XXXVIII IAH Congress

Groundwater Quality Sustainability

Krakow, 12–17 September 2010

Abstract Book

Volume 1 and 2

Editors:
Andrzej Zuber
Jarosław Kania
Ewa Kmiecik

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of Silesia
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Foreword

This Abstract Book contains abstracts of the presentations submitted to the XXXVIII IAH Congress held in Kraków, Poland, whereas the attached CD-ROM contains extended abstracts and keynote presentations. If the extended abstract was not supplied, the CD-ROM contains only the initial short version given in the Abstract Book. About 400 abstracts have been submitted of about 70 countries in five continents for oral or poster presentations.

The leading theme of the XXXVIII Congress is "Groundwater quality sustainability" which is of great importance for the preservation and/or remediation of groundwater resources for future generations, and which is linked with the implementation of the EU Water Framework Directive, as 2010 is the year when the formulation of programmes aimed at preventing further deterioration of groundwater quality in EU Member States must be completed. More than 15% of submissions are directly related to the leading theme, of which about one tens has clear methodological character and the remaining nine tens are related to case studies covering practically all the subjects of hydrogeology. The presented case studies are in most cases also very instructive, and as that valuable and worth of studying. Submitted presentations which are devoted to other subjects can in fact be also regarded as related to the leading theme, as any hydrologic method or any case study on a groundwater system can, to a certain degree, be used within the scope of the leading scheme. These other subjects are covered under five additional main topics: groundwater and dependent ecosystems, aquifer management, mineral and thermal water, data processing in hydrogeology, and general hydrogeological problems. It is hoped that as a consequence of these broad subjects, all the scientific and professional activities of the IAH members will be properly represented at the Congress sessions.

The *Table of Contents* of the Abstract Book refers to "the main topics", which were placed in the first circular. Within each topic, abstracts are arranged by ID allotted in the online abstract registration process. For practical reasons, the Abstract Book consists of two volumes. Volume 1 contains abstracts of topics 1–2, while Volume 2 contains abstracts of topics 3–6. In order to facilitate the use of the book, two kinds of indexes are available — the *Index of Authors* in alphabetical order and the *List of Abstracts* arranged by ID of abstracts, both placed at the end of Volume 2.

Editors: *Andrzej Zuber*
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Ewa Kmiecik

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1 Groundwater quality sustainability

1.1 Evaluation and management of groundwater — sustainable exploitation

Abstract ID: 113

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

Under the premise of the need for an integrated approach for water resource management it is important to take into account the relations between drainage basin (catchment area) and the aquifer through the near coastal zone, and to develop adequate science based policies oriented to achieve sustainable water management. The Mediterranean basin is a perfect example of the attempts of application of a holistic approach (not only through IWRM and ICZM) in order to perform the best management practices and to achieve the sustainability goals. This area has been object of several studies and conventions; however discrepancies at political social economical, and therefore environmental, level still exist between the European rim countries and the Middle East and North Africa (MENA) region ones. Moreover, even for areas where increasing attention is paved to coastal zone, transition zones, and lagoon system protection, so far most of the interest was focused on the ecological functions of these lagoons and the possible exploitation for aquaculture activities.

The lagoon of Nador (Morocco) is a perfect example of this situation. Understanding the role of the aquifers in the lagoon circulations and the interaction between fresh groundwater and saline or brackish lagoon waters is of crucial importance for the protection of the fragile lagoon dynamics.

Understanding the present subterranean hydrology means to comprehend their past morphologic conditions and to evaluate their recent geological evolution.

Therefore this work is focused on the role of hydrogeology and hydrogeochemistry in guiding the integrated water management processes, and on the definition of groundwater quality in the Bou Areg coastal plain also considering its interaction with the lagoon of Nador. Groundwater samples from ten wells have been collected in November 2009, as a preliminary investigation on the general quality of the aquifer. 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. As the area is mainly exploited for agricultural activities, the natural abundance $\delta^{15}N–NO_3$ 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.

Abstract ID: 133

EVALUATION OF THE AGRICULTURAL DEVELOPMENT IMPACT IN AN ARID-SEMIARID REGION OF THE ARGENTINE REPUBLIC

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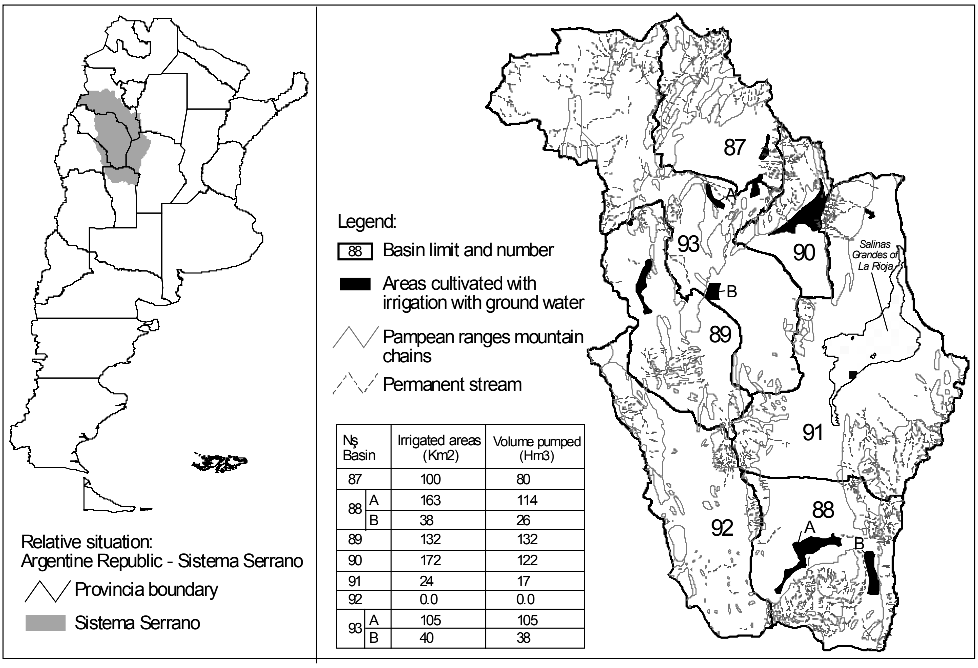
Keywords: irrigation, intensive exploitation, mathematical models

The groundwater is of paramount importance in the water provision an a great part of the Argentine Republic. Total in the rural areas and partially in the cities with important population growths. This resource favoured the agricultural and industrial parks expansion in the interior of the country. Nevertheless, inadequate management and overexploitation have contributed to problems, such as level depressions and deterioration of water quality in urban areas. The word overexploitation intends to qualify a concerning evolution from certain points of view, but has no precise hydraulic meaning (Custodio, 2002). Nowadays in Argentina an important change is under way, since the society is becoming aware of needing a rational use of the water resource for the agricultural economy and the public provision.The present article analyzes the changes produced in a region of Northwest Argentina, called *Sistema Serrano* (Fig. 1).

This region extends over 181,000 km^2, and is in the arid and semiarid part of the country, where productive agriculture is possible only by irrigation. Based on non systematic historical data and hydrogeologic studies decided by governments in order to determine the sustentability of intensive exploitation, the present study aims to give a panorama of the current development of groundwater use and inform about actions to attain a more effective management of the resouce. At about the late 1980's began in Argentina the incorporation of modern pressurized irrigation systems with groundwater, which gave way to an accelerated growth of irrigated surfaces throughout Western Argentina (Chambouleyron, 1993). This growth was enhanced with the application of tax reductions for the development of modern technologies. The irrigated areas reach 77,000 hectares and their increase continues. In (Fig. 1) is presented the *Sistema Serrano*, which includes an interior basin where all the groundwater closes its cycle in the Salinas Grandes of La Rioja. This figure indicates also the analyzed areas, which have been intensively exploited with groundwater. In the majority of these areas this exploitation has not produced water level drawdowns which could indicate overexploitation, if compared with records from the 1970's. In the basins Nº89 and 93, where only are available data from recent years, a drawdown has been observed in the piezometric levels. This can be explained by historical pluviometric records, which from 1974 or 1975 indicate a marked increase in rainfall, but after the year 2000, a tendency to drier conditions.



Nş Basin		Irrigated areas (Km2)	Volume pumped (Hm3)
87		100	80
88	A	163	114
	B	38	26
89		132	132
90		172	122
91		24	17
92		0.0	0.0
93	A	105	105
	B	40	38

Figure 1. Situation of the *Sistema Serrano* and areas cultivated with groundwater.

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). In this way, in some analyzed areas were made mathematical models (Bucich, 2009) and has been advised a continuous adjustment of them, as well as periodical measurements of level and expansion of pluviometric networks, in order to monitor the growth of agricultural demand and make it compatible with the potable water provision systems.

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Abstract ID: 179

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

The basement rock aquifers of the Limpopo Province are geologically and structural complex, shaped by multiple tectono-metamorphic events spanning at least 600 million years (Kramers et al., 2006). These aquifers are often referred to as fractured water-bearing igneous and metamorphic rocks with low storativity and poor permeability. Due to their extent and readily availability basement aquifers maintains the livelihood of thousands of people living in the rural communities of this semi-arid region. In addition, the surface water resources in many areas of the Limpopo surface water management area's (WMA's) are now fully utilized and almost the only opportunity left for further development lies in the exploitation of groundwater. However, there is a perception amongst water users that groundwater resources are not as viable as surface resources. Remote communities without any other source of water view abstractions from a borehole as second hand and regard it as a poor man's resource. Recent internal strategy perspectives (ISP) of the Limpopo WMA's have indicated that groundwater resources are evidently under-utilized and under-developed. The prospect of groundwater to successfully eradicate backlogs in provision of water could be severely jeopardised by inadequate control or management of groundwater qualities in the Limpopo Province.

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 basement aquifer region under investigation. The dataset is based on the national groundwater database and the Limpopo groundwater resources information project. Approximately 4000 samples was used in the classification.

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

	EC	Ca	Mg	Na	SO_4	Cl	N	F	Final Class
Class I	76%	97%	74%	89%	100%	78%	61%	89%	27%
Class II	22%	3%	17%	9%		18%	20%	5%	39%
> Class II	2%	0%	**9%**	2%		**4%**	**19%**	**6%**	34%

SANS 241:2006; Class II (max. allowable human consumption for limited duration).

Almost 35% of samples show major ion concentration far from ideal. The most noticeable elements of concern for water consumption is nitrate (measured as nitrogen (N)), with magnesium, fluoride and chloride also exceeding the recommended drinking water quality limits. The main inputs of nitrate to groundwater are derived from anthropogenic activities such as fertilizer application to land, sewage sludge application to soil, wastewater irrigation, on-site sanitation, deforestation, and mineralization and mobilization of natural soil nitrogen by tilling of the soil. However, the large extent of nitrate pollution requires a closer investigation and understanding (Fig. 1). Flouride in groundwater has both natural and anthropogenic sources. High intake of fluoride from drinking water is the main cause of flourosis and may lead to many other health problems.

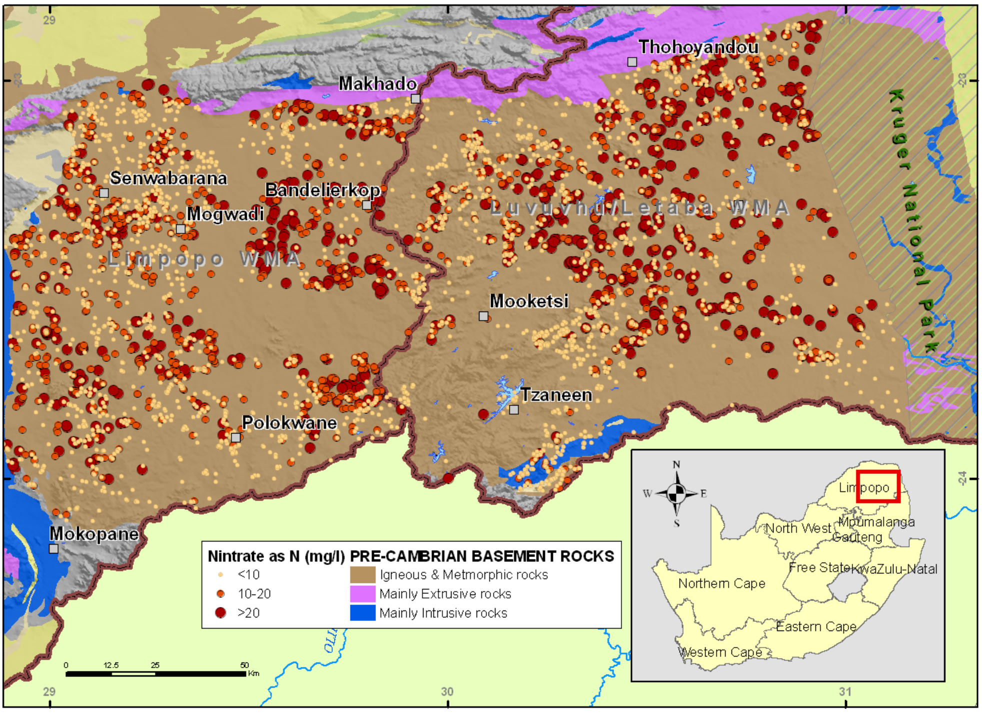

Figure 1. Simplified map showing the distribution of nitrate in groundwater in the Limpopo and Levuvhu/Letaba WMA's.

Results show that many rural groundwater supplies are contaminated. Approximately 35% of rural communities in the region are dependent on groundwater alone and 50% of have conjunctive use of both surface- and groundwater. Inappropriate on-site sanitation at rural villages and animal feedlots frequently lead to pollution and the abandoning of well fields. 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.

Abstract ID: 184

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 ($0.33 \leq n \leq 0.40$). 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

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

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 mineralized area, centered on the Entre-deux-Mers region, between the Garonne and the Dordogne rivers, where the groundwaters show strong mineralization and anomalous levels of critical elements, such as sulphates and fluoride, leading to difficulties of resource exploitation for drinking water supply.

Initiated early 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. The main objectives of this project are to improve the understanding of the origin of the salinity of this mineralized area and to investigate how these mineralized waters circulate in the Eocene aquifer and/or in this multi-layer aquifer system.

For that purpose, combined geochemical analysis (major and trace elements) and classical isotopic methods using $\delta^{18}O_{H20}$ and $\delta^{2}H_{H20}$, $\delta^{34}S_{SO4}$ and $\delta^{18}O_{SO4}$ is 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

The deposit sequences characterizing the Eocene aquifer system are progradational westward, from detrital deposits to carbonates. The Eocene sands and the Eocene limestones are hydraulically connected, the extension limit is located under the city of Bordeaux. 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.

The first investigation, carried out in autumn 2009, allowed the characterization of 50 groundwater sampling points in the mineralized area. The *in situ* electrical conductivity ranges from 130–1630 µS/cm.

Ongoing analyses of major elements confirm the salinity variation in the system and the multi-isotopes results will be presented at the conference, in order to decipher the origin of this salinity.

Abstract ID: 217

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

In southern Luxembourg as in many regions of intensive farming, groundwater resources from a large fracture sandstone aquifer have become increasingly at risk from pollution by pesticides. In order to avoid further deterioration of this 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 tool (Klaus et al., 2008) was developed that links predicted leached concentrations in the soil to the spring chemical fingerprinting via an inverse iterative procedure based on consistent mass flow equations.

First, a typical pesticide leaching forward modeling was performed for the substances measured at spring level and for the different soils, land uses and pesticide application rates encountered in the catchment of interest (Petach et al., 1991). A linear optimization scheme (Loucks et al., 1981) was then applied to the leaching maps, and boundaries of the spring's capture zone calculated by minimizing an objective function subject to a number of constraints (Fig. 1):

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

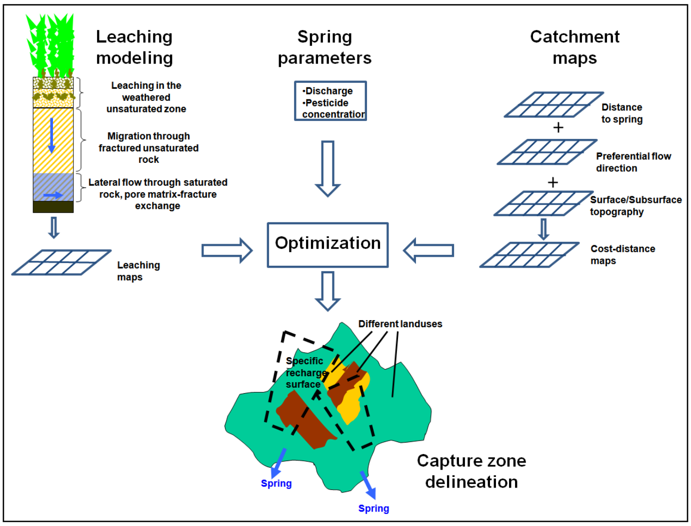

Figure 1. Spring capture zone delineation workflow.

Spatial variability was simulated by running multiple optimizations with different leaching maps generated from randomly sampling the frequency distribution of the leached substance. The final capture zone resulted from the union of all optimal solutions. Additional information such as flow direction derived from surface and subsurface analysis (no-flow boundaries such as rivers, topography of the aquifer's basis, geological survey) can be integrated in the optimization procedure by modifying accordingly the cost-distance matrix of the objective function.

The advantages of the proposed methodology are:

- 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 (from surveys, tracer tests, risk mapping) of different quality and origin.
- Computer-based tool to assist the delineation process.

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Abstract ID: 224

GROUNDWATER QUANTITY IN THE ZAGREB AQUIFER

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Keywords: Zagreb aquifer, groundwater quantity, overpumping

1. INTRODUCTION

The Zagreb aquifer is built of gravel and sand deposits stretching along the Sava River at the City of Zagreb territory. The municipal water supply relies on the groundwater from the aquifer. The aquifer is of unconfined type and its upper margin of saturation is a water table exposed to the atmospheric pressure. The aquifer is generally replenished by infiltration from the Sava River, infiltration of precipitation, and underground inflows from both west and south.

The present paper is intended to assess the groundwater quantity in the Zagreb aquifer by using an analysis of the groundwater table, pumping rates, precipitation and runoff data from the 1970s onward.

2. GROUNDWATER QUANTITY ANALYSIS

The analysis of the groundwater table fluctuations measured at about 500 observation wells indicates an average groundwater table decrease at the entire aquifer area of 1–2 m every 10 years (Fig. 1).

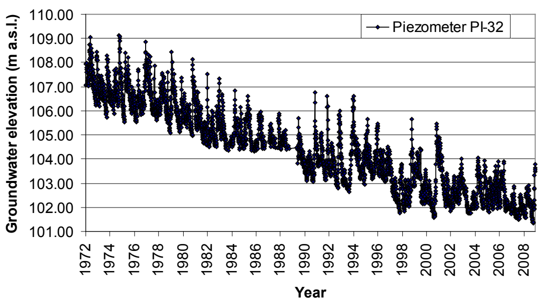

Figure 1. Typical hydrograph.

The analysis of the water surface at minimum groundwater tables and of the Zagreb aquifer bedrock enabled us to determine the volume of water in the water bearing stratum pores beneath the lowest recorded water table. Gradual decrease in the volume has been recorded since 2006 (Fig. 2).

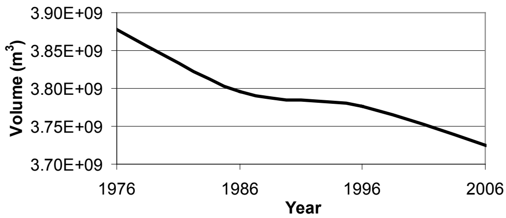

Figure 2. Groundwater volume beneath minimum annual groundwater tables.

Natural replenishment of the aquifer is determined by an analysis of the water surfaces at minimum and maximum groundwater tables. It is determined that the volume shows no strong trend, which is understandable since it depends on annual precipitation.

Comparison of natural replenishment 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 natural replenishment rates (Fig. 3).

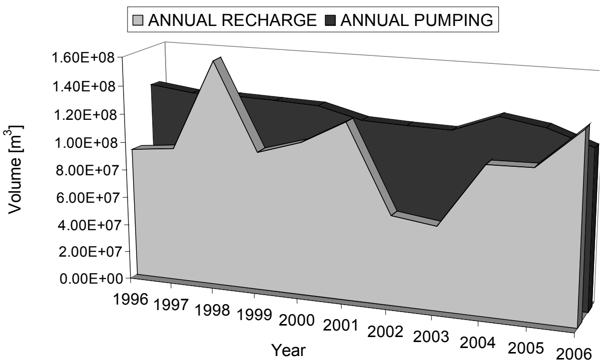

Figure 3. Comparison of natural replenishment with pumping rates.

3. CONCLUSION

The analysis of the groundwater table data collected for the City of Zagreb area indicates an average groundwater table decrease of 1–2 m every 10 years. Reasons for the groundwater table decrease include: (1) deepening of the Sava riverbed caused mostly by construction of the power plant reservoirs on the Sava upstream from Zagreb, training of tributaries, and gravel mining in the riverbed, and (2) increase in groundwater abstraction for the City of Zagreb water supply.

Total annual pumping rates for all Zagreb well fields exceed the annual groundwater replenishment rates, which mean that the Zagreb aquifer is "overpumped". That part of the quantity pumped that exceeds the replenishable reserves is made up from permanent 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.

Abstract ID: 237

USING A STOCHASTIC APPROACH TO REDUCE RISKS IN GROUNDWATER RESOURCES DEVELOPMENT: A CASE STUDY IN SUR, OMAN

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Keywords: groundwater development, stochastic, modelling, risk management, desalination

Industrial operators are commonly 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. A stochastic approach can be used to quantify the risks and help decision makers. In this work, the Sur project in Oman is described as a case study of such approach.

The aquifer beneath Sur is strongly heterogeneous and is made of early Palaeocene-Eocene carbonates deposited 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. Thus, water supply at Sur city relies on seawater desalination.

A project was built involving the design, construction and 22-years operation of a new 80200 m^3/day capacity Seawater Reverse Osmosis (SWRO) desalination plant at a given site close to the city. Such facility should be supplied with up to 9200 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 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. It was demonstrated by the three field campains: a first series of four recognition wells, sub-surface geophysical measures (ERT) and a series of 19 recognition wells.

An analysis of the uncertainty of groundwater availability was presented to the Project's founders. This analysis was based on stochastic inverse modelling: Monte Carlo analysis of 200 simulations of transmissivity and storage coefficient fields conditioned to available data (i.e. a geostatistical model of the geophysical aquifer properties and the response to tidal fluctuation and to long term pumping tests) was carried out. The statistical analysis of the results proved the availability of the targeted 9200 m^3/h at the site. 100 out of the aforementioned 200 equiprobable simulated transmissivity fields were then used to design an optimum well field layout. The optimisation was carried out by a genetic algorithm that minimizes 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 optimum well field layout included 33 beach wells producing either 360 or 250 m^3/h each. Not all the 33 selected beach wells were drilled at the modelled location due to various technical constraints. Nevertheless, the total yield required for the new plant facility can now be withdrawn from the site with an acceptable drawdown, making Sur the largest SWRO desalination plant in the world fed only by beach wells.

Abstract ID: 278

WATER MANAGEMENT IN ABANDONED LIGNITE OPEN PITS IN POLAND

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Keywords: water management, open pits

1. 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 reservoirs with ground water, supported by surface water. This paper is an informative one. Its objective is to acquaint the participants of the XXXVIII IAH Congress held in Poland with reclamation of post-mining lignite open pits in the host country by flooding (Tab. 1). Besides, it provides some data on hydrogeological conditions of lignite mines in Poland.

Table 1. Water management in post mining excavations in polish lignite mines.

Region of lignite mining	Open pit	Completion of lignite production	Area [ha]	Depth [m]	Volume [million m^3]
TURÓW	Turów	2040	1865	200	1600
BEŁCHATÓW	Bełchatów	2019	1690	205	1323
	Szczerców	2038	2200	165	1752
KONIN-ADAMÓW	16 open pits	1953–2037	4120	3–65	1220

2. 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 and have different hydrogeological conditions (Libicki, 1987). 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. Depending on the open pit, the groundwater table is lowered from 40–100 m, and the radius of cone of depression is 4–7 km. The mine water inflow for all open pit mines in the region is in average 310 m^3/min. 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.

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 bar depending on the depth. The mine water inflow is 20 m^3/min. 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. 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. Annual precipitation in the regions of lignite basins varies from 500–700 mm/year. All deposits are below the natural groundwater table that occurs most frequently right under the terrain surface (from 1 down to 5 m).

3. WATER MANAGEMENT IN ABANDONED LIGNITE OPEN PITS IN POLAND

As demonstrated by to-date observations and investigations, filling the huge post mining excavations with ground water drainage only is likely to take even several dozen years. For this reason in the Konin-Adamów Basin the process of natural groundwater recharge is enhanced with water from dewatering of adjacent open pits and surface water from neighboring rivers. Because of scarce resources of groundwater, the most likely option for the Turów open pit is filling the excavation with surface water from the surrounding courses at the rate of about 3.87 m^3/s (Fiszer et al., 2005). The two post mining reservoirs in Bełchatow lignite mine will be filled with water in a natural way, with additional recharge from river at a rate of 2.25 m^3/s or 4 m^3/s (Kasztelewicz et al., 2008). The use of surface water speeds up the process of filling the voids with water until 10–30 years and protects from water acidification as result of contact with some lignite seams left.

4. SUMMARY

The management of large abandoned open pits will bring about appearance of a number of geotechnical and hydrogeological problems. Early standing with work on the solution of these problems will make it possible to carry out appropriate mining operations and also, will allow providing real financial inputs which will be allocated for reclamation of future open pits.

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Abstract ID: 279

GROUNDWATER QUALITY STATUS AND PROBLEMS OF SUSTAINABILITY IN AZERBAIJAN

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

1. MAIN AQUIFERS

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). In mountainous areas of Azerbaijan, groundwater is basically found in the areas of weathering and tectonic faults, where discharge process generally occurs by means of springs on the foothills and the yields of these springs vary between 5 and 10 l/s. The springs with higher yields (60–100 l/s) are encountered mainly in the areas of karstic limestone formations.

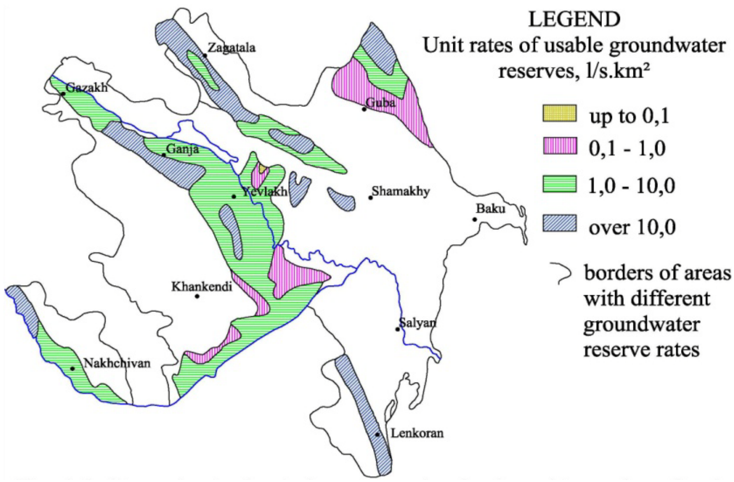

Figure 1. Groundwater in piedmont troughs, fresh and low-mineralized.

Aquifers in piedmont and intermountain troughs are rich in fresh and low-mineralised (ca. 1–3 g/l) groundwater (Fig. 1). These aquifers are formed by merged coarse-grained alluvial fans of rivers, effective thicknesses of which reach 300–500 m, and rarely 1000–1500 m. Yields of wells drilled here into unconfined and confined aquifers vary between 0.1–30 l/s and 0.1–98 l/s, respectively. Numerous springs with yields of 0.1–0.3 l/s and 15–20 l/s recharge from the unconfined aquifer. Piezometric levels of pressurized water are both below and above ground surface. The flow rates recorded during pump tests are between 0.1–0.2 and 57–98 l/s. Producible stock of groundwater in Azerbaijan is estimated to be 24 mln m^3/day.

2. GROUNDWATER QUALITY

Groundwater in the mountainous areas is of drinking quality and the chemical contents include HCO_3–Ca. Hydrosulphuric and hydrocarbonate mineral waters are also observed in the mountainous zones.

Fresh and low-mineralised waters are widely spread within the borders of piedmont plains. In the lower parts, however, fresh and low-mineralised waters get rapidly shifted by saline, medium and highly saline waters. High TDS content is a common feature of artesian aquifers composed of sediments of marine origin. Groundwater hardness varies between 1–24 mg-*eq*/l; pH 6.6–8.4; chloride content 4–1900 mg/l, sulfates 4–1400 mg/l. Groundwater in the lowlands is salty, and solid residues may reach up to 100–200 g/l. Chemical composition of groundwater is represented by all possible combinations of anions and cations (Alekperov et al., 2008).

3. QUALITY SUSTAINABILITY CONCERNS

In the territories of Georgia and Armenia, wastewaters containing hazardous substances such as chemical dyes, oil products, phenols, ammonium nitrogen etc. are discharged without any substantial treatment into Kur and Araz rivers, which are the two main recharge sources of groundwater in Azerbaijan. While crossing the borders of Azerbaijan, these rivers already contain contaminants in volumes beyond admissible norms.

Contamination is enhanced in the territory of Azerbaijan by agricultural pollutants and wastewater from industrial premises and cattle farms (Alekperov et al., 2006).

The main reason of such situation in these two rivers is the lack of effective drainage systems, treatment facilities and technical insufficiency of existing plants in most towns and settlements.

In huge parts of the lowland, subsoil and aeration zones are exposed to natural pollution and salinisation in the range 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 nearby fertilizer storages. Lands 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. Groundwaters in the territory of the country are not exposed to regional pollution. Locally observed pollutions include chemical and bacteriological pollutions originating from domestic, industrial and agricultural sources. No pollution of confined groundwater has been witnessed.

It is considered necessary to survey recharge conditions, hydrochemical and bacteriological contents of groundwaters influenced by rivers; to develop diagrams for integrated use of water; and identify possible ways of avoiding pollution and ensuring the quality sustainability.

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Abstract ID: 308

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

Any kind of human activity, whether the use of water or other use of underground space, is considered as processes that proceed in a certain sequence of conditions of hydrogeological systems (HGS). The system condition and its structure are identified by functions of its components and are generated by connections within the system and outside it. The system condition is determined by its potential (a set of parametrized and non-parametrized properties). On the basis of studying laws of development and evolution of hydrosphere there should be a regulation of anthropogenous influence on ground and superficial water resources for the purpose of preservation of natural and natural-anthropogenous systems stability. Theoretical foundations of HGS stability, methods of estimating of parameters on a basis of mass flows of matter were considered. It defines such important characteristic as margin of HGS stability. Evolution (or path dependency) of HGS is defined by variations of a margin stability, and their elasticity — by the degree of reaction to external influence. Variations of atmospheric precipitation and change of the formation environment of underground water are considered as such influences. By the example of the lake Baikal basin there was considered the influence of a complex of factors on a margin stability of HGS which is calculated for the basic catchment basins. Territories with the most and least stability were found out and their mapping was realized. The most stable HGS are forming at high altitudes with the increased values of the water exchange. However the value of stability is not always coincide with geoecological well-being of allocated systems. The stability formation in rock masses and intermountain area is considered as an example. The offered types of stability can be a basis for calculation and compilation of a series of applied maps.

Abstract ID: 322

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

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 and stressed the need of an integrated water resource management (IWRM) scheme. A qualitative and quantitative screening of groundwater sources for integration into the public water supply system of the 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. This is done using numerical modeling.

Currently 17 aquifer systems are described in the Algarve region, mainly supported by Jurassic, Miocene and Quaternary formations, covering an area of 1,074 km^2 in the coastal Mesocenozoic strip. The most productive aquifers are built up of karstified limestones and dolomites. The mean yearly groundwater recharge is estimated to be 216 million m^3, of which 50% is currently consumed. Crop irrigation is by far the largest consumer (80%). The total storage of the 17 aquifer systems is not known precisely, but is believed to be more than 50 times that of the surface reservoirs, including the large Odelouca reservoir, yet to be completed. The key question is what fraction of groundwater storage is exploitable, both on a short-term (i.e. yearly) and long-term basis.

Based on aquifer characteristics, well yields and water quality, six aquifers are considered most relevant for public water supply. Due to its large area, significant recharge and high productivity, the Querença-Silves aquifer system constitutes the most important groundwater reservoir in the Algarve Region. The main outlets of the aquifer are springs where important surface/ groundwater ecotones and dependent ecosystems have developed. Overexploitation of this aquifer, as well as the other relevant aquifers, could lead to wetland desiccation, as well as seawater intrusion near the coast. Climate change is expected to increase this problem, due to a combination of rising sea levels and lower recharge rates (Giorgi, 2006; Santos, Miranda, 2006). The climate scenarios and related consequences for groundwater recharge are currently being studied in the scope of the CIRCLE-Med project CLIMWAT (Stigter et al., 2009b), using regional climate model (RCM) data from the PRUDENCE and ENSEMBLES projects.

The concept of sustainable yield is studied for the public water supply aquifer systems of the Algarve, by analyzing different groundwater recharge/capture/discharge scenarios. Capture is defined as the sum of the increase in recharge and decrease in discharge (Lohman et al., 1972), caused by abstractions due to pumping. During (temporary) overexploitation, an important additional pumping volume is supplied by removal of water in storage. In semi-arid regions such as the Algarve, the increase in recharge from fresh surface water due to pumping is generally negligible, so that capture solely results in a decrease of groundwater discharge and a removal of water in storage. Initially the analysis is performed for the Querença-Silves aquifer system, and results are compared with finite element numerical modeling results. Subsequently the analysis is performed jointly for the six public supply aquifers. A period of six (hydrological) years is considered, starting in October 2001, when the surface water supply system was fully operational and groundwater consumption was comparable to the present-day situation. The hypothetical evolution of aquifer storage is calculated for different discharge scenarios and compared to observed piezometric records.

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Abstract ID: 379

TEN YEARS OF GROUNDWATER EXPLORATION AND DEVELOPMENT IN THE CARIBBEAN ISLANDS

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Keywords: groundwater, Caribbean, exploration, sustainable

This paper reports on the sustainable development of groundwater supplies in deep volcanic aquifers on three Caribbean islands utilizing an integrated multi-disciplinary exploration program. For 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. These islands are primarily volcanic in origin, highly vegetated, have incomplete geological mapping, 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 developing a sound conceptual hydrogeological model for each island.

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. Remote sensing and geological mapping 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. Annual precipitation ranges from 1500 mm up to 2500 mm in the higher elevations. A hydrogeological map and recharge analysis of the island was developed and favorable zones for geophysical exploration were mapped. The geophysical techniques that were selected included those that are effective in delineating fracture zones such as VLF electromagnetic, magnetic, micro-gravity and resistivity surveys. Prior to this program, no wells had ever been drilled into the bedrock aquifers. 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 is considerably younger than Tobago (28 to 33 my) and is part of the eastern volcanically inactive island arc. The geology varies from mafic consolidated volcanoclastic rocks and lava flows in the west and younger shale and limestone deposits overlying the volcanic rocks in the east. An exploration program was conducted that focused on developing groundwater in the volcanic portion of the island in fault and fracture zones. The annual precipitation is considerably lower than Tobago, with an average of between 900 to 1400 mm. 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 large supplies of fresh groundwater apparently do not exist in the volcanic rock, we estimate that between 2.0 and 4.0 imgd of brackish water could be developed, representing an opportunity to substantially reduce desalination costs.

The island of Nevis, part of the volcanically active island arc, 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 to 3000 mm. 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. The preferred technique applied was Controlled Source Audio-Magneto Tellurics (CSAMT) which has the capability of providing a resistivity profile to depths of up to 1000 meters. Thousands of meters of CSAMT geophysical profiles were run throughout the island to identify the optimum locations for high yield wells. Four test wells and three production wells, each capable of producing about 0.5 migd with a TDS content of 250 mg/l or less were drilled.

In summary, the knowledge and experience gained from these projects resulted in the development of a unique perspective that can be applied when evaluating new island environments.

Abstract ID: 401

AUTOMATIC BASEFLOW SEPARATION

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

Monthly baseflow values in majority of hydrogeologic regions are reported yearly by CHMI in accordance with Water Framework Directive (WFD). Information on low flow characteristics is required for such water resource management issues as water supply, irrigation, and water quality and quantity estimates. Contemporary development on recession analysis tends to work out automatic and objective methods, which eliminate some of the subjective elements of recession analysis.

Lyne and Hollick (1979) appear to have been the first to suggest the use of a digital filter that allows partitioning the stream flow into two components, direct runoff and baseflow They utilized the theory of signal analysis and filtering by which electrical signal can be separated into signals of different frequency. The Lyne-Hollick algorithm was used by Nathan and McMahon (1990) and Arnold and Allen (1999), for instance. Chapman and Maxwell (1996) further improved and simplified the filter equation. Then, Eckhardt (2005) has developed the extended two parametric filter algorithm constructed under the assumption that the outflow from an aquifer is linearly proportional to its storage:

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

subject to $b_k \le y_k$, where a denotes filter parameter and $\mathrm{BFI}_{\max}$ maximum baseflow index.

Eckhardt's filter among several others has been tested on a set of 206 gauging stations managed by CHMI in the period 1971–2003 in daily time step. The filter parameter a can be expressed as the recession constant of depletion curve. Therefore, it can be objectively derived by recession analysis during dry-weather periods. For this purpose, the *recess* program has been developed. The recession is considered to start 10th day after the peak flow and should last at least 30 days. The length of recession period is limited to 60 days. It can be recommended to smooth the stream flow records prior performing the recession analysis. The filter parameter $\mathrm{BFI}_{\max}$ is the maximum rate of baseflow to total stream flow. According to our experience $\mathrm{BFI}_{\max}$ can be derived by manual calibration with a values already known. The comparison of calibrated $\mathrm{BFI}_{\max}$ values with hydrogeological maps reveals the very good fit with catchment lithology giving $\mathrm{BFI}_{\max}$ higher (0.7–0.85) in sandstone basin aquifers and lower in low permeable aquifers in crystalline rocks (0.25–0.4). 30 gauges out of the whole set have been compared with the results obtained with the commonly used *kliner-kněžek* separation method where the baseflow is forced by corresponding borehole level or spring yield measurement (Kliner, Kněžek, 1974). The monthly baseflow mostly differs up to 10% (often to 5%) relatively to total discharge. Higher differences have been registered in stations where corresponding borehole or spring measurement is inadequate for a range of reasons. The regionalization of baseflow has been conducted under the assumption of regression between specific baseflow and long-term precipitation for particular geological conditions. These are represented by hydrogeological regions that share common lithology, i.e. they are built on gravel and sand, crystalline rock, limestone, sandstone, siltstone, slate, granite or mudstone. The regression model performs quite well even on monthly time scale for crystalline rocks or granites (explained variance of 70–90%) and relatively poor for sandstone group of hydrogeological regions. It's not surprising owing to high storage capacity and variable ground water gradients that are characteristic for sedimentary cretaceous formations and eliminates the role of precipitation.

ACKNOWLEDGEMENTS

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Abstract ID: 410

LIMITS FOR USE OF THERMAL WATERS IN THE BOHEMIAN CRETACEOUS BASIN

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Keywords: groundwater flow, Bohemian Cretaceous Basin, thermal waters

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 s^{-1} in the Usti area and 250–300 l 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 (Uhlik 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.

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Abstract ID: 425

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

THE DEVELOPMENT OF A GROUNDWATER QUALITY INDEX FOR THE NIGER DELTA REGION, NIGERIA

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Keywords: groundwater, quality, Nigeria

An assessment of groundwater quality of the Niger Delta Region was studied. Six parameters namely: static water level (SWL), total dissolved solids (TDS), pH, chloride (Cl^-), sulphate (SO_4^{2-}) and nitrate (NO_3^-) were considered to compute a groundwater quality index. Findings highlighted the deterioration of groundwater mainly due to seawater intrusion in the coastal part of the Niger Delta.

Abstract ID: 470

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

Tordera's Delta is a tiny alluvial aquifer close to Barcelona city, in Catalonia, NE Spain (Fig. 1). It is subject to problems similar to other Mediterranean coastal aquifers.

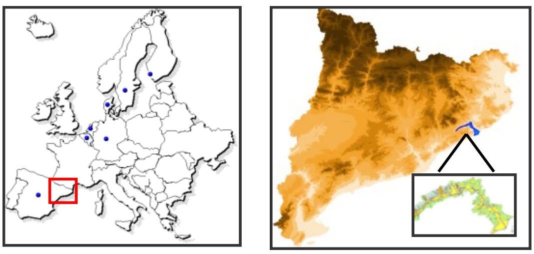

Figure 1. Location of Tordera's Delta aquifer, 70 km NE Barcelona, in NE Spain.

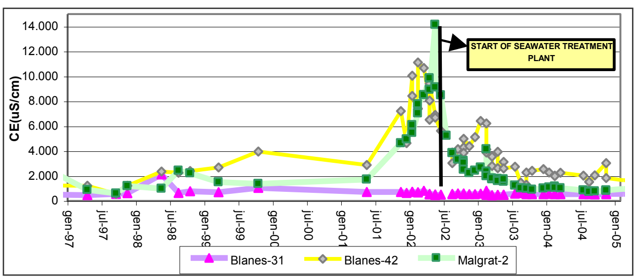

Figure 2. Electrical conductivity evolution at three points in Tordera's Delta (1997–2005).

Between 1997 and 2000, marine intrusion affected seriously the aquifer, reaching in 2002 chloride concentration as high as 2,500 ppm 2.5 km inland and peak electrical conductivities of 14,000 μS/cm (Fig. 2). This is why the Catalan Agency of Water (*the Agency*), which is the organism responsible of water resources management and planning in the Inner Catalan Basin (NE Spain), decided to (1) build a seawater treatment plant capable of producing 10·10⁶ m³/yr of drinkable water, in order to reduce groundwater extraction, and (2) develop a groundwater flow and transport numerical model for management purposes.

The original model (year 2002) did not include a transport calibration. The updated model, finished by the end of 2009, is based on a more elaborated conceptual model (including new data on geology, recharge, heads and measured concentrations) and has been calibrated with regard to chloride concentrations. This has resulted in significant differences concerning the new simulated scenarios, mainly when higher pumping strategies are compared (Tab. 1).

Table 1. Comparison between de 2002 and the 2009 Tordera's Delta model (1 and 2).

	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	Y	Y	VIABLE	UNVIABLE	UNVIABLE

Model 1 only showed small piezometric head variations (-0.5 m) in wells close to the shoreline when pumping was increased by $4 \cdot 10^6$ m³/a. On contrary, the new model 2 yields chloride concentration increased by a 2–3 factor. This also allows assessing other alternatives: if current abstraction increased by $6 \cdot 10^6$ m³/a but an adequate managed recharge scheme was adopted, then it would be possible to preserve groundwater quality even in wells near to the coast (three options have been simulated, Fig. 3).

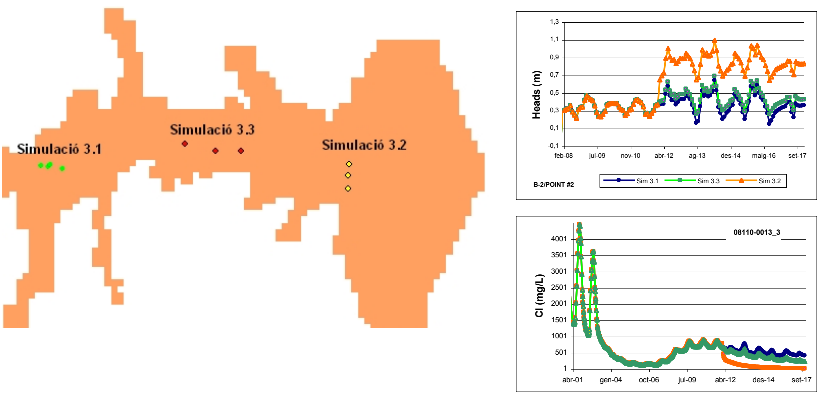

Figure 3. The new model allows to analyze more complicated scenarios, such as the best choice for artificial recharge facilities.

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. This explains why the improved model 2 is far more robust than the original one and can be wisely used for integrated water resources management needs: nowadays, Tordera's Delta aquifer has recovered good groundwater quality and the saltwater treatment plant is being extended so that it will be exporting potable water in the near future — a scenario that was unlikely in year 2002, before efficient actions were undertaken by the Agency.

Abstract ID: 490

GROUNDWATER SUPPLY DETERIORATION DUE TO AN UPCONING PROCESS

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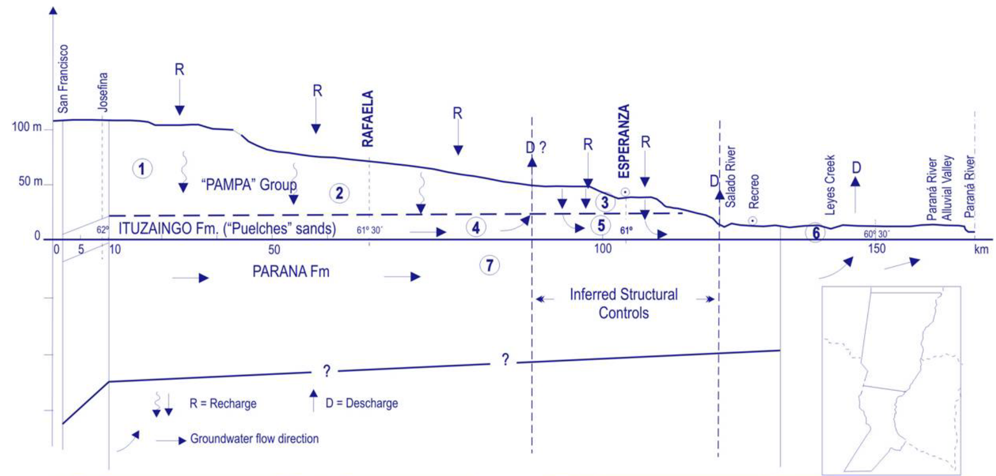
Keywords: groundwater deterioration, upconing, Esperanza city, Argentina

Groundwaters are of fundamental importance at Esperanza town, Santa Fe province, Argentine Republic (Fig. 1), since there is no other water supply to satisfy all local and 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.

Figure 1. Location of the study area.

Grey sands and green clays of marine origin underlie the fluvial sands (Fig. 2). The aquifer has been intensively exploited since the beginning of the 70's. 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 sulphate was due to an upconing process. 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.



	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).

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Abstract ID: 493

INTEGRATED WATER RESOURCES MANAGEMENT: FROM MONITORING TO ECO-STRATEGIC INITIATIVES

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

Act locally, plan and interact globally. The sustainable and responsible management of the Water Resources is the baseline for Nestlé Waters business. Effectively, despite each site and each water source are particular, the overall approach towards groundwater survey is going through the following steps:

- Hydrogeological investigations to fully understand how the aquifer systems are functioning from the recharge area to the catchments, leading ideally to a schematic conceptual model.
- Efficient monitoring system (production wells and piezometers) to ensure full overview of the Water Resources' status in terms of quantity and quality.
- Vulnerability study with proper risks assessment and water balance to help preserving the Water Resources over the long term in an efficient and proactive way.
- Definition and triggering of strategic 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).

The groundwater management cannot be separated from the global water cycle. For this reason, where it is needed, the approach intends to stimulate and to coordinate at the level of the whole recharge area, a number of preventive eco-strategic initiatives. The objective is to harmonize the economic development on the one hand, and the sustainable preservation of the environmental resources on the other side (i.e. biogas, phytoremediation, biodiversity). The Group is 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.

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. 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 quality monitoring system (chemistry and microbiology) is carried out from the water sources to the filling machines, including water transportation via pipes, water storage tanks and water treatment processes.

The key data provided by each industrial site is then regularly processed and reviewed by the Zone Water Resources Manager. This Hydrogeologist is then consolidating and organising these important figures on a centralised server. From there, just like an intranet site, all the Markets have always access to the most updated water resources databank, including relevant maps, pictures and documents through Google Earth.

Abstract ID: 500

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

ARSENIC IN GROUNDWATER IN WESTERN ANATOLIA, TURKEY: A REVIEW

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Keywords: groundwater, arsenic, water quality, western Anatolia

Occurrence of arsenic (As) in groundwater has been a major problem worldwide for the last hundred years. Considering its toxic effects on human health, presence of elevated levels of arsenic in groundwater resources used in drinking water supply has been an active research field throughout the world. 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, human health effects and in-situ and ex-situ treatment techniques. 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. In this regard, high arsenic concentrations in groundwater have been detected in many provinces of Western Anatolia including but not limited to Izmir, Kutahya, Canakkale, Afyon, Manisa, Aydin and Denizli with values ranging from 20 to 560 ppb in groundwater much exceeding the national and international drinking water quality criteria of 10 ppb. On the other hand, levels in geothermal fluid are about three times higher than the corresponding levels in groundwater. Considering the potential of contamination of regional groundwater reserves with geothermal fluid, levels in hot waters of Western Anatolia demonstrate additional problems. Based on these fundamentals, this study discusses the potential sources and levels of arsenic in water resources of the region with particular emphasis on local geologic and tectonic properties of Western Anatolian Plate.

Abstract ID: 181

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).

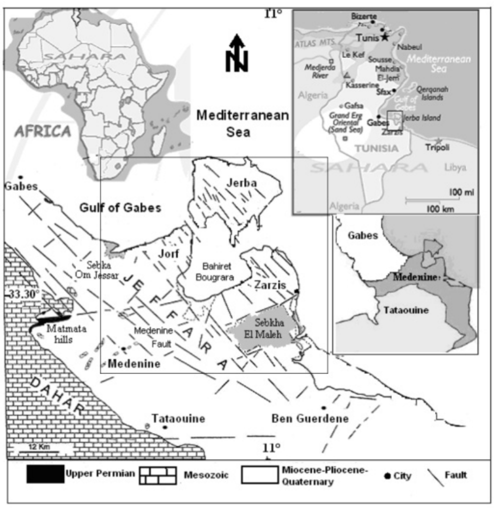

Figure 1. Location and geologic map of the study area.

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.

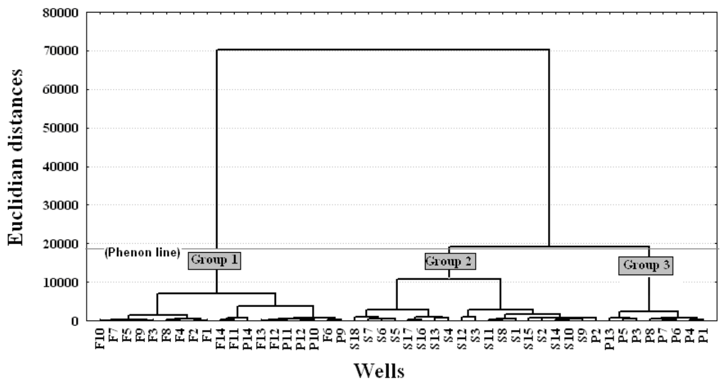

Figure 2. Dendrogram of Q-mode cluster analysis (Ward's linkage method and squared Euclidean distances).

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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Abstract ID: 206

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

The aim of this paper is to reconstruct a lithostratigraphical 3D model of a pyroclastic-alluvial aquifer and to define the extent of the nitrate contamination and to identify the possible sources of this pollution.

The sample areas (about 170 km^2) is located in the Garigliano River basin (southern Italy) and the main aquifer is affected by strong nitrate groundwater contamination.

The stratigraphical reconstruction of the study areas has been obtained by interpolating stratigraphical data from 80 boreholes. They have been first analyzed and codified in the light of the aim of this work. The software used for the lithostratigraphical model creation is *ROCKWORKS 2006*, which allows the reconstruction of a 3D model for three-dimensional or bidimensional representation. The reconstruction allowed to identify the main aquifer in the thick alluvial and marine clastic sediments.

The piezometric pattern (defined by the piezometric surface monitoring) shows the groundwater flow directed toward the sea and the Garigliano river.

The hydrogeochemical sampling was conducted in more than 60 wells. NO_3 is the most pervasive contaminant widely exceeding drinking-water quality guidelines. Finally, to discriminate nitrate sources in groundwater, thematic maps of the Garigliano plain were drawn up: The *SINTACS Map* (Civita, De Maio, 2000), which assesses the aquifer contamination vulnerability and the *IPNOA Map* (Padovani, Trevisan, 2002), which assesses the potential hazard of nitrate contamination originating from agriculture on a regional scale.

The Potential Agricultural Nitrate Contamination Risk Map, obtained by multiplying hazard and vulnerability, presents a good spatial correlation with the nitrate content of the aquifer 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.

Moreover, 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.

Abstract ID: 252

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 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.

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 studies 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 groundwater recharge (GROWA), groundwater flow velocity (FEFLOW) and nitrate leached from the soil profile (SWAT) 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 (Fig. 1).

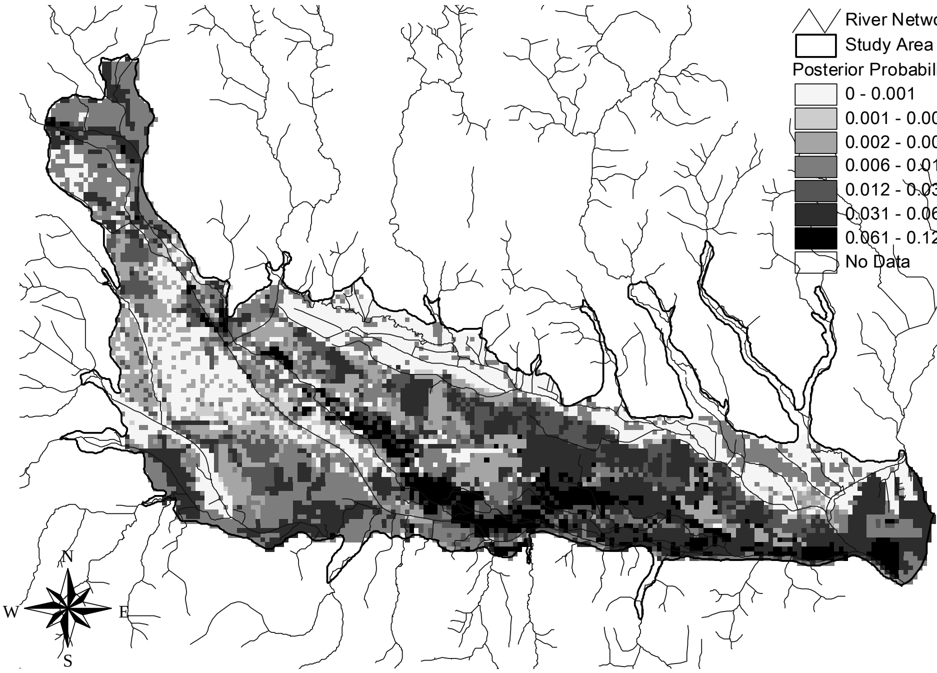

Figure 1. Posterior probability map of groundwater nitrate occurrence in the Lower Savinja Valley aquifer.

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. The cross-validation of the dissolved oxygen and dissolved nitrate response theme confirmed the accuracy of the groundwater nitrate prediction. 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 order to plan the groundwater nitrate reduction measures and optimize the programme for monitoring the effects of these measures.

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Abstract ID: 283

WELLHEAD PROTECTION AGAINST DIFFUSE POLLUTION AT CATCHMENT SCALE

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

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. A methodology was developed 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., 2008).

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. The aquifer is made up of Fontainebleau sandstone et cretaceous chalk. Ten catchment areas were defined and the vulnerability was assessed from a continuous aquifer approach. The crossing between vulnerability and pressures gives maps of risk areas for agricultural pollution and for industrial and urban 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.

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Abstract ID: 318

THE LEVEL OF AWARENESS OF GROUNDWATER QUALITY ISSUES AMONG PRIVATE WELL USERS IN IRELAND

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Keywords: groundwater contamination, health, private wells, awareness

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 <10 m^3/day. Many of these supplies are at risk from microbial and chemical contaminants from a variety of diffuse and point sources, including agriculture and septic tank systems. 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. Interim results are presented from 227 face-to-face interview surveys, completed over 5 study areas.

Survey results confirm that private groundwater sources in Ireland are not regularly tested for water quality. The awareness survey has identified a number of knowledge gaps amongst private groundwater users. Around a quarter of respondents did not recognise adjacent septic tanks or grazing animals as potential contamination threats. 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 risks to human health. The next phase of the research will investigate whether this is the case and, if so, 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.

Abstract ID: 326

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

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, for more precise evaluation of groundwater protection and vulnerability a large number of input parameters are needed and as a consequence the whole procedure became very complex. This is especially evident when groundwater vulnerability maps of large areas are created. That's why the 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 part 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 km^2, and the protection zone of the park covers the area of nearly 940 km^2. This large region is characterized by very complex geological structure which resulted in existence of different types of aquifers.

This is the main reason why the DRASTIC method is chosen for creation of groundwater vulnerability map. Although this method combines seven different maps, each of them can easily be created in the small scale. The most difficult was to define the first two parameters (D — depth to groundwater and R — groundwater recharge) because of the lack of data. The maps of these two factors are made by using special GIS methodology which is also described in the paper.

Abstract ID: 385

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

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

Although the Water Framework Directive 2000/60/EC (WFD) pays special attention to the protection of waters used for human consumption, it lacks direct reference to the important matter of the protection of groundwater intake resources and detailed indications relating to delineation and setting up of protection zones. This does not mean however, that the Directive does not give appropriate attention to the matter of protection of groundwater, especially of that of special meaning for the human supply. The problem is captured, however, in a general way, leaving a large freedom in an approach to a solution to the individual member states. Generally, we can say that WFD is set on the diagnosis of the state of groundwater resources, understood as the permanent control of their qualitative and quantitative state (monitoring). However, the matter of their protection, which is introduced in the form of prohibitions, orders and limitations in the use of the terrain, is left to the decision of individual countries.

In the interpretation of the Directive, the subject of protection is not the groundwater intake with its recharge area, but the so-called "groundwater body" (GWB) understood as 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 on the assurance of such protection are presented in the Guidance document No 16, "Groundwater in Drinking Water Protected Areas". According to them, the protection GWB should be realized by marking and formal setting up for the so-called "Drinking Water Protected Areas" (DWPAs). For this purpose, the so-called "safeguard zones" (SZ) can be set up for the groundwater intake used for the collective supply of the population. Measures proposed for DWPAs and SZ should be part of programmes of measures taken for the protection of waters for each river basin district. Although setting up of the protection zones for the drinking water supply is not required in European regulations, most of the UE countries attach great importance to this and the implementation of the WFD did not alter anything in this subject. The principles of delineation and setting up of the safeguard zones, so as the effectiveness of the protective measures often differ considerably in various countries. Because setting up of the protection zones for the water intakes is important, but often underestimated element of the protection of groundwater resources, interesting and important for the realization of European policy in this range can be the comparison and confrontation of the regulations and the experiences of various European countries. In the following article, comparison of the rich and long experience of Poland in this range with the experience of different countries, mainly France, Germany and Great Britain, was undertaken. The following questions were subject to comparative analysis:

- The current state of protection of the groundwater intakes for the collective supply in drinking water.
- Regulations concerning principles of delineation and setting up of protection zones.
- Criteria, principles and the methodology of delineation of the protection zones.
- The principles and requirements in establishing protective measures in safeguard zones.
- Control of delineation of protection zones and execution of the established protection regulations.
- State participation in the activities for the protection of the groundwater intakes recharge areas.
- Participation of the society in the process of setting up of protection zones for drinking water intakes.

The author believes that the protection of ground waters against their quantitative and qualitative degradation should begin with the protection of recharge areas of abstraction wells for human consumption and in the second order, the areas which could be used for this purpose in the future (perspective, strategic). To be effective, these activities must be supported by the active policy of the state. Unfortunately, the approach to the problem of the proper protection zones for drinking groundwater intakes in the European countries differs very much and often is belittled. The author proposes a wider cooperation on the forum of European Union to deal together with this problem. The expected effect of this cooperation should be the preparation of common politics and the uniform methodology of delineation and setting up safeguard zones for the underground water intakes for the collective supply.

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Abstract ID: 409

IMPROVEMENT OF ORIGINAL DRASTIC MODEL FOR GROUNDWATER VULNERABILITY ASSESSMENT OF THE IZEH PLAIN

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Keywords: groundwater, vulnerability, DRASTIC

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 north-west in comparison with other areas of the basin.

Abstract ID: 424

VANADIUM AS AN INDICATOR OF GROUNDWATER ARSENIC CONTAMINATION IN URBAN ENVIRONMENTS

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Keywords: groundwater arsenic, vanadium, aquifer contamination, particulate

INTRODUCTION

Since early 90's arsenic, As, concentrations over Mexican standards for drinking water has been detected in the Salamanca aquifer system (Rodriguez et al., 2005; Mezquita, 1980). Vanadium, V, was also 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.

METHODOLOGY

A preliminary groundwater monitoring was based on in situ As determinations using the a portable test kit for arsenic, Arsenator. 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. Analyzes including vanadium, V, some trace metals that conform hydrocarbons; Chromium, Cr, lead, Pb, Zinc, Zn and nickel, Ni. The main monitoring was carried out in the industrial zone, where is located a thermoelectric plant, a refinery and chemical industries. A second monitoring was carried out in a rural area, northern Irapuato City, avoiding the industrial influence.

Descriptive statistic (mean, median, standard deviation, range, minimum, maximum and variation coefficient) was done using STATISTICA 7.0 Stat Soft, Inc., and OriginPro 8, OriginLab, Co. Correlation and determination coefficient was calculate to determine relationships between variables and its linear tendency (STATISTICA 7.0). Multiple correlations and principal component analysis (PCA) were applied to analysis the variable relationships.

RESULTS

Out of the city, in the rural area, soil V is related to regional geology, to volcanic rocks like basalts and rhyolites, whereas in the urban area, it has not relation with the geology. Urban soil V concentrations were higher that rural values. Maximum values up 600 ppm were found. Higher concentrations are associated to particulate distribution. Particulate emitted by industries using foil num 6 contain great contents of V, As, Ni and Zn. In the urban area must be also a geologic contribution.

After As and V deposition over urban soils, rain infiltrations facilitates its incorporation to the local aquifer system. Infiltrations occur in vulnerable areas. (Mejia et al., 2007).

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Abstract ID: 474

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.

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

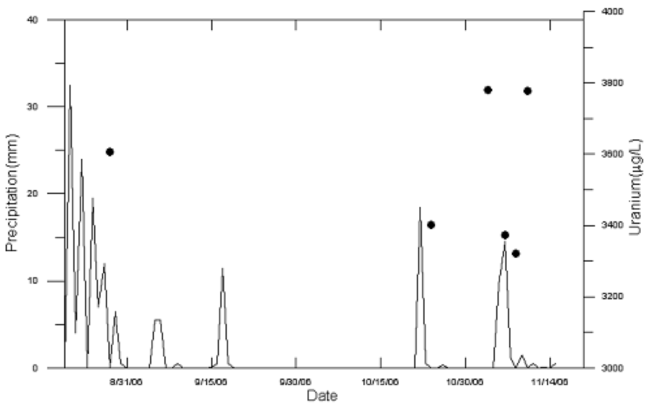

Figure 1. Radon concentration of a well in two-mica area as a function of time.

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Abstract ID: 501

GROUNDWATER RESOURCES SUSTAINABILITY INDICATORS

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Keywords: groundwater resources, sustainability indicators

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 computed at the global, national and aquifer level.

Groundwater indicators serve a variety of policy goals. They help in the improvement of groundwater resources planning and management policy 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 most common use of groundwater indicators is describing the current status of the resource (*descriptive*). Regular measurements of indicators provide time series (*showing trends*) that may inform on the functions of the system or its response to management. They therefore act as important *communication* tool for policy makers, managers and the public, and also permit evaluation of the effect of specific policy actions and promote development of new actions. 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.

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.

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 (groundwater availability and use), economic (groundwater abstraction both renewable and non-renewable and treatment requirements) and environmental (groundwater quality, vulnerability, depletion) aspects of groundwater development and resource management.

The following groundwater indicators have been developed and tested at the aquifer, national and global scale level: Renewable groundwater resources per capita, Total groundwater abstraction/Groundwater recharge, Total groundwater abstraction/Exploitable groundwater resources, Groundwater as a percentage of total use of drinking water at national level, Total exploitable non-renewable groundwater resources/Annual abstraction on non-renewable groundwater resources, Groundwater quality, Groundwater depletion, Groundwater vulnerability and Groundwater treatment requirements.

UNESCO-IHP was also entrusted by the Global Environmental Facility (GEF) with the development of groundwater indicators oriented on environmental, socio-economic, legal and institutional aspects of transboundary aquifers; those will be also discussed in the paper.

The following experts, mostly IAH members, joint UNESCO/IAEA/IAH Working Group on Groundwater Resources Sustainability indicators: Jan Girman, Naim Haie, Ricardo Hirata, Annuka Lipponen, Elena Lopez-Gun, Bill Wallin, and Jaroslav Vrba. The work has been coordinated by Jaroslav Vrba.

Abstract ID: 512

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

1. INTRODUCTION

On the well field located in Odra River ice marginal valley near Zawada village significant water quality changes were observed after three years of water pumping start. These changes were connected with iron sulphide oxidation process. This process caused drastic deterioration of groundwater quality in the range of iron, sulphates, hardness and manganese.

In spite of this water have been still pumping because abstracted ground water was mixed with surface water, which resulted in coagulation processes leading to the improvement of surface water quality.

In this situation Zawada well field has been exploited since 1966 year with practically constant yield and this unique situation gives a possibility to analyse the extreme groundwater quality changes under steady state hydrodynamic conditions for nearly 40 years period.

2. HYDROGEOLOGICAL SETTING

Zawada well field consists of 22 wells taping ice marginal aquifer (Fig. 1).

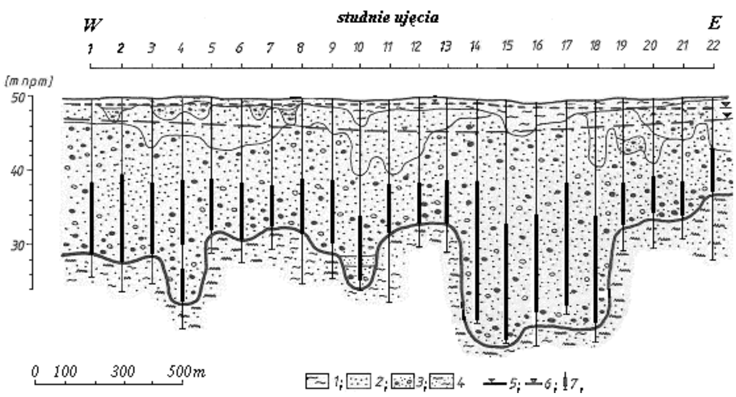

Figure 1. Hydrogeochemical cross section along Zawada well barrier. Explanations: 1 — silts and muds; 2 — fine and medium sands; 3 — sands and gravels with pebbles; 4 — silts and clays with sand; 5 — water level before pumping; 6 — water level during pumping; 7 — well screen.

The bottom part of the valley deposits, underlain by impermeable or slightly permeate drift deposits, is composed of fluvioglacial coarse-grained sands and gravels. The upper stratum is composed of fluvial fine-grained sands. The top unit is composed of overbank flood deposits (silts and muds). Fluvial deposits contain dispersed organic detritus and iron sulphides as a uncrystallized troillit (FeS). In natural conditions aquifer was confined by silts and muds layer and water table was near the surface (0.3–0.7 m depth).

During groundwater exploitation water table declined several meters and iron sulphides were oxidized in newly created aeration zone.

3. GROUNDWATER QUALITY CHANGES

Quality of groundwater before the start of exploitation in 1966 was very good with iron concentration below 0.5 mg/L, manganese 0.19 mg/L, sulphates 10 mg/L and hardness 3.2 meq/L. After four years of pumping concentration of iron increased up to 30 mg/L (Fig. 2) and was accompanied by increase of sulphates (to 325 mg/L), manganese (to 0.8 mg/L) and hardness (to 9.5 meq/L).

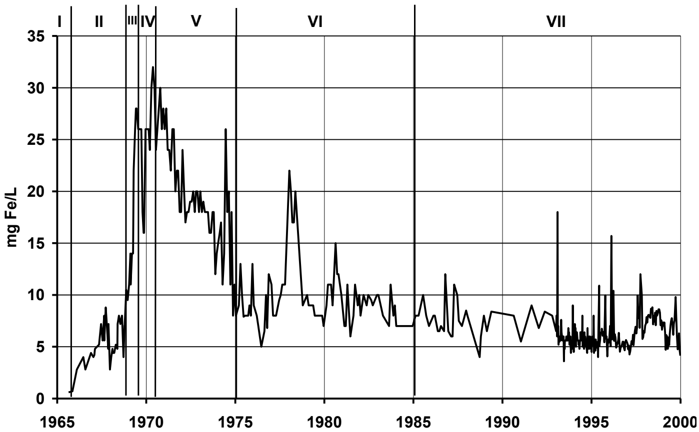

Figure 2. Phases of iron concentration changes in ground water from Zawada well field. I–VII — phases of iron concentration changes (see explanation in the text).

The increase of hardness was the result of neutralization of sulphur acid from oxidation reaction by carbonates contained in fluvioglacial deposits. During the exploitation seven time phases of changes in iron concentration can be distinguished (Fig. 2):

- I — no changes;
- II — slow increase;
- III — quick increase;
- IV — temporary equilibrium with maximum concentrations on the level 25–30 mg/L;
- V — quick decrease to the concentration of 12 mg/L;
- VI — slow decrease;
- VII — relative stabilization of concentration, in the range of 7–8 mg/L.

The whole period of the iron sulphide oxidation influence on the groundwater quality was about 20 years with very high concentration of iron above 15 mg/L in the period of about 6 years.

Half-time attenuation of the iron concentration in the phase of quick decrease according to exponential kinetics of reaction can be calculated on about 3.2 years.

1.3 | Urban hydrogeology

Abstract ID: 250

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

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Abstract ID: 298

THE IMPACT OF RECENT URBANIZATION ON A HARD ROCK AQUIFER IN MALAYSIA

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Keywords: urbanization, hard rock aquifer, Malaysia

Urbanization often significantly affects groundwater systems, changing recharge rates and distributions in time as well as space, modifying existing flow systems, and modifying water quality. It is therefore essential to understand the impacts of urbanization on groundwater systems if they are to be properly managed, especially in cases where urban groundwaters are an important resource. In Malaysia, relatively little work has been done on urban groundwater systems, with more focus having been on finding groundwater sources. Shah Alam, in the Klang Valley Region, has been chosen as a study area. It is the first planned town in Malaysia to experience rapid development from agricultural to industrial urban land use and therefore should indicate urban impacts different from long-established cities elsewhere in the world. There are serious concerns about the future water resources in this region, and a deeper understanding of the water system is urgently required. The city is underlain by a Lower Palaeozoic hard rock aquifer, a type of aquifer on which relatively little work has been carried out in the context of urban supplies. Water quality is often excellent, with very low total dissolved solids: however, there is a significant minority of sampling sites where a range of pollutants have been identified, including coliforms, organics, nitrate, ammonium, and transition metals. Initial work has concentrated on understanding the groundwater flow system, and to this end analytical and numerical modelling analysis of 34 pumping tests at industrial abstraction sites is indicating a complex, compartmentalized flow system, involving both recharge boundaries and barrier boundaries. This conceptual model will be tested further using a regional flow model over the next few months. This model will then be used to investigate the groundwater quality patterns identified. However, it is already clear that the groundwater, which is extensively used by industry, is vulnerable, being strongly connected to surface water bodies and having little pollutant attenuating capacity.

Abstract ID: 331

EVALUATION OF GROUNDWATER QUALITY IN THE WIDE URBAN AREA OF CAGLIARI (SOUTHERN SARDINIA, ITALY)

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Keywords: coastal aquifer, monitoring, contamination

Urbanization has a great impact on the aquifer beneath the area under analysis where groundwater is subject to modification in quality and quantity because of human activity.

The coastal aquifer beneath the Wide Urban Area of Cagliari (Fig. 1) (southern Sardinia – Italy) represents a typical case for the study of the dynamics which involved the aquifer beneath an urbanized area.

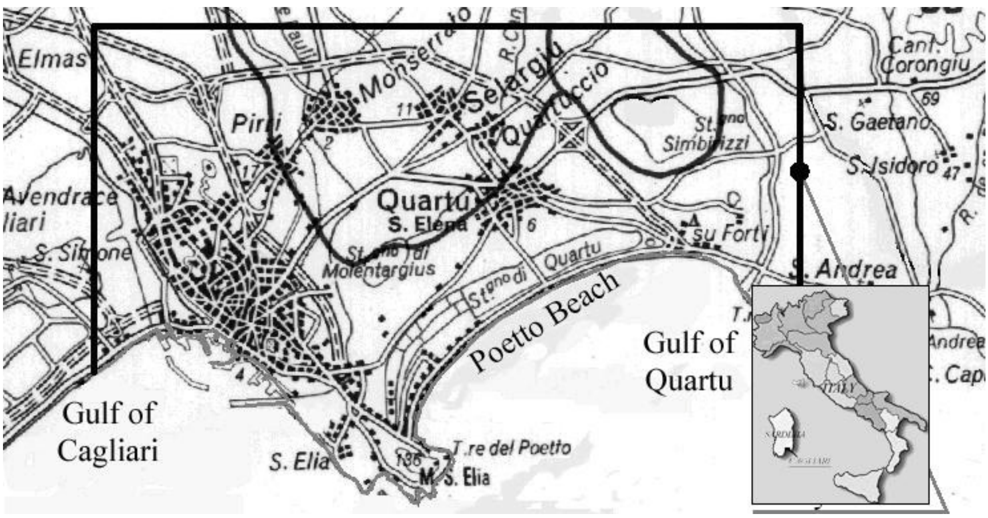

Figure 1. The study area.

The study area has a surface of 100 square kilometers with a population of about of 300,000 inhabitants. 40% of the Sardinian population lives and works in this area.

This area is very complex (Fig. 2): there are several wetlands of great naturalistic and environmental relevance like the pond of Molentargius, the Poetto beach, and the Santa Gilla lagoon, which are considered among the most important wetlands of the Mediterranean area (the RAMSAR convention of wetlands, 1977). Also the orography is varied; there are both wide areas more or less at the sea level, and a few hills with elevations about 140 meters above the sea level.

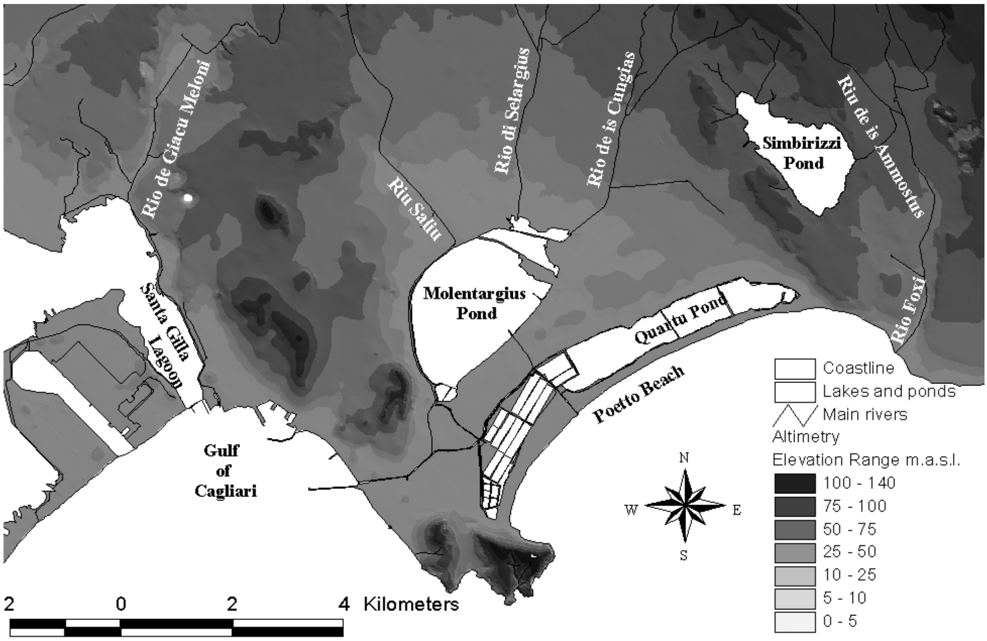

Figure 2. Morphology of the area.

The study aims at pointing out how urbanization influences the groundwater quality and which natural or artificial factors can amplify or mitigate these effects.

The result of the study, which involves the shallow aquifer, is that 75% of the sample has a relevant human impact with poor hydrochemical characteristics; 15% has an important human impact with general good hydrochemical conditions, but with a few signs of compromising; and only 10% has a reduced human impact, sustainable over long periods and with good hydro-chemical characteristics.

Abstract ID: 332

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

Mar del Plata city, the main tourist resort in Argentina, registered a massive migration process during the second part of the last century, at a rate of 100,000 inhabitants each decade. During its rapid development 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. Salinization led to abandonment of many urban pumping wells 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 to recover 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 (Fig. 1).

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 from underground structures leakage. 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. Chemical data shows that water 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). Still, mixing ratios could be obtained using Cl, total N, ^2H, and ^{18}O as conservative tracers.

Results indicate that the average mixing ratios for leakage into underground structures flooding are: runoff water 35%; sewage leakage 19%; rain water 30%; seawater 7%; and aquifer water level rising 9% (Fig. 2). The applied method is simple tool for preliminary identification of runoff water and sewage pipe lines leaking.

Figure 1. Basement flooding and damage of the reinforced concrete structures.

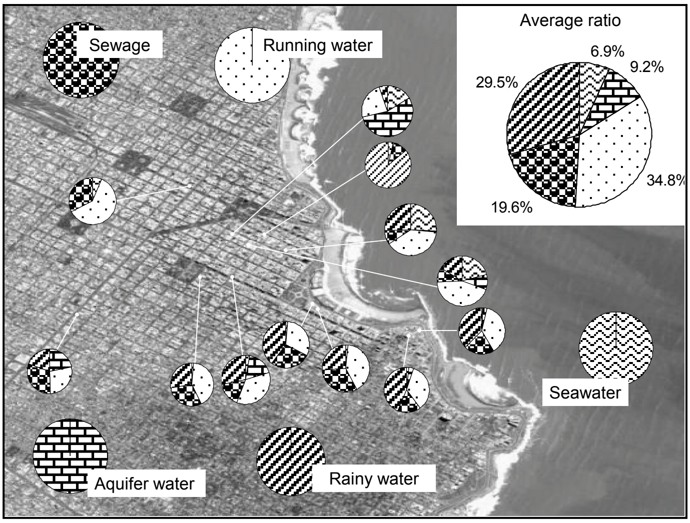

Figure 2. Spatial distribution of mixing ratio with end members.

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Abstract ID: 349

GROUNDWATER TABLE FLUCTUATIONS TYPES IN URBAN AREA, WROCLAW, SW POLAND

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Keywords: grundwater table fluctuations, Wroclaw, urban hydrogeology

In the city of Wroclaw (SW of Poland) observational tests of the position of the shallow groundwater table were performed during two hydrological years (2004–2005). Their levels were weekly observed in over 100 hydrogeological boreholes. The results were evaluated and analyzed from the groundwater table fluctuation standpoint. The shape, periodicity, and the time of the extreme state were shown on hydrographs from 85 hydrogeological boreholes.

This way, the four main types of groundwater table fluctuations of the first aquifer were found in the city of Wroclaw.

Type I — 4–extremal, comparable to the natural cycle (Konoplancew, Siemionow 1979) (Fig. 1). Two minimal levels and two maximal ones during a period of one year distinguish this type. The first minimal levels started appearing in spring time — between April and May and then in the months of June and July the table was rising to reach its peak in the middle of the month July. Right around October and November appeared the second minimal level and in December and January we could observe the second maximum, which was slightly lower than the spring one. This kind of periodicity of groundwater table fluctuation was being noticed in 10 observational points.

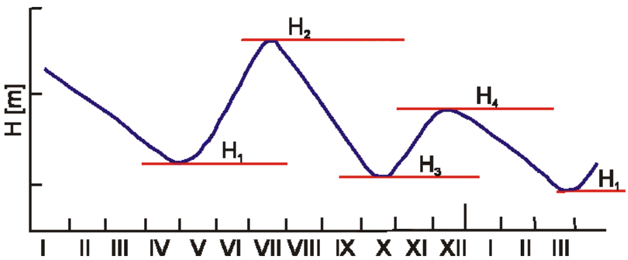

Figure 1. General groundwater hydrograph for Type I of groundwater table fluctuations.

Type II — 2–extremal (Fig. 2), was characterized by one distinct minimum and one maximum. The rise of the groundwater table was noticed until April, and then it was gradually lowering until it reached a minimum in October and November. This type qualifies as the most common type of groundwater table fluctuation in the city of Wroclaw (39 hydrological boreholes).

Type III — 2–extremal, influenced by the waters of the Odra river (Fig. 3). This kind of groundwater table fluctuation was described by a high frequency depended on the level of the Odra. Despite of the frequency the two extremes (spring and fall) were still noticeable on the hydrograph. This type was observed in 25 hydrogeological boreholes in the Odra river valley and the area directly influenced by this river.

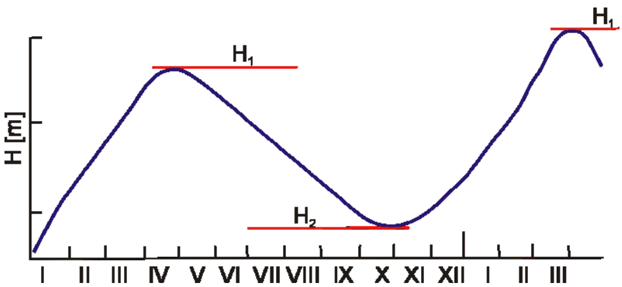

Figure 2. General groundwater hydrograph for Type II of groundwater table fluctuations.

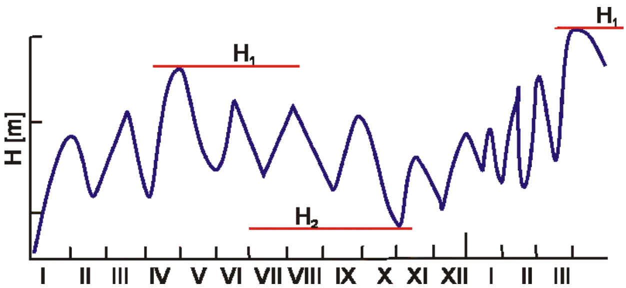

Figure 3. General groundwater hydrograph for Type III of groundwater table fluctuations.

Type IV — irregular and being a result of incidental anthropogenic events (Fig. 4). Hydrographs that present the Type IV of groundwater table fluctuation (11 observation points) show numerous disturbances of the fluctuation rhythm–sudden, high drops and rises of the groundwater level. Further analysis of the local circumstances 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.

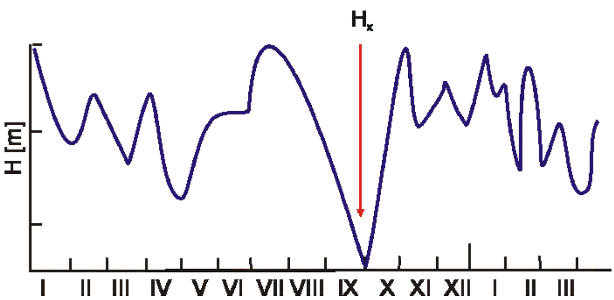

Figure 4. General groundwater hydrograph for Type IV of groundwater table fluctuations.

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Abstract ID: 363

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

Major subsurface construction projects often require dewatering and in urban areas, detailed design and management of the dewatering program are needed for authority approval and optimising program design. Lowering the groundwater table in urban areas without sufficient hydrogeological data can result in general ground settlement, damage adjacent buildings, mobilise contaminants, and affect water supply and quality. Recent incidents related to dewatering programs for metro construction projects in Amsterdam, Holland and Köln, Germany highlight the importance of optimising dewatering design and reducing risks.

In central Copenhagen a new metro Circle line, Cityringen, comprised of twin bored tunnels 15.5 km long, 17 deep stations and 3 crossover caverns is planned. Major urban condition concerns in the area include 1) settlement in old buildings built on soft soils or wooden piles 2) impact on nearby major water supply 3) potential risk of saltwater intrusion and 4) mobilisation of contaminants at known polluted sites at planned construction zones. The Municipality of Copenhagen prohibits lowering of the groundwater table in the inner city with regulations established strictly governing dewatering. Furthermore, the site contains complex conditions such as variable bedrock surface, potentially disturbed limestone and variability in sediment layers comprised of glacial till, meltwater sands and gravels and urban fill. These concerns and experience from investigations related to the construction of the first Metro line built through the 1990's contributed to the development of a comprehensive hydrogeological investigation program for input into the tender design phase of the Cityringen.

The program was comprised of 17 long duration pumping tests at station and crossover cavern locations, single-well pumping tests at over 500 screened locations, geophysical logging at over

250 locations, more than 400 water and soil samples, and geophysical surveys consisting of geo-electrical surveys, 15 km of seismic and over 40 vertical seismic profiles. The data serve as basis for obtaining hydraulic parameters, mapping of relevant bedrock structures, identification of the location and magnitude of flow horizons, contamination levels, and further characterisation of variations in bedrock and sediment property distribution. Integrated analyses of the survey data was used in the planning and optimisation of construction methods and interim dewatering systems, mitigating measures, and environmental monitoring.

Furthermore, monitoring of the groundwater level in approximately 300 standpipes in the project area has also been initiated representing both the uppermost fill layers, the secondary and primary aquifers. Of these standpipes approximately 130 are monitored with online data loggers that automatically transfer data to a central server on a daily basis. In this way a reference groundwater level is obtained and, most importantly, rapid action can be taken if changes in the groundwater level are recorded at a later stage in the project.

Geophysical logging results were used to establish a log stratigraphy of the region to gain understanding of regional structural features. Seismic reflection results provided structural information and seismic refraction results detailed areas with variations in bedrock properties of potential consequence to hydrogeological properties.

The geological and geophysical data has allowed setting up a detailed geological model for input into a regional groundwater flow model for the entire project area allowing for site-scale groundwater modelling, including further detailing and calibration of the groundwater model at each of the deep structures. The results have been used in each of the station and cavern design and the depth of the caverns and cut-off walls have been optimized, including significant changes of the design in some places. Also, possible locations of pumping and infiltration wells have been identified and it has been found that at some stations, contamination necessitates precautionary actions in order to meet environmental requirements.

It is expected that the carrying out of the large-scale hydrogeological and geophysical site investigations and monitoring program before the tendering phase contributing to a comprehensive integrated hydrogeological analyses will significantly reduce potential risks not only during dewatering but also to the overall project.

ACKNOWLEDGEMENTS

The authors acknowledge Metroselskabet I/S for permission to present these results. The work was carried out by Cityringen Joint Venture partners COWI, Arup and Systra (CAS) and their cooperation is appreciated. The site investigations were carried out by GEO A/S with the exception of the seismic and geo-electrical surveys which were carried out by CAS.

Abstract ID: 372

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 vulnera-

bility 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

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, mining, Triassic, groundwater, 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.

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).

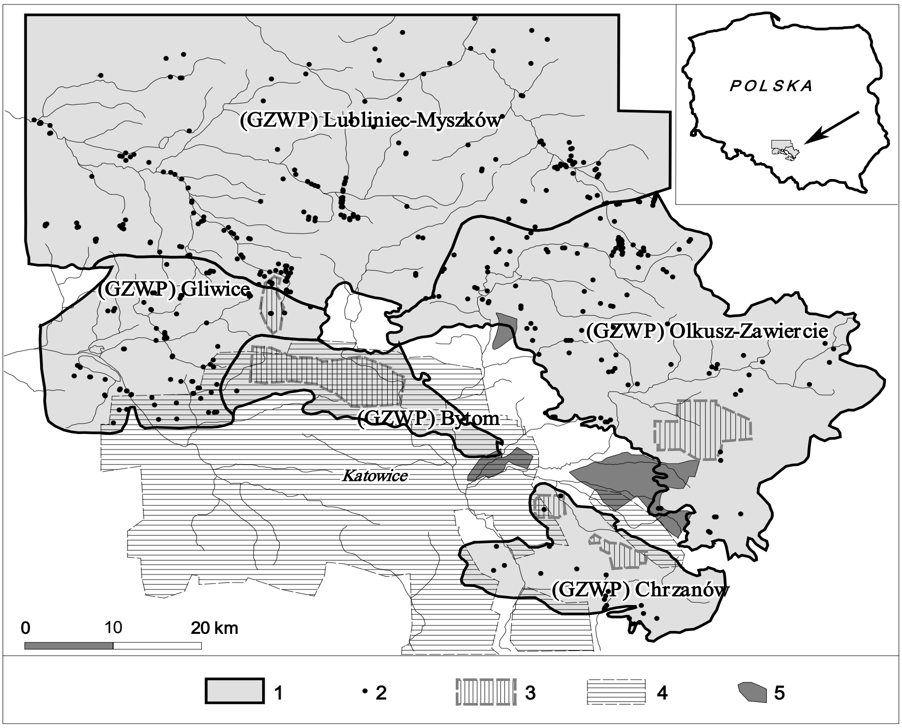

Figure 1. Location of wells and mining areas within the Triassic major aquifers in the Upper Silesia region (Southern Poland). 1 — extend and boundary of the Triassic major aquifer (MA) systems; 2 — wells; 3 — Zn-Pb ore mining areas; 4 — hard coal mining areas; 5 — sand open pits.

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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Abstract ID: 497

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.

Abstract ID: 503

URBAN WATER CYCLE

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Keywords: groundwater, water supply, urbanization, 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

GROUNDWATER CONTAMINATION BY NITRATES, SALINITY AND PESTICIDES: CASE OF THE UNCONFINED AQUIFER OF TRIFFA PLAIN (EASTERN MOROCCO)

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Keywords: aquifer, contamination, nitrate, pesticide, Morocco

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

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, groundwater quality, groundwater recharge, northeastern India

1. INTRODUCTION

The northeastern region of India, having an area of 255,090 km^2, is predominantly hilly. The region is endowed with rich natural water resources but their indiscriminate use and mismanagement, coupled with the prevailing resource depleting crop land use systems, have affected the quality and quantity of groundwater. There is an annual loss of 601 million tonnes of soil with runoff, out of which shifting cultivation alone is responsible for 88.3 million tonnes. 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. 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.

2. MATERIALS AND METODS

A long-term multidisciplinary study was undertaken on watersheds having slopes varying from 32% to 42% to see the effect of different land uses (Tab. 1), and fertilizer use on the recharge and quality of groundwater. 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.

3. RESULTS AND DISCUSSION

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. The variation in 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.

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

This may be attributed to the application of inorganic fertilizers in these land uses (Sharma, 1990, 1999). The nitrate may be derived from the application of inorganic fertilizers, septic systems, animal manure, atmospheric deposition and transformation of soil organic matter to nitrate. Sulphates, Cl, Ca, Zn, Mn, Fe and mg 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 SO_4, Cl, Ca, Zn and Mg 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. 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. The groundwater recharge was maximum in livestock based land use system, followed closely by agriculture, horticulture and forestry land use systems (average 34.7% of precipitation) as against only 8.3% in shifting cultivation. 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 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. The observed and predicted values agreed relatively well.

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Abstract ID: 140

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

In deriving management policies to control groundwater nitrate pollution is important to conduct an integrated modeling which takes into consideration soil, unsaturated and saturated zone. In management regional studies the influence of the unsaturated zone is often neglected. In this paper the influence of the different zones in deriving optimal fertilizer use is analyzed and the importance of the unsaturated zone is highlighted. The unsaturated zone can have an important influence in the time delay of the nitrate transport and therefore in accomplishing the good groundwater status as 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 a synthetic case where different policies were derived taking into account the unsaturated zone and comparing them with the case where only the saturated zone was used.

Abstract ID: 160

ALLUVIAL GROUNDWATER RESPONSE TO VARIABLE RAINFALL RECHARGE AND PROLONGED PUMPING: LOWER LOCKYER CATCHMENT, QUEENSLAND, AUSTRALIA

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Keywords: alluvial groundwater, Lockyer Valley Queensland, hydrochemistry, stable isotopes

The Lockyer Valley supports intensive irrigation based on groundwater drawn from Quaternary alluvial deposits within channels that overlie sandstone bedrock. The lower valley is becoming degraded due to continued local and upstream extraction, and the effects of a decade-long drought. Groundwater here ranges in salinity from 300 to 27,000 µS/cm EC. The distribution and causes of this salinity have been studied over a 30 km section of Lockyer Creek with an area of 120 km^2 . Recharge to the alluvial aquifer system is primarily from ephemeral stream flow, fed by rainfall on the surrounding ranges, which are mostly capped by Tertiary age basalt flows. By 2007 water levels were the lowest for over 20 years, and in this lower section of the catchment the watertable has been substantially drawn down. Within the 25–35 m thickness of the alluvium continued extraction has resulted in a saturated thickness of around 5 m, and much of this is central to the main flow path. The lack of significant recharge has caused some shallower bores to dry up.

Hydrochemical and isotopic analyses have enabled the determination of the recharge processes and the mixing of water within this area. Most groundwater extraction is from the lower layers of coarse sands and gravels within the alluvium. Measurements of the alluvial watertable over a 25 km distance shows it has a gradient of around 1.2 m/km, and due to the drought conditions is drawn down over 10–15 m below the main stream channel. Most of the alluvial groundwater has an EC of 800 to 2,000 µS/cm, and sandstone groundwaters an EC of 1,500 to 8,000 µS/cm.

Thirty-one boreholes have been investigated with physico-chemical and depth measurements. Twenty-four groundwater and one surface water samples were collected and analysed for major and minor elements, and stable isotopes. Most groundwater samples are of Na, Mg–Cl, HCO_3 type, with $Na^+ > Mg^{2+} > Ca^{2+}$. The chemical analyses indicate 4 major groups of water: Group A, recharging surface water and bores close to the stream; Group B, groundwater in the alluvial gravels, some near the bedrock interface; Group C, groundwater in middle and upper alluvium, mostly distant from the stream; and Group D, bores extracting from the bedrock (Gatton Sandstone). The various chemical and isotopic scatter plots show that Groups B and C receive mainly recharge from rainfall-sourced stream flow, but also from sandstone. Recharge from the sandstone bedrock is shown to be enhanced by pumping when groundwater levels are low. Figure 1 displays water grouping based on a HCO_3 vs Cl plot, and also shows the high salinity bore #635.

The mixing of different waters depends of the location of the bore and where in the hydrogeological profile the screens are located.

Isotopic studies have clearly identified two main sources of recharge to the alluvial aquifer system of the lower Lockyer Creek catchment. A δ^2H and $\delta^{18}O$ signature in groundwater more depleted than stream/surface water indicates some recharge from the Gatton Sandstone, which is likely to be older water. In areas close to the stream, δ^2H and $\delta^{18}O$ values indicate that the groundwater receives modern meteoric recharge. Bores more distant from the stream are relatively enriched along the global MWL; many other bores further from the river show strong evaporative enrichment.

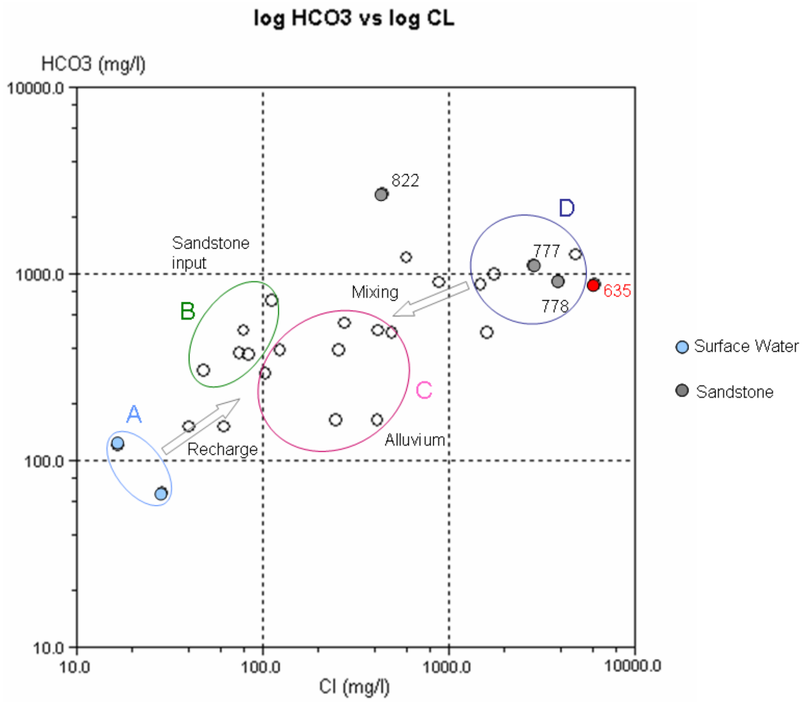

Figure 1. Plot of log HCO_3 vs log Cl for groundwater bores in the lower Lockyer Creek area, showing grouping. The high salinity bore #635 is included.

Very high salinities in several bores appear due to ponding of groundwater in basement depressions. For the most saline bore 635 (EC = 27,000 µS/cm) combined chemical, isotopic and stratigraphic data suggests that the salinity is not due to evaporative processes or to substantial recharge from the sandstone (δ^2H value = –23.6‰ VSMOW), but is most likely due to the structure of the bedrock. A bedrock depression may lead to groundwater stagnation and concentration of dissolved salts carried by the water infiltrated in the alluvium. It is possible there may also be semi-confinement by clay layers and some salt concentration, notably Na^+, by diffusion.

Abstract ID: 164

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

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. La Aldea aquifer is located on the western side of the island (Fig. 1) and 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. The geology of the area consists of a sedimentary unit (alluvial and scree deposits) that overlie Miocene basalts.

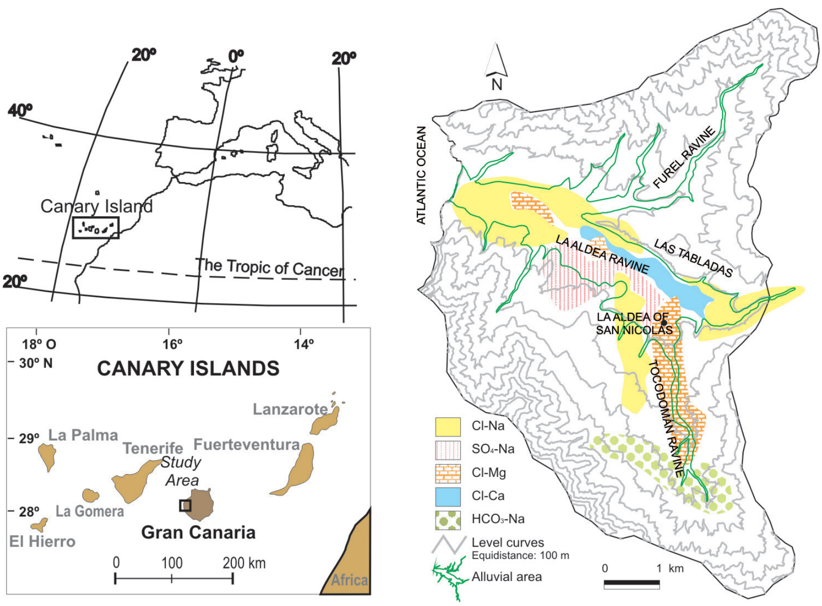

Figure 1. Location of the study area and spatial distribution of groundwater types at La Aldea aquifer.

HYDROGEOCHEMISTRY CHARACTERIZATION, GROUNDWATER QUALITY AND RESULT

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. The electrical conductivity of groundwater ranges from 837 µS/cm in HCO_3^-–Na^+ type water to 11 370 µS/cm in Cl^-–Na^+ type water. The resulting spatial distribution of groundwater types is shown in Fig. 1. The hydrogeochemical inputs that have been modelled are: rain water (considering the influence of marine spray at the coast and the Saharan dust deposition), dams and runoff water, irrigation returns and the geologic prints. The geologic inputs identified are two: groundwater from basalts and trachyte-rhyolitic ignimbrites that form the scree deposits and saline waters located in the Las Tabladas area that have been attributed to hydrothermally altered materials (locally called "Azulejos").

Two chemical models have been made simulating the chemical reactions taking place under the natural flow regime in unsaturated zone, that is schematized in Fig. 2, and along a flow line in the aquifer using PHREEQC (Cruz, 2008). The quantification of these 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.

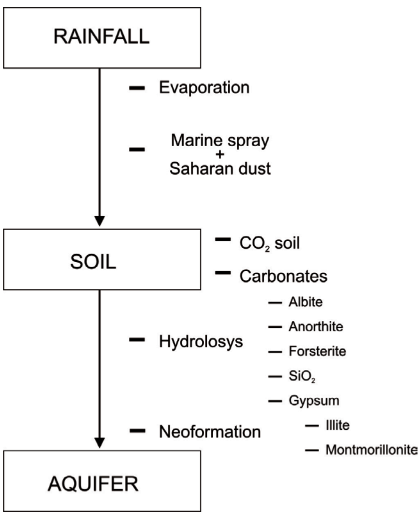

Figure 2. Conceptual model of the groundwater mineralization under a natural flow regime in unsaturated zone.

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Abstract ID: 168

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

The chemical and isotopic characteristics of surface and groundwater of the Banana Plain were studied 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.

Water samples from rain, streams, lake, springs, wells and boreholes were collected and analyzed for major ions, stable isotopes and dissolved silica. In general the waters are Ca/HCO_3 and $Ca–Mg–Na/HCO_3$ dominated. Weathering of silicate minerals controls the concentration of major ions such as calcium, magnesium, sodium and potassium in the waters of this area while NO_3 and Cl are of anthropogenic origin. In general, the chemical composition of the groundwater in this area is influenced by rock–water interaction, dissolution and deposition of silicate minerals, ion exchange, and surface water interactions. ^{18}O and ^{2}H data indicate that groundwater have been recharged by meteoric water without significantly affected by evaporative processes either during or after the recharge. Limiting surface and groundwater use for potable and domestic purposes are contents of NO_3 and Total Hardness (TH) that exceed the World Health Organization (WHO) drinking water limits. Calculated values of %Na and Sodium Adsorption Ratio (SAR) indicate that these waters are suitable for irrigation.

Abstract ID: 172

THE ROLE OF THE UNSATURATED ZONE IN DETERMINING NITRATE LEACHING TO GROUNDWATER

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Keywords: nitrate, leaching, modeling, tracers, manure

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. A comprehensive model is given for the *Pianura Padana* floodplain, an intensively exploited area in northern Italy, with its lower part, facing the Po River Delta (Ferrara Province), already declared vulnerable to nitrate from agricultural sources. Groundwater nitrate contamination is a well known phenomenon. However, key factors of patterns and processes governing N transport and transformations through the vadose zone to the water table are not fully clarified.

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. 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) in the previous year, while the loamy soil had not. 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).

The flow and transport processes were quantified by inverse modeling with the finite element numerical code HYDRUS-1D (Šimunek et al., 2008). Results showed a good model fit of water content and head pressure at various depth, 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).

A good match between calculated and observed bromide concentrations was obtained in both sites. A robust reconstruction of the field velocity and of the dispersion coefficient was achieved and 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. In the loamy soil, nitrate followed bromide behavior suggesting low rates of denitrification. While denitrification was active in the sandy soil where nitrate disappeared within the first meter of soil, with no measurable concentration left at the 0.75 m depth. Mass recovery of bromide was near 90% for sandy and loamy soils, suggesting that homogeneous transport processes were present at the field scale. Nitrate leaching was observed in the loamy soil while in the sandy soil residual content of organic matter from fertilization in the previous year (fraction of organic carbon: 0.042 and acetate: 34 mg/l) very likely prevented the nitrate migration towards the saturated zone by removing the excess via denitrification (Fig. 1). In the loamy soil nitrate mass transfer to the unconfined aquifer was slow and concentrated at the end of the winter season.

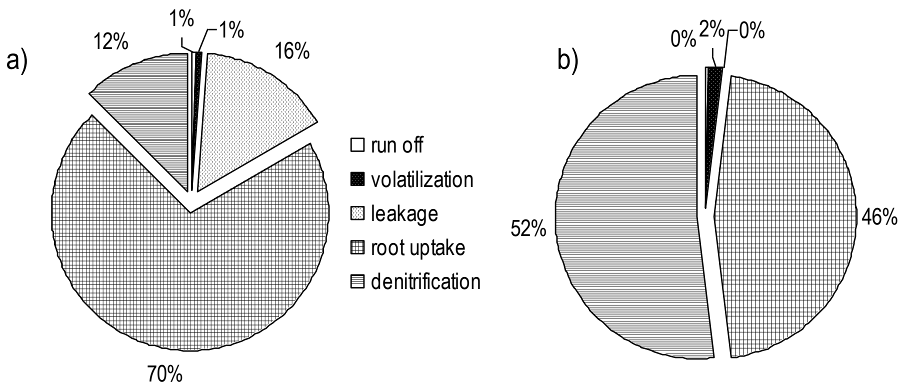

Figure 1. Nitrate balance cake plot for: a) loamy soil; b) sandy soil.

Results highlight the reliability of the use of conservative tracers and numerical modeling jointly, to understand nitrate mass loading rate and mass balance. In the more permeable and intrinsically vulnerable soil, the addition, in the previous year, of a relatively low amount of organic matter as manure, was sufficient to prevent nitrate leaking.

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Abstract ID: 183

USE OF ^{15}N AND ^{222}Rn 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

On the Ryukyu Islands, a chain of islands in the southwestern Japan, the Ryukyu Limestone is extensively distributed. Because the Ryukyu Limestone is very porous and permeable, surface water is scarce, so the inhabitants obtain water for agricultural and domestic uses primarily from groundwater in limestone aquifers. In recent years, however, rising nitrate concentrations in the groundwater have become a problem. Okinawa Island is the largest of the Ryukyu Islands. The southern part of Okinawa Island is a suburban region with many sugarcane and vegetable farms and also many livestock farms. Nitrate concentrations in limestone springs in this region increased during the 1990s, that is presumably because of chemical fertilizer applied to the sugarcane farms (e.g., Yoshimoto et al., 2007). To control groundwater quality, nitrogen sources affecting groundwater quality must be identified and the characteristics of fluctuations in groundwater quality determined to develop simulation methods for prediction. In this study, we studied sources of nitrates by using nitrogen isotopes and radon as indicators.

The study area was located at the southern tip of Okinawa Island. Water samples were collected twice, in February 2007 and March 2008, from 19 sites. We categorized the sampling sites into three types: upland field (UF), residential area (RA), and cave and cavern (CC). CC sites are those near two caverns in the study area, regardless of the surrounding land uses. Concentrations of nitrate nitrogen (NO_3–N) were analyzed by ion chromatography (TOA–DKK, ICA-2000). Isotopic analyses for $\delta^{15}N$ in nitrate were done by EA-IRMS (Thermo Fisher Scientific, Delta V plus). Radon (^{222}Rn) concentrations in water samples collected in 2007 were measured with a liquid scintillation counter (Packard 2250 CA) after in situ extraction.

The average NO_3–N concentration was 10.3 mg/L, and the range was 5.5–18.9 mg/L. The average value of $\delta^{15}N$ was 8.4‰ at UF sites, 10.2‰ at RA sites, and 9.6‰ at CC sites (Fig. 1). The average ^{222}Rn concentration was 4.7 Bq/L, and the range was 0.6–13.5 Bq/L. At CC sites, the ^{222}Rn concentrations were relatively low (less than 2 Bq/L) with one exception.

In the Ryukyu Islands, including the study area, application of chemical fertilizer is often considered the major cause of increasing nitrate concentrations in groundwater (e.g., Yoshimoto et al., 2007). However, $\delta^{15}N$ values at all sites (Fig. 1) were higher than the literature values (−4‰ to +4‰; Heaton, 1986). In fact, the average $\delta^{15}N$ value at UF sites was 8.4‰, probably because of the use of composted livestock manure on upland fields along with the effects of denitrification and ammonia volatilization. The average $\delta^{15}N$ value at RA sites, 10.2‰, was even higher than that at UF sites, which implies that livestock manure and domestic wastewater affect groundwater quality more strongly around residential areas. These findings suggest possible improper management of livestock manure and effluent percolation from septic tanks. Although many CC sites were situated among upland fields, the distribution of $\delta^{15}N$ values at these sites was similar to that at RA sites (Fig. 1). We attributed this similarity to rapid groundwater flow in caves and caverns carrying nitrates from upstream residential areas. We also inferred the rapid flow from the ^{222}Rn data. In general, the concentration of ^{222}Rn in groundwater in the Ryukyu Limestone aquifer is not low, but in caves and caverns the ^{222}Rn concentrations tends to decrease. In the study area, the ^{222}Rn concentration at all but one CC site was low. In addition, groundwater levels and nitrate concentrations in groundwater at CC sites showed large short-term fluctuations (Yoshimoto et al., 2007). These findings suggest that the rapid groundwater flow in caves and caverns and support our inference.

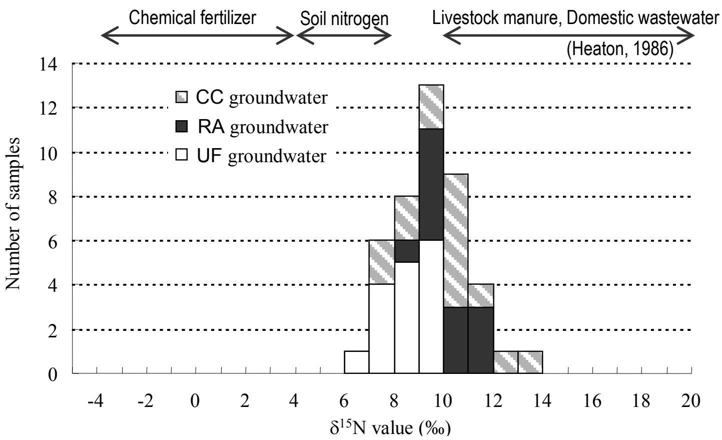

Figure 1. $\delta^{15}N$ values of groundwater nitrates compared with those of common sources.

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Abstract ID: 185

GROUNDWATER AS A DRIVER OF SALINITY IN THE WYBONG CREEK CATCHMENT

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Keywords: salinisation, dryland salinity

Wybong Creek is a 90 km long river which runs into the Goulburn River, in the upper Hunter Valley of New South Wales. Previous research identified Na–Cl at concentrations in Wybong Creek which decrease the water quality of the Goulburn River and impact agriculture. This study aimed to identify the origin of solutes in the Wybong Creek catchment and the processes which caused salinisation, in order to identify salinity mitigation measures.

Surface water was sampled at ten sites along Wybong Creek. Ground water was sampled from most bores occurring in the valley. Major ion analyses indicated that saline, Na–Cl dominated water arose abruptly in the mid-catchment area, with surface and groundwater in the upper catchment being dominated by fresher, Na–Mg–HCO_3 type water. Based on these findings, more intensive research including soil sampling and piezometer installation was conducted in the mid-catchment area.

Results from research in the mid-catchment area showed only slightly saline soils with up to 2185 mg TDS kg^{-1} soil occurring within a salt scald. Ground water samples, however, had 4500–6300 mg TDS L^{-1}. This ground water was found to arise at the break of slope, before it flowed to the salt scald. Smectite produced by weathering of basalt in the floodplain of Wybong Creek appears to be impeding this saline ground water from flowing further down its flow path, causing groundwater to mound and evapoconcentrate near the ground surface at the salt scald. Nearby, weathered and iron-stained fractures in the sandstone adjacent to Wybong Creek and point source increases of salinity in Wybong Creek indicate that though smectite impedes some of the ground water flow from the salt scald through the regolith, saline groundwater enters Wybong Creek through fractures in this mid-catchment area.

Abstract ID: 190

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

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

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

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 elevated NO_3^- and Cl^- content in few sampled solutions. High content of NO_3^- and Cl^- in water samples highlights the influence of human activities on groundwater quality.

The chemistry of the groundwater progressively evolved from Ca^{2+}–HCO_3^- to Na^+–HCO_3^- and Mg^{2+}–HCO_3^- water types. The total dissolved solid (TDS) concentration indicate large differences between Ca^{2+}–HCO_3^- and Mg^{2+}–HCO_3^- types with a maximum value of 2160 mg/L in deep groundwater reflecting primarily high mineralization of silicate weathering of major cations (Fig. 1a). The pH ranged from 6.8 to 8.5, with an average pH of 7.4. The calculated internal partial pressure of CO_2 is significantly higher than that of the Earth's atmosphere ($10^{-3.5}$ atm) suggesting the presence of soil CO_2 and additional external CO_2 source (Fig. 1b). The CO_2-rich groundwater (mostly deep wells) can evolve toward very high solute concentrations of variable cation concentration 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 calcite as well as cation exchange between groundwater and clay minerals. While the chemistry of the shallow groundwater is governed by the uptake of soil CO_2, silicate weathering at elevated pCO_2 is relevant in the deeper aquifer. The decrease of Ca^{2+} and raise of Mg^{2+} in samples could be explained primarily by incongruent weathering and/or leaching of Mg^{2+} from ferromagnesian silicates (Fig. 1c). 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. 1d).

Stable isotopic (δ^2H and $\delta^{18}O$) data suggests that the groundwaters are of meteoric origin. Most of δ^2H and $\delta^{18}O$ values (Fig. 2) plot along and near Global Meteoric Water Line (GMWL) and Regional Meteoric Water Line (GMWL). Few groundwaters show a stable oxygen isotope shift to heavier $\delta^{18}O$-values due to prolong water-rock interaction that increases with depths. 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.

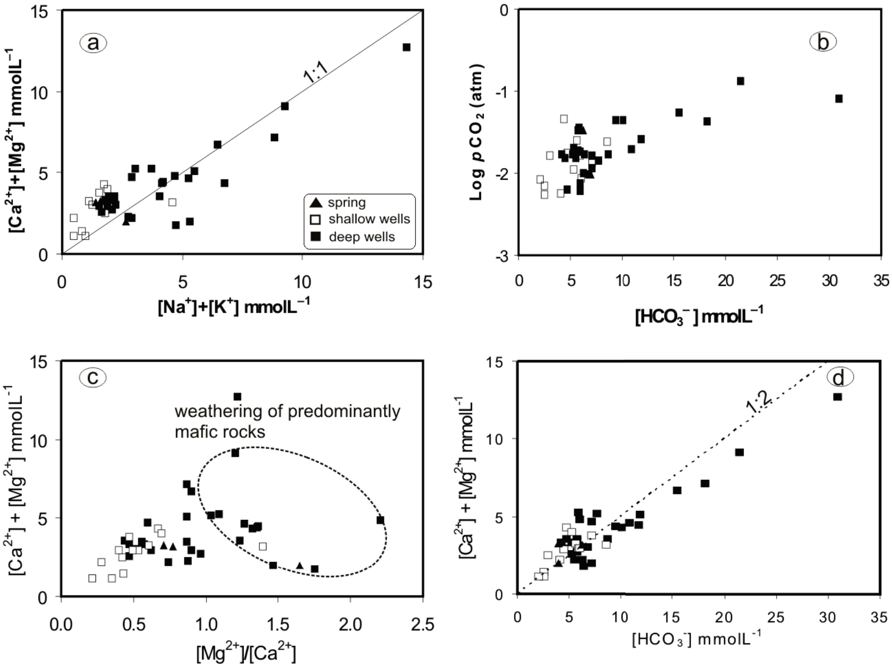

Figure 1. Plots of: (a) $[Ca^{2+}]+[Mg^{2+}]$ vs. $[Na^{+}]+[K^{+}]$; (b) pCO_2 vs. $[HCO_3^{-}]$; (c) $[Ca^{2+}]+[Mg^{2+}]$ vs. $[Mg^{2+}]/[Ca^{+}]$ and (d) $[Ca^{2+}]+[Mg^{2+}]$ vs. $[HCO_3^{-}]$ for Axum groundwaters.

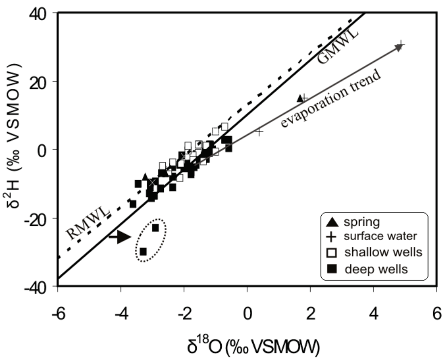

Figure 2. $\delta^{2}H$ vs. $\delta^{18}O$ values for all sampled solutions. GMWL (solid line) refers to global meteoric water line whereas RMWL denotes the regional meteoric water line for Addis Ababa, ($\delta^{2}H = 7.5\delta^{18}O + 12.9$).

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Abstract ID: 208

WATER QUALITY ASSESSMENT IN NORTH-EAST INDIA

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Keywords: physico-chemical characteristics, microbial assay, pesticide residue analysis

1. 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.

2. 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.

3. 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.

4. 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.

5. 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.

6. 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

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

The intensive use of nitrogen fertilizers in agricultural areas promotes contamination of aquifers by nitrates. The migration of nitrogen throughout the unsaturated zone is controlled by the processes of unsaturated flows and nitrogen cycle in soils, taking into account hydroclimatic conditions and soil properties. Agriculture practices with the application of nitrogen fertilizers and the irrigation are the major factors that control the contamination of groundwater.

This study aims at assessing the waters fluxes which pass through the unsaturated zone and reaches the aquifer and its nitrates concentrations.

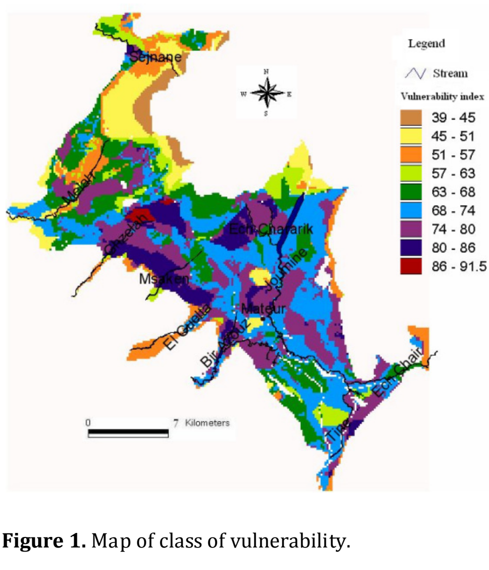

Figure 1. Map of class of vulnerability.

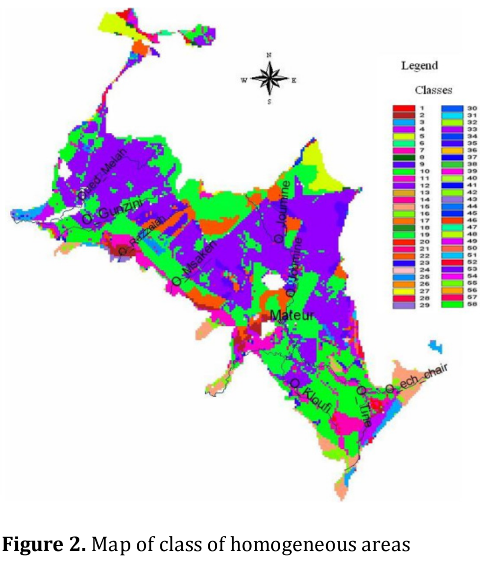

Figure 1. Map of class of vulnerability. **Figure 2.** Map of class of homogeneous areas

Based on a study of the vulnerability of Mateur aquifer (Fig. 1) study area is divided into homogeneous areas (Fig. 2). The flow and transfer of reactive nitrogen compounds were simulated with a daily time step using the deterministic mechanistic model LEACHM (Leaching Estimation Chemistry Model) (Hutson, 2003). This code solves the Richards equation and the transport of reactive nitrogen compounds on the vertical dimension. This model is used to calculate the infiltration and actual evapotranspiration, taking into account the atmospheric fluxes, the hydrodynamic parameters of soil profile and the water content on the its surface (Lotse et al., 1992). The different nitrogen compounds and the geochemical interactions among them are represented in the model LEACHM according to the chemical reactions kinetics (Singh and Sondhi, 2001).

As a result, we obtained the average flow of water percolation to the aquifer and the lixiviated nitrates amounts. In order to obtain annual averaged values, we have simulated each profile for several years with the same averaged daily data as far as to obtain a stabilized annual recharge and nitrates mass reaching the aquifer. The mass of nitrates is then used to calculate an annual average concentration for groundwater recharge. Integrating these results in the whole plain has allowed us to produce maps of the groundwater recharge (Fig. 3) and its nitrates concentrations (Fig. 4).

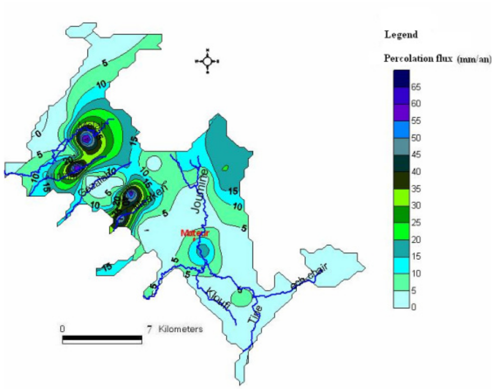

Figure 3. Map of groundwater recharge.

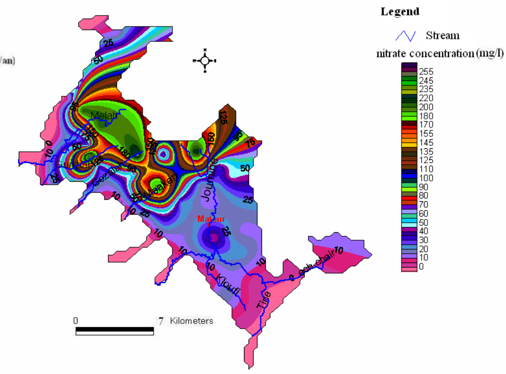

Figure 4. Map of nitrate concentration.

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Abstract ID: 239

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).

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.

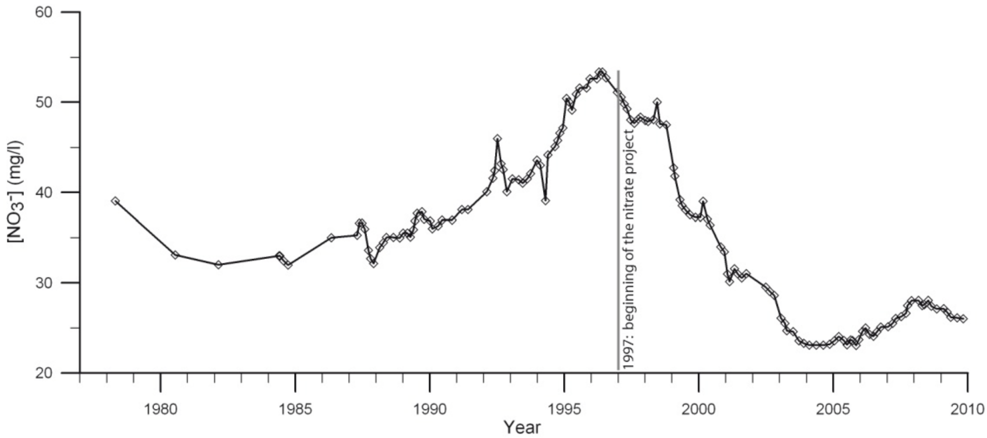

Figure 1. Evolution of concentration of nitrate in the pumping station.

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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Abstract ID: 287

AGRICULTURAL WASTE MANAGEMENT AND GROUNDWATER PROTECTION

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Keywords: intensive agriculture, agricultural wastes, groundwater pollution

Agricultural communities that are very large cause numerous problems arising from applications of pesticides, fertilizers and other substances that are likely to pollute soils, watercourses and groundwater. An even greater problem arises when thousands of tonnes of plant waste are to be eliminated, where there is a possibility of using these as agricultural compost. Collection and storage, enrichment, treatment and final processing of this material for subsequent use as compost can pose a serious risk of groundwater pollution, if adequate measures are not taken (Sara, 2003). Such is the problem in the case study we present in this article, which concerns a plant waste treatment facility in the province of Almería.

The brisk pace of development of intensive agriculture over the last twenty-five years has generated environmental problems in Almería. Currently, the province produces around one and a half million tonnes of plant waste, six thousand tonnes of diverse wastes and thirty thousand tonnes of plastic waste (Callejón, Lopez Martinez, 2009). Unauthorized incineration of waste has been expressly prohibited due to the atmospheric pollution it causes, but this strategy only partly solved the problem, and various other alternatives have been suggested. One proposal is the commissioning of recycling facilities for the plastic and plant waste arising from all the greenhouses, which includes the prunings collected during the period of cultivation, and the leaves, stems and roots pulled up at the end of the harvest season.

Another seasonal problem is the accumulation of large quantities of fruit waste, due to imperfections in the fruit or because of low market prices that lead to fruit being dumped in inappropriate locations. This dumping encourages insects and other pests, and the leaking of a highly organic leachate from the rotting fruit (Fenton et al., 2008).

Over the last ten years, numerous treatment facilities have been installed for recycling agricultural plastic, and others for transforming plant residues into compost and agricultural fertiliser. The ideal siting of such plants would be on impermeable material, in order to avoid the leachates from polluting the subsoil. Where this is not possible, the storage and transformation facilities must be impermeabilized and the leachates tightly controlled. The design of completely impermeable ponds for storing the waste is also required.

In this paper, we present the case of a plant waste treatment facility some 30 km East of the city of Almería. This facility lies over rock materials, some of which have a very low permeability and others which have high or very high permeability. The measures taken to impermeabilize the site were insufficient (Poggi-Varaldo, 1999), and this has led to generalized pollution as the leachate has leaked out into the ramblas (the mainly "dry" watercourses characteristic of this semi-arid region of Spain). In addition, residues have accumulated over areas of highly permeable strata. Overall, there is an inappropriate planning of land-use. Vertical monitoring of the groundwater beneath the treatment facility and downstream of it have shown up significant pollution, characterized by TOC values of between 27–37 mg/L, CODs of between 27–35 mg/L, BOD_5 of 10 mg/L, and up to 8 mg/L NH_4. Iron content was between 11 and 600 μg/L and manganese between 22 and 300 μg/L.

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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 ground waters 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 groundwater 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 groundwater and increase of mineralization of the upper layer the lasts. Thus the essential change in chemical compound of groundwater 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 (0.52–1.5 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.

Abstract ID: 309

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

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 ≥ Z, one meets a value ≥ 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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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

Groundwater is a significant component in the water balance of rivers and lakes recharge. The results of the research show that the groundwater runoff 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 change.

The paper presents the evaluation of pollution of ground water with nitrates based on the analysis of their content in the Warta River water in the years 1959–2008 (Fig. 1) at the gauging section in city of Poznań. The section comprises the upper and central part of the Warta catchment with the area of 25 083 km^2.

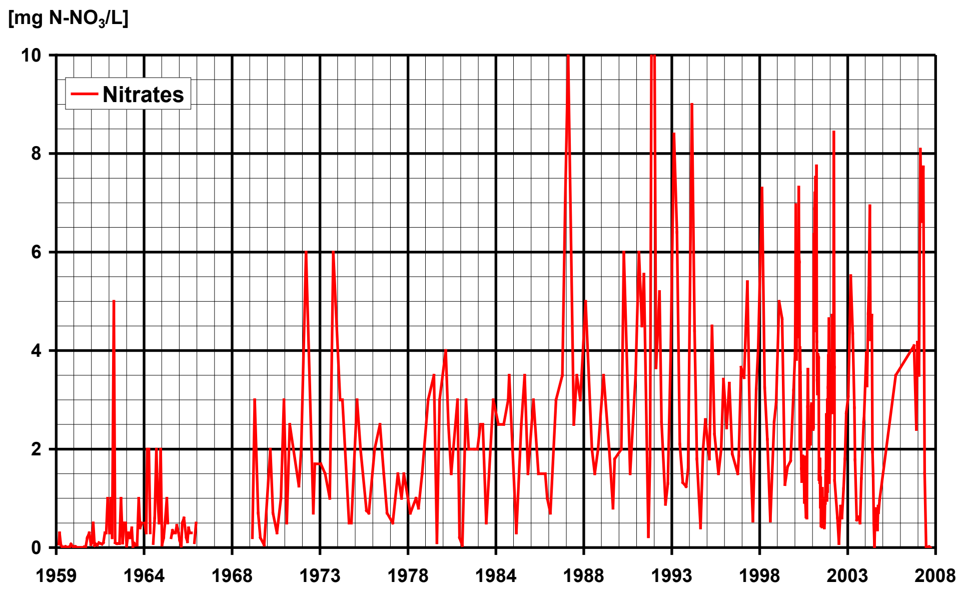

Figure 1. Changes in nitrates concentrations in the Warta River water in the Poznan-city gauging section.

The groundwater runoff in this catchment constitutes 65.5% of the annual average flow of the river, which amounts 102 m^3/h. The graph presenting the content of nitrates in the river water (Fig. 1) indicates the clear trend towards the increase of nitrates, which should be connected with their increased content in groundwater. The concentrations of nitrates in the river water show large, short- and long-term, oscillations. The short-term oscillations result from the seasonal variability as the maximum concentrations occur only in the post-vegetative periods, i.e. in late autumn, winter and early spring. In the vegetative period biological absorbtion of nitrates by the river flora and fauna occurs. The graph (Fig. 1) also presents long-terms oscillations which may be linked to hydrological situation as well as, to a certain extent, to the level of use of nitrate fertilizers on agricultural land, which dominates in the area of the investigated catchment.

The influence of hydrological situation is illustrated by the occurrence of maximum concentrations in the years 1992–1994. It reflects the influence of hydrological drought in the years 1989–1992. In this period, in the conditions of highly limited infiltration recharge of groundwater, the accumulation of nitrates in soil and aeration zone occurred. After the end of drought the nitrates were moved to shallow groundwater and next to surface water. This phenomenon was also confirmed by the study of nitrates conducted within the network of 8 observation wells in the area of the unconfined aquifer in the ice marginal valley.

The study revealed that the average concentration of nitrates in the period of drought reached 0,14 mg $N–NO_3$/l, and 2,2 mg $N–NO_3$/l about 3 months after the drought ended, and again 0,15 mg $N–NO_3$/l one year after the drought finished. The general increase trend of the nitrates concentrations in the river water may be to a large extent related to the level of nitrate fertilizers use on agricultural land in Poland. 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 in the graph by the decrease in the concentrations of nitrates in the years 1995–1998. However, the decrease was short-lasting and at present the use of nitrate fertilizers is reaching the level of 70 kgN/ha.

The presented materials prove a great usefulness of the analyses of nitrates 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. It is also of a great educational value in terms of showing interrelations between ground and surface water, as well as the necessity to take necessary action to protect groundwater, which is also essential for the protection of surface water.

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Abstract ID: 333

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

The water supplied at the Bajo Almanzora region (Fig. 1) for agricultural and domestic uses is saline. This region possesses very limited water resources that are variable, depending on the year. The water requirements of the population and the agricultural activities need to be aided by the use of groundwater. The application of the Water Framework Directive of the European Union needs to be aided on the knowledge of the hydrogeochemical processes.

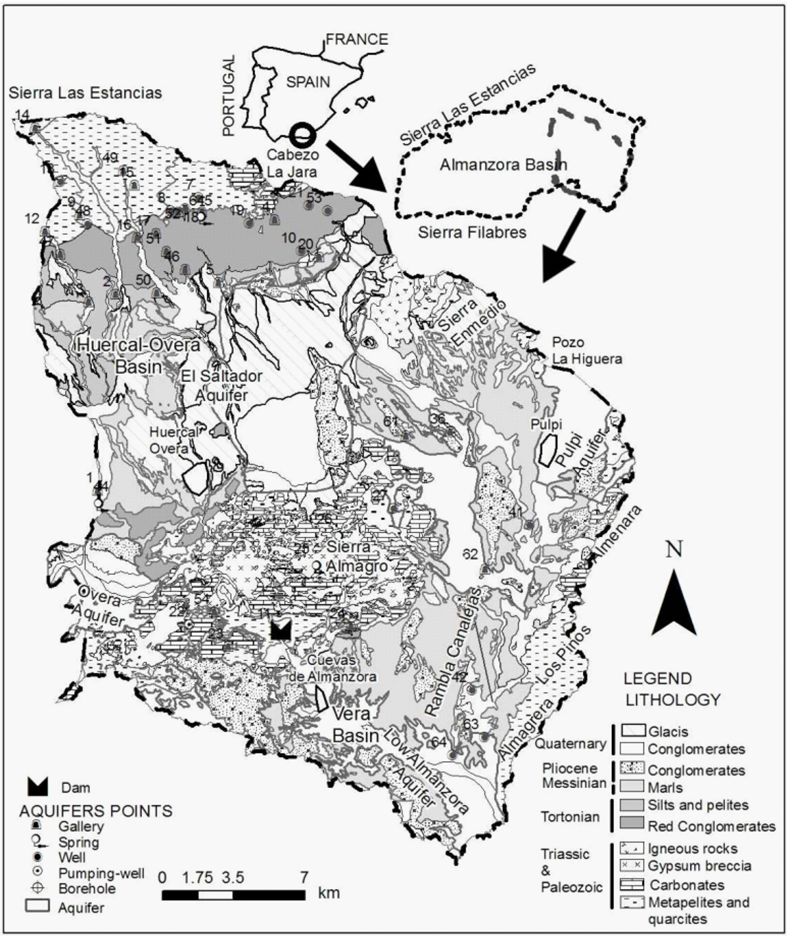

Figure 1. Hydrogeological map of the Bajo Almanzora region.

The main aquifers are the quaternary and plio-quaternary conglomerates that fill in the depressions. In addition, the small alpujarride limestone outcrops that crown the mountainous alignments constitute strategic aquifers.

Flow patterns were defined on the aquifers and aquitards in the area. Springs, galleries, wells and boreholes in the region were sampled during December 2004. Hydrogeochemical facies were determined and related to different sources of physical-chemical variability. The physical-chemical variability was interpreted on the conceptual frame of the hydrogeology and hydrogeochemistry of the area. To considerate hydrogeochemical processes affecting waters, inverse and direct modelling was used to assess the possible chemical reactions. This methodology has provided evidence of the different hydrogeochemical processes on this area: salinization, nitrate contamination, carbonates precipitation, ionic exchange on clays, as the more relevant ones.

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Abstract ID: 336

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

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

The use of pesticides has affected the groundwater quality in the catchment area of the River Meuse. The presence of pesticides forms a risk for achieving the objectives of the European Water Framework Directive, specifically for the targets that have been set for groundwater destined for human consumption. This study shows that the use of pesticides do not currently pose a significant risk to the groundwater quality of the Chalk aquifer in the province of Zuid-Limburg, the Netherlands.

The government of the Province of Limburg and the drinking water company of Limburg (WML) instructed Witteveen+Bos in cooperation with CLM Research and Advice and KWR Watercycle Research Institute to undertake a desk study into the fate and transport of pesticides in the Chalk aquifer for seven drinking water production sites. The study was undertaken to assist in the identification and implementation of measures to reduce the risk of pesticide use to the public water supply.

Pesticides have been detected at significant concentrations in the groundwater of the Dutch part of the catchment area of the River Meuse. These pesticides were detected in groundwater samples taken from springs and groundwater abstraction boreholes. Because of this, the use of pesticides was generally expected to form a risk to the groundwater quality in the Chalk aquifer and it was also expected that concentrations of pesticides would rise in the future. The main research question therefore was not "if" but "when" the groundwater quality would deteriorate.

During the study presented in this paper all data were reanalysed and new recent data on groundwater quality, were also included in the analyses. This analyses showed that during the last five years pesticides were only detected in samples taken from shallow boreholes or springs. No pesticides were detected in any of the deep groundwater samples. This analyses has shown that the use of pesticides does not significantly affect the deep groundwater in the Chalk aquifer of Limburg.

Following on these analyses, a qualitative risk assessment was undertaken combining fate and transport characteristics of pesticides and the knowledge of the local hydrogeological system. This risk assessment has shown that pesticides are currently not likely to pose a risk to the deep groundwater in the Chalk aquifer.

The risk is small because physical and chemical processes during the transport of pesticides in the unsaturated and saturated zone cause pesticides to attenuate and decay. The risk is further reduced because the chalk aquifer is protected by an extensive protective cover of loess and flint deposits. 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 this study were confirmed by research undertaken in the Chalk areas of the United Kingdom. Chilton et al. (2005) conclude for instance that the "time bomb" scenario does not apply for pesticides as it does for nitrate.

From the analyses of all available data, the qualitative risk assessment and the literature review is concluded that the use of pesticides is not likely to pose a risk to the deep groundwater in the Chalk aquifer as long as the pesticides are used according to current rules and regulations. A field exercise will be undertaken during the next stage of the Pesto project to confirm these conclusions.

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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

The North East region of Morocco has several plains under a Mediterranean climate, with low rainfall (245 mm/year). These agricultural plains are generally small, but they have a very important economic role in the development of the region. The plains are separated by Moulouya river: on its right bank are located the plains of Triffa and Saïdia and on its left bank there are the plains of Bou Arreg, Gareb and Kerte (Fig. 1).

The Quaternary outcrops are formed by silts, sands and gravels. These deposits constitute the upper unconfined aquifers. The bottom of the aquifers consists of marl of Mio-Pliocene age on the right bank of Moulouya river and of Messinean age on its left bank.

In the coastal zone, the groundwater is affected by high salinity. In the plain of Bou Arreg, near the Mediterranean sea and the lagoon of Nador, the salinity originates from the seawater intrusion, increasing salinity up to 18000 $\mu S/cm^2$. Up stream, the salinity is induced by leaching of Messinean marls and it reaches up to 21000 μS/cm (El Mandour et al., 2008 and El Yaouti et al., 2009). The Saïdia plain shows higher salinity values, the maximum observed is 55000 μS/cm. The salinity is probably caused by residual brines related to previous marine transgressions (El Mandour et al., 2008).

In the mainland, the groundwater in Triffa, Gareb and Kerte plains is affected by a lower salinity than the coastal zone. However, it varies between 1000 and 13000 $\mu S/cm^2$ (El Gettafi et al., 2007). It is related to leaching of marly gypsiferous deposits of Messinean and Mio-Pliocene age as attested by their enrichment in sulfate. Another source of salinisation is the recycling of brackish groundwater by irrigation pumping wells during the periods of drought. On another hand, the high levels of nitrates (up to 150 mg/l) in groundwater of the plains of Triffa, Bou Arreg and Kerte, indicate the existence of a heavy agricultural pollution.

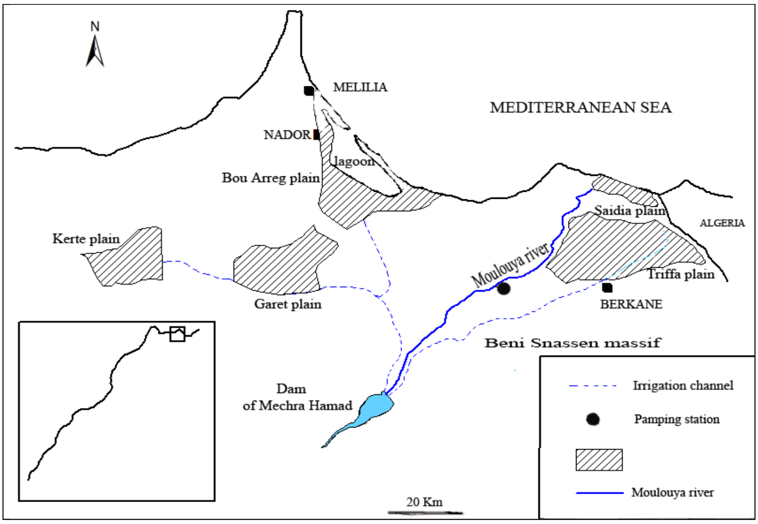

Figure 1. Location of the study area.

The sustainable management of Machrie Hamadi dam, supplying presently the plains of irrigation water, would contribute to reduce the salinization 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 still not widespread in the study area.

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Abstract ID: 362

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

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. The U.S. EPA (1991) defines a wellhead protection area (WHPA) as the surface and subsurface area surrounding a water well or well field, supplying a public water system, through which contaminants are reasonably likely to move toward and reach such water well or well field. Several methodologies have been developed to delineate the WHPAs depending on the complexity of the hydrogeologic conditions. Under specific conditions the WHPA is identified by means of 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 the aquifer vulnerability, representing the (intrinsic) sensitivity to being adversely affected by an imposed contaminant load (Foster, 2002) 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). On the opposite wells exploiting vulnerable aquifers requires extended WHPAs (high TOT) to ensure adequate safeguard for withdrawn groundwater. Therefore the proper evaluation of the aquifer vulnerability and the consequent selection of suitable TOT for WHPAs is important to avoid overestimates (or underestimates) of land protection measures. This is particularly important in developed agricultural areas where fertilizers, agrochemicals and pesticides are intensively utilized.

In this study the problem of a suitable combination of aquifer and well protection has been explored by means of a significant test site experience in the southern Po river plain in the Piemonte region (NW Italy) (Fig. 1). A 3-dimensional steady numerical FEFLOW (Diersch, 2005) model was developed and used with a MODPATH particle tracking code to determine the protection areas for a well supplying a local municipality (Castagnole) whilst the (low) exploited aquifer vulnerability has been evaluated by means of the GOD methodology (Foster, 2002). A conceptual model with three layers was simulated using physical properties appropriate to the hydrogeology of the formation (Fig. 2). 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, exploited by the well.

The soil protection capacity as regards the groundwater pollution has been considered to individuate the allowed agricultural practices within the defined WHPA.

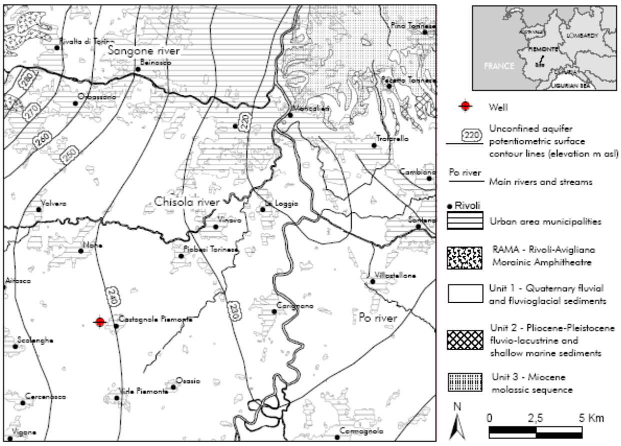

Figure 1. Hydrogeological map of the southern Turin area and location of site.

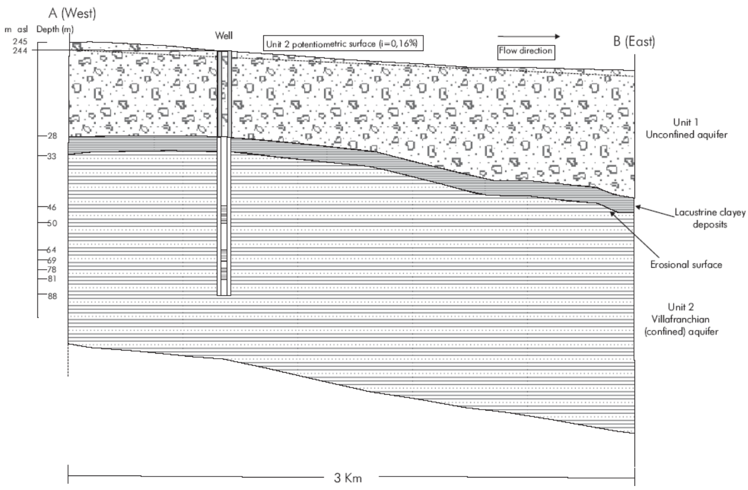

Figure 2. Schematic hydrogeological cross section of the site under study.

Supplementary protection measures are necessary due to the presence of a minor road crossing the WHPA. They are mainly aimed to prevent contaminant migration from ground surface due both to accidental spills and to the infiltration of dusts and leaching water originated on the road surface.

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Abstract ID: 376

GROUNDWATER HYDROCHEMISTRY OF THE QUATERNARY ALLUVIAL AQUIFER IN VARAŽDIN REGION — CROATIA

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Keywords: alluvial aquifer, hydrochemistry, ammonia, nitrite, nitrate

The study area is situated in the north-western part of Croatia. It is quite developed region where agricultural production is among the most important economic branches. Industrial activity plays less important role and is almost completely situated in Varaždin town, which is the central point of the region. 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. There are several polluters — intensive agricultural production together with abundance of poultry farms, as well as lack of sewerage network.

Favourable hydrogeological conditions enabled development of three pumping sites — Varaždin (situated in Varaždin town), Bartolovec (situated southeast from Varaždin town) and Vinokovšćak (situated north from Varaždin town). Bartolovec and Vinokošćak pumping sites still operate with full capacity, while the pumping site Varaždin, which was the major drinking water supplier in the past, has recently decreased its capacity as the result of groundwater quality deterioration.

The aquifer is composed of gravel and sand with variable shares 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). At utmost north-western area its thickness is less than 5 meters and is gradually increasing in downstream direction reaching its maximum of roughly 105 meters at the eastern part of investigated area. In the central part, near Varaždin town, a tiny aquitard appears dividing the aquifer in two hydrogeological units — the first aquifer and the second aquifer.

Groundwater samples were taken from wells in various hydrological conditions. Water samples for chemical analyses were collected and analysed in the Laboratory of the Department of Hydrogeology and Engineering geology of Croatian Geological Survey. On-site analyses included T, pH and EC with WTW probes, as well the alkalinity. Also, periodical chemical analysis made by VARKOM was used for interpretation.

According to the chemical composition, groundwater from the Varaždin aquifer belongs 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 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. The highest value was measured in groundwater from the catchment area of Varaždin pumping site. In the most samples from the catchment area of Varaždin pumping site, measured concentrations of nitrate are over the MPC value. On the contrary, they vary from 3 to 38 mg/l in waters from the wells located at the catchment areas of Vinokovšćak and Bartolovec pumping sites. In piezometer PDS-7 (near Varaždin pumping site) concentrations of nitrite are high, while, at the same time, concentrations of nitrate are low. Such phenomena are the consequence of denitrification processes. 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 places. 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. The values of physical, physical-chemical and 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

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Abstract ID: 382

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 METHODS

The objective of the project was to propose the modelling of the nitrate transfer from soil to the output of an alluvial aquifer that would 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. The Ain River is crossing an alluvial aquifer discharging in the Rhône River.

RESULTS AND DISCUSSION

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^2H, $\delta^{18}O$, CFC-11, CFC-12, CFC-113, SF_6, ^3H. Data interpretation allowed confirming that the Ain River is quite independent to groundwater. Water residence time of water and associated solutes with the alluvial aquifer is 8 years in average but vary from 1 to 18 years within the area. The aquifer presents also a high hydrodynamic heterogeneity due to numerous glacio-fluvial sediment deposits.

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. 1). The collect of data from 30 years was necessary for nitrate transfer modelling that was carried out at 13 sites corresponding to long term monitoring of NO_3 in groundwater.

The hydrodynamic and hydrodispersive modelling using MARTHE calculation code 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. The coupled models will be used to assess the efficiency of various scenarios for a nitrate contamination decrease.

The scenarios were prepared based on socio-economic studies considering changes in land use and land management practices. Various scenarios are discussed with the local stake holders and only three contrasted ones are finally selected. The transfer modelling is also taking into account climate variability. 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).

Calibration and validation of the model 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.

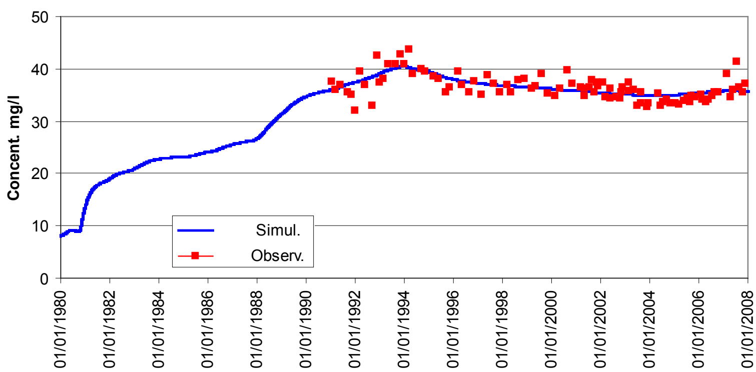

Figure 1. Nitrate transfer simulation using BICHE and observed concentration of nitrate in groundwater at site.

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Abstract ID: 383

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 repre-

sents 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 and 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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Abstract ID: 402

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.

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.

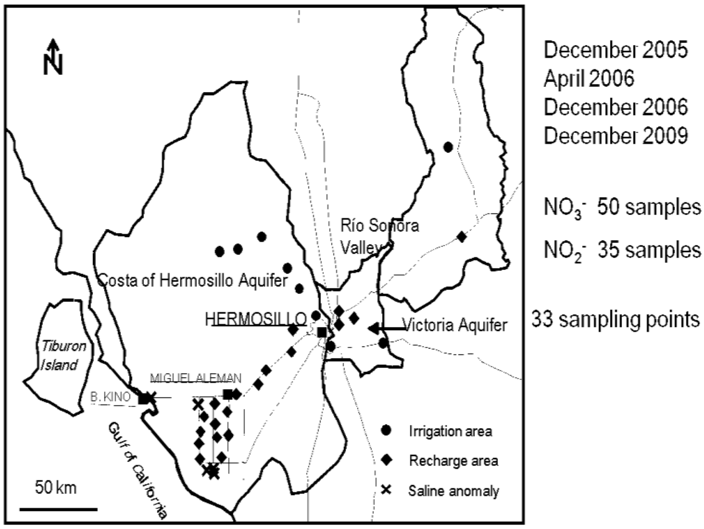

Figure 2. Sampling location.

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

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

ASSESSMENT OF NITROGEN COMPOUND CONTAMINATION 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.

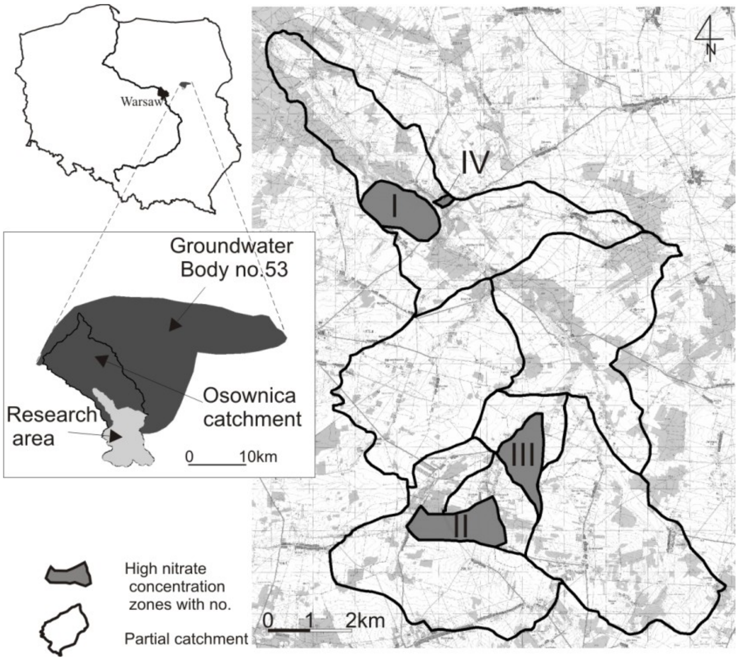

Figure 1. Location of the research area in the background of Groundwater Body no. 53.

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

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

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

Lijevče 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 Lijevče polje represents a very populated area, in which the ground waters are used as the sole resource of water.

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 orthophoto shots the areas of fields for agriculture have been identified, where the agrochemicals are mostly used. The aim of the study 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 causes. On the most sensitive locations the samples were taken and 20 active substances (pesticides) regularly used on the given area were examined.

The results of the analysis established five locations with high MDK content of pesticides, in comparison with the EU Directive 98/83/EC.

Out of the natural factors the vulnerability of groundwaters was defined as characteristics of a hydrogeological environment and pelological 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.

Abstract ID: 494

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 table1-3. 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.

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Abstract ID: 496

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).

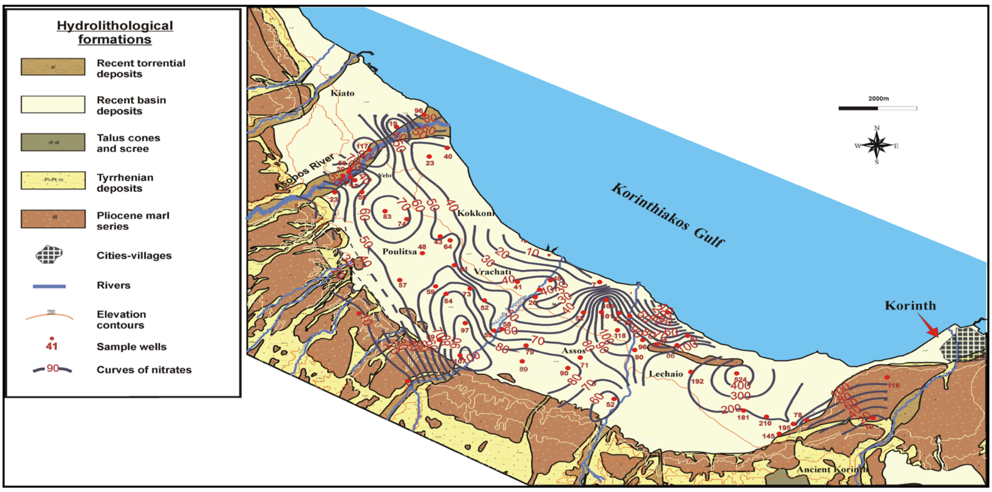

Figure1. Hydrogeological map of study area.

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 $T = 2\times10^{1}$–9×10^{2} m^2d^{-1} and $S = 0.2$–5×10^{-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.

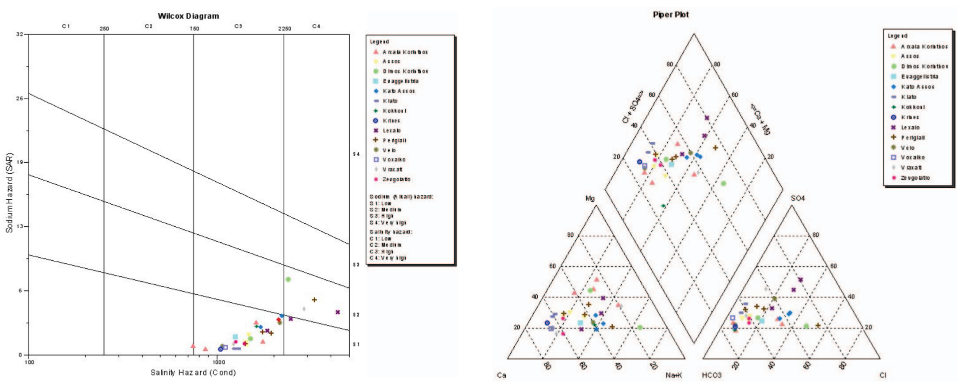

Figure2. Wilcox diagram and Piper Plot.

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Abstract ID: 509

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

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 (Fig. 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.

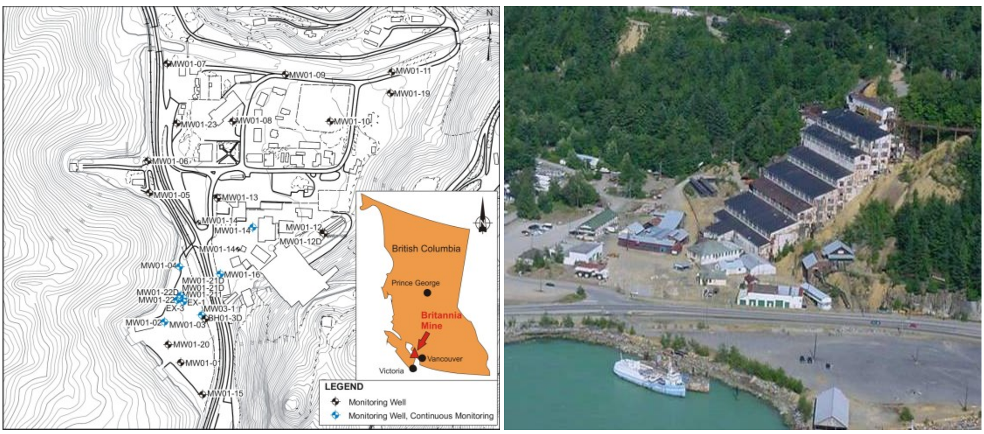

Figure 1. Site location and aerial view of Britannia Mine in 2005.

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 (Fig. 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.

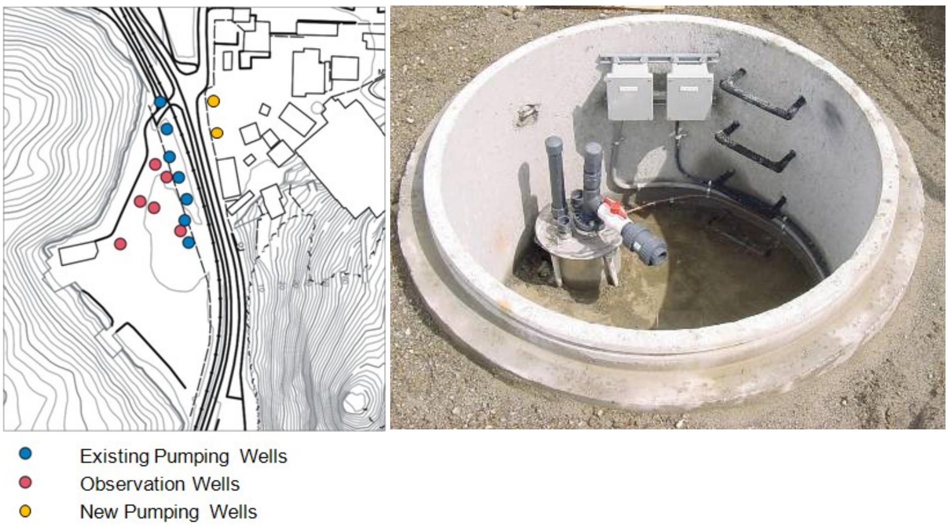

Figure 2. Pump and treat system components and typical wellhead completion.

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Abstract ID: 176

THE EFFECTS OF TAKHT COAL MINE (MINOODASHT, IRAN) ON THE GROUNDWATER QUALITY

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Keywords: coal mine, groundwater quality, Takht Mine

1. INTRODUCTION

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 most cases sulfate minerals such as pyrite accompany coal layers, tunnel effluent are usually acidic and thus, carry heavy metals (Laus et al., 2007). In some cases, neutralizing agents such as lime and dolomite exist in the area which cause increase in pH. This augmentation in pH consequently causes the precipitation of heavy metal although this does not affect the concentration of sulfate (Butler et al., 2000; Rose, Cravotta, 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). 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.

2. METHODS AND MATERIAL

Samples were taken from the groundwater sources, 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).

3. 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 acid mine drainage (AMD) into NAMD. NAMD is responsible for increment in pH of groundwater from 7.23 in upstream to 7.58 in downstream. 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. 1a).

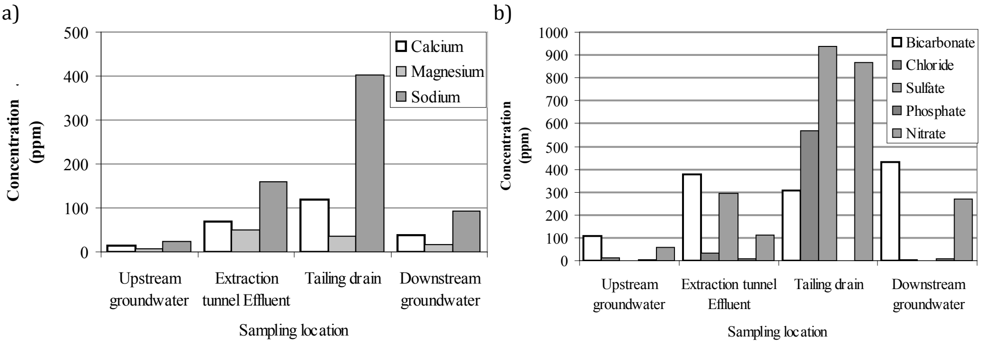

Figure 1. Cation (a) and anion (b) concentration in the samples

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. 1b).

4. CONCLUSION

It can be concluded that in the case of release of the NAMD 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 quality.

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Abstract ID: 177

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

1. 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. 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). 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 (Deschamps et al., 2005; Lasate, 2002). In Asia, groundwater in Cambodia, Laos, Pakistan, Myanmar, Vietnam, and Nepal is highly polluted with arsenic (Zeng, 2003). Gold mines can change the concentrations of other 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.

2. MATERIALS AND METHODS

Samples were taken from five qanats and four wells throughout the region. The pH was measured in site while the arsenic concentrations were determined by ICP-MS techniques.

3. RESULTS AND DISCUSSIONS

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. 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 Fig. 1. The results also indicate a direct correlation between pH and arsenic concentration in water. In terms of distribution of the concentration of arsenic in groundwater, 4 zones could be identified (Tab. 1). Concentration of arsenic is highest in south-west and north-east of the region. 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.

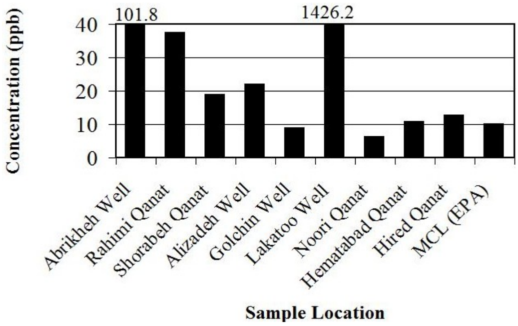

Figure 1. Concentration of arsenic in the groundwater resources in the study area.

Table 1. 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

4. CONCLUSION

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 current situation is due to natural geological condition.

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Abstract ID: 236

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 AND OBJECTIVE

Determination of processes affecting groundwater quality in an aquifer is very complex. Generally, the variability of the water quality parameters is linked to various processes such as 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 this paper, the multivariate statistical analysis such as principal component analysis (PCA) and Hierarchical cluster analysis (HCA) have been applied to the data set 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 water quality in the coastal aquifer of Puri city, India. The aquifer is a 16 SqKm. urban catchment located on the coast of Bay of Bengal. The area receives rainfall during monsoon season (2nd week of June to October). The aquifer is sandy and unconfined with a depth of about 40 m lying on a clay layer. Thin clay layers are also found in isolated lens and patches at shallow depths within the unconfined zone.

MATERIALS AND METHODS

The PCA was performed to group the water quality parameters into few factors based on their correlations to reveal underlying data structure and highlight relationship between parameters. The Kaiser criterion is followed in retaining the factors in the analysis. The factor loadings were rotated using varimax orthogonal rotation to maximize the relationship between the variables and the factor loadings. The HCA using Ward's method, which is an unsupervised pattern recognition technique was performed to uncover intrinsic structure or underlying pattern of a dataset and to classify the parameters into clusters based on their similarities. This resulted in a dendrogram providing visually meaningful picture of clusters with their proximity in a rescaled distance cluster combine.

RESULTS AND DISCUSSION

The nonparametric Spearman's rank order correlation provided significant correlations between cations and anions which were subjected to PCA and HCA. The variability of the parameters in two seasons (wet and dry) is shown in Figure 1. The concentration of Na increases while that of Mg and Ca decreases in dry season. Table 1 gives loading pattern of factors of PCA in two seasons and based on the loadings, each factor is assigned a process likely to be associated. Cation exchange and mineral precipitation are interpreted for change in the facies concentration in June 2007 dry season. The common processes in the two seasons are iron reduction and anthropogenic pollution due probably to on-site sanitation. The analysis of two datasets by HCA provided two dendrograms that revealed grouping of parameters and clusters consistent with respective factor loading pattern rendered by PCA. Thus, PCA allowed interpretation of processes in two seasons in the coastal aquifer.

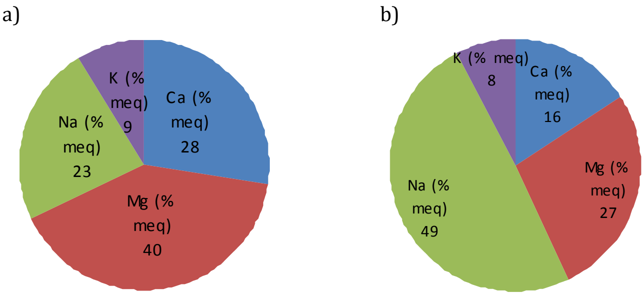

Figure 1. Changes in chemical facies (median value of cations in % milli-equivalent) in groundwater samples in a) post-monsoon (Nov 2006) and b) pre-monsoon (June 2007).

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%)**	**Factor 1 (35%)**	**Factor 2 (24%)**	**Factor 2 (19%)**	**Factor 3 (12%)**	**Factor 3 (15%)**	**Factor 4 (10%)**	**Factor 4 (12%)**
	Post-monsoon	**Pre-monsoon**	**Post-monsoon**	**Pre-monsoon**	**Post-monsoon**	**Pre-monsoon**	**Post-monsoon**	**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
SO_4	0.845	0.856	0.284	0.245	-0.104	0.333	0.039	0.014
NO_3	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*

Abstract ID: 296

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

The Catalan Potassic Basin (CPC), located 70 km NW from the City of Barcelona, is usually described as a tick regressive-sedimentary Tertiary 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 river in the basin is the Llobregat River. The current hydrogeological knowledge of the area is lacking and it is basically restricted to the sallower formations (less than 300 meters depth).

The natural salinity of the quaternary alluvial sediments 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 deep. The piezometric relation between these two aquifers also controls the hydrogeological and hydrogeochemical behavior in the Basin. Both aquifers, specially the alluvial one, are used in 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.

In the CPC area intense underground mining activity used in the exploitation of K-rich salts (mainly Silvite and Carnalite) during the last century, has provoked some problems related to surface, springs (Fig. 1) and groundwater salinization and probably it is also responsible for the existence of subsidence areas.

The current hydrogeological studies in the CPC area are focused on the characterization of the Tertiary aquifer and the definition of its 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, hidrochemical compositions, thermal gradients and isotopic signatures. The main objective of these studies is to determine a robust conceptual model that clarifies the possible relationship between groundwater-natural or antrophic contamination and/or subsidence around the old and actual mining areas and the origin of the highly saline springs that occur in the basin (Dorca et al., 2009; Ribera et al., 2010). This model should be one of the tools for an integrated territorial planning of the area.

Figure 1. High salinity groundwater flowing across the Carbonate Tertiary Fracture System and related halite crystallizations. Soldevilla Springs Complex (Sallent).

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Abstract ID: 344

INFLUENCE OF RUNOFF AND GROUNDWATER 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

1. 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.

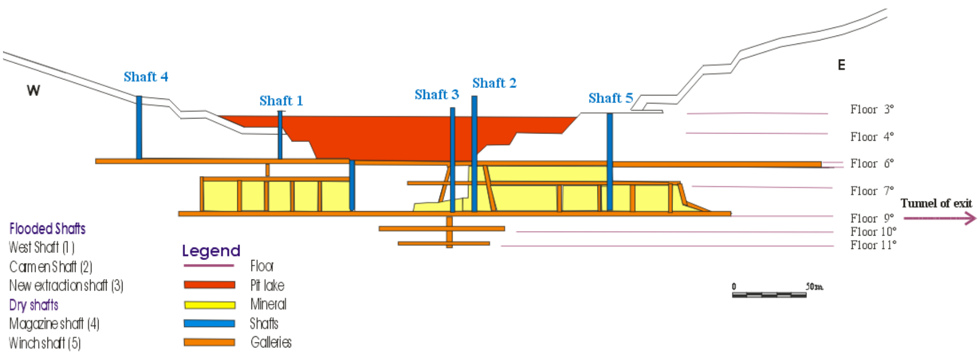

Figure 1. Sketch of underground mining and opencast in Concepción mine.

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.

2. 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.

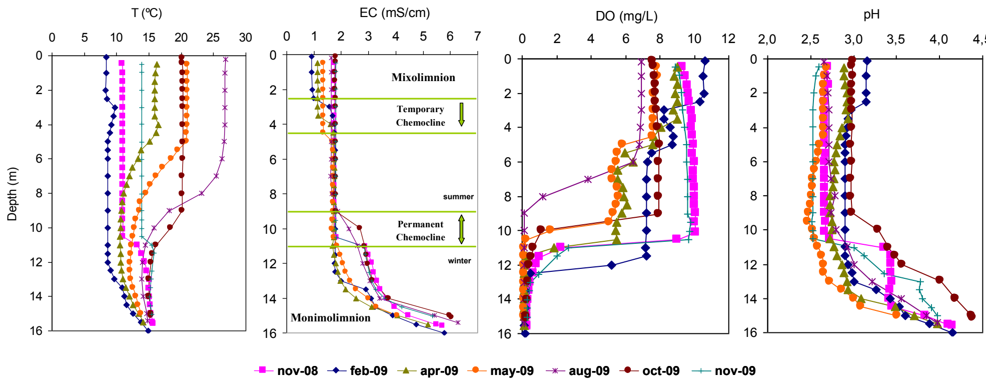

Figure 2. Depth profiles of temperature (T), electric conductivity (EC), dissolved O_2 (DO) and pH in the mining pit lake of Concepción.

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

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

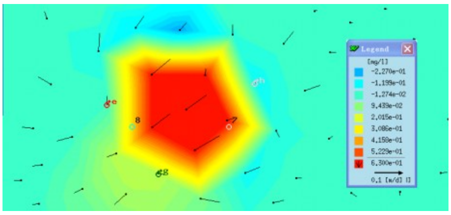
The effect on pollutants dispersion is of real significance, analyzing of groundwater flow under different pump rate in aquifer. Under different pump rate of 1200m^3/d, 1700 m^3/d, 2200 m^3/d in limestone of upper Taiyuan Formation ,the groundwater flow of aquifer are shown in Figure 1 and 2. The results 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.

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.



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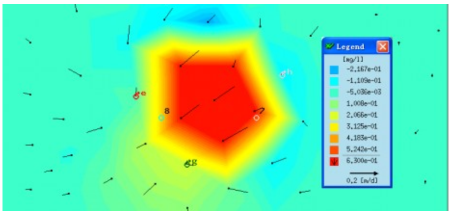

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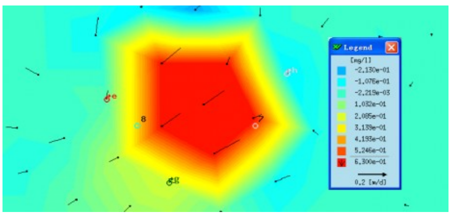

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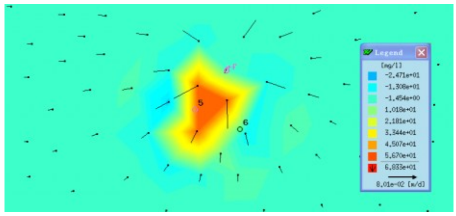
Figure 1. Ranges of Fe dispersion at pump rate of 1200 m³/d (a), 1700 m³/d (b)and 2200 m³/d (c).



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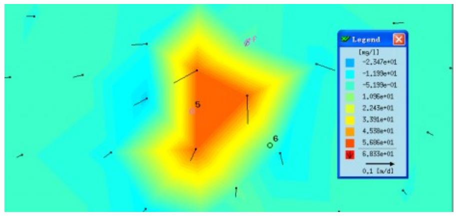

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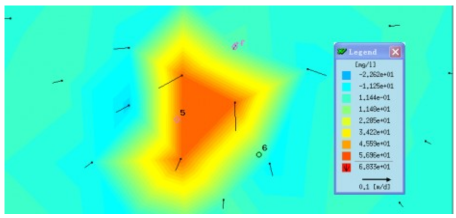

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Figure 2. Ranges of SO_4^{2-} dispersion at pump rate of 1200 m³/d (a), 1700 m³/d (b)and 2200 m³/d (c).

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

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

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, Official gazette RS 4/89) 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.

On the roof of Kopaonik, more precisely below its highest peak, the peak of Pancic (2017 m 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. As the current situation stands, 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. Due to all this, the National Park is sustaining immense consequences on account of the inability of widening the high-mountain protection zone around the abandoned mine thus representing a permanent danger to the visitors of the area.

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 of the Suvo Rudište mine, in the quantity of 10–30 l/s, polluted with iron, manganese, copper, zinc, nickel and cadmium. The mining stream in question, since the abandoning of the mine, has been completely "dead", devoid of all living things, because the proscribed restoration and revitalization of the underground facilities and hallways has not been done, and a significant amount of mining equipment and tools was left behind. 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 fulfilment 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 Rudiste 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 Rudiste, which would serve as a multi-purpose water collector, of volume 300,000–350,000 m^3 (Fig. 1).

The aim of the Project is to give a feasible technical solution of the building of an entire system in the function of economic justification through a realistic period of exploitation, where, by the means of the suggested solution, a large number of existing infrastructural issues connected to the very roof of the mountain Kopaonik, would be eliminated (the non–existence of an organized anti-fire system of the high-mountain area, the non-existence of water accumulation of the gravitational character for the renewal of the skiing sites Kopaonik, the possibility of inclusion of the excess of the intake waters for the improvement of the overall state of water supply on Kopaonik, the development of systems with the aim of securing a certain amount of water for the provision of heat and technical needs of the users etc).

In accordance to all the discoveries and the existing infrastructural facilities on the location of the abandoned mine Suvo Rudište, the complete hydro-technical system "Suvo Rudište" on Kopaonik would consist of the following parts: 1) The groundwater source–water intake structure; 2) The facility for groundwaters treatment; 3) Pumping stations 1 at the height of 1740 m a.s.l. and a high pressure transport pipeline up to the water collector; 4) The water collector within the area of the surface dig "Suvo Rudište"; 5) Pumping station 2 within the future water collector.

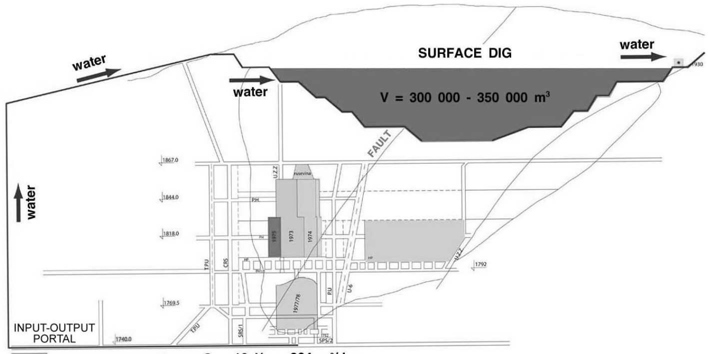

Figure 1. The design solution of water intake structure and water collector.

Abstract ID: 406

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

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Abstract ID: 476

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 overlapping impact of different factors and chemical processes in time and space.

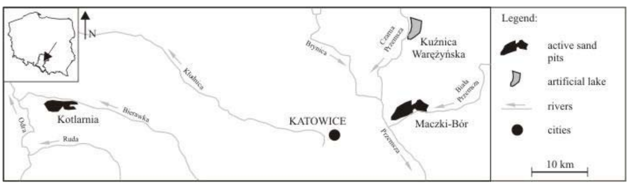

Figure 1. The location of open sand pits in the Upper Silesian region.

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Abstract ID: 477

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 m^3/h.

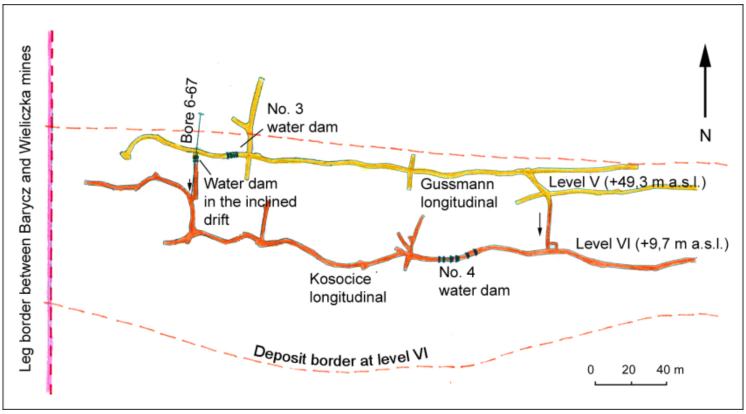

Figure 1. Location of water dams no. 3 and 4 in the western section of the Wieliczka Salt Mine.

The NaCl contents in the inflow was between 200–290 g/dm^3 (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):

1. Loam and concrete dam (No. 4) built in the Kosocice longitudinal at level VI,
2. Concrete dam built in the inclined drift between levels V and VI,
3. Block-loam-concrete dam (No. 3) constructed in the Gussmann longitudinal at level V (Fig. 2).

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).

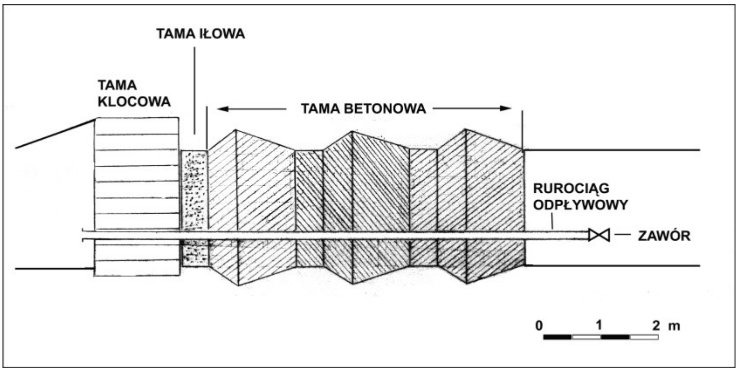

Figure 2. Structure section of the block-loam-concrete water dam in the Gussmann longitudinal (Level V).

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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Abstract ID: 479

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

In October 2007, after 15 years of conducting works aimed at preserving the mine from the water inflow entering the Mina traverse on Level IV, the gate valve on the drainage openings was closed off. This inflow originating at the sand formations of the Chodenice Beds, regarded as the Middle Miocene, deposited in the northern forefields of the "Wieliczka" rock salt deposit was considered, between the years 1992–2007, as the most dangerous water inflow entering the underground excavations of the "Wieliczka" Salt Mine.

The pulsative character of the inflow changing from several to several thousand dm^3/min., and the changing value of solids carried by the water, max 1593.16 g/dm^3, created a hazard to the safety of the underground "Wieliczka" Salt Mine and the town situated above the mine (Garlicki, Wilk, 1993).

Protecting the mine from the inflow of water flowing to the Mina traverse included the construction of a water dam which consisted of block, loam and concrete segments closing the excavation ending, drainage bore holes D-1, D-2 and D-3 which allowed the control of drained water from behind the dam, and the sealing of the orogen by means of the hole injection method for the purpose of creating a spatial bowl sealing around the Mina traverse ending (Gonet et al., 1997).

The termination of works connected with the sealing of the orogen around the Mina traverse end allowed to eliminate the D-1 drainage bore, and then to close the gate valve at the D-2 and D-3 drainage holes (Bromowicz, Brudnik, 2007). In consequence of these actions the inflow of water flowing towards the Mina traverse was completely cut off.

Hydrogeology monitoring is conducted in the "Wieliczka" Salt Mine as part of which volume capacity is measured of all registered water inflows to underground excavations as well as the chemical and isotope analysis of the inflows.

The hydrogeology conditions of the "Wieliczka" deposit indicate, that the greatest inflows into the mine are supplied by the Chodenice Beds (Winid, 2003). Currently, following closing the inflow into the Mina traverse, these are the inflows in the Fornalska 2 chamber (WVII-16) and the inflows below the Z-32 chamber (WVI-32). These inflows, in 2006, i.e. prior to closing off the inflow to the Mina traverse reached 54% of the summed total of natural inflows to the underground mine excavations which equalled 202,566 m^3. In 2009, these inflowes equalled 80% of the summed total of natural inflowes, which equalled 134,028 m^3.

The analysis of the measured inflow capacity in the Fornalska 2 chamber and below Z-32 chamber, and the chemical determinations allows to state that the closing off of the inflow to the Mina traverse has not made an impact on these inflows. The inflow volume to the Fornalska 2 chamber and below the Z-32 chamber are the same as registered prior to closing the inflow in the Mina traverse (Fig. 1).

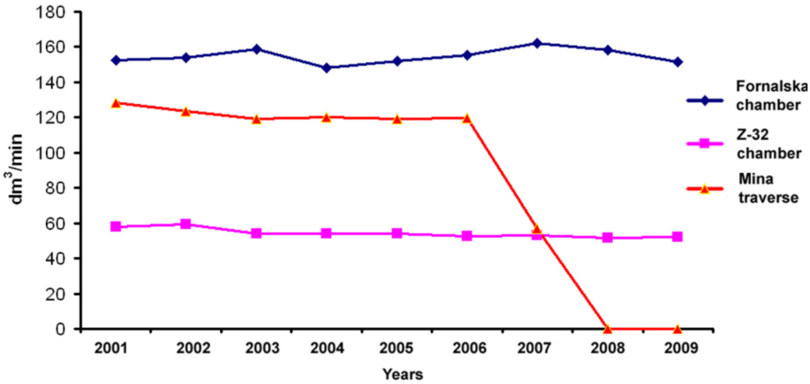

Figure 1. Average inflow volume to the Fornalska 2 chamber, Z-32 chamber, and Mina traverse between the years 2001–2009.

The hydrogeology monitoring in the Mina traverse includes the registration of pressure changes observed on manometers fitted on the closed drainage holes D-2 and D-3, whereas the water table in the piezometric B-3 bore is measured on the surface. This bore registers the changes of the water table within the area of the sand formations of the Chodenice Beds located in the northern forefields of the Mina traverse.

The pressure readings at the D-2 and the D-3 drainage bores revealed its rapid rise following the closing of the inflow in the Mina traverse, and the stabilization of pressure at the level of 1.5 MPa (Fig. 2).

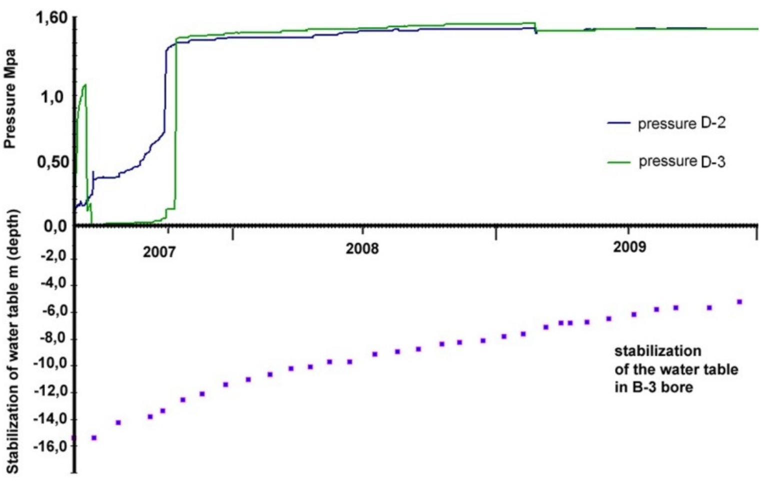

Figure 2. Pressure changes at the drainage holes D-2 and D-3 in the Mina traverse after shutting off the inflow to the traverse and the stabilization of the water table in the B-3 bore.

The rapid rise of pressure indicates to the lack of free space within the zone of the sealed orogen at the northern forefield of the Mina traverse. Whereas, the stabilization of pressure indicates to the complete recovery of the water level in the orogen to the state before 1992. This condition is confirmed by the measured data obtained from the registration of the water level in the piezometric B-3 bore.

The results of hydrogeology monitoring coincide with the results obtained from isotope research performed annually since 1973 on water samples collected from the inflows into the mine's excavations (Zuber, Duliński, 2004). The authors of these tests confirm that a significant number of water subsystems exist within the Chodenice Beds, and, although quite probably general hydraulic connectivity between these subsystems exists, they are still significantly separated from each other.

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Abstract ID: 480

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 dm^3/min. 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).

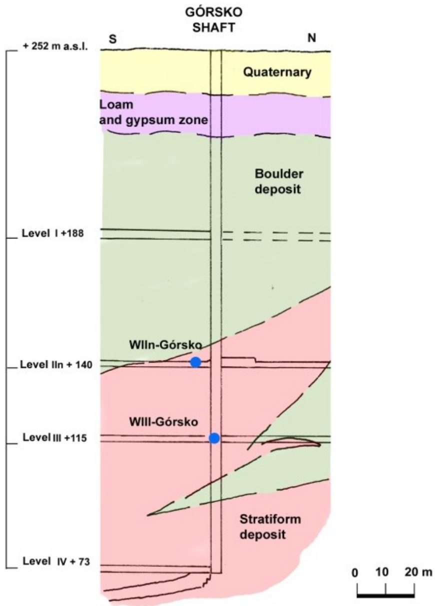

Figure 1. Geological profile of the Górsko shaft. Prep. by J. Przybyło, 2010.

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

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–Sniezniansk a 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.

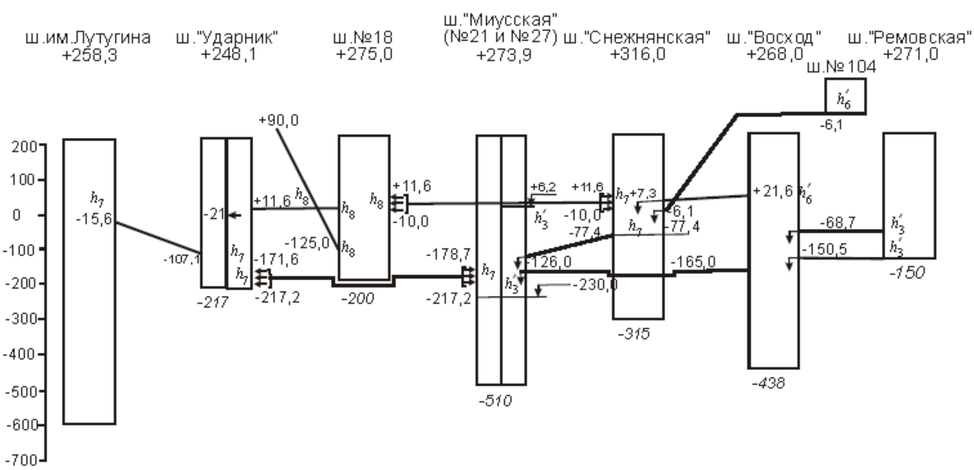

Figure 1. Schematic section of the interconnected mine dewatering system based around pumping from Miuskaya closed mine.

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.

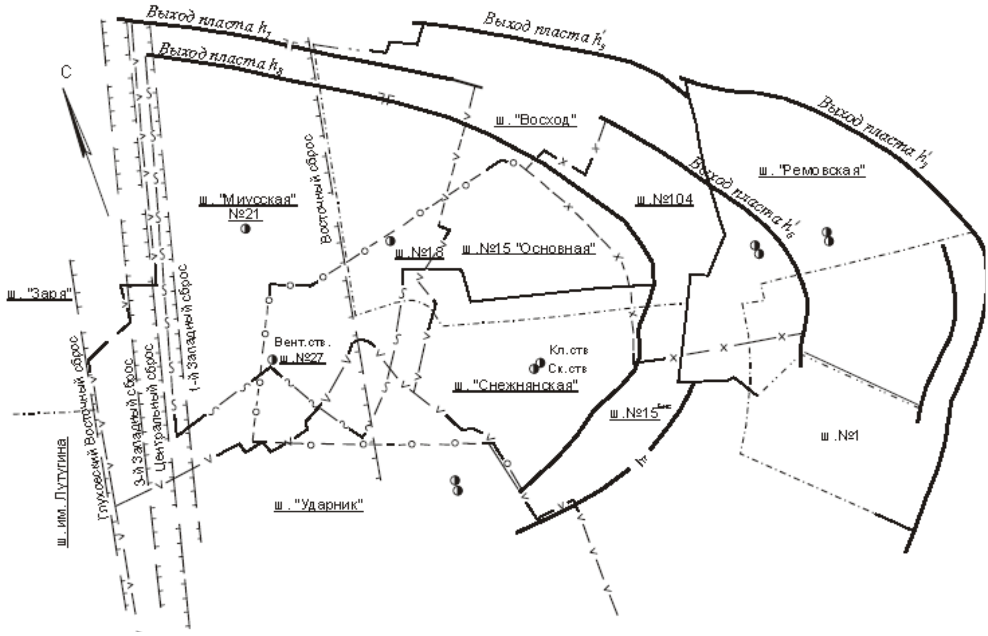

Figure 2. Plan of the Chistyakwo-Snieznianka closed syncline, showing mine locations.

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

Abstract ID: 134

GROUNDWATER LEVEL MONITORING: THE IDEAL NETWORK VERSUS REALITY

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Keywords: groundwater, monitoring, water levels, network, conceptual modelling

1. 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.

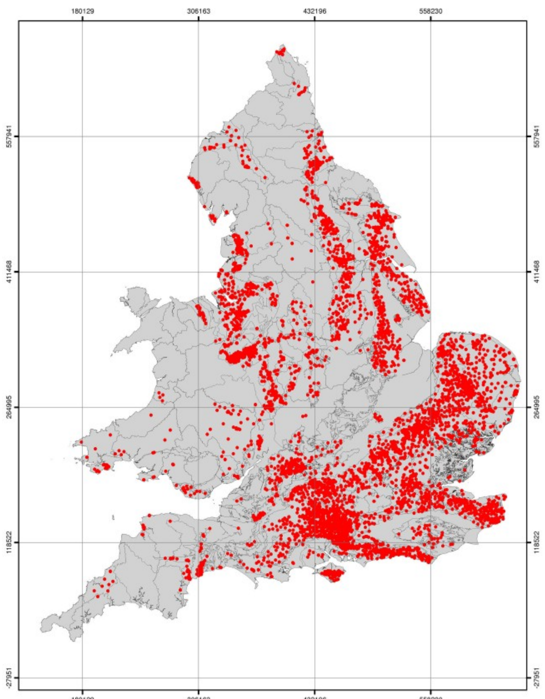

Figure 1. Locations of groundwater level monitoring sites in England and Wales

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, which is approaching its conclusion.

2. 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 WFD seems to suggest 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, and a stable groundwater level does not necessarily indicate that the groundwater body is not at risk of failing to meet the environmental objectives of the WFD. Absolute groundwater levels measured at particular points (in monitoring boreholes) can be misleading, especially if they are being influenced by other factors such as the borehole construction or the proximity of large surface water bodies. It is 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 groundwater quality data.

3. HOW DO WE REFINE THE GROUNDWATER LEVEL 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. This paper describes how the Environment Agency is answering these questions.

Abstract ID: 170

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 1/10th 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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Abstract ID: 198

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

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Abstract ID: 233

OPTIMIZING A MONITORING CONCEPT FOR A RIVERBANK FILTRATION SITE

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Keywords: monitoring, riverbank filtration, water supply

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 behaviour 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 a maximum of safety as well as efficiency in well field and treatment plant operation.

At a RBF site located at the River Elbe in Saxony, Germany, 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 a large number of observation wells was installed across the entire catchment area (Fig. 1). During the past 15 years a substantial database has been generated. Data result from regular measurements of water table and in-situ parameters, water and soil 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.

Currently no research project is in progress nor planned for the near future at this RBF site. Therefore, for the sake of optimizing operations and cost reduction the extensive research-oriented monitoring program had to be transformed to an operation-oriented program. On the basis of legal requirements site specific objectives were formulated within a general monitoring concept. To transpose the general concept into an optimal monitoring program the existing data were analyzed and compared in different regards such as content of relevant information or equality of information. Data series were analyzed statistically to determine trends and inconsistencies. From this a reduced number of observation wells, decreased monitoring frequencies and analysis spectrum were derived and the reliability of the simplified monitoring program was proven. Technical and operational demands, like maintenance and preservation of the observation infrastructure were regarded in the program as well. Furthermore, decision recommendations for dynamic, results-based adjustments or a temporal, event-based expansion of the program were worked out.

The intention of the presentation is to illustrate the features of an optimized monitoring program under complex boundary conditions as present at the investigated RBF site. Emphasis will be put on the statistical analysis of existing data, the validation of the optimized monitoring program and the possible adaption processes in the future. The general applicability of the results will be discussed.

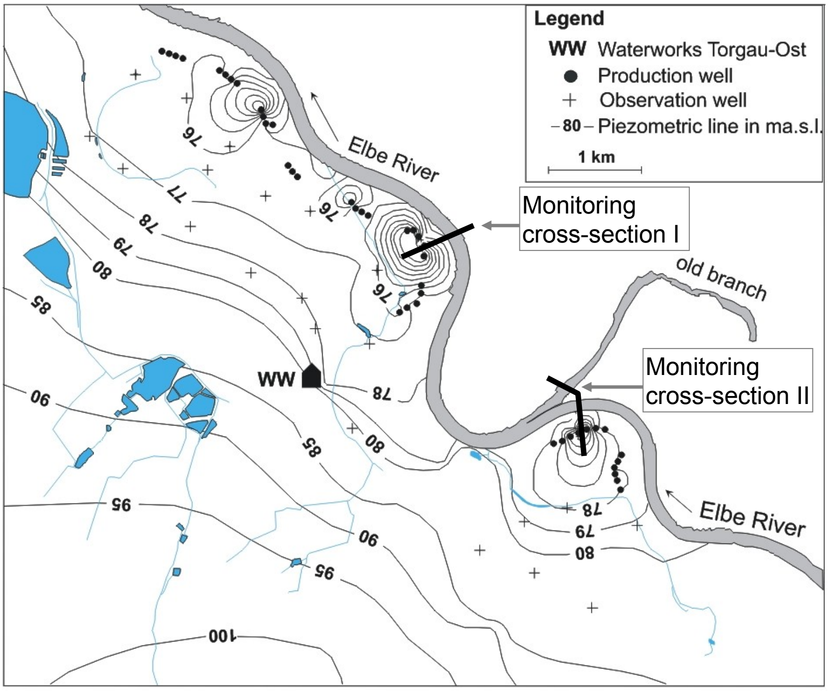

Figure 1. Catchment of the waterworks Torgau-Ost.

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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

This paper presents a new method of assessment and optimization of groundwater quality monitoring network taking into account the assessment criteria derived from the Shannon information theory (Shannon, Weaver, 1949). If we assume that the monitoring network is a signal communication system capable of providing environmental information, we can use the entropy-based criteria to measure the amount of information that can be supplied to the control system. 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 related to groundwater quality data recorded in different sampling points of monitoring network. Transinformation shows the reduction of uncertainty included in one variable due to the knowledge of another variable. For discrete random variables the transinformation can be calculated using contingency tables (Mogheir, Singh, 2002).

Some methods relating to Shannon information theory were developed to assess quality monitoring networks (Harmancioglu, Alpaslan, 1992; Mogheir, Singh, 2002). The entropy-based criteria were used to analyze the structure of spatial variability and minimize redundant information.

Our study involved the groundwater monitoring network of contaminant reservoir located in the West-South part of Poland, called "Żelazny Most" 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 world's biggest industrial waste disposal site. The groundwater monitoring network consists of 278 piezometers. Sampling is not regular. Some monitoring points were sampling 3 times per year while some other were sampling one time per 4 years. In this study for furthermore investigation three variables were chosen: Chloride (Cl), Cuprum (Cu) and Sodium (Na). Data for computational analysis came from 1996 to 2005 period and concerned 55 points. The transinformation value for these three variables for all sampling points in monitoring network were calculated using the following equation:

$$T(X,Y) = -\sum_{i=1}^{N}\sum_{j=1}^{N} p(x_i, y_j)\log\left[\frac{p(x_i, y_j)}{p(x_i)p(y_j)}\right]$$

where X and Y are two discrete random variables, corresponding to different sampling points, defined in the same probability space with probability $p(x_i)$ and $p(y_j)$.

In the optimization problem the following objective function is minimized:

$$\frac{1}{3N(N-1)}\sum_{s=1}^{3}\sum_{n\neq m} T_s(X_n, X_m)$$

where s is an index of the investigated variable (Cl, Cu, Na), n and m are indices of sampling points.

To minimize the objective function the simulated annealing algorithm (Kirkpatrick et al., 1983; Nunes et al., 2004) was used. 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.

As a result of the optimization a reduction of existing groundwater quality monitoring network is proposed and different scenarios of reorganization of the network are discussed.

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Abstract ID: 260

WELL BORE CROSS-AQUIFER CONTAMINATION

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Keywords: groundwater monitoring, cross-aquifer contamination, well purging, ambient well bore flow

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.

Abstract ID: 266

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

The Doñana aquifer system is a 3000 km^2 area in southwestern Spain, around the Guadalquivir river estuary and lower sedimentary basin, which holds one of the largest coastal, natural parks of Europe. The area has been studied in detail since the 1970s and in the 1990s a dedicated groundwater monitoring network was constructed, with point piezometres at different depths to understand the 3–D groundwater flow. Temperature profiles from these boreholes show variable vertical thermal gradients according to the upward or downward flow in the up to 150 m thick sand layers. In some areas native brush vegetation was substituted by fast growing eucalyptus plantations and later on large areas were transformed to irrigated crop land, at the time some extensive urban and tourist area developed. This altered surficial temperature and thus modified the temperature profiles. Results are presented of the study of these changes, which show than rainfall derived recharge is up to 200 mm/a, in agreement with other calculations.

Abstract ID: 268

APPLICATION OF SUSTAINABLE DEVELOPMENT IDEA FOR OPTIMIZATION OF GROUNDWATER MONITORING ON PETROL STATIONS

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Keywords: sustainable development, groundwater monitoring

In the paper global definition of sustainable development defined by Hans Carl von Carlowitz is applied for local definition of sustainable development 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.

The strategy of the sustainable development concern:

- stimulating the processes of the development, to threat the environment in the smallest 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,
- realization of postulates cannot cause undesirable reducing the pace of the economic growth, either spreading the margin of poverty.

This paper is developing the idea of SuRF-UK presented by prof. Jonathan Smith and co-authors in this conference.

This redefined sustainable development ideas are applied for practical problems connected with monitoring of the influence of petrol stations to environment. It means minimization of threats and minimization of the preventive repair costs. Reduction of sustainable development costs should take place on the basis of scientific knowledge and best available practice connected with specific hydrogeological know-how.

The idea of sustainable development is described on the examples from Germany and Hungary, where reduction of contamination of soil risk was conducted by natural attenuation and frequency of required groundwater monitoring visits were reduced. On this basis another program was established. The way of calculating of groundwater flow for hydrogeological conditions of central Poland for specific petrol stations is described and explained. The program of sustainable reduction of investigations for the petrol company operated in the whole Poland is proposed and received results are discussed. The economical effect connected with redefined strategy of sustainable development is shown and it is approved that proper solutions based on hydrogeological knowledge has no negative influence on the environment.

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Abstract ID: 275

OPTIMIZING GROUNDWATER MONITORING NETWORKS USING THE PARTICLE SWARM ALGORITHM

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Keywords: particle swarm optimization, monitoring network, traveling salesmen problem, groundwater

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 optimum particles. As a case study, the particle swarm algorithm technique 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. 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. 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 noticeable loss of information. The root mean square error (RMSE) for the final optimized network was 0.322 m.

Abstract ID: 293

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

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Abstract ID: 325

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

Up to date most of research into monitoring of groundwater contamination concern dissolved contaminants. Problems of monitoring of the subsurface contaminated with petroleum products 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 of sites contaminated with petroleum products must be a constituent part of environmental monitoring including monitoring of waters (groundwater, surface water and waste water), bottom sediments and the unsaturated zone.

Since petroleum products are immiscible fluids and they can migrate in the subsurface as a liquid, a gas, an emulsion, dissolved in water and be retained in soil, monitoring of petroleum contamination is rather specific and different from monitoring of groundwater contamination with dissolved chemical substances. Observation wells do not represent levels and thickness of light petroleum product lenses on a groundwater table as well as a volume of light petroleum products retained in unsaturated soils.

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 light petroleum product migration.

Monitoring conception at different stages of research including *estimating*, *special* and *controlling* monitoring is developed.

Estimating monitoring is carried out during research into determination of subsurface contamination rate and environmental threat. Works are carried out into four stages:

1. Distribution of contaminants in space and lithological and hydraulic properties of the subsurface are estimated by rapid field methods.
2. Monitoring of the subsurface is carried out to estimate dynamics of contamination and detect biological degradation and its rate.

3. Dynamics of contamination is estimated, and contamination spreading is predicted taking into account natural biological degradation.
4. Risk for objects exposed to contamination is determined.

The method of risk determination based on predictions of extreme conditions by groups of parameters accelerating and decelerating the process of contamination.

Crisis situation and critical, high, moderate, and low risks are defined. The sequence of decisions and actions during estimating monitoring is developed depending on situation.

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.

During remediation monitoring is carried out to determine the efficiency of remediation and correct a volume and rate of works.

Controlling monitoring of contamination plume spreading is carried out in the environment when there is a moderate or low risk of contamination for an object in order to prevent a high risk. It 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.

The problem lies in the fact that observation points are projected when there is no contamination in the period of object design and contamination sources are not known (for example, we do not know where the coating of a sewage pond bottom can be broken). It is shown that observation points must be located in the most sensitive nodes of imitation models, which realize different variants of sources and environmental conditions. A number of observation points is determined thus, costs of their allocation will be less than a possible penalty and costs for remediation in a compliance zone without remediation in an optimal zone.

Conclusion. Presented conception and procedure of monitoring enable to reveal, estimate and control the impact of petroleum contamination on the environment and develop methods for prevention, localization and liquidation of contamination.

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Abstract ID: 328

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

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. 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 paper presents the characterization of groundwater in the zone of hydrochemical anomaly and in the surrounding area, where the formation of groundwater chemistry is influenced by the infiltration recharge from the Quaternary aquifer. The characterization is based on the current hydrochemical investigation comprising the determinations of the following physiochemical parameters: pH, temperature, electrolytic conductivity, colour, alkalinity, hardness of Cl^-, SO_4^{2-}, F^-, PO_4^{3-}, NO_3^-, NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}, Fe, Mn, Cd, Cu, Cr, Ni, Pb, Zn, As_{Total}, As^{3+}, As^{5+}, Sb_{Total}, Sb^{3+}, Sb^{5+}, Se_{Total}, Se^{4+}, Se^{6+}, Al, Ag, Ba, Be, Li, Mo, Tl, V, Hg, Ce, Cs, La, Nd, Pr and Sm. The investigated elements were determined using the following analytical techniques: ion chromatography (IC), flame atomic absorption spectrometry (F–AAS), hydride generation atomic absorption spectrometry

(HG–AAS), inductively coupled plasma atomic emission spectrometry (ICP–AES), inductively coupled plasma mass spectrometry (ICP–MS) and cold-vapour atomic fluorescence spectroscopy (CV–AFS). During the analysis of the variability of chemical composition of the Miocene aquifer groundwater in relation to its circulation systems, the following zones were indicated: the zone of recharge from Quaternary aquifers, the zone where water flows to the discharge zones (transit zones), the zones of water discharge flowing from the two aforementioned zones and the zones of water discharge where there is ascent of water from the Mesozoic basement. It was stated that the Miocene water in the ascent zone, and namely within the areas of tectonic fault zones and marked by favourable permeability due to the lithology of sediments (the Lower Jurassic formations), reaches anomalous concentrations of chlorides 421 mg Cl^-/L and sodium 256 mg Na^+/L (Fig. 1).

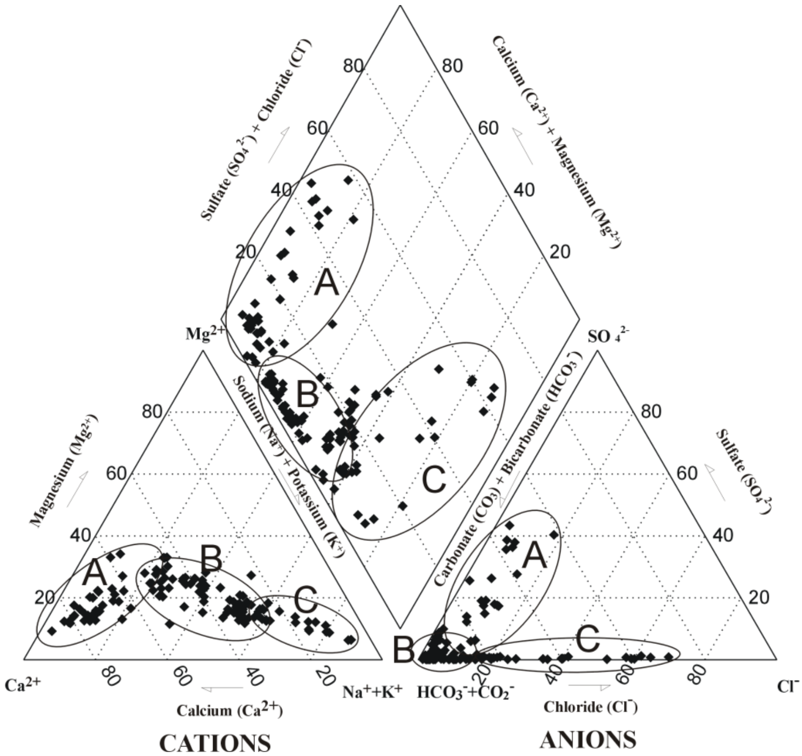

Figure 1. The Piper diagram with the marked points located: A – recharge zones, B – transit and discharge zones, C – discharge zones of water ascending from Mesozoic basement.

Water hardness reaches the level < 4 mval/L, manganese < 0.1 mg/L, and sulfates mostly occur at the level <10 mg/L. Locally, in the areas of Triassic formations, the concentrations of sulfates >100 mg/L occur and water hardness increases. In some parts of this zone colour of water reaches anomalous concentrations of up to 4000 mg Pt/L. In general, the water in this area is of Na^+–Cl^-, and locally of Na^+–Cl^-–SO_4^{2-} type. In the regions of tectonic fault zones, the increase in Ni, Pb, Al, Li, Mo, Tl, V, As_{Total}, Se_{Total}, Hg, Ce, Cs, La, Nd, Pr and Sm concentrations was also observed in relation to the other indicated zones. In the case of determinations of inorganic metalloid speciation forms, a predominance of more toxic forms As^{3+}, Sb^{3+} and Se^{4+} was observed. The Miocene water in the zone of recharge is marked by the total hardness >6 mg mval/L, concentration of chlorides <20 mg Cl^-/L, colour <10 mg Pt/L, manganese >0.1 mg/L and local occurrence of increased concentrations of sulfates and iron in relation to the other zones. In this zone water types HCO_3^-–Ca^{2+} and HCO_3^-–Ca^{2+}–Mg^{2+} dominate. In the transit zone the decrease in water hardness to the range of 4 to 6 mval/L may be observed, chlorides occur also at the level <20 mg Cl^-/L, colour reaches the concentration level <80 mg Pt/L, and manganese < 0.1 mg/L. The change of water type into HCO_3^-–Na^+–Ca^{2+}–Mg^{2+} may also be observed. The water in the discharge zones from the Miocene to Quaternary aquifer, situated outside the zones were is the ascent from Mesozoic basement has the chemical composition similar to the transit zones.

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HYDROGEOCHEMICAL ZONING IN THE DELTA OF THE RIVER ANDARAX (ALMERÍA, SE SPAIN)

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Keywords: seawater intrusion, monitoring network, detritic aquifer

1. INTRODUCTION

The delta of the River Andarax occupies the coastal section of a detritic aquifer that extends along the central sector of the valley of this river and 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. Its piezometric surface show wide variations as a function of rainfall and the surface water flow in the River Andarax.

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 correspond fundamentally to coarse detritic deposits: gravels with some 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 to coarse gravels. The underlying unit has a more heterogeneous lithology, composed mostly of 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.

The main 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 fact that saline deposits are also present, coupled with levels of varying permeability, all of which contributes to the presence of different water types with varying salinity and highly contrasting geochemical evolution.

2. RESULTS AND DISCUSSION

The zoning of water salinity was determined from the down-hole logs of electrical conductivity, differentiating the three bands of fresh water, mixing water and salt water. The thickness of the freshwater band increases with distance from the coast. The thickness of the interface in the boreholes furthest from the coastline varies from 25 and 30 m but it is much narrower closer to the coast (15 m). Based on these results, four groundwater sampling points were then selected for geochemical analysis at different depths in each borehole.

There is clear zoning of the major ions in the water bands, in keeping with the conductivity results: the freshwater band shows salinity of less than 10 mS/cm, a sodium-calcium chloride-sulphate facies, and nitrate concentrations in excess of 60 mg/L; the interface shows a salinity of between 20–30 mS/cm, a sodium chloride facies and nitrate concentrations of between 20–30 mg/L, while the salt water band has a salinity of between 50–60 mS/cm, a sodium chloride facies and nitrates below 0.5 mg/L).

The water chemistry in the freshwater band is directly linked to the groundwater inflow to the detritic aquifer, which extends all along the Andarax valley. The elevated nitrate content is a consequence of the intensive agricultural activity in the area. The lower, more saline bands of water re chemically more diverse, especially when the major ions are considered in conjunction with Br, B, Li and Sr. This variability manifests itself in the ion ratios, which are unlike that of seawater, especially at depth. In these levels, the lutitic intercalations favour ion exchange. In addition, Plioquaternary marine deposits containing evaporite salts have been identified, which markedly affect the hydrogeochemical evolution of the groundwater.

3. FINAL CONSIDERATIONS

Hydrogeochemical study of coastal detritic aquifers requires a conjoint approach using various techniques (detailed reconnaissance of the borehole columns, logging of temperature and electrical conductivity) over a hydrogeochemical network that allows groundwater sampling at various depths. This is fundamental, since these aquifers show frequent changes of facies, both vertically and horizontally, which means that there levels of varying permeability. In addition, the presence of evaporite salts of marine origin exerts a strong influence on the hydrogeochemical evolution of the waters, making it difficult to study seawater intrusion processes.

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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

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

Municipal waste landfills classified as other than hazardous or neutral frequently constitute a direct or indirect threat for the soil and water environment. 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).

Over the last few years the authors have conducted studies of the quality of surface waters and groundwaters in the vicinity of several landfills where the deposited municipal waste is obviously a potential contaminant. Figure 1 presents the variability of characteristic surface water contamination indicators in the municipal waste landfill impact zone located in the vicinity of Krakow above and below the facility. Figure 2 presents the variability of characteristic indicators in groundwaters of the first water bearing horizon in the impact zone of a closed down landfill in the Podkarpacie region at observation boreholes located at water inflow and outflow.

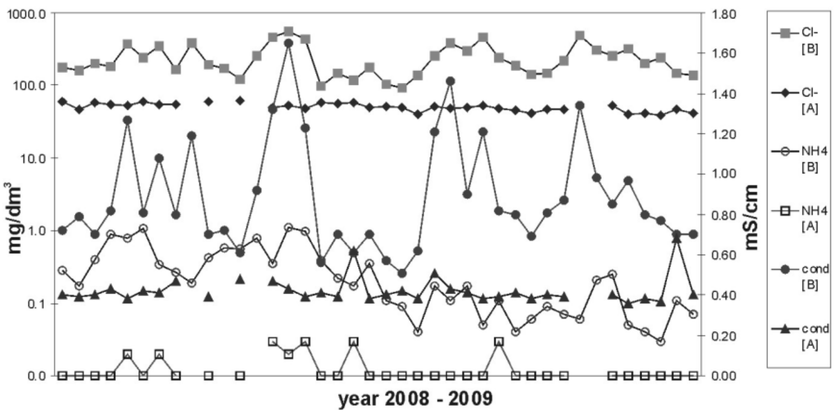

Figure 1. The changing values of characteristic surface water contamination indicators in the impact zone of a municipal waste landfill (A — site located above the facility; B — site located below the facility).

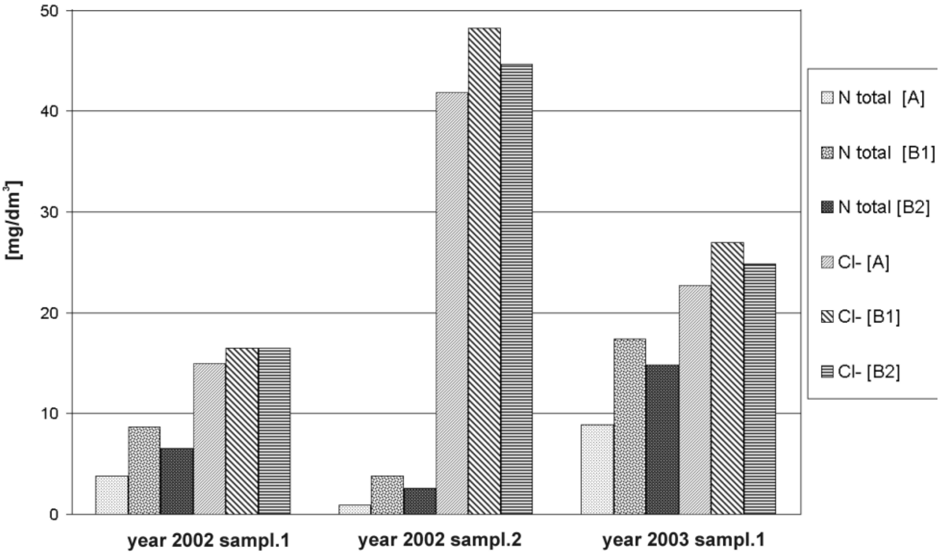

Figure 2. The changing values of characteristic groundwater contamination indicators in the impact zone of a municipal waste landfill (A — observation borehole at inflow; B — observation borehole at outflow of water from the landfill).

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 zone of the existing facilities justify the need to expand the scope of monitoring studies. The studies extended in such a manner reflect the actual threats for the environment.

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Abstract ID: 471

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).

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).

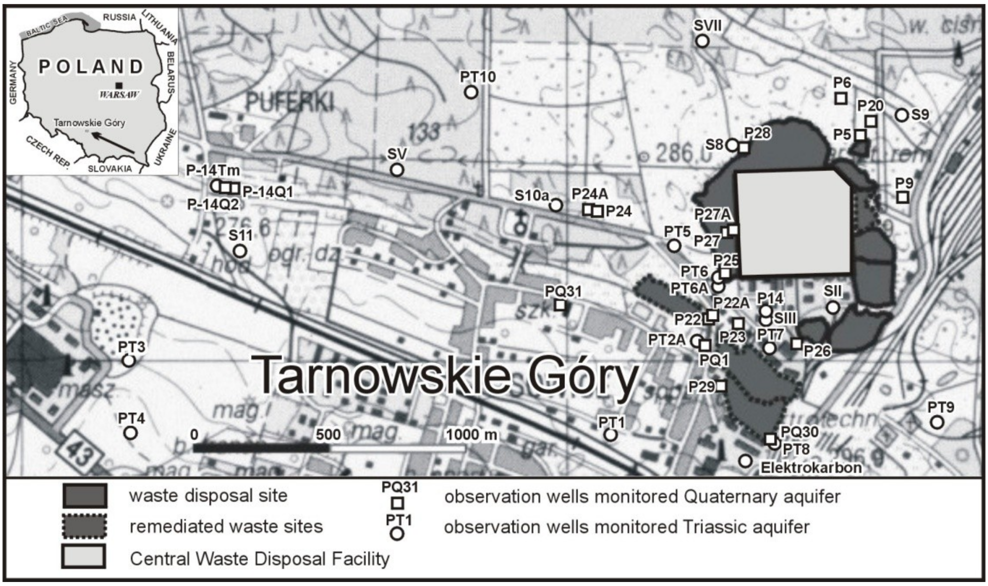

Figure 1. Location of the waste disposal sites and groundwater quality monitoring network.

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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Abstract ID: 478

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

Integrated monitoring of sources pollution is one of main tools for valuation groundwater chemical status, in problematic point sources pollution. 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).

One of the main aim of the Water Framework Directive 2000/60/EC is achievement of good groundwater/surface water status to the year 2015. It is a need for a greater integration of qualitative and quantitative aspects of both surface waters 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.

Target of this database is consistent knowledge of groundwater qualitative status in particular localities like surroundings industry areas, waste dumps, piles, sludge beds, and to differentiate potential polluters from the real polluters upon the data from groundwater monitoring. Another step of this evaluation will be evaluation of particular localities and its data. Following the results of evaluations systematic measures will be proposed.

Abstract ID: 511

MONITORING OF THE IMPACT OF AGRICULTURE ON GROUNDWATER IN LATVIA

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Keywords: groundwater, monitoring, agriculture

The objective of the study is to investigate the overall status of groundwater (quantity and quality) and 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. 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.

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. High groundwater level in autumn; spring and lowering of the groundwater levels in summer time is typical for soils in Latvia.

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. One of the important future tasks is to organize comprehensive national groundwater monitoring network covering both confined and unconfined aquifers.

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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 program, 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.

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1.7 | Groundwater policy and legal aspects

Abstract ID: 399

PROPOSED PROCEDURE TO EVALUATE THE CHEMICAL STATUS OF GROUNDWATER BODIES

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Keywords: Water Framework Directive, chemical status, background values

1. INTRODUCTION

Water Framework Directive (European Commision, 2000) establishes in article 4 that the environmental objective for European groundwater' is to reach the good chemical and quantitative status. Water Framework Directive (WFD) establishes general criteria to determine if a water body has good status; however, it does not expose a specific methodology. The objective of this work is the proposal of a procedure for the evaluation of the chemical status in groundwater bodies with the data obtained from the water quality networks. Some physical-chemical parameters and threshold values extracted from national normative and rules are proposed.

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.

2. DEFINITION OF GOOD CHEMICAL STATUS

In accordance with annex V of the WFD (subtitle 2.3.1), the basic parameters to establish the chemical status of groundwater bodies are the electrical conductivity (EC) and the concentration of contaminants in water. In a first approach, the good chemical status is reached when: (1) the EC indicates an absence of salinization or sea-water intrusion and (2) the concentration of contaminants are below the water quality levels of Directive 2006/118/CE (Groundwater Directive). Furthermore, both parameters must not produce damage in the surface water and ecosystems that are supported by a groundwater body.

3. PROPOSAL OF PARAMETERS AND BACKGROUND VALUES

In Table 1 is exposed a list with the physical-chemical parameters and background values proposed for the evaluation of chemical status of groundwater bodies (Sánchez, 2010). The first four parameters (Electrical conductivity, chloride, sodium and sulphate) are proposed as indicators of bad chemical status due to salinization or sea-water intrusion. Background values for nitrate and pesticides are a consequence of annex I of the Groundwater Directive and the rest of parameters have been obtained from Directive 2008/105/CE, concerning environmental quality rules for surface water (Annex VIII of WFD) and Spanish "Real Decreto" 995/2000, which sets up quality objective for certain contaminants.

Table 1. List of parameters and proposal for background values.

Parameter	Background value		Parameter	Background value	
1. Electrical conductivity	Upward temporary evolutions		(d) Benzo(g,h,i)-perylene	MA: Σ>0,002	
2. Chloride			(e) Indeno(1,2,3-cd)-pyrene		
3. Sodium			35. Simazine	MA>1	>4
4. Sulfate			36. Tributyltin compounds	MA>0,0002	>0,0015
5. Nitrates	>50 mg/L		37. Trichloro-benzene	MA>0,4	
6. Pesticides	>0,1 (indiv.)	>0,5 (total)	38. Trichloro-methane	MA>2,5	
7. Alachlor	MA>0,3	>0,7	39. Trifluralin	MA>0,03	
8. Anthracene	MA>0,1	>0,4	40. (a) Total DDT	MA>0,025	
9. Atrazine	MA>0,6	>2,0	(b) P,p-DDT	MA>0,01	
10. Benzene	MA>10	>50	41. Aldrine	MA: Σ>0,01	
11. Brominated diphenylether	MA>0,0005		42. Dieldrine		
12. Cadmium: <40 mg/L CaCO3	MA>0,08	>0,45	43. Endrine		
40-50 mg/L CaCO3	MA>0,08	>0,45	44. Isodrine		
50-100 mg/L CaCO3	MA>0,09	>0,6	45. Carbon tetrachloride	MA>12	
100-200 mg/L CaCO3	MA>0,15	>0,9	46. Tetrachloro-ethylene	MA>10	
≥200 mg/L CaCO3	MA>0,25	>1,5	47. Trichloro-ethylene	MA>10	
13. C10-13 Chloroalkanes	MA>0,4	>1,4	48. Chloro-benzene	MA>20	
14. Chlorfenvinphos	MA>0,1	>0,3	49. Dichloro-benzene	MA>20	
15. Chlorpyrifos	MA>0,03	>0,1	50. Ethyl-benzene	MA>30	
16. 1,2-Dichloroethane	MA>10		51. Metolachlor	MA>1	
17. Dichloromethane	MA>20		52. Terbutilazine	MA>1	
18. Di(2-ethylhexyl)-phthalate	MA>1,3		53. Toluene	MA>50	
19. Diuron	MA>0,2	>1,8	54. 1,1,1-Trichloro-ethane	MA>100	
20. Endosulfan	MA>0,005	>0,01	55. Xilene	MA>30	
21. Fluoranthene	MA>0,1	>1	56. Cyanides	MA>40	
22. Hexachloro-benzene	MA>0,01	>0,05	57. Fluoride	MA>1,7 mg/L	
23. Hexachloro-butadiene	MA>0,1	>0,6	58. Arsenic	MA>50	
24. Hexachloro-cyclohexane	MA>0,02	>0,04	59. Cupper: ≤10 mg/L CaCO3	MA>5	
25. Isoproturon	MA>0,3	>1,0	10-50 mg/L CaCO3	MA>22	
26. Lead and its compounds	MA>7,2		50-100 mg/L CaCO3	MA>40	
27. Mercury	MA>0,05	>0,07	>100 mg/L CaCO3	MA>120	
28. Naphthalene	MA>2,4		60. Total chromium	MA>50	
29. Nickel and its compounds	MA>20		61. Chromium VI	MA>5	
30. Nonylphenol	MA>0,3	>2,0	62. Selenium	MA>1	
31. Octylphenol	MA>0,1		63. Total zinc: ≤10 mg/L CaCO3	MA>30	
32. Pentachloro-benzene	MA>0,007		10-50 mg/L CaCO3	MA>200	
33. Pentachloro-phenol	MA>0,4	>1	50-100 mg/L CaCO3	MA>300	
34. Polyaromatic hydrocarbons:			>100 mg/L CaCO3	MA>500	
(a) Benzo(a)pyrene	MA>0,05	>0,1	Total phosphorus	>50	
(b) Benzo(b)fluor-anthene	MA: Σ>0,03		65. Biological oxygen demand	>4 mg/L	
(c) Benzo(k)fluor-anthene			66. Ammonium	>0,5 mg/L	
			67. Phosphate	>0,5 mg/L	

"MA": mean annual concentration; the other values are expressed as maximum allowable concentrations

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1.8 | Economic tools to protect groundwater

Abstract ID: 353

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

EFFECT ON THE GROUNDWATER RECHARGE AND THE SPRINGWATER RESTORATION BY INFILTRATION FACILITIES

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Keywords: infiltration facility, groundwater recharge, springwater restoration, artificial recharge experiment

1. INTRODUCTION

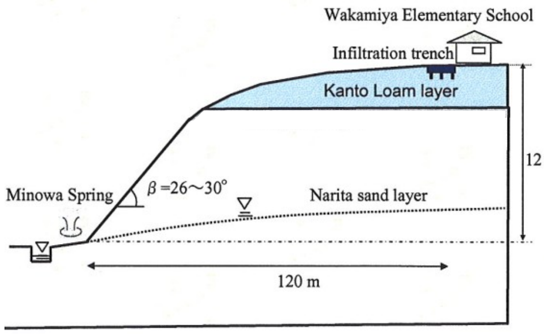
It is well known that the urbanization around catchment basins has been causing the decrease in the quantity of rainwater infiltrating to the ground in proportion to the increase of impermeable surfaces of roofs, road pavement, etc. As the result, decrease in groundwater level, dryness of spring water 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. Although there have been several simulation researches on those effect, the verification of those effect based on the observed data has been 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.

2. METHODOLOGY

In this study, the artificial recharge experiments were done at the comparatively narrow catchment area for the existing spring water in order to verify the effectiveness on the groundwater recharge and springwater restoration by rainwater infiltration facility. Minowa spring basin located in Ichikawa City was selected as an experiment site. Infiltration facility (width 0.5 m, height 0.6 m, length 4.4 m) was installed at Wakamiya Elementary School where it is on the hill at the upstream of Minowa Spring (Fig. 1 and Fig. 2). Infiltration capacity of the facility was estimated to be about 1.5m^3/hr by the preliminary infiltration test on site.

The groundwater table observation holes were newly set up near the infiltration facility and the Minowa Spring. The measurement of springwater flow was done by the v-notch weir at the channel where springwater was discharged. Since the main target of this investigation was to know the quantity of groundwater recharge and springwater restoration, there were no investigation for the change in the chemical composition of ground- and springwater.



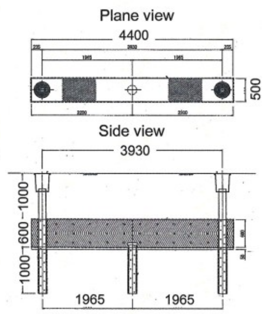


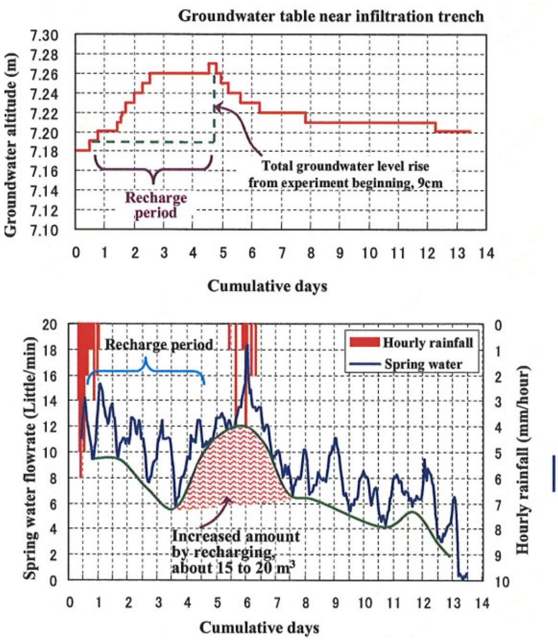
Figure 1. Experiment site.

Figure 2. Structure of infiltration facility.

Experiments were carried out by artificial recharge and rainfall recharge (cullis water which flow to infiltration facility). Here, the recharge water used in experiments was tap water, public water supply pipe, which was laid at Wakamiya Elementary School. Because of the experiments works were conducted in school premise, it was difficult to conduct longtime artificial recharge. Therefore, water injection was stopped when it was confirmed that infiltrated water reach to groundwater surface and then groundwater level rose up.

3. RESULTS

From the results of artificial recharge experiment, the groundwater level rose up and the springwater flowrate had changed to the rise since about the fourth day though the springwater flowrate was a decrease tendency from the beginning of the experiment (Fig. 3). This tendency is roughly corresponding to the results of the two dimensional seepage flow analyses (Fig. 4).



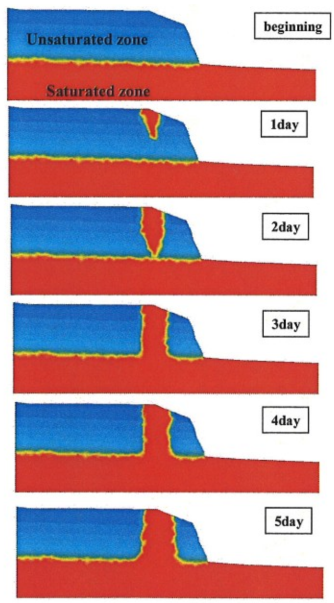


Figure 3. Groundwater recharge and springwater restoration effect during experiment.

Figure 4. Seepage flow analyses

Therefore, the effectiveness on the groundwater recharge and the springwater restoration by the infiltration facilities has been verified based on the observed data.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the cooperation by Ichikawa City, Chiba Prefecture on carrying out the experiments.

Abstract ID: 194

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

CLIMATE CHANGE AND GROUNDWATER VULNERABILITY IN THE CZECH REPUBLIC

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Keywords: climate change, groundwater, Czech Republic

During recent years, T.G. Masaryk Water Research Institute in Prague has carried out a number of studies which were focused on the possible impacts of climate change on groundwater resources. For these studies, the Bilan water balance model (Tallaksen, van Lannen, 2004) was initially used to simulate the water cycle components (including groundwater recharge and base flow), both for conditions unaffected by climate change and also for those modified according to climate change scenarios. The main results of the individual studies were described in a number of research reports and presented at international conferences and symposia (e.g. Kněžek, Krátká, 2005; Novický et al., 2007; Uhlík 2006 and 2008).

The quantification of groundwater regime is indispensable for the purpose of groundwater management planning in present and possible future conditions. 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. In present study, 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) have been determined. The groundwater storage was estimated by the use of water balance model for the periods of decreasing flows, when the only component of the total runoff is baseflow. 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 observed groundwater level and simulated water storage. 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 as a part of other study. The simulated changes in groundwater storage were then related to the estimated total volume of stored groundwater to assess the vulnerability of the groundwater reservoir.

The results of the study showed that in the Cretaceous layers (Metuje River) deficits in active storage ($0.80\ 10^6\ m^3$) of groundwater are acceptable even in extreme situations when compared to the estimated available storage ($24\times10^6\ m^3$ for Teplice n. M. station and $79\times10^6\ m^3$ for Hronov station). On the other hand, in the mountain crystalline formations (Divoká Orlice) the maximum decrease in groundwater storage ($3.41\times10^6\ m^3$) and estimated available storage (from $4–5\times10^6\ m^3$) 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. 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

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Abstract ID: 232

POLLUTION OF GROUNDWATER IN SHALLOW AQUIFERS — A CRITICAL MOMENT IN UGANDA

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Keywords: pollution, slums, contamination, groundwater, aquifer

Groundwater is the main and safest source 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 4 km in the north, it fringes on the lowland of Lake Victoria with a population density of about 27 000 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 × 107 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 30 m 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.

Abstract ID: 256

SUSTAINABILITY OF RIVER BANK FILTRATION

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Keywords: river, bank, filtration, sustainability, clogging

Bank filtration is important in Germany where groundwater derived from infiltrating river water provides about 8% of drinking water supplies. Over a century of experience exists in the operation and maintenance of bank filtration schemes in Germany. The Duesseldorf Waterworks has been using bank filtration since 1870 (Eckert, Irmscher, 2006). 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.

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 therefore reduces the flow rate of the filtrate through the riverbed. At the Elbe River in Dresden, erosive conditions in the river and floods limit the formation of a clogging layer by disturbing the riverbed via increased flow velocity and increased turbulence. Between 1914 and 1930 a significant decrease in groundwater levels at Dresden–Tolkewitz was observed and discussed as a result of riverbed clogging due to the increased infiltration rates since 1901 and clogging by suspended materials. In the 1980s strong river water pollution caused by organics from pulp and paper mills in conjunction with high water abstraction caused unsaturated conditions beneath the riverbed. After improvement of river water quality in 1989–1993 the hydraulic conductivity of the riverbed increased. In 1992 similar water levels as in 1930 were observed. Looking at the long-term operation of the waterworks, it is obvious that observed clogging of the riverbed did not result in the closure of wells under the given conditions of an erosive river. After a period with additional organic pollution there was a recovery of hydraulic conductivity of the riverbed.

After 1950 the quality of the Rhine River began to deteriorate gradually. The consequence of this and the increasing organic load in the river water changed the redox situation in the adjacent aquifer: it switched from former aerobic to anoxic conditions. But more important for the sustainability of riverbank filtration was the effect of particulate organic matter which intensified clogging of the riverbed and thus reduced the well yield significantly. Field studies of the riverbed in front of the Flehe Waterworks (Duesseldorf) in 1953, 1954 and 1987 were carried out with a diving cabin. 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 g/m^3. In the investigated areas in front of the Flehe Waterworks, the clogged areas spread out during flood events due to the high concentration of suspended solids and the high gradient between the river level and the water table of the adjacent aquifer.

Understanding of clogging processes and limitation of infiltration rates per square metre river bed is of main importance for the design of bank filtration facilities worldwide. Experiences from Germany will be discussed together with case studies from the Ohio River, USA, and from the Ganga River, India (Grischek et al., 2005). Simple parameters such as suspended solids concentration and basic hydrological and hydrogeological information could be used to estimate the risk of clogging and to determine appropriate pumping rates and distances between wells and the river bank at new sites to achieve sustainability of bank filtration. Furthermore, some examples will be given for long-term RBF site operation in India and other countries.

Besides clogging, water quality aspects will be discussed. Since 1950 the water quality of large rivers in Germany began to deteriorate. It became necessary to treat the pumped raw water. At many sites, subsequent technologies such as ozone treatment, biological filtration or GAC adsorption were established. Nowadays, bank filtration has again become a reliable resource for raw water abstraction. No indication of a decrease in attenuation capacity of the aquifer with time was observed. At many sites, simple treatment technologies such as pH-regulation, rapid sand-filtration and disinfection are sufficient for meeting drinking water standards today. Activated carbon filtration often is only used as safety measure to remove persistent trace organics present in river water and bank filtrate. Long-term experiences and results of the evaluation of historic and recent data and of investigations using modern modeling tools prove that river bank filtration is a sustainable water resource for water supply in Germany. Thus, it is a promising technique also for densely populated areas and large cities e.g. in Asia, where drinking water supplies are mostly coming from surface water sources (Ray, 2008).

ACKNOWLEDGEMENTS

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Abstract ID: 261

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

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

Karst areas in Croatia are a part of the regional geologic structure of Dinarides which cover an area from Slovenia across Croatia and Bosnia and Herzegovina up to Montenegro. Almost half of the Croatian territory belongs to the karst area of specific surface and underground morphological characteristics. In Croatia the karst groundwater quantities make a little less than a half of total disposable state potable water quantities. Geologically speaking, those are mostly carbonate rocks with fully developed karst forms.

It is exceptionally difficult to separate the groundwater from surface waters in karst areas. Therefore the groundwater and surface water interaction is extremely large. Particular rivers start their flow at karst springs, flow partly on the surface, then swallow when facing the well permeable carbonate rocks, only to resurface again as ground waters at springs in the lower catchment area parts. The similar situation occurs in karst fields which, in the rainy parts seasons, are partly flooded due to the ground water level rise, while in the dry periods the springs in the fields run dry or are significantly reduced in the water amount. The water flows and disappears underground several times within the same catchment area, accepting all catchment area loadings created by human activities. From that reasons karst areas require an integrated water quality and quantity assessment as well as water resources risk assessment for each groundwater bodies (GWB).

A part of Croatian karst waters is accumulated and used for electric power production, which causes changes in both outflow regime and dynamics and even changes of groundwater outflow directions. The largest part of karst area belongs to the Adriatic catchment and is subterraneously drained towards coastal springs and hydrologically uncontrolled submarine springs in the Adriatic littoral area. Consequently, the karst catchment areas are neither unambiguous (they depend on hydrological conditions), nor easily determinable.

In heterogeneous karst conditions there are considerable difficulties in delineation of GWB's as well as in assessment the groundwater quality and quantity status which must be performed according to the EU Water Framework Directives (WFD). The fact that the groundwater monitoring is in Croatia in a developmental stage is an additional problem, so that the initial characterization and groundwater risk assessment have been performed according to data from the 2000–2007 period. This paper presents the methodological approach which was applied on Croatian karst area as well as the abbreviated summary of conducted analyses.

Seventeen GWB's have been delineated in the Croatian karst area, nine of which are of transboundary character due to the characteristic shape of Croatia. In the quantity status assessment has been used the measured climatological and hydrological data as well as data of different forms of water usage, the regional hydrological analyses and estimations have been conducted as well as the time trends assessment. The regression relations between different hydrological elements have been established from which has been separated the catchment surface, mean annual flows and lowest mean monthly flows. The hydrological catchment area data have been extrapolated to the GWB level. It has been established that the global water resource utilization for water supply needs, industry and irrigation is extremely low compared to the total water potential — it amounts to an average of 2.3% only. Despite this fact there are two GWB's with an estimated poor quantity state and two GWB's with a probable poor state. The quantity status has been assessed as good for thirteen ground water areas. By estimating the risk of not meeting the WFD requirements additional two GWB's have been listed as “at risk”.

In order to asses the quality status spatial analyses of natural vulnerability, hazard and pollution risk have been conducted. The GWB quality status assessment was performed by analyzing the water quality within the 2000–2007 period, taking water samples from 55 karst springs in monthly intervals (the total of 3887 analyses). The monitoring network mostly uniformly covers the singled out karst GWB's. For quality status assessment the following parameters have been used: the dissolved oxygen, pH, electric conductivity, nitrates and ammonia according to the WFD requirements, as well as the entire pesticides, arsenic, cadmium, lead, mercury, chloride, sulphate, trichloroethylene and tetrachloroethylene according to the Groundwater Directive requirements. Regarding the specificity of karst water system, the quality status analysis has also included the free CO_2, the temperature, the orthophosphates, the turbidity, iron, manganese and mineral oils. It has been established that thirteen GWB's have a good quality status, two poor. In case of the remaining two the status has been assessed to be probably good based on an expert estimation since there were no or not enough data.

An important element in assessment of the quality risk in accordance with the Article 4 of the WFD was the natural background level (BL) and threshold value (TV) for the selected parameters. Based on extrapolation of observed trends during the referential period of 2000–2007, the changes in several quality parameter characteristics have been established. At that time the value of 75% of the boundary value determined when estimating the groundwater quality status was taken as a risk indicator. It has been established that eleven GWB's are at no risk while four are at a potential risk.

The paper points out the need to discuss the applied methodological procedures used for ground water state and risk estimation within the framework of their application on specific conditions of karst aquifers and under conditions of a limited fundus of available data.

Abstract ID: 290

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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Abstract ID: 323

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

North ThangLong and QuangMinh industrial zones are located on northwestern part of Hanoi, Vietnam where is the left side of Red river. The climate of studying area is humid tropical monsoon with hot and wet summer and cold and dry winter. The annual relative humidity is 84% with rainfall is 1600 mm and pora 900 mm. Absolute elevation is 5–10 m.

In the studying area we constructed 3 monitoring wells to 60 m of depth from 2008. The results of investigation show that, there are 2 aquifers: *Holocene aquifer* (qh) is exposed on the surface, widely and continuously distributed from the Red river. The water bearing formations consists of 2 sequences: the upper sequence is composed of sandy clay with low permeability, with thickness from small to about 10m. The lower sequence is composed of sand with various grain sizes, in some place mixed with the gravel at the bottom, with average thickness of 10 m. The transmissibility (T) of the water bearing formations is 20–800 m^2/day. The specific yield (μ) varies from 0.01 to 0.17. The dept to the ground water level is about 3–4 m below the surface. Mainly rainwater, irrigation water and river recharge the aquifer (during the rainy season). The groundwater is discharged to the river (during the dry season). The groundwater in the qh aquifer is fresh, with TDS usually below 0.5 g/l, mainly of calcium-bicarbonate type. The iron content in the water in most of the area is 0.4 to 10 mg/l. This aquifer is significant for small-scale water supply. The rural people usually dig wells and drill shallow and small diameter boreholes for extracting the groundwater from this aquifer.

Pleistocene aquifer (qp), also called the lower aquifer, distributed from the North continuously to the South of studying area. The dept to the top of the aquifer is 15–30 m. The qp aquifer by the low permeability confining layer of Vinh Phuc formation (Q23vp2), in particular in the strips along the Red river and Duong river due to erosion of this confining layer the two aquifers lie directly on each other forming a hydraulic window. Between the aquifers and the rivers, there is the close hydraulic connection. The water bearing formation is composed of sand mixed with coble and gravel with the thickness of 10–35 m and this aquifer is classified as of very high productivity.

The ground water in the qp aquifer is fresh, with TDS from very small to 0.78 g/l, mainly of calcium-bicarbonate type, in some places, calcium-sodium-chloride-bicarbonate. The iron content in the water is high from 0.4 to 20 mg/l, in some places to 50 mg/l. Due to its high productivity the qp aquifer is being intensively abstracted and is the main source of water supply for the industrial zones. This aquifer is not much exposed to direct pollution but pollutants can move from the Holocene aquifer (qh) into it through hydraulic windows by industrial activity.

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Abstract ID: 352

UZBEKISTAN KARIZES AND USE OF ANCESTORS EXPERIENCE ON BUILDING GROUNDWATER GALLERY

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Keywords: kariz, gallery, operation

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 6500 m. 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. 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. 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 loca-

tion, drilled in Paleozoic fractured rock in which roof faces of two operational wells settle down. 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.

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 8 m. Capacity of Paleozoic (Pz) crust of weathering is estimated in 30 m. 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. The groundwater intakes construction of this kind operates in desert Central Kyzyl Kum.

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

WATER RESOURCES MANAGEMENT IN THE BOTTLED WATER BUSINESS

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Keywords: water resources management, water resources protection, bottled water, Nestlé

Nestlé Waters is the world's leader in the bottled water business. We operate 103 factories in more than 35 countries producing different categories of bottled water: natural mineral water, natural spring water, drinking water…

Our bottling activities firstly depend on the underground water resources everywhere we operate. Thus, sustainable growth of Nestlé Waters's business is inseparable from sustainable management of each water source we operate.

The long term stewardship of our catchments has always been a core strategic asset of our company. This is the reason why we have put in place a sound and continuous monitoring system to insure the sustainable supply of our factories in terms of quantity and quality. Our rigorous measurement is completed by techniques that have been specifically developed for the bottled water requirements: drilling under good hygiene conditions, possibility to clean and disinfect a well in case of quality deviation, quality of the materials used, choice of the surface equipment, design of the wellhead, active and passive security systems… All these specificities were needed to insure the permanence of our water resources installation and their protection over the long term.

Moreover, maintaining the availability, the quality and the biodiversity of the water resources we use is also the result of collaborative and open discussions with the communities where we operate. In particular Nestlé Waters is working along local stakeholders (authorities, local communities, farmers…) to put in place innovative and sustainable protection initiatives, covering today thousands of hectares of aquifers' recharge areas. Initiated in the early 70's, the Agrivair program in Vittel (France) is today considered as a worldwide reference in groundwater resource preservation.

Abstract ID: 374

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

Groundwater is a basic source of supply for populations and for other activities related to the human development. Nowadays there exists an increase of the demand and threats of pollution to which this basic resource meets submitted.

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 Water Framework Directive. 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. This water destined to human consumption have not been still an object of adaptation to the Spanish legislation of there the need to define a conceptual frame for the development of a methodology that allows to delimit safeguard zones as global figure of protection in all the groundwater bodies destined to the human consumption.

The size of the safeguard zones will be able to be very changeable, in many cases they will be minor that the groundwater bodies and several will be able to exist in the same groundwater bodies or to spread out of the same one, like it happens in certain karstic aquifer. On the other hand, also they can correspond to the totality of the extension of the groundwater bodies or be the surrounding one of the wellhead protection areas of the existing captations.

By the above, it is necessary to create a methodology that provides the distribution of the captations in the groundwater bodies, hydrogeology criteria, pressures and vulnerability evaluation considering also the wellhead protection areas. processing and analyzing data which are considered to be necessary to process by a Geographical Information System will allow the delimiting safeguard zones in the groundwater bodies.

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.

Abstract ID: 448

COMPARISON OF COMMON AND NEW METHODS TO DETERMINE INFILTRATION RATES IN LAKE SEDIMENTS

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Keywords: infiltration rates, methods, lake bank filtration

Lakes and rivers have been and continue to be major sources of water supply. In many countries of the world, alluvial aquifers hydraulically connected to a water course are preferred sites for drinking water production. Lake bank filtration has been used for drinking water supply e.g. in Germany, Finland, the Netherlands, India and Brazil. In Berlin, Germany, large capacity waterworks are located at the lake Müggelsee, the lake Tegel and the lake Wannsee. In north of the city of Dresden, Germany, a bank filtration site along the Radeburg reservoir is in use since 1986. In Goerlitz, Germany, an artificial lake is used to increase water recharge (Grischek et al., 2009). Lake bank filtration has also been used at the lake Nainital in Northern India for more than 15 years (Dash et al., 2008).

The determination of infiltration rates in the lakes is necessary for water management. Various methods have been used during the last years to answer questions about infiltration regimes during bank filtration. This study will provide a comparison of common and new methods to determine infiltration rates in lake sediments. Literature data will be combined with results from own field site investigations. These investigations are focused on lake bed characterization, determination of infiltration rates using different tracer techniques, e.g. fluorescent tracers (Gunkel et al., 2009), Rn-222 (Macheleidt et al., 2006) and temperature, infiltration experiments in the field and column experiments in the laboratory. The applicability and limitations of applied methods will be discussed.

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Abstract ID: 517

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 as shown in Fig. 1, the north part of the Vast North China Plain. 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 131 000 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.

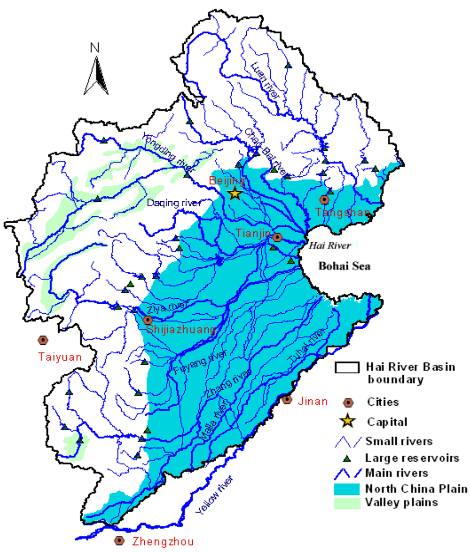

Figure 1. The North China Plain and the Hai River Basin.

Main groundwater issues in the plain are summarized, which include groundwater level declining (Fig. 2) and 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.

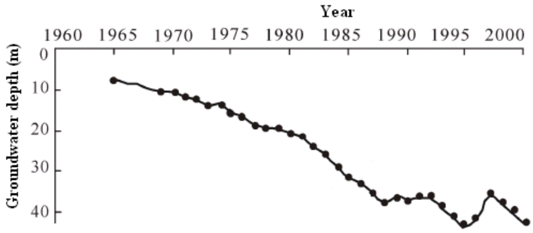

Figure 2. Annual variation of groundwater level in the funnel center in Shijiazhuang city in the plain.

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 River. 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.

ACKNOWLEDGEMENTS

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1.10 Decision support tools for sustainable groundwater management

Abstract ID: 112

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 com-*

promising 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: 136

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

Within the framework of the technical cooperation project "Management, Protection and Sustainable Use of Groundwater and Soil Resources" between the Arab Center for Studies of 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 quantitative 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 includes various options to determine water flows from soil to groundwater by simulation models of the soil water balance. On a regional scale alternative tools are needed to estimate long term means of the percolation rate. From the soil scientist's perspective percolation beyond the lower boundary of the root zone equals groundwater recharge. To avoid high costs of field measurements and limitations in the availability of model input parameters robust methods such as empirical equations / nomograms are needed, based on input variables that can be determined easily or are available from existing databases. Wessolek et al. (2008) use the term "hydro-pedotransfer functions" (HPTFs) to characterize this kind of approaches.

The same methodology as applied within the framework of the new Hydrological Atlas of Germany (HAD) (BMU 1998, 2001, 2003) was used to develop similar nomograms or empirical equations for countries of the Arab region. For this purpose a simulation model of the soil water balance was used to calculate actual evapotranspiration and percolation for different climatic regions, soils and land use classes. 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. For estimating long-term means of actual evapotranspiration in the Arab region the CROPWAT model (Clarke et al. 1998) can be used which was developed by the Land and Water Development Division of FAO for planning and management of irrigation. Agroclimatic data from 188 meteorological stations from eight Arabic countries (Morocco, Algeria, Tunesia, Libya, Egypt, Jordan, Lebanon, Syria) were taken from the CLIMWAT database which is also available via download from the FAO homepage.

For a first investigation three typical kinds of land use (winter wheat, citrus trees, pastureland) were taken into consideration. Mean annual groundwater recharge rates (*gwr*) can be predicted from information on mean annual precipitation (*prec*), mean annual potential evapotranspiration and available water capacity (*awc*) of the uppermost meter of the soil profile. As proven by correlation coefficients, the accuracy of these HPTFs is generally high: e.g. in case of pastureland $r^2 = 0.93$ for all Arabic countries, $r^2 = 0.95$ for selected countries like Syria. Nomograms were developed for specific crops and varying soil properties, for specific crops and varying irrigation practices, and for specific locations and varying kinds of land use. Visualizations of such models are presented in Figure 1 and one exemplary regression equation is given. It has to be emphasized that all statistics and equations shown here are based on a limited database and represent preliminary results.

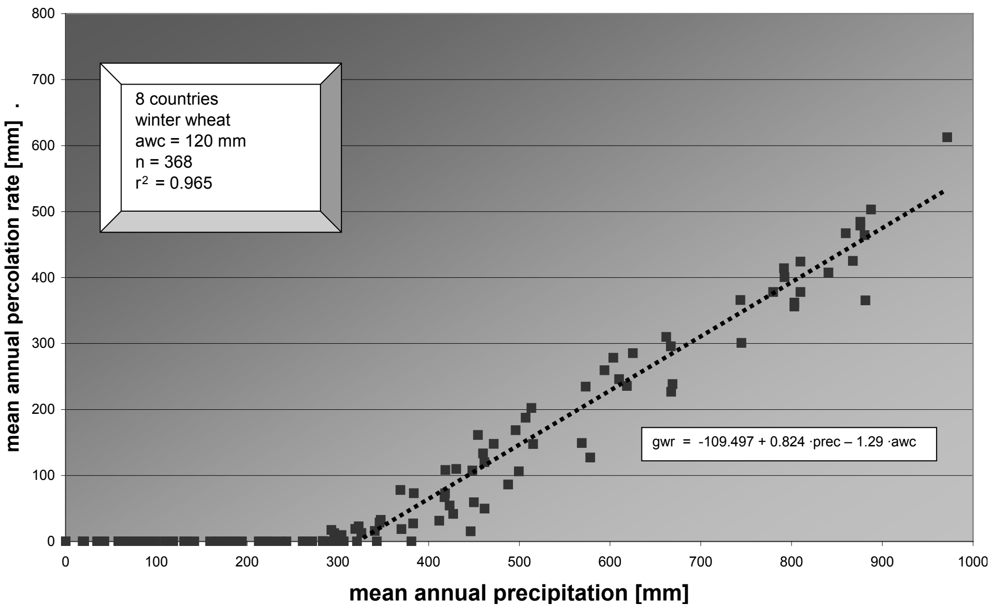

Figure 1. Annual percolation rate as a function of annual precipitation for land use type “winter wheat” and derived regression function.

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Abstract ID: 145

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

Hydrogeologic cartography offers diversified studies, due to the credibility of used data. It directly finds reflection in the accuracy and likelihood of estimation of the extent of groundwater bodies, their resources and reliability of hydrogeology mathematical model. The proper use of the information (or the lack of the information) leads to searching for ways to represent this kind of data in environmental researches.

The main study objective was to evaluate the probability that an unconfined aquifer may be found in each pixel location on the surface represented in the studied area. The probability value represents here, in same way, degree of knowledge (recognition) about aquifer system.

The research area covers 360 km^2 in the east part of the Pomeranian Lakeland in Poland (one sheet of map in a scale 1:50 000 no 0166 – Łąg). The geology of this area is predominantly composed of the Pleistocene postglacial sandur sediments. The shallow unconfined aquifer was taken into account in the study 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.

Data analyses were carried out in the Geographic Information System. The Dempster-Shafer probability theory supported by the module BELIEF of IDRISI software was applied to the algebra of pixel maps.

The resulting image showed a map of the aquifers' extents in a probabilistic scale i.e. in a range between 0 (the lack of the aquifer, which is confirmed by research) and 1 (confirms the occurrence of the aquifer proved by research). 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.

ACKNOWLEDGEMENTS

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Abstract ID: 195

DECISION SUPPORT SYSTEM FOR THE MULTI-OBJECTIVE OPTIMIZATION OF BANK FILTRATION SYSTEMS

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Keywords: bank filtration, well field operation, cost-benefit analysis, water quality

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 traveltime 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' bank filtration 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 and Boisserie-Lacroix, 2009). 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. maximisation of both, BF share and minimum traveltime) 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

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Abstract ID: 213

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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Keywords: protection, recharge, groundwater management, policy

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

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

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 for the coming years 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? A Decision Support System (DSS), based on computational models, renders assistance in this complex issue.

Within the framework of a technical cooperation project, ACSAD and BGR, supported by the SEI (Stockholm Environment Institute), have jointly worked on the development and dissemination of an easy to use and inexpensive DSS software for water resources management (Droubi et al., 2008). This DSS, as depicted in Fig. 1, mainly consists of two components: the water evaluation and planning software WEAP (developed by the SEI, Yates et al., 2005) and the 3-d groundwater flow model MODFLOW (U.S. Geol. Survey, Harbaugh et al., 2000).

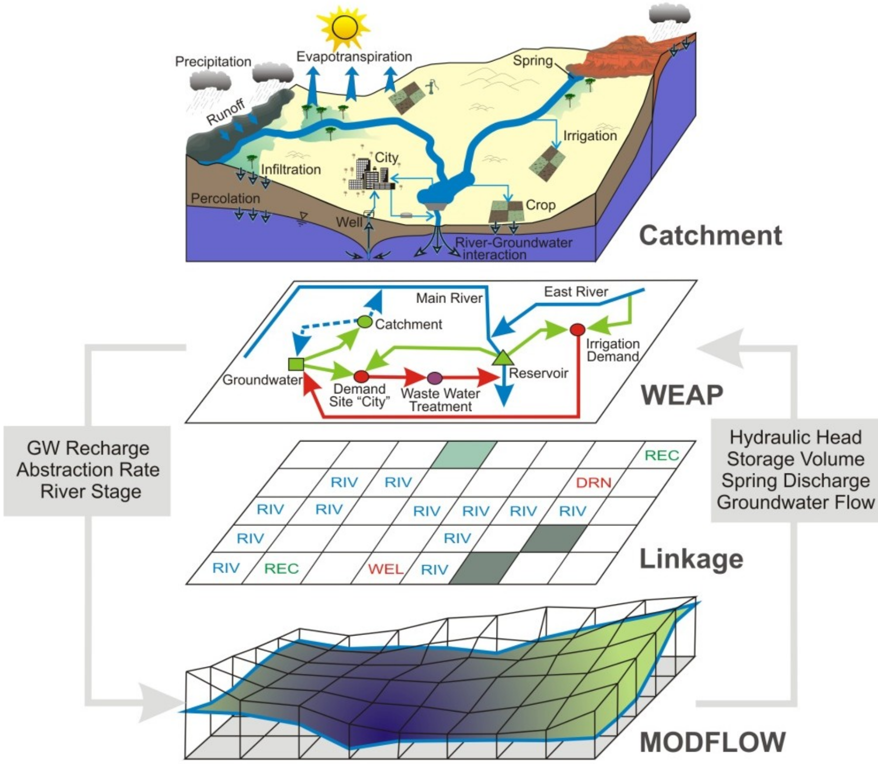

Figure 1. Schematical setup of the WEAP-MODFLOW DSS.

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. Thus, a dynamically linked model is obtained, which enables the simulation of river-groundwater interaction and spring discharge. Additionally, management constraints regarding the groundwater head or discharge can be considered.

The calibrated DSS provides the capacity to investigate, compare and evaluate various water management scenarios. Future constraints, as changes in demography, economy, climate, land use, 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. Present developments aim at the integration of a simple particle tracking model 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.

The WEAP-MODFLOW DSS has successfully been applied in pilot areas, e.g. the Zabadani-Basin in Syria. The strength of the DSS, especially considering the impacts of climate changes or variations in demand and supply on the water availability, has been proven. Due to its user friendly, inexpensive and efficient character, the DSS is already established in several institutions within the Arab region.

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Abstract ID: 242

FIELD TESTS FOR SUBSURFACE IRON REMOVAL AT A DAIRY FARM IN SAXONY, GERMANY

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Keywords: subsurface iron removal, decision tool

Iron and manganese are commonly present in anoxic groundwater worldwide. High iron concentrations are not harmful to human and animal health, but result in technical problems: clogging of production wells, precipitation and incrustation in the water supply distribution systems and orange/brown colour of drinking water. Thus, according to the drinking water guidelines in many countries the total iron concentration should be less than 0.2 mg/L. In dairy farms, where water is needed for the animals and for cleaning the facilities and technical equipment, low iron concentrations are also demanded.

Besides conventional iron removal using filters in a treatment unit above surface, low cost in-situ treatment for iron removal of groundwater can be used. As the cost of investment for in-situ iron removal is high, it is advisable to conduct a small-scale pilot experiment to determine the suitability of the aquifer for the application of this technique.

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 Saxony, Germany. There, the water supply is based on two groundwater abstraction wells. The thickness of the sandy aquifer is 10 to 14 m. 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. 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.
2. 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 well.
4. Using the second well for abstraction and the first well for infiltration of aerated/oxygenated water.

By adsorption in the reaction zone, it is also possible to remove arsenic, manganese and DOC. Limitations of subsurface iron removal are low pH, low hardness, high Fe(II), Mn(II) and ammonia concentrations.

In 2008, a mobile unit on a car trailer was developed for pilot tests to determine the applicability of subsurface iron removal. It contains an aeration unit, the possibility for 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.

At the field site, a tracer test to determine the dimension of the reaction room was conducted by measuring the electrical conductivity (EC) and dissolved oxygen concentration (O_2). The infiltration water containing 25 mg/L O_2 and a chloride tracer was injected in the production well. O_2 and EC were measured in the production well and in a groundwater observation well separated by a distance of 5 meters. The results (Fig. 1) show a breakthrough of the injected tracer in the monitoring well 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 the groundwater monitoring well after about 7 days and peaking at 22 mg/L by 8.5 days.

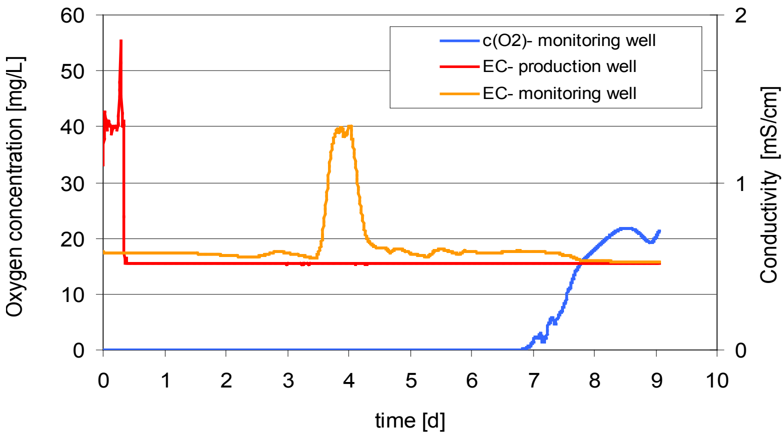

Figure 1. Oxygen concentration and electrical conductivity in the infiltration well and monitoring well.

After application of the subsurface iron removal technique, an iron concentration of less than 0.2 mg/L was achieved in the abstracted groundwater within one week. The results from the tracer test (Fig. 1) enabled the determination of the dimension 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 are used to choose the optimal subsurface iron removal treatment technique, especially to decide 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 demonstrate if subsurface iron removal can be applied at this site.

Abstract ID: 295

HYDROGEOLOGICAL DATABASE, A DECISION SUPPORT TOOL

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Keywords: hydrogeological database, GIS, barrier effect

Centro Internacional de Hidrología Subterránea Foundation (FCIHS) has developed a Hydrogeological Database (BDH) integrated with a geographical information system (GIS).

This relational database stores spatial-referenced hydro geological information as groundwater levels, hydrogeochemistry, hydrogeological parameters, balance terms, litological register of wells, geophysic sounding, numeric models results, etc. All the information has suffered a validation process with a methodology that has been generated specifically for this kind of data.

BDH has a main objective: to be a methodology instrument for FCIHS investigation and development projects. One example is to carry out a methodology to determinate a tolerance valour of barrier effect.

Starting point of this methodology is the study of the current pumping aquifer state with preexisting infrastructures. For each aquifer, the method defines two conditions: one of general measure (stablish unsaturated zone) and the other with specific considerations (presence or absence of waste filling, urban zones, water points or damp zones).

The result of all information layers incorporation by means of GIS is an integration cartography. This combination allows a infrastructure zoning to determinate the maximum variation of water table caused by barrier effect.

This methodology expects to be a easy support tool with a big range of applications in hydrogeological section writing of infrastructures projects (Fig. 1).

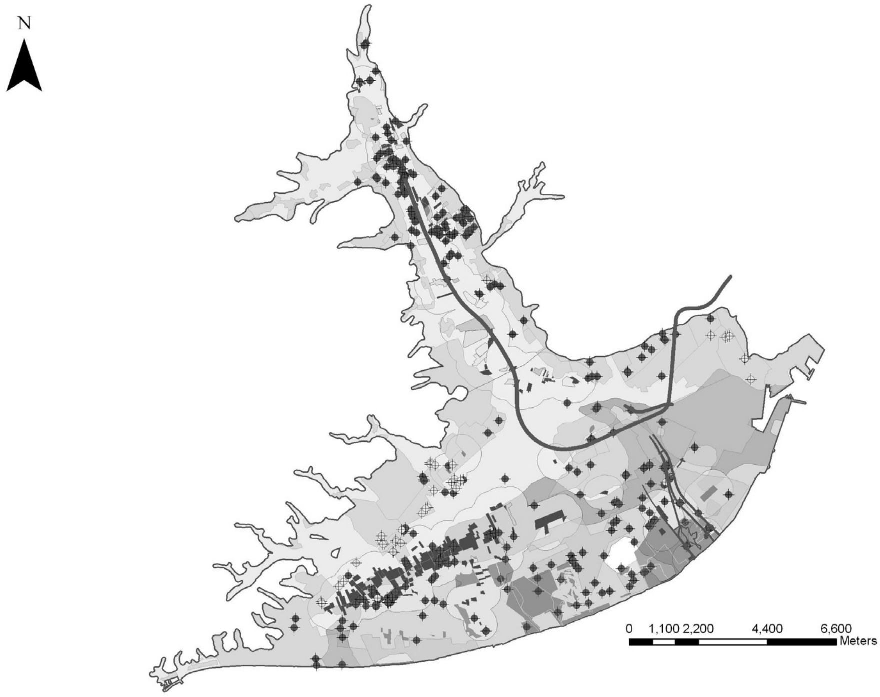

Figure 1. Integration of all information layers, general measures and specific considerations in Vall Baixa and Delta of Llobregat River (Barcelona, Spain) to obtain a tolerance valour of barrier effect in this area. Black continuous line indicates the position of the high velocity train across the aquifers.

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Abstract ID: 310

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

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

Extended over an area of 6000 km^2, the Haouz-Mejjate basin is part of a tectonic depression, filled by siliciclastic deposits (alluvial fans, fluviatile formations, etc.) of the Neogene and Quaternary. These sediments are brought from the High-Atlas mountains by several rivers crossing the basin from south to north. The plain of Haouz-Mejjate contains the city of Marrakech and a population of about 2.5 million of inhabitants. It holds important agricultural land, where citrus, vegetables, fruits, cereals, olives are produced. An important tourist activity is growing in Marrakech and its surroundings, receiving about 2 millions of tourists a year.

The water resources consist of groundwater mainly provided by the unconfined aquifer of the Haouz, and surface water of the rivers of the High-Atlas mountains. Additional surface water is transferred from the hydraulic basin of Oum Er Bia. The groundwater is exploited for irrigation by about twenty thousands of private wells, pumping about 300–400 Mm^3/year. In the early seventies, the net withdrawn volume was about 140 Mm^3/year, extracted mainly by a large network of Khettaras, which are now completely dry. Indeed, due to the conjunction of exploitation and drought impacts, the groundwater surface is lowered by a rhythm of 1 m/year to 3 m/year in the most exploited zones.

A Decision Support System (DSS) for integrated management of water resources in the Haouz-Mejjate plain is being developed. The DSS 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.

The DSS is composed of several tools. The ones being presently applied are:

- 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.
- 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 groundwater balance. Through a 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. Depending on the agricultural activities and the irrigation types, the study area is divided into land use sectors that constitute the basic units of water budget calculation.

Abstract ID: 438

POTENTIAL OF SEMANTIC WIKI TOOLS TO ORGANIZE INTERDISCIPLINARY IWRM APPROACHES

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Keywords: IWRM, decision support, knowledge management, Lower Jordan River Catchment

The presented work is part of the SMART-Project in the Lower Jordan Valley and aims at contributing an efficient knowledge management concept to the development of a transparent decision support system for sustainable water resources management in the Lower Jordan River Catchment.

Following the principles of 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. For this reason effective IWRM decison making requires an intensive knowledge management process. Unfortunatly this aspect is lacking adequate consideration in state of the art aproaches on IWRM-DSS, thus hampering the efficient selection of decision relevant information from the available knowledge pool and considerably amounts for the significant gap between scientific modelling and the actual planning practice.

This study focuses on the developement of a flexible knowledge-management framework for IWRM-related problem analysis and impact assessment in the Lower Jordan Valley.

In order to provide the necessary functionality, the SMART Knowledge Management Tool is based on a “Semantic Wiki System” and embedded in the framework of a decision support process. By combining the advantages of the popular Wiki approach with semantic web technologies the SMART Knowledge Management supports users to (1) easily gather, structure and edit available and newly generated IWRM knowledge, (2) establish meaningful links between related information elements, (3) detect and address critical knowledge gaps, (4) efficiently query for necessary and related information, and (5) to allow for flexible presentation of information according to the contents context. The implemented basic knowledge structure allows experts to model their domain knowledge within an interdisciplinary context and link information elements through an evolving network of cause-effect relationships and related background information, thus supporting the user during problem analysis and planning. This shall result in a highly flexible and adjustable, yet easy to use SMART Knowledge Management tool, which will contribute to make IWRM decision processes more informed, more transparent and more reusable. The paper explores the state of the art on IWRM decision support systems on one hand and the web-based, semantic wiki tools on the other hand.

A prototype of the SMART Knowledge System, which is still under lively development, is build for a side Wadi of the Jordan Valley, where management conflicts arise from insufficient waste water treatment and leakage, nitrate pollution of spring waters, groundwater overpumping and lacking groundwater protection zones. Within interdisciplinary discussions with partners from governmental agencies, research facilities and development coorporation institutions, the SMART Kowledge Base is structured and filled with content from project partners. A set of scenarios with different management options for the Wadi provides a use case for proving the functionality of the knowledge management concept within the decision support framework.

2 Groundwater and dependent ecosystems

2.1 Global climate change and water budget

Abstract ID: 157

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)

The High and the Middle Draa basins are located in the southeast of Morocco, it extends over a surface of 34.603 Km² and it is limited in the north by the south part of the High Atlas. The climate of Draa basin is arid to semi-arid; it is characterized by low precipitation ratio which decrease with the elevation and showing inter and intra annual variability. The evaporative power in the region knows a very remarkable increase caused by the degree of temperatures which can reach up to 56°C as maximal extreme value in Tagounite station.

Evapotranspiration is an important parameter of the water balance which influences the availability of water resources, particularly for agriculture and which constitute a very rarely measured factor. In the study region, 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 principal aims of this study are based on the detection of change in evaporation series via parametric and non parametric statistical tests, the correlation between the potential and lake evaporation variation, and the application of cross-correlation test between rainfall and evaporation time series.

The statistical analysis purposes are based on the detection of trend using the Mann Kendall non parametrical test, and the detection of Mean Magnitude change using cumulative deviation and Student's t-test. Trend and change in studied series was identified by estimation of significance level using bootstrap resampling technique which is a robust method particularly useful when the test assumptions are violated (1000 samples are required). The studied series comes from four stations located in the high Draa basin (Agouim, Ait Mouted, Iffre and Mansour-Eddahbi); and it concern the mean annual evaporation records measured on each station over a period of 25 years. The Mann Kendall test for trend showed a relative homogeneity of series with a presence of a significant downward trend for Ait Mouted and Agouim stations. The cumulative deviation test showed a

significant variation of mean tending to a decrease during the last twenty years. Generally, the student's t-test do not detect a major change in mean for the series during the studied period except for Agouim data station where the difference in mean between studied period is significant.

The comparison of the potential evaporation measured according to the Thornthwaite empirical method and the lake evaporation in the four stations shows a similarity in the curves evolution; therefore, the significant values were observed for June, July and August. The most important peaks are registered in July when the relative humidity presents the lowest values. The application of Mann Kendall test for lake and potential evapotranspiration data proves that the examined series accept the presence of trend at the significance level of 5% for all stations.

Precipitation and evaporation are the most parameter to diagnose the climate change and variation. The evaluation of the temporal evolution of precipitation and evaporation was identified by the cross correlation test; the data comes from 7 stations (Fig. 1) where the most are located in the high Draa basin. The evaporation data are measured according to Piche evaporometer. The mean annual cross correlation results show in Fig. 1; a negative values and values close to 0 which can be explaining by the fact that the evapotranspiration and precipitation data are independent or conversely proportional.

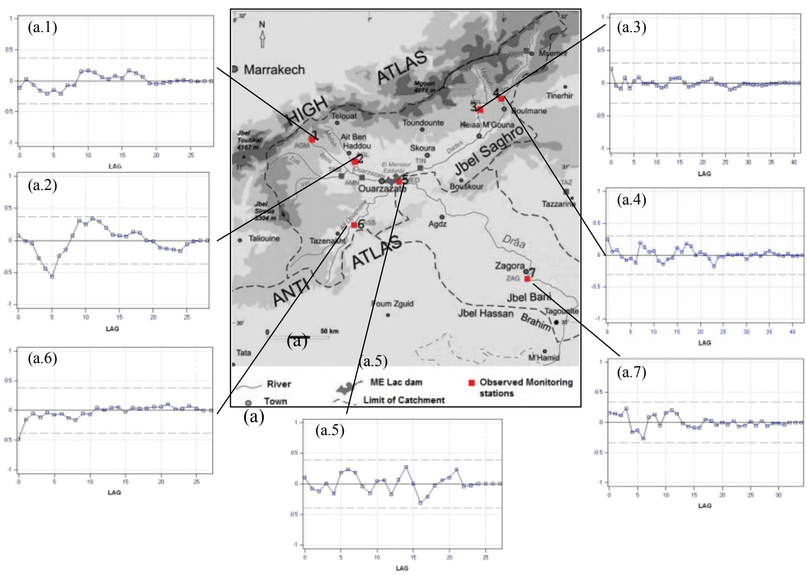

Figure 1. Mean annual cross correlation test of precipitation to evaporation time series: a) localisation of monitoring stations in high and middle Draa catchment. (a.1) Agouim station (a.2) Agouilal (a.3) Iffre (a.4) Ait Mouted (a.5) Mansour-Eddahbi (a.6) Assaka (a.7) Zagora.

Most water resources projects are designed and operated 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. In this current study, the statistical tests reveal the existence of 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.

Abstract ID: 366

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

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.

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Abstract ID: 381

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

The aim of this study was to estimate the impacts of anticipated global climate change on runoff in small-forested 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. To forecast hydrological patterns for the period 2071–2100, outputs from two general circulation models, HadAM3H and ECHAM4/OPYC3, were downscaled by an RCAO (regional climate model), which ran the SRES emission scenarios A2 and B2 for each model. Simulated RCAO atmospheric data for the control period (1961–1990, respective 1967–1990 in case of LYS and PLB) 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. Corrected RCAO daily outputs were used in combination with the hydrologic model Brook90. 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. For the calibration and validation of the model was used 13–16 years of runoff observation from the selected study sites. 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). These changes would have serious ecological consequences, since streams could regularly dry-up for short periods of time. 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.

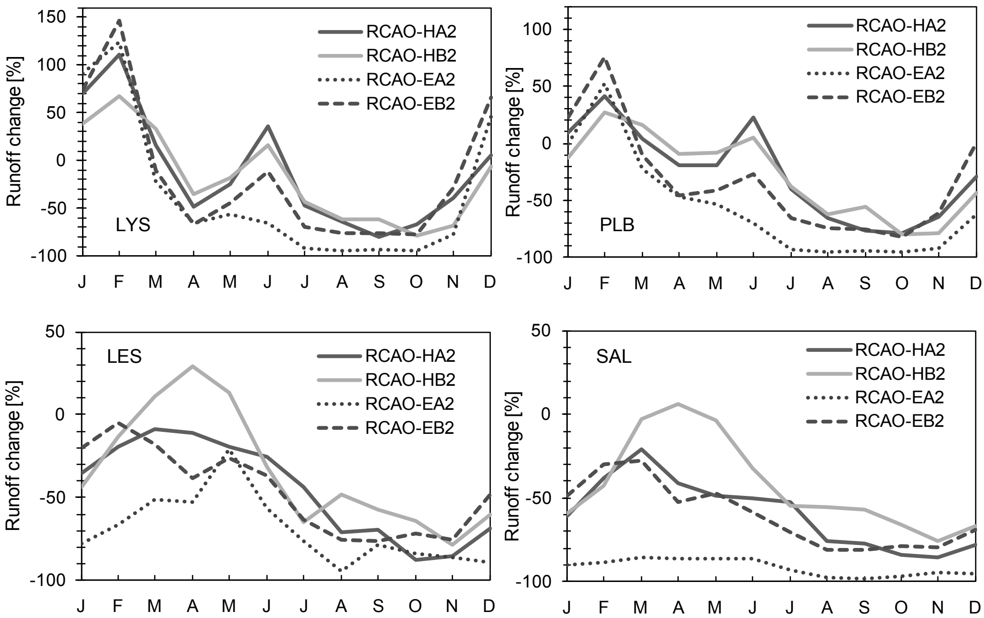

Figure 1. Mean annual cycle of runoff changes for Lysina (LYS), Pluhův Bor (PLB), Lesní potok (LES) and Salačova Lhota (SAL). Changes between runoff were calculated using observed data for the control period (1961–1990, respective 1961–1990 for LYS and PLB) and future runoff in 2071–2100 was simulated based on bias-corrected RCAO outputs (using the HadAM3H and ECHAM4/OPYC3 with SRES A2, B2 scenarios).

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Abstract ID: 465

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

LAND USE VS. CLIMATE CHANGE

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Keywords: groundwater, water supply, urbanisation, water cycle

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:

1. Ljubljana field, gravel aquifer that is the drinking water source and where urban land use prevail and
2. 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.

Abstract ID: 507

FACTORS AND DRIVING FORCES AFFECTING WATER WITHDRAWALS IN FUTURE

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Keywords: groundwater, water budget, emission scenarios, climate change

According to IPPC reports observed climate changes are caused by human activity. Changes are inevitable and will affect mainly next generations therefore it is necessary to undertake adaptive actions.

Since 2008 Institute of Meteorology and Water Management is carrying out research project KLIMAT "Impact of climate changes on environment, economy and society". Project is co-financed from European Union resources under the Programme Innovative Economy which is one of six national programmes under National Strategic Reference Framework. Objective of the project is to develop adaptation system of society, economy and environment to observed results of climate changes and to adjust laws to new environmental conditions. Those actions will be done for two time horizons: year 2030 and 2100. Project results will be used by polish strategic government departments. One of the project's task is sustainable water, geological and forest resources management.

In Poland after political transformation water use in all sectors has been decreasing. During the last decade in Poland relation between GDP and water use has been significantly limited which is very important in country not rich in freshwater. Like in many countries in Poland large part of water withdrawals to supply in drinking water depends on groundwater. In Poland in year 2008 over 68% of the water supply in drinking water depended on groundwater. The official national information about size of drawing groundwaters as well as using them through different sectors of national economy are published by the Central Statistical Office (GUS). The GUS's calculations show that groundwater consumption is diminished. What is more consumption of groundwater in 2006 was lower than 2000. According to the GUS's data consumption of groundwater both in large industrial areas and cities is diminished. But on the other hand drawing of groundwater outside these areas is higher. Main reasons of such situations are extension of water-supply systems, connecting new users to the water supply system and growth of demand for water agriculture needs. Many challenges result from requirements of two directives: 2000/60/EC establishing a framework for the Community action in the field of water policy (Water Framework Directive) and 2006/118/EC on the protection of groundwater against pollution and deterioration. These challenges depend on recovery of the costs of water services included costs of water and also predictions of results of the climate changes influence on water supplies. The available data show that cost of water for people and for industry are almost the same. There is no doubt the cost of water in our country will significantly increase.

The Intergovernmental Panel on Climate Change in 4th Assessment Report underlined scientific findings about key aspects of climate change. The SRES (Special Report on Emissions Scenarios) scenarios are classified in four groups (A1, A2, B1 and B2). These groups represent different, alternative development pathways taking into account driving forces as demography, economy, technology and resulting GHG emissions. The project conducted by IMGW covers the following combinations of scenarios: B1, A2, A1B. The most important challenge in that part of the project is to estimate possible pressures on water bodies resulting different development pathways and to combine them with suitable scenarios of water availability. Such estimation is possible only by prediction of key factors of water use based on estimation of trends and comparison with other high developed countries. Such predictions are important for water planners and managers.

Effective planning in water management should enable predicting some problems that may occur in this field, analysing alternative options of management and offering policies with precise activity providing an optimal usage of water resources. It should be emphasized that possible limiting water access in environment which is subject to climatic changes and anthropogenic activity pressure might determine the limit of social and economic development. Quantitative changes of sources also affect their quality. From the point view of the water planners necessary adaptation to the effects of climate change should be based on range of plausible scenarios of water use and availability resulting SRES scenarios. Scenarios undertaken in IMGW project will be use in tasks of the water component with special attention to the general strategy of protection surface and groundwater bodies.

Abstract ID: 519

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

Typical of the Mediterranean situation, the Merguellil catchment central Tunisia has undergone rapid hydrological changes over the last decades (Fig. 1). The most visible signs are a marked decrease in surface runoff in the upstream catchment and a complete change in the recharge processes of the Kairouan aquifer downstream. Fluctuations in rainfall have had a real but limited hydrological impact. Much more important are the consequences of human activities such as soil and water conservation works, small and large dams, pumping for irrigation. Several independent approaches were implemented: hydrodynamics, thermal surveys, geochemistry including isotopes. They helped to identify the different terms of the regional water balance and to characterize their changes over time. However, major uncertainties remain and our results may contradict previous interpretations or calculations.

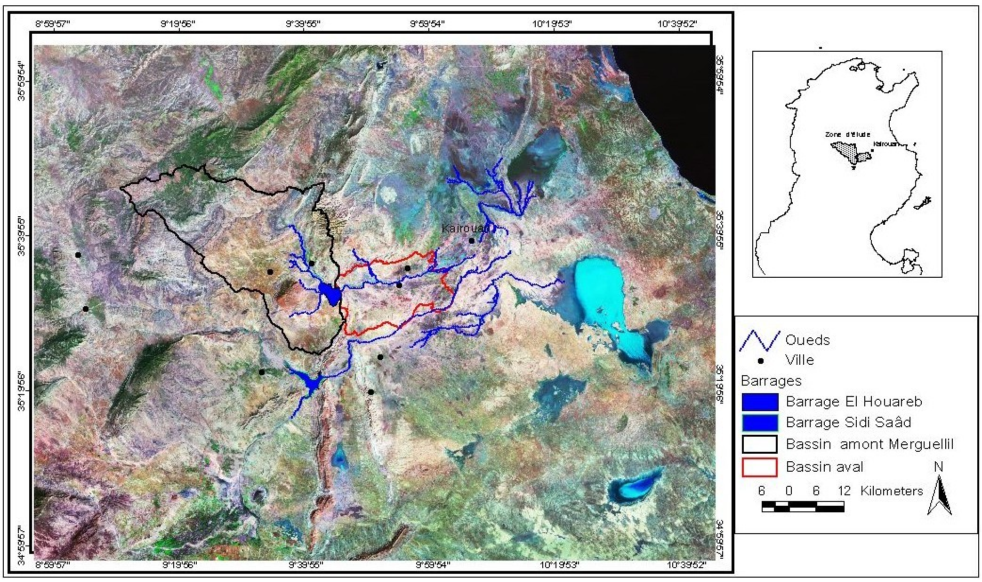

Figure 1. The Merguellil catchment basin localisation.

Conservation works, now covering more than a quarter of the upstream catchment, drastically reduce the runoff production from rainy events lower than 40 mm. Wadi Merguellil now ends in the big El Haouareb dam that loses more than half of its water by infiltration through karstic fissures, and 30% by evaporation, the rest being pumped or released. This dam was built in 1989 and has often dried up in the last decade.

The major modifications in groundwater flow resulting from construction of the dam are observed in the geochemical tracers in the first seven kilometres downstream from the dam. Thermal measurements confirmed the recent invasion of new water. The rest of the Kairouan plain aquifer retains the signature of older recharge but the whole aquifer is affected by the decrease in the water-table (about 1 m per year), the consequence of the ever increasing pumping for irrigation.

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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

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

1. INTRODUCTION

Area Lake Ciseupan a rest area sand mining activities and stones that run from 1980 to 1990. Mining activity is leaving the excavation site to reach 300 meters in diameter, surrounded by hills with a height between 690 to 720 meters above sea level (m a.s.l.). The lake water is utilized by the surrounding residential and industries. The volcanic aquifer consists of tuff and volcanic sand as part of Formasi Cibeureum, underlaid by impermeable breccias, and bordered by intrusion at the southern part.

2. METHODS

A finite difference modeling with Visual ModFlow is a powerful tools to identify the hydrodynamic interaction between surface water and groundwater around the lake. The total modeled area is 810,000 m^2 with dimensions of 900 m × 900 m. The modeling is based on geoelectric-resistivity measurement coupled with groundwater level observation and hydrochemical data.

3. RESULTS

The result shows that the groundwater flows westward with radial pattern and 0.05 hydraulic gradient. Based on the modeling 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 diversed 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 modeling 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.

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Abstract ID: 153

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

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

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 Júcar river basin, and encompasses parts from the provinces of Albacete, Cuenca and Valencia. MOS has some 300,000 inhabitants, with some 60% dwelling in Albacete city. Since the 80's, the exploitation of groundwater resource has become a key driver for the socioeconomic 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 Júcar Hydrological Plan, which is 320 Mm^3. The overexploitation has caused two major quantitative impacts, namely a steady drop in groundwater level and a reduction of MOS discharge to Júcar river (Sanz et al., 2009). The quantitative analysis made by Júcar 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.

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. 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. 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. 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.

ACKNOWLEDGEMENTS

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Abstract ID: 156

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.

Abstract ID: 165

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

River restoration has been identified as appropriate tool for achieving a good ecological status of a regulated stream, but the scientific understanding of the effects on groundwater quality and quantity are still limited. A key proxy for water quality used in the assessment of seepage rates and bank filtration is the travel time of the infiltrated river water during the passage through the subsurface. We analyzed time series of temperature and electrical conductivity (EC) in the river, the riverbed and adjacent groundwater observation wells to investigate travel times of young hyporheic groundwater in adjoining channelized and restored sections of River Thur in North-East Switzerland.

A wide range of methods and materials exist to estimate water fluxes between surface water and groundwater. Due to advances in sensor technique and data loggers, work on heat as a tracer in hydrological systems has increased recently, especially with focus on surface water–groundwater interaction. A new promising method is Distributed Temperature Sensing (DTS). DTS 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 high spatial resolution (1 m). For estimation of seepage rates we measured highly resolved vertical temperature profiles in the river bed. To this end, we wrapped an optical fiber around a piezometer tube and measured the temperature distribution along the fiber. 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). From the travel time and attenuation of the diurnal time signal, we estimated the apparent velocity and diffusivity of temperature propagation, which then can be used to quantify infiltration rates. A particular strength of the new measurement technique lies in the high spatial and temporal resolution, enabling us to detect non-uniformity and temporal changes in vertical water fluxes.

To quantify mixing ratios and mean residence times in the adjacent groundwater we performed cross-correlation analysis and non-parametric deconvolution of the EC time series. Diurnal oscillations of EC observed in the river and closest-by observation wells, facilitated analyzing temporal fluctuations of infiltration. We conclude that the lateral position and depth of the thalweg as well as the type of bank stabilization control the infiltration processes in unregulated pre-alpine rivers.

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Abstract ID: 212

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 (residual) 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:

1. 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.
2. 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. 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. 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

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

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Abstract ID: 253

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 over the role of surface water-groundwater interactions on the phreatic aquifer contamination by salt water.

In 2008 a preliminary surface water and top groundwater monitoring was performed and we could identify 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 deeper 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 deeper salty groundwater is allowed by the lowering of the groundwater head that falls below the sea level. Evaporation of the surface water in the Summer induces the precipitation of salt solid phases at the bottom of ponds and ditches. The rainwater, which recharges the surface water bodies in Autumn is contaminated by the salts deposited at the bottom and in the hyporeic zone of ditches and ponds during the Summer, therefore the infliltration water is already brackish before reaching the aquifer. The low hydraulic gradients and the scarcity of rainfall, which 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 more 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 also measured at the top and at 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.

Furthermore, in Summer 2009 we 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 in the proximity of these 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.

First results show that in observation wells located in the surroundings of ditches and ponds, the salinity of the top aquifer groundwater is higher than that measured at the bottom of the aquifer in contrast to what is commonly registered in coastal aquifers. Chloride concentrations gradients in the hyporeic zones of the surface water bodies also decreases with depth.

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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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

1. 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.

2. AN INNOVATIVE EXPERIMENTAL DESIGN

The experiment (Fig. 1) 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 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.

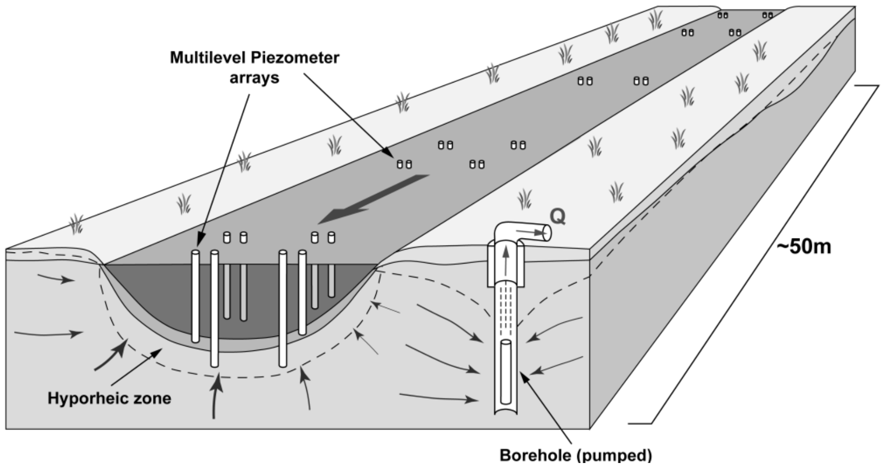

Figure 1. Schematic view of the experimental design.

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.

3. RESULTS AND INTERPRETATION THROUGH A 3D HYDROGEOLOGICAL MODEL

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. 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

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

1. INTRODUCTION

Groundwater and surface water are connected and form one single precious resource. Sustainable water management requires detailed knowledge of exchange flow direction and magnitude. The use of heat as a tracer promises to be an excellent alternative to traditional exchange assessment methods. Streambed boundary cross flow has been shown to vary greatly on a temporal and spatial scale (Schmidt et al., 2006; Schmidt et al., 2007; Keery et al., 2007; Essaid et al., 2008). Analytical solutions to the 1D reduced conductive convective heat flow equation have been developed (Stallmann, 1965; Silliman et al., 1995; Hatch et al., 2006; Keery et al., 2007). In particular, the Hatch method is based on the analysis of temperature time series recorded at two depths in the streambed. Vertical flow velocity distinctly impacts on thermal response at these points, such as amplitude damping and shift of phase (Hatch et al., 2006). Testing of this method under realistic field conditions has provided interesting results that exhibit unresolved artefacts like dynamic fluctuations over time and large deviation between amplitude and phase derived velocities (Rau et al., in revision). Theoretically, deviations can be caused by natural parameter variability in the field potentially introducing non-uniqueness. However, the reduced method dimensionality is the most important limitation to be considered in field applications as streambed flow is a truly complex multi-dimensional flow phenomenon (Lautz, in press; Rau et al., in revision).

2. METHODOLOGY

Analytical and numerical simulations were performed in order to clarify the impact of variability and non-ideal field conditions. The study focuses on three major points: 1) variability of sediment properties, 2) multidimensional flow and anisotropic heat propagation caused by thermal dispersivity, and 3) spacing between two points of temperature measurement. For 1, amplitude and phase shifts dependent on a range of velocities were calculated and 75% and 90% confidence intervals re-interpreted using Monte Carlo analysis with variation of sediment density, specific heat capacity, thermal conductivity and dispersivity as found in literature. For 2, a vertical model domain using VS2DH (Healy, 1996) representing a 2D slice of streambed was set up. Temperature boundary conditions were: diel sinusoidal temperature change at the top and constant temperature at the both sides as well as the bottom. Flow boundary conditions were: constant downward flow and ten different steps of horizontal flow (expressed as ratio of horizontal and vertical velocity component V_h/V_z between 0 and 2) for different model runs. 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 Hatch method.

3. RESULTS

Monte Carlo analyses using the analytical models illustrates that variability in specific heat capacity of the sediment impacts on calculated vertical streambed flow with less than 10%. The major impact by variation in thermal properties is caused to amplitude ratio by thermal conductivity and dispersivity in particular for upwards flow. The distortion proves to be a function of velocity which introduces non-uniqueness to the interpretation. The directional dependence of thermal transport (thermal dispersivity) strongly alters the phase derived velocity results dependent on the horizontal flow component (Lautz, in press). In comparison, the amplitude derived results vary less when the direction of flow changes and do not show much dependence on measurement spacing. Variations in results are also a function of measurement spacing.

4. CONCLUSION

The outcome of this investigation highlights that caution must be applied when analytical methods are used to interpret temperature field results. Although knowledge about sediment thermal properties prior to velocity calculation is helpful, it does not play an important role for systems with downward flow because there is 90% confidence in deviations of less than 20%. For upward flow, thermal dispersivity has a large impact thus must correctly be estimated. The numerical model suggests that deviations between amplitude and phase derived velocities are an indication that horizontal flow is present in the streambed. In this case vertical flow is generally overestimated. Applying the Hatch method can help enhance understanding of streambed water exchange by offering a robust estimate of vertical streambed flow as well as the potential to detect horizontal flow components.

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Abstract ID: 291

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

Longwall mining may impact surface water and groundwater as a consequence of mining-induced subsidence, which includes the vertical and horizontal deformations and displacement of the ground mass. As a result of fracturing streambeds and rockbars, surface flow is diverted to subsurface routes and surface water-groundwater connectivity is enhanced. The interaction between surface water and groundwater can occur laterally and longitudinally to a stream. Several types of interactions are possible based on the extent of fracturing in the aquifer; from a single recharge-discharge zone to multiple recharge-discharge zones.

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, New South Wales, 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).

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.

A reduction in streamflow may not only be the result of fracturing streambeds and rockbars in the main stream overlying an active longwall mine; mining-induced fracturing can extend across the catchment and its tributaries, generally bounded by the limit of subsidence. Increased fracturing allows rainfall to infiltrate and recharge fractured aquifers, reducing runoff available for recharging streams. Although rainfall recharge to the shallow aquifers can increase, groundwater levels can also decline due to the mining-induced fracturing of the rock mass, causing the dewatering of shallow aquifers and reducing baseflow discharge. Fracturing of the banks of streams and tributaries can also reduce streamflow during high flow conditions. Streamflow reduction is also 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 the streams.

Prior to mining the streams in this area were usually connected-gaining, with groundwater level above the lowest streambed elevation. However, shallow piezometers located near the stream close to the edges of already mined longwall panels indicate that shallow groundwater close to the stream is affected by subsidence, causing the majority of groundwater levels to be below the streambed, causing the stream to be disconnected-losing with the diversion of surface water into subsurface voids. It is expected that lateral flow dominates natural rainfall recharge of the aquifer, whereas longitudinal flow is expected to dominate subsurface flow. Fractures, joints and bedding planes still provide pathways for subsurface flow, however the openings are smaller than they would be above the active mining panel. There is usually surface flow in the stream at this location, however surface flow also recharges the subsurface system with a relatively fast infiltration rate, indicating a high hydraulic conductivity of the aquifer. In an area where the compressional phase of subsidence is present fractures are partially re-closed and there is limited vertical and horizontal extension of fractures and bedding planes, the groundwater level has partially recovered and groundwater discharges through via vertical fractures under pressure often in streambeds (Jankowski et al., 2008).

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Abstract ID: 292

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

Hydrochemical data from the Waratah Rivulet a small stream in the Southern Coalfield, New South Wales, Australia, shows significant changes in water chemistry and quality along the rivulet. Surface water flowing through the mining-induced subsidence area and downstream of longwall panels has a much higher EC, pH and concentration of major, minor and trace elements, and significantly lower Eh and dissolved oxygen content compared to surface water flowing in a pristine environment (upstream of longwall panels, tributary stream, pre-mining data). The surface water chemistry in the rivulet shows significant changes in concentration over the 2 km length of the sampled streambed. The salinity of surface water upstream of the subsidence area is low, with EC values ranging between 200 and 280 μS/cm. The salinity increases along the rivulet as more water re-emerges from the subsurface, with concentrations between 260 and 340 μS/cm.

Assessment of chemical data shows that concentrations of major, minor and trace elements are higher in groundwater than in surface water. Also higher concentrations are present when fracture networks are well developed. The EC of groundwater in the impacted area varies between 400 and 700 μS/cm, and the pH of groundwater varies from acidic where metal-sulfur minerals are abundant, to slightly alkaline where carbonate minerals are more abundant in the rock mass. Ca, Na, HCO_3 and Cl are the dominant ions in the groundwater system. The higher concentrations are related to well developed fracture networks and exposure of more rock strata to water-rock interaction, which causes the dissolution of carbonates, reductive dissolution of oxides and hydroxides, and oxidation of metal-sulfur minerals. These processes mobilise Ca, HCO_3, Fe, Mn, Ba, Sr and S (SO_4) from the rock mass. The pH upstream is slightly acidic, with a range of 6.5 to 7.1, increasing to pH 7.7 where subsurface water dominates surface flow. 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, indicating high rates of dissolution reactions of soluble minerals during water-rock interaction. Elevated concentrations of Fe and Mn in surface water flowing through areas not impacted by mining are caused by baseflow discharge. Dominant minor elements in surface water that are mobilised during subsurface flow in the mining impacted area are Fe, Mn, Sr and Ba.

The increase in salinity, ion and metal concentrations are related to subsidence-induced fracturing streambed, which increases the exposure of fresh rock to inflowing surface water. Where subsur-

face cracks and new fracture networks allow surface water to mix with flowing groundwater, the resulting mixture may enhance chemical reactions during water-rock interaction. 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 surface cracking to surface water.

Chemical reactions increase the concentration of Ca, Na, Mg, HCO_3, Cl and SO_4 in water discharging from subsurface routes to the surface. The pH and HCO_3 increase due to chemical reactions involving carbonate minerals calcite, siderite, rhodochrosite, strontianite and barite, which are the most abundant carbonates present in the aquifer matrix. The presence of metal carbonates in the rock mass causes iron, manganese, strontium and barium to be mobilised, significantly increasing the concentration 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 to 6 and surface run-off infiltrate the subsurface system and mobilise metals from carbonate minerals.

Concentrations of iron and manganese initially rise in surface flow as groundwater discharges from the subsurface. However, a few hundred metres downstream dissolved metal concentrations decrease as Fe and Mn oxides and hydroxides are precipitated, causing yellowish through orange/red to brownish stains on the streambed. 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. Barium and strontium remain in solution and act as natural tracers that can be used to locate discharge points where groundwater re-emerges to the rivulet. Both elements are present only in the rock matrix, unless they are mobilised during subsurface flow. Oxidation of traces of pyrite (FeS_2) during subsurface flow increases the concentration of iron and sulfate.

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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.

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.

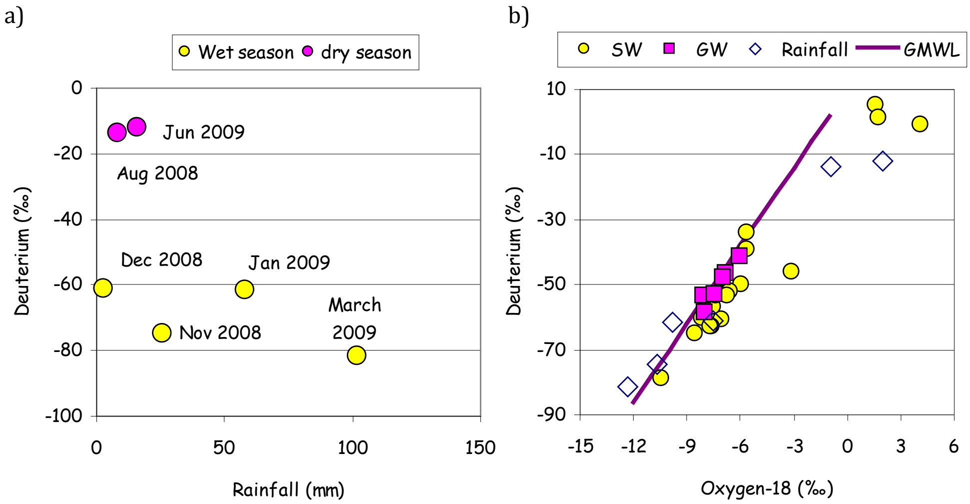

Figure 1. a) Deuterium concentrations versus amount of rainfall in the study area; b) Stable isotope concentrations in groundwater, surface water and rainfall. GMWL is plotted for comparison.

ACKOWLEDGMENTS

We thank Dr Grzegorz Skrzypek from West Australian Biogeochemistry Centre (John de Later Centre), The University of Western Australia for measurements of δ^2H and $\delta^{18}O$.

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Abstract ID: 320

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

Groundwater resource management is increasingly moving towards a conjunctive approach. For this to be successful the interaction 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 considering the surface groundwater interaction. 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.

A thermal approach using arrays of temperature loggers was employed to investigate the river-aquifer interactions. Six arrays each consisting of three loggers mounted in a PVC pipe was installed vertically into the streambed with loggers located 0, 15 and 30 cm below the streambed. Initially 6 arrays were deployed in a single pool within the Namoi River to investigate spatial variability within a pool (November 2007 to April 2008), and subsequently in several pools over approximately 1 km stretch of the river (April 2008 to July 2009). The loggers were set to record every 15 mins. In addition, a pressure transducer was also installed to log the river stage every 15 mins. Seepage velocities were calculated on the basis of the 1D convection-conduction heat transport differential equation for fully saturated conditions. From this equation, two values of vertical seepage can be independently calculated by comparing the diurnal amplitude damping and phase shift of temperature time series recorded at different depths. Data processing and computations were done using Matlab scripting routines.

The measured temperature time series showed strong diurnal heat patterns as well as longer-term heat trends and noise. The data was filtered to isolate the diurnal variations. The resulting time series revealed a damping of amplitude and shift of phase with depth at each location. The amplitude ratio and phase shift for the upper and lower loggers were used to compute seepage velocities based on the analytical solution.

At all locations the computed long-term seepage velocities were approximately 0.1 to 0.6 m/day downwards, indicating losing river conditions. In the single pool investigation there was no apparent spatial variability in seepage rates. This was somewhat surprising as it was anticipated that the heterogeneity of the streambed as well as potential upstream in-flow and downstream out-flow 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. The seepage velocities derived from the phase shifts were consistently greater than those calculated from the amplitude ratios. This is possibly due to heterogeneity and/or violation of the 1D flow assumption (Rau et al., in revision). Regardless of this discrepancy, both sets of results showed the same overall patterns.

The time series of calculated velocities revealed a number of interesting features. Firstly, there was an increase in seepage velocity during river flood events, demonstrating a relationship between river stage and river loss. Secondly, seepage rates were constant for long periods but changed irreversibly at flood events. It is hypothesised that this irreversible change is due to scouring of the streambed. The removal of potential colmation layers would then cause an increase in streambed hydraulic conductivity and therefore seepage velocity. Thirdly, for short periods of times, following flow events in the river, upwards seepage was observed. This was presumed to reflect a return of bank-storage to the river.

This study demonstrated how surface water groundwater interactions can be understood and quantified using thermal investigations. The use of temperature arrays, in combination with a pressure transducer, proved to be a useful way of quantifying this important hydrological process. 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 of the catchment, leading ultimately to improved management of the water resource.

Abstract ID: 407

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).

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Abstract ID: 429

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

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Abstract ID: 430

THREATS TO A COASTAL AQUIFER IN NORTHERN ALBANIA

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Keywords: coastal, intrusion, heavy metals, recharge, isotopes

INTRODUCTION

There are multiple threats to coastal aquifers, they are often densely populated, providing good agricultural land, factors leading to high demand for water and a risk of sea water intrusion. In the future, climate change with an increasing sea water level is another risk. Moderate gradients for flow and a slow turnover of the water may mirror past sea level changes in the groundwater composition (Haile et al., 2007). The aim of the study was to identify threats to a coastal aquifer comprising sea water intrusion and Cu and Cr pollution from mining activities in the catchment.

SITE AND METHODS

The Mat river has formed a coastal plain in northern Albania about 30 km long and 20 km wide. At the entrance of the river into the plain there is an alluvial cone in contact with underlying sand and gravel beds. Towards the sea gravel and sand beds are intercalated by clay beds and a clay layer of about 15–20 m thickness covers the outer portion of the plain.

Sampling of groundwater was done on four occasions covering the seasons. Filtering (0.2 μm) and pH measurement was done on site. Cations and trace metals were analysed by ICP-OES and anions by ion chromatography. 6 samples were taken for ^{14}C-analysis, 6 samples for $\delta^{18}O$ analysis and 10 samples for $\delta^{34}S$.

RESULTS AND DISCUSSION

The groundwater close to the coast had elevated chloride contents up to about 1000 mg/l. These groundwaters were found to have ages between 2000 and 7000 years (Fig. 1). Wells close to the coast were artesian. The high ages of the more mineralized groundwater is likely to date back to the Flandrian transgression. The highest level of the Flandrian transgression was close to the inner part of the plain (Fouache, 2006). ^{18}O analyses indicated that the elevated chloride concentrations were not due to mixing in of sea water as the chloride concentrations were not followed by heavier water but rather due to diffusion from the intercalated clay beds (Fig. 2). To differentiate between groundwater drawn from the sea side and that formed by recharge in the alluvial cone sulphur isotopes could be used. The $\delta^{34}S$ turned out to make up two clusters, one in the more mineralized groundwater with $\delta^{34}S$ values around 21‰ similar to that of sea water while the fresh water in the inner portion of the plain and in the well-fields had $\delta^{34}S$ of 4–5‰, a mix of sulphide sulphur from the mining activities and wind born sulphate from the Adriatic sea. The sediments in the river bed had elevated concentrations of Cu and Cr. A high and stabile river pH due to the presence of limestone and ophiolitic rocks, the latter hosting the orebodies, in the catchment provide good adsorption of the metals.

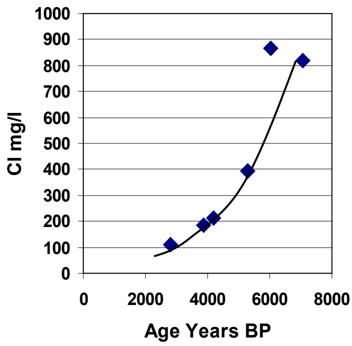

Figure 1. ^{14}C age versus chloride in groundwater.

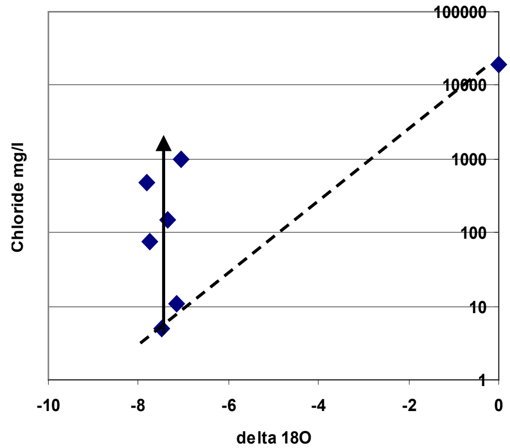

Figure 2. $\delta^{18}O$ versus chloride in groundwater. The hatched line is the mixing line.

CONCLUSIONS

The risk for sea water intrusion is currently small as wells close to the seaside were artesian. The $\delta^{34}S$ values indicate that more or less all groundwater in the aquifers come from recharge in the alluvial cone. There is little risk for Cu and Cr pollution of the groundwater. However, extraction of sand and gravel in the alluvial cone represents a threat as it will decrease the pressure head and could clog the sand as well as cause oil spills from the digging machinery.

ACKNOWLEDGEMENTS

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Abstract ID: 446

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.

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Abstract ID: 451

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

Natural rivers, including their riparian zones, belong to the most diverse, dynamic, and complex ecosystems on the world's continents, and they play key roles in the regulation and maintenance of biodiversity in the landscape (Dynesius, Nilsson, 1994). Hydropower has a major macro-economic impact since it supplies more than 50% of national electricity production in 65 countries (Koch, 2002). Today about two-thirds of the fresh water flowing to the oceans is obstructed by approximately 40,000 large dams and more than 900,000 smaller ones (Petts, 1984; McCully, 1996). Hydropower regulation of river bodies was for a long time considered to be an environmentally friendly source of energy (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).

A comparison between one regulated and one pristine river with similar features, both located in Northern Sweden, has been conducted (Collomp, 2001). The Luleå River comprises 15 reservoirs and has been regulated for almost a century (72% of the annual river runoff can be stored in its reservoirs) (Dynesius, Nilsson, 1994). The Kalix River, the last major unregulated river in Europe, is used as a reference for geochemical conditions in a pristine river.

Water storage in reservoirs affects seasonal water discharge, water temperature, conductivity and concentrations of nutrients, dissolved oxygen, organic matter and metals. Spring peaks are truncated and postponed and average base flow is higher than that under pristine conditions. Due to increased sedimentation in the reservoirs, the transport of Fe, Si, Al, Mn, DOC, P and N has decreased (Drugge, 2003). Retention of nutrients leads to eutrophication of reservoirs, creating favorable conditions for certain aquatic biota.

The aim of the outlined study is to increase knowledge regarding the effect of river regulation on riparian groundwater geochemistry by:

- analysing river water measurements with respect to river-groundwater exchange;
- measuring riparian groundwater quality at one site in each of the two rivers.

In both rivers, sampling sites were chosen approximately 100 km upstream of the river mouth. The geological settings and climatic conditions are similar in the two chosen areas, with precipitation rates of about 400 mm/year. In the regulated Luleå River, frequent water level fluctuations cause continuous mixing of river water and groundwater. Land use in both areas is equally non-intensive, and hydropower exploitation of the Luleå River is the only notable difference in land use in the two areas.

The monitoring program at each site includes installation of 2–3 groundwater wells, with data loggers continuously recording groundwater levels, temperature, pH, conductivity, DO and ORP. Water samples will be taken weekly or bi-weekly for metal and nutrient analyses, and the hydraulic conductivities at the sites will be determined in soil samples.

Expected outcome: Improved knowledge regarding river regulation impact on riparian groundwater, based on comparison of a one-year cycle of seasonal variations in groundwater flow and quality in a heavily regulated and a nearby pristine river.

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Abstract ID: 458

THE PISTON MODEL OF GROUNDWATER RECHARGE

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Keywords: infiltration, piston model, vadose zone

INTRODUCTION

Surface–groundwater interaction is usually described by a discrete model of flow in an aeration zone. The most popular model is one-dimensional and it is complicated by the spatial distribution of parameters and requirement of large number of data on infiltrating stream. When one is interested more in general groundwater movement than in infiltration itself it seems reasonable to look for a model which supply only a couple of the most important data but is simpler in use. Here is a place for the piston model of infiltration capable to describe a fully unsteady process.

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 two variables describing the water movement — the position of the front z_f and the 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 water front there is only the initial water content θ_o. Water content above each water front remains stable while front position changes continuously. 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. Continuity of recharge for the lowest wetting front was reconstructed according to the author's model.

PROFILE OF SOIL WATER CONTENT

Groundwater recharge is limited by soil permeability and present position of a wetting front. When precipitation exceeds soil infiltration capacity, soil becomes fully saturated. For less intensive rainfall a hydraulic gradient is equal to 1 and water content is determined as assuring infiltration equal to recharge. Hence, every increase of rainfall intensity causes appearance of a new wetting front while decrease results in a negative front budget and gradual decrease of water content until the balance is reached again.

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 (Fig. 1).

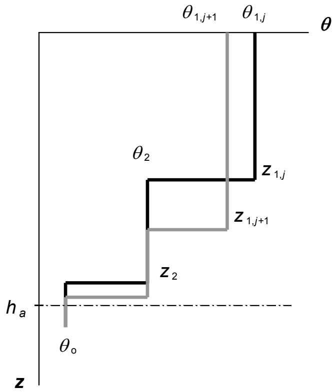

Figure 1. Water budget for two wetting fronts.

CONCLUSIONS FOR GROUNDWATER RECHARGE

Groundwater recharge is connected to accretion of a wetting front on the upper edge of a capillary fringe. Such approach enables to avoid complex calculations of a 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. This enables also to consider easily fuzziness of a wetting front and to achieve continuity of recharge variation. The presented model is a useful tool enabling to determine in an easy way time-dependant groundwater recharge for many soil profiles (Fig. 2). Good model results make the model recommendable for simulation of groundwater flow.

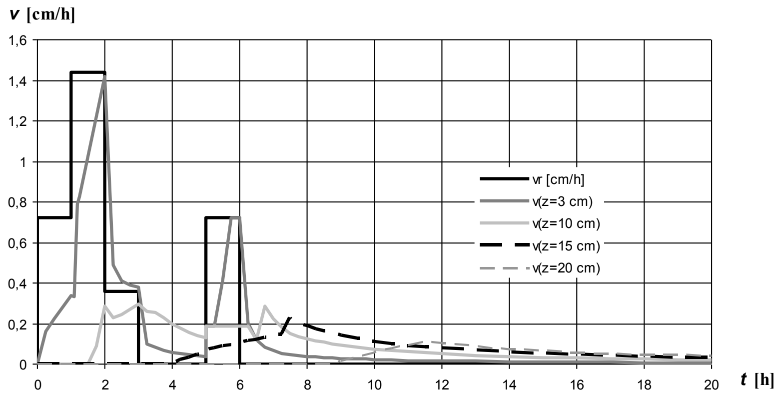

Figure 2. Unsteady infiltration.

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Abstract ID: 469

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

Aquifers of the Santa Coloma River Basin, a range-and-basin are of about 320 km^2 at the NE of Spain has been the objective of several studies, among others, from the Catalan Agency of Water (the Agency) with the aim to assess groundwater resources management and meet environmental goals. A complex geological context, a non well-known hydrogeological behaviour, uncontrolled pumping rates and uncertain aquifer-river interaction explain significant discrepancies among the studies carried out: some of them foresaw depletion of groundwater resources due to overexploitation. However, these resources have a strategic importance regarding the domestic and industrial supply since towns in the basin do not have external water supply.

Recently, the Agency, in collaboration with other institutions, has concluded a study in order to build-up a more robust conceptual model that clarifies former differing hypothesis about this hydrogeological system and yields a realistic water balance suitable for management purposes. The study has just focused in the sedimentary aquifer formations up to 30 m depth, and underlying granitic and tertiary sedimentary formations (Fig. 1). For almost one year, two survey campaigns, that included continuous head and temperature data acquisition, were carried out to define the hydrological boundaries of the alluvial aquifer and the hydrogeological role of the underlying formations. Afterwards, a groundwater flow numerical model has been developed to investigate flow relationships between these hydrogeological units and the river-connected alluvial, as well as estimating flow rates. The model was implemented using the Visual Modflow 4.3 platform.

The results of the simulations have showed head distribution maps that are consistent with the conceptual model and water balance, with 0.03% error. Nevertheless, the yearly variations on heads have indicated the rainfall recharge is meaningful, therefore the system is not in equilibrium. The most important outflow is linked to perennial and non perennial streams and not with pumping rates, although locally they may have impact especially in discharge stream flows in summer. Besides, the model has also allowed to check out and quantify the contribution of lateral and/or deep flows that were necessary to fit the observed groundwater heads and stream discharge flows. Finally, the river-aquifer interaction and water balance are not only related with the quaternary alluvial formation but also with the hydrogeological role of surrounding neogene formations.

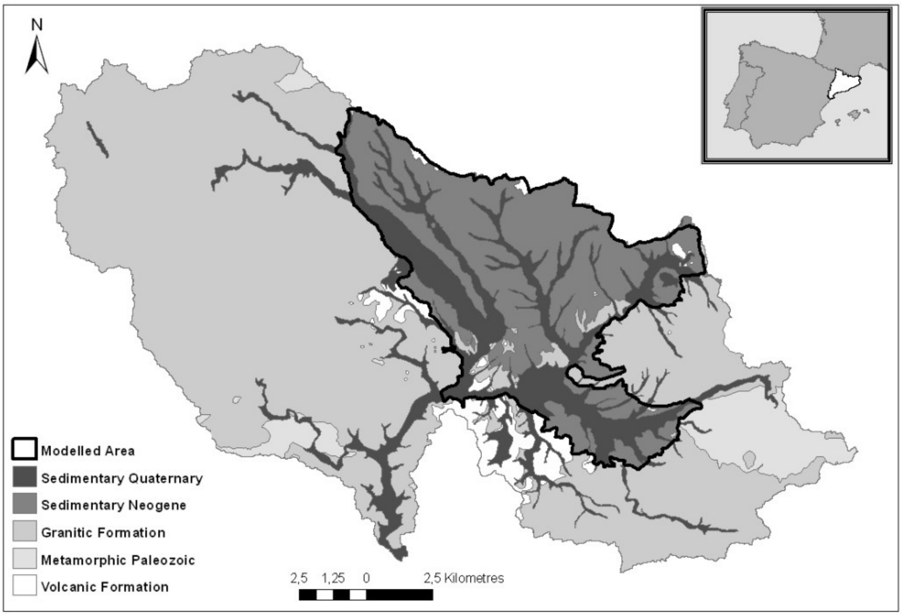

Figure 1. Aquifers of the Santa Coloma river basin with the modelled area.

In conclusion, this study demonstrates that the superficial aquifers of the Santa Coloma river basin are not overexploited at all, and that the main challenge of the basin is how to manage water withdrawal to minimize the impact on rivers and streams. Quantitative estimations point out the importance of the streams flows in the water balance, which have to be considered for the determination of minimum ecological flows in the main river and streams and especially, for the integrated water resources management plans in the area.

Abstract ID: 483

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.

2.4 Water in extreme conditions (arid and polar regions)

Abstract ID: 130

CRYOPEGS OF THE YAKUTIAN DIAMOND–BEARING PROVINCE (RUSSIA)

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Keywords: cryopegs, permafrost, hydrogeochemistry, isotopes

The Yakutian diamond-bearing province is located in the northern part of the Siberian platform. The province, with a total area of 840,000 km^2, is unique in view of the extreme cooling of the geological section. It is characterized by continuous permafrost, low mean annual rock temperatures (–2.9…–8.8°C), high rock thermal conductivity (2.2–4.1 W/(m °K) and lowest (0.021–0.027 W/m^2) intensity of heat flow.

Cryopegs (intrapermafrost and subpermafrost negative-temperature saline waters and brines) as a major component of cryolithosphere circulate in the cooled Cambrian sedimentary rock and Late Devonian-Early Carboniferous Kimberlite pipes, forming aquifers regionally distributed. The interaction between permafrost 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). Thus, the total thickness of cryogenic ground reaches up to 1450 m.

The origin of cryopegs is one of great scientific interest. This study helps in understanding of cryopegs formation and accordingly will be useful in diamond exploration and drainage brines disposal. The water samples (more than 500) collected from the Yakutian diamond-bearing province were examined and divided on three different groups (Fig. 1).

Group A samples are Cl-Mg-Ca groundwaters. They pumped from depths 600 to 1450 m and are characterized by TDS 224 000–404 000 mg/L. Cryopeg's temperatures vary from –2.6 to –1.0°C. The δ^2H versus δ^{18}O values of this group of samples range between –73.3‰ and –67.7‰; and between –8.2‰ and –2.43‰, respectively. The δ^{37}Cl and δ^{81}Br values range between –0.4‰ and –0.2‰; and between –0.07‰ and +0.24‰, respectively. Based on their chemical composition and isotopic signatures, it is postulated that they are residual brines of evaporated paleoseawaters (Alexeev, Alexeeva, 2003; Shouakar-Stash et al., 2007).

Group B samples are not characterized as one primary water type. However the majority of these groundwaters have Cl–Ca–Mg composition. Samples are from various depths ranging from 110 to 650 m and are characterized by TDS values between 31 000 mg/L and 252 000 mg/L. Cryopeg's temperatures vary from –4.0 to –3.0°C. The δ^2H and δ^{18}O of *group B* range between –139.6‰ and –95.9‰; and between –16.5‰ and –10.2‰, respectively. The δ^{37}Cl and δ^{81}Br values of these samples range between –0.4‰ and +0.52‰; and between –0.8‰ and +0.73‰, respectively. The chemical compositions and isotopic signatures of these groundwaters showed differences so that data interpretation could not lead to a definite brine source. However, the available data suggest that groundwaters were modified greatly via a number of scenarios; geochemical evolutionary processes such as permafrost freezing, mixing, dilution, leaching of salt and water-rock interaction.

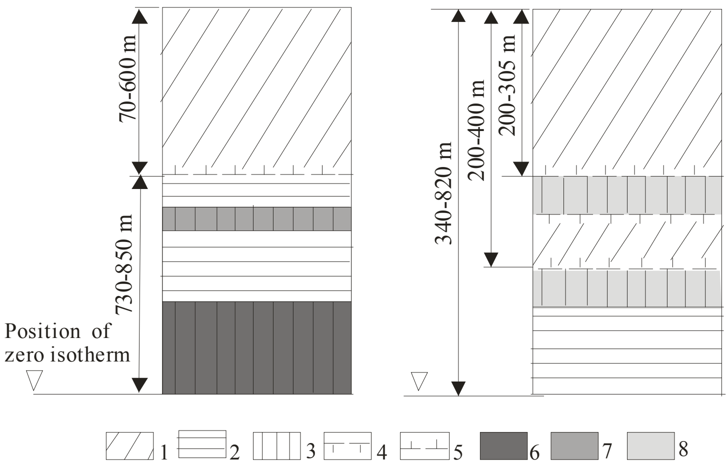

Figure 1. The generalized permafrost structure of the Yakutian diamond-bearing province. Explantions: 1 — ice-rich permafrost; 2 — "dry" permafrost; 3 — basal cryopegs; 4 — permafrost table; 5 — permafrost base; 6 — Cl–Mg–Ca cryopegs (group A samples); 7 — Cl–Ca–Mg cryopegs (group B samples); 8 — Cl–Na cryopegs (group C samples).

Group C samples are Cl–Na type waters. They occur at shallower depths (200–400 m) and their TDS values range between 28 000 mg/L and 165 000 mg/L. Cryopeg's temperatures vary from –2.5 to –0.5°C. The δ^2H versus $\delta\ ^{18}$O O values of *group B* samples range between –171‰ and –113‰; and between –19.7‰ and –9.6‰, respectively. The δ^{37}Cl value of one sample is +1.54. 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.

ACKNOWLEDGEMENTS

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Abstract ID: 186

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

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 800 m 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 20–25 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 (2200–2900 mg/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 optimize 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 po-

lymer 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.

Abstract ID: 249

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

1. 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.

2. 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.

3. 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 subbasin. 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.

Abstract ID: 370

THE HYDROGEOLOGY OF THE GLACIATED CATCHMENT IN THE ARCTIC ENVIRONMENT

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Keywords: polar catchment, water balance, groundwater

The article presents the results of the research performed during melting season (summer of 2008) in glaciated catchment located at Central Spitsbergen (Petuniabukta region, northern part of the Billefjorden). The aim of the research was the recognition of the subsurface flow occurring within catchments and the calculation of the flow rate of groundwater that recharge Ebba River. Groundwater flow is weakly recognised component of water balance in polar environments (Killingtveit et al., 2003).

The Ebba valley area covered mainly by slope deposition thaws seasonally and forms a shallow active layer, which enables the flow of groundwater (Shur et al., 2005). The flow of water begins usually in June (when temperature rises above 0°C). The maximum active layer thickness varies between 0.3 and 1.6 m. Mainly streams that flow from the mountain ridges recharge the groundwater found within the active layer (Fig. 1). In some cases these streams disappear in the upper portions of the slopes and form subsurface flows.

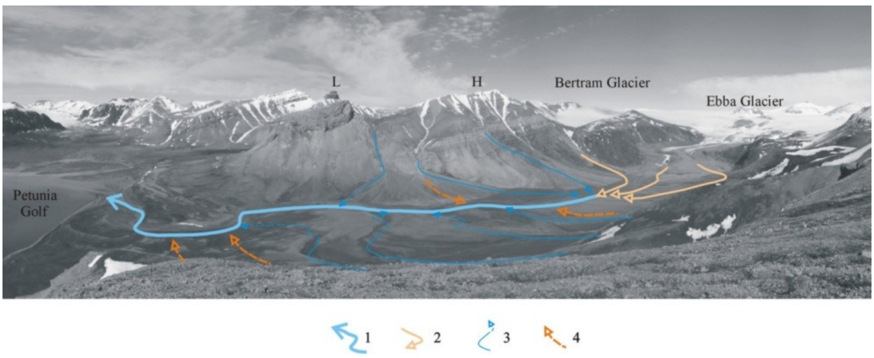

Figure 1. The conceptual model of water circulation within Ebba River catchments. Explanations: 1 — Ebba River Q_{EBBA}; 2 — recharge from glaciers Q_{GL}; 3 — recharge from Ebba tributaries and surface runoff Q_{SU}; 4 — recharge from groundwater flow Q_{GW} (the arrows were marked at places of piezometers installation).

Five groups of PCV piezometers equipped with a 5 cm long PCV screen and a gravel pack were installed during the summer season of 2007. The hydraulic conductivity (K) of the active layer was assessed in the field (using slug-test method). In all piezometers, measurements of water level and temperature were taken at three-day intervals. Runoff from the Ebba River was measured at three hydrometric stations every five days (11 measurement series performed with the use of an electromagnetic hydrometric meter). The recharge from groundwater was calculated with use of specific discharge and then calculation of flow rate of groundwater (using Darcy equation). The surface runoff was calculated as difference of flow rate of Ebba River between station 1 (close to starting place of the river) and station 3 (close to river estuary) minus groundwater flow rate.

The results of the study show high differentiation of total flow rate of different Ebba recharge components during summer season (Fig. 2). The most important component of the Ebba recharge is the flow of water from glaciers (Table 1).

Table 1. The average total runoff of Ebba River and components of Ebba River recharge [m³/s] during summer melting season of 2008.

Ebba River flow rate ***(Q_{EBBA})***	**Recharge from glaciers** ***(Q_{GL})***	**Recharge from Ebba tributaries and surface runoff** ***(Q_{SU})***	**Recharge from groundwater flow** ***(Q_{GW})***
		$Q_{EBBA} = Q_{GL} + Q_{SU} + Q_{GW}$	
3.96	3.22	0.49	0.24
100.00%	81.49%	12.51%	6.00%

At the start of July the melt of snow accumulated seasonally on the glacier surface was observed (Fig. 1). After that in the second half of July the melt of glacier was observed. Similar temporal differentiation of flow rate was observed during summer seasons of 2007 and 2009 (data not presented). This phenomenon is known as "Stenborg's effect".

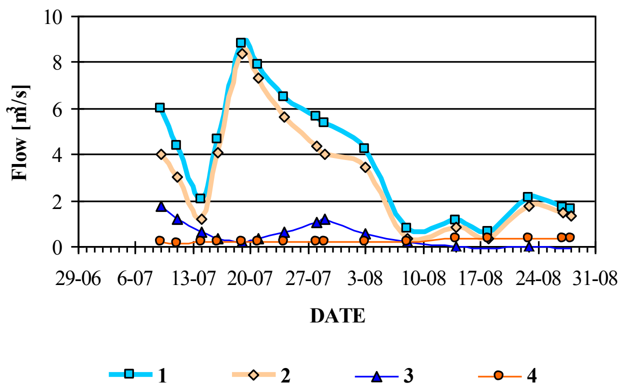

Figure 2. The total runoff of Ebba River and components of Ebba River recharge (explanations like on Fig. 1).

Surface runoff is related mainly with the melting of snow on the mountains ridges surrounding Ebba valley. The flow rate of groundwater that recharge Ebba River was calculate to 6% and increase systematically during melting season. The estimation of groundwater recharge have unique character because was calculated using direct measurements. Usually in polar environments this water balance component is estimated approximately or calculated using conceptual models (Killingtveit et al., 2003).

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Abstract ID: 428

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

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.

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 at the Hydrochemical Laboratory of the Institute of Geography and Spatial Management at the Jagiellonian University in Kraków (Poland). Assuming very low ion concentration, charge balance error was rather low (on average 5.7%). Additionally, relationship between conductivity measured in the laboratory and in the field were significant and positive ($r = 0.96$).

The concentration of dissolved solids in the surface waters of the investigated basin is very low (about 5.47–7.44 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^- (3.37 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). 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 ion exchange processes.

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.

ACKNOWLEDGEMENTS

Author 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

GROUNDWATER MODELLING AND WETLAND FLOW SYSTEM ANALYSIS OF CZERWONE BAGNO, BIEBRZA VALLEY, POLAND

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Keywords: groundwater, wetlands, Biebrza, MODFLOW

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

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Abstract ID: 306

DETERMINATION OF WATER POLLUTION AT SULTANSAZLIGI WETLAND KAYSERI — TURKEY

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Keywords: pollution, water chemistry, groundwater, Sultansazligi Wetland, Develi Closed Basin

1. 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

2. 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.

3. 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.

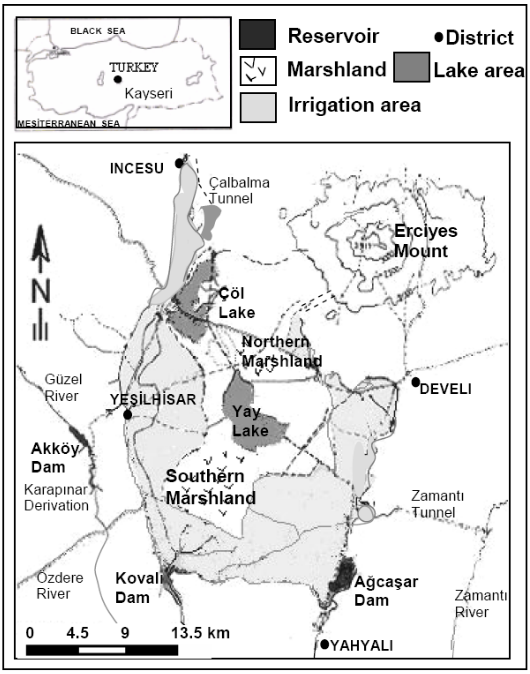

Figure 1. Location of Develi Closed Basin.

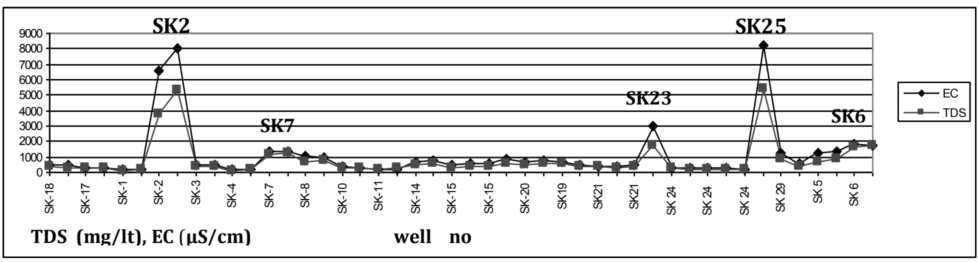

Figure 2. TDS and EC values of groundwater samples.

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Abstract ID: 389

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.

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.

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.

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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.

a)

b)

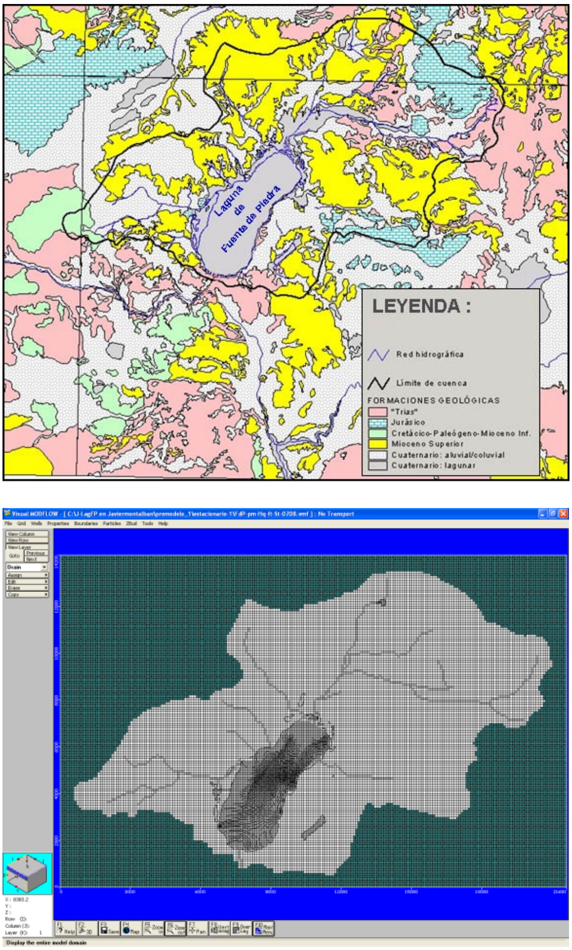

Figure 1. a) Geology of Fuente de Piedra lagoon; b) Levels associated with the condition of drain to the bed of the lagoon.

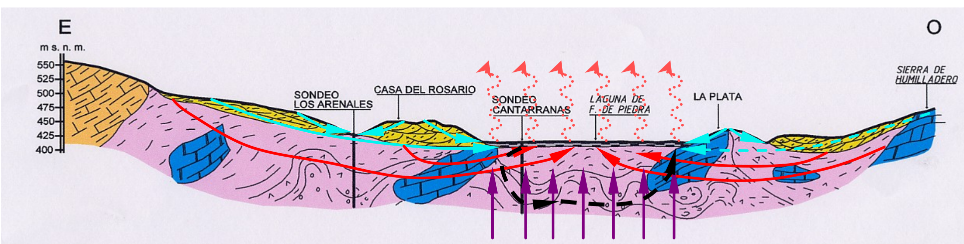

Figure 2. Conceptual model. Genesis brine: process evaporative + evolution hydrogeochemistry + factor lithology.

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Abstract ID: 437

RANGE DETERMINING FACTORS AND TENDENCIES OF GROUNDWATER LEVEL CHANGES IN WETLAND AREAS

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Keywords: renaturalization, wetland areas, groundwater level

Preservation of existing wetland ecosystems and renaturalisation of chosen degraded areas are important elements of ecological improvement strategies, biodiversity protection and water resources formation. Research concerning wetland areas are obligatory theme of international conventions, projects and treaties for example: Ramsar Convention, European Ecological Networks such as ECONET and NATURA 2000, The Council Directive (92/43/EEC) The Water Framework Directive (2000/60/EC), etc.

Characteristic of factors determining groundwater level changes and assessment of tendence changes, till to effort of forecasting direction of changes were conducted in Kampinoski's National Park (KNP) wetland areas (Studies financed from project: „Development of the method for reconstruction of primary hydrological conditions in Kampinoski National Park in order to restrain nature degradation and improvement of biodiversity status" and own resources of Warsaw University, Faculty of Geology). Mentioned areas include about 14200 ha, which represents 40% of the park's surface (Fig. 1).

Geostatistical data's analysts of data from monitoring system (about 13 000 observations in piezometres), completed with hydrodynamic rationales, enable to show conclusions in fluctuation of groundwater level, which results are input data to forecast groundwater level changes.

Specific characteristic of KPN wetland areas are shallow location of groundwater table —mean depth to groundwater is formed from 0.51 to 2.28 metre. Groundwater levels are characterised by large dynamic of changes. Mean annual amplitude in observation wells is formed from 0.68 to 1.18 metre. In all observation episode (1998 to 2009) appeared spring inundation areas, which was persisting in some areas 28–30 weeks.

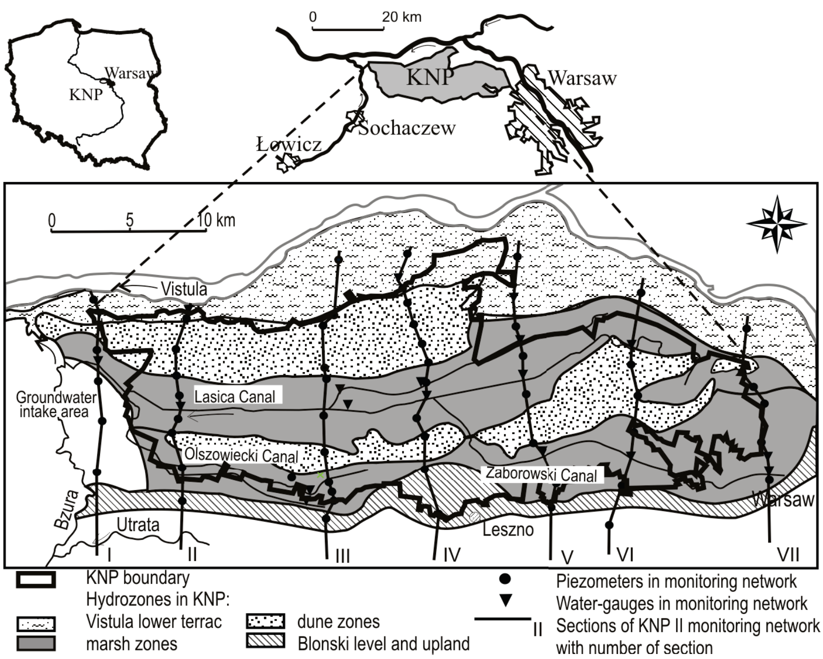

Figure 1. Groundwater monitoring network within the Kampinoski National Park.

On the basis of the groundwater level changes diagrams, equations of the third degree polynomial trend lines were appointed (Tab. 1). Good conformance of trend line (in 65% of cases trends are statistically important) is shown by high value of line regression index R, contained in a range from 0.28 to 0.51. Trend line reminding cosinusoide graph, has two maximum — in 1999 and 2007. These years are beginning of the dry periods and ending wet periods. On the assumption of heretofore tendencies, its reversal will follow after 2011 (after extreme dry year).

Table 1. List of statistic characters and groundwater level trend changes in selected wetland area in KPN based on observations in piezometres.

Wetland area	No. piezometre	Groundwater table level			R	Trend line equation (degree polynomial)	Statistically important
		mean	max	min			
North maarsh zone (fig.1)	P9	0.86	1.45	0.18	0.25	$y=1E\text{-}07x^3-6E\text{-}05x^2+0.0075x+0.7084$	NO
	P10	0.63	1.11	–0.19	0.28	$y=1E\text{-}07x^3-6E\text{-}05x^2+0.0068x+0.4931$	YES
	P18	0.91	1.52	0.30	0.35	$y=3E\text{-}11x^3-4E\text{-}06x^2+0.1385x-1790.3$	YES
	P19	1.38	2.14	0.34	0.30	$y=1E\text{-}08x^3-1E\text{-}05x^2+0.0031x+1.1397$	YES
	P32	0.86	1.35	0.27	0.47	$y=2E\text{-}07x^3-9E\text{-}05x^2+0.0087x+0.7804$	YES
	P33	1.30	2.03	0.59	0.27	$y=2E\text{-}07x^3-1E\text{-}04x^2+0.0121x+0.9303$	YES
	P37A	1.16	1.62	0.57	0.51	$y=2E\text{-}07x^3-0.0001x^2+0.0144x+0.6863$	YES
	P38	1.11	1.75	0.10	0.49	$y=4E\text{-}07x^3-0.0002x^2+0.0203x+0.5086$	YES
	P39	0.61	1.26	0.04	0.30	$y=3E\text{-}07x^3-0.0001x^2+0.0116x+0.3327$	YES
	P40	1.46	2.16	0.87	0.26	$y=2E\text{-}07x^3-1E\text{-}04x^2+0.0111x+1.181$	NO
	P46	0.98	1.60	0.25	0.30	$y=1E\text{-}07x^3-6E\text{-}05x^2+0.008x+0.6707$	YES

R – line regression index

Groundwater level analysis points at their change by impact of many overlaid anthropogenic and natural factors. Among geogenic factors, the most important sense have distribution and seasonality of precipitations, shallow groundwater drainage by watercourses and evapotranspiration process. Anthropogenic factors, which are: groundwater take off and irregular draining system, have not changed in recent years, so their influence can be called as "steady" and acceptably to eliminate in case of elaborating for example: programs of wetland areas renaturalisation.

Abstract ID: 513

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

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. 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. 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.

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.

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.

2.6 | Groundwater in eco-hydrology

Abstract ID: 114

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 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: 182

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).

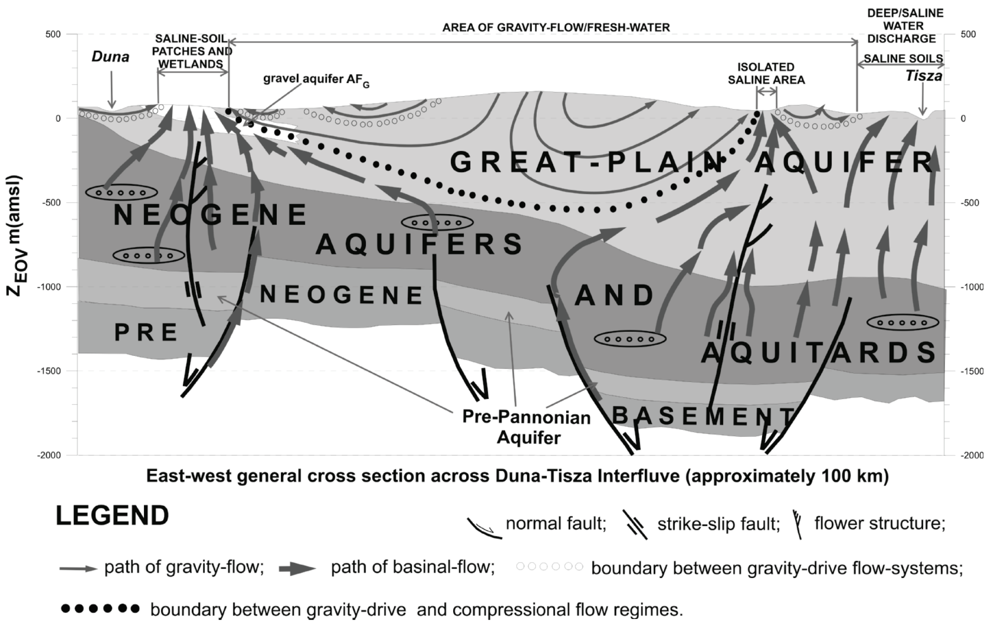

Figure 1. The Duna-Tisza Interfluve Hydrogeological Type Section.

(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 10 000–38 000 mgL^{-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.

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Abstract ID: 202

FROM INDIVIDUAL CELLS TO AQUIFERS: MODELLING THE GROUNDWATER ECOSYSTEM

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Keywords: individual-based model, groundwater ecosystem, contamination degradation, natural attenuation, physiology

1. 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.

2. 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

ASSESSMENT OF THE GROUNDWATER ECOSYSTEM

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Keywords: groundwater, community, ecosystem, microbial, threshold

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, show that the biomass of this ecosystem has great importance. The EC groundwater directive (2006/118/EC) demands "Research should be conducted to provide better criteria for ensuring groundwater ecosystem quality".

An assessment of the groundwater ecosystem has to refer to main and can only refer to microorganisms.

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. There are additional problems in the sample technique with nets or tube pumps in the well. The conditions in the well water are different from the environment. It is necessary to use a sampling technique that collects organisms of the representative groundwater area. This is easier for microorganisms, because one can use a radial pump with high through flow according to the DIN/ISO.

The groundwater microbiocoenosis in the area of nine German landfills are characterised by DGGE-Fingerprints (Kilb, 1999; Eschweiler, 1999). Parallel the emissions from the landfills into the groundwater are determined.

The 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). It was possible to define a threshold of non-toxic emissions, which causes significant differences in the groundwater ecosystem.

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 860 mg/L. So groundwater with concentrations of groundwater main ions <800 mg/L are defined as not influenced (neutral wells).

It can be shown that in groundwater 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 cluster-dendrograms (Tab. 1).

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 adaptions of the bacterial settlement to the emissions, which lead to an increase of bacterial amounts, caused by better nutrition situation downstream of landfills.

Table 1. Addition and separation of groundwater wells in clusters of Sørensen-indices.

Wells added to the neutral well	Groundwater main ions [mg/L]	Wells separated from the neutral well	Groundwater main ions [mg/L]
5003, 4010*, 4024*, 4042*, 4019, 5006, MA2a, MA16, P5/01, P4/01	260-1174	4007, 5001, 4125, 5002, 4653, 4654, 4010*, 4024*, 4042*, 4003, 4011, 5008, 5009, 4002, 4012, 5007, 4001, DE16, DE II, DE VI, DE VIII, GWM 8, GWM 9, GWM 12, W08/029, W08/032, GWM 18, Ma3b	(726) 942-5189

* at one landfill wells are added to the neutral well

Quantifications of bacteria at the investigated landfills show that both effects can be observed. A significant change of groundwater biocoenosis caused by non toxic landfill emissions is possible. This is of great importance for the assessment of groundwater biocoenosis.

The outlined investigation could be improved by using DNA-microarrays and is a field proved measure for the description of the groundwater ecosystem quality.

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PROPOSED CLASSIFICATION SCHEME FOR GROUNDWATER-DEPENDENT ECOSYSTEMS IN MOUNTAINOUS REGIONS

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Keywords: groundwater-dependent ecosystems, mountains, hydroecology, stable isotopes, Switzerland

As it is mentioned in the Groundwater Directive of the European Parliament (2000/60/EC), 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. Groundwater is a connector for the biocenoses in the aquifer itself and a supply of water, nutrients and energy with various patterns for many surface waters and terrestrial ecosystems (Eamus, Froend, 2006). New strategies for the ecological characterization of groundwater bodies and the protection of its biodiversity are currently developed (Hahn, 2009) and specific environmental and climatic features of mountainous areas (*e.g.* glaciers, snow) have to be taken into account (Viviroli, Weingartner, 2004).

In order to evaluate the ecological role of groundwater resource in alpine areas, we are developing two axes of research that should be of primary importance for further managements of GDEs:

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 implied species on the groundwater resource.

The GDEs typology, in addition with the knowledge of species and communities that depend on groundwater, 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…). Two major kinds of *driver* (hydrologic regimes, geologic and geomorphologic settings) constrain this *variability*. This later has *ecological consequences:* it leads biocenoses to structure and adapt. All these parameters are inter-connected (Fig. 1).

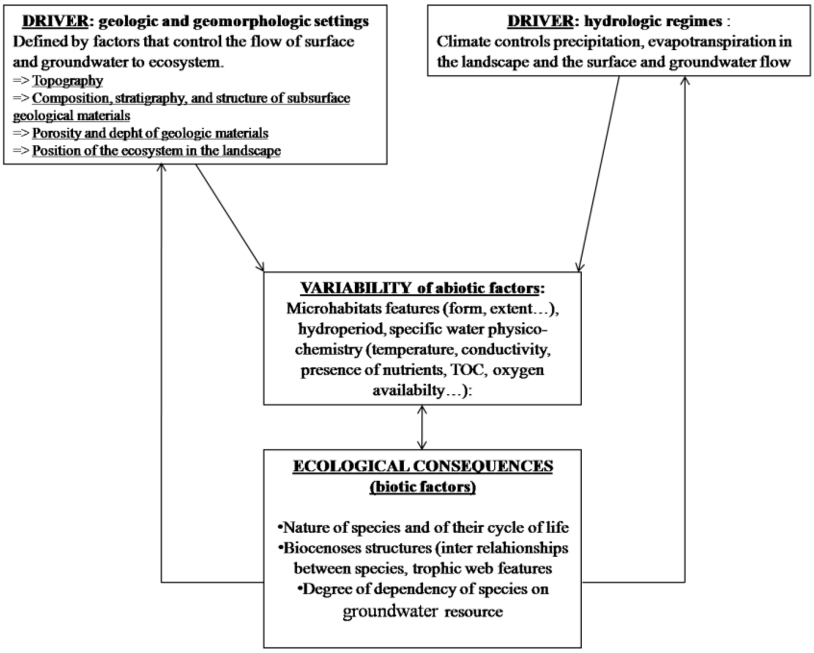

Figure 1. Conceptual scheme of drivers and variability relevant with aquifers functioning and ecological consequences on the GDEs.

Concerning axis #2, we investigate how qualitative and quantitative alterations of groundwater impact groundwater-dependent biodiversity. For this purpose, sites located in karstic and riverine environments, already studied from a hydrogeological point of view, were selected. In order to demonstrate the flux of groundwater to the ecosystem and distinguish groundwater from other water source, natural tracer studies are carried out ($\delta^{18}O$, $\delta^{2}H$ in all compartments of the water cycle) and a water balance is established for ecosystems. This approach should permit to assess ecological uses of groundwater under diverse hydrological conditions and could provide conceptual schemes dealing with the effects of climatic change or land-use impacts on GDEs.

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This study is supported by the GENESIS project (7th FP 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

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, subsidence, GWTDE, restoration

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. Consequent restoration measures can be developed when the wetland is considered to be at risk of "significant damage" due to local anthropogenic pressures.

Current research underway at Clara Bog, Ireland, indicates that the bog is not an isolated hydrological entity, as often perceived of bogs, but rather it is intrinsically linked to the regional groundwater table, which appears to provide a significant "support" function to the bog. Such a groundwater linkage is not obvious on the ground, as the bog contains no groundwater dependent vegetation. However, the bog is characterised by distinct ecological systems, or ecotopes, which are controlled by the relationship between surface slopes, flow path lengths and drainage conditions on the bog. Though a relatively intact raised bog, it has been extensively damaged in the past and is still subjected to local peat-cutting activities along its margins. Associated with such peat-cutting activities, is the development of drains, which deepen as cutting extends into the main body of the bog. As a result, the western half of Clara Bog, Clara Bog West, has subsided significantly in the recent past due to drainage, thereby altering the surface level gradients on the bog which in turn alters the local flow paths that maintain sensitive ecotopes on the bog. Subsidence, which has extended up to hundreds of metres into the high bog, is a result of significant water loss arising from consolidation of the peat substrate. Recent hydrogeological monitoring and analysis has shown that water losses are not simply a result of lateral seepage of water through the peat profile at the bogs margins but are a result of vertical water losses in the peat profile in the main bog body.

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 "lag" zone vegetation. However, in Clara Bog West it appears there is also a connection between the regional groundwater table and the high bog. Such a connection appears to be unique to Clara Bog West as a result of the prevailing geological conditions. A succession of Carboniferous Limestone to relatively permeable glacial till (subsoil) deposits to low permeability lacustrine clay sediment is the predominant underlying geology of the bog. However, there are areas in Clara Bog West where this subsoil aquifer protrudes through the lacustrine clay beneath the high bog at localised connections. The hydrological and hydrogeological data now suggest that drainage on the bog margin has created a hydraulic connection between these "subsoil subcrops" and the marginal drains developed within the same subsoil, thereby lowering the regional groundwater table, steepening the hydraulic gradient and resulting in significant water loss from the main bog body. Distinct zones of groundwater seepage occur where the potentiometric surface of the regional groundwater table is coincident with, or below, the elevation at the base of the drain

Clara Bog is in danger of losing its distinct ecological communities if water losses from the bog are not addressed. To arrest the subsidence of Clara Bog West, restoration activities are currently proposed to concentrate in an area of cutover bog that lies in the path of converging regional groundwater flow. Groundwater discharge from the high bog to peripheral drains in this area must therefore be minimised to reduce the steep hydraulic gradients of regional groundwater flow. Over time, reduced hydraulic gradient should create conditions suitable for ecotope development, which is indicative of 'healthy' raised bogs.

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Abstract ID: 484

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 graduatly. 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 ususlly. 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

Abstract ID: 151

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 (Fig. 1). 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 (Fig. 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.

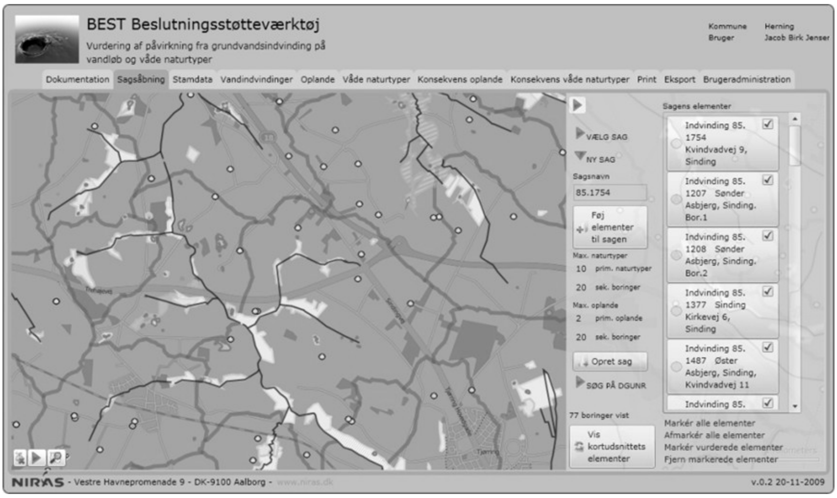

Figure 1. Map based dialog used to select the wells that are to be analyzed as well as showing the potential ecosystems that can be affected, multiple wells can be selected for analysis.

The interface to applying the response matrix to determine effects is based on a web-service application (Fig. 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.

Abstract ID: 169

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

1. 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).

2. 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.

3. 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.

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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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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

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 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 wells as water use. In order to review the present situation and measures on European scale, 17 test cases have been evaluated. The areas include the Mediterranean zone, Central and Western Europe as well as Scandinavia; 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 future scenarios of groundwater systems use can be deduced from the test sites considering all relevant stakeholders, which will lead to the development of economical and social viable measures for groundwater protection. Thus, the basis will be provided for model development testing and scenario simulations.

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 for the use in agricultural irrigation, affecting (and sometimes reversing) flow patterns of hydraulically connected surface water reservoirs. The next reason deals with more general kinds of land use like gravel mining activities, increased sealing of ground surfaces due to urbanisation and industrialization, artificial groundwater recharge and regulation of rivers that interact with groundwater, which all disturb natural conditions. Finally, climate change and with it the modification (or reduction) of seasonal water availability will likely influence groundwater systems, especially in mountain regions.

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 fertilizer in agriculture leading to observed nitrate concentrations in groundwater much higher than EU limits. Cold climates represent a special condition in this respect since slowly degradation of fertilizers and pesticides can form an important threat to deterioration of groundwater resources.

Moreover, groundwater pollution may be linked to an entire mixture of emission sources comprising leaky sewerage, municipal landfills, illegal waste depositories (containing all kind of chemical wastes), non-authorized gravel pits and also industrial facilities, that partly discharge waste water in uncontrollable manner. In some cases, leaching of substances into groundwater can also be favoured by hydrogeologic conditions (e.g. Karst aquifers, very thin soil layers).

Most often threats to groundwater dependant ecosystems may have a quantitative background, consist of 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 ecosystems exists in such different environments as lagoon systems or shallow weathered bedrock aquifers. In strongly regulated rivers (e.g. for power production) the riparian zone processes are also altered leading to retention of chemical elements that induce the production of diatom in stored water. The application of tracer methods has proven beneficial 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 flow and transport modeling.

With respect to the Water Framework Directive and the Groundwater Directive possible gaps are related to unconsidered processes (e.g. climate change leading to an imbalance between water availability and water use), non-existing tools for particular conditions, missing thresholds and the negligence of uncertainty bounds and implementation deficits (e.g. incomplete definitions of protection zones).

Finally, the investigated test sites strongly vary regarding the already existing use of modeling approaches. At some sites a lot of modeling experience already exists in diverse aspects, thus future aims comprise extension, further refinement, better characterization of particular processes or coupling of yet individual models up to the development of socio-hydro-economic modelling frameworks. On the other hand, clear visions exist about initial model applications including verification of conceptual models, improvement of process understanding and provision of the basis for predicting the impact of various land management practices on groundwater conditions.

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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 ecossistems

The Almádena-Odeáxere aquifer system (AO) with 63.5 km² is located in Algarve (south Portugal) and is hydraulically connected to several surface water bodies. The most significant of which are linked to the aquifer systems main discharge areas: (1) along the mouth of the Bensafrim stream and (2) at the "Boca do Rio". These two areas are effluent reaches of rivers in hydraulic connection with the AO and feed wetlands associated with diffuse discharge of groundwater. Therefore, the extraction of groundwater from the AO affects the baseflow in these sensitive groundwater dependent ecosystems.

In order to investigate the quantitative relations of the datasets available for the historical data of aquifer extractions in municipal water wells and the state variables resulting from the monitoring of the AO a regional finite element model was implemented. In a first phase of this work the model was calibrated using inverse modelling tools and integrating the previously available information regarding the aquifer system geometry, boundary conditions, geological cartography and relevant hydrological historical data. Considering its current state of development it is now possible to proceed with the validation of the model, to assess its accuracy and, in addition, to perform an analysis of the impact of the various extraction scenarios to which this aquifer system has been exposed over the last two decades. Therefore, the simulated scenarios for the period of 1989 up to the current day allow the analysis of the impact of important changes in the regional water resources management, not only in the exploitation of the AO in terms of regional scale hydrogeologic dynamics but also at the scale of the AO local discharge areas and the associated relations between groundwater and surface water. These areas consist most importantly of ecologically relevant diffuse upward seepage from the aquifer system into wetlands known as the Paul de Abedoeira (SE corner) and Boca do Rio (SW corner).

Results showed that the extraction regimes during the last few years in which the AO was used as a source for public water supply were already affecting the regional scale hydrogeologic dynamics as well as the local discharge areas, and subsequently the surface water bodies which depend on them, by reducing the amount of groundwater flow from the aquifer to the streams. These results were sufficient to validate the functionality of the numerical model based on "soft" data, namely reports of the Paul de Abedoeira wetlands drying up during periods of intense extraction from the boreholes in the area and analysis of changes in land coverage in the wetland areas. Nevertheless a more detailed analysis of the validity of the model for the simulation of extraction scenarios is recommended for future research. Furthermore, 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. Therefore it is suggested that future investigations 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.

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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.

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3 | Aquifer management

3.1 | Regional groundwater systems

Abstract ID: 120

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 $\delta^{18}O$) 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 ($\delta^{18}O$ 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 $\delta^{18}O$ and –34.43 ±24.32‰ SMOW for δ^2H. The $\delta^{18}O$ 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).

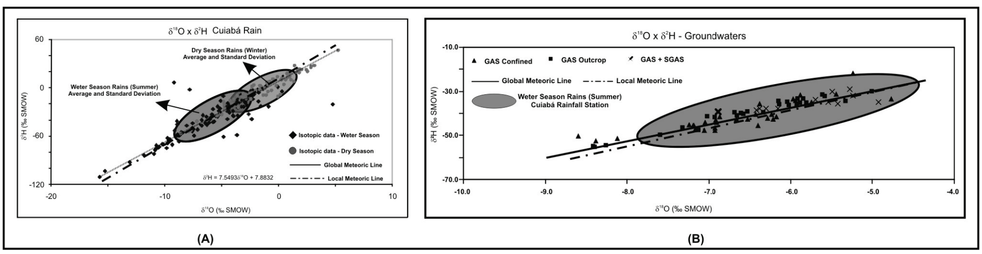

Figure 1. (A) $\delta^{18}O$ versus δ^2H cross plot of rain water. (B) $\delta^{18}O$ versus δ^2H cross plot for GAS groundwaters.

The spatial distribution of groundwater $\delta^{18}O$ 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 $\delta^{18}O$ groundwaters are in the confined zone (Fig. 2).

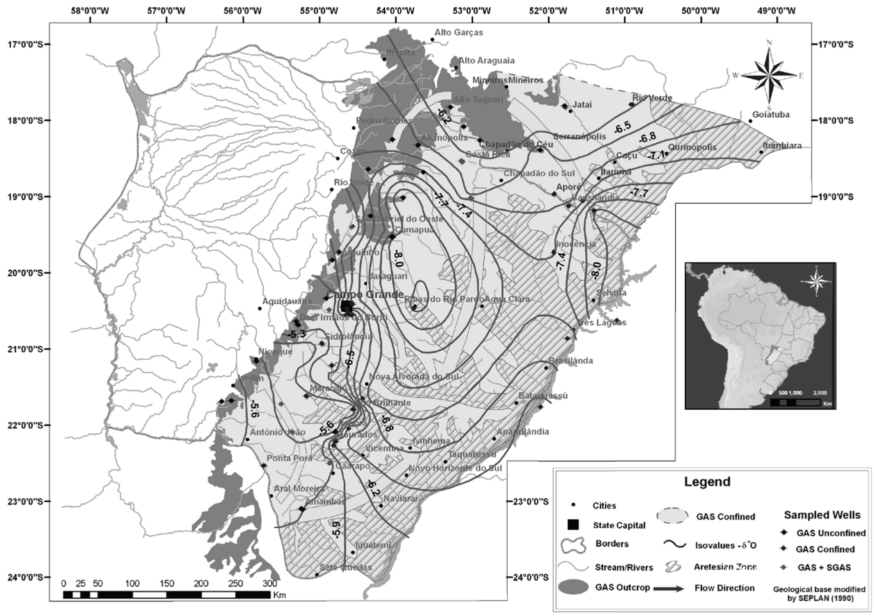

Figure 2. Map of $\delta^{18}O$ GAS groundwater spatial distribution in the western portion of the Guarani Aquifer System.

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 $\delta^{18}O$ and $\delta^{2}H$ than the present day. These ratios are similar to those observed in the central portion of the study area (–8.2‰ SMOW $\delta^{18}O$ and –45‰ SMOW $\delta^{2}H$). Groundwaters more enriched in $\delta^{18}O$ 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.

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CREATING OF REGIONAL HYDROGEOLOGICAL MODEL FOR THE SOUTH-EAST OF LITHUANIA

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Keywords: groundwater, regional modelling

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 (Fig. 1). This groundwater body covers one third of the country. The rectangular HM area has the size 290 km×210 km= 60 900 km^2. Local river basins comprise the active HM area of highly irregular shape (Fig. 2). The model area exterior to the active one, does not take part in simulation.

Figure 1. Model location.

Figure 2. Model area (290 km × 210 km, h=0.5 km).

The Quaternary groundwater system to be modelled is highly irregular (most of aquifers and aquitards are discontinuous, numerous hydrogeological windows are present, etc.) (Fig. 3). To account for its complexity, HM contains 11 layers (planes). The finite difference 3D scheme was applied with the plane approximation step size 500 metres. Therefore, the HM grid plane contains 481×421=244 601 nodes and HM includes 2 690 611 nodes. The Groundwater Vistas (version 5) system was used for creating of HM.

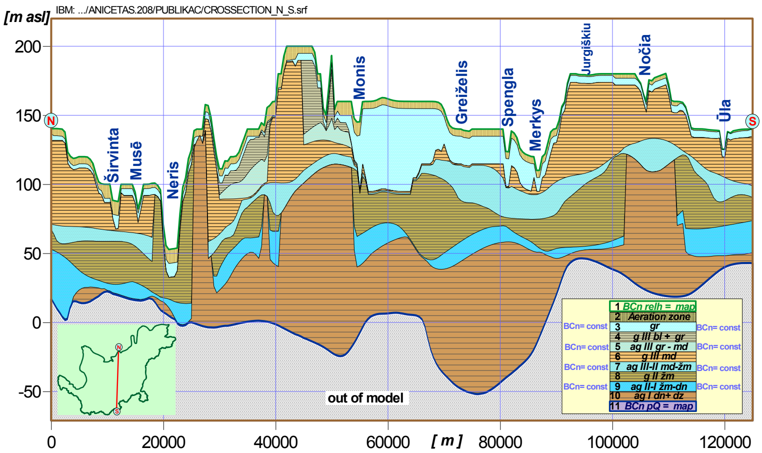

Figure 3. Geological cross section NS.

Piezometric boundary conditions were applied on the top and bottom planes (1 stand 11-th) of HM, on the borderline of the active HM area. The land surface elevation map (plane 1) regulates the infiltration flow which is various for the local river basin areas. The plane 2 represents the aeration zone as a formal aquitard with a variable leakance. The HM plane 3 simulates the first unconfined Quaternary aquifer. The next three aquifers (planes 5, 7, 9) are the confined ones. The hydrogeological network (rivers, lakes) was implemented in the HM plane 3.

The task of creating top and bottom surface elevation maps of the HM layers is the most complex and burdensome one, because no negative thicknesses of layers are allowed. To postpone the final solution of this difficult task, in the "start on" version of HM, the uniform flat layers were applied as a substitute for the real geometry of HM. To make HM calibration simpler, the thicknesses of these layers was 1.0 metre. For aquifers, the transmissivity maps of high quality were used instead of the normally applied ones of their water permeability. In areas of hydrogeological windows, large values of vertical permeability were used. To calibrate HM, iterative searching was done for the distributions of aquitard permeability. As the calibration targets, known groundwater levels in monitoring wells and infiltration distributions were applied. Due to this uncommon approach, HM calibration was accomplished rather easy. If no transport processes are tried on HM (migration of contaminants, particle tracking, etc.), it is not necessary to introduce the real geometry of the geological environment. For the reported HM, the real geometry was implemented, because, sanitary protection zones of well fields were simulated. This implementation results in formal grid calculations which produce permeability maps for aquifers and aquitards, if the real thicknesses of layers are used. The above mathematical transformation does not change flows and piezometric levels of calibrated HM. The proposed presentation may be useful for modellers dealing with large models.

Abstract ID: 135

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

The Cracow Sandstone Series (CSS) (Westphalian BCD) is the uppermost part of the Carboniferous productive formation situated in the central and the eastern part of the Upper Silesian Coal Basin (USCB). The CSS covers the area of about 1500 km^2 and is represented by a sandstone-claystone-siltstone formation containing coal seams. The thickness of this formation is changing from tens to 1140 m. It is underlain by older Carboniferous sequences. Taking into account the permeability of the cover sediments two hydrogeological subregions of the diverse geological structures and recharge conditions of the CSS hydrogeological complex may be distinguished within the discussed region.

The CSS formation is the most water-bearing complex of the productive Carboniferous in the USCB. The Carboniferous water–bearing sandstones and conglomerates have thickness ranging from a few to several dozen meters. They are isolated one from another by intercalations of impermeable claystones, except of permeable fault zones, zones of sedimentary wedging as well as areas of mining.

Geogenic factors and mining activity determine actual development of the groundwater environment and influence on the evolution of the hydrodynamic and hydrogeochemic fields and geothermal conditions. Gradual closure of coal mines lead to radical changes of hydrogeological conditions, which have been established for tens of years (Różkowski, 2003).

The most important geological factors which determine groundwater conditions of the CSS are: the geological structure and thickness of the described complex, decrease of sandstones permeability with depths as well as permeability of the cover sediments. Clayey Neogene sediments form the hydrodynamic barrier isolating the Carboniferous complex. Permeable cover sediments allow the recharge of Carboniferous aquifers by atmospheric waters and development of deep zone of low mineralized groundwaters in the CSS complex.

Extension of underground coal mining on the industrial scale is dated back from the end of the 18th century. Several mining areas have been located in this area. The depth of mining workings is up to above 500 m. The maximal pumping rate was about 153 m^3/min. Coal mining caused the disturbances of the natural conditions of the hydrogeological environment including the drainage of rocks, alteration of groundwater chemistry and changes of flow field. Dynamic development of mining processes causes increase of the rocks permeability and hydraulic connections of waters from different aquifers. Scale of drainage is determined by geological structure as well as by surface and depth of mining workings.

There is a great variety of hydraulic properties and water bearing values of the CSS sandstones (Różkowski, Witkowski, 2004). Variations of open porosity, specific yield and permeability values of sandstones depend on variation in granulometric and mineral composition of these rocks, litification process as well as mining activity. A marked trend of downward decrease in hydraulic properties and water-bearing values of sandstones is apparent in the laboratory and field investigations results. The values of hydraulic conductivity vary from 3.3×10^{-4} m/s to 5.0×10^{-8} m/s while the effective porosity — from 31.7 to 4.6%. Specific capacity of sandstones decreases from 10.2 m^3/h/1mS on the depth about 60 m to 0.03 m^3/h/1mS on the depth 850 m.

The gravity flow takes place in the CSS basin. The pressure gradients vary from 0.9 to 1.1 MPa/100 m. Piezometric head increases with depth from 0.19 to 9.2 MPa. The CSS hydrogeological complex consists of generally confined aquifers of fractured–porous or porous types.

The Carboniferous aquifers are recharged in the outcrop zones or through permeable cover rocks in the northeastern part of the described region. The CSS hydrogeological complex under natural conditions was drained by river valleys and along regional fault zones what is strongly marked by increase of groundwater salinity. High index of underground runoff ranging actually from 5 to 7 l/s/km^2 is however a measure of mining drainage intensity. The groundwater in the CSS complex varies in chemical composition and total mineralization (Różkowski, 2004). Mining exploitation is the primary factor which modifies the natural chemical composition of groundwater. Deep infiltration of low–mineralized waters from cover layers, the ascension of brines along the dislocation zones and the inflow of technological waters to mining workings changes the chemical composition of natural waters. Results of isotope investigations have shown that groundwaters of different origin and residence time can be distinguished in the hydrogeological profile of the CSS. Within the CSS area can be observed a geothermal anomaly which is marked by low value of geothermal gradient (1.89°C/100 m).

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Abstract ID: 148

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

The evaluation method is based on the assumption that the catchment subsurface system operates like a big lysimeter (BL) (Fig. 1) the outflow from which is measurable as the underground runoff Q_U to the river system. As the groundwater flow across catchments boundaries Q_L is often much less than Q_U (Hydrogeological Map of Poland, 2004) the BL approximation can be applied in many cases.

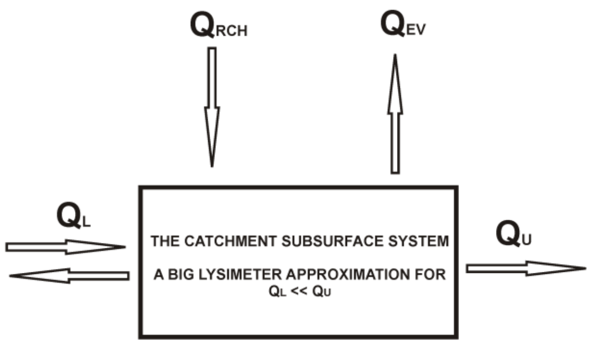

Figure 1. The concept of the catchment subsurface system as a big lysimeter. Q_U — underground runoff to the river system, Q_L — groundwater flow across the catchment boundary (in or out), Q_{RCH} — recharge, Q_{EV} — field evaporation.

With this approximation the underground runoff Q_U is practically the same as the catchment renewable groundwater resources which are equivalent to the recharge Q_{RCH} less the field evaporation Q_{EV} taking place mainly in the river flood terraces.

The catchment available groundwater resources (AGR) must be viewed as a certain fraction of the renewable resources Q_U according to formula:

$AGR = C \cdot Q_U; \; 0 < C < 1$

With the estimated Q_U the distribution of the catchment available groundwater resources AGR was calculated for the maximal C value which satisfies the imposed constraints like for example the allowable regional water table drawdown.

The distribution of the available groundwater resources AGR was calculated using the constant volume transformation (CVT). The CVT is the algorithm that changes the shape of a given surface keeping permanent the volume contained between this surface and the reference level.

This algorithm calculates according to the previously defined weight functions. In the presented case study these weight functions were the distributions of:

- the aquifer hydraulic transmissivity,
- the recharge and discharge zones,
- the allowable regional water table drawdown,
- the areas of the main groundwater reservoires,
- the areas of good and bad groundwater quality.

The result of the CVT algorithm calculations for the Leba river catchment (1801 km^2) situated in N Poland is shown in Fig. 2. This algorithm was built into the mathematical flow model.

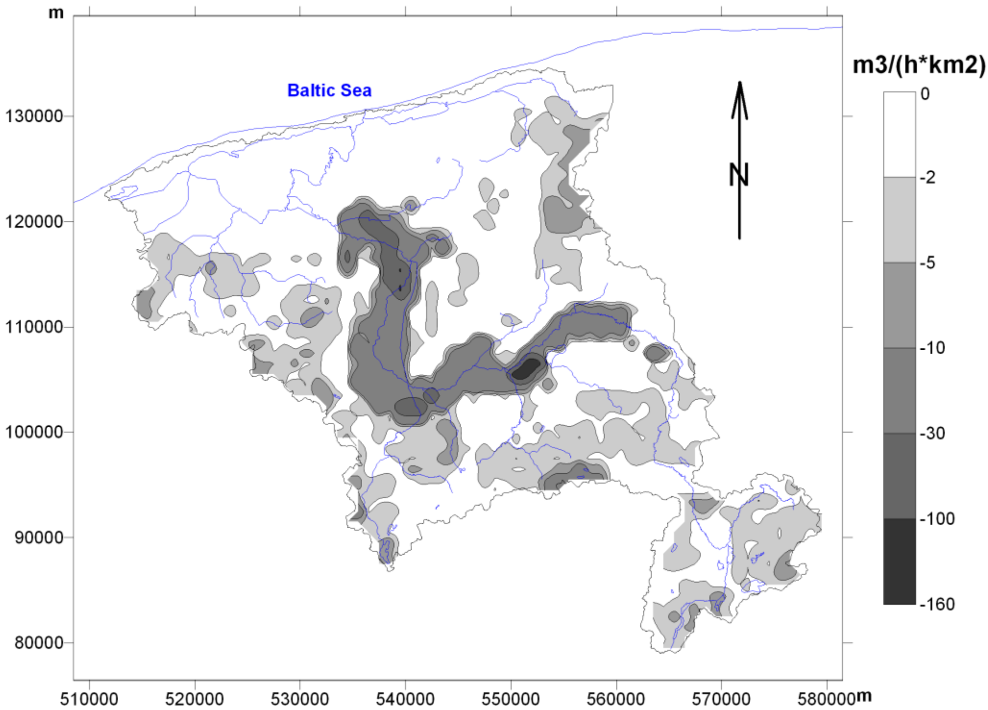

Figure 2. The calculated distribution of the available groundwater resources for the Leba river catchment. For this case $C = C_{max} = 0.4$.

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Abstract ID: 191

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

1. 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 (Yoshizawa et al., 2008).

2. 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.

3. 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.

4. 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. 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.

5. 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

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

In recent years, climate change impacts global environment more strongly. The analysis of rainfall data observed in Taiwan shows that the rainfall amounts for entire year are keeping stable, but the lengths of raining seasons are greatly decreasing. Therefore, the rainfall intensities are greatly increasing especially centralized in typhoon events. However, because of the effect of time heterogeneity for rainfall, only using reservoir systems to store the plentiful rainfall in raining seasons becomes harder to supply without deficiency in drought seasons. Thus, groundwater resources play a vital role in Taiwan water supply and the protection of groundwater resource becomes an important issue today. For the goal of groundwater protection, spatial profiles of recharge potential for study areas is required for further definition of primary recharge area and groundwater resource conservation zone. Nine groundwater areas have been demarcated in Taiwan and Chou-Shui Alluvial Fan, located at western Taiwan, is one of the most important areas. In this study, the spatial potential profile for Chou-Shui Alluvial Fan has been proposed.

Seven contributing factors, including land use, surface soil type, lineaments, average annual rainfall, the correlation between rainfall and groundwater level variation, the variation of aquifer storage for unit area, and hydraulic conductivity, have been proposed to determine the spatial profile of recharge potential. First, the original data for each contributing factors is collected from field gauges, remote sensing data and geographic information system (GIS). Each contributing factors are translate from the original data to factor grades. The grade range for each factor is from 0 to 100 and high grade value means high recharge potential. Each factors need to be spatially discretized on a set of 1 km^2 square cells. Second, seven factor weights, which indicate the strengths of influence for difference factors, and contributing factors are used to determine the spatial profile of recharge potential by using weighted average method. The result of recharge potential shows that the grades of recharge potential decreases form the proximal fan to the distal fan and also indicates that the primary recharge area locates at the proximal fan of Chou-Shui River.

Abstract ID: 219

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.

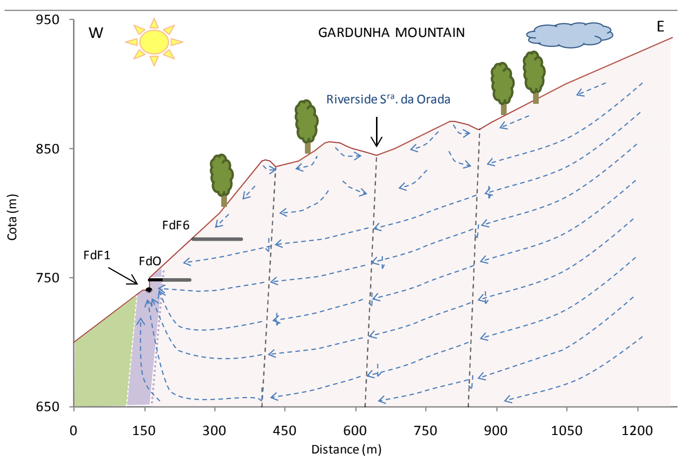

Figure 1. Schematic cross-section of the region in study.

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

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Abstract ID: 228

HYDROGEOLOGICAL CHARACTERISATION OF THE HETEROGENEITY OF AQUITARDS FROM A MULTILAYERED SYSTEM

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Keywords: aquitard, borehole logging, multilayered system, hydrogeological model

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".

In Aquitain Basin (South-West of France), groundwater resources are broadly pumped for different uses (freshwater supply, geothermal energy, thermal water, agricultural and industrial domains…). The north part of the Aquitain sedimentary basin is a multilayered aquifer system within which 6 aquifers are separated by confining units or aquitards. The two hydrogeological models developed in this area both demonstrate the existence of vertical flows through the aquitards. Currently, the hydrodynamic properties of these confining units are arbitrarily defined and assumed constant all across the thickness of the aquitard. The lack of knowledge about aquitard structures and associated hydrodynamic measurements leads to those uncertainties. A direct or indirect measure of these properties becomes necessary to confirm the models' results.

In the region of Bordeaux, three tertiary aquifers (Eocene, Oligocene and Miocene) are mainly exploited for freshwater supply. This study intends to assess the properties of the aquitards separating these three aquifers. As part of this project, geophysical borehole loggings such as natural gamma-ray, resistivity and flowmeter are used, as a complement to geological data, to assess the heterogeneity of aquitards. This allowed to redefine facies boundaries with depth and then precise the architecture of the aquitards. Furthermore, it allowed to assess the geological nature of rocks composing the aquitards in order to provide relative information on permeability values related to each facies.

During this study, a eighty-meters depth borehole, drilled using both rock coring and air-rotary methods, was performed for the first time in the region, directly in the aquitard. From geological data and borehole loggings, five levels of control were determined in order to observe on the long term the evolution of the hydraulic gradient. In addition, geological and hydrogeological characterisation of cores (grain size, porosity, permeability…) as well as *in situ* measurements of hydraulic conductivity confirm the heterogeneous nature of the aquitards.

The integration of geological and hydrogeological properties of aquitards in the numerical models allows to quantify the impact of local heterogeneity on groundwater flow. 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.

Abstract ID: 272

SPATIAL DISTRIBUTION OF POTENTIAL AQUIFER RECHARGE FROM PRECIPITATION FOR THE PERIOD OF 1951–1980 OVER SLOVAKIA

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Keywords: effective precipitation, potential evapotranspiration, actual evapotranspiration, geostatistics, Slovak Republic

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. 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 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 $l \cdot s^{-1} \cdot km^{-2}$). 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 Vysoké Tatry Mts., Malá and Veľká Fatra Mts., western part of the Nízke Tatry Mts. and Slovak Beskydy Mts. The high level of effective rainfall in Bukovské vrchy Hills (easternmost part) is also interesting. In these 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. Some other contrary but expected discrepancies arise from comparing individual regions and their effective precipitation amounts.

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.

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. By using the knowledge about groundwater discharge in larger number of watersheds and information about geology and geomorphology of these, a very precise estimation of the rainfall separation for individual basic lithological types could be possible. Similarly, an increased effort must be taken towards the characterization of larger areas from the groundwater recharge point of view, which can be accomplished by accounting for the distribution of effective precipitation over time.

Abstract ID: 284

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

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 and an increase in population density of over 400% over the last 40 years (Lusaka City Council, 2008). According to the National Water and Sanitation Council (NWASCO), the water supply coverage by the Commercial Utility, the Lusaka Water and Sewerage Company (LWSC) is 68% (National Water and Sanitation Council, 2009). 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 up to 140,000 m^3/d from the local groundwater systems whereas the remaining water is sourced from the Kafue river situated about 40 km south of the City. The estimated water demand by the year 2030 is 640,000 m^3/d (KRI, 2008).

The very productive, karstic aquifers are characterised by shallow water tables and a lack of a protective cover, and therefore considered very vulnerable to pollution. Industrial effluents and improper disposal of sewage and waste constitute major risks for groundwater quality. According to NWASCO, the sanitation coverage is only 17%.

The Lusaka area is covered by strongly folded overthrusted metasedimentary rocks of Katanga (Neoproterozoic) age which have been intruded by granitic and basic bodies. The carbonate rocks cover an area of 1600 km^2 (see Fig. 1). The main aquifer is hosted by the marbles of the Lusaka Dolomite Formation which is known to form a terrain undergoing recent and active karstification.

First investigations carried out during the preparatory phase of the study included the development of a groundwater information system and GIS, the establishment of a groundwater and spring and surface water monitoring network, remote sensing studies and water quality sampling campaigns. Satellite imagery was used to determine current land use distribution and to identify directions of maximum principal stress and the main trends and types of faults.

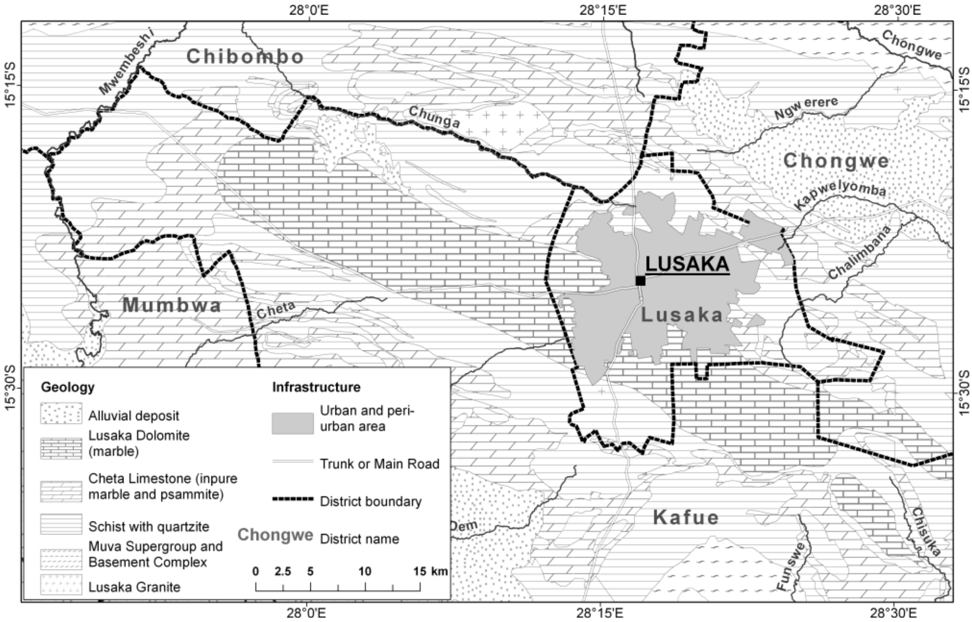

Figure 1. Geology of the study area.

Water quality sampling included inorganic constituents and heavy metals as well as microbiological indicators. The results could be used to assess the chemical water composition of areas that are affected by human pollution sources.

The study proved that microbiological (including faecal) contamination and pollution is widespread throughout the City area. 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.

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Abstract ID: 319

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.

Groundwater circulation in the Tatra Mts. has been well recognized mainly by: Chowaniec, 2009; Małecka, 2003; Różański, Duliński, 1988; Zuber et al., 2008). They stated hydraulic connection between the aquifer in the High Tatra Mts. built of Paleozoic igneous rocks and the karst aquifer in the lower parts of the Tatra Mts. built mainly of the Mesozoic carbonates, sandstone and shales. Mesozoic formations are drained by numerous vaucluse springs with very low mineralization which proves their crystallinic 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 small discharges. Hence, the aim of the research is investigation of recharging small than vaucluse springs i.e. springs of V class of discharge which are not common in this area. There were investigated 5 springs located in the Olczyska Valley built of Mesozoic sedimentary series (Tab. 1).

Table 1. Properties of investigated springs.

Spring	Altitude [m a.s.l.]	Mean annual discharge [$dm^3 \cdot s^{-1}$]	Type of outflow, geology
Olczyskie	1065	500	crevasses, dolomites
Eljasz South	1000	2.2	crevasses, quartzitic sandstones
Eljasza North	998	1.5	crevasses, squartzitic sandstones, spongolites
Spring no. 64*	1080	0.5	debris, shales, limmestone
Spring no. 65*	1030	0.3	debris, shales, limmestone

* No according to Oleksynowa, Komornicki 1989

Water samples were collected once a month in 2009. Water temperature, electrical conductivity and pH were measured in terrain (Elmetron CX-401). Chemical analyses were done in the laboratory at the Institute of Geography and Spatial Management, Jagiellonian Univeristy using ion chromatography (DIONEX ICS-2000).

The chemical composition of the Elias springs is very similar to the Wywierzysko Olczyskie. It is possible, that the Elias springs drain also the crystallinic aquifer, but this preliminary assumption need additional investigations involving tracer methods.

ACKNOWLEDGEMENTS

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Abstract ID: 356

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 Quaternary 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 (Fig. 1). However, the results from individual monitoring objects provided important information for further, more detailed evaluation of hydrogeological zones.

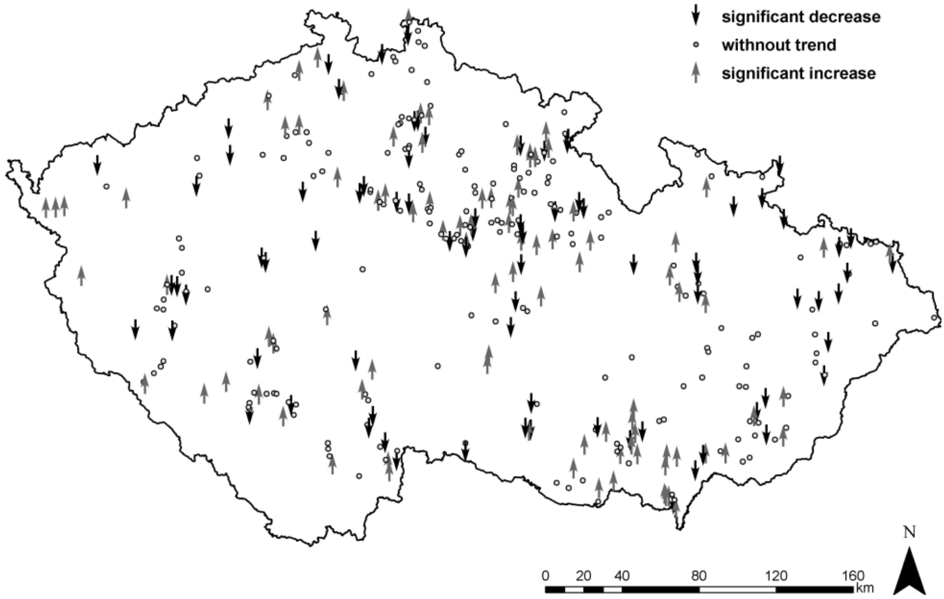

Figure 1. Trends in groundwater levels in the Czech Republic between 1971 and 2009.

ACKNOWLEDGEMENTS

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Abstract ID: 357

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

The study area is located in the Lower Yom River Basin and covers an area of about 970 km² in the lower part of the northern Thailand. Large amount of shallow groundwater usage for rice growing has caused groundwater levels to drastically decline below the normal threshold for viable pumping (8 meters below the ground surface) in some areas. The objective of this paper is to characterize the hydrogeological parameters and groundwater flow systems by detailed field investigations (Fig. 1).

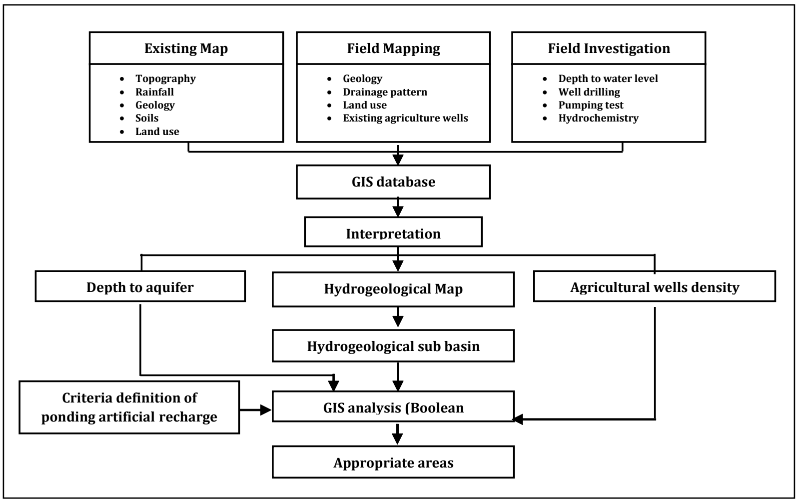

Figure 1. Working protocol of the study.

These investigations include field surveys of hydrologic, land use, geologic and hydrogeologic 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; shallow aquifer (5 to 15 m deep) consists of sand silt and clay of the Yom flood plain deposits and the deeper aquifer (15 to 60 m deep) consisting of gravel, sand silt and clay of an alluvium fan deposits of the Ping–Yom River Basin (Fig. 2). There is a thin clay layer with an average thickness of one to five meters separating the shallow and deeper aquifers. Most of the farmer wells (2,393 wells) in the 13,900 km² study area are being pumped from the shallow aquifer with a total annual abstraction of approximately 1,170 million m³. The transmissivity values of the upper aquifer range from 300–7,000 m²/day and the average thicknesses range from five to ten meters. The regional groundwater is flowing from the west to east, whereas the local flow systems actively flows from north to south or south to north directions. Several geologic 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 significant parameters are important for locating the potential zones for establishing managed aquifer recharge schemes. Moreover, detailed water balance and surface and groundwater interaction mechanisms are being simulated with the aid of numerical modeling.

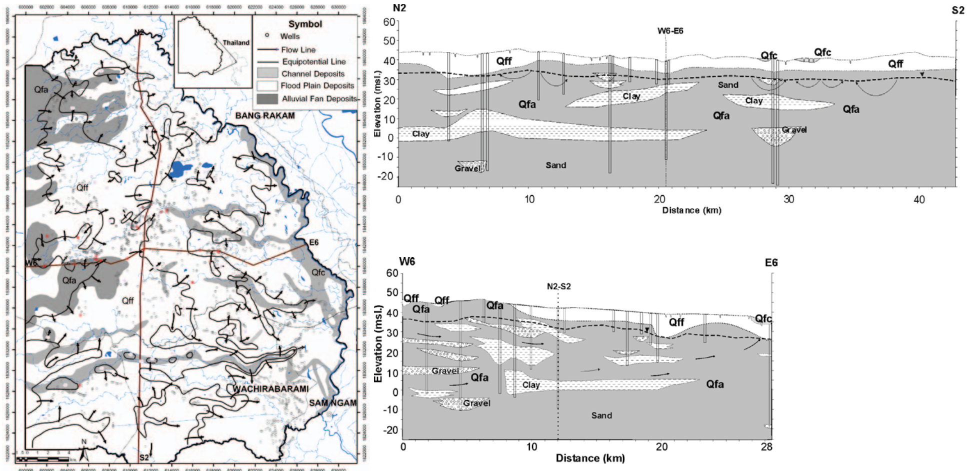

Figure 2. Hydrogeological map and hydrogeological cross sections.

ACKNOWLEDGEMENTS

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Abstract ID: 396

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 $dm^3 \cdot s^{-1}$, however, most of the springs produced much smaller rates of discharge.

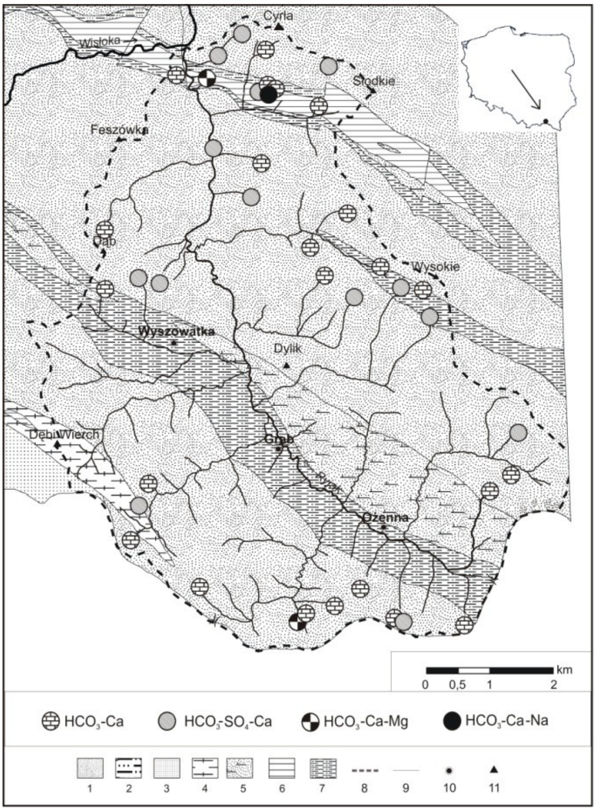

Figure 1. Hydrochemical classes of springs, based on on Szczukariew-Priklonski classification, in Ryjak catchment on geological map (self-processing based on A. Slaczka 1968): 1 — Oligocen thick-layered sandstone and shale (Magura beds); 2 — Eocene shale with sandstone insert (Magura beds); 3 — Eocene 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

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.

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.

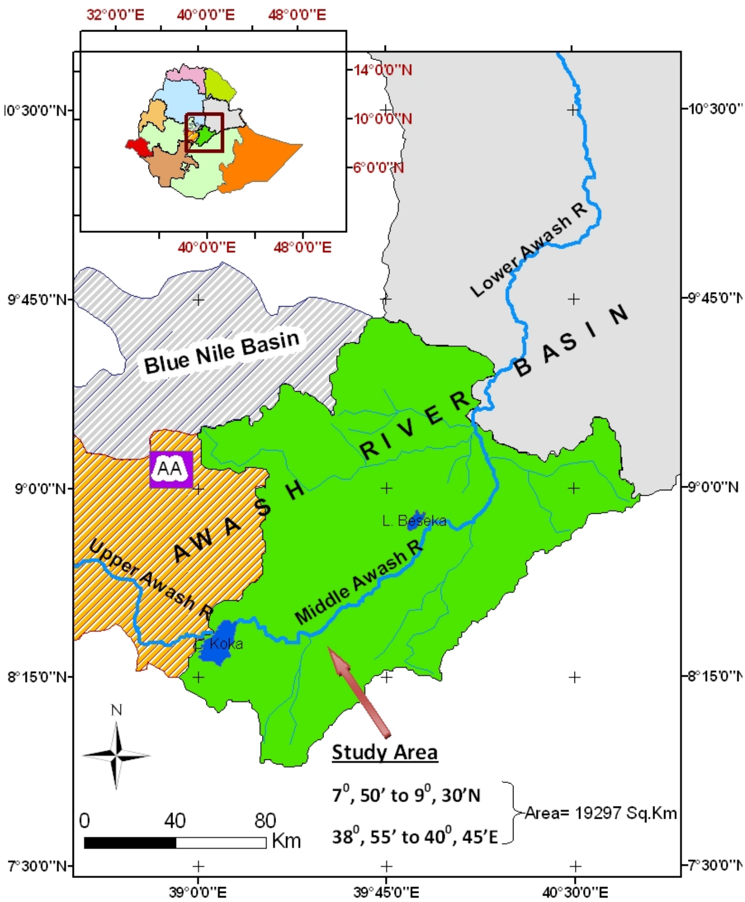

Figure 1. Location map of the Middle Awash Basin.

Abstract ID: 432

REGIONAL GROUNDWATER MANAGEMENT IN ONTARIO, CANADA

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Keywords: regional groundwater flow, database management, Quaternary stratigraphy

In an effort to advance an understanding and management of the groundwater system across a large part of southern Ontario, Canada, a partnership was developed between three regional municipal governments (York, Peel, Durham — YPD), the City of Toronto and the nine conservation authorities located along the Oak Ridges Moraine. The study, 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 (Fig. 1). 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. The Oak Ridges Moraine has long been the focus of significant attention by the Provincial Government as well as by the public owing to the pressing land development pressure imposed from the rapidly growing communities surrounding Toronto.

The groundwater management program has spearheaded a series of technical studies, including regional numerical groundwater modeling investigations, as well as strategic data acquisition initiatives. A significant component of the study is to set up consistency across the study area in terms of guidelines and policies for managing and protecting groundwater resources. 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.

Since its inception in 1999 the program has transitioned through three stages:

Stage 1 — 1999 to 2001 — this stage of work was undertaken by a consultant team and was focused on identifying issues related to groundwater management and protection. The work culminated in a report (AMEC Earth and Environmental et al., 2001) that documented some of the groundwater work taking place in other jurisdictions across Canada and the U.S. The report also inventoried and prioritized areas and issues to be considered for additional work.

Stage 2 — 2001 to 2007 — this stage of work has been characterized by developing and building an analysis system that includes several tools required for understanding and managing the groundwater flow system across the area (e.g. database, digital geology, groundwater flow model).

Stage 3 — 2008 to 2013 — This stage of is focused on implementing the tools within various upcoming groundwater studies that arise in the next few years. This stage is also directed to infilling geological and hydrogeological data gaps and on maintaining and updating the available tools.

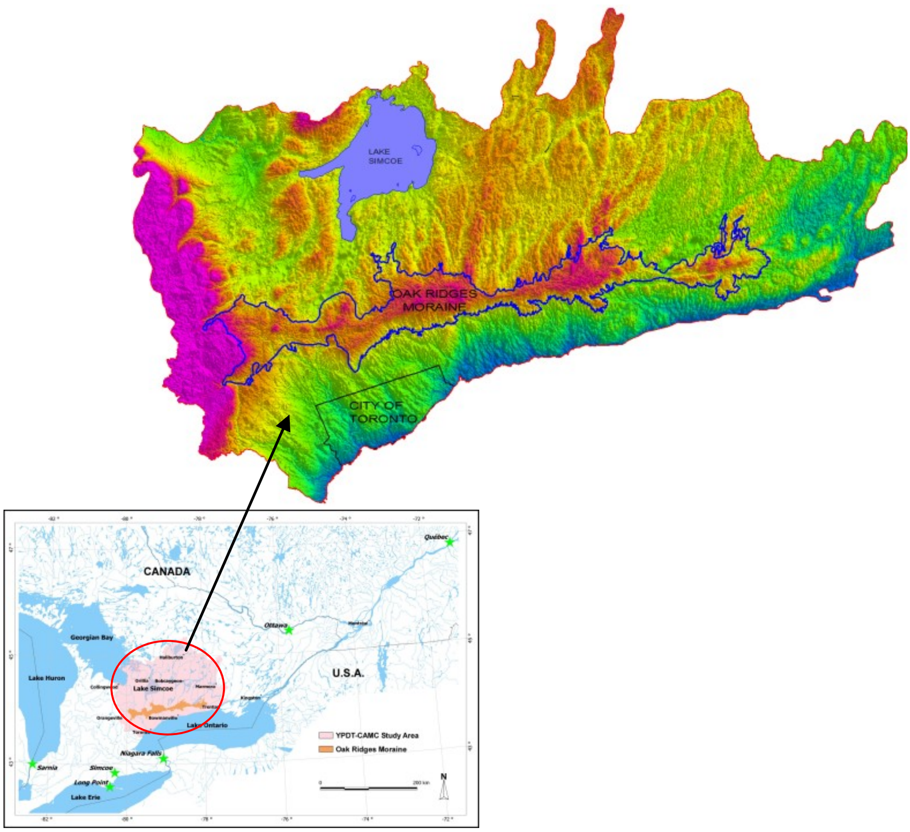

Figure 1. Location and DEM of the Oak Ridges Moraine, Toronto, Canada.

Abstract ID: 435

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

THE GROUNDWATER AGE AND DILUTED IN WATER HELIUM DISTRIBUTION IN THE LITHUANIAN AQUIFERS

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Keywords: groundwater, radiocarbon age, tectonic fracture, helium

Conventional radiocarbon dating of groundwater of southern part of the Baltic basin is quite controversial due to complicated evolution of DIC (Dissolved Inorganic Carbon) and mixing of groundwater originated from different sources in regional flow during palaeoclimatic changes, which have taken place in Pleistocene and Holocene. The objective of this study was to study of seepage via tectonic fractures and to estimate the corrected groundwater radiocarbon age of Middle Devonian and Cretaceous aquifer systems in Lithuania. Hydrogeochemical and isotopic data were used for this evaluation. The interpretation of groundwater residence time in aquifer system by radiocarbon data is complicated and apparent. 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. Age versus depth diagram shows that the modern recharge water is spread for the Quaternary, Cretaceous 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 20 000÷25 000 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. The correction of radiocarbon ages is made according to isotope mixing and Fontes-Garnier matrix exchange models, also by more simplified

alternatives approaches of the dilution factor values evaluation with the tritium and carbon-13 data. Dissolved in groundwater inorganic carbon adjusted radiocarbon ages revealed that in the eastern part of Lithuania shallow lying groundwater ages is modern, mostly characterized like to “future”, the intermediate groundwater in the central Lithuania from the several thousand to about 10 000÷15 000 and in the western coast side part more than 20 000 radiocarbon years BP correspondingly. For the Baltic Basin the groundwater radiocarbon ages could be corrected by geochemical reaction and dilution factor 0.3÷0.5. Old ages in the rivers valleys and in vicinities of hydraulically permeable tectonic fractures has confirmed by geogenic helium anomalies locations. In vicinities of hydrogeologically active tectonic fractures zones the groundwater radiocarbon age and dissolved in water helium values are significantly higher. The high values of dissolved in groundwater helium content confirm leakages through the tectonic lineaments from the crystalline basement.

Abstract ID: 467

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/l 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:

$$M_{0.24}\frac{HCO_3 80.7 Cl 9.4 SO_4 8.8 NO_3 1.0 F 0.3}{Ca 46.4 Mg 31.5 Na 20.3 K 1.7} pH 6.75 \quad (1)$$

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:

$$M_{1.36}\frac{Cl 37.3 SO_4 32.5 HCO_3 29.3 NO_3 0.5 F 0.4}{Na 56.7 Ca 21.7 Mg 19.3 K 2.3} pH 7.50 \quad (2)$$

The average chemical composition of underground waters of the supergene zone is expressed by Kurlov's formula:

$$M_{0.47}\frac{HCO_3 48.9 Cl 26.7 SO_4 23.4 NO_3 0.6 F 0.3}{Na 44.9 Ca 29.9 Mg 23.2 K 2.0} pH 6.9 \quad (3)$$

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

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 considered to be 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.

A 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 section thickness – from surface up to the bottom. All mentioned lakes are characterized by an active water exchange in the water body, what is confirmed by isotope hydrochemistry data and by hydro-chemical 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" was worked out and published. The map was base for explanation of the processes which occur on the different layers of the subterranean hydrosphere in the region and it revealed big prospects of using mineral waters not only in balneology but for supplying with hot water and even for electricity at small geothermal power stations.

As to seismic and tectonics, the Mongol-Baikalian region is active with pretty complicate combination of rift zones and lifting zones. The formation and evolution of the nitrogen hydrothermal systems in the zones are genetically connected with the source of heat. In the rift zones there is a regional thermal flow, in the lifting zones — mantle plums. We can assign a province within Mongol-Baikalian region with distribution of the cold carbonaceous waters which are connected with the mophettes stage of the volcanic activity. On the base of some sources are different resorts available, mineral water pouring is organized, but their resources are used not fully.

A specific type of hydro-mineral systems are lake complexes, which include surface waters of high mineralization, clay brine, as well as rocks forming lake bottom and slopes of their synclines. Mineral lakes are the prospective sources of valuable components such as lithium, bromine, iodine etc.

The influence of Cenozoic volcanism, fracture tectonics and climate change onto formation and modern state of hydro-mineral system condition and possibility of using subterranean hydrosphere in the region for balneology and as drinking water, is suggested.

Abstract ID: 515

HYDROGEOLOGICAL ASPECTS OF QUATERNARY SEDIMENTS IN POLAND

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Keywords: hydrogeology of Poland, Quaternary aquifers, porous aquifers, regional groundwater flow systems

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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3.2 | Transboundary aquifers

Abstract ID: 173

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

To explore the applicability of a laminary appearing formation on the northern edge of the Northern Calcareous Alps as a solid, well protected and sustainable drinking water resource the aquifer characteristics of the dolomite formation were examined by means of measuring points between Reit im Winkl in Bavaria and Waidhofen/Ybbs in Lower Austria. The purpose of the study was to find statements on hydrogeologic features of this special type of aquifer and to compose a generally applicable concept for targeting exploitation of dolomite waters.

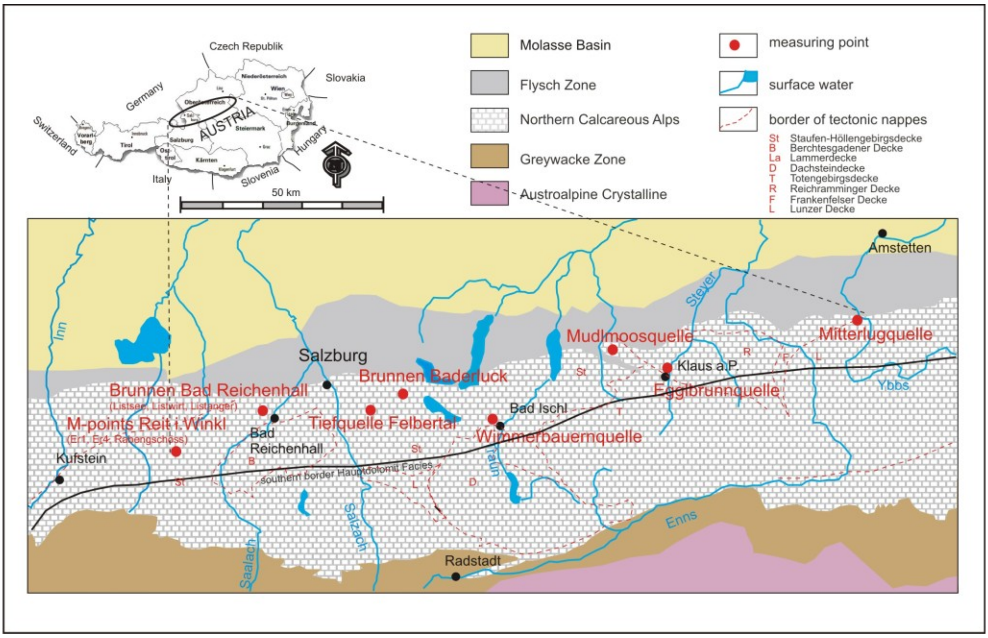

Figure 1. Overview of the study area (simplified after Beck-Mannagetta and Matura 1980, Geol. Karte von Österreich 1 : 1.500.000) supplemented after Tollmann 1976).

The pure dolomite with its characteristic large to micro fissure structures therefore proves as well applicable for an enduring drinking water supply as it features the necessary retention capacity and very slow diffuse flow on micro fissure systems and exhibits the necessary larger structures for water sampling, conduit flow and discharge. The study carried out that the combination of both types of structures inside the aquifer is necessary to provide a suitable discharge. As micro fracturing is not developed consistently over the whole aquifer the absence of micro fracturing on the surface as typical known weathering structures in dolomite is no secured sign for the absence of those structures inside the aquifer. Of more importance concerning the hydrogeological surface situation is the lack of karstified limestone units in the catchment area for those units are responsible for dolomite karstification.

A pure dolomite aquifer can be identified by only a few hydrochemical parameters: The calcium-magnesium ratio is significant as is the lack of extraneous ions like sulphate, sodium and chloride. In addition the saturation indices of the most important phases calcite and dolomite give good evidence to identify pure dolomite waters.

Mean residence times of two years to approximately two decades are conducted by an age distribution which ranges very young (one year) as well as more than fifty years old components. As the very young component was found in every measuring point the study doesn't support the assumption that smaller protection areas and fewer restrictions for land owners are necessary in using dolomite springs for drinking water supply. The most important advantage of dolomite aquifers over limestone aquifers is the lack of karstification and the comparably steady discharge which is less influenced by precipitation and seasonal variations.

Due to the regional diversity in structural, geological and facial conditions within the dolomite formation quantitative regionally valid conclusions concerning the dolomite aquifer can only be estimated. However, the calculations demonstrate that the amount of water available from the dolomite formation considerably exceeds the predicted requirements for the study area on the northern edge of the Northern Calcareous Alps.

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Abstract ID: 201

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.

In order to achieve the sustainable water management of the investigated internationally shared aquifer (Lenart et al., 2003), the main tasks of the international project were:

- development of a common hydrogeological data-base;
- additional field measurements;
- interpretation of the geology for a common conceptual hydrogeological approach;
- creating the conceptual flow model of the transboundary aquifer;
- regional scale groundwater modeling;
- model simulation of different scenarios for groundwater management purposes;
- 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 data. It is already and will be in the future very useful for a possible joint management of groundwater resources. 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 , supplies drinking water to a population of about 100000 inhabitants in Ukraine and in Hungary. 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 the following aspects: piezometric levels; 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.

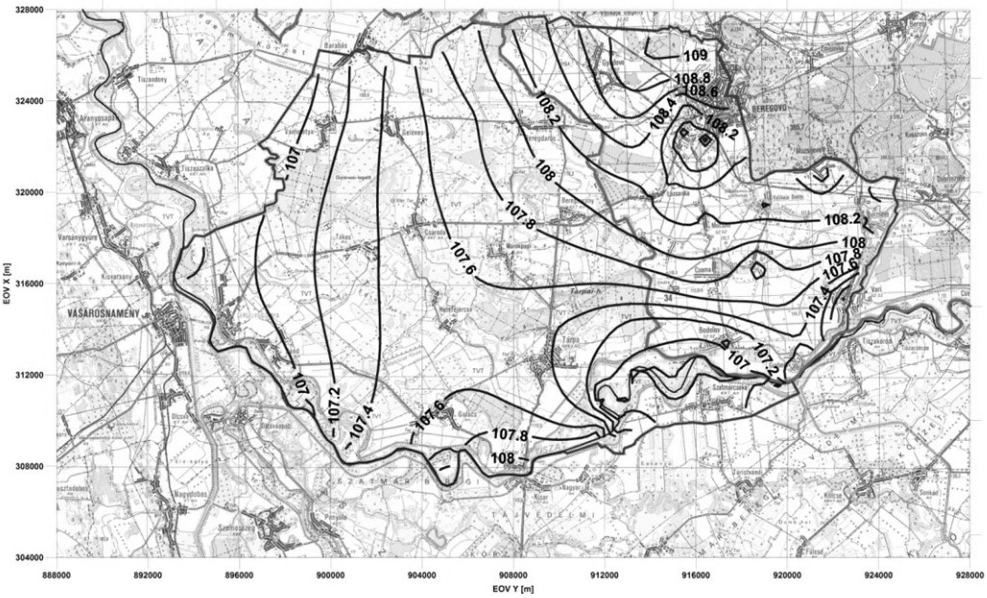

Figure 1. The calibrated hydraulic head map for the transboundary aquifer in case of the steady-state regional groundwater model.

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Abstract ID: 235

TRANSBOUNDARY WATER RESOURCES MANAGEMENT BETWEEN TUNISIA, ALGERIA AND LIBYA AQUIFER NWSAS

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Keywords: transboundary, water management, Tunisia, Algeria, Libya

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

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

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 transboundary 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 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 from 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

TRANSBOUNDARY AQUIFERS IN RUSSIA

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Keywords: aquifers, natural resources, vulnerability, groundwater flow

In recent years the problem of transboundary waters using has become especially actual in many countries. This concerns not only inter-country boundaries where the use of marginal or transboundary rivers in many cases is regulated by special international agreements. As examples one can mention the agreements between Russia and China on usage of the Amur River waters, the agreement between the Governments of Russia and Estonia on corporation in the field of protection and regional use of transboundary waters and other international agreements.

The problem of transboundary water usage regulation is rather acute in 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 actually independently, but coordinating only basic legislative acts 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, define limits for allowable water extraction for those or other demands of a state, and implement control over water quality and levels of contamination by different components.

It should be marked that the problem of assessment of possible and perspective groundwater use in transboundary areas is of great importance for many countries of the world. Moreover this problem is one of the most weakly studied in hydrology and hydrogeology. If do not touch very important social and economic aspects of this problem, it should be marked that the problems of groundwater resources management from hydrogeologic point of view are not essentially developed. The specialists have to answer on a several important in practical sense questions, that are: what is mutual hydrodynamic influence of existed water intakes on groundwater; how much water can be withdrawaled from transboundary aquifer by each country without depletion of groundwater resources; is there a danger of aquifer contamination; what are the perspectives of groundwater use in boundary areas of each country accounting nature-protected measures and etc. The careful analysis of hydrogeologic, and most of all hydrodynamic, conditions in boundary zone by specialists from both sides is necessary for solving of such problems.

The following basic problems of transboundary aquifers study and use that are often tightly connected with each other can be distinguished:

1. Quantitative estimation 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.

2. Determination of chemical, biological and radionuclide compositions of groundwater and an allowable level of its changes.
3. Estimation of fresh groundwater vulnerability in transboundary aquifers to anthropogenic contamination penetrating from the earth's surface.
4. Scientific and methodical substantiation of inter-country agreements on allowable limits of groundwater use from transboundary aquifers, including, in the first turn, geoenvironmental aspects, allowable levels of groundwater extraction, a risk of aquifer contamination and depletion.
5. Development of joint inter-country monitoring of groundwater use and protection of transboundary aquifers.

On the border territory of Russia with the neighbouring countries there are distinguished 13 regions (within on-land boundaries), where transboundary groundwater systems are spread. Some regions are subdivided into sub-regions, according to hydrogeological conditions. Brief characteristic of these regions and sub-regions is reported.

On present stage of hydrogeologic investigations in Russia the main problem lie in development of scientific bases of rational use and forecast of groundwater resources of transboundary aquifers of Russia. The main tasks are: analysis of peculiarities of fresh groundwater formation and distribution in boundary regions of Russia; development methodologies for forecasting of rational use of groundwater of transboundary aquifers; development of principles and criteria of permissible joint groundwater withdrawal from transboundary aquifers accounting nature-protected limits including groundwater protection from contamination and depletion; development of constant-working mathematical models of groundwater deposits distributed in boundary areas of neighboring states aimed to determine conditions and values of hydrodynamic flows recharge and discharge; approbation of models on concrete examples of boundary areas between Russia and neighboring countries of the former USSR.

Abstract ID: 498

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.

3.3 Geophysical, geological and geochemical methods in groundwater exploration

Abstract ID: 110

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

The aim of the present work has been the reconstruction of hydrostratigraphical features of the aquifer succession in the northwestern sector of the Calabrian Crystalline Basement and the associated post-orogenic sequences. The study area is located in the Crati River Valley (*Cosenza* province, Southern Italy), representing a Plio-Pleistocene asymmetric half-graben, with a N–S trend in the southern part and a SW–NE trend in the northern part, delimited on the eastern side by the *Sila* Mountains and on south and west by the *Catena Costiera* relief. The local geological succession, from top to bottom, can be mainly divided into:

1. Calabrian marine deposits (Late Miocene to Pleistocene): basal sand and sandstone formation, blue clay and sand formation, sand and conglomerate with interbedded gravel formation;
2. Biotite and garnet-biotite gneiss and schist (Palaeozoic);
3. Acid intrusive complex (Palaeozoic): quartzdiorite, quartzmonzonite, granodiorite and granite. Often, granitic outcrops are intruded into metamorphic rocks.

This study was carried out taking into account the stratigraphical information collected 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.

The hydrogeological features of the Calabrian Crystalline Basement and of the Crati River Valley sequences were defined by the realization of some hydrogeological sections. These hydrogeological sections and the terrain hydraulic permeability features, as well as the study of depositional sequences, have enabled us to identify two main types of aquifers:

1. Sila aquifers: they are hosted in the Acid intrusive complex and in the Biotite and garnet-biotite gneiss and schist rocks;
2. Crati River Valley aquifers: hosted in Plio-Pleistocene sandy-gravely-conglomeratic deposits and in Holocene alluvial deposits. Impermeable Plio-Pleistocene clayey-sandy deposits limit laterally and vertically these aquifers.

The aquifers of the Calabrian Crystalline Basement are deeper and highly productive, those of Crati River Valley are more superficial and have less capacity. The crystalline basement hosts, in fact, a regional aquifer with a good lateral continuity, even if, also due to the heterogeneity of these rocks, local groundwater circulation is very articulated. It is probable that there is a groundwater-streamwater exchange active system between the water bodies of crystalline basement and those occurring in the alluvial deposits. In the latter, a series of small suspended and overlapped groundwater bodies have been characterized; they are stored in the gravel and sand levels and seem to constitute a multilayer aquifer. The dimension and the hydraulic potential of these groundwater bodies vary with the not well-known horizontal extension of the layers in which they are stored, but probably the potentiality is limited due to their low permeability. The blue clay formation generally represents the *aquiclude* level of the sequences. Furthermore, beneath the alluvial deposits, in the basal sand and sandstone formation, the presence of a regional aquifer separated from the overhanging water bodies by the Plio-Pleistocene clays is probable.

Further investigations may be aimed to define the likely connections among the Crati River Valley aquifers and those hosted in the Calabrian Crystalline Basement and the existence of possible *drainance* processes among them. Finally, since the Crati River Valley aquifers are located below the riverbed, the potential contamination risk of this groundwater by the streamwater should be opportunely controlled.

Abstract ID: 111

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

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 $^{1}H^{+}$ 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.

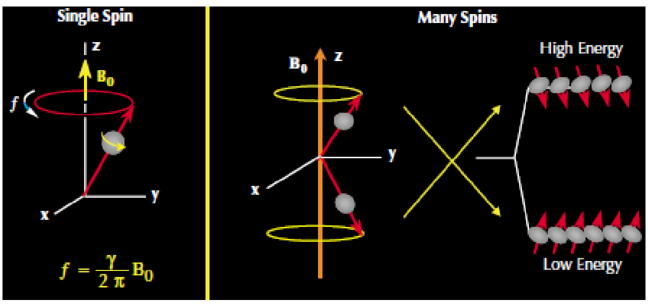

Figure 1. In an external magnetic field (left), the precessional frequency of a nucleus depends on the gyromagnetic ratio of the nucleus and the strength of the external field. The alignment of the precessional axis of the nucleus with respect to the direction of the external field (right) determines 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.

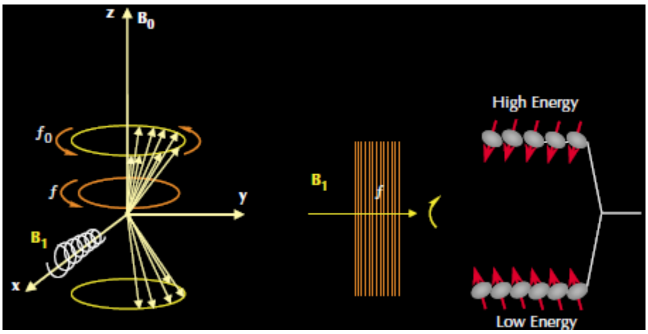

Figure 2. For effective interaction with protons (left), the oscillating magnetic field must have a substantial component perpendicular to the static field B_0 and must have frequency f equal to the proton's Larmor frequency f_l in the static field. In this case (right), the protons will precess in phase 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

EVALUATION OF GROUNDWATER OCCURRENCE OF METROPOLITAN LAGOS, SOUTHWESTERN NIGERIA

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Keywords: Metopolitan Lagos, geophysical, geological, groundwater potential, geochemical data

1. 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.

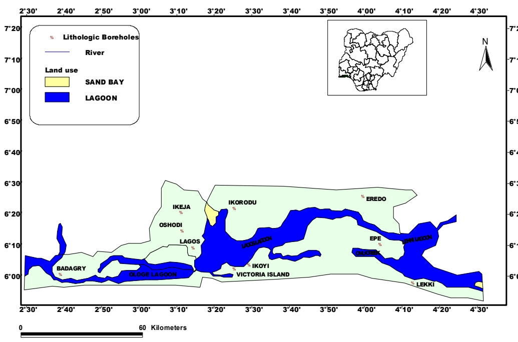

Figure 1. Location map of study area.

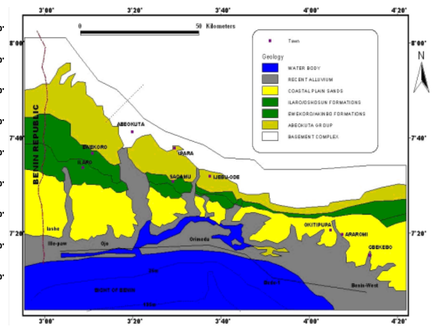

Figure 2. Geological map of Eastern Dahomey Basin (modified after Agagu, 1985).

2. GEOLOGY OF LAGOS

Regionally, Lagos Metropolis is underlain by the rocks of the eastern Dahomey basin (Fig. 2). 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).

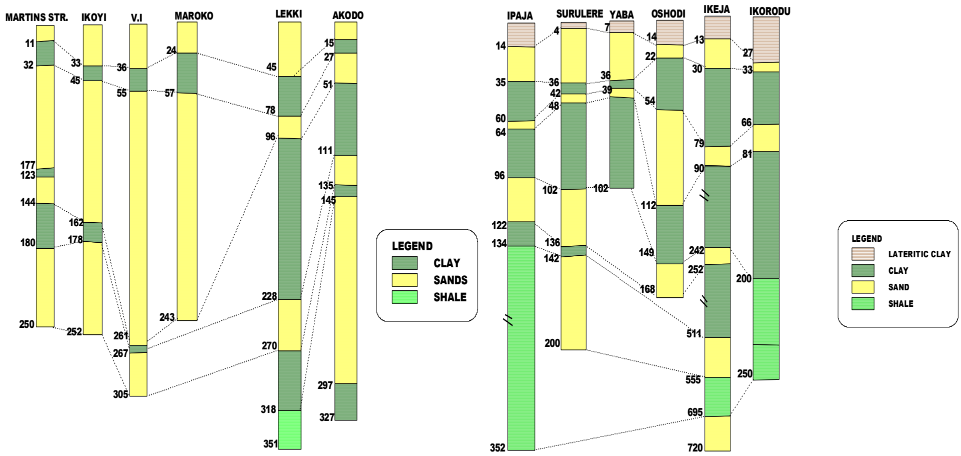

Figure 3. Stratigraphic sequence: a) from Martins Street to Akodo (E-W); b) from Ipaja to Ikorodu (E-W).

3. 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

SALT ACCUMULATION AND GROUNDWATER RECHARGE ON GRANITE SLOPES IN SOUTHEASTERN AUSTRALIA

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Keywords: recharge, stable isotopes, tritium, radiocarbon dating, salinity

1. 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.

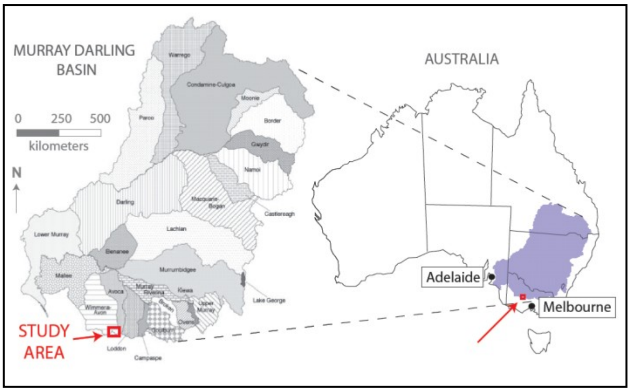

Figure 1. Study area location.

2. 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.

3. 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).

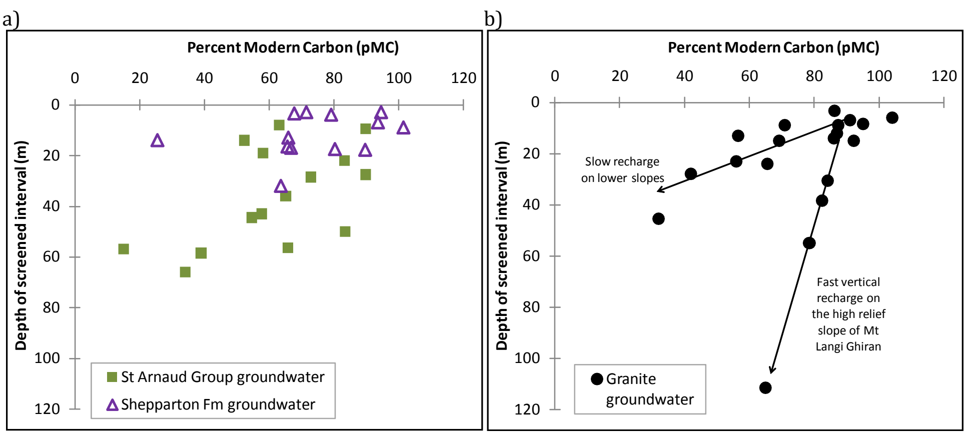

Figure 2. Groundwater percent Modern Carbon versus depth in a) St Arnaud Group and Shepparton Formation groundwater and b) granite groundwater.

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

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Abstract ID: 197

RESISTIVITY AND BOREHOLE DATA INTERPRETATION FOR CHARACTERIZING THE HYDROGEOLOGY OF WESTERN MANAGUA, NICARAGUA

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Keywords: resistivity, hydrogeology, Nicaragua, borehole, pyroclasts

1. INTRODUCTION

Electrical profiles (CVES) and borehole data interpretation has been performed in the Cuajachillo area, located in the western part of the Managua Graben (Frischbutter, 2002; Girard et al., 2004) (Fig. 1). This graben is a consequence of tectonic activity, where several volcanic processes also have taken place. The result of both processes was the deposition of several pyroclastic materials in Managua city. The main objective of this work is to characterise the hydrogeological properties of the study area by analysing and comparing the resistivity values with the lithological interpretation.

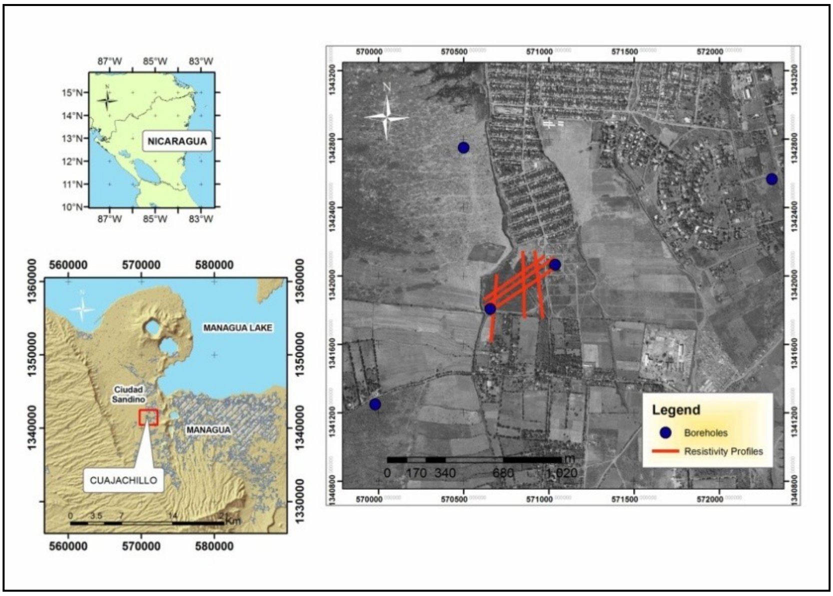

Figure 1. Location Map. Orthophoto map of the Managua area (#2952-303, right side) showing the electrical profiles and boreholes.

2. METHODS

The resistivity data was acquired using the Lund Imaging system with a multi-gradient array. Two dimensional electrical surveying was performed along the profiles (CVES 1-6). The resistivity measurements were processed and inverted with the Res2din software using the least-square method (Loke 1997–1999). The borehole data were interpreted based on the stratigraphical setting of the Managua city and its vicinity. To describe and define volcanic deposits several parameters were also taken into account such as grain size characteristic of the deposit unit, grain shape description, borehole location according to volcanic source and lithological composition. (Németh, Martin, 2007).

3. RESULTS

The resistivity values illustrated three well defined electrical units (Fig. 2). The deposits of the study area, according to the Managua stratigraphy, belong to Chiltepe Tephra, Masaya Tuff, Masaya Triple Layer and Cuesta El Plomo Tuff, mainly composed by pyroclastic surges and fall deposits. Combining the CVES results with the borehole data revealed the existence of one main aquifer unit in the Cuajachillo area. It also showed that the aquifer is formed by unconsolidated pyroclastic deposits and that the materials mainly come from the Cuesta El Plomo Tuff and Las Sierras Ignimbrites with very high porosity. Finally, the resistivity values obtained in this survey were compared with previous electrical data, showing similar results. Both results support the presence of three geoelectrical layers for the unsaturated zone and one layer for the saturated zone.

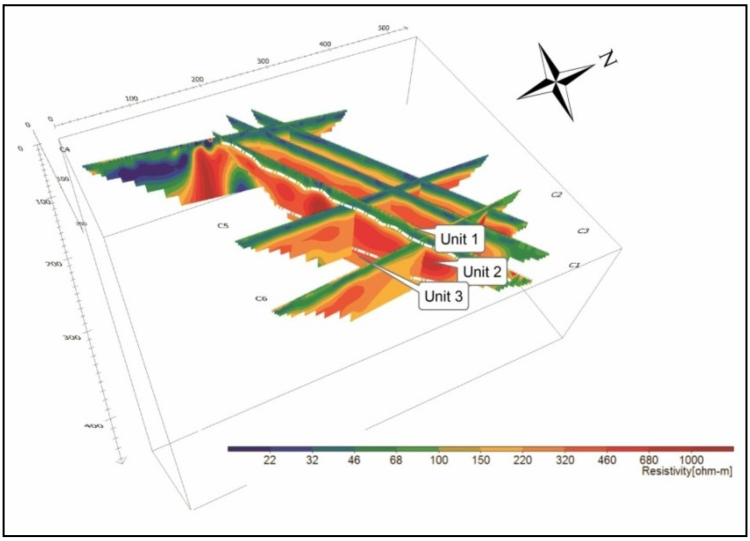

Figure 2. 3D fence diagram. Least squares inversion results (V/H: 1.00) of the electrical profiles.

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Abstract ID: 199

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

STUDY AREA

Slug testing was applied to estimate hydraulic conductivities in the Las Sierras aquifer, located in Managua-Nicaragua and constituted by unconsolidated and lithified volcaniclastic deposits. Five different locations were selected taking into account the site accessibility and the availability of additional borehole information regarding well completion and lithological description. The slug tests were initiated by applying the pneumatic approach with small modifications (Butler, 1998). In total six wells were tested by carrying out multiple slug tests in each of them (Fig. 1).

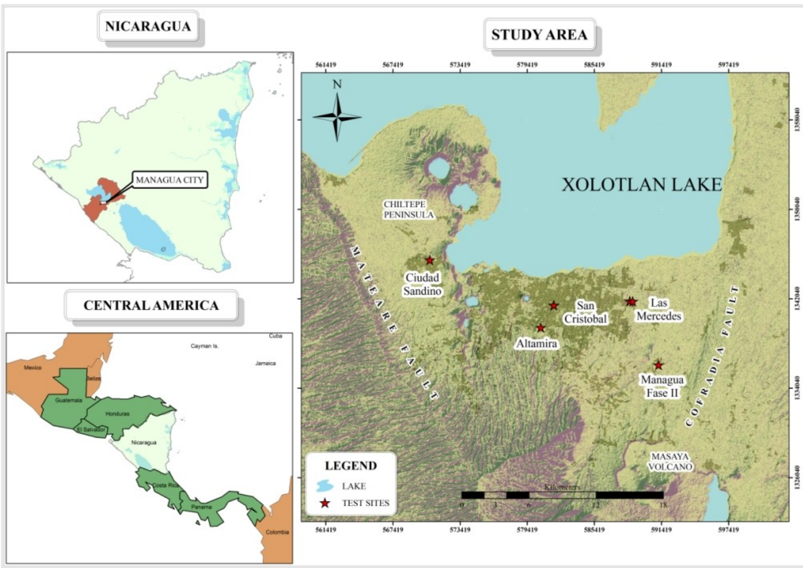

Figure 1. Location study area and tested sites.

RESULTS

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 (Tab. 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	Tested Wells	Tests/Well	Geological Deposits	K (m/sec)
Las Mercedes	2	8	*Qal + QvM + TQpsM	1.50E-04
San Cristóbal	1	7	*TQpsM	8.10E-06
Managua Fase II	1	4	*QvM + TQpsM	1.20E-05
Altamira	1	5	QvM + TQpsM	1.30E-05
Ciudad Sandino	1	8	Qal + *QvChiltepe	5.20E-05

*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.

ACKNOWLEDGEMENTS

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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

GEOPHYSICAL AND GEOCHEMICAL GROUNDWATER EXPLORATION (ESSAOUIRA BASIN, MOROCCO)

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Keywords: Essaouira, aquifer system, flow patterns, geophysical, geochemical

The aquifer system of the basin of Essaouira is the only source of water supply to the Essaouira city, located on the Atlantic coastline, in a semi arid climate area. The senonian marls constitute an aquiclude that separate a turonian confined aquifer from a shallow, unconfined Plio-Quaternary aquifer.

Management of the basin' s water resources requires improved understanding of regional flow patterns. The study undertaken on Plio-Quaternary aquifer shows as 1976's piezometric map that the main groundwater flow direction is from SE to NW towards the Atlantic Ocean with a divide groundwater line separating the area in North and South parts. According to these results, the interpretation of the mineralisation evolution can't be explained validly neither by the direction of flow nor by a lithological change in the aquifer matrix.

The Plio-quaternary substratum map collected at the SCP (Societe Cherifienne de Petrol) compiled with the piezometric map that we carried out showed two new facts (i) a rise of substratum in the occidental area due to diapiric tectonics which prevents the arrival of groundwater to the ocean, (ii) existence of a topographic inversion which make possible the connection between the North and the South parts.

We also proceed to the interpretation of seismic profiles collected at the ONAREP (Office National de Recherche et d'Exploitation Petroliere), to draw up the structural map of the turonian aquifer.

These data were used to elaborate a new groundwater flow patterns, which makes possible to correctly interpret the hydro-chemical data of the Plio-Quaternary aquifer. To confirm that, we carried out isotopic analyses on some water points, the results obtained supported the proposition suggested.

Abstract ID: 220

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. 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 are not 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.

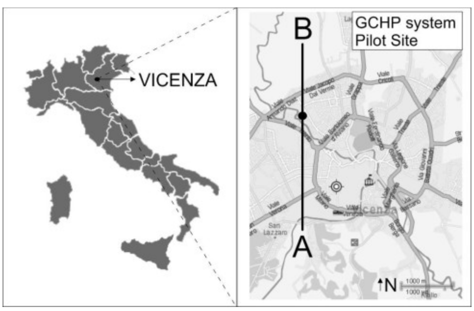

Figure 1. Location of the studied area.

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).

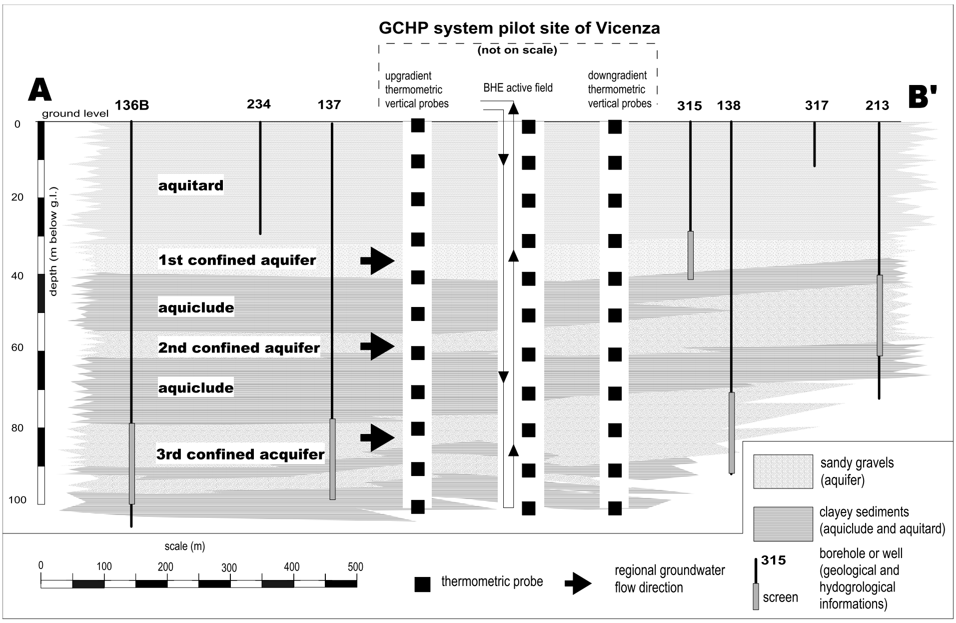

Figure 2. Section assessment of the pilot site.

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

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 terestrial 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.

ACKNOWLEDGMENTS

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Abstract ID: 273

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.

Chemical denudation, understood as processes leading to the removal of the earth materials from the land masses, is one of the components of the elemental cycle in nature, which influences chemistry of surface and ground waters 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 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 been not typically included 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, Joliocoeur, 2002; Hodson et al., 2002).

A new approach which uses a numerical model, 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).

The study area included the Bialy Potok watershed, located in the West Tatra Mountains, south of Zakopane, Southern Poland. Lithologically, the watershed is predominantly composed of carbonate deposits — Sub-Tatric Units dolomites and limestones.

Physical and chemical parameters of atmospheric precipitation, surface water and ground water corresponding to hydrologic cycle in the study area and mineralogical composition of the phreatic zone were used as input data in the model.

The model uses program PHREEQC v. 2.11, including corresponding thermodynamic data base phreeq.dat (Parhust, Appelo, 1999). The program has been selected it allows for direct and inverse modeling, characterizes the aqueous solution, includes temperature changes along the flow paths, and evaporation effects on ionic concentrations. Above all, this program is very commonly used to model geochemical processes (Macioszczyk, Witczak, 1999; Zenisova et al., 2002; Ozdemir, Nalbantcilar, 2002; Dobrzyński, 2005; Lachmar et al., 2006; Demirel, Cuneyt, 2006; Broder, Planer-Friedrich, 2008).

Verification of the models has been conducted by comparing the modeling results with the laboratory and field research data. Verified correlation typically exceeded 95%.

Mass transfer obtained from the modeling allowed to determine dissolution and precipitation processes of the mineral phases occurring in the studied areas. Further, total volume of the dissolved minerals in a unit volume of aqueous solution was determined based on the calculated dissolved mineral phases and their density. These data were used with flow volumes of surface and ground water and the size of the watershed (determined using ArcView GIS 9.3), for to quantitative evaluation of the chemical denudation of the study area.

The calculated rates of the chemical denudation were verified using empirical methods. This verification was conducted in two-steps:

1. qualitative evaluation of processes in the phreatic zone, including chemical weathering identified in thin sections cut from rocks occurring in the study area which were "buried" in the phreatic zone, and
2. quantitative evaluation of the chemical weathering of rock disks "buried" in the phreatic zone.

The results of this research indicate, that the rates of the chemical denudation which were previously determined based on the hydrologic processes are considerably higher that these based on geochemical modeling which included processes occurring in the phreatic zone. Thus, commonly used hydrologic approaches to evaluation of the chemical denudation can overestimate the rate of karst processes even as much as 30–40%.

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Abstract ID: 314

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

One of the most reliable ways to gather aquifer properties is drilling exploration boreholes and conducting hydraulic tests. However, field estimates of aquifer properties are often scarce because 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, and the relationships between geophysical and hydrogeological properties are usually site specific and valid only for their calibration range (Vereecken et al., 2006). As compared to other geophysical methods, magnetic resonance sounding (MRS) is selective with respect to groundwater (Legchenko, Valla, 2002). Since the 1990s, this distinctive feature has been used by several scientists to assess the links between MRS parameters and hydrogeological properties of aquifers. This paper presents the main results that can be achieved nowadays using MRS for characterizing aquifers.

NON-CONSOLIDATED AQUIFERS

MRS contribution to characterize aquifers down to about 100 meters deep is highly valuable in rocks that exhibit behaviour of non or poorly-consolidated aquifer (that are young sediments, sandstones, weathered and fissured hard-rocks, densely fissured or highly interstitial porous carbonates). Comparisons between MRS and borehole/pumping test results reveal that depths to the water table and to the bottom of saturated aquifers, and the transmissivity is estimated from MRS parameters with an acceptable accuracy (Fig. 1, Vouillamoz et al., 2007b). Moreover, experiences show that the characterization of aquifer using MRS can efficiently be used to improve boreholes setting in several hydrogeological contexts including coastal aquifers (Vouillamoz et al., 2002; Vouillamoz et al., 2007a) and to better constrain groundwater model (Boucher et al., 2009; Vouillamoz et al., 2008). The aquifer characterization is improved when MRS is used in the framework of a hydrogeological methodology and jointly with complementary geophysical methods.

MAJOR LIMITATIONS OF MRS

In rocks that exhibit behaviour of fractured aquifer (that are low density fractured crystalline basements and limestone, karsts) MRS is a useful complementary method but is not always effective for common engineering studies. Moreover, quantitative relationship between MRS results and effective porosity or specific yield has not yet been achieved although there is a strong theoretical basis for the relationship (Boucher et al., 2009; Vouillamoz et al., 2005).

Finally, the electromagnetic noise makes urban areas difficult to survey. However, the current limits of MRS methods create opportunities to the hydrogeophysical community for improving the method for the benefit of everyone.

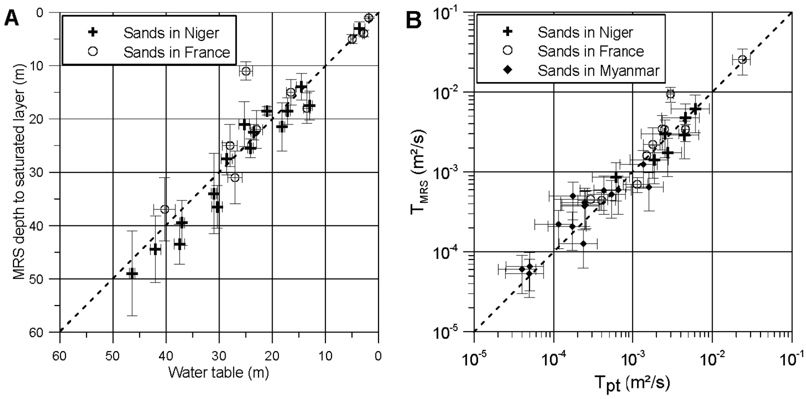

Figure1. Examples of MRS results: A) Estimate of the depth to water table; B) estimate of the transmissivity (modified from Vouillamoz et al., 2007b).

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Abstract ID: 315

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

The present work displays an integrated geological, geophysical, hydraulic and geochemical analyses in order to characterize groundwater flows in a faulted multiple aquifer system. As a result of the complex investigation, the hydraulic behaviour of the identified faults and also their role in hydrocarbon entrapment was determined.

The study area (Fig. 1) was chosen in the Trans-Tisza Region of Hungary based on the presence of a previously observed significant anomaly in the fluid-potential field (Tóth and Almási, 2001), as well as thermal water (Spa of Berekfürdő) and hydrocarbon accumulations (Tatárülés-Kunmadaras gas field). The geological framework was determined by the joint interpretation of geological and geophysical data, such as seismic sections, well-logs and lithostratigraphic subdivision data. Consequently, the heterogeneity of a thick (ca. 1000 m) and regionally extensive argillaceous aquitard unit was established, which is divided by structural elements and relatively thin (150–200 m) sandy aquifer units. Furthermore, there were identified two major strike-slip fault zones connecting the overpressured Pre-Neogene basement also with the uppermost aquifer unit, intersecting each other in the south of Berekfürdő. Afterwards, the groundwater flow system was characterized i) hydraulically by analyzing stabilized water level and pore pressure data; whereas ii) hydrochemically by analyzing the Na^+, Cl^- and H_2SiO_3 water compounds.

Finally, as a combination of all of these results, it could be determined that the identified faults represent direction dependent control over the fluid flow systems of the study area. Since, both proved to be vertically conduit but transversally barrier, they enable pressure dissipation and intensive water upwelling from the Pre-Neogene basement resulting in the fluid-potential anomaly, and at the same time in hydrocarbon entrapment. The peak of the potential anomaly forming a “plume” is located at the junction of the fault zones and “provides” the thermal water of the Berekfürdő Spa.

Eventually, the integrative application of the different research techniques has allowed of a complex petroleum hydrogeological interpretation, which suggests that this methodology could be generalized and applied also on other research areas.

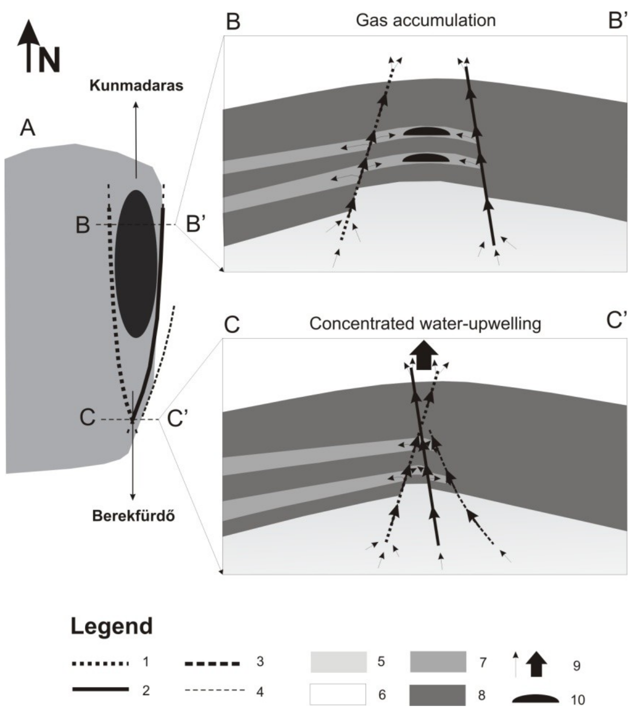

Figure 1. Diagram of the interpreted phenomena in the study area. Explanations: A — The Local Study Area in top view; BB', CC' — Cross sections from the northern and southern part of the local research area; 1, 2 — strike-slip master faults; 3 — reverse fault; 4 — trace of cross section; 5 — Pre-Neogene basement; 6–7 — aquifer units; 8 — aquitard units; 9 — fluid flow direction; 10 — gas field.

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Abstract ID: 317

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

Coal-mining is a source of the bulk amount of mine waste, which brings about complex environmental problems, particularly related to groundwater contamination. Long-term potential pollution of mining waste to the aquatic environment results mainly from the chemical composition of coal mining waste and their transformation products. Geophysical methods were used to assess the impact of the leachate from coal mining waste dumps on contaminant distribution in groundwater. The results of geophysical investigation were compared with hydrogeological observation obtained at the same time.

The investigation is carried out within the frame of the grant project No. N525 398034 "Application of geophysical methods for investigation of migration of contaminants from the coal mining waste dump".

Water samples were collected from selected wells and from some surface hydrological sites. Major chemical constituents as well as trace elements were determined in the laboratory by ICP-MS. These results led to mapping the spatial distribution of contaminants in the tested areas and were compared with the interpretation of geophysical data.

The georadar measurements and geoelectrical methods were chosen for the geophysical investigation. The measurement results have been interpreted on the base of physical theory giving the relation between the physical parameters distribution in the rocks and the results of the geophysical investigations. It was shown, that the changes of electrical resistivity depends on chemical components concentration in the water, the porosity and permeability of the medium. The changes of this parameter can be used for the identification of contamination distribution with geophysical methods. The advances and limits of the use of geophysical methods for the assessment of contaminant migration from the mining waste mineral deposits have been discussed.

The electrical resistivity of rocks depends on the water saturation and its mineralization. The geoelectrical method has been used for measurements, particularly the geoelectrical profiles were located along the lines appointed in the hydrogeological map, where an intensive gradient of mineralization was observed. The electrical imaging method was used and the 2D electrical resistivity distribution was obtained in result of the measurements. The results allow to recognize not only very shallow distribution of contaminant but also deeper parts of geological medium.

Along the same profile the reflected georadar waves were recorded and the coefficients of reflection were estimated. The coefficient value is related to the water mineralization value and it can be used for an assessment of the contaminants distribution.

The paper presents the correlations between the changes of reflection coefficients and the electrical resistivity changes, the latter being a function of mineralization.

The geoelectrical, georadar and hydrogeological data are correlated proving that the geophysical methods are useful in location the contaminated, mineralized water.

Abstract ID: 324

GEOPHYSICAL INVESTIGATIONS FOR GROUNDWATER AUGMENTING IN SAND DUNES AREA, BINHTHUAN, VIETNAM

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Keywords: geophysical tool, investigation, groundwater augmenting, monitoring well

The study area is located in the HongPhong village, BacBinh district, BinhThuan province where the extensive red coastal sand dunes occur. This area is the driest part of Vietnam, with the latitudes 11°01’00 and 11°05’00 north, and longitudes 108°15’00 and 108°22’00 east. BauThieu mountain is situated in study area which the top is 302 m of high and the rest part is hilly and coastal plain with changeable relief from west to east. The complex geophysical methods were used for investigating deep geological structure to locate an aquifer as well as magnetotelluric sounding (MTS) for very deep structure, resistivity sounding or profiling (VES and EP), magnetic prospecting (MP), transient electromagnetic method (TEM) and seismic refraction (SR) for shallow structure, very low frequency electromagnetic (VLF) method frequency domain electromagnetic method for near-surface structure and magnetic resonance sounding (MRS) for comparing with boreholes in the area. The target of geophysical investigation is hydrogeological condition for groundwater augmenting in the studying area then the geoelectrical methods and electromagnetic methods are employed very commonly as active methods because of more economical and effective than other geophysical techniques. To achieve these objectives, conventional Schlumberger and Wenner soundings and profilings are currently used worlwide.

On the study area were carried out 10 geoelectrical profiles by Schlumberger configuration for sounding with maximum current electrode spacing AB = 1000 m and for profiling with AB = 400 m. The VES data are interpreted using a stable iterative procedure to delineate subsurface structure. The result of VES and EP interpretation give useful information regarding the water saturated layer down to 50 m for NuocNoi1, NuocNoi2, op profiles and the water saturated zone down to 40 m for ab, qr profiles.

The 8000 m of seismic refraction profiles were done by seismograph Terraloc MK6 24 channels by 5 m spacing of geophones for bedrock delineation and interface of sedimentary layers by seismic velocity values.

The VLF and frequency domain electromagnetic data are interpreted using filtered techniques and give information regarding the conductive zone down to 40 m on the NuocNoi and ab profiles. This zone is related with water saturated sand.

Two places in the studying area are located for perspective of hydrogeological condition on the basic of complex geophysical investigation. First one is on the west part of area where were situated op and qr VES profiles and the water saturated zone is down 40–50 m. The second place is located on east part of area with the water saturated zone down to 50 m where were situated VES profiles NuocNoi1-2 and ab. Ground water in the aquifers is fresh water because the values of resistivity calculated by geoelectrical data are ranged 20 Ω.m.

Inspite of very dry sand on the surface of the studying area, we should choose agreeable period in the raining season to collect geoelectrical data (VES, EP) and SR and dry season to do MP, MRS, VLF and TEM for geophysical investigation. This results are useful for understanding of hydrogeological structure to groundwater augmenting in studying area and proved by 6 monitoring wells.

Abstract ID: 346

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).

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 ~300 m 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 190 m 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. Tidal sand bodies are sand flats with sheet geometry, while fluvial sand bodies are lenticular channel fills and lobate crevasse splays. 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. 1).

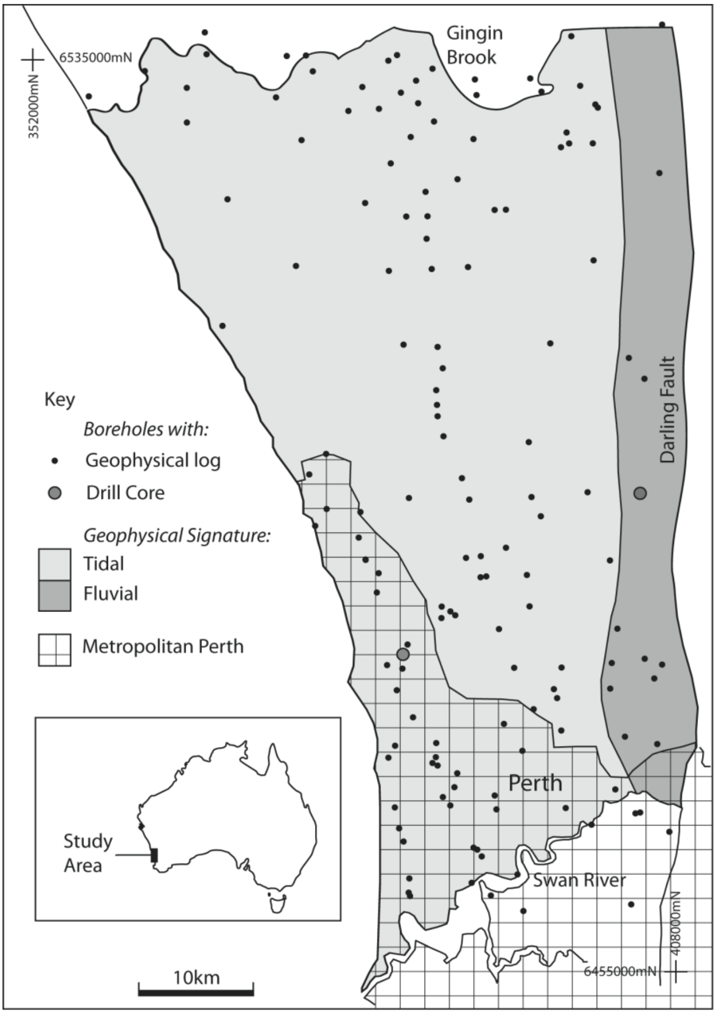

Figure 1. Map showing study area, boreholes and zones of geophysical signature.

Borehole gamma-ray logs were categorised, interpreted and correlated in 3D, and we outline zones (~10 km wide and ~100 m 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

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

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. During the hydrogeological investigations for determination of the sanitary protection zones of the groundwater source, hydrochemical data were used as additional tool for better understanding of groundwater renewability, circulation time, geochemical evolution, rock-water interaction etc.

The study area (Mt. Ivanšćica) is located in the north–west part of Croatia. Ivanšćica is the highest mountain in this area with the highest peak 1061 m a.s.l. 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 are also impermeable sediments. Carbonate rocks of Triassic ($T_{2,3}$) age are dolomite and limestone which are the main aquifers. Cretaceous sediments are clastic carbonate sediments, which have poor permeability. The Miocene sediments are subdivided into lower Miocene (marly limestones, clayey sand and clay — impermeable sediments), middle Miocene (lithotamnium limestones — aquifer) and upper Miocene deposits (marl — impermeable sediments). The Quaternary sediments are proluvial sediments mainly found on slopes. The four major springs (Šumi, Beli Zdenci, Bistrica, Žgano Vino) 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.

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 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: 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 the basic cations: 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 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.

According to majors 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. Very low concentrations of nitrate, sulfate and chloride were observed, whereas concentrations of ammonium and phosphate were below detection limit. The spring waters are not microbiological polluted. The stable isotope ratio confirms the aquifer recharge by precipitation. The tritium content indicates the long circulation time of groundwater but also the groundwater renewability by precipitation.

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Abstract ID: 452

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

INTRODUCTION

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 region of occurrence. The Barreiras Formation deposits occur in the northern coast of Rio de Janeiro State, Campos Sedimentary Basin, Brazil, are usually composed of tabular sandstone layers, interbedded with mudstone lenses, and are associated to braided rivers deposits .

METHODS

In this study, sedimentological and permoporous tests were conducted in two outcrops (according to Klingbeil et al., 1999). Laboratory and field tests were carried out (Dickinson, 1970; Folk, 1980; Fetter, 2001) in order to define porosity, hydraulic conductivity (Ezzy et al., 2006; Elrick et al., 1989) and textural aspects of Barreiras Formation sediments, to characterize heterogeneity, define hydrofacies (Anderson et al., 1999; Anderson, 1989) and to evaluate the reservoir quality of the Barreiras aquifer.

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, Weyl, 1973). The sandstone lithofacies have a relatively low permeability, ranging from 10^{-4} to 10^{-5} cm/s (hydrofacies 1), albeit considered as the local aquifer. The mudstones lithofacies hydraulic conductivity ranges from 10^{-5} to 10^{-8} cm/s (hydrofacies 2), and represent the aquitard. 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.

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Abstract ID: 481

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 was originally designed for hydrogeological and environmental investigations. Since 2004 the system has been intensively used in Denmark for large scale mapping of groundwater resources. World wide, more than 150 000 line km of airborne data has been collected with the SkyTEM system in relation to either groundwater or mining projects. The method has shown its ability in mapping shallow geological structures as well as deep aquifers related to coarse-grained sediments or structural elements in the subsurface. The system has been 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 groundbased TEM systems (Fig. 1).

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.

RESULTS

A SkyTEM survey project basically includes airborne dataaquisition, data processing through several steps and imaging of the results. The results reflect the electrical resistivity of the subsurface at different depths (Fig. 2). The relationship between resistivity levels and specific sediment- or rock types makes it possible to interpret the results in a hydrogeological perspective. In the example given both limestone and sand/gravel deposits (high resistivity) 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 the low hydraulic conductivity in the fine grained sediments. As illustrated, 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.

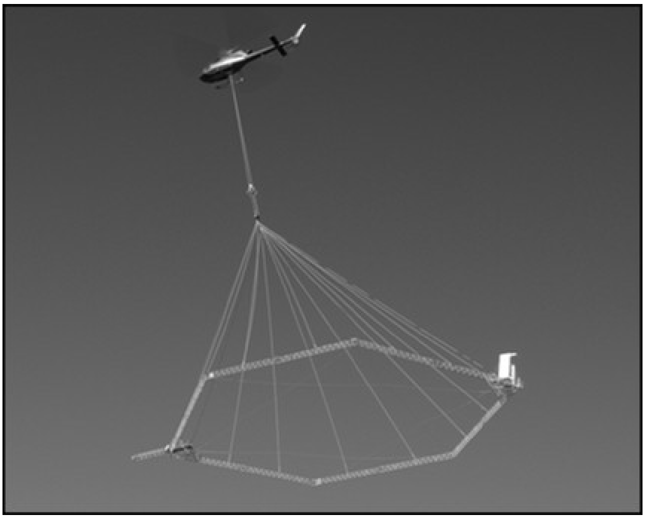

Figure 1. Picture showing the SkyTEM system in operation (Photo: SkyTEM ApS).

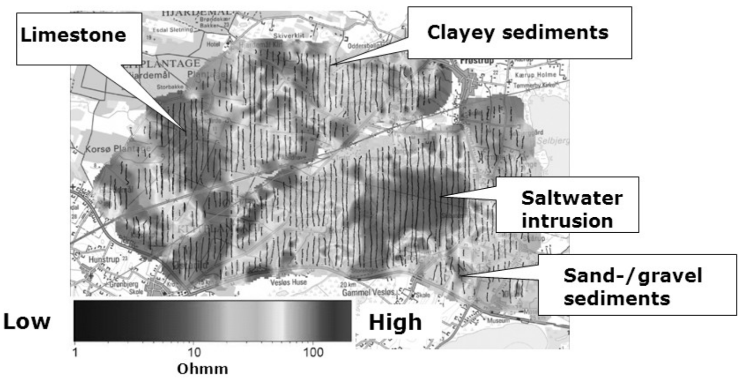

Figure 2. Image illustrating the electrical resistivity (ohmm) based on SkyTEM data (selected level 20–30 metres below the surface). Note that original image is colorized.

The chosen example in Fig. 2, mainly serves as a presentation of the SkyTEM resistivity mapping concept. Other SkyTEM cases of relevance concerning groundwater issues will be included in the final presentation.

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Abstract ID: 489

NEW HYDROGEOPHYSICAL METHOD FOR HYDROGEOLOGISTS CALLED MRS FOR QUANTIFICATION OF WATER IN SUBSURFACE AND GROUNDWATER MANAGEMENT

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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 and 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

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. 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. Results also show that because of photochemical decay, eosin is the most unstable tracer if subjected to sun light. $KMnO_4$ turns to brown under sun light and higher temperature conditions and may lose its characteristics as a tracer. The fluorescence intensity of rhodamine B decreases with increasing temperature and NaCl and KCl induced salinity. Uranine and eosin have high resistance against high temperature and salinity. With regards to adsorption in porous media, 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. 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.

Abstract ID: 123

THE GAS CHROMATOGRAPHIC METHOD IN MEASUREMENTS OF HELIUM CONCENTRATION IN GROUNDWATER

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Keywords: gas chromatography, helium, groundwater dating

Helium concentration in groundwater is a fine indicator in water dating in a range from a hundred to tens of thousands of years (Andrews, 1989; Zuber et al., 2007). Gas chromatography (GC) measurements of helium (Zuber et at., 2007) can be used as an alternative to mass spectrometry (MS) determinations of ^{4}He for groundwater dating.

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.

The system consists of a gas chromatograph equipped with a Valco TCD detector of 2 µl 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. Water samples are taken to the stainless steel containers of volume 2900 cm^3 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. 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. There are used three columns K1, K2 and K3. Columns K1 and K2 are filled with molecular sieve 5A (Sugisaki et al., 1981; Sugisaki et al., 1987) and column K3 is filled with a mixture of molecular sieve 5A and activated charcoal 50%/50% (Zieliński, 1961).

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^{3}STPg/g_{H2O}.

ACKNOWLEDGEMENTS

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Abstract ID: 128

VULNERABILITY OF WATERS IN THE AREA OF THE FRUITLAND FORMATION, SOUTHEASTERN COLORADO

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Keywords: tritium, groundwater age, coal bed methane, vulnerability

In 2008 a sampling program in Southeastern Colorado was undertaken to understand the potential perturbation of surface and groundwaters to the production of coal bed methane in the Fruitland Formation. Among the analytes measured was tritium to give estimates of the age range of waters in the system. "Old" waters are considered relatively safe from perturbations while younger waters are potentially sensitive to contamination during exploitation. Water samples ranged from those obtained from deep wells and mines to those obtained from shallow unconfined aquifers, springs, and surface waters. Approximately 135 samples have been analyzed to this point, and the tritium distributions are bimodal with about 10 percent of the concentrations less than 1.5 TU and about 75% ranging between 4.5–7 TU (Fig. 1).

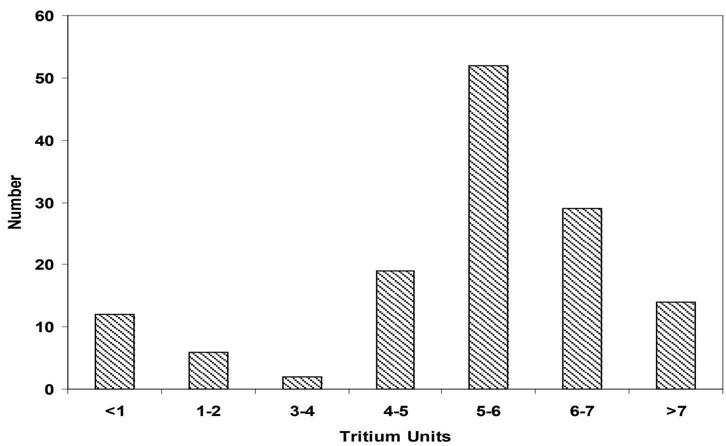

Figure 1. Distribution of tritium concentrations measured in area of the Fruitland Formation, Southeastern Colorado.

The lower concentration waters are “old” water and primarily recharged prior to the bomb transient with an occasional small admixture of recent water. Carbon-14 analyses of the dissolved inorganic carbon in these deep waters provide an upper age of about 10,000 years. The other major mode is composed of waters with tritium concentration close to recent precipitation in southeastern Colorado, which is significantly lower than in the northern part of the state due to the influence of air masses from the gulf region in summer. 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. An exponential model indicates that most of the waters in the second mode were deposited well after the peak of the bomb transient (mid-1960s to the 1970s) and are likely decadal in age. There is little difference in the age of water in shallow aquifers, springs, and surface waters. These results suggest that care must be taken during methane exploitation in these areas to avoid adverse affects on water quantity and quality.

Abstract ID: 143

STABLE CARBON PATTERN IN BELGRADE CATCHMENT AREA, SERBIA

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Keywords: carbon isotope, dissolved inorganic carbon, particular organic carbon, Belgrade

In this work, we have studied the stable isotopic composition of DIC (dissolved inorganic carbon) and POC (particular organic carbon) 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. 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 consists of gravels, sandy gravels, gravely, sand (intergranular porosity) and that sporadically alternate towards the terrain surface (Dimkić et al, 2007). In some locations floor is made of lime stones dating from lower-Cretaceous and Sarmat. In the area of Ostruznica village alluvial aquifer lies over upper-Cretaceous (Ostruznica) flysch.

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. Water samples were collected in March, May and July of 2008 and 2009 in the area of Belgrade from surface water (the Sava River and channels) and groundwater (piezometers and production wells). 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 (Fig. 1). 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‰ pointed out an occurrence of intensive photo-

synthetic activity of phytoplankton in summer and they are significantly controlled by water temperature. A mean value for $\delta^{13}C_{DIC}$ of −13.1 ± 1.1‰ in groundwaters is near 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 ($\delta^{13}C_{Ca}$ about 0.0‰). Therefore, it is considered that $\delta^{13}C_{DIC}$ is mainly controlled by two primary sources: soil CO_2 and the dissolution of carbonate minerals which were varied depending on location. Evolution of $\delta^{13}C_{DIC}$ in respect to {[CO_2(aq)]+[H_2CO_3]}/alkalinity ratio during sampling campaigns was compared to the theoretical evolution of the $\delta^{13}C_{DIC}$ (Amiotte-Suchet et al., 1999) in isotopic equilibrium with different soil CO_2 phases.

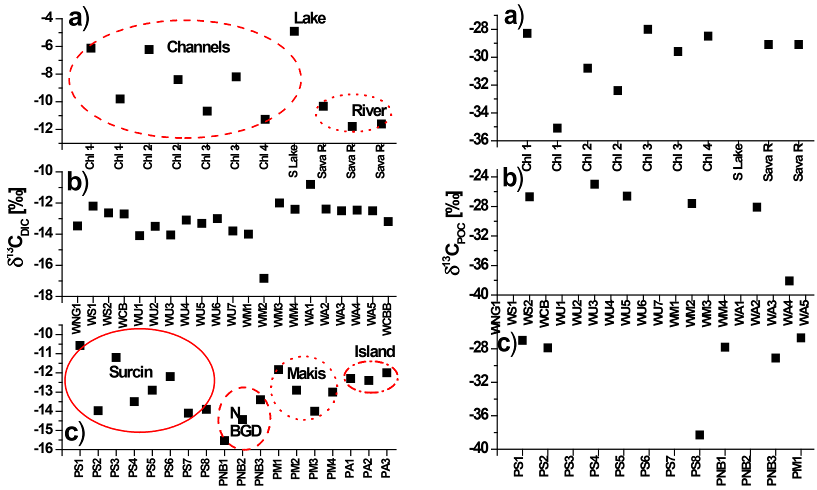

Figure 1. Spatial variations of $\delta^{13}C_{DIC}$ and $\delta^{13}C_{POC}$ in: a) surface waters, b) operation wells and c) piezometers in Belgrade area.

The $\delta^{13}C$ values of the POC in analyzed samples range from −38.3‰ to −25.0‰. The $\delta^{13}C$ values of the POC in analyzed waters range from −38.3‰ to −25.0‰. The most negative values $\delta^{13}C_{POC}$ of −38.1‰ and −38.3‰ found in operating well (WA4) and piezometer (PS8) respectively, are associated with the presence of anaerobic bacterial decomposition of organic metter producing very depleted methane $\delta^{13}C$ around −50‰.

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Abstract ID: 149

EVENT BASED MONITORING AND EARLY WARNING SYSTEM FOR GROUNDWATER RESOURCES IN ALPINE KARST AQUIFERS

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Keywords: karst aquifer, event sampling, on-line measurements, environmental isotopes, early warning system

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.

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 generates new knowledge of the dynamics, mass transport and substance transfer being of fundamental importance for the sensible use of early warning systems. As an example the correlation between SAC254 and *E.coli* during the course of the event is shown in Figure 1. 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.

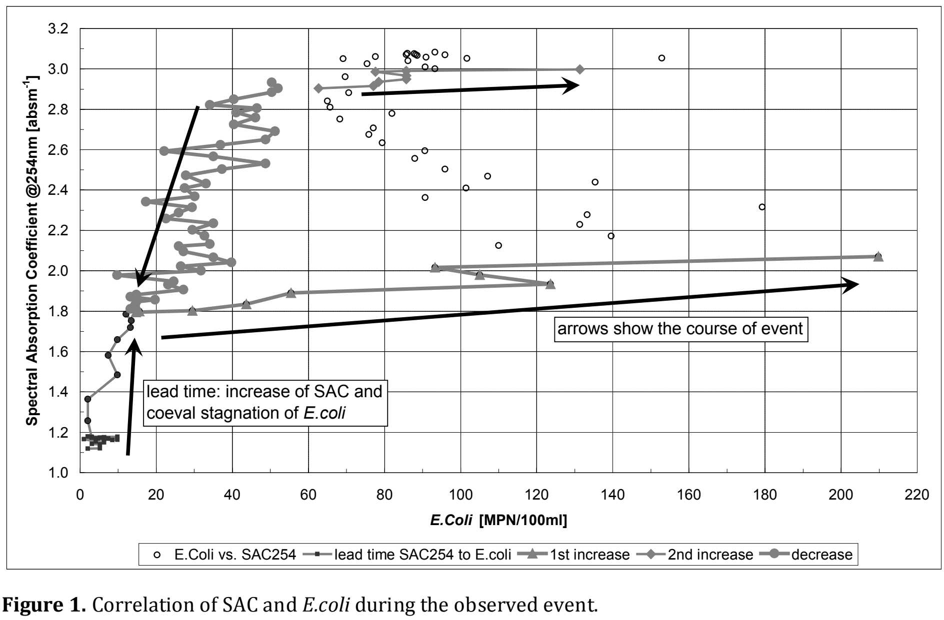

Figure 1. Correlation of SAC and *E.coli* during the observed event.

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Abstract ID: 158

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

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 modelling approaches e.g. of Heinl and Brinkmann (1989), Gossel et al. (2008) and Sefelnasr (2007). The groundwater is taken in the oases from deep wells with a depth of 500–1200 meters to ensure high quality and safe yield. The water table of the confined aquifer reaches about 2–50 meters below ground, in some cases the wells are free flowing. The water is used for drinking water supply and irrigation. 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 focusses the main component analysis, the analysis of metals and the measurements of hydrogen and oxygen. 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 lead to an indifferent picture of the climatic conditions during the recharge times. By the hydrochemical and isotope analyses the genesis and 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 should be investigated.

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 a MS. The results hydrochemical analyses were further modelled by using the geochemical code PhreeqC to obtain a consistent picture of redox conditions in the aquifer and the rock water interaction.

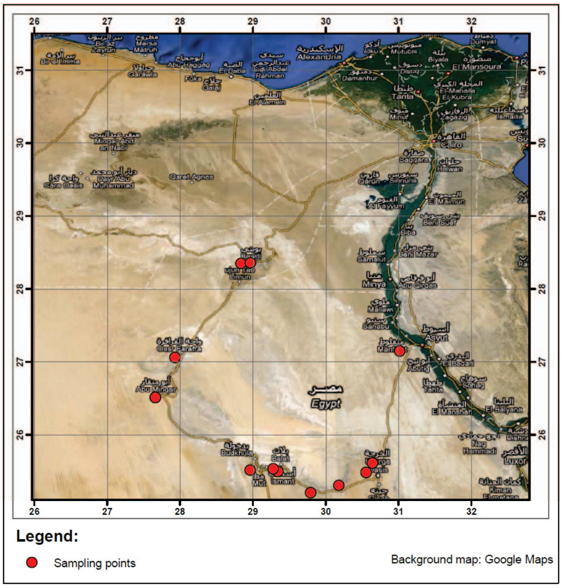

Figure 1. Sampling locations of the Egyptian Oases and Assiut.

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 and only in rare cases of other metals. A factor- and cluster analysis showed a differentiation between groundwater from the rim of the Nile valley, the North of Kharga Oasis and the other locations. 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. The results of the isotope analyses are also consistent with former investigations but 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 water has to be focussed again. About 300 to 1000 ky ago the infiltrating precipitation water must have undergone a long history of evaporation and condensation processes.

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Abstract ID: 159

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

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). 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 sampling of pumped tubular wells for evaluating the hydrochemistry and radioactivity due to the nuclides ^{238}U, ^{234}U and ^{222}Rn in Bauru and Serra Geral aquifers with the aim of coupling the information generated with those already existing for Guarani aquifer.

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). 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 = 0.96–4.84 (mean = 3.44); ^{222}Rn = 0.93–21.18 Bq/L (mean = 6.70 Bq/L). The range of the existing and obtained values for groundwater samples from Guarani aquifer (n = 85) was: ^{238}U = 0.004–15.36 μg/L (mean = 0.86 μg/L); $^{234}U/^{238}U$ activity ratio = 1.01–27.88 (mean = 4.42); ^{222}Rn = 0.05–57.44 Bq/L (mean = 15.06 Bq/L). 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 $^{234}U/^{238}U$ activity ratio (AR) 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. 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 1.4×10^{-3} g.cm^{-3} for Guarani aquifer. Thus, uranium is a

potential tracer for indicating the water provenance. One freshly crushed and sized sample (16 kg) of diabase (SGF) was subjected to chemical etch/leach in the laboratory at room temperature (~20°C); the etchant was distilled water equilibrated with the atmosphere. A comparison of the data obtained for this rock type with those for several carbonate matrices indicated some similar values, suggesting that the etching/leaching of exposed areas of calcite/dolomite surfaces in volcanic rocks of the Paraná basin may release bicarbonate, uranium and others compounds during the water-rock interactions occurring in the fractures flow.

ACKNOWLEDGEMENTS

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Abstract ID: 163

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

1. 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).

2. 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. 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).

Figure 1. Map of the study area in the North China Plain showing sampled wells

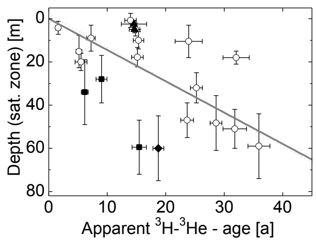

Figure 2. Vertical profile of the apparent ^3H–^3He age versus saturated depth

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

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

1. 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.

2. 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 50 m 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

QUANTIFYING GROUNDWATER DYNAMICS IN A SEMI-ARID SILICATE AQUIFER, MURRAY BASIN, AUSTRALIA

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Keywords: environmental tracers, isotope geochemistry, hydrogeology

The semi-arid Lower Murrumbidgee region of Australia's Murray Basin is characterized by extensive application of surface water and groundwater for irrigated agriculture. This study quantifies groundwater recharge and salt loading rates in the heterogeneous, silicate-dominated Tertiary aquifer system using environmental tracer concentrations measured in over 150 surface water, groundwater, and precipitation samples collected across the study area.

Cl/Br ratios (Fig. 1) and $^{2}H/^{18}O$ results (Fig. 2) from rivers, farm supply bores and environmental monitoring bores (EMB) suggest groundwater quantity in the Lower Murrumbidgee is regulated by lateral inflows from adjacent catchments, while quality is strongly influenced by leakage of irrigation water and shallow saline groundwater into the deep aquifers, possibly through aquitard discontinuities identified by Timms (2001).

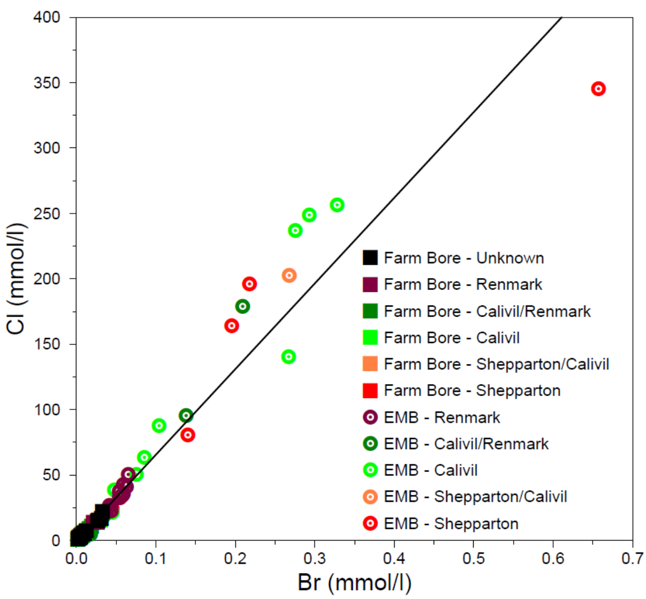

Figure 1. Dissolved chloride and bromide concentrations [mmol/L] in surface and groundwater.

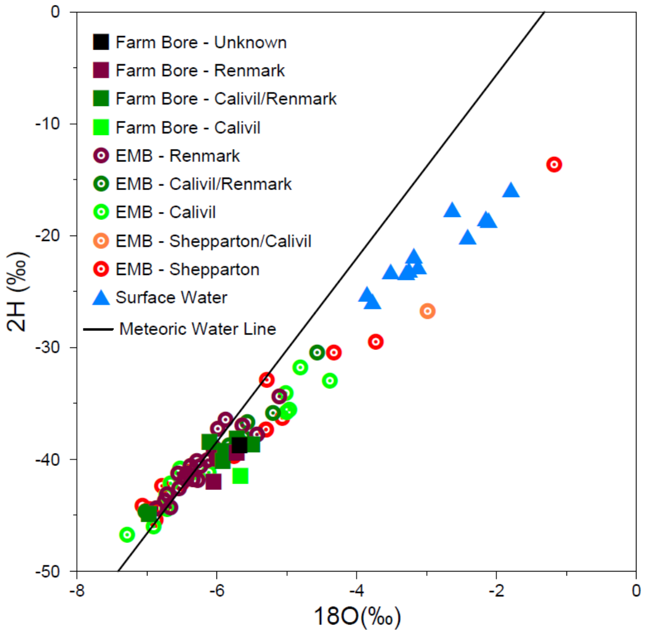

Figure 2. δ^2H and $\delta^{18}O$ values in water samples.

The environmental tracers are used to compare the recharge and salt loading rates of the Murrumbidgee and Coleambally irrigation areas which exhibit contrasting groundwater salinities despite sharing the same sources of irrigation water. Emphasis is placed on the roles of historical irrigation practices and geological heterogeneity play in the observed salinity differences.

Future research will include isotopic measurements (e.g. ^{14}C, $^{87/86}Sr$, ^{36}Cl) to further constrain the kinetics of processes in the catchment (evapotranspiration, water-rock interaction, fluid mixing) and to refine historical groundwater age estimates.

ACKNOWLEDGEMENTS

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Abstract ID: 214

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.

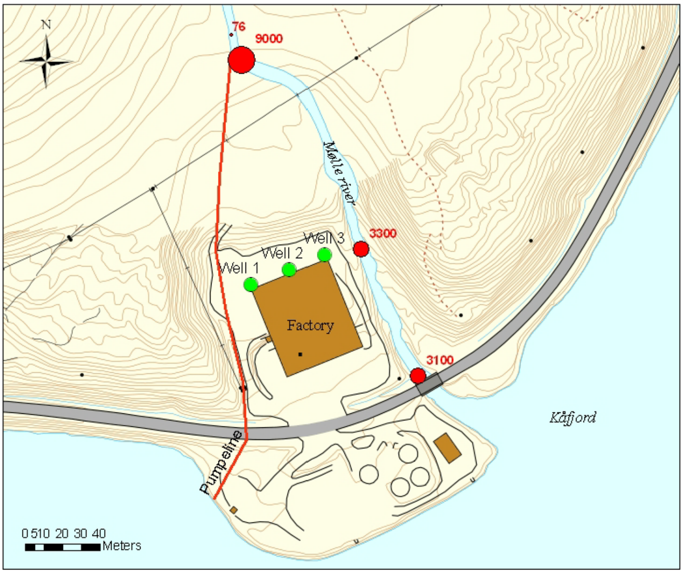

Figure 1. Field site with wells, pump line for seawater and measured EC (us/cm) in Mølle river after 5 hours of seawater pumping (20 l/s).

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.

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.

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 (Fig. 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 (Fig. 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.

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.

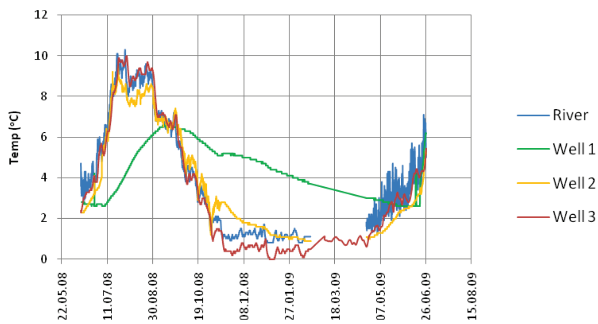

Figure 2. Long time temperature measurements in Mølle river and groundwater at Møllenes.

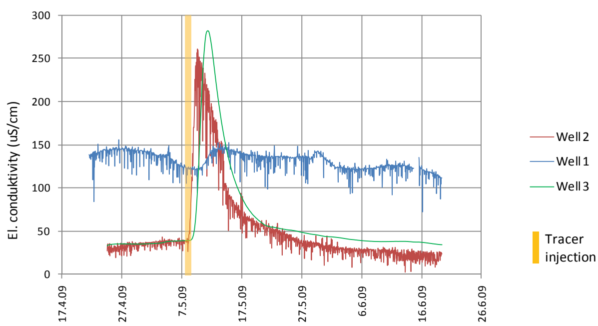

Figure 3. EC measurements in groundwater wells before, during and after seawater introduction to the Mølle river.

Abstract ID: 218

LONG-TERM MIGRATION OF SOLUTES IN THICK, SURFICAL, CLAY-RICH AQUITARDS USING MULTIPLE ENVIRONMENTAL TRACERS

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Keywords: isotopes, tracers, aquitards

Over the past decade, high resolution 1-D depth profiles of multiple tracers (^{3}H, δD and $\delta^{18}O$, ^{14}C-DOC and -DOC, ^{36}Cl, ^{4}He, 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

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

1. 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, ^4He, ^{14}C and ^3H–^3He. 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.

2. PRELIMINARY RESULTS

^4He 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.

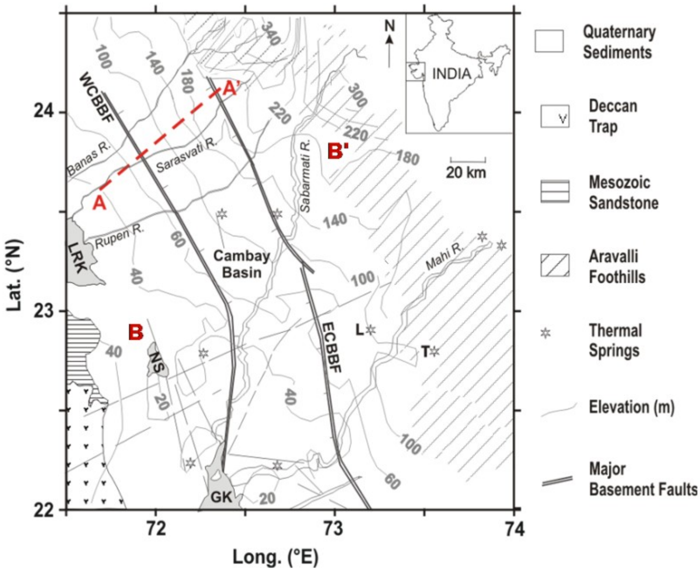

Figure 1. Map of the North Gujarat – Cambay region showing sampled transects.

δ18O- 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).

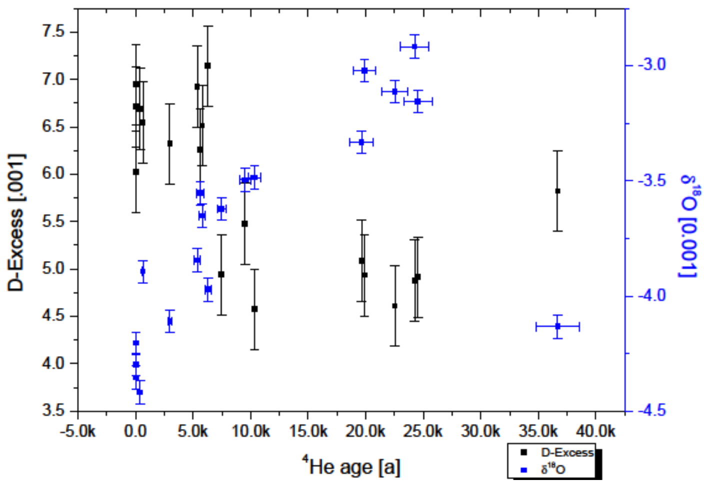

Figure 2. $\delta^{18}O$ and deuterium excess of the northern transect versus groundwater age.

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

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 0–3 m of sandstone. Rock outcrops are common in this terrain, but overburden thickness can be greater than 4 m. Twenty-two bedrock wells were drilled between 2004 and 2008 to depths from 30–45 m 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

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 at large tunnel projects.

METHODOLOGY

Three shallow (7 m) and sixteen deep (40–174 m) observation wells have been sampled. The shallow wells represent an unconfined aquifer in the top soil layer, 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, southern Sweden, which is used as study area. The deep wells have been sampled by a simplified depth specific method using two pumps simultaneously. The samples have been analyzed by GEUS, Denmark, as regards major hydrochemistry and contents of CFC. Ten selected samples have also been analyzed by Geological & Nuclear Sciences, New Zeeland, concerning contents of tritium.

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. In many cases the different results are giving a common picture with either high contents of nitrate and tritium and a low CFC-based age (GVR610, shallow well in a recharge area) or very low contents of nitrate and tritium and a high CFC-based age (MI26, deep well outside the area of influence of the tunnel). However, there are also intermediate cases like GVR720 with a low but not negligible content of nitrate, a high content of tritium and a moderately low CFC-based age or like MI23 with a high content of nitrate and tritium but with a moderately low CFC-based age. In BP31 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.

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 bs)	Site characteristics	Nitrate (mg/L)	Tritium (T.U.)	CFC-based age (years)
GVR610 Shallow	6	Not very close to tunnel area Recharge area	6.00	8.46	< 5
GVR720 Shallow	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
	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
	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
	35 (31-40)	Outside area of influence	< 0.02	0.052	60

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.

Abstract ID: 262

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(2,503 mm), 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 H_2 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, 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 δD=0‰, $\delta^{18}O$=0‰ and δD=-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%, δD=19%) and F3 has the lowest ($\delta^{18}O$=9%, δD=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

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

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

Longwall underground coal mining activities near or beneath streams or other surface water bodies can cause subsidence and substantial fracturing of stream beds. This subsidence induced cracking can alter flow paths causing dewatering and/or rerouting of surface water. Depending on the depth of coal mining and extent of cracking, surface water may either be lost permanently or temporarily. In cases where surface waters lost to the subsurface re-emerge downstream, the chemistry of water is significantly altered due to mixing with groundwater and enhanced reactions during water-rock interactions with minerals and compounds present in the subsurface strata.

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 of the worst affected catchments, the Waratah Rivulet catchment, was selected for a detailed investigation to provide a more comprehensive understanding of longwall mining impacts on groundwater and surface water quality and flow. A three year study using environmental isotopes including both stable isotopes (oxygen-18 and deuterium) and radiogenic isotopes (radon-222, radiocarbon and tritium), and applied tracers was undertaken to assess changes in groundwater-surface water linkages due to mining-related subsidence.

The stable isotope results (Fig. 1) clearly show groundwater-surface mixing in the impacted zones along the Waratah Rivulet.

Tritium and radon-222 values also confirm groundwater-surface water mixing in the mining-impacted zone. In groundwater in a non-impacted part of the catchment, tritium and radon-222 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. Radon values in the impacted zone are much lower, due to mixing with surface water, and range from 4 to 14 Bq/L.

Two applied tracer tests were undertaken to quantify baseflow loss from Waratah Rivulet and to verify results of environmental tracer and hydrological modelling. The first tracer test involved the short-term application of a fluorescent dye tracer (fluorescein dye) to monitoring boreholes over one hour and monitoring breakthrough at various locations along the creek bed.

Breakthrough was incredibly fast, with the first dye breakthrough occurring within 15 minutes at a distance approximately 50 m downstream of the injection point, indicating heavy fracturing of the streambed and short circuiting of surface water-groundwater connectivity. The results of the dye tracer test were used to assess the connectivity of the fracture system, measure solute transport times, identify groundwater discharge zones and quantify groundwater baseflow.

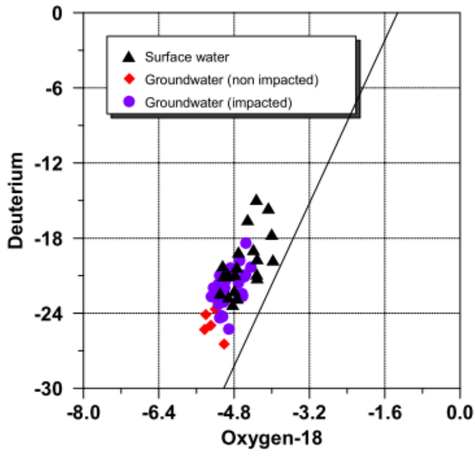

Figure 1. Stable isotope data, showing mixing between groundwater and surface water in the mining-impacted zone.

The second tracer test involved the application of a salt solution to the Waratah Rivulet. The purpose of the continuous tracer application to the Waratah Rivulet was to verify stream loss, measure solute transport times and quantify the percentage of stream water lost to the subsurface. A salt solution was added over a period of three hours and monitored in groundwater monitoring bores and at various locations along the Rivulet. The dye test provided quantitative data that was used to verify the results of hydrological modelling.

The outcome of the study was an enhanced understanding of the impact of longwall mining activities on surface water flow and quality, and water balance. The results of the study have provided sound scientific data which can be utilised to develop future management options and a framework for the monitoring and assessment of the impacts of longwall mining on flow and water quality in drinking water supply catchments.

Abstract ID: 335

OXYGEN ISOTOPIC COMPOSITION IN A RIVERBANK FILTRATION SYSTEM — CASE STUDY ON SZENTENDRE ISLAND, HUNGARY

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Keywords: riverbank filtration, oxygen isotope, Danube

Hungary's capital, Budapest, and a number of surrounding settlements are supplied with drinking water largely from the bank filtered aquifer at Szentendre Island of the Danube River lying to the north of the city. Precise knowledge of regional hydrogeological processes in riverbank filtrated aquifers are indispensable for aquifer protection and adequate quality water supply. To reach this goal, the origin and velocity/transit time of filtrating water was studied by stable isotopic, e.g. ^{18}O tracing measurements. The basis of these studies was the fact that $\delta^{18}O$ of Danube water (–10.9‰ as a mean) differs from the locally infiltrated precipitation (shallow groundwater, –9.5‰) as a consequence of the "altitude effect" on the river water. Additionally, conductivity, temperature and various hydrochemical parameters were measured.

Water samples were taken on a daily basis from the Vác arm of the Danube, as well as from the water producing Kisoroszi-2 horizontal collector well, lying at the bank of Danube on the Szentendre Island. Collectors of this well are aligned to two horizons at the depth of ca. 12 m in the Pleistocene gravels. Electric conductivity and temperature were measured daily from the Vác Danube and weekly from the Szentendre arm of the Danube. This was supplemented by daily $\delta^{18}O$ measurements of the Vác Danube for characterizing the infiltrating water; and also by hydrochemical sampling every week.

Monitored parameters in the Vác and Szentendre arms of the Danube showed no significant difference, thus, the composition of water in both arms can be regarded as equal. Positive peaks in hydrochemical parameters correlated with episodical highs of the water level. Conductivity of the Kisoroszi-2 well did not exceed values measured in the Vác Danube. This might be explained by inhomogeneities of subsurface media. Combining the hydrodynamic model of Budapest Waterworks PLC. with $\delta^{18}O$ data, a robust forecasting equation for $\delta^{18}O$ values of the Kisoroszi-2 well has been constructed. The temperature of monitoring wells close to the shoreline is determined by Danube temperatures shifted with a few months. No seasonal variations exist, however, in the central zone of the island. Shallow depth and the immediate vicinity of cover formations above in one of the monitoring wells resulted in the anomalously high percentage of water infiltrated from the local precipitation. The sulphate anomaly observed here could be attributed to agricultural activity in the vicinity.

Abstract ID: 338

GROUNDWATER RECHARGE ESTIMATIONS IN THE DENSU RIVER BASIN, GHANA, USING ENVIRONMENTAL ISOTOPE DATA (δ^2H, $\delta^{18}O$)

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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

INVESTIGATION OF RECHARGE PATHWAYS AND RECHARGE RATES USING ENVIRONMENTAL ISOTOPES (^{2}H, ^{18}O, ^{14}C AND ^{3}H) IN THE MAULES CREEK CATCHMENT, NSW, AUSTRALIA

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Keywords: isotopes, groundwater, recharge, surface water groundwater interactions

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 has 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.

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. 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. Flow in the main river, the Namoi River, also appears to have become more intermittent over the same period.

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. 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. 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. The uncorrected ^{14}C and the ^{3}H results generally indicate increasing apparent groundwater ages with depth beneath the ground surface, with the deepest water having apparent radiocarbon ages of up to 21,000 yrs. However, noticeable differences to this pattern are observed. Near the Namoi River, older groundwater is generally found at much shallower depths than anticipated. This indicates an upward discharge of groundwater into the river (gaining river conditions). It is uncertain whether this is a relict of past discharge patterns because presently there appears to be little or no discharge of groundwater to the river. Other variations in the ^{14}C and ^{3}H results observed with depth occur in some areas near the river, where groundwater abstraction is causing large seasonal drawdown, here the opposite pattern is observed with modern water found at depths of up to 60 m. 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.

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, recharge and porosity. Based on this, a long term diffuse recharge of 4–10 mm/yr was estimated. 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. Further validation and assessment of these recharge rates will be presented based on ^{3}H and corrected ^{14}C results to verify this model.

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.

Abstract ID: 360

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, ^3H, Japan

INTRODUCTION

Securing fresh water resources is vital for the human beings, and is more critical for 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 the sustainability of the society. This study attempts to reveal the groundwater flow system in the Nakano-shima Island, Japan, using major components, CFCs, and ^3H as tracers. The island is composed mostly of trachy-basalt and trachy-andesite rocks and partly of alkali olivine basalt lava (Tiba et al., 2000). Basalt/andesite rocks are rich in fractures, and groundwater exists manly in fractures (Tsukimori, 1984).

METHODS

Groundwater and spring water samples were taken from 15 wells and 3 springs in the island in June and September 2009. Field parameters, including temperature, pH, EC, DO, and ORP were measured before sampling. All samples were analyzed for major components (Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, SO_4^{2-}, NO_3^-) and CFCs. Several samples were also analyzed for ^3H.

RESULTS AND DISCUSSION

Groundwater samples obtained from shallow wells tend to be rich in Na^+ and Cl^-, while those from deep wells were rich in Ca^{2+} and HCO_3^- (Fig. 1). This implies that major components of shallow groundwater are influenced by sea salt. On the other hand, major components of groundwater obtained from the area covered by alkali olivine basalt lava were rich in Mg^{2+} and HCO_3^-, suggesting that the components are controlled by geology (Fig. 1). ^3H concentrations of W4 and W7 were 0.3 tritium unit (T.U.) and 0.6 T.U., respectively, lower than other samples (Fig. 2a). CFCs concentrations of these 2 samples were also lower (Fig. 2b). These results indicate the existence of the groundwater flow system with longer residence time at least locally.

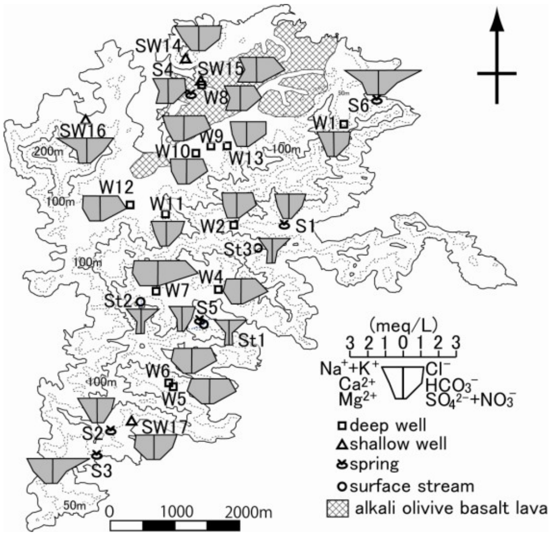

Figure 1. Concentrations of major dissolved components of water samples.

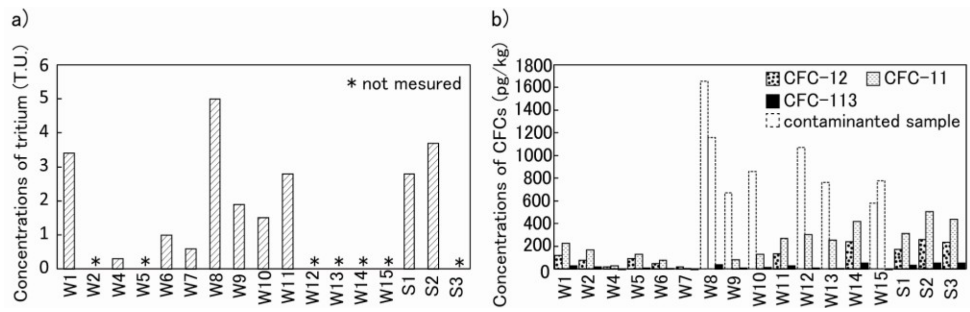

Figure 2. Concentrations of: a) ^3H, and b) CFCs of the groundwater samples.

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Abstract ID: 364

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

1. 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.

2. 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.

3. 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)

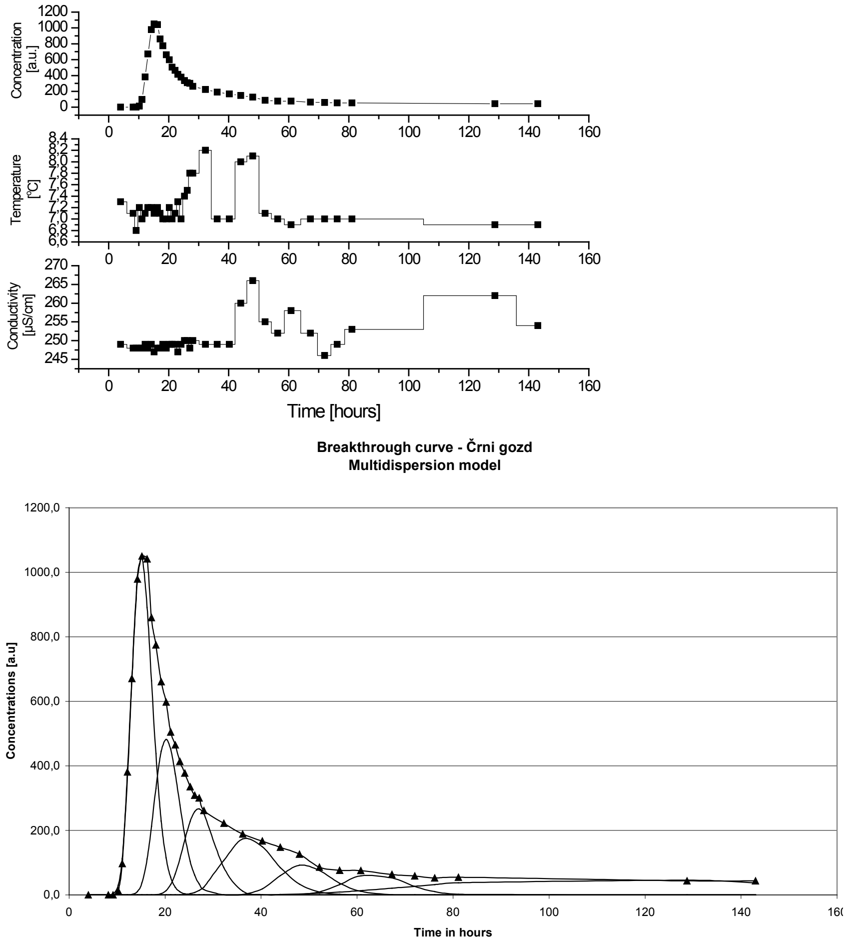

Figure 1. Results of tracing experiment in the Košuta aquifer in the region of Lajb Črni gozd — Slovenia.

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

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).

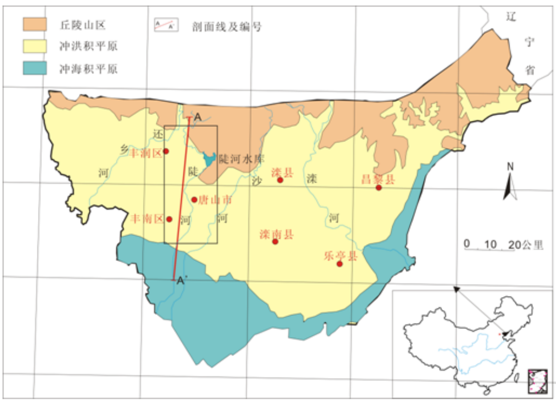

Figure 1. Location of Tangshan area.

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).

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.

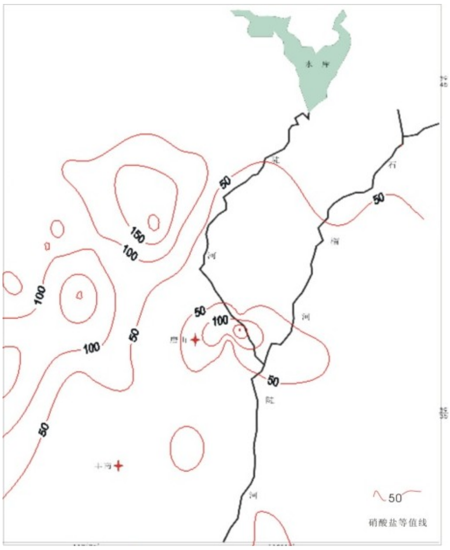

Figure 2. Isolines of nitrate concentration in groundwater.

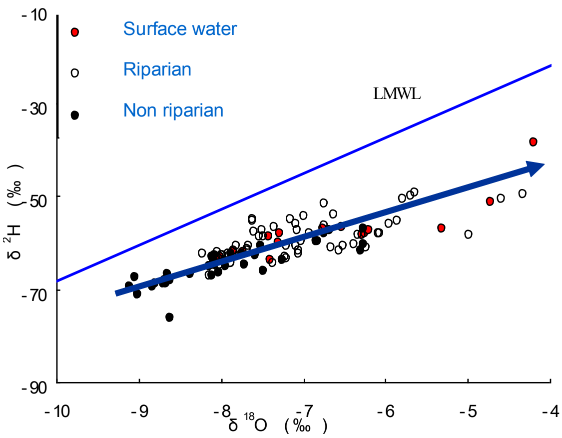

Figure 3. The relationship between δ^2H and δ^{18}O in the samples from the study area.

The average resident time of the karst aquifer is 20 a, changing to 27 a towards central part of the plain. Tritium concentration varies with depth, and top one has the shortest residence time.

Other aquifers vary from 50 a to 5 a. 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

AN INVESTIGATION OF HETEROGENEOUS WATER FLOW AND TRANSPORT PROCESSES IN AN OXIDIZED GLACIAL TILL USING ENVIRONMENTAL ISOTOPE (δ^2H, $\delta^{18}O$) 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 ^2H) 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 δ^2H 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

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

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

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

ASSESSMENT OF DENITRIFICATION RATES IN FISSURED-KARSTIC AQUIFER NEAR OPOLE (SOUTH-WEST POLAND): COMBINED USE OF GASEOUS AND ISOTOPE TRACERS

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Keywords: fissured-karstic aquifer, denitrification, gas chromatography

Denitrification is the only process leading to reduction of nitrate concentration in groundwater (Kendall et al., 2007). Here we report the results of combined measurements of excess gaseous nitrogen and ^{18}O and ^{15}N isotope composition of dissolved nitrate in fissured-karstic Triassic aquifer located in south-western Poland, in the vicinity of Opole. Hydrological conditions on the investigated area are determined by monoclinal structure of geological layers (Kryza, Staśko, 2002). In southern part of the system, where well-permeable zone of Muschelkalk outcrops is located, preferable conditions for recharge and groundwater flow occur resulting in elevated concentration of nitrates, often exceeding 50 mg NO_3/dm^3. Recharge in northern part of the aquifer is very limited due to sick cover of loamy sediments of Keuper. Generally, the wells located in that confined part of the aquifer reveal greatly reduced nitrate content, between ca. 0.3 and 2.7 mg NO_3/dm^3.

The denitrification process is being suggested as the main reason for those contrasting 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. 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 7 in Fig. 1). Those analyses were supplemented by measurements of dissolved nitrate and tritium content. Also basic physico-chemical characteristics measured in-situ (temperature, pH, Eh, electrical conductivity, dissolved oxygen) are available for these wells (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, were available for those wells from former studies (Kleczkowski et al., 1988; Różański et al., 2007).

Sharp decrease of nitrate content in wells located in the confined part of the aquifer, together with $\delta^{18}O$ and $\delta^{15}N$ data, suggest well-advanced denitrification process. The observed enrichment in ^{15}N and ^{18}O of the remaining nitrate corresponds to initial nitrate content in the order of 1.5 to 12 mg NO_3/dm^3. Lack of tritium in those wells suggest the pre-bomb age of water and natural range of the initial nitrate content. In majority of the measured wells nitrogen excess has been below the detection limit of ca. 3.5 mg NO_3/dm^3. This method is not sensitive enough to detect denitrification of natural nitrate which concentrations in groundwater in the study area were generally below 10 mg NO_3/dm^3.

The study demonstrated that combining isotope analyses of nitrates with tritium or other transient tracer may provide additional insights into the dynamics of water and nitrate transformation in groundwater systems.

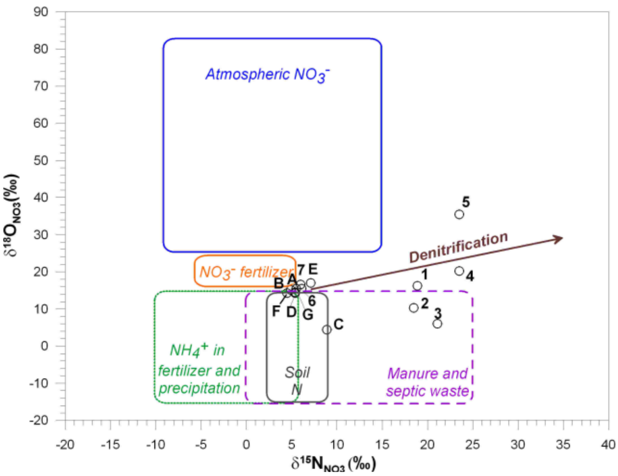

Figure 1. $\delta^{15}N(NO_3)$ – $\delta^{18}O(NO_3)$ relationship for the wells discussed in the text. Ranges of $\delta^{15}N$ and $\delta^{18}O$ values for different sources of nitrate are shown after Kendall et al. (2007).

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Abstract ID: 518

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 groundwater 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 groundwater 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 groundwater, 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 groundwaters, 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 groundwater 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 groundwaters points out an intensive connection between the river and groundwater 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 groundwater. 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 groundwater. 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

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

The Catalan Agency of Water (l'Agència) is the institution that has full competences concerning the control, management and planning of water resources in approximately the Estern half of the Catalan territory, in NE Spain. L'Agència has commissioned a model of the aquifers involved in Camp de Tarragona at the southern part of Catalan territory mainly for management purposes (Fig. 1).

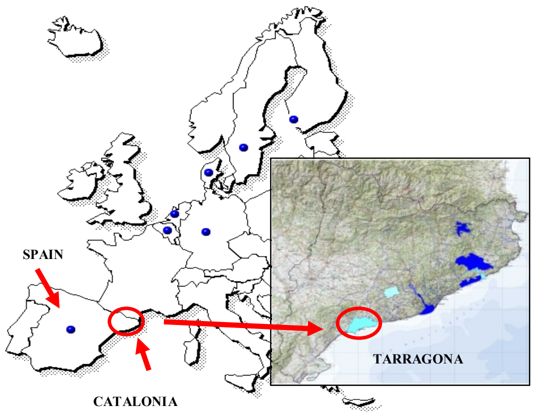

Figure 1. Situation of the Camp de Tarragona.

One of the key issues to quantify are the agricultural extractions, since they represent the most important activity in the zone, as is shown in the Figure 2 of soil uses. This determination is not simple since it involves social, economical and technical aspects.

The first step was to calculate the irrigation needs by means of an specific program, that includes the nearest meteorological station data, the type of crop and conventional parameters. The figure obtained per hectare and for each kind of crop was implemented in a GIS areal map. It resulted in an average of 100×10^6 m^3/year of agricultural extraction.

However, the obtained results did not fit in the model, which demanded lower values to reproduce measured piezometric heads. For some reason, the current agricultural pumping seemed to be lower than the theoretical needs, and after a through discussion it was concluded that the key lied in the economic or social aspects.

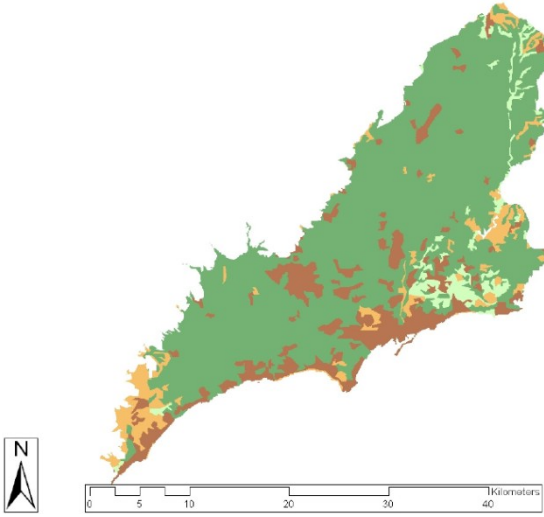

Figure 2. Soil distribution use (in green, agricultural) Agència Catalana de l'Aigua (2009).

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 fact 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. They even prefer to reduce the crop yield but with a lower associated cost. The irrigation habits in the area are to apply low irrigation techniques, such as hydrical stress (that implies not to irrigate during July and August) and not irrigating all the soil area that is included in the GIS maps.

Making the necessary arrangements on the calculation of the average agricultural extraction, a total is 68×10^6 m^3/year. This result matches completely with the model, and also with the conceptual model of the zone.

In parallel, l'Agència 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 to the previous discussion. So the same theory of utilisation of water has been applied in the Management Plan.

In short, it is not only necessary to know well the irrigation techniques in agricultural activity in order to determine the water consumption, but it is also essential to get information about the economic and social aspects.

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4 | Mineral and thermal water

4.1 | Geothermal resources

Abstract ID: 102

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

WESTERN EXTENSION OF THE HIMALAYAN GEOTHERMAL BELT

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Keywords: hydrochemistry, hot springs, reservoir temperatures

The Himalayan Geothermal Belt' (HGB) was first described (Tong, Zhang, 1981) as manifested by at least 600 hot and warm spring systems occurring within a 150 km wide and c. 3000 km long belt stretching from the Pamir Mountains through Tibet into Yunnan. In many locations the geothermal anomaly is high enough for generation of electricity. Thailand has a binary plant producing 300 kWe (from 117°C water). Yangbajang, in Tibet, generates 25 MWe, providing Lhasa with about 40% of its electricity. In Tibet and Yunnan, an additional 7 MWe are generated in 7 small plants. The westward extension of the HGB is manifested by the dry steam geothermal system of Nanga Parbat Haramosh Massif, and warm to hot springs clustering along the Main Karakoram Thrust (MKT), Main Mantle Thrust (MMT) and Main Central Thrust (MCT) in the Peshawar Region of Pakistan. According to Chamberlain et al. (1995) during the last 10 m.y., the Nanga Parbat Haramosh Massif has been intruded by granitic magmas, has undergone high-grade metamorphism and anatexis, and has been rapidly uplifted and denuded. The dry steam zone at Nanga Parbat has formed according to Craw et al. (1998) due to near-isothermal depressurization of very hot fluid during rapid tectonic uplift at rates > 3–6 mm/year. In the Peshawar Region the warmest, 68°C Garam Chashma Hot Springs emerge from the post-collisional leucogranites of the Hindukush Range, which yield K–Ar (biotite) age of 20–18 Ma. Hot-end reservoir temperature estimates computed using various chemical geothermometers ranged from a low of 105°C calculated from chalcedony and 155°C from quartz solubility curves, while the Mg–Li geothermometer indicated the hot-end temperature of 128°C. Much higher estimates of about 260°C were obtained comparing mixing diagrams for a conservative solute, e.g. Cl^- with the enthalpy (temperatures). The source of the elevated heat flow within the HGB has been attributed to "advective sweeps of infiltrated meteoric water from the hot brittle, upper crust" (Hochstein, Regenauer-Lieb, 1988). Using the geothermal gradient of 0.026°C/m, as reported by Hochstein and Yang (1995) from wells to the east from our study area, permits inference of a 2000-m-deep circulation of meteoric water. Yet, the presence of a regionally dominant compressional tectonic regime (Molnar, Tapponnier, 1977; De Mets et al., 1994; Paul et al., 2001), with intense mylonitization along the thrust faults, raises doubt regarding the feasibility of a simple topography-driven mechanism for such deep "advective sweeps of infiltrated meteoric water". The topography-driven pressure from the highest ridges to the north of the study area may attain a maximum of 25 MPa as compared to the tectonic lateral stress of 90 MPa. The question remains open as to which of these is prevalent for driving deep groundwater circulation.

Abstract ID: 203

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.

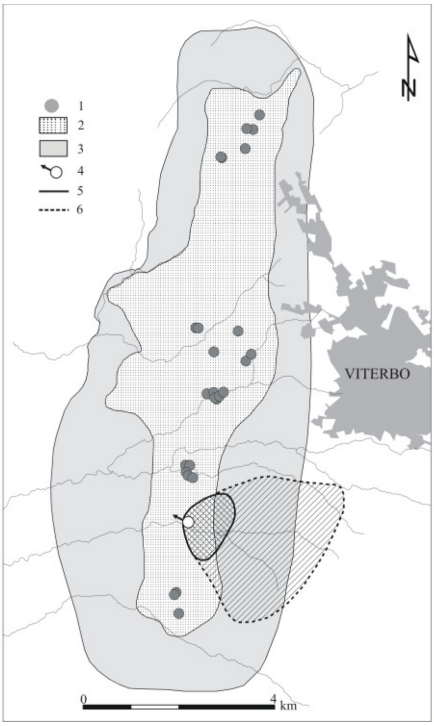

Figure 1. Protection zones of the hydrothermal area of Viterbo: 1) thermal spring and well, and ZT immediate protection zone (not to scale); 2) ZPI intermediate protection zone; 3) ZPII distant protection zone; 4) drinking water spring; 5) 90-day isochrone for drinking water spring; 6) 365-day isochrone for drinking water spring.

The 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.

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

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

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. Four doublet systems are in use and 8 other doublets 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 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).

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. 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. Well productivity is highly dependent on the location of the exploration well. Transmissivities in a range between 0,1 to > 3000 m^2/day reflect the heterogeneity of the carbonatic aquifer. 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. 1). Temperature anomalies in the region are supposed to have their origin in convective heat transport linked to fault zones.

In a first step a 3D-seismic survey was carried out in the central investigation area "Unterhaching" (5×5 km). 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 (Fig. 2). Processing of the 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 which will cumulate in a hydrogeological model (HGM) for Greater Munich. Finally, based on the HGM a numerical model will be applied to simulate the interaction between neighbouring doublets.

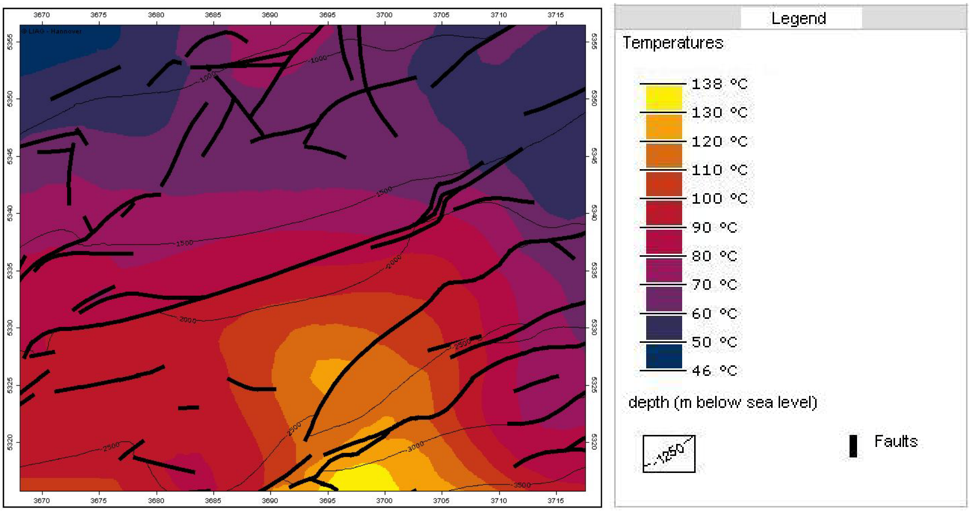

Figure 1. Temperature distribution TOP Malm (www.geotis.de).

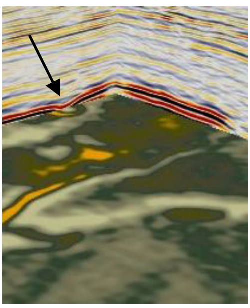

Figure 2. Subset of 3D cube with potential sinkhole (collapse structure, diameter ca. 50 m), view from south, inline 301, crossline 163, timeslice 2466 m below sea level).

ACKNOWLEDGEMENTS

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Abstract ID: 227

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.

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.

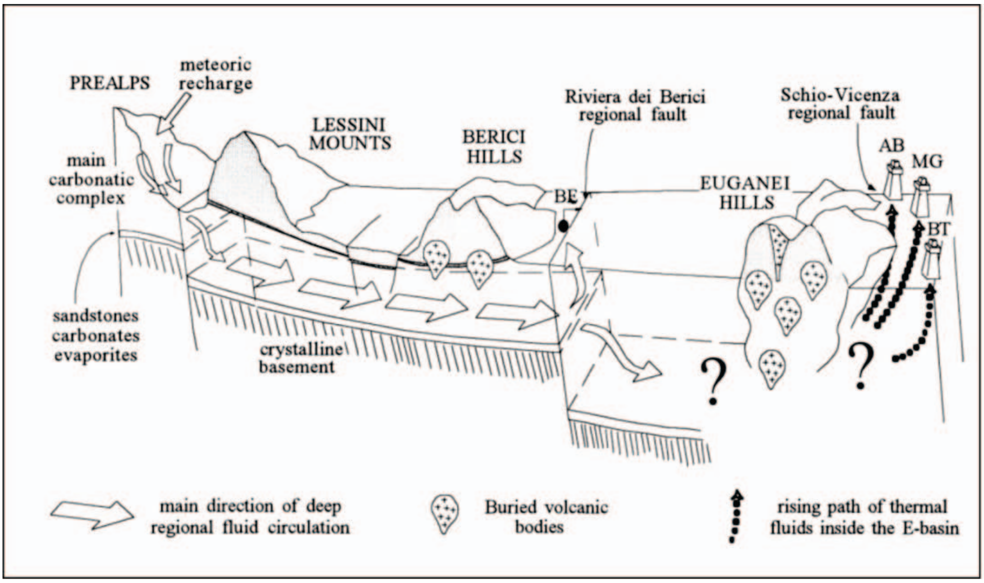

Figure 1. Hydrogeological model of the hydrothermal circulation in the Euganean area (from Gherardi et al., 2000). The outflow may be controlled by a local extensional zone developed at a bend of the Schio-Vicenza fault.

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

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

BACKGROUND

A previous study revealed that Ivry-sur-Seine (Ile-de-France, France) town has attractive potential for an Aquifer Thermal Energy Storage (ATES) technology based on an excess of heat production in summer with a relevant heat networks adapted to the winter demand. 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 depth of the targeted aquifer is about 1500 m (Dogger aquifer in the Paris Basin). The heat vehicle to be 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.

ATES OPERATIONS EXAMINED AND THE MODELLING APPROACH

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. 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.

The ATES geochemical modelling analysis is based on water samples composition collected from geothermal wells already existing at the target aquifer in Ivry-sur-Seine region (Azaroual et al., 1997; Criaud et al., 1989). Three geochemical modelling approaches were used to simulate the ATES operations: (1) equilibrium batch modelling; (2) kinetic batch modelling and (3) a 1D reactive transport model integrating thermo-kinetic processes of mineral dissolution/precipitation reaction.

RESULTS AND DISCUSSION

The geochemical modelling of mass exchanges induced by heat storage/heat production cycle accompanied by temperature and pressure variations highlights an effective risk of scaling problems due to the following trend:

1. 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".
2. Chalcedony, microcrystalline gibbsite, 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".

Finally, these results must be integrated in the further analysis integrating other technical constraints to define the management strategy of the ATES technology in the context of the Dogger aquifer.

CONCLUSIONS

Reactive modelling study simulating different scenarios of temperature perturbation highlights some potential scaling risks (i.e. precipitation of carbonate and sulfate minerals in the "hot bubble" and precipitation of chalcedony and clay minerals in the "cold bubble"). Once these models will be completed, operating rules with good practices of the ATES technology will be defined allowing operators to plan out management strategies for the future ATES site of Ivry-sur-Seine town.

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Abstract ID: 466

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, Mszczonow, Uniejow, Stargard Szczecinski. Total installed geothermal power is estimated at about 44.8 MWt with annual production of energy ranging about 480 TJ/a (Kępińska, 2005).

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; Górecki (ed.), 2006b).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 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).

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 energy 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, recalculated into the energy units — Joules, 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°C.

Energy accumulated in waters of the Lower Jurassic aquifer was calculated to 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).

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). For the calculations it was assumed that waters are exploited by a doublet and the injection temperature does not exceed 25°C. 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).

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. 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. 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

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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Abstract ID: 527

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

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4.2 | Origin of mineral and thermal waters

Abstract ID: 117

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

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

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) has three installations that use deep water: the Marlioz and Thermes Nationaux spas, to the south, and the Raphy Saint Simon (RSS) mineral water plant, to the north. 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. 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.

1. 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 and a box fold to the south. 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).

2. 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 L^{-1} vs. 100 mg L^{-1}). 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.

3. 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 but not in RS4. In addition, we observed cyclical variations in the flow rate of the RSS well, as well as variations related to atmospheric pressure. These phenomena were not observed at the natural thermal water outlets in the southern block.

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.

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Abstract ID: 175

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

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, 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 karstified limestone corresponds to the upper part of an overthrusting anticline. 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. 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. 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 aim of this study is to reproduce the plume behaviour, using a pumping test in which the drawdown, temperature, conductivity were monitored simultaneously.

During the period of arrest and recovery operations, the time to return to a stabilized value is variable for the 3 monitored parameters. In particular, the temperature is stabilized 8 hours before the electrical conductivity.

The initial interpretation leads to the following hypotheses:

- A mixing of two waters by simple advection on pumping time as short (48 h) may not have such an effect of dispersion-diffusion. The transport phenomena beyond differences between thermal convection and chemical advection require the presence of 3 types of water.
- The interpretation of the drawdown and its logarithmic derivative led to the calibration of an unlikely model. Although the leakage model obtained is consistent with a deep upwelling, the hydraulic conductivity of the aquitard (K = 9×10^{-4} m s^{-1}) is higher than that of the aquifer (K = 2.6×10^{-7} m s^{-1}). The differences between these two values tend to prove that the rising plume is concentrated through fractures with a high hydraulic conductivity.
- The thermal water plume cannot be located vertically to the pumping well. The plume is necessarily situated more downstream or farther upstream.

Trial and error tests performed using a finite element model (Fig. 1) coupling hydrodynamic and transport processes led to the following results:

- The thermal water plume is in a downstream position compared to the well.
- The mixing of the thermal and shallow waters is essentially realized in a long fracture going upstream to downstream in the urgonian series. This fracture being in the lower part of the urgonian series, the shallow water has a higher temperature than the temperature observed at outlet, but always the same electrical conductivity. That (not completely) explain why the temperature shows so little variations during the pumping test compared to the electrical conductivity.
- The long fracture is crossed by the well in the upper part of the borehole section. Indeed, because the upper part of the well is entirely cased, the water is abstracted only in the lower part of the urgonian limestones (between 171 and 250 m depth). The thermal water plume reaches the long fracture more than 10 m downstream to the fracture/well intersection.

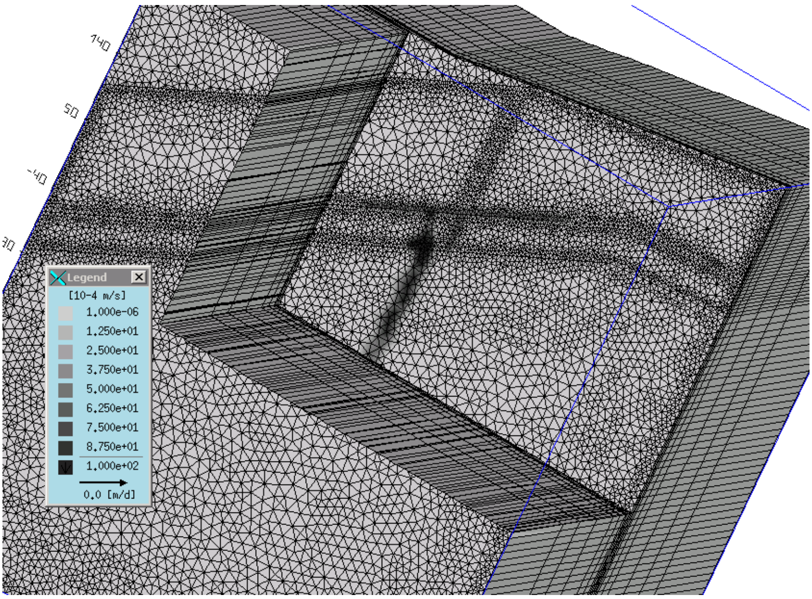

Figure1. Hydraulic conductivities of the model shown on a partial 3D view.

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Abstract ID: 271

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 to 15 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

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).

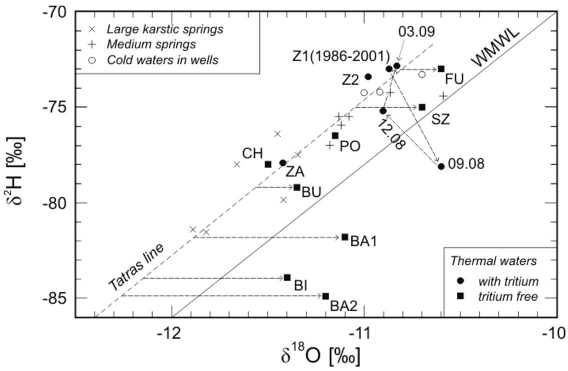

Figure 1. Isotope composition of the investigated waters with indicated shifts (horizontal lines) of δ¹⁸O from the local meteoric line (see text in relation to changes in the Z1 well).

The most negative δ²H 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 δ²H of thermal waters are similar to those of medium springs (Figs 1 and 2) indicating the low altitude recharge. Thus, the most negative δ²H 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.

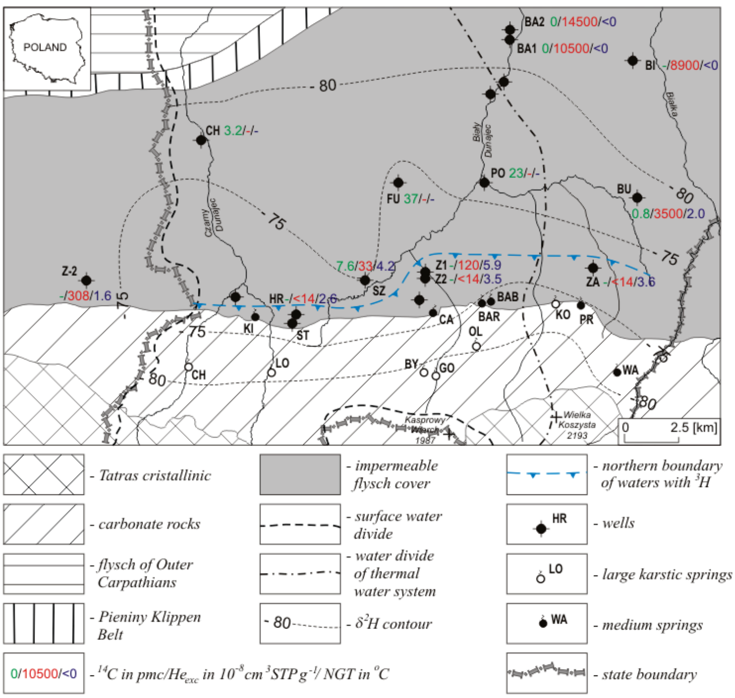

Figure 2. Environmental tracers in the Tatras and thermal waters of Podhale Basin.

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

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.

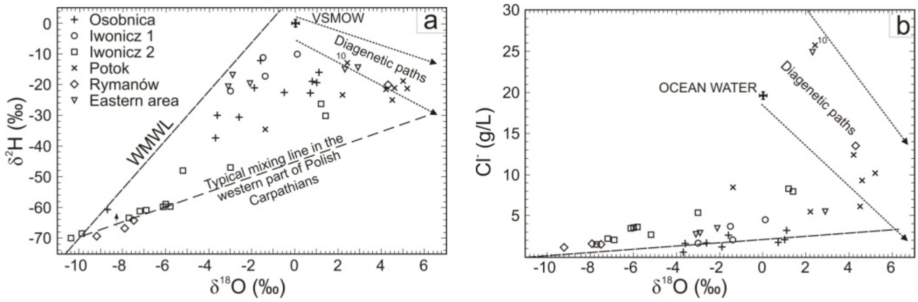

Figure 1. $\delta^{18}O$–$\delta^{2}H$ (a) and $\delta^{18}O$–Cl^- (b) data of Central Carpathian Synclinorium (adapted from Porowski 2006, sample 10 from Zuber and Chowaniec 2009).

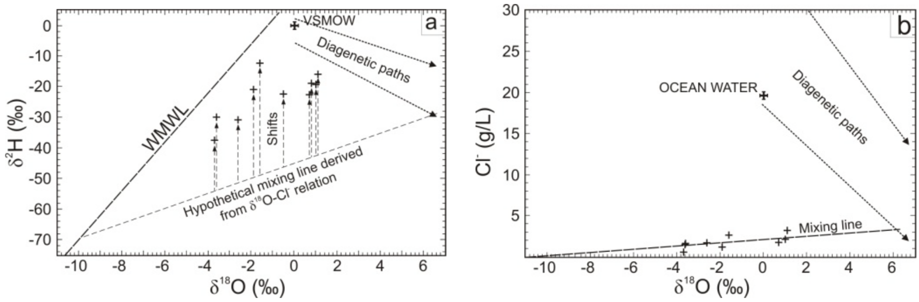

Figure 2. $\delta^{18}O$–$\delta^{2}H$ (a) $\delta^{18}O$–Cl^- (b) data of the Osobnica area selected from Fig. 1. Extrapolated $\delta^{18}O$–Cl^- relationship suggests the heavy end-member to correspond to the final stage of diagenesis whereas the $\delta^{2}H$ values in (a) do not correspond to the expected mixing line due to shifts to heavier values, which is caused by generation of hydrocarbons (catagenesis).

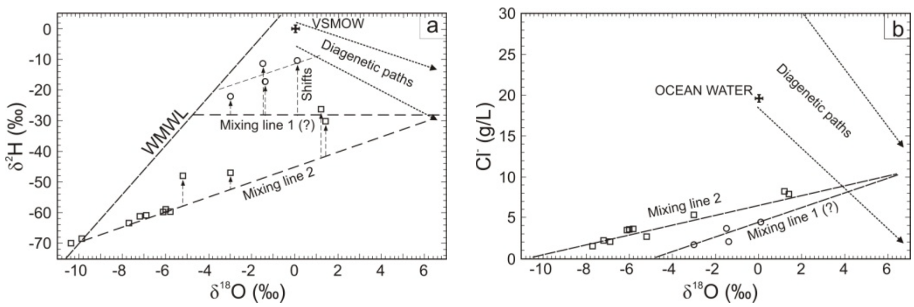

Figure 3. As in Fig. 2, but for the Iwonicz Spa area where two groups of samples can be distinguished. The $\delta^{18}O$–Cl^- relations suggest a similar isotopic heavy end-member as in Fig. 2 but with a higher Cl^- concentration. The mixing lines shown in (a) are deduced from the $\delta^{18}O$ values 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

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).

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.

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.

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GEOCHEMISTRY AND ORIGIN OF MINERAL GROUNDWATER FROM FADEEVSKOE SPA (FAR EAST OF RUSSIA)

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Keywords: mineral groundwater, high pCO_2, CO_2 origin

The Fadeevskoe deposit of high pCO_2 mineral groundwaters is located in south part of Russian Far East, in Primorye region, in the upper reaches of the Klyuch Ivanov Creek. 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. 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 (J3–K1sm).

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 Klyuch Ivanov Creek is the main surface water stream of the area. Its drainage area is only 20 km^2. The creek is 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 manifold increases during floods. The module of the surface runoff is 2–3 l/s per a km^2. The creek waters are hydrocarbonate with a mixed cation composition and characterized by low TDS (up to 240 mg/l) and pH (5.5–6.8).

The fresh subsurface waters are confined to weathering, brecciation, and fracturing zones in the volcano-sedimentary rocks constituting the upper part of the Samarka Formation and are distributed through the entire study area. They are head waters and hydrocarbonate sodium and calcic in their composition with an elevated content of silica. The waters are characterized by low TDS (up to 0.1–0.2 g/l), which is explained by the intense water exchange.

High pCO_2 mineral groundwater is hydrocarbonated and characterized by relatively low TDS (0.3–0.5 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 mineral waters in the deposit, 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. The content of HCO_3^- is also varied from borehole to borehole 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. The content of the main cations in this type of groundwater is significantly differed in boreholes 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 contents are recorded in the waters from boreholes 4 and 1, respectively. The Mg 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. The hydrogen and oxygen isotope ratios indicate the atmospheric genesis of the aqueous component (δ^2H = –117‰; ($\delta^{18}O$ = –15.4‰). The mineral waters 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.

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

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

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)

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ORIGIN OF MINERAL WATER FROM ROGAŠKA SLATINA (SLOVENIA)

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Keywords: Rogaška Slatina, mineral water, origin, sustainable management

Rogaška Slatina is famous by mineral water, which is stored in fractured layers of the Oligocene tuff. 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. The groundwater discharge is 0.1 to 1.4 l/s, the temperature is 11.9 to 28.4°C, the specific electroconductivity is 5160 to 11000 μS/cm and pH 6.4 and 6.9.

Numerous investigations of Rogaška groundwaters were subjects to balneology and to larger exploitation quantities (Nosan, 1975), so 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 (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. Hence, complex geological, hydrogeological, chemical, geochemical, isotopic and microbiological investigations were performed in this area to answer the discussed open questions. The aquifer system of the Boč massif was mapped into detail (scale 1:5000). The lithological map clearly indicates the interdependence between changes of rock basement and a hydrological network. Data were applied for construction of a structural geological model to define the contact between Permian-Triassic and Miocene rocks. The results indicated that the carbonate Boč massif is not overthrusted through the Miocene clastic rocks in the northern part as it is illustrated in the basic geological map 1:100 000 (Aničić, Juriša, 1984), but the contact between the carbonate and clastic rocks inclines at about 75° to the N-NW direction. This information is essential to confirm the research hypothesis and represents bases for a development of a local hydrological model during the next research phases.

The discharge of important surface streams and boreholes was monitored and precipitation was registered at three different altitudes to get data for hydrological balance of the study area. The quality monitoring run parallel–groundwater was sampled for ^{18}O, ^{2}H, ^{3}H, ^{13}C-DIC and ^{14}C isotopic analyses. The results of ^{3}H and ^{13}C are presented in Figure 1a and b, respectively. ^{3}H data points out old mineral waters RSL-1, RSL-2, RSL-6, RSL-7 and RSL-11. RSL-3 is also mineralized, but it should be mixed with young fresh water.

a) b)

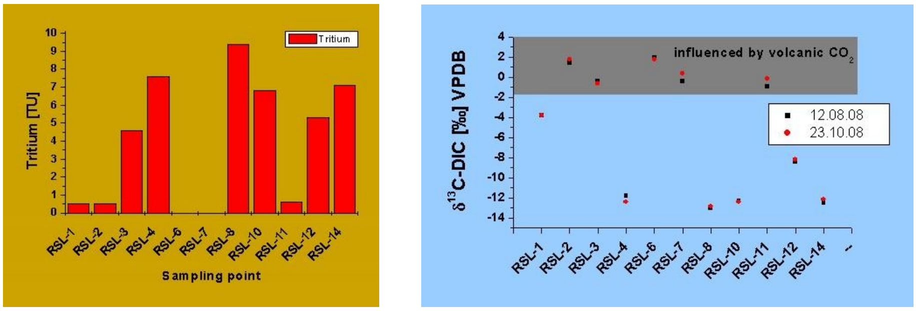

Figure 1. a) Tritium concentrations, b) ^{13}C isotopic composition in groundwater, sampled in the Rogaška Slatina area.

Figure 1b illustrates groundwaters that are influenced by volcanic CO_2: RSL-2, RSL-3, RSL-6, RSL-7 and RSL-11. All these waters are highly mineralized, as it was mentioned in the previous paragraph. The RSL-1 water has lower mineralization, which is reflected in ^{13}C-DIC values.

The synthesis of results enabled precise definition of the study water body and construction of a local hydrological model in the next research phase, which will enable insight into mechanisms of groundwater flow and solute transport processes in the research area. 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.

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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‰) $\delta^{13}C$.

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Abstract ID: 495

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

The Polish Outer Carpathian constitutes the so-called the Outer Carpathian Geothermal Region. 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. The thermal waters in this region have been encountered in several exploratory drillings (in majority connected with oil and gas exploration), and are utilized only in few places for balneological treatment (for example: Ustroń, Rabka). The main reservoirs of these waters in the eastern part of the region are linked to flysch sediments from Lower Cretaceous to Oligocene. Usually, the perspective horizons with thermal waters occur in depth of about 1000 m and more. Vast majority of thermal waters in this area is brackish and saline, in various degrees associated with oil and gas deposits. 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 sometimes 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 hydrogeothermal systems in the area of Outer Carpathians is hardly possible. The recharge areas for thermal waters are still not known, their origin is poligenetic and their resources might be limited. To evaluate the potential hydrogeothermal systems in the light of their prospectiveness to further exploration of thermal energy resources, we took an attempt to apply selected isotopic and chemical geothermometers to assess the maximum possible temperatures which may be encountered at depth. The reservoir temperatures estimated by chemical geothermometers are very diverse and variable. Although the chalcedony geothermometer estimate quite well the outflow temperature of water from some wells, it is not the case for other typical oil-associated waters. Generally silica and Na-K geothermometers indicate reservoir range of temperatures in the eastern part of the flysch Carpathians equal few dozen degrees of centigrade (i.e., between 48 and 83°C). The Mg–Li geothermometer, which is specially recommended for estimation of reservoir temperatures in the areas of oil fields (Kharaka and Mariner, 1987), indicate maximum temperatures between 105–126°C. 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 further investigation taking into account the complex origin of waters in this area. But there are some premises for supporting the idea about possibilities of high temperatures (i.e. in the range of slightly more than 100°C) in deeper parts of the flysch Carpathians. The highest temperatures estimated by Mg–Li geothermometers are connected with the isotopically heaviest waters, i.e. those having the largest admixture of dehydration waters. Dehydration of mixed layers smectite/illite occurs in sedimentary basins where shale sediments are subjected to increased temperatures during diagenesis, usually 80–120°C, and

geothermal gradient of about 2.4°C/100 m would be enough to initiate dehydration at the depth of about 3000 m. 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. The range of these temperatures in the Central Carpathian Synclinorium coincide with the mineralized water reservoir temperature range between 50 and 130°C, calculated on the base of the Mg and Li geothermometric ratio. All these facts seem to support the idea about higher temperatures dominated in eastern part of the Polish Outer Carpathians in geological past and/or about origin of waters connected with deeper parts of the basin. Nowadays the whole basin is considered to be cooled down, and the reservoir temperatures of mineralized waters calculated with application of Mg–Li geothermometer should be treated tentatively as kind of residual paleotemperatures. However, in the vicinity of Wiśniowa, Skole Unit, the water with outflow temperature of 84°C was found in exploratory borehole, which is quite optimistic premise for the future explorations.

4.3 Hydrogeochemical characteristics of mineral and thermal waters

Abstract ID: 115

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

INTRODUCTION

Portugal is one of the world's richest countries in thermal and mineral waters. Inventories of the richness in mineral springs in the country 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 a number of 668 locations with one or more waters with therapeutic characteristics, 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. Almost all mineral 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). In the last decades the interest in a general view of the natural mineral waters seems to have declined. Several modern studies are known, but they all only have a local/regional focus (e.g. Marques et al., 2006). However, we believe that it is important to have a countrywide overview of the chemistry of mineral waters. As mineral waters normally have a relatively deep source and a recharge area far away from the springs, mapping them can also provide a good overview of the chemistry of the deeper geology.

DATA COLLECTION

Analyses from Portuguese mineral waters were collected, as much as possible, from published literature (mostly from reports and books available in the library from IST) and the internet. We collected 822 analyses from 606 springs from about 500 locations in the Portuguese mainland. Multiple analyses from the same source (from different years) were averaged. Compositions from sources from which multiple analyses were available (sometimes representing a period of over 100 years) generally showed only little variation over time, showing that mineral springs have constant compositions, but 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.

RESULTS

From most springs and wells only the more common elements were measured. For this reason we were only able to draw maps from the major and the "most major" minor elements (such as F^- and HS^-). As examples we present in this abstract three maps showing clear variations in the distribution of some geochemical signatures over the country (Fig. 1).

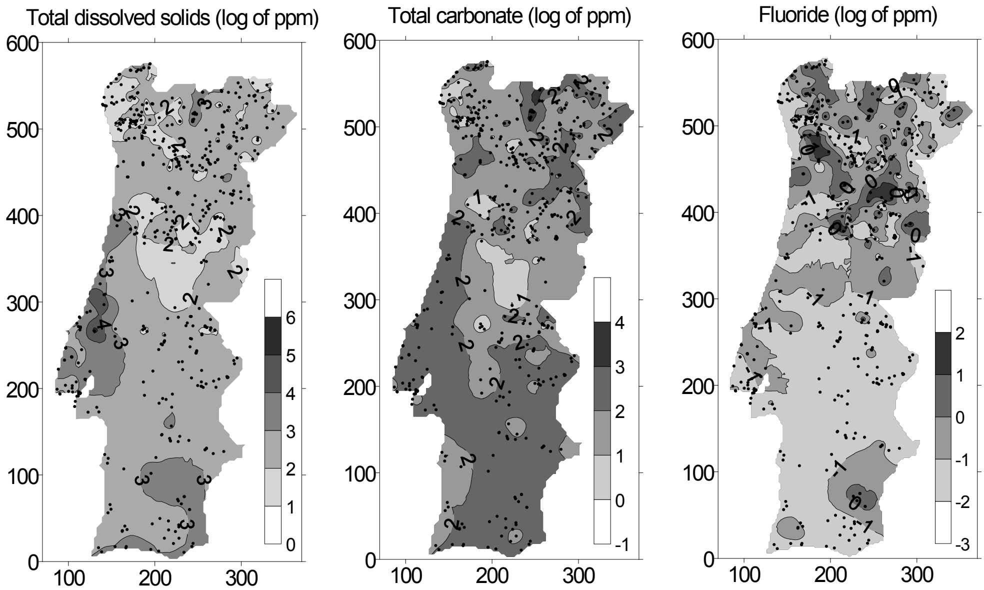

Figure 1. Distribution of TDS, ΣCO_3 and F^- in mineral waters in from the Portuguese mainland.

The highest TDS values are found in mineral waters circulating in the W and S coastal regions, related to the presence of salt deposits (e.g. diapirs) in these sedimentary basins. The highest (bi)carbonate is found in several mineral waters which catch most of their CO_2 from upper-mantle sources. The relatively high carbonate concentrations in the south are the result of water-rock interaction with carbonates. Fluoride is regulated very much by the solubility product of fluorite (CaF_2) and as such especially high in the granite dominated north of the country where calcium concentrations are low. These preliminary results show the usefulness of this hydrogeochemical approach to get a countrywide view on mineral water distribution.

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Abstract ID: 162

HYDROGEOCHEMISTRY OF BOTTLED MINERAL WATERS OF SERBIA

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Keywords: chemistry, geology, water

There have been over 230 mineral springs and about 30 factories for bottling mineral water registered in Serbia. Detailed chemical analyses for 13 representative bottled waters have been done by the working groups of the EuroGeo Survey Geochemistry from Berlin. Based on results of chemical analyses of waters it is noticed that some of samples have high concentration of dissolved substances. When it comes to anions bicarbonates are dominant in all waters, and when it comes to cations, sodium is characteristic for carbonated waters while calcium and magnesium in other samples. Besides macrocomponents, this analyses also include specifing of large number of microelements. They can have great importance in both practice and theory. Practical importance can be in possible valorisation of content of some microelements essential for humans. Relation between microelements in groundwater and rocks can give us an answer to the question of mineral water genesis. Every examined water has its own characteristic microelements (e.g. B, Cs, Ge, K, Ni, Rb, Sb, Ti, W etc.) and in this work hydrochemical conditions of appearance of some microcomponents in examined bottled waters in Serbia, as well as other factors like lithology, tectonics, vulcanics etc. are defined.

Abstract ID: 245

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

CO_2-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

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 area (Kralj, Kralj, 2000). Mineral waters occur in shallow aquifers or spring out along fault systems (Kralj, 2001). The main cause of their formation is penetration of carbon dioxide from pre-Tertiary basement towards the surface (Kralj et al., 2009).

Mineral waters in the Benedikt and Ščavnica valley area have relatively variable composition and belong to the Na–Ca–HCO_3, Ca–(Na)–HCO_3, or Ca–Mg–(Na)–HCO_3 hydrogeochemical facies. The amount of total dissolved ions ranges from about 900 mg/L to over 4.5 g/L. Based on chemical composition of major ions and trace elements, the formation of mineral can be ascribed to the following processes:

1. Penetration of carbon dioxide into shallow clastic aquifers and the consequent water-rock interaction mainly with limestone and dolomite rock fragments. Locally diverse mineralogy of the aquifer sediments may be reflected in disproportionally high abundance of Mg^{2+} ions and trace elements like boron or barium.
2. Uplift of thermal waters from deeper central parts of the basin that mainly belong to the Na–HCO_3 hydrogeochemical facies (Kralj, 2001; Kralj, 2004), their cooling and chemical modification related to precipitation of solids. Mixing with cold ground-waters and contemporaneous or subsequent alteration by dissolution of carbon dioxide and water-rock interaction. Estimated proportions of admixed modified thermal waters range from some 5–25%.
3. The influence of ion-exchange can be recognized in some waters from shallow aquifers. The waters may reflect fractionation of some geochemically related elements by preferential adsorption on clay minerals, like for K^+ and Rb^+ ions, where relatively more K^+ ions are adsorbed and more Rb^+ ions remain in the water.

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Abstract ID: 274

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.

Sulphate mineral water which have been found in Permian sedimentary rocks, in Sokołowsko, south of Wałbrzych (the Intra-Sudetic Synclinorium, the Sudetes Mts.) shows the chemistry (Tab. 1) unique against a background of the Sudetes, where CO_2-rich mineral water with varied cationic composition dominate. Geochemical investigations, which included aqueous chemical and isotopic composition, chemistry of mineral phases, geochemical modelling, and tritium and radiocarbon groundwater dating were performed for elucidating the origin of water chemistry.

Table 1. Chemical and isotopic characteristics of sulphate groundwater found in Sokołowsko, the Sudetes, Poland (after Dobrzyński 2009). Concentrations in ppm.

Parameter	Value	Parameter	Value	Parameter	Value
T [°C]	15.3	NO_3	0.00	Mn	0.126
pH	7.60	Ca	322.9	Mo	0.022
pe	1.278	Mg	20.2	NH_4	0.13
SEC_{25}[1]	2070	Na	129.5	Sr	7.836
DOX[2]	0.60	K	1.5	Zn	1.052
H_2S	0.44	Al	0.045	^3H [TU]	2.44 ÷ 3.20
SiO_2	19.8	As	0.1023	^{14}C [pmC]	26.94 (±0.19)
SO_4	1113	B	1.114	$\delta^2H_{(VSMOW)}$ [‰]	–68.3 ÷ –71.04
HCO_3	116	Ba	0.011	$\delta^{18}O_{(VSMOW)}$ [‰]	–10.22 ÷ –10.31
Cl	0.2	Fe	0.66	$\delta^{13}C$-$DIC_{(VPDB)}$ [‰]	–16.26 ÷ –16.51
F	0.01	Li	0.121	$\delta^{34}S$-$SO_{4\ (VCDT)}$ [‰]	+10.60 ÷ +13.87

[1] – specific electric conductivity (in μS/cm) compensated for 25°C

[2] – dissolved oxygen.

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). The mixing of these components appears to be the main process responsible for the observed aqueous chemistry. The share of SMW component in the sulphate mineral water horizon have been estimated to be about 65% (Dobrzyński, 2007b) after geochemical modelling (by using PHREEQC code; Parkhurst, Appelo, 1999). Inverse mass balance modelling coupled with isotopic (S, C) data indicates that chemistry of the SMW was shaped by the process of dedolomitization driven by gypsum dissolution (Dobrzyński, 2007a, 2009), accompanied by the organic matter decomposition and ion exchange. The increase in porosity due to the reactions which formed chemistry of SMW is estimated to be lower than 0.04%. The MTW component revealed mean tritium transit time of 98 years, based on the lumped-parameter approach (by applying FLOWPC code; Małoszewski, Zuber, 1996, 2002). The calibrated radiocarbon-age of SMW is estimated to be of 5.9(±0.3) ka BP, i.e., it infiltrated during the so-called Mid-Holocene Climatic Optimum. During radiocarbon dating complex corrections have been applied, i.e., effects of the initial ^{14}C activity in recharge zone (Dobrzyński, 2008), mixing of two water components (Dobrzyński, 2007b), effects of chemical water-rock reactions in saturation zone (after inverse mass balance modelling), and variations of atmospheric ^{14}C in the Holocene. The mean apparent reaction rates for the main phases responsible 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). The studied system has only about 40 km^2. One should be noticeable that reaction rates found are well consistent with the reaction rates for a vast regional Madison aquifer, USA (Plummer et al., 1990; 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

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

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 $^{3}He/^{4}He$ 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 $^{3}He/^{4}He$ ratios is observed (0.036 to 1.76 ($\times10^{-6}$)), showing evidence that while radiogenic ^{4}He 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 ^{3}He and $^{4}He/^{20}Ne$ 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.

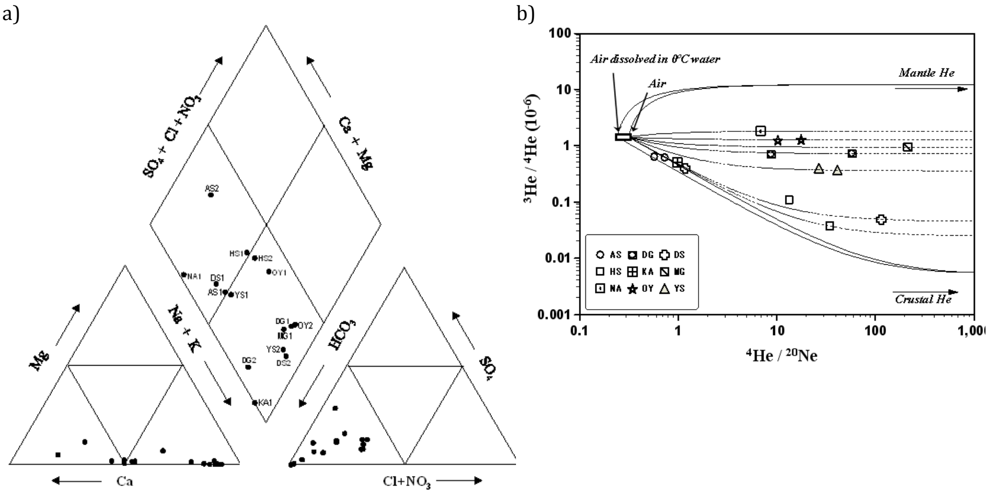

Figure 1. Trilinear Piper diagram of major ion compositions of geothermal water Samales (a), and plot of $^3He/^4He$ versus $^4He/^{20}Ne$ ratios for waters and gases (b).

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.

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Abstract ID: 368

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

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 multicomponent chemical calculation of chemical equilibrium proposed by Reed and Spycher (1984) were applied to estimate thermal 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. Both sites provide hot waters, at 44°C and 59°C in Lądek (L-2) and Cieplice (C-2), respectively. The Cieplice/Lądek thermal waters differ mainly in pH, calculated PCO_2, E_H, and concentration of main solutes (Ca, Na, SO_4, alkalinity), silicon and hydrogen sulphide (Tab. 1). In addition to mineral saturation plots which provide a temperature at depth, geochemical reaction paths revealing how the chemical composition is formed at presence of a genuine mineral assemblage have been modelled. The PHREEQC code (Parkhurst, Appelo, 1999) with LLNL thermodynamic database has been used for all calculations. 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 110±10°C. The resulted temperatures are higher than proposed earlier by Ciężkowski et al. (1992), Leśniak, Nowak (1993), and generally are close to the recent estimate by chemical and isotopic geothermometry (Dowgiałło, 2000; Dowgiałło et al., 2005).

The gneisses of Lądek metamorphic complex and Karkonosze granites of Cieplice are composed mainly of plagioclases, K-feldspars, biotites, and muscovites. The main difference is that plagioclases in Lądek gneisses are more sodic (avg. $Ab_{85}An_{15}$) than plagioclases in granite (avg. $Ab_{65}An_{35}$). Taking into account the estimated temperatures, PCO_2 values and a genuine rock-forming mineral assemblage a reaction paths have been modelled by trials and errors. 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 waters of interest. Concluding, the main features of water chemistry in both systems are probably formed by dissolution of plagioclases, biotites, and fluorites and precipitation of Ca-beidellite, calcite, and silica. In addition to the above mineral assemblage, to account for water chemistry in Lądek the precipitation of Na-beidellite and amount of H_2S were also added.

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 [ºC]	44.3	58.8	Na	47.778	169.773
T[2] [ºC]	80±5	110±10	Ni	0.002	0.001
$\log PCO_2$[3]	–4.50	–2.75	P	0.024	0.026
$\log PCO_2$[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-NO_3	0.007	0.002
Fe	0.033	0.027	N-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 mg$CaCO_3$/L

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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.

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). By a chemical analysis, significant quantities of H_2S of 19 mg/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.

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	—	—

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

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

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

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

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 (Dowgiałło et al., 1969; Paczyński, Płochniewski, 1996; Madeyski et al., 1979). They have different chemical composition and origin.

It is also possible to use mine waters from the Carboniferous formations of the USCB for therapeutic purposes. Studies of the chemical composition and the origin 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 Goczałkowice, Dębowiec, Ustroń and Zabłocie have different chemical composition and origin. These waters are characterised by the pharmacodynamic parameters in compliance with the regulations of the Polish law. Some chemical components of the mineral water from the borehole "Korona" in Zabłocie in the period 1950–2008 are presented in Table 1. Concentration of iodides and iron ion (II) is almost constant during more than last thirty years.

MINE WATERS FROM ABANDONED COAL MINES IN THE SOUTHERN PART OF THE USCB

From 1989 when the coal mining reforms had been commenced in Poland, many coal mines have been closed. In the southern part of USCB "1 Maja", "Moszczenica", "Rymer" and "Żory" coal mines have been abandoned. Some chemical components in the mine water flowing from the abandoned "Żory" Coal Mine in the period 1997–2008 are presented in Table 2. Results of the pharmacodynamic parameters: the iodide and iron ion (II) are in quantities exceeding the values of mineral waters therefore can be used for hydrotherapeutics.

Table 1. Concentrations of chloride, iodide and iron ions in the mineral water from the borehole „Korona" in Zabłocie in the period 1950–2008.

Parametr	Borehole "Korona"				
	1950–1976	**1976**	**2001**	**2007**	**2008**
Cl^- [g/dm^3]	25.8–26.8	26.4	26.2	24.6	25.3
I^- [mg/dm^3]	121.0–137.2	128.7	130.0	134.0	138.0
Fe^{2+} [mg/dm^3]	8.6–59.5	15.8	14.9	10.5	14.0

Table 2. Concentration of chloride, iodide and iron ions in the mine water from the abandoned "Żory" Coal Mine in the period 1997–2008.

Parameter	Waters from abandoned "Żory" Coal Mine				
	1997–1998	**1999**	**2000**	**2001–2002**	**2002–2008**
Cl^- [g/dm^3]	44.0–46.0	47.0–53.0	54.0–58.0	59.0–66.0	64.0–68.0
I^- [mg/dm^3]			40–60		
Fe^{2+} [mg/dm^3]			30–60		

CONCLUSIONS

Some groundwaters from the Miocene (Badenian), the Carboniferous and Devonian formations in the southern part of the Upper Silesian Coal Basin are used as mineral waters. Mine waters from the abandoned coal mines in this region can be utilized as brines for medical therapy.

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Abstract ID: 431

HYDROGEOCHEMICAL CHARACTERISTICS AND THEIR BASIC TYPES THERMOMINERAL WATERS IN SERBIA

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Keywords: geological composition, hydrogeology, hydrogeochemical, thermomineral waters, basic type

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 were 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 g/kg to 20 g/kg. Maximal temperature of the natural springs is 96°C. Maximal temperature of thermal water from wells is 111°C.

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Abstract ID: 450

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

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VARIABILITY OF MAJOR PARAMETERS OF WATER FROM THE MAIN SPRING (ZDRÓJ GŁÓWNY) IN KRYNICA ZDRÓJ

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Keywords: Krynica Zdrój, Zdrój Główny spring, carbonated waters

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^-, was based on the results of 40 physical and chemical determinations carried out between 1796 and 2005 (Fig. 1). 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 18th century when Hacquet (1796) gave the first scientific description of the Krynica water properties and determined them as carbonated waters.

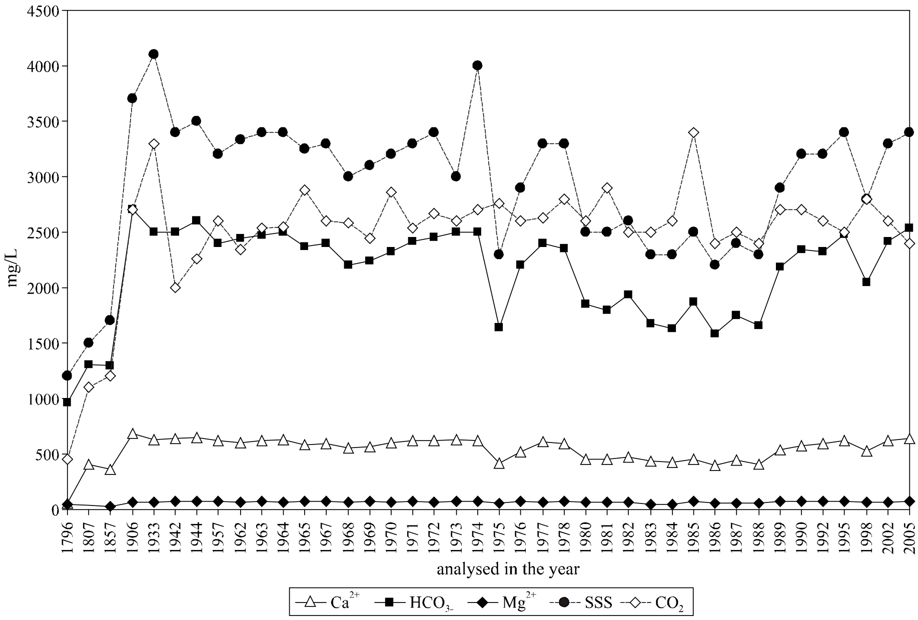

Figure 1. Variability of major parameters of water from the Main Spring (*Zdrój Główny*) in Krynica Zdrój (determined from a database assembled at the Chair of Economic and Mining Geology, AGH).

The 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

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Abstract ID: 463

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/dm^3 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:

1. Carpathian (including the Carpathian Mts, and the fore–Carpathian basin,
2. Sudetic (including the Sudetes Mts and the fore–Sudetic block and
3. The Polish Lowlands province.

1. The Carpathian Mts 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 Triassic deposits. Typical of the Outer Carpathians are waters: a) carbonated, b) Cl–Na, c) mixtures of a) and b). The first ones 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, sometimes appearing in springs (being the groubd 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 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 not situated in fault zones. This is the reason why the use of thermal waters (to be certainly found in deep boreholes) did not develop so far. The Carpathian fore-deep provides saline waters from thick Miocene sediments. Saline 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 reduction, and are used for therapeutics in health resorts like Busko, Solec or Horyniec.

2. The Sudetes Mts. are an area, where in a number of renowned health resorts mineral and thermal waters are recognized as medicinal and used for hesaling 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 2000 m deep borehole reached water outflow with temperature exceeding 86°C.

3. The Polish Lowlands province is typical of a thick Cenozoic series covering in its NW part the formations belonging to the Caledonian platform and in the SE part — the Precambrian 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. 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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The number of relevant references amounts to several hundred and they cannot be listed here.
Opening paper to be presented at the IAH Mineral and Thermal Waters Commission meeting

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GEOCHEMISTRY OF THERMAL WATERS OF SIKHOTE-ALIN RIDGE, RUSSIA

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Keywords: thermal waters, hydrogeochemistry, nitric waters

The results of geochemical studies of low-temperature geothermal waters, occurring on the coast of Japan and Okhotsky seas of Russia are reported in the paper and compared with similar well-known areas of the Primorskiy region (Tab. 1). All thermal water systems occur in Sikhote-Alin ridge (Fig. 1). All the waters are classified as alkaline Na–HCO_3–SO_4 or Na–HCO_3 type of waters.

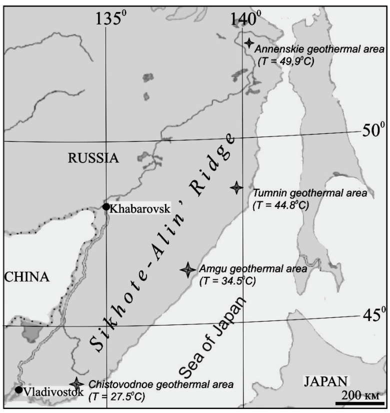

Figure 1. Continental margin of the Far East of Russia.

Based on $\delta^{18}O$ and δ^2H isotopic ratios (Fig. 2), origin of the low-temperature geothermal waters have been recognized.

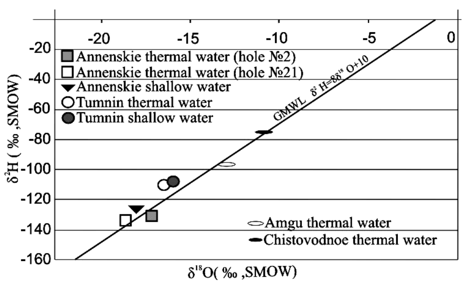

Figure 2. Stable isotopes ratios.

Received data indicate that geothermal waters have meteoric origin and chemical composition is forming as a result of water-rock interaction. Also subsurface temperatures for studied geothermal areas were estimated using different types of geothermometers.

Table 1. Representative data of studied waters.

	Annenskie (№ 21)	**Tumnin (№ 9)**	**Amgu**	**Chistovodnoe**
pH/°C	9.2/49.9	9.3/44.8	9.1/34.5	8.9/27.5
		mg/l		
HCO_3^-	112.8	35.8	57.3	56.0
Si	26.6	19.2	17.5	14.2
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
Na^+	61.0	35.6	34.4	25.3
K^+	0.8	0.5	0.4	0.35
Ca^{2+}	5.2	7.8	2	4.34
Mg^{2+}	1.4	0.04	0.04	0.04
		μg/l		
Ge	2.65	0.65	0.65	0.72
Mo	6.23	13.81	21.98	15.6
Li	71.49	11.39	6.26	46.17
Cu	3.79	2.59	0.38	0.09
Ga	2.1	1.32	2.27	1.79
As	14.32	21.28	6.26	3.42
Rb	6.91	1.15	1.65	0.25
Sr	69.99	17.14	24.35	42.93
U	1.1	1.29	0.05	5.91

New data on gas-geochemistry of thermal waters of Sikhote-Alin folded area is shown in the paper. Studied waters belong to alkaline HCO_3 –Na hydrogeochemical type (Fig. 3). Main gas is nitrogen, going from the atmosphere. Water exchange time is low. It is proved by hydrogen and oxygen isotopic data and by geochemical modeling. New data on REE elements gave the understanding of water-rock interaction occurring during process of water forming. The sources of Ce and Eu anomaly are discussable. Along with tritium and gas composition it led us to insure the model of evolution of Sikhote-Alin thermal waters.

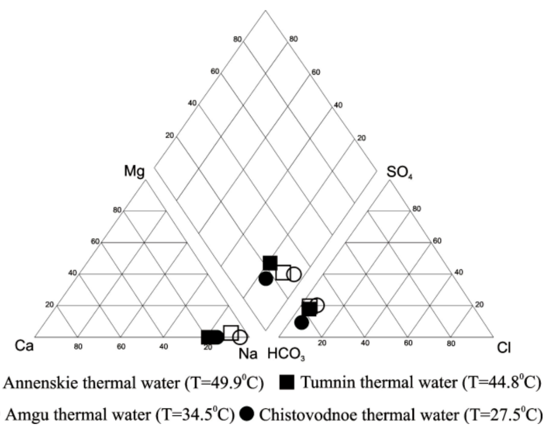

Figure 3. Piper diagram illustrates the major ion geochemistry of the study area.

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Abstract ID: 510

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.

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PESTICIDES IN MINERAL WATERS OF THE TRANSCARPATHIAN REGION

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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. We 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); organophosphoric pesticides (methaphos, carbophos); fluorine-containing pesticide (trephlane).

Analytical experiments were performed using a gas chromatograph's method. 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). In 1997 there were performed determinations in three fields of mineral waters: Luzhanskoye, Poljanskoye, Uzhgorodskoye. 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". 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 reacher 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;
- ΣHCCH is present in 100% of samples in the concentration range 10^{-7}–10^{-5} mg/L;
- 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. Analysis of the situation at the 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 water-saturated zone, the technical state of wells and regime of their exploitation, permeability of the near-well surface and the confined and unconfined charakter of the aquifer.

During the last ten years, DDT content in the waters significantly decreased, while HCCH concentrations remained practicaly the same level. This suggests that HCCH was periodically used at the agricultural lands and forests of Transcarpathian. 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. As soon as DDT is concerned, there were no new income to natural ecosystems, and retrospective pollution gradually decreases ten years (for one order). 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.

Abstract ID: 521

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 between 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 inorganic 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 $AgNO_3$. Following 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 contents. 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 attributed to isotope fraccionation between soil-CO_2 and DIC only. 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.

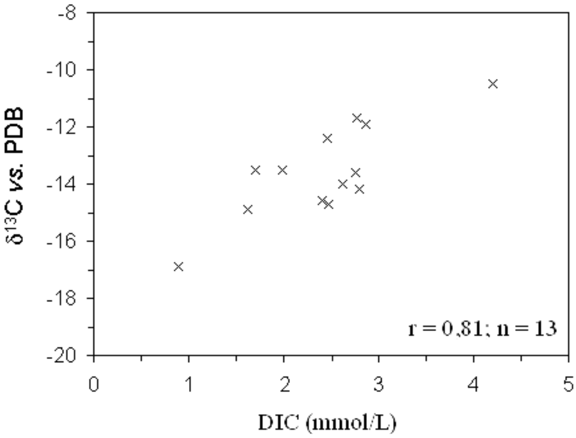

Figure 1. Relation between Total Dissolved Inorganic Carbon and $\delta^{13}C$.

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.

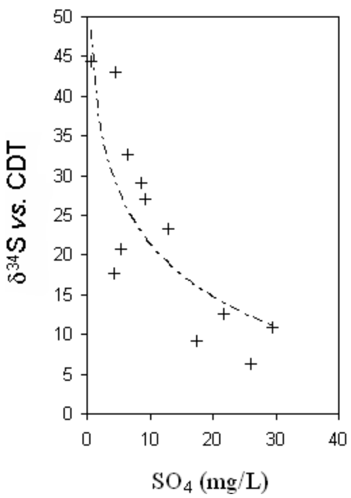

Figure 2. Comparison of sulphate concentrations and $\delta^{34}S$ values.

4.4 | Social, ecological and economic implications

Abstract ID: 180

HEALTHY SAFETY OF NATURAL MINERAL WATERS

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Keywords: mineral water, safety

The mineral waters world market is growing rapidly at a rate of 12% a year. This fact was the contribution of mineral water production and quality control procedures creation. 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.

Guarantees and safety of mineral waters consumers can be assured by the following quality systems:

- 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 system of hazard analysis concerning critical control points (HACCP) has been described. The rules of HACCP system introduction into mineral water factories have been shown. The maximum and minimum HACCP system quality limits concerning the content of microbiological, chemical and physical elements of mineral waters have been presented.

The main rules of HACCP 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.

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Abstract ID: 475

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.

WATER DESALINATION METHODS

Desalination processes based on thermal and membrane separation are the most important ones for drinking and domestic water production (Tsiourtrtis, 2001). 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).

PILOT INSTALLATION

A pilot thermal water desalination installation in Poland will be 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 (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. 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 will be 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. 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 (2007) concerning the quality of water intended for human consumption. Primary criterion in selection of water desalination technology was dependability 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 — 7.19 mg/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, mineralization — 2482.59 mg/dm^3. After preliminary calculated there was selected the technology for the pilot installation. Four treatment steps will be created: preliminary filtration 1000 μm, ultrafiltration UF (for SDI < 4), activated carbon AC filtration double reverse osmosis RS.

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Abstract ID: 482

LEGAL AND FINANCIAL BARRIERS FOR DEVELOPMENT OF GEOTHERMAL ENERGY IN POLAND ON THE BACKGROUND OF GTR-H PROJECT RESULTS

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Keywords: geothermal regulation, heat, GTR-H framework

INTRODUCTION

In the period from December 2006 to 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 an 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.

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" (www.gtrh.eu) 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).

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); 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

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 work deals with the development of a mathematical model to simulate the dynamic behaviour of the water table fluctuation in the presence of seepage due to intermittently applied any number of canal irrigation and groundwater pumping from any number of wells. The model is developed by solving 2-D linearised Boussinesq equation. 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. Application of the model in the prediction of water table fluctuation has been demonstrated by using numerical example. The model may be useful for appropriate planning of conjunctive use of surface and ground water in order to prevent or at least minimize the effect of water logging.

Abstract ID: 124

ESTIMATION OF SOIL WATER RETENTION CURVE PARAMETERS BY GENETIC ALGORITHM OPTIMIZATION TECHNIQUE

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Keywords: water retention curve, genetic algorithm

Water retention curve (WRC) is of interest to soil scientist, hydrogeologists and branches of civil and agricultural engineering with a very of background. This curve showing the relationship between water content for a soil and the soil suction is called soil-water characteristic curve or retention curve. If known, water retention curve can be used to determine fluid retention and calculation the volume of water removed or recharged in groundwater artificial recharge. In this study, the Van Genuchten model is used to distinguish of water retention curve and its parameters. In these research, samples contain 6 samples with texture description were used to perfume the experimental part. A MATLAB genetic algorithm, a popular evolutionary computational methodology, was used for the optimization and modeling process. In this study, we observed that GA is useful and suitable to optimization and estimation of hydraulic parameters of water retention curve.

Abstract ID: 137

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

1. 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.

2. 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.

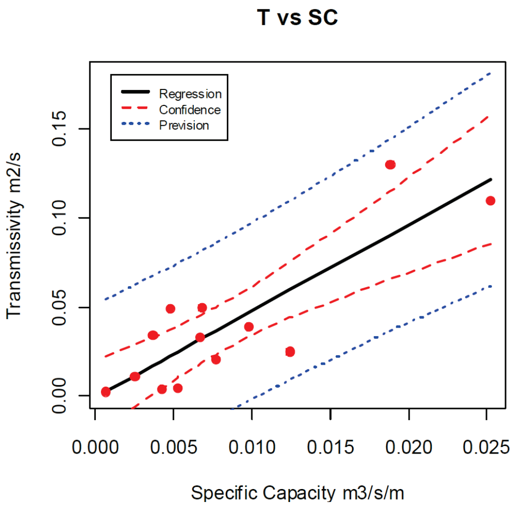

Figure 1. Linear regression Transmissivity vs Specific Capacity.

3. 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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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

The Llobregat's Delta Aquifer, in the proximity of Barcelona area, are an important water resource for urban, industrial and rural supply. Overexploitation in the 70's, and the proximity to sea, caused an important saline intrusion. An increase of users' awareness focused to save resource, and the worsening quality of water, produced a progressive reduction of pumps and consequently an increase of piezometric heads and a decrease of rate of seawater intrusion. Moreover, the recharge of the aquifer through infiltration has reduced because of the urbanization and the big infrastructures construction. Therefore the mass balance can not to revert its tendency.

Two artificial recharge measures to compensate the negative mass balance, has been done by the supply company of Barcelona (SGAB) during last 30 years: deep injection and scarification (clean of mud of river bed). Moreover it has been projected some corrected measures as hydraulic barrier (to correct the seawater intrusion) or recharge basins (to compensate the reduced infiltration).

A numerical model of flow and transport of low basin aquifers of Llobregat River has been done in 2004 by Hidrogeology Group of Technical University of Catalonia (UPC). The model has been built by their own code TRANSIN III (Galarza et al., 1995) to order of the Catalan Water Agency (ACA). The objective was the accuracy knowledge of the hydraulic behaviour of the aquifers focused in the management, planning and arrangement. The Users Water Community of Llobregat Delta (CUADLL) got that model in order to know it, update it and improve it as well as to take part of the aquifer's management, planning and arrangement.

In this way CUADLL has the model ready to use with different objectives according the necessities.

At the end of 2006 was created a mixed commission formed by technicians from ACA and CUADLL, as the technical support for the Arrangement Plan of Llobregat Delta and Low Valley Aquifers. The commission realised about ten technical meetings at the moment, and discussed and suggested a work plans focused basically in the conditions of the future simulations. The simulation results assess the impact of the measures as positive actions.

On the other hand, during these works, the Llobregat basin suffered an important drought. One of the measures to fight against the drought was the recovery of some wells and the increase of pumps. CUADLL became concerned because the probably worsening of the mass of water. For that reason CUADLL used the numerical model to study the consequences from drought to the aquifer, and bring forwards the events.

Because of the drought the seawater intrusion has increased. In some supplies company SGAB's wells, it observed a moderate but worrying increase of salinity. SGAB, as a one of most important user of the aquifer, was worked together with the technical department of CUADLL with the objective to control and prevent the increase of salinity. Besides the definition of a control network, CUADLL used again the numerical model to find the better distribution of pump of the company, and to assess the extraction volume in these environment conditions.

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Abstract ID: 152

A NOVEL APPROACH TO GROUNDWATER MODEL DEVELOPMENT

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Keywords: modelling, mapping, uncertainty

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.

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 1). Furthermore, the methodology documents in a clear manner the interaction of data versus manual interpretation.

Figure 1. Contact points between horizons 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 2). 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 3).

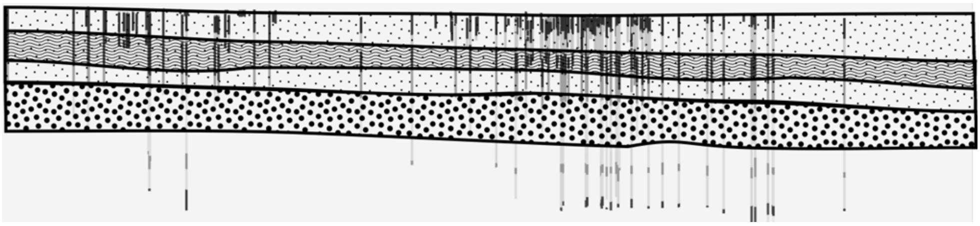

Figure 2. RBF's are used to describe geological units as bodies, the method ensures the entire subsurface is described.

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.

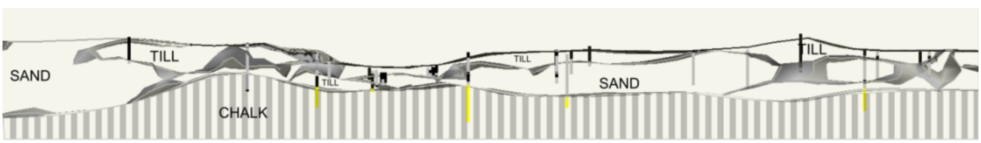

Figure 3. The method is not restricted to describing continuously layered systems.

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Abstract ID: 255

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. 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. 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. Such locations are termed "high recharge edges" in this work.

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. 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, particularly in comparison with recharge estimated using the deterministic geological model, which is not within the recharge limits defined by the stochastic models. 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.

Abstract ID: 257

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.

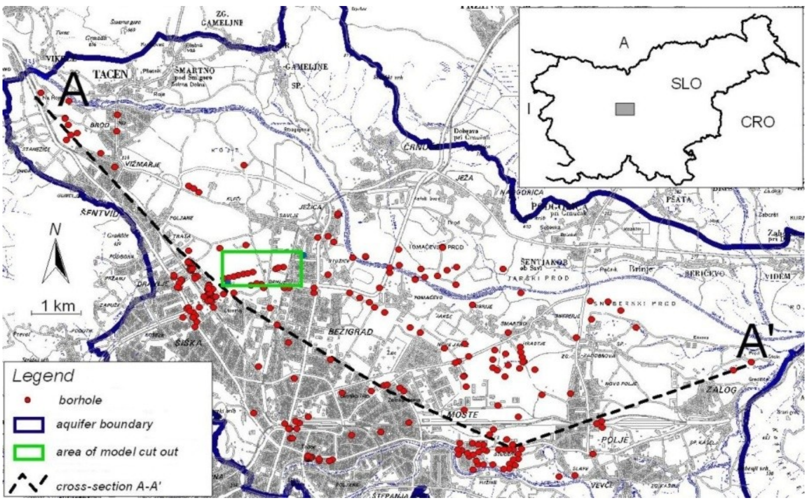

Figure 1. Study area with locations of the boreholes, area of presented model (Fig. 3) and cross-section (Fig. 2) (Janža, 2009).

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).

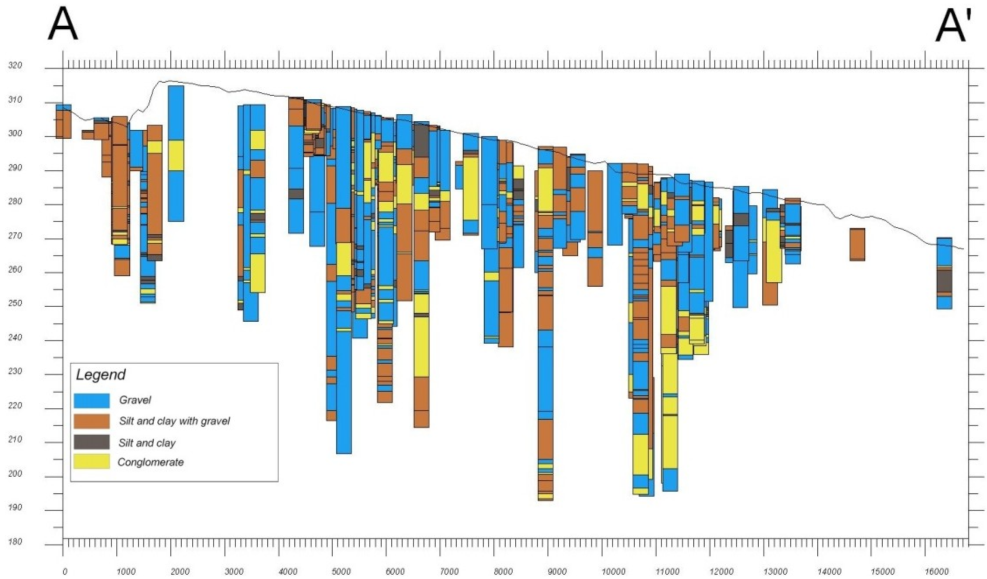

Figure 2. Boreholes in cross-section.

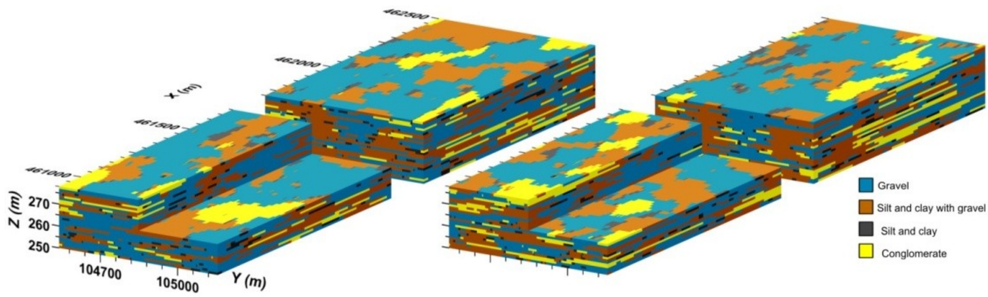

Figure 3. Parts (Fig. 1) of two realisations of geostatistical hydrogeological model of Ljubljana polje.

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Abstract ID: 282

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.

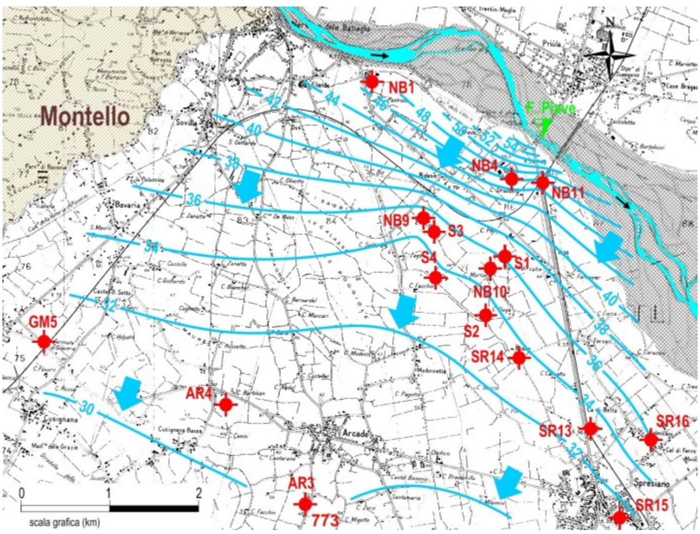

Figure 1. Hydrogeological map of the study area.

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.

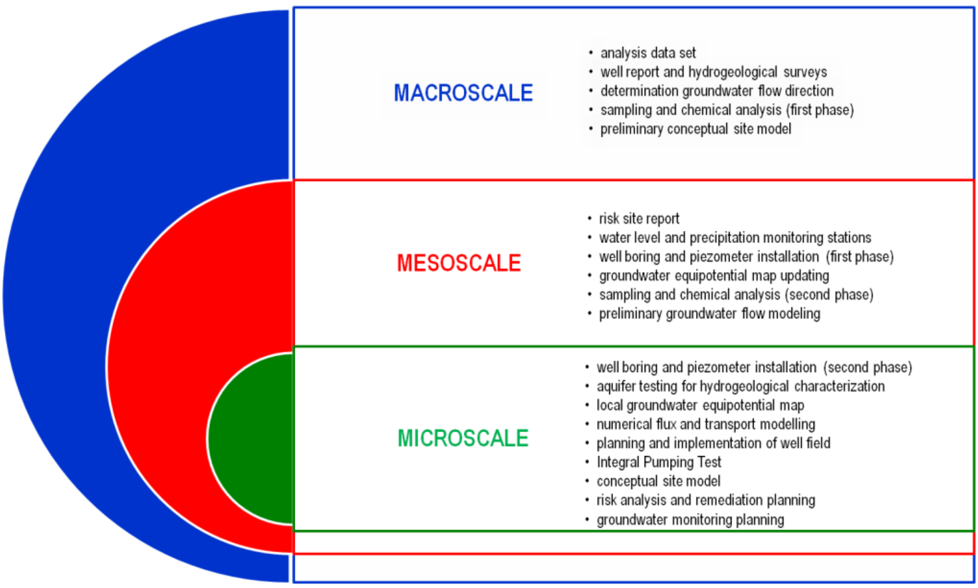

Figure 2. Survey preliminary schedule.

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Abstract ID: 302

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

Due to the year-round high water needs for growing rice in Thailand, farmers are drawing heavily upon the groundwater from the shallow aquifer consisting of gravel, sand, silt and clays of the alluvium and alluvium fan deposits of the Ping-Yom River Basin. The average groundwater level within the 13,900 km^2 study area is about 8 to 15 meters below the ground surface. 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 maintaining 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 for MAR using ponding system. There are four significant groups of parameters to consider, 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 (Tab. 1).

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 2,800 km^2 (Fig. 1) in the southwest region of the study area is considered as very suitable for MAR. It is recommended that all available data should be derived from the same scale maps and more detailed subsurface investigations should be done in order to obtain a more reliable result.

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	
	2.4 Fluvial deposits	1	
	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	

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We would like to thank you the Department of Groundwater Resources, Ministry of Natural Resources and Environment for providing financial support to the project and Groundwater Research Center, Faculty of Technology, Khon Kaen University, Thailand for providing information support.

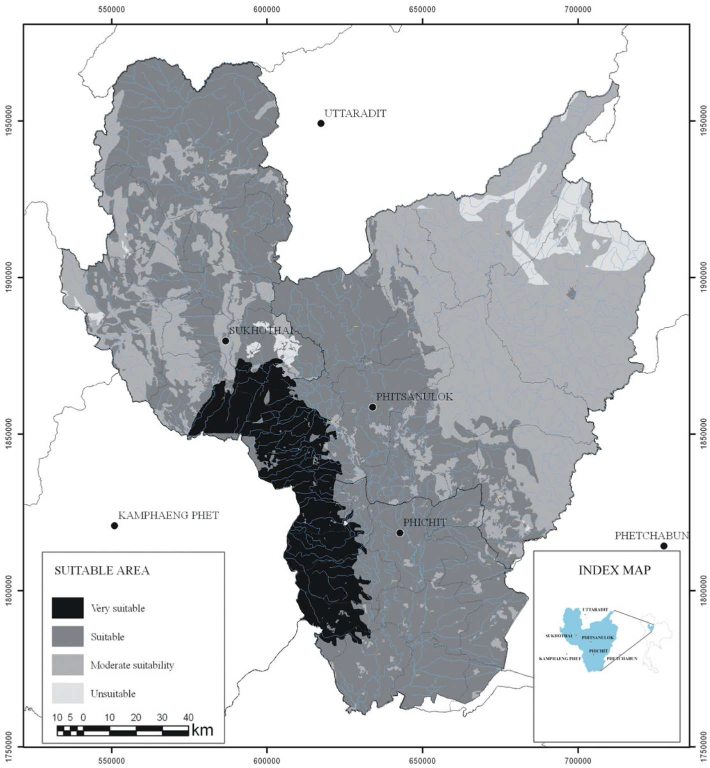

Figure 1. Suitable areas for MAR in the Lower Ping-Yom River Basin.

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Abstract ID: 358

APPLICATION OF REACTIVE SOLUTE TRANSPORT MODELS TO GROUNDWATER RISK ASSESSMENT

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Keywords: risk assessment, models, contamination, reactive transport, pesticides

Tiered risk assessment forms a key part of the UK guidance for implementation of European and national legislation, including the Water Framework Directive. This approach allows for a very simplified and rapid initial screening of risk, with progression to more sophisticated assessment only when a significant risk is predicted. 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, but tends to overestimate the risks.

For more complex problems, more sophisticated models are appropriate, simulating 2-D or multi-layered flow and reactive transport of dissolved contaminants, using packages such as Modflow and MT3D. Although modelling of groundwater contamination requires fine resolution, in more detail than normally used for flow models, 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 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 practical source of contaminant properties. As much of this is based on laboratory experiments, scaling up remains problematic for half lives and sorption rates. However, in most applications, a poorly constrained source term exerts the greatest influence on the results, and choice of dispersion parameters is also a source of significant uncertainty where monitoring data for calibration is sparse.

Two examples of local contaminant transport models are used to illustrate the approach, uncertainties and outcomes for groundwater risk assessment.

At the first site, prediction of fluoride concentrations in a thick Triassic Sandstone aquifer was required for rapid assessment of risks to the aquifer and requirements for remediation, following a large spill of fluorosilicic acid. Simulation of unsaturated transport with PHREEQC predicted significant retardation and very slow release of fluoride into the saturated zone. The calculated concentrations were input as recharge to the Modflow and MT3D models, which simulated steady state flow in the saturated aquifer, and reactive transport using the nonlinear-Langmuir sorption isotherm. Inputs were based on experimental data for average sorbed fluoride in Triassic sandstone (Gresswell, 2005). Even with conservative assumptions, the results indicated that fluoride concentrations would remain below the drinking water limit for at least 50 years at the compliance point, 150 m downgradient of the source, thus monitored natural attenuation was the preferred option.

The second illustration is an investigation into the causes of rising pesticide concentrations in an abstraction borehole in a rural area. The borehole abstracts from the unconfined Chalk aquifer, which is a fine grained fractured limestone and highly vulnerable to pollution. Both point and diffuse sources of pesticides appear possible but no definite source has been confirmed. An initial risk assessment used the Environment Agency's Remedial Targets Worksheet to simulate 1-D fate and transport of five pesticides and identified three compounds of concern. 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 characteristics was obtained from the Pesticide Properties database (University of Hertfordshire, 2009). As the location, size and concentration of the pollution source remained uncertain, each possible source was modelled separately using MT3D and an approximate calibration carried out to match modelled results to historical trends. This approach ruled out a diffuse source, and provided a better understanding of the likely future risks even if the source cannot be located and remediated.

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Abstract ID: 434

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

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).

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).

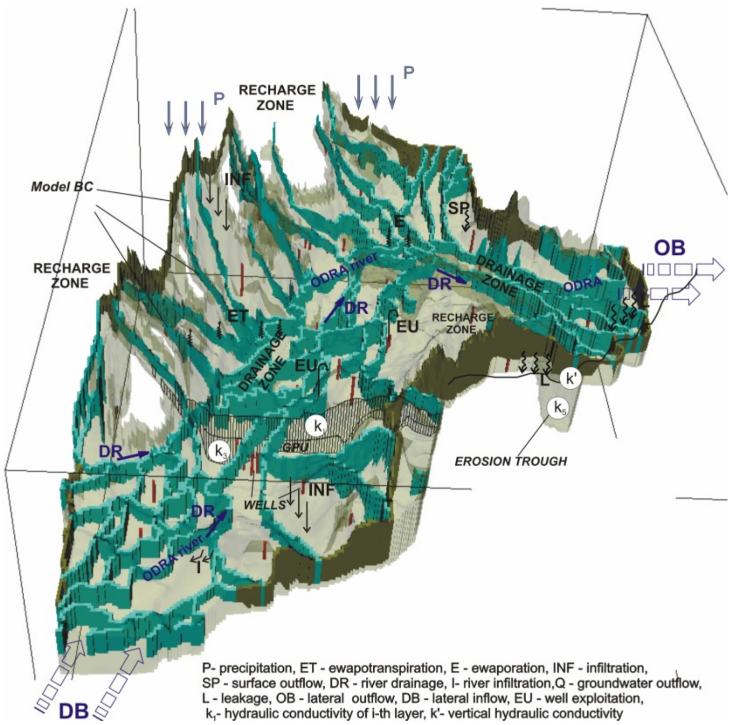

Figure 1. Conceptualisation of groundwater flow system within complex Quaternary MGWB on 3-D numerical model.

A highly complicated hydrogeological conditions are found as well within Quaternary/Neogene (Fig. 1) as Mesozoic MGWBs that were studied. The examples of different type and varying scale were selected to show crucial steps of conceptualization. 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.

The results of the model are presented on the sets of numerical maps and diagrams, but full 3D model (Fig. 1) gives also opportunity of pathlines analysis which is a basis for MGWB protection zone determination.

ACKNOWLEDGEMENTS

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Abstract ID: 449

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.

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.

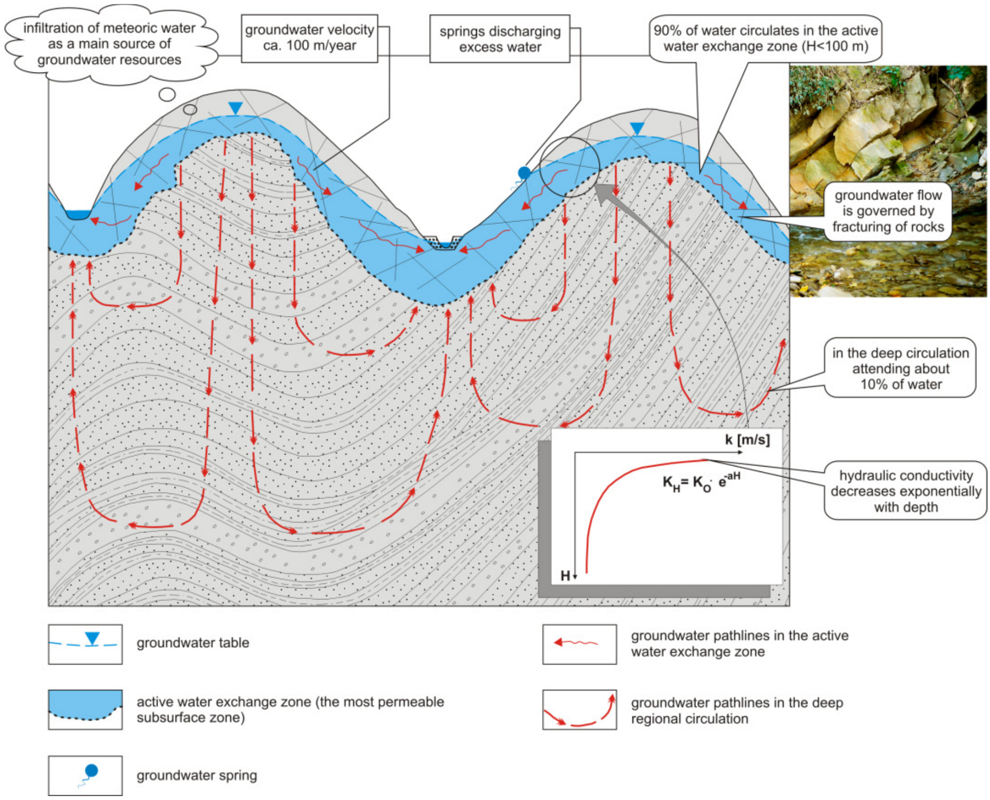

Figure. 1. Conceptual model of groundwater flow system in the studied area (Kania et al., 2010, submitted).

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

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5.2 Groundwater flow and solute transport modelling

Abstract ID: 131

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

This paper deals with the development of a steady state chloride transport model in a volcanic-sedimentary aquifer in Gran Canaria (Canary Islands, Spain). La Aldea Valley is located on the western side of the island (Fig. 1) and the aquifer is unconfined and represents a discharge area to the sea. In some areas water quality problems occurs, due to the existence of intensive greenhouse horticulture and to geologic contamination produced by hydrothermal deposits. More than 370 large-diameter wells are operative in the area. Four hydrogeologic domains have been defined: alluvial deposits, scree deposits, Las Tabladas unit (a residual relief) and Miocene basalts (Fig. 1).

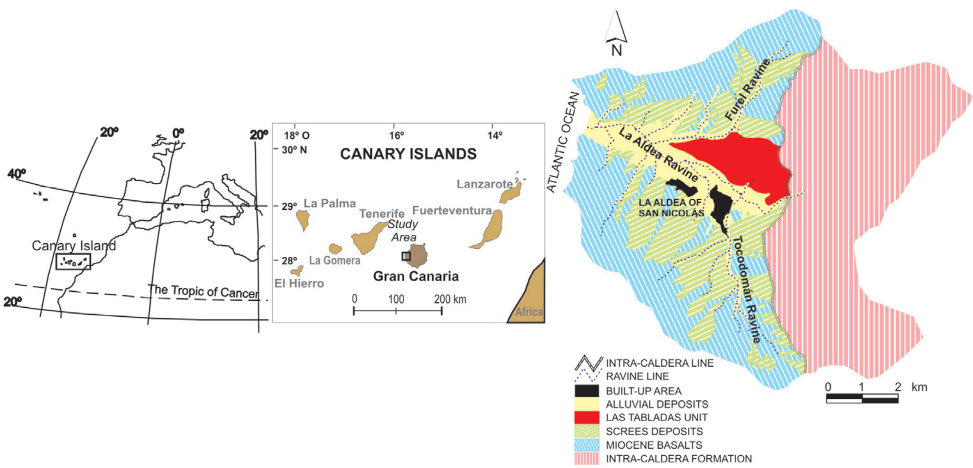

Figure 1. Localization of La Aldea aquifer in Gran Canaria (Canary Islands, Spain) and geological map that shows the main geological units.

CHLORIDE TRANSPORT MODELLING AND RESULTS

A chloride transport model for a saturated porous medium has been developed with MT3DMS in Visual MODFLOW graphical environment in steady-state for the average hydrologic year 1991/92, assuming an anisotropic and heterogeneous environment and constant density (Cruz, 2008). The geometry of the model is conditioned by the geology and the topography, and three layers were considered: the surficial layer includes sedimentary materials and altered basalts, while the other two layers represent basalts. The limits of the northern and southern areas and the bottom surface have been defined as no-flow boundary conditions. To the west, the coastal line has been defined as a constant level and chloride concentration (elevation: 0 m and concentration: 20 270 mg/L). The eastern limit has been considered to be a constant flow and chloride concentration along the contact line. The upper surface boundary conditions correspond to the recharge of rainfall, irrigation returns, supply network leaks and lixiviation in Las Tabladas area.

The simulation results indicate that rainfall recharges are well characterized as the best fits were obtained in the wells that are not affected by irrigation returns (Fig. 2).

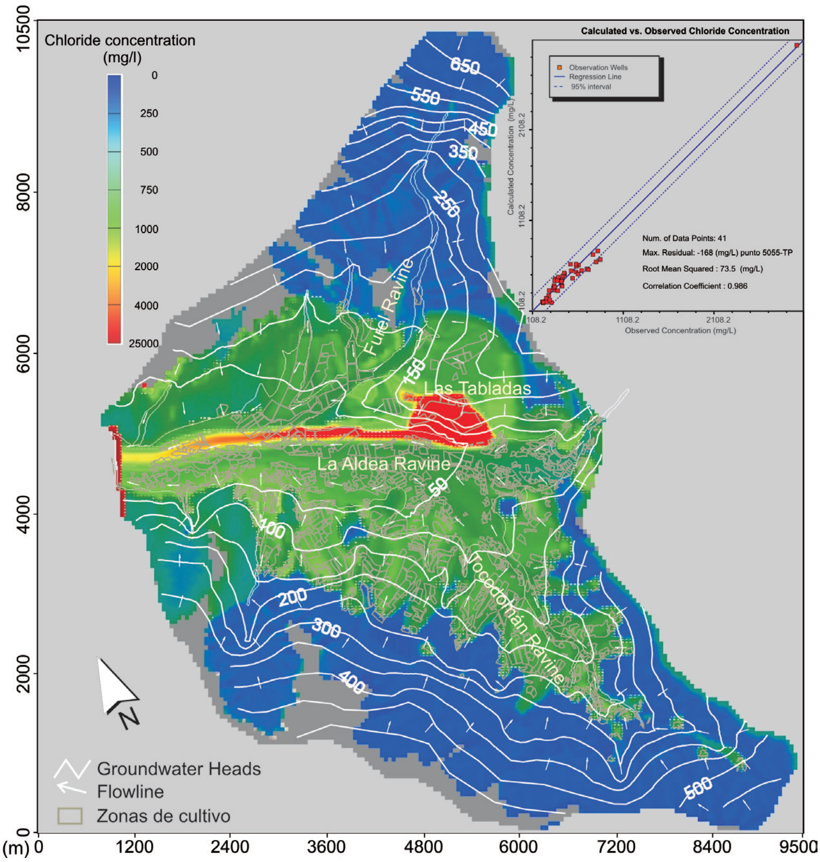

Figure 2. Steady-state water-table map, calculated vs. observed chloride concentration and simulated chloride concentration distribution.

The minimum chloride concentrations are located in the basalts of the upper zones (Fig. 2) where the water comes from rainfall only, uninfluenced by ocean spray. The chloride due to irrigation returns is principally distributed throughout the alluvial areas and the screes (to a lesser degree) and was calibrated in 600 mg/L (best calibration). The plume generated by hydrothermal deposits in Las Tabladas area reaches concentrations above 8000 mg/L and is discharged into the sea, affecting only wells located along the way. 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. Other parameters obtained by the model are observed in Table 1.

Table 1. Parameters obtained in flow and chloride transport models.

	Permeability (m/d)	Coefficient storage	Effective porosity
Alluvial areas	5.5–106	0.08	8–9
Basalts	0.0009-0.005	0.0002	0.3
Scree deposits	0.25–1.2		

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Abstract ID: 200

SIMULATION OF PHOSPHORUS TRANSPORT IN AN UNCONFINED AQUIFER: A CASE STUDY

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Keywords: eutrophication, phosphorus, groundwater, MODFLOW

1. INTRODUCTION

Intensifying loading of nutrient into water reservoir such as pond and groundwater reservoir is an important environmental issues (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). The Malaysian government limited 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).

2. METHODOLOGY

An area of 16.03 hectares inside the campus of University Putra Malaysia, Serdang, Selangor, Malaysia with annual average rainfall of 2990 millimeters, was chosen as the study area. A pond and a sludge are located in the site. Visual MODFLOW was employed to simulate the condition of the phosphorus movement 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. 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 required data and parameters for simulations were collected between January, 2007 and March, 2008 (Saghravani, 2009).

3. RESULTS AND DISCUSSIONS

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 and 2 show the directions of phosphorus movement in Layer No. 2 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.

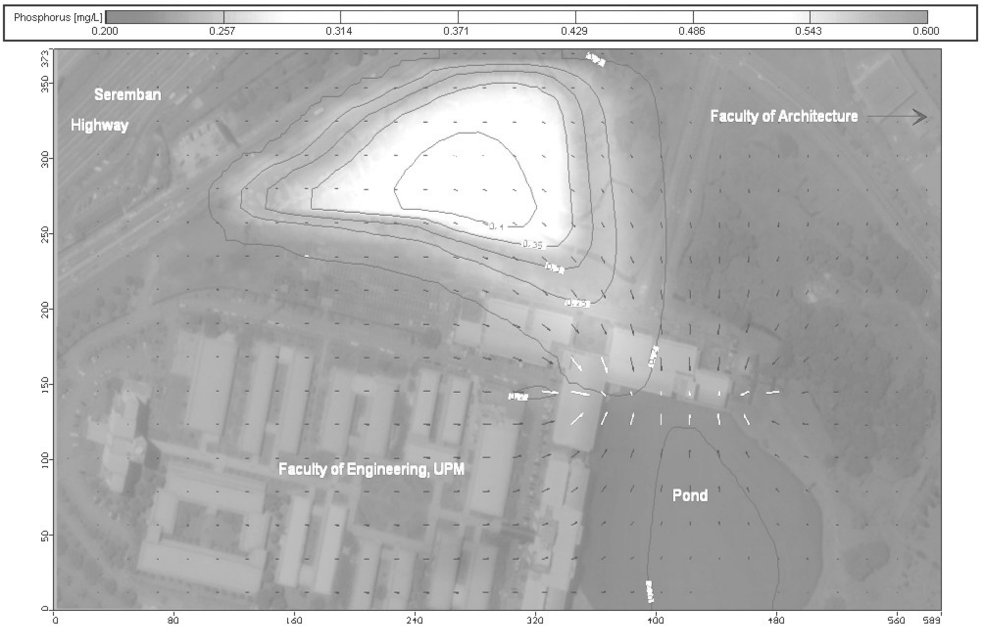

Figure 1. Phosphorus concentration in layer No. 2 (3650 days).

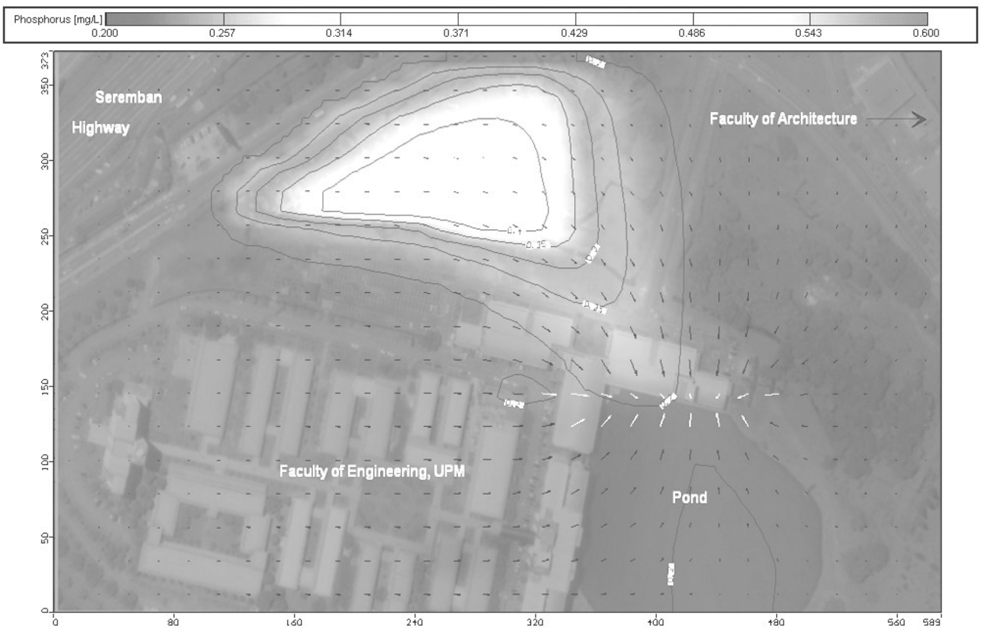

Figure 2. Phosphorus concentration in layer No. 2 (18 250 days).

CONCLUSION

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

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.

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 ($1.5\pm0.9\times10^{-9}$ 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

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).

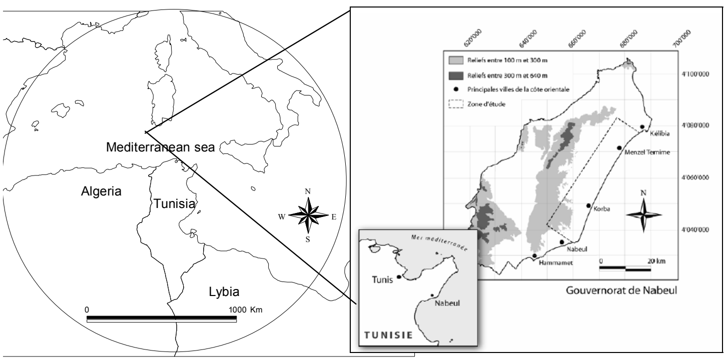

Figure 1. Location of Korba coastal aquifer.

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).

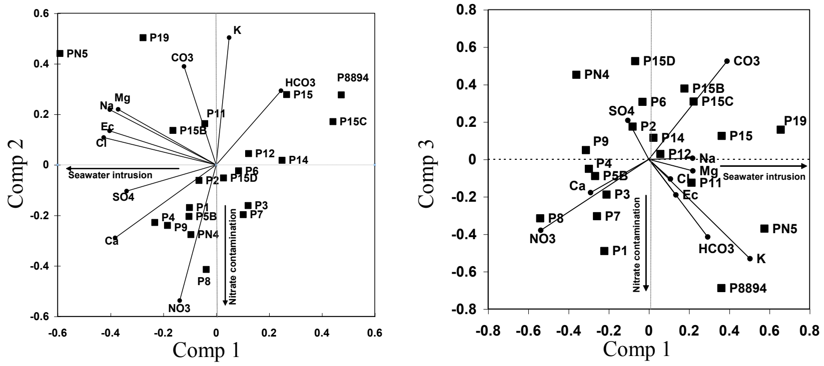

Figure 2. Principal Component Biplot of variables and observation points in the first transect for the dry sampling survey.

Electrical conductivity as well as major ions profiles, show salt accumulation in the soil surface reaching 17.5 mS/cm (Fig. 3).

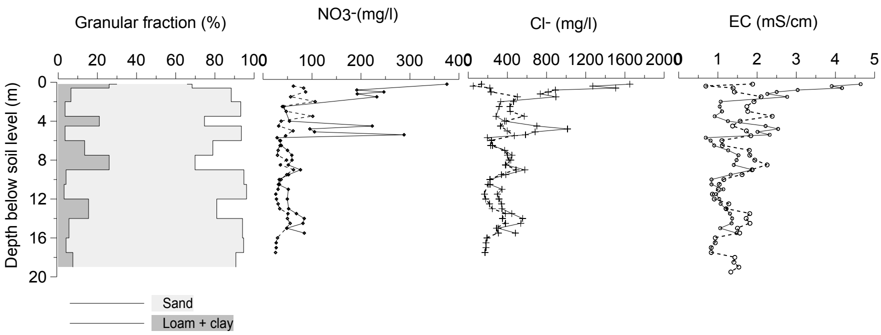

Figure 3. Distribution of granular fraction, chloride, nitrates, and electrical conductivity, along a 19 m soil profile. Variables (Cl, NO_3 and EC) were measured in August 2006 and April 2007 (dashed line).

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

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Abstract ID: 355

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

A fundamental understanding of filter, buffer and storage functions of soil/water systems are required for a suitable use of water resources. Heterogeneous systems, which include different flow paths (e.g. karst and fissured aquifers and/or multilayered porous media) are of special importance. The aim of the investigation was to assess the heterogeneity of water fluxes and quantify the transport processes in an aquifer system model (2D, 3D). Experiments with a range of artificial tracers with different diffusion properties (Bromide, Uranine, Tritium) have been designed because only by multi-tracer experiments is it possible to detect flow heterogeneity in space and time. The experiments have been performed in an indoor groundwater aquifer system in 2-dimensional and 3-dimensional modus. A dense net of monitoring points have been used to quantify the transport processes in different scales, and to understand the scale effect on the evaluation of system heterogeneity.

Mathematical mass transport models based on analytical and numerical methods were used, and adapted for describing heterogeneity in the model system.

Abstract ID: 472

THE VELOCITY ORIENTED APPROACH REVISITED

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Keywords: groundwater flow modeling, velocity oriented approach, continuity of water flux

A great deal of hydro-geological situations requires an extremely accurate calculation of the 3-dimensional groundwater pore velocity, or specific discharge, 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. The notoriously difficult, and still not fully solved problem, is the numerical determination of the vertical component of the groundwater velocity field. In nature this component is two, or even three orders of magnitude smaller than the horizontal velocity components. In such cases application of Darcy's Law to the numerically calculated hydraulic heads obtained from a finite difference or finite element method may lead to extremely inaccurate vertical velocity components. More specifically, when estimating vertical velocity components in cases where the Dupuit approximation (negligible vertical head gradients) holds numerical differentiation of hydraulic heads yields zero vertical velocities, which violates the mass balance equation. In the 1980s of the last century it was proposed by Zijl (1983) and by Zijl and Nawalany (1993) to invert the order of calculating the velocity field by elimination of the hydraulic head from the mass balance equation (continuity equation) and Darcy's Law. For 2-dimensional flow this was conventionally done by the introduction of a stream function as primary variable. However, at that time a 3-dimensional extension did not seem feasible and, therefore, the specific discharge components have been chosen as the primary variables, rather than the head. This approach was called the Velocity Oriented Approach (VOA). It has been proven to yield a high accuracy for all three components of the specific discharge, including the relatively small vertical component, especially in cases where the subsoil smoothly heterogeneous in the horizontal directions. (Heterogeneity in the vertical direction was allowed to be arbitrary.) In the paper the good characteristics of the original VOA approach will be shown and illustrated with examples. In the 1990s the mixed-hybrid finite element method was developed (Kaasschieter, 1994). The physical interpretation of this method led to the way to improvement of the VOA by replacing the velocity as primary variable with a feasible 3-dimensional stream function (Zijl, Nawalany, 2004). This extension will be outlined in the paper together with examples worked out by Mohammed (2009). In conclusion, the velocity oriented approach indicates a change in paradigm regarding the accurate calculation of specific discharge in groundwater flow.

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5.3 Groundwater mapping — approach and results

Abstract ID: 132

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

1. 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).

2. 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.

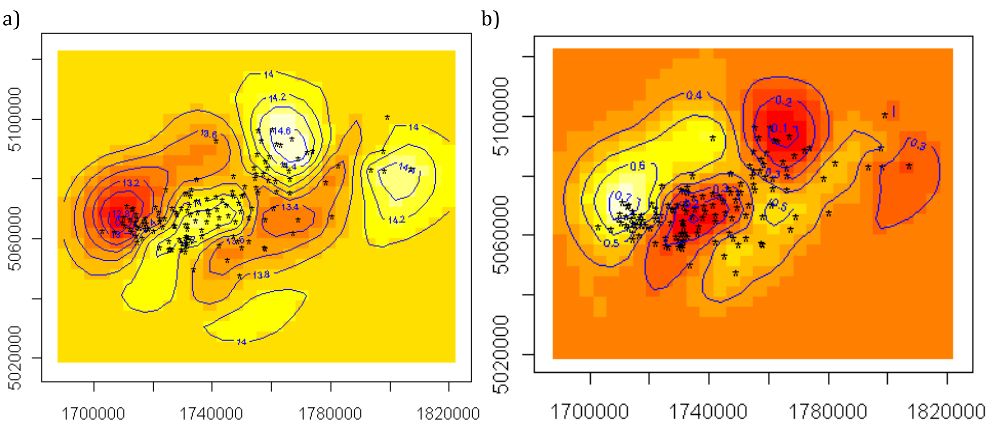

Figure 1. Prediction map of groundwater temperature distribution in Veneto region: a) Ordinary kriging; b) Indicator Kriging for the first quartile (< 13°C).

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.

3. 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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Abstract ID: 393

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.

Abstract ID: 522

GROUNDWATER RESOURCES AND ENVIRONMENTAL GEOLOGICAL MAP OF ASIA

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Keywords: Asia, groundwater resources, environmental geology, mapping

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.

Abstract ID: 523

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

One of the main objectives of the EC water framework directive is to achieve a good qualitative status of groundwater bodies. For this purpose, a knowledge of background values of groundwater bodies is indispensable, because only then a significant deterioration of groundwater quality can be identified and countermeasures be taken.

For this reason, in a joint project the geological surveys of Germany produced a countrywide map of the background values of groundwater. Only naturally occurring inorganic parameters were taken into account, including relevant trace elements (total of 36 parameters). For the basis map the digitally available Hydrogeological Survey Map of Germany in the scale 1:200,000 (SGD 2009) with its more than 1100 units was aggregated into a map of hydro-geochemical units (around 200 units). More than 52,000 groundwater samples were collected in a database and allocated to their respective hydro-geochemical units (HGU). The statistical analysis was performed using probability nets (Walter et al., this issue), separating the anomalies of a data set from the underlying normal population. The 90^{th} percentile of this population is regarded as its threshold value and is defined as groundwater background value.

The results are available in the internet through a web map service under the following URL: (http://www.bgr.de/Service/grundwasser/huek200/hgc_p90/). Thus they can be viewed from any computer with access to the internet.

The parameter specific maps show the hydro-geochemical units in colours, shaded in 5 classes depending on the specific background values. Upon clicking on the surfaces of hydro-geochemical units the parameter specific statistical evaluation pops up in a separate window giving the box-whisker plot of the normal distribution and further statistical data (numerical data of box-whisker plots, numbers of samples taken into account, etc.).

The values of the parameters at the sampling points are equally shown in a similar classification scheme. By clicking on sampling points, concentration, name of the hydro-geochemical unit and filter depth can be obtained.

These maps of parameter specific background values of hydro-geochemical units are an ideal basis to answer many questions in the field of 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 viewed in the regional context and polluted sites can easier be identified. Additionally, the data can be used for the evaluation of the qualitative status of groundwater bodies.

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Abstract ID: 524

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

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 bore-hole 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

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)

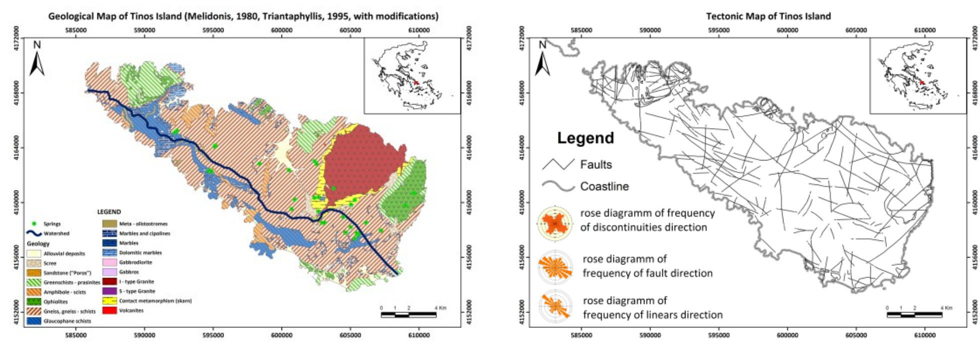

Figure 1. Geological (a) and Tectonic (b) map of Tinos Island (Melidonis, 1980; Triantafyllis, 1995; with modifications).

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

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.

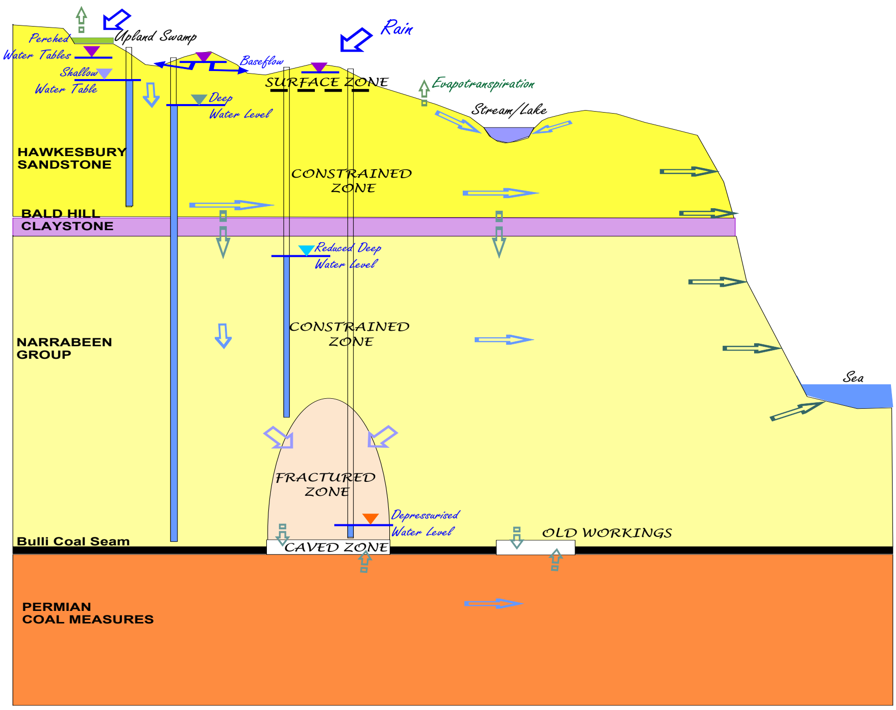

Figure 1. Conceptual hydrogeological model for a longwall coal mine in Australia.

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.

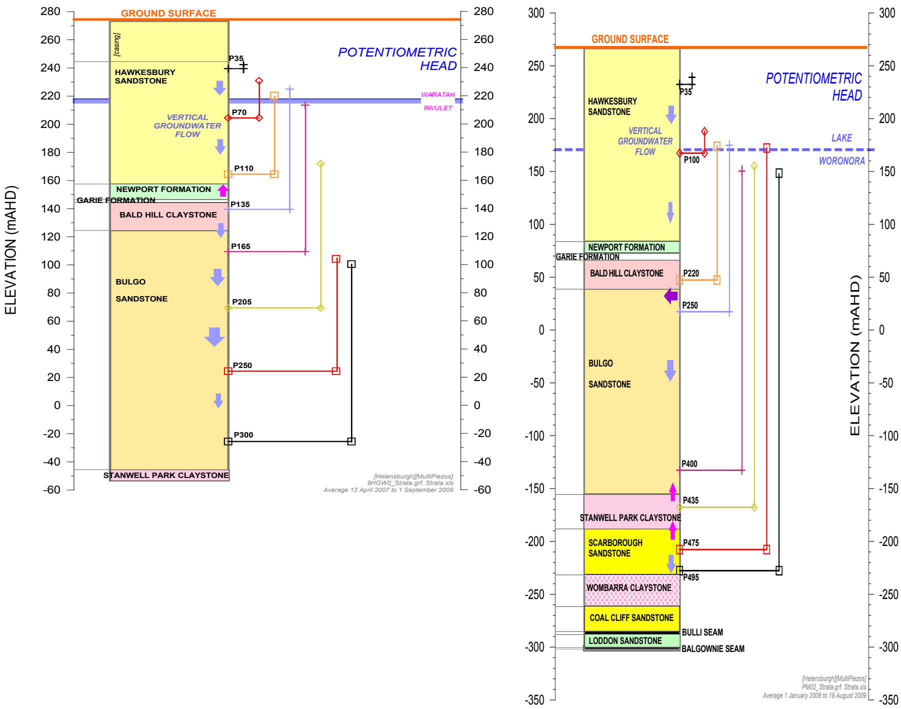

Figure 2. Vibrating-wire piezometer heads, vertical hydraulic gradients and inferred vertical flow directions at a mined area (left) and an unmined area (right).

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

ESTIMATE OF FRACTURED AQUIFER THICKNESS USING MULTIPLE PUMPING TESTS ANALYSES

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Keywords: weathering, hydraulic conductivity, storage, hydraulic test, India

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).

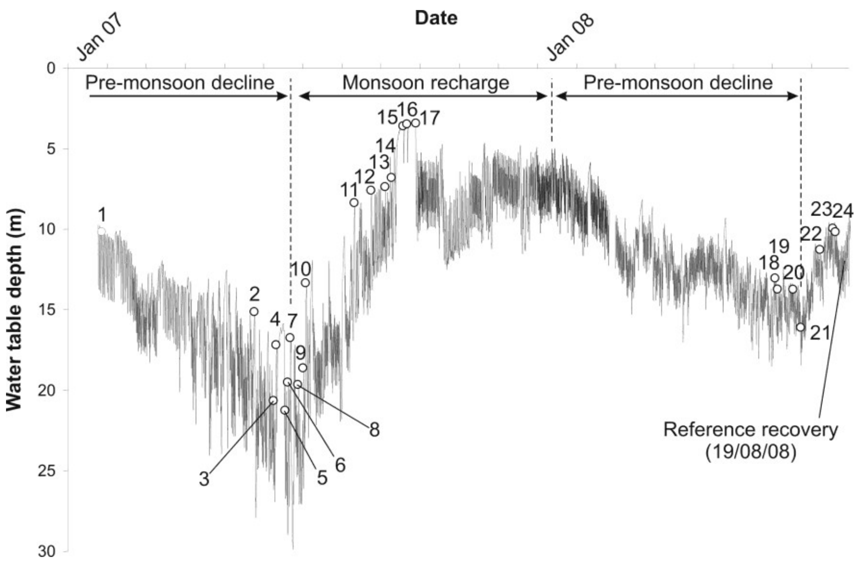

Figure 1. Water table depth fluctuations at observation well during the monitoring period (analyzed pumping cycles are numbered from 1 to 24).

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.

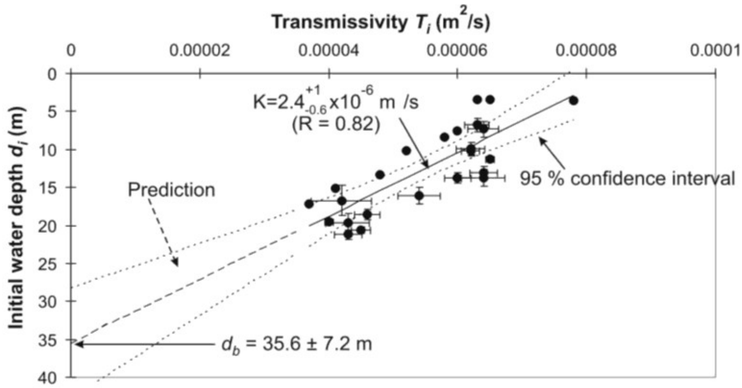

Figure 2. Transmissivity obtained from multiple pumping tests at CMP1 as a function of initial water table depth using unconfined aquifer model.

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.

Abstract ID: 460

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. 80 to 90% of groundwater reserve is located in a fissured layer, the deepest horizon of weathering profiles, where porosity and permeability result from cracks related to inflation of some minerals (biotite, pyroxenes, olivine…) during weathering.

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.

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 have 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 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.

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 Magnetic Resonance Sounding, will conduct to groundwater reserve mapping. 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.

6.2 | Hydrogeology of karst

Abstract ID: 116

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).

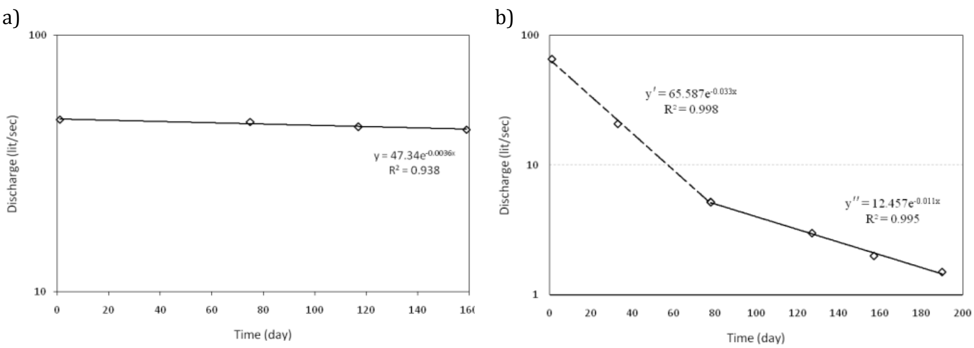

Figure 1. Recession curves in study areas: a) Gholghol spring recession curve (Dasht-Bou); b) Gilas spring recession curve (Cheshme Gilas).

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

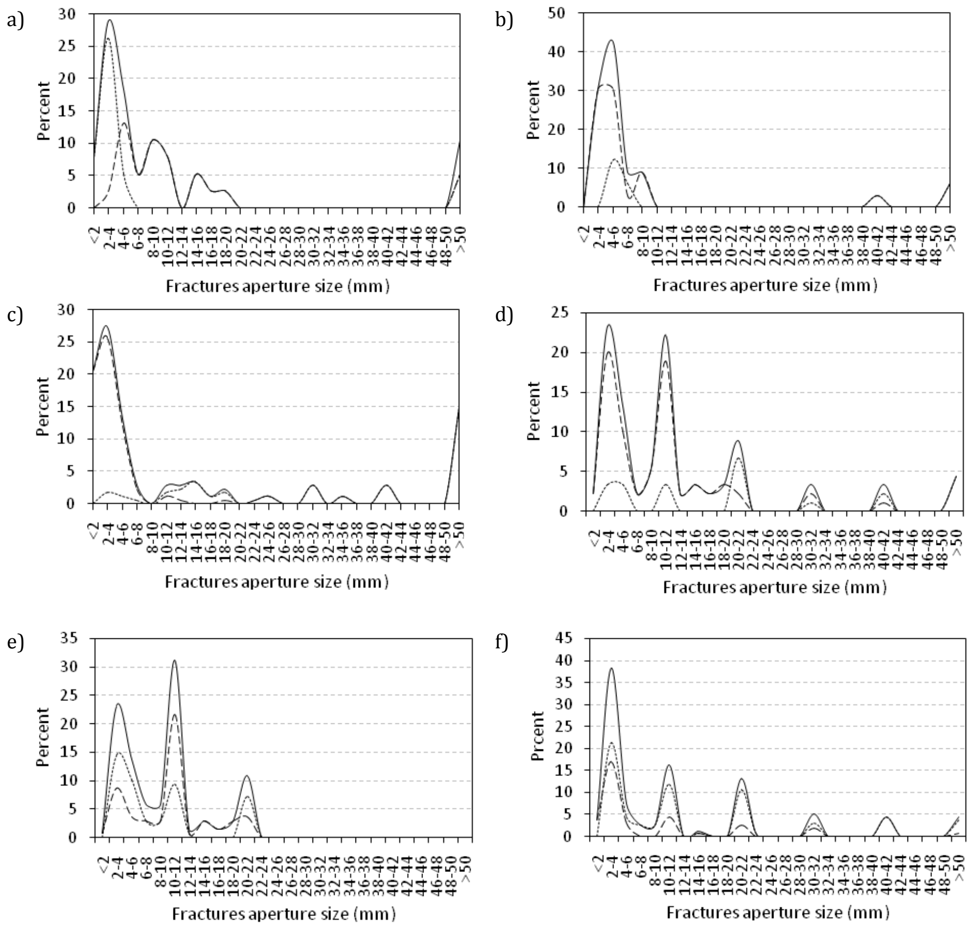

Figure 2. Fractures aperture size distributions for various types of joints in the both study areas. Dotted lines illustrate non-filled fractures; while, dashed ones are demonstrate those which are filled. Continues lines reveal overall percent of fractures: a) Cheshme Gilas relaxation fractures; b) Cheshme Gilas tensional fractures; c) Cheshme Gilas shear fractures; d) Dasht-Bou relaxation fractures; e) Dasht-Bou tensional fractures; f) Dasht-Bou shear fractures.

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).

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Abstract ID: 139

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

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 Geographic Information System (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

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

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Abstract ID: 221

SINKHOLE DISTRIBUTION AND DENSITY IN THE ISTRIA COUNTY (CROATIA)

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Keywords: sinkhole distribution, sinkhole density, Istria County

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.

Sinkhole density is the number of sinkholes per unit area. For this research, a unit area is 1 km^2 and sinkholes were counted by hand for each section from 30 topographic maps at a scale of 1:25,000. To quantify the number of sinkholes in each section, sinkholes were defined as any closed-contour topographic depression. Thus, if a compound sinkhole had two or more separate closed-contour depressions, each depression was counted as a sinkhole.

This paper presents the relationship between sinkhole distributions, similar geologic and topographical settings and solution and erosional processes that eventually form more new sinkholes in the Istria County.

Abstract ID: 225

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 Mountains 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. The springs have drained carbonate Eocene rocks, which neighboring from north Podhale flysch rocks. Differences between hydrogeological properties of carbonate Eocen rocks and Podhale flysch rocks are conducive for occurrence of springs in this zone. The aim of investigation is to investigate physical and chemical characteristics of springs water.

There were investigated 18 springs. Field works were conducted in 2007 during three periods: spring, summer and autumn. Water temperature, electrical conductivity and pH were measured in terrain (Elmetron CX-401) and water samples were taken. Chemical analyses were done in the laboratory at the Institute of Geography and Spatial Management, Jagiellonian University using ion chromatography (DIONEX ICS-2000).

Springs discharge was 0.01–10 $dm^3 \cdot s^{-1}$. The type of springs water was HCO_3–Ca–Mg or HCO_3–Ca, the sum of ions was 100–500 mg dm^{-3}, and 7.1–8.3 pH. Physical and chemical characteristics were stable in each seasons. It may be stated, that these types of water are representative for water circulating in carbonate Eocen rocks.

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Abstract ID: 288

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

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.

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, were monitored by two high resolution multi-parameter auto-recordable instrument of CTDP300 during the hydrological year of September, 2007—September, 2008. Other monthly hydrogeochemical 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.

Marked seasonal and storm-scale variations were found for pH, conductivity, pCO_2, SIc and $\delta^{13}C$ of the two springs, indicating that both springs were dynamic and variable systems. However, there were differences in the magnitude and direction 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. Moreover, 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. 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. In addition, the higher concentrations of Ca^{2+}, SO_4^{2-}, Mg^{2+} and conductivity of Dengzhanhe Spring were due to the dissolution of more gypsum and dolomite minerals in the strata of Dengzhanhe Spring catchment. Therefore, the karst hydrogeochemical parameters, including pH, conductivity, HCO_3^-, Ca^{2+}, Mg^{2+}, SO_4^{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).

Abstract ID: 345

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

For the efficient planning of protection of karst springs against various sources of pollution it is essential to understand and consider the characteristics of groundwater flow and the processes of its exchange with surface waters. In the described case study the monitoring of physical and chemical parameters at the Unica and Malenscica karst springs, as well as at the water flows within their recharge area, was applied for this purpose. Both springs are located at the southern border of the Planina karst polje in south-western Slovenia (Fig. 1).

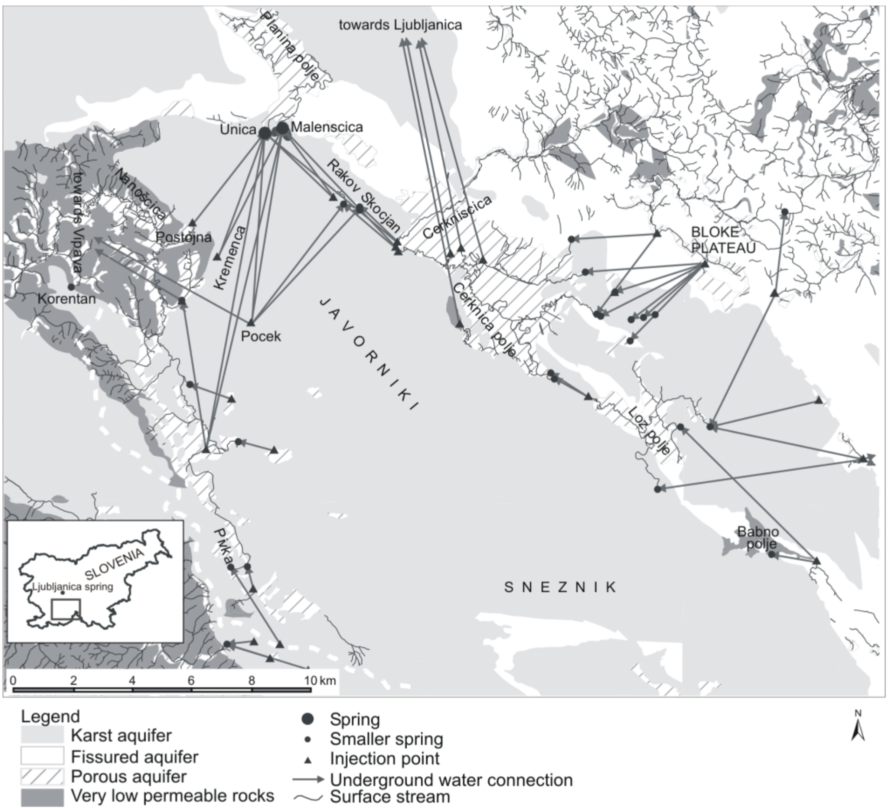

Figure 1. Hydrogeological map of the recharge area of the Unica and Malenscica springs with proved underground water connections.

The Malenscica spring is an important source of water supply for two municipalities with altogether 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. Hydrological characteristics of the catchment are very interesting because of changing between superficial and underground parts of the general water flow with sinking streams, temporary flooded karst poljes in several levels, large karst springs and numerous karst caves. Most of the area is covered by forest, but especially in the area of karst poljes there are settlements, industrial areas and agricultural land. The main sources of pollution are untreated waste waters, landfills, roads, military training area, industry and agriculture. Different human activities result mostly in temporary organic pollution and heavy metals in spring sediments. Specific problem is poor water quality of sinking streams which represent a direct input into karst aquifers.

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. In order to study the relations between different contribution areas a monitoring net was installed within the catchment in 2007. Three rain-gauges were set in the three contribution areas. The sondes for measuring of discharge, temperature and electrical conductivity were installed at 2 karst springs and 5 water streams within their catchment. Based on the interpretation of measured parameters at all observation points in the total period of two hydrological years, the influences of different types of recharge, exchanges between surface and underground waters, relations between the inflows from various parts of the catchment and their contributions to the discharges of springs were assessed. It was proved that the characteristics of flow and transport of substances within the catchment of the two springs are strongly dependent on meteorological and hydrological conditions and are changing very fast.

Abstract ID: 394

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

1. INTRODUCTION AND METHODOLOGY

The experimental site is situated at less than 1 km from the Mediterranean sea (Fig. 1A). It is located over a regional aquifer made up of Triassic dolomitic marbles which host an important show cave: the Nerja Cave (Malaga province, Andalusia, S Spain).

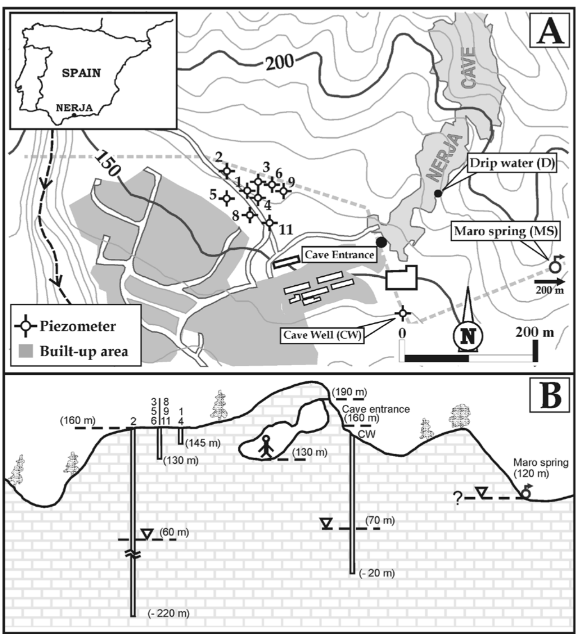

Figure 1. Hydrogeological map of the Nerja experimental site area (A) and cross-section (B) with main characteristics of water points.

The study site is equipped with 10 boreholes (Fig. 1A). Nine of then –designed by numbers- are investigation piezometers; other (CW) is a production well which was built to supply the cave facilities, now used for monitoring purposes. With the exception of piezometer 2 (P-2), all the investigation boreholes have depths between 15 m and 30 m, and are drilled in the vadose zone of the aquifer (Fig. 1B). The saturated zone is drilled in two points: CW and P-2. These two points allow us to measure the height of the groundwater level at roughly 70 m a.s.l. This value does not match with that of the nearby Maro spring altitude (120 m a.s.l.), suggesting some kind of low permeable boundary between them.

2. RESULTS AND CONCLUSIONS

We have modelled the hydrochemical evolution of the precipitation water through the epikarst and the vadose zone, in order to reproduce the observed drip water (Tab. 1). The important increase in bicarbonates, calcium and magnesium contents is due to the high CO_2 partial pressure in the vadose zone (30,000–60,000 ppm). This model results has been validated by the composition of the vadose water sampled in point 6, where a perched groundwater level develops. The observed D values show the effects of the intense CO_2 degassing and calcite precipitation: HCO_3^- (275 mg/L), Ca^{2+} (30 mg/L) and Mg^{2+} (45 mg/L). In addition, the vadose water has a pH near 7.4, but inside the cave it rises up to 8.3 (Benavente et al., in press). Some variations from the model are presented, based on data obtained in samples from the saturated zone (MS, CW and P-2). Samples from CW and MS show a slight decrease in the Mg/Ca ratio and a important increase in the sulphate content. The average concentration of this last ion in the spring is about 200 mg/L. The origin of this sulphate is from the gypsum hosted in the dolomitic marbles, as suggested by sulphate isotopic values ($\delta^{34}S_{SO4}$ = 15.4‰, $\delta^{18}O_{SO4}$ = 12.3‰). In this context, the composition of point 2 (P-2) is anomalous. There are not significant differences in ion contents with depth. Only TOC shows high values (18 mg/L) related to groundwater level and less than 3 mg/L in the rest. Contents of bicarbonate contents (<50 mg/L), calcium and magnesium (<10 mg/L) and pH (~10.0) suggest an aqueous carbonate equilibrium with abnormally low dissolved CO_2 contents, which is in contrast with the measured values of 30,000-60,000 ppm of the Vadose Zone (Benavente et al., 2010).

Table 1. Hydrochemical values of samples. GWL: Groundwater level, EC: Electrical Conductivity (μS/cm), TOC: Total Organic Carbon. Concentrations in mg/L.

Name	Reference	GWL	EC	Tª	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

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Abstract ID: 411

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

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Abstract ID: 419

INTERPRETATION OF PUMPING TESTS IN A MIXED FLOW KARST SYSTEM

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Keywords: modelling, France, double continuum approach, matrix, spring

A long-duration pumping test performed in the conduit of a mixed flow karst system (MFKS) is analyzed and interpreted. It constitutes a unique experiment of catchment wide response of a karst system, with drawdowns measured both in the pumped conduit and in the fractured matrix.

Figure 1 shows a conceptual model of the Cent-Fonts mixed flow karst system with well F3 intersecting the conduit.

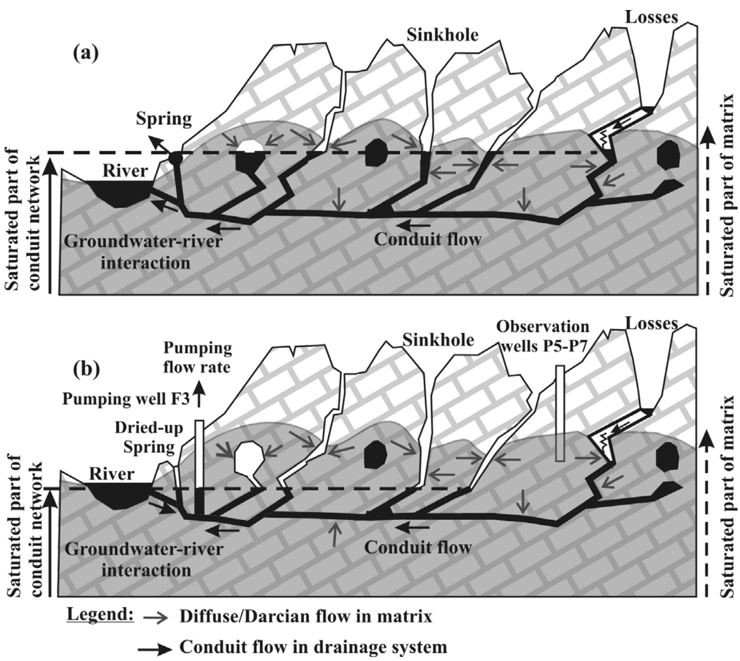

Figure 1. Conceptual model of the Cent-Fonts karst system (a) under natural low flow conditions and (b) when pumping is done in a well intersecting the solution conduit of the same karst system (black: Water in solution voids and conduits; grey: Water in matrix).

The karst system (Fig. 1a) 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. 1b), 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. 2).

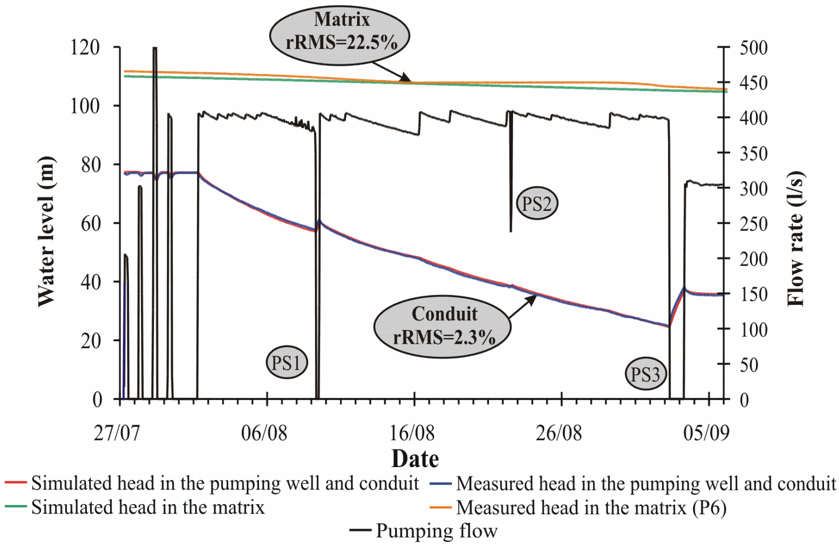

Figure 2. Temporal evolution of simulated and measured drawdown in the conduit and in the matrix using the model (rRMS is computed on drawdown referred to initial water level; PS: pump stop).

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 flow exchange is modelled using the superposition principle and the hypothesis of Darcian flow in the matrix considered as an equivalent porous media. The karst conduits are assumed to have an infinite hydraulic conductivity.

Model calibration results (Fig. 2) 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 (hydraulic conductivity and storativity) have a greater influence on the drawdown than the storage capacity of the conduit network. The accuracy of the model relies mostly on a very good knowledge of both pumping rate and natural discharge at the spring (with and without pumping). This type of approach represents an advance in double continuum modelling of karst systems. It also provides a methodology for the management of water resources from karst aquifers.

Abstract ID: 462

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 m³/s.

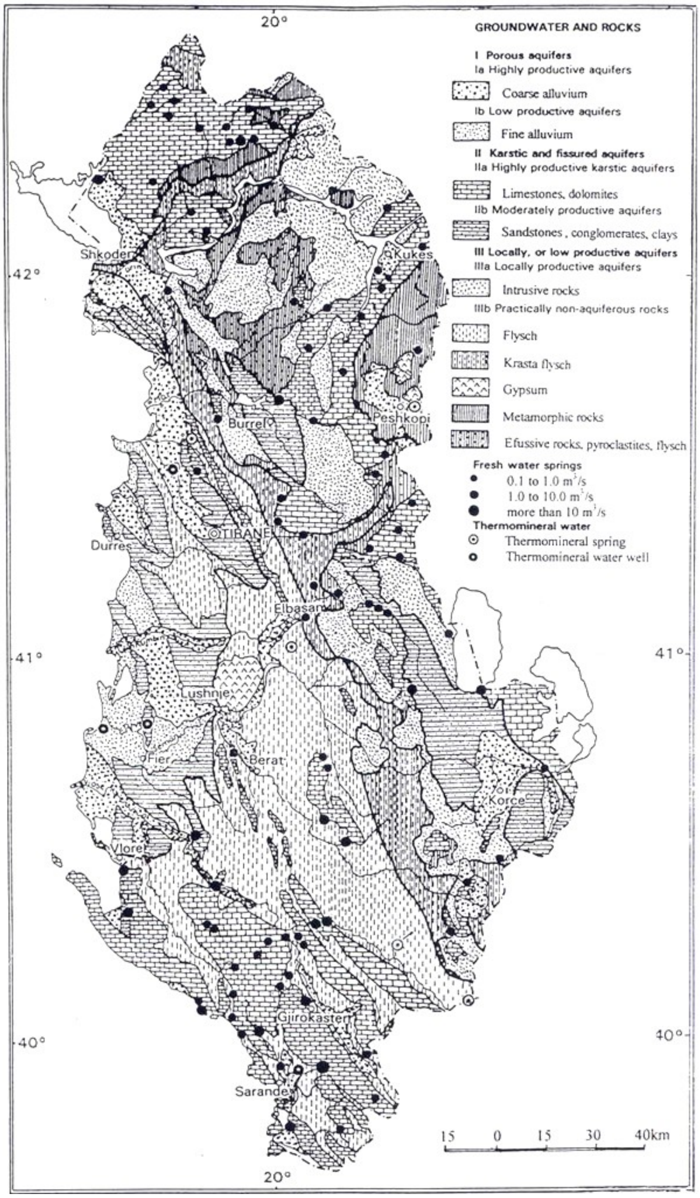

Figure 1. Simplified Hydrogeological Map of Albania.

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Abstract ID: 491

CHARACTERIZING AQUIFER BEHAVIOUR OF TWO KARST SYSTEMS FORM S SPAIN BY HYDRODYNAMIC AND HYDROCHEMICAL DATA

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Keywords: karst aquifers, hydrochemistry, hydrodynamic

Karstic spring monitoring provides information about hydrogeological functioning, water resources and their vulnerability to contamination for a suitable management and exploitation in karst aquifers. Hydrochemical and hydrodynamical control of karstic waters from El Burgo and La Fuensanta springs allowed to specify main chemical processes and flow conditions variability in Sierra Blanquilla and Sierra Hidalga aquifers (Málaga province, south of Spain), for 18 months sampling period.

Electrical conductivity (EC) time series and statistical processing suggests significant differences in the hierarchical organization of the aquifers drained for each spring. EC frequency curves of El Burgo spring present unimodal morphology (low degree on the functional karstification), meanwhile in the case EC curves of La Fuensanta spring has a multimodal shape. This distribution shows a clearly karstic behaviour, since each EC data family reflect different infiltration modalities in the aquifer.

Discharge variations in La Fuensanta spring are faster than El Burgo spring, although lower (0,068 m^3/s opposite 1 m^3/s, respectively, as average discharge rate). Hydrochemical characteristics in both springs indicate different degree in the functional karstification. Chemical components dissolved in El Burgo spring waters present a fewer variation that confirm a quick circulation in the aquifer, not through karstic conduits but enlarge fractures by dissolution processes. EC vary in accordance with total alkalinity (TAC), Ca^{2+}, Cl^- and TOC contents. NO_3^-, SO_4^{2-} and Mg^{2+} change their concentrations in the opposite way (Fig. 1A).

Waters from La Fuensanta spring shows a wide variation in the majority of the chemical parameters as Ca^{2+}, TAC, SO_4^{2-}, Mg^{2+}, NO_3^- Cl^- and TOC (Fig. 1B). Present a typically karstic functioning and, in high water conditions, predominant flow is by conduits. In low flow conditions, discharge is due to drainage from vadose zone and saturated zone. Epikarst zone include water storage in fissures and matrix, with higher content in Ca^{2+}, TAC, and Mg^{2+} because of long time residence in the rock.

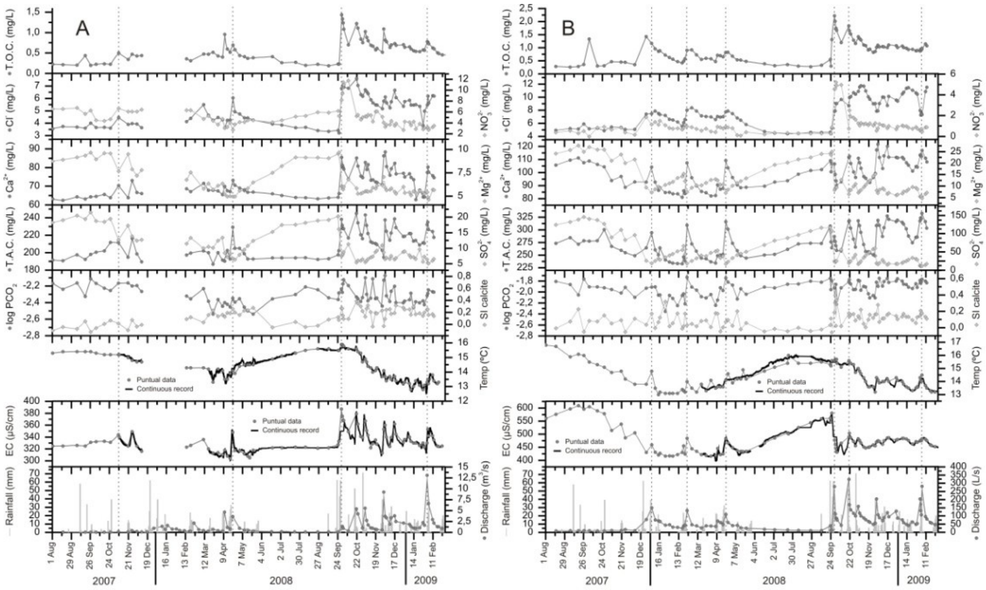

Figure 1. El Burgo (A) and La Fuensanta spring (B) hydrochemical and hydrodynamic time series (2007 to 2009).

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6.3 Groundwater contamination — monitoring, risk assessment and restoration

Abstract ID: 101

HUMAN RISK ASSESSMENT OF ARSENIC CONTAMINATED GROUNDWATER IN INDIA

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Keywords: arsenic, groundwater, contamination, risk assessment, environment

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 were level of arsenic in drinking water are often higher than WHO permissible limits. Many persons of either sex died of cancer and millions are suffering from arsenicosis, melanosis, keratosis, and gangrene and skin cancer. The worse arsenic poisoning level covers large alluvial and deltaic aquifer. The geochemical and hydrogeological characteristic of these sediments influence the mobility of arsenic from groundwater to human through oxidation and reduction processes of the chemical elements. To assess the severity of contamination and delineate the hot spot a testing programme covering all public wells was carried out in 30 Km^2 corridors along the river–Ganga at Patna–Bihar. Initial testing indicates that the contamination is confined within the Holocene deposits affecting only the top 60 m. About 70% of the wells are affected (>50 ppb) and maximum arsenic contamination was found to be 350 ppb. The hot spots occur as isolated pockets spread over 5000 Km^2 affecting 800 habitation with 1.8 million population living in risk-zone. Within each hot spot the contaminated wells are marked by patchy occurrence. Depth-wise the contamination is confined within the top 60 m. of the deposits, pre-dominantly made up of clay, sand and silt with 10–20 m. Thick sand beds forming the life line of rural water supply. The deeper aquifer system below regionally extensive clay beds lying between 60–80 mbgl. The potential aquifer system (transmissivity 5000–8000 m^2/day) is being tapped for water supply in the affected area. The effective long and short term water management and arsenic mitigation programme have been initiated for safe drinking water and sustainable development.

Abstract ID: 109

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

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

The present work provides a methodological approach to evaluate the impact of poorly constructed wells (completely leaking, with no gravel pack) or abandoned wells for facilitating the transfer of contaminants between aquifers at different depths (Lacombe et al., 1995). The research approach was based in the use of nitrate as tracer (Pulido-Bosch et al., 2000), as nitrate attenuation mediated by denitrification processes is unlikely for high dissolved oxygen concentrations, and the MIX_PROGRAM (Carrera et al., 2004) code for water mixing calculations. Associated low uncertainty of mixed samples concentration (mainly affected by analytical errors) can be used to reduce uncertainty in end-members (high spatial and temporal variability) by imposing consistency, according to the numerical code results. End-members should fall in the mixing line and mixed waters should fall within the interval defined by end-members.

Proposed methodology was applied to the Campo de Cartagena (SE Spain), where intensive irrigated agriculture takes place along with a high density of wells (1.18 wells per km^2) for groundwater exploitation. The hydrogeologic unit consists of a multi-layer system constituted by a deep confined aquifer (Pliocene) and an upper unconfined aquifer (Quaternary). Due to the important surface area of the aquifers, three regions were defined. The unconfined aquifer is heavily impacted by agricultural activities presenting high nitrate concentration in groundwater. Since no agricultural development or anthropogenic activities take place in the confined aquifer recharge area (Northwestern part of the basin), much lower nitrate presence, even nil, should be expected.

Results show the increase of the upper unconfined aquifer inter-connexion in the lower confined aquifer along the groundwater flow direction toward the coast, as shown by nitrate concentration presence in the confined aquifer (Fig. 1a, b). However, this general pattern is controlled by local factors (pumping, intensity of agricultural practices, density of wells and groundwater residence time). Average computed mixing ratio of Quaternary mass fraction being transferred to the Pliocene aquifer (*MFQIP*) ranges between 0.07 and 0.74.

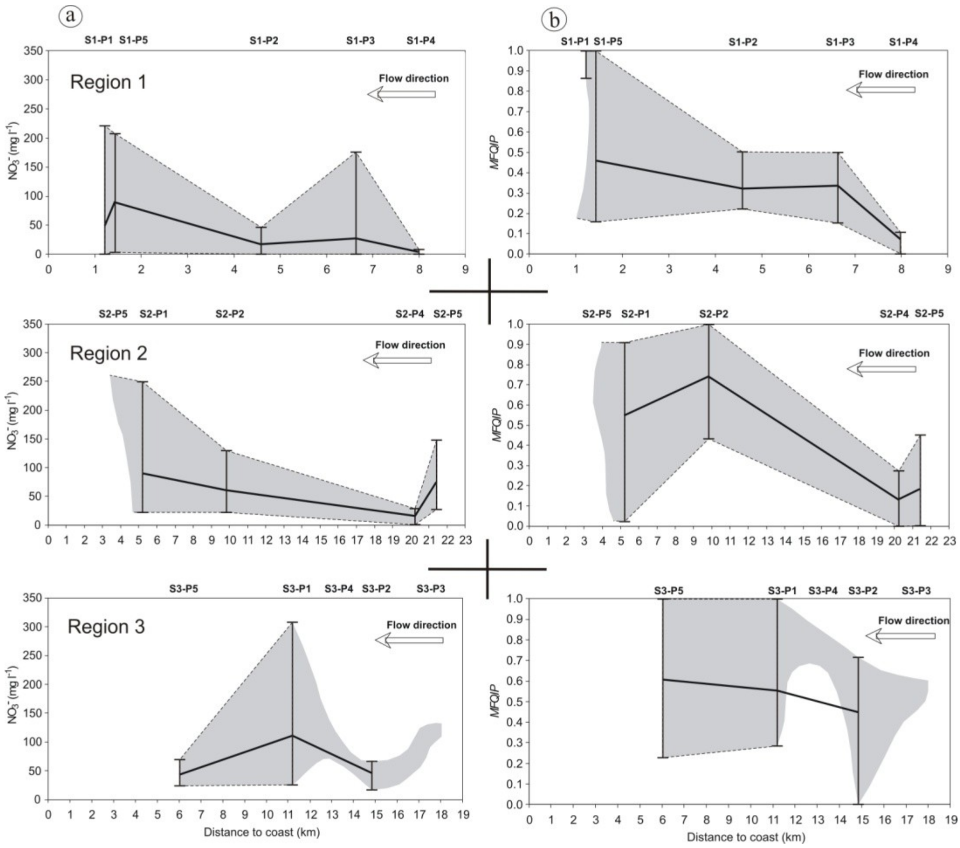

Figure 1. a) Nitrate concentration of Pliocene selected samples subset versus distance to coast for each region; b) Quaternary aquifer water mass fraction (computed mixing ratios-*MFQIP*) that is introduced into the Pliocene aquifer versus distance to coast (vertical bars: variability in each sample point; solid line: average value for nitrate concentration and *MFQIP* in each sample point; arrows: groundwater flow direction).

ACKNOWLEDGEMENTS

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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. 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 (Mellissa et al., 2007). Cortez et al. (1998) reported vinasse production varies from 10 to 15 liters of vinasse to each 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 capital. 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.

METHODS

A borehole was drilled into this old vinasse disposal lagoon, and 27 samples of soil were collected until 24 meter of depth. Six samples were selected to analyze soil texture in the following intervals of depth: 2–3, 6–7, 9.5–10, 12–13, 15–16 and 18–19 meters. The percentage of ignition loss was determined in 27 samples according to Pott (1992). Leach tests (Hageman, 2007) were executed in 27 soils samples, and cations and anions were analyzed by ion chromatography. pH, Eh (mV) and electric conductivity (μS/cm) had also been determined. 5 soil samples (intervals: 0–1, 3–4, 13–14, 18–19 and 23–24 m) were selected to analyze metal ions and trace elements, by ICP-MS, using solutions from soil lixiviation with nitric acid.

RESULTS AND DISCUSSION

The texture results presented sand in over than 60%, silt from 25.6 to 34.4%, of all depths indicating that the main material is homogeneous and sand-silty, belonged to Botucatu Formation (a Guarani Aquifer System formation). The values of ignition loss indicated a percentage decrease along the profile (from 15% to 11%). Regard to physical-chemical parameters from leached solutions, the pH results indicated acidity in the surface (average pH 5.2) and getting neutral when in deeper soils (average pH 7.0). Eh results (from +105 to –45 mV) indicated oxidant environment in surface samples becoming reduced in deeper samples. The lower values of electric conductivity (11 μS/cm) were found in shallow 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). Cations and anions analyses indicated higher concentrations of SO_4, NO_3, Na, Mg and Ca in lower depths (mainly the interval 6 to 9 meter depth) decreasing in concentration in deeper profile. Fluorine concentrations presented higher values in deeper samples, and Mg, Al and Ce had the same behavior. These elements could be related to vinasse migration and the reduced environment along the soil profile.

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). The leach test methods applied in this study showed two distinct oxi-reduction zones (24 meters depth): 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.

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Abstract ID: 243

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

INNOVATIVE SOLUTIONS IN USING REACTIVE BARRIERS

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Keywords: PRB, heavy metal contaminated groundwater, natural reactive material, laboratory testing, modeling aided design

The paper discusses 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 of 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.

The core of the research contains the (1) reactive material development, (2) processing of the reactive material, its (3) chemical and (4) hydrological analysis and (5) investigation of energy recovery alternatives of the same material. The 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 are significantly cheaper than the active carbon, and even though its contaminant retention capacity (CRC) is by far bellow 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 (eg. 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 and foreign coals have 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.

The harmonization of the individual design tasks and investigation of their impact on each other is a major task. Each single step of the design has its impact on the technical feasibility of the PRB, in fact there are interactions among each innovative tasks. The paper introduces a set of technical parameters needed for the chemistry, hydrogeology and technical aspects of the design.

Abstract ID: 286

WATER AND SOLUTE TRANSPORT IN UNSATURATED ZONE OF THE SAVA RIVER, CROATIA

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Keywords: Zagreb aquifer, unsaturated zone, trace elements, pollution, modeling

The object of this study is unsaturated zone of unconfined Quaternary aquifer, 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).

The Sava River, which drains the area and feeds the aquifer, has been exposed to intensive pollution by mining, industry and urbanization in the past. The pharmaceutical and chemical industry, the city dump, the district-heating plant, and the airport are located in close proximity of the water-protection area.

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. 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

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Abstract ID: 348

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)

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. 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.

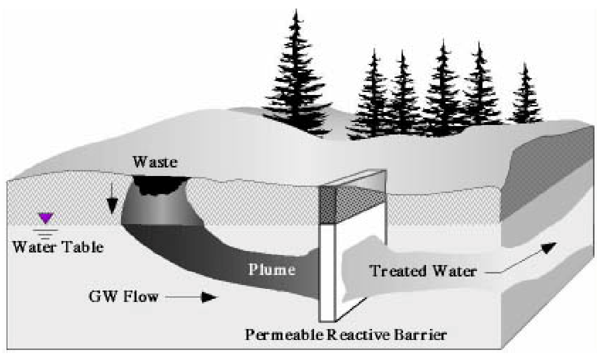

Figure 1. The concept of a permeable reactive barrier (PRB).

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.

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. 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. PIMs can be used for: (i) treatment of landfill leachates to minimize the risk of groundwater contamination, and (ii) reduction of heavy metals concentrations in the groundwater flow.

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.

The experiments were carried out in a permeation cell, in which the membrane film 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.

The feasibility study showed the possibility to reduce the Cr(VI) concentration from 54.0 to 1.0 ppm (results of run no. 1). Moreover results of run no. 2 indicated that the groundwater transport through PIM allows for reducing chromium(VI) concentration 1000 times, i.e. from 1.0 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.

Abstract ID: 354

QUALITY OF GROUNDWATER IN THE SHALLOW AND DEEP AQUIFERS OF THE GEFARA PLAIN, TRIPOLI REGION, LIBYA

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Keywords: groundwater, Great Manmade River Project, aquifer, Sahara

The Libya as North African Arabic country is located in North Africa, and covers a big surface area. Groundwater is the main source of drinking water 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 drinking 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

SELECTION OF MODELS FOR HYDROGEOLOGICAL RISK ASSESSMENT OF LANDFILLS

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Keywords: risk assessment, landfill, models, dual porosity

The UK regulators require Hydrogeological Risk Assessments for landfills as part of the permitting process, to demonstrate compliance with both the Landfill Directive and Groundwater Regulations. In 2009, new Groundwater Regulations were introduced to implement the Groundwater Daughter Directive, replacing the 1998 version. Under the new regulations, Hydrogeological Risk Assessments form part of the "prior examination" of a discharge to groundwater.

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 constructed to "dilute and disperse", alongside modern engineered cells with liner, control and management of leachate and gas, cap and drainage. In addition, the older sites often 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, thus it is difficult to distinguish the impacts of different phases.

The standard approach 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 Environment Agency's preferred tool. LandSim uses a probabilistic approach and simulates 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 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. As the overlying sediments have been removed, the site lies directly on the Chalk aquifer, a fractured limestone with a fine grained, porous matrix. The site was operational for over 30 years, with five main phases of disposal, which range from unlined to fully contained.

Observed patterns of conservative species such as chloride implied that retardation and significant dispersion are occurring. Concerns about ongoing groundwater contamination required an alternative approach to risk assessment and predictive modelling of contaminant concentrations hydraulically downgradient of the landfill. Due to limitations of time and budget, 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 term based on measured groundwater concentrations at the boundary of the landfill. 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 those from 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. This allows a more realistic prediction of future risks to local abstractions and a baseflow fed river.

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Abstract ID: 403

HYDROGEOLOGICAL STUDY OF CONTAMINATION IN THE AQUIFER SYSTEM OF SINES, SOUTH PORTUGAL

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Keywords: contamination, karst and porous aquifer

The Aquifer System of Sines is located in the western coast of South Portugal (Fig. 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 porous, unconfined, composed by tertiary sands interbeded with more clayish formations, and the second one confined, composed mainly by limestones, with 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 the south part of the aquifer, where now the upper and the second aquifer are sometimes linked, sometimes interrupted by tectonics, etc., with a extreme variance, not so easy to understand.

In the seventies, some industries based in oil products begun to be installed and entered in activity in the south part of the system (Fig. 1). The expansion and creation of urban areas to guaranty workers for these industries and the public supply water for the industries themselves lead to an increase on the demand of quality water. The supply has been based in groundwater from this aquifer system, being the water for industry based in an artificial lake created nearby the city of Sines, using water transference from another river east of Sines. Some of the main abstracting areas for public supply are based in the unconfined aquifer, near the city of Santo André (Fig. 1), protected by an impermeable layer of clay on the top of the limestone and also by some 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 in natural discharge at surface. Most part of these wells work without the need of pumping, using only the natural discharge. These wells supply the city of Santo André and the industrial area of Sines (Fig. 1) in drinkable water. In the south part of the aquifer, northeast of the city of Sines, other group of wells supply water to this city (except the industrial area).

These non artesian wells were drilled inside the industrial area and, in 2009, some analysis showed the presence of hydrocarbons in groundwater. At the same time, contaminated soils were identified inside the industrial perimeter. This had led to three basic actions: the decontamination of the contaminated soils, a deep study of the aquifer contamination, including the modeling of the flow patterns (natural flow and anthropogenic interference), considering the attenuation, degradation, diffusion or miscibility processes of each kind of pollutant, and a geological and geophysical study to implement new supply wells for the city of Sines.

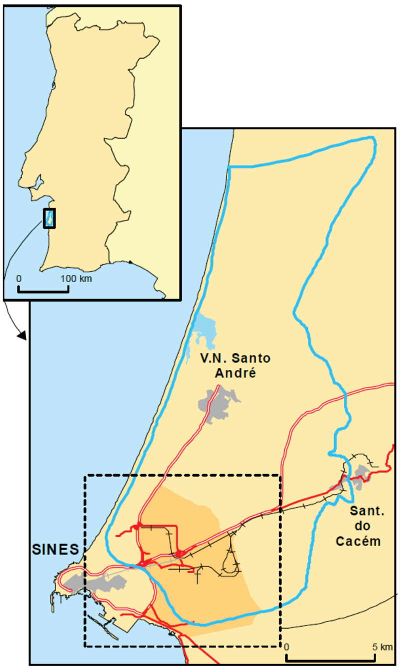

Figure 1. The Aquifer System of Sines (inside the dashed line), in the western cost of South Portugal. In the shaded area of the south part of the system an industrial area was installed in the seventies, including a refinery and other industries based in the oil resources (ICCE, 2009).

In this document, the actions related with the hydrogeological study of the Aquifer System of Sines will be presented. This study will involve a deep geological and hydrogeological analysis, the application of an hydrogeological modeling, trying to understand the flow and the carbon chemistry processes, and to define the flow natural processes and the influence of abstractions in the same area. The aim is to define the origins of the contamination, the water time travel and the degree of degrading of the different pollutants along the time. Based in these conclusions, the study must be able to appoint solutions for the aquifer remediation, defined accordingly the economic and technical conditions which can be applied in the area.

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Abstract ID: 404

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

The investigation of groundwater chemistry of a semi-confined buried valley aquifer (Wielkopolska Buried Valley aquifer —WBV, Poland) was performed in the year 2000. In spite of very small spatial variation of groundwater chemistry, the classification of hydrochemical zones was performed and used for the identification of the groundwater flow pattern within the aquifer (Dragon, Górski, 2009). Also, zones of groundwater anthropogenic contamination were identified even though semi-confined conditions occur (Dragon, 2006). For the identification of temporal groundwater chemistry changes, wells tapping WBV aquifer were resampled in 2009 year. The objective of this paper is the identification of the temporal variability of groundwater chemistry. Special emphasis is being placed on the hydrogeochemical processes initiated or intensified by anthropogenic contamination.

The thickness of water bearing sediments (mainly sand and gravel) ranges from 20 to 50 meters. The confining layer has a thickness between 20 and 50 m and is composed of glacial tills. A layer of Tertiary clays occurs in the aquifer bottom and isolates the WBV aquifer from the Tertiary aquifers. 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. The recharge by the inflow from the intertill aquifers, located to the north of the WBV aquifer, also takes place.

In order to recognize temporal groundwater chemistry changes, water samples from 41 drilled wells were taken in the summer of 2009 from among 61 wells sampled in 2000 (unfortunately some of wells sampled in 2000 were closed). The identification of hydrogeochemical processes controlling temporal changes of groundwater chemistry was completed using traditional graphs and basic statistics as well as the multivariate statistics (factor analysis). More details on data processing can be found in Dragon (2006).

The results of chemical analysis show relative small water chemistry variation over time. Nonetheless, in case of some parameters the 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. 1), thus the parameters reflecting water anthropogenic contamination (Dragon, 2006).

The most intensive increase of concentrations is visible in the zones identified using factor analysis as the most vulnerable parts of the aquifer (Dragon, Górski, 2009). The typical changes of groundwater chemistry in these zones is presented on Fig. 2A. The increase of concentrations of anthropogenic input indicators in these zones is incomparably higher than in the whole data set (compare Fig. 1B and 2B). These observations confirm earlier findings that the intensity of anthropogenic contamination of the WBV aquifer is the highest within these zones even though semi-confined conditions occur there.

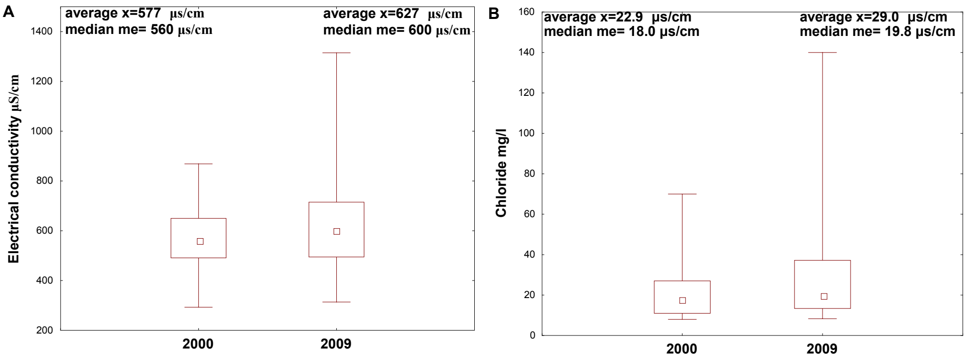

Figure 1. Variability of groundwater chemistry (example parameters) during period between 2000 and 2009 years (number of samples n = 41).

The nature of anthropogenic changes of water chemistry of the WBV aquifer indicates that these waters 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 concentration over time creates serious hazard for groundwater quality deterioration and its utilities for use in the future.

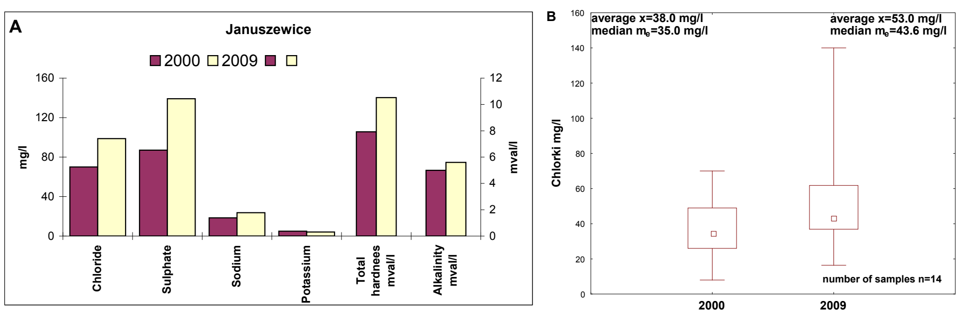

Figure 2. (A) The typical variation of water chemistry (example well located in zone of anthropogenic input) and (B)chloride variability in zone of anthropogenic input.

ACKNOWLEDGMENTS

The author would like to thank Prof. Dr. J. Górski for his valuable contribution to the topic and important discussions during the study period.

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Abstract ID: 417

GROUNDWATER CONTAMINATION AT LANDFILL SITES IN SELANGOR

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Keywords: landfill, contamination

A study to determine the impact of leachate from the operating and closed landfills into the surface water and groundwater systems in the state of Selangor was conducted in the year 2009. There are 20 landfill sites in the state in which 7 of them are still operating and 13 are closed. The landfills are classified into four categories, which are:

1. landfills that are operating at critical stage without any control to prevent pollution into the environment;
2. open dumpsites that have capacity to continue to accept waste but need to be upgraded to manage leachate and gas;
3. landfills that are closed but no safety closure plan was carried out; and
4. engineered landfills with up to date technologies.

As most of the landfill were built prior to 1989, they are not subjected to the EIA requirement, hence, they are being poorly managed and as well as badly sited. The non-engineered sites have no proper pollution controls such as cover materials, liner materials, groundwater monitoring wells, leachate collection ponds and treatment, and methane gas collection pipes. The study reveals that the surface water and groundwater at and nearby the landfill sites are contaminated at various levels due to the landfills siting and operation. Comparison between the current quality of surface water and groundwater with their respective standards and their background levels were carried out to survey the trend of the contamination.

Abstract ID: 421

GEOPHYSICAL INVESTIGATION (ELECTROMAGNETICAL INDUCTION METHOD) AS A USEFUL TOOL FOR MONITORING THE REMEDIATION OF GROUNDWATER AND SOIL POLLUTION

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Keywords: monitoring, EM induction method, groundwater pollution, remediation

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.

Abstract ID: 508

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 superior unconfined AQGWB aquifer is regarded as particularly vulnerable to contamination due to: (1) sediments high permeabilities; (2) unsaturated zone low thickness; (3) plain topography; and, (4) high recharge rates. 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 subject of 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.

Recent work developed in the study area (Ordens, 2007) characterized the groundwater contamination and identified the processes behind the hydrochemical evolution of groundwater, including interactions with surface water. This study indentifies electromagnetic anomalies that can be related to different spatial origins of contaminants and to groundwater-surface water interactions and, untimely, it delimitates the extension and the magnitude of the contaminant plume.

Generally the hydrochemical data shows groundwater contamination levels that compare well with the electromagnetic survey data. 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, potassium and, eventually, bromides; (4) mercury sludges: high concentrations of mercury. The 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.

Organic contaminants present in the groundwater of the study area include chloroform, benzene, trichlorethylene, tetrachlorethylene, chlorobenzene, phenanthrene, naphthalene, aniline, vinyl chloride, 2-chlorofenol and mononitrobenzene. 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.

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 CRUDE project 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, modelling, 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

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6.4 Cost-effective measures to control and contain groundwater contamination

Abstract ID: 108

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

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 (the ambient standards). 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. 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.

Abstract ID: 192

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

During the Federal Ministry for Education and Research (BMBF) funding priority KORA (Acronym for the German — **Ko**ntrollierter **R**ückhalt und **A**bbau), natural attenuation processes in groundwater affected by of landfills/waste site leachates 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 titled: "NA — Concept for handling groundwater damages originating from landfills". As active sanitation/remediation measures are for most of these specific groundwater contaminations too expensive, this concept provides a basis for planning, granting permission by public authorities and remediation measures of landfills for acceptable costs for the public. It has a hierarchical structure and was successfully evaluated on landfills in Germany under the guidance of the German environmental agency (UBA).

During *part A* an extended investigation about and around the landfill is conducted, to sample information about the size, the content, the age and the geological siting of the landfill. Secondly the emissions of the landfill into the groundwater should be thoroughly explored using the "groundwater screening" (Kühn, 2009) and the spreading downstream should be know. Furthermore data about the hydrogeological situation, the use of the surrounding area and the 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 which 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.

Part 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, a steady state or reduction of the emission should be achieved by NA. 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, AOX and the DOC/TOC. 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. This distance depends on multiple factors as groundwater velocity and the distance to the next sensible protective goods. 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. The Theta-method ($\Theta t/\Theta$) (Holzbecher et al., 2009) 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-suspect 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. In *part B3* the contamination reduction by microbiological organisms is demonstrated, as NA effects should not solely attributable to physico-chemical factors, but also to microorganisms. The contribution by groundwater microfauna can be checked with the PCR-DGGE method (Struppe et al., 2006) or more reliable with the newly developed DNA-microarrays (Kühn et al., 2009). This methods can be used to differentiate bacteria and archea as well as their activity. Only when all three methods are positive NA can be used for the reduction of the groundwater contamination. To control the effectivity *part C* proposes a monitored natural attention concept (MNA). Based on the results of the investigation done parameters and sampling sites are derived and together with the environmental authorities a target should be defined to which 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.

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Abstract ID: 426

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).

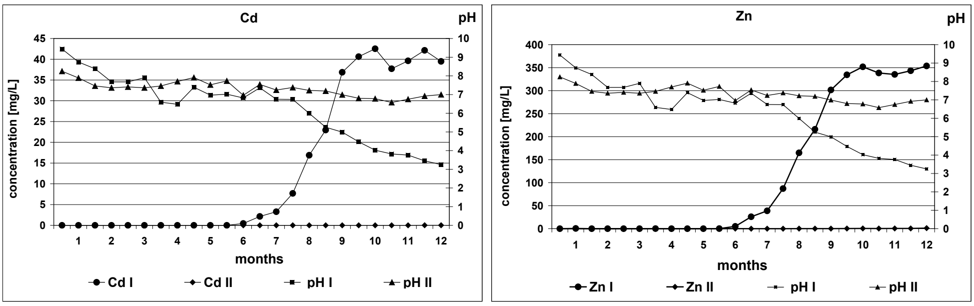

Figure 1. Concentrations of metals (Cd and Zn) in leachate from ARD infiltration through coal mining waste layer 1 m thick: (I) reference column without protective barriers; (II) column with protective barriers.

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.

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Abstract ID: 461

GROUNDWATER EXTRACTION CONTROL FOR PROTECTING THE WATER WORK IN LOBODNO (SW POLAND) AGAINST CONTAMINATION WITH NITRATES

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Keywords: hydraulic control, groundwater intake protection, extraction regime, nitrates, resources management

The water works in Lobodno (5 deep wells with the total discharge of 820 m^3/h) is extracting potable water for the population of the city of Czestochowa and neighbouring communes (SW Poland) from the fracture-karst upper Jurassic Major Groundwater Basin (MGWB 326). 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 showed in 1996–1997 a constant increase of nitrate ions (NO_3^-) concentrations in the recharge areas of the water works in Lobodno, 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 of 50 mg NO_3/dm^3, and in 2008 the mean annual concentrations 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 in Czestochowa.

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 protect water resources and wells of the water works against contamination with NO_3^-. Observations of the water works operation within 1985–2008 showed a gradual increase of NO_3^- concentrations in the extracted groundwater with decreasing wells discharges. Therefore, it was assumed that at the continuous groundwater extraction with high rates the NO_3^- concentrations will tend to decrease. To find an effective extraction regime for the water works in Lobodno, 15 operation variants with diverse overall and specific discharges of wells were designed and tested. The variants were selected based not only on specific water demands, but also taking into account other factors (and their correlations), such as: (i) current admissible discharges of wells, (ii) NO_3^- concentrations in the extracted water and the water delivered to clients, (iii) NO_3^- loads leached out the aquifer, (iii) location of contamination sources within groundwater recharge areas of wells.

Discharges of wells in studied variants assured the lowest possible concentrations of NO_3^- in the delivered water, or the highest amounts (loads) of NO_3^- leached out the aquifer, keeping concentrations in the extracted water below the permissible values. The admissible discharge rates of wells no. 3 and 8 were assumed within the range of 200–245 m^3/h, with their suggested period-ic reduction to ca. 100 m^3/h. It allowed for more frequent operation of these wells (currently significantly limited due to very low water extraction resulting from low water demands) and, consequently for more flexible operations of the water works. Simulations using developed groundwater and contaminant transport models showed an increase of NO_3^- concentrations and loads leached out the aquifer with increasing total discharges of the water works: discharge rates from 100 to 820 m^3/h, NO_3^- concentrations from 22.11 to 48.29 mg NO_3/dm^3, NO_3^- loads leached out the aquifer from 1,677 to 70,564 tons NO_3/a. The lowest NO_3^- concentrations in the extracted water were found for variants, in which wells no 3 and 8 were not operating, while the highest when they were in use. The maximum NO_3^- loads leached out the aquifer were in a variant, in which these wells operated at the admissible discharge rates. The most effective variants at current water demands were these with the reduced admissible discharges of wells 3 and 8. Groundwater extraction regimes according to other variants could be possible as water demands increase, or after the permanent reduction of NO_3^- concentrations in the water extracted by wells no 3 and 8.

Effective control of the extraction regime of each well will allow for reduction of groundwater contamination with NO_3^- within the recharge area, and consequently for delaying or eliminating the need for treatment (a NO_3^- removal installation) to be applied at the water works in Lobodno.

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6.5 Risk-based groundwater management (brownfields, industrial/postindustrial and urban areas)

Abstract ID: 456

THE BEST LOCATION FOR A PUBLIC SUPPLY WELL — AN ANALYSIS USING A GIS

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Keywords: public water supply, aquifer, GIS

In order to determine an area of the regional aquifer for a location of a new public water supply well, the detailed study of severe pumping and recharge conditions has to be analysed. These are not only the geological and hydrogeological conditions, such as: the depth, thickness, permeability or conductivity of the aquifer but also the economic factors, such as: the distance from the pipe networks, electric lines, roads and also environmental such as: protected areas or sources of water pollution. To maintain such an amount of spatial and descriptive data, the computer procedure basing on the geographical information system (GIS) seems to be the best approach. The results of the study searching for the best location of 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 long-term mining of coal, zinc and lead ores and sand along with the other industries caused many changes in the natural environment, among them the extensive cones of depression and groundwater pollution. The Quaternary, Triassic and Carboniferous aquifers have been identified beneath Jaworzno area. 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, but the resources of three abstraction wells are not sufficient for the water supply of the town.

The first step of the study was the analysis of published and archival materials and the field investigations (measurements of depth of water table and water sampling), and the verification and the updating of geological and hydrogeological data. Then the GIS was created (using Geomedia software), which consisted of 26 data layers. After that the computer analysis was carried out. The following factors were analyzed: land surface, climate, surface waters, the landuse, sources of groundwater pollution, geology, hydrogeology (recharge, discharge, wells), the water-supply network, quality of groundwaters, aquifer vulnerability as well as the mining of coal, zinc and lead ores and sand. The series of the topological operations such as: overlying, buffering and extraction of these data layers were performed. The analysis resulted in the selection of 8 areas with the best conditions for the location of water supply. 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 Triassic aquifer.

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 the mine drainage, the areas suitable for the location of public water supplies occupy only 3% of the town area. A GIS analysis is very useful for this kind of studies, but it requires a high computer proficiency and a wide geological and hydrogeological experience. The results of this analysis may be furthermore used by waterworks and environmental decision-makers.

6.6 | Coastal zone management

Abstract ID: 267

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

The main aquifer of the Llobregat Delta (Barcelona, Spain) is affected by seawater intrusion since 1970. The Catalan Water Agency has promoted the construction of a positive hydraulic barrier in order to stop and redress the advance of the seawater intrusion due to intensive development of the confined, deep aquifer. The hydraulic barrier consists of 14 wells, injecting highly treated and osmotized reclaimed waste from the Waste Water Treatment Plant of the Baix Llobregat. A preliminary pilot phase of the project started in late 2007, showing highly positive results. Hydrogeological and hydrochemical monitoring data indicate a very efficient performance of the hydraulic barrier. Quantitative evaluation of such efficiency has been analyzed by hydrochemical mapping and water mixing calculations, and is discussed. A second phase started in mid 2009 and by the end of the year the full barrier will be operating.

Abstract ID: 299

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).

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.

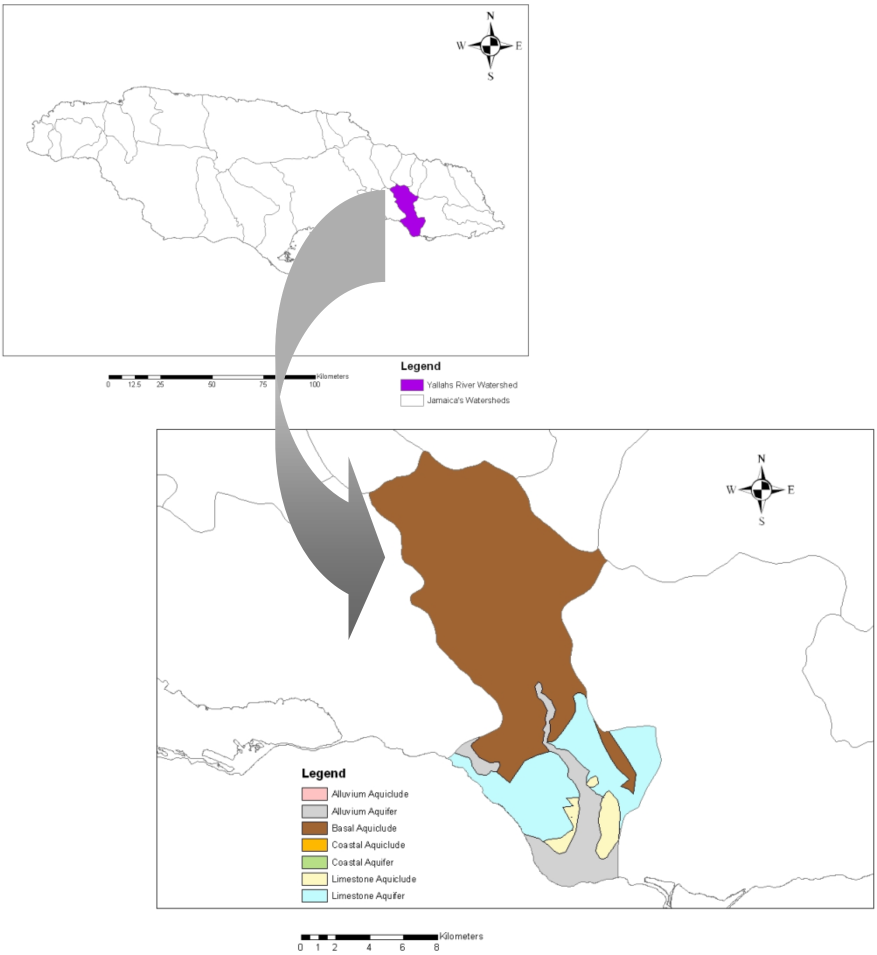

Figure 1. The Yallahs Watershed Management Unit (Jamaica). Geographic location of the Yallah alluvial aquifer and delta (medium grey).

ACKNOWLEDGEMENTS

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Abstract ID: 334

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

1. 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.

2. 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

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Abstract ID: 414

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

The cause of groundwater salinization is identified by several investigations and analyses at the Suyeong County in Busan, Korea. The sea is located at the southeastern part, and the salinized river is located at the northeastern part of the study area. The study area has long tunnels for subway and electrical cable. The quantity of groundwater discharged from two subway lines is 751,000 m^3/year, and the quantity of groundwater used by residents is 1,531,000 m^3/year. So the total groundwater discharged from the ground is 2,282,000 m^3/year. The sustainable development yield of groundwater is about 951,000 m^3/year at the study area. It is 2.4 times the sustainable development yield of groundwater at the study area.

The groundwater level is seriously decreased at the study area. The groundwater level around the subway is located at the maximum 30~32 m below the mean sea level. The deep drawdown of groundwater level brought about the inflow of sea water and salinized river water. The groundwater around the subway lines is contaminated by sea water and the salinized water of the Suyeong River.

Temperature, pH and Electrical Conductance (EC) of groundwater, discharged groundwater and salinized river water were measured in the field. Groundwater quality in EC exceeded over 800 µS/cm (about 500 mg/L in TDS) around subway tunnels and the coastal area. The quality of groundwater doesn't reach to the standard of potable, domestic, agricultural and industrial uses. 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 TDS of groundwater discharged from the Milrak subway station ranged from 3,800 to 7,500 mg/L, and the concentration of Cl^- reaches to about 1,900 mg/L (Table 1).

Table 1. 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

The distribution maps of groundwater level and quality were produced using a geostatistical method, i.e., kriging (Fig. 1, Fig. 2). The maps were very useful to find out the sources of groundwater salinization at the study area. The gray colored area in Fig. 1 and Fig. 2 indicated the area of which groundwater level was below the mean sea level, and the area of which EC exceeded over 800 µS/cm (about 500 mg/L in TDS), respectively. The maps identified that the sea water and river water infiltrated the inland groundwater and salinized the groundwater around the subway lines.

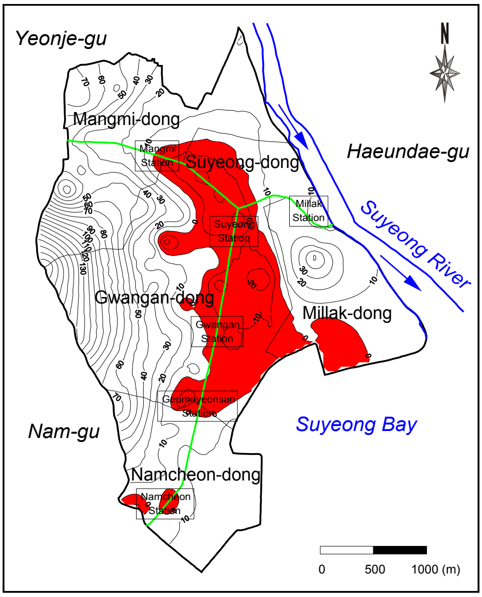

Figure 1. Distribution map of groundwater level.

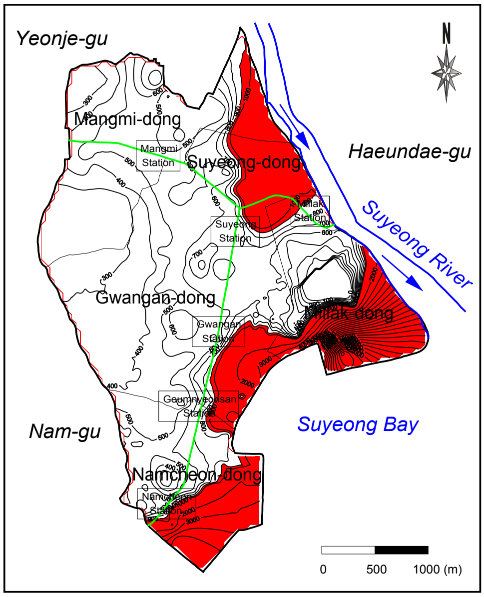

Figure 1. Distribution map of groundwater level. **Figure 2.** Distribution map of EC.

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Abstract ID: 516

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

RECHARGE MANAGEMENT IN DELTA LLOBREGAT AQUIFERS

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Keywords: artificial recharge, management, users

The Llobregat's Delta Aquifers, in the proximity of Barcelona area, are an important water resource for urban, industrial rural and supply. Overexploitation in the 70's, and the proximity to sea, caused an important saline intrusion. An increase of users' awareness focused to save resource, and the worsening quality of water, produced a progressive reduction of pumps and consequently an increase of piezometric heads.

Furthermore during last decades, the metropolitan area of Barcelona has had a big growth. Consequently the recharge has remarkably decreased because of the urbanization and the construction of big infrastructures (highways, TGV and the enlargement of airport). This reduction is considered 10 hm^3/year, and represent between 15 and 20% of the total annual pump.

Barcelona's Water Supply Company (SGAB) perform two actions of artificial recharge from seventies. First SGAB recharge treated drinking water by means of wells that were adapted for this action, when production exceeds water demand. On the other hand SGAB perform a plough to clean of mud of riverbank (scarification) with the goal of improving the infiltration of river water to the aquifer.

Nowadays it has been projected some corrected measures as hydraulic barrier (to correct the seawater intrusion) or recharge ponds (to compensate the reduced infiltration). The first stage of hydraulic barrier works from 2007, and it includes four wells situated beside the coast, in the right margin of riverside. 5.5 hm^3/year of reclaimed water from Baix Llobregat WWTP are planned to inject in a second stage which is starting in 2010.

At the same time two artificial recharge systems through infiltration ponds are ready to start soon and third system has been projected as well. The whole predicted flow infiltration of three systems working together are about 15 hm^3/year.

The Users Water Community of Llobregat Delta (CUADLL) is collaborating with Catalan Water Agency (ACA) with the objective of implementing and managing the superficial recharge systems. Specifically CUADLL is the responsible for: reconstruction of Castellbisbal recharge ponds (2 ha); a recharging test in Sant Vicenç dels Horts ponds (1 ha) and its revamping as well; finally the geological and hydrogeological characterization where Santa Coloma de Cervello ponds (10 ha) are going to be constructed.

CUADLL has assessed the artificial recharge measures' impact by means of numerical models as well.

Moreover a recharge protocol is being writed. This protocol contains quality and quantity variables, economical cost, and the joint viability of the different recharge systems.

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Abstract ID: 209

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

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. The drinking water is produced by 16 caisson wells (10 m diameter) abstracting bank filtrate that are located between the Upper Ganga irrigation canal (UGC) and Ganga river, and by 25 vertical wells. Even when the demand for drinking water peaks to supply up to 8 million additional pilgrims on 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 and UGC is controlled by the *Bhimgoda* 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 paper investigates the impact of the canal closure and high seasonal fluctuation in the Ganga river discharge on the travel-time and flow-path of bank filtrate. The effect of four different typical seasonal surface flow scenarios on the bank filtrate is also investigated.

No previous site-specific data existed, hence two monitoring wells were installed in the study area in 2005. Hydrogeological field and laboratory investigations were conducted from 2005–2009. The results of the investigations were incorporated into a groundwater flow model (PMWIN), to get an improved understanding of the complex surface water–groundwater interaction. The travel-time and flow-path of the bank filtrate was determined by particle tracking. Major hydrochemical and bacteriological parameters were also determined in surface and groundwater. Dissolved organic carbon (DOC) and heavy metals were monitored occasionally.

Results for two selected RBF wells located on the *Pant Dweep* island between the UGC and Ganga that were studied in detail, indicate that under normal pre- and post-monsoon conditions the shortest travel time of the bank filtrate to the wells (no. 18 & 40), at a distance of 15 m and 115 m, is 2 and 84 days respectively (Fig. 1a). The bank filtrate from the reservoir of the *Bhimgoda* weir (Ganga river) takes nearly 455 days to reach well 18. The long travel-time is associated to the clogging of the reservoir by fine sediment. However, the presence of surface water on all sides allows for conducive natural cross-flow conditions on the island resulting in a high abstraction of more than 80 % bank filtrate, especially for well 40. During the monsoon, due to the greater hydraulic gradient, the travel time to wells 18 and 40 decreases to 77 days and less than 2 days respectively.

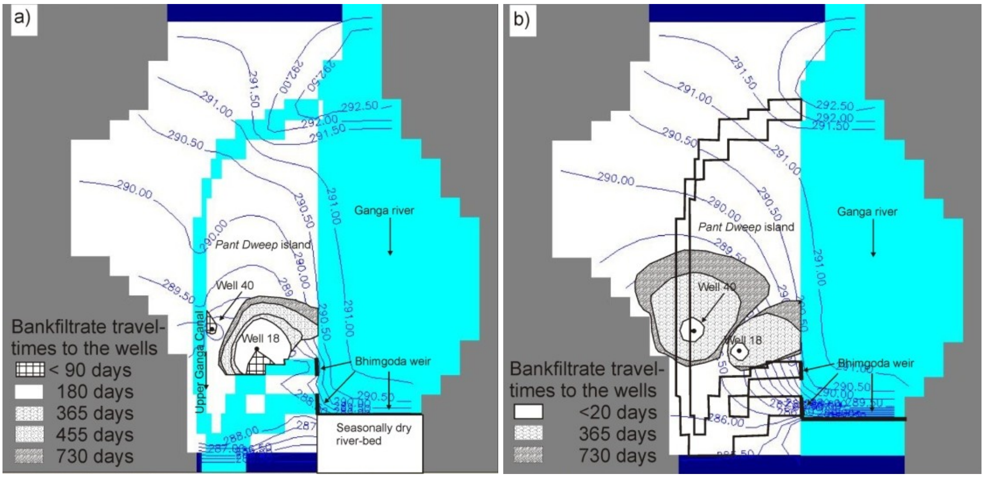

Figure 1. Bank filtrate travel-time: a) normal canal operation; b) canal is closed

In the event the UGC is closed for maintenance (Fig. 1b), the normal operation of well 40 is reduced from 19 hours/day to around 12 hours/day (alternating 3 hours pumping and recovery phases). Though the proportion of groundwater (from the west of the UGC) abstracted increases, there is still a significant flow of older bank filtrate from the north-east of the *Pant Dweep* island. This is a result of lesser clogging and a higher gradient of the river upstream of the reservoir, and also a steeper groundwater gradient to the south of the island. This also results in a slightly faster travel-time to well 18 which only receives bank filtrate from the direction of the Ganga (to the east). A similar scenario is observed for the remaining RBF wells to the south of the island.

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 more than 2 years old bank filtrate infiltrated along the river upstream of the *Bhimgoda* weir where the flow remains significant throughout the year. The annual UGC maintenance closure also removes the clogging layer of the canal, and depending on the locations of the dredging and levelling of the bed, the yield of certain wells increases.

Abstract ID: 246

EFFECT OF VEGETATION COVER ON INFILTRATION RATES IN ARTIFICIAL BASINS

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Keywords: infiltration, vegetation, infiltration basin

The area of impervious surfaces in urban areas, including roads and railways is continuously increasing. To limit the impact on the water balance and groundwater levels, surface water run-off is collected and transported to artificial infiltration basins or natural infiltration areas. The infiltration capacity of infiltration basins, ponds and constructed wetlands is often decreasing after several months or years. Input of small sediment particles and organic material into the pore space results in outer and/or inner clogging and reduced infiltration rates. It is expensive to technically remove the clogging layer to achieve the original infiltration capacity.

There is a dispute over the advantages or disadvantages of planted infiltration basins among practitioners and researchers. Some researches analysed that the infiltration rates are increasing with vegetation cover compared to bare soils (Gajic et al., 2008; Orradottir, 2008; Hatt, 2009; Martinez-Zavala, 2008). Vegetation cover may change as a result of climate change, e.g. long dry periods during summer. This affects the efficiency of infiltration rates in case of storm events. Lange and Scheufele (1987) illustrated that grassland has a positive effect on infiltration rates. The infiltration rates are increasing due to higher soil humidity (cooling air inlet) and roots of vegetation in the upper soil layer. However, the infiltration capacity can decrease if a biofilm is created when the reservoir is filled over a long time and the vegetation is not suitable for the site conditions.

To quantify the effect of vegetation cover on infiltration rates at different locations in Saxony, Germany, a project was started in March 2009. The study includes investigations at four sites, a new constructed wetland for wastewater treatment in Reichenbach, a storm water infiltration basin at a motorway near Dresden, a fallow field near Meissen and a rain water infiltration trench in Dresden-Pillnitz. The constructed wetland consists of five basins with different plant species. The infiltration rates of the basins are measured monthly during plant growth and operation with increasing wastewater discharge. In the storm water infiltration basin and in the fallow field the species *Juncus inflexus* has been planted at an area of more than 10 m^2 to determine the effect of the roots on infiltration rates. The infiltration trench has been divided into five sections, four planted with different species (*phragmites australis, carex acutiformis, juncus inflexus*) and sod grass lawn.

The infiltration basin at the motorway has been studied for the last three years. The infiltration rates were determinate using three different methods: double ring infiltrometer tests, sieving analysis and laboratory column experiments. Results from 2009 were compared with measurements three years ago in summer 2006. Infiltration rates were measured using the same methods at the same places in the basin like in the year 2006 (Fig. 1). The average hydraulic conductivity dropped from $2.7 \cdot 10^{-5}$ m/s in 2006 to $1.1 \cdot 10^{-5}$ m/s in 2009. It is expected that the infiltration rate will increase at the planted area in the basin.

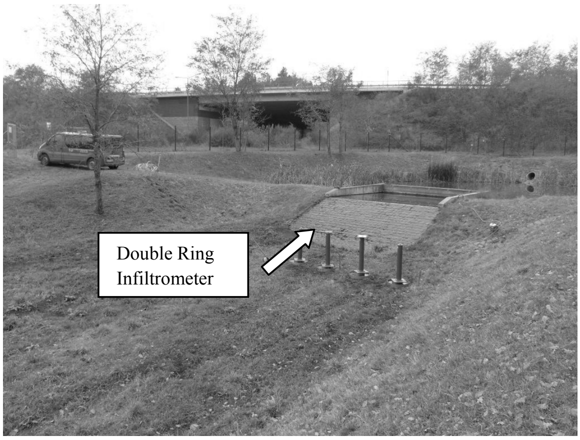

Figure 1. Seepage reservoir with double ring Infiltrometer tests.

Furthermore, first results from the measurements at the other sites will be presented and the effect of special plant species at infiltration rates in artificial basins and constructed wetlands will be discussed.

ACKNOWLEDGEMENTS

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Abstract ID: 269

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

The balance of atmospheric deposition and recharge chloride content is a simple, effective means to obtain local average long–term diffuse recharge to aquifers if a set of conditions are fulfilled, such as steady chloride flow through the unsaturated zone and groundwater samples from the very top of the water table. However most groundwater sampling wells and boreholes are deep and/or have long–screens. Thus, the sample is a mixture of water recharged throughout the aquifer recharge area, which may be spatially variable. This effect may be important for extensive aquifers, especially for sloping lands with important altitude changes. The ratio of calculated groundwater and chloride flow from upstream must match the chloride content of the sample, thus yielding an estimation of recharge distribution upflow if it follows a given spatial distribution function. This is commented and some application examples are given. Results obtained in Spain from aquifers of the Iberian Peninsula and the Islands compare favourably with other calculations, both in semihumid and arid conditions.

Abstract ID: 294

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

An Aquifer Storage Transfer and Recovery (ASTR) project was established in 2006 in a confined brackish aquifer at Salisbury South Australia using wetland treated urban stormwater. This is the only known ASTR operation in an initially brackish aquifer. Salinity of native groundwater is a significant constraint on use of recovered water for non-potable and drinking water supplies. Hence a groundwater model (FEFLOW) was used to simulate injection and recovery operations in well fields of various designs (Pavelic et al., 2005), and following site construction and initial operations, 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 bore field consists of 6 wells positioned within a rhombic domain (4 outer wells and 2 central wells), with a uniform 50m separation between injection and recovery wells. 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 operations, and water was recovered from the two inner wells.

The captured stormwater is injected to the confined carbonate aquifer between depths of 160–220 m. The ambient groundwater was brackish (3650 µS/cm on average) with a temperature of 27 degrees, whereas the injected stormwater is fresh (250 µS/cm on average) and exhibits temperature variations in the range of 8–15 degrees in winter, when most water is injected.

Injection of 377 ML of stormwater over 857 days of operation resulted in the decrease in EC of groundwater from 3650 µS/cm to 700 µS/cm at the outer wells (Fig. 1). Electrical conductivity is considered to be a conservative tracer here, although dissolution of calcite due to injection of storm water is feasible. During flushing, the temperature decreased from 27 to 20.5°C and the temperature breakthrough curve is retarded (R ≈ 2) compared with EC (Fig. 1). The modelled values fit the observed data well. Nevertheless, the verification of the model against data taken from a prolonged storage and recovery periods is required.

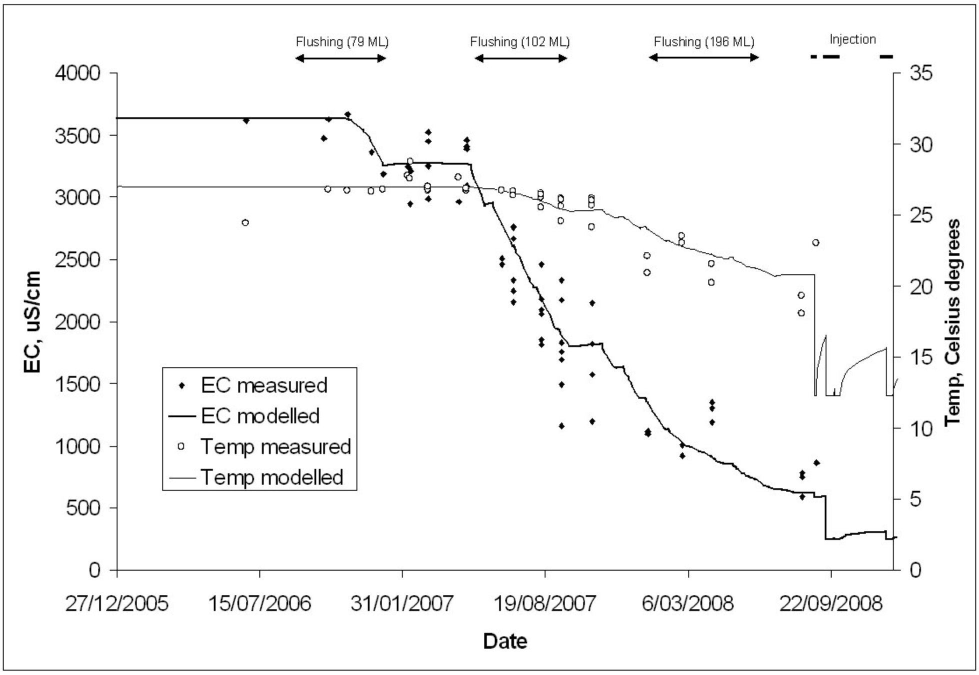

Figure 1. Observed and modelled breakthrough values of EC and temperature of water in the outer well IW3. (This well was first used as an injection well in Sept 2008).

The numerical model was used to simulate a range of operating scenarios in typical, as well as dry and wet, sequences of rainfall years when varying quantities of stormwater would be harvestable for recharge. 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. Results suggests that at this site ASTR can be an effective means of improving quality of recharged water while meeting salinity constraints.

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Abstract ID: 343

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

GROUNDWATER RECHARGE — EVALUATION, METHODS AND RESULTS

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Keywords: groundwater, recharge, Poland

General information on groundwater recharge in Poland is followed by overview of applied methods. Different methods including base flow analysis, soil moisture balance, lysimeter, water table fluctuation, field experimental measurements and modeling results has been discussed and illustrated. Groundwater recharge is an important issue considering water management and water quality protection from land surface contamination. An overview of process and techniques could be found in many papers summarized for example in de Vries and Simmers (2002) and Scanlon et al. (2002).

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 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 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 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. Baseflow analysis of stream hydrographs provide valuable insights into groundwater contribution to stream flow. Obtained data on baseflow values for rivers and creeks form Institute of Meteorology and Water Management has been applied for evaluation of the groundwater runoff value. This value could be expressed in millimeter of rainfall or as a liters per second form one square kilometer of river basin (catchment) — $l/s\ km^2$. Analysis showed values of effective infiltration in range 50–200 mm for different types of aquifer condition and pretty good correlation between both method's results. Detailed analysis is presented.

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 al. (2007) for deeper Tertiary aquifer.

Base on field measurements in mountainous region a comparison of different methods and results is illustrated. 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. Four recharge assessment methods were applied: (1) lysimeter infiltration monitoring; (2) monitoring of groundwater drainage by gallery; (3) monitoring of river baseflow; (4) monitoring of groundwater table fluctuation. 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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Abstract ID: 433

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.

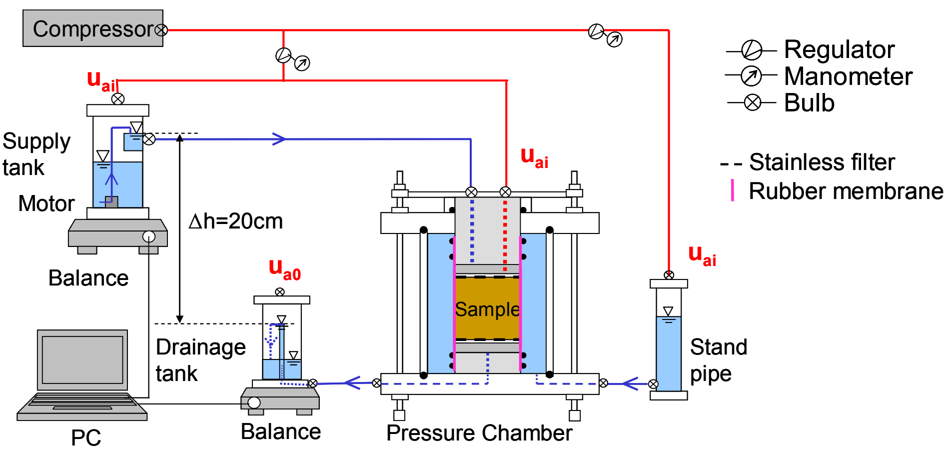

Figure 1. Configuration of the proposed measurement method for unsaturated soil properties.

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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Abstract ID: 488

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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6.8 Understanding and communication on groundwater — education and public involvement

Abstract ID: 167

ENVIRONMENTAL EDUCATION AND THE GUARANI AQUIFER IN A DOCUMENTARY: AN APPROACH TO A BROADER EDUCATIONAL PROCESS

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Keywords: environmental education, Guarani aquifer, groundwater resources, socio-environmental conflict

The Guarani Aquifer has continental dimensions, extending over some 1.2 million km² within the Paraná sedimentary basin in South America. Their waters are utilized by 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, but the right number is unknown due to the existence of a lot of clandestine ones. The over-exploitation without any criteria may affect the quantitative and qualitative potential of their waters.

Such problem is an example pointing out to the need of educating the society to face the challenges inherent to 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 70s of last century, 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. The First Intergovernmental Meeting on Environmental Education (EE) was held in 1977, organized by UNESCO in Tbilisi, Georgia. General guidelines on 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 concerning the causes and proposals for action when facing environmental problems. Moreover, they also reflect different understandings about education itself. Although the socio-political-economical aspects were highlighted in Tbilisi, breaking up with a view of ecological reductionism, EE still has a great tradition as a way of studying nature and 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 can be 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, the projects on EE must deal with the dimensions of knowledge, values and political participation (Carvalho, 2006), for the development of the citizenship and construction of a democratic society, where all citizens have voice and can participate of the decisions that affect everybody.

Under this view, I present an educative proposal to deal with the questions related to Guarani aquifer from a documentary relative to it. The film “Guarani: caminhos das águas” (Guarani: the water ways) presents an “encounter” with the Guarani Aquifer, starting with the conduction of scientific research. When the over-exploitation and contamination problems are presented to the spectator, some tracks are provided in order he or she not constructs a commitment only in an individual level relating to the water care. The problems involve interests of several segments, i.e. public and private interests that are behind these risks. So, initiatives to take care of this environmental resource need them also in a collective action in order to demand measures from decision makers for attending the collective interest of the population.

EE implies more than to deal with conclusive knowledge and specific behaviours. It means the challenge to review and change world’s visions, values and practices, to discuss and looking for democratic decisions, a learning that involves all citizens of the society, in and out schools.

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GROUNDWATER EDUCATION: ONE DROP PLUS ONE DROP EQUALS SELF MANAGEMENT

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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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