinary approaches to understanding the scientific basis of an environmental controversy may be causally tied to competing value-based political or ethical positions. The necessity of looking at nature through a variety of disciplinary lenses brings with it a variety of normative lenses, as well;
- third, it follows from the foregoing that scientific uncertainty, which so often occupies a central place in environmental controversies, can be understood not as a lack of scientific understanding but as the lack of coherence among competing scientific understandings, amplified by the various political, cultural, and institutional contexts within which science is carried out.

In accordance with the authors already referred to, I point out that the environmental question in general is closely associated with socio-political issues and the conflicts that come with them. From this perspective, for educational work based on environmental issues, it is necessary to change traditional approaches that try to show conclusive knowledge and behaviors looking for the harmony among human beings and nature: more important that the concepts of harmony and balance, will be the concepts of crisis, controversy, polemics and, in the specific case of environmental education, the socio-environmental conflict (Nicolai-Hernández, Carvalho, 2006).

FINAL CONSIDERATIONS

According to Nicolai-Hernández and Carvalho (2006), the option of working with controversial issues is presented as an interesting possibility of EE, which implies a positioning far from the liberal environmental ideas in which the idea of an "apparent consensus" on the environmental issue is being encouraged, thus generating conditions to ideologically dissimulate and disguise the controversies and the socio-environmental conflicts.

Strauss and Westland (2005) emphasize the importance of learning about controversial issues, that can build skills such as listening, debate, handling conflict, self awareness, distinguishing between fact and opinion, creative problem solving, critical thinking, ethical reasoning, recognizing bias, evaluating evidence, justifying an argument, logical reasoning, etc, critical skills for survival in an increasingly complex world.

Agreeing with these authors, I emphasize the benefits of dealing with the controversies, conflicts and uncertainties that take part in the environmental question. Considering Guarani aquifer, there are several problems involving its use and protection that must be presented and discussed with the participation of the society.

However, as Gayford (2002) pointed out from an investigation involving science teachers, the inclusion of controversial issues within the school means a challenge that we need to face. It is not easy to organize classes in which the subjects include uncertainties, conflicts and dilemmas, which means a change in the traditional approaches to teach and learn.

In conclusion, EE actually implies more than to deal with conclusive knowledge and specific behaviours. It means the challenge to review and change our world's visions, values and practices, discussing and looking for more democratic decisions, a learning process that involves all citizens of the society, inside and outside schools.

ACKNOWLEDGEMENTS

FUNDUNESP (Foundation for the Development of UNESP – University of São Paulo State), FAPESP (Foundation for Supporting Research in São Paulo State) and CNPq (National Council for Scientific and Technological Development) in Brazil are greatly thanked for financial support of the documentary *Guarani: caminhos das águas*.

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IAH 2010
Krakow

abstract id: **351**

topic: **6**
General hydrogeological problems

6.8
Understanding and communication on groundwater — education and public involvement

title: **Groundwater education: One drop plus one drop equals self management**

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keywords: groundwater, education, communication, audience, information

Groundwater scientists around the world have done some groundbreaking research over the past four decades. Each day we are improving our understanding complex issues like fractured rock aquifer hydraulics, contaminant transport and long-term planning. But somehow we are still struggling to engage all role-players and align environmental policies to ultimately manage groundwater resources optimally. The key to this? Products and tools to facilitate groundwater education and public involvement.

Groundwater education products and tools can manifest as many things: written media, a populated website, interactive discussions and games, as well as the visual and audio media through television inserts and radio interviews. We need to make sure that any specific media chosen has to adhere to basic criteria for optimal audience impact. These criteria include 1) contextualisation of information for the target audience; 2) identifying and designing a combination of the most appropriate communication media; and 3) highlighting of knowledge benefit to the target audience. Going hand in hand with these criteria, is the design of the minimum factual information needed to successfully convey the science message.

To address this challenge, the Water Research Commission of South Africa has started a range of projects. This includes the publication of a book on groundwater that focuses on easy-reading for the general public, from scholars to farmers and water management decision makers. Many more communication media will be utilised in more projects, but the book forms the first important stepping stone to fill an important knowledge gap.

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International Association of Hydrogeologists

AGH University of Science and Technology

2-vol. set + CD
ISSN 0208-6336
ISBN 978-83-226-1979-0