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ABSTRACT

Groundwater resources are facing increasing pressure from consumptive uses (irrigation, water supply, industry) and contamination by diffuse loading (e.g. agriculture) and point sources (e.g. industry). This causes major threats and risks to valuable groundwater resources and on groundwater dependent ecosystems. The impacts of land-use changes and climate changes on groundwater resources are difficult to separate as they partly result in similar changes in the ecosystems affected. Moreover, the effects are highly interwoven and complex.

Within the EU seventh framework program the integrated GENESIS project was approved. It is the basic concept of GENESIS to base research on different relevant aquifer sites in various European countries to test scientific issues and find advanced solutions to the important problems. The most relevant and actual impacts on groundwater recharge, groundwater dependent ecosystems and substances leaching into aquifers will be revealed. Their mathematical implementation into models will then be pursued and likely scenarios of future aquifer use calculated. Thus, a basis for the revision of the Groundwater Directive and better management of groundwater resources is being developed.

INTRODUCTION

During the seventh framework program of the EU an integrated project on assessing climate change and land-use impacts on groundwater systems (acronym: GENESIS) has been initiated in 2009. The project consortium consists of 26 partners from 17 different European countries. It is the basic idea of the project to improve scientific insight and to create new concepts and tools for the revision of the Groundwater Directive (GWD) and better management of groundwater resources.

Typical aquifers in the European Union differ widely with respect to their geologic background, climate conditions, size and land as well as water use. In order to review the present situation and measures on European scale, 16 test cases have been evaluated including Po aquifer (Italy), Rokua-Hailuoto Esker (Finland), Mancha Oriental aquifer (Spain), Czestochowa aquifer (Poland), Koycegiz-Dalyan coastal catchment and lagoon (Turkey), Transfleuron site (Switzerland), Lule river (Sweden), Feucherolles site (France), Sumava region (Czech Republic), Vosvozis river basin (Greece), Grue site (Norway), De Kroome Rijn (Netherlands), Bogucice aquifer (Poland), Murtal aquifer (Austria), Zagreb aquifer system (Croatia) and the Bitterfeld site (Germany). The locations of the sites are shown in Figure 1. The corresponding hydrogeological regimes range from lagoon systems, fractured rock, sand and gravel aquifers and karst systems to peatlands and eskers.

Based on the analysis of the case studies the most relevant and actual impacts and threats on (i) groundwater dynamics, recharge and water balance of groundwater systems, (ii) substances leaching to groundwater aquifers due to different land-uses and (iii) groundwater dependent ecosystems interacting with surface water shall be revealed. These results will be input for further research on processes in groundwater systems and their mathematical implementation in models. Additionally, likely scenarios of future aquifer use can be inferred from the test sites considering all relevant stakeholders, which will lead to the development of economical and social viable measures for sustainable groundwater use and protection.

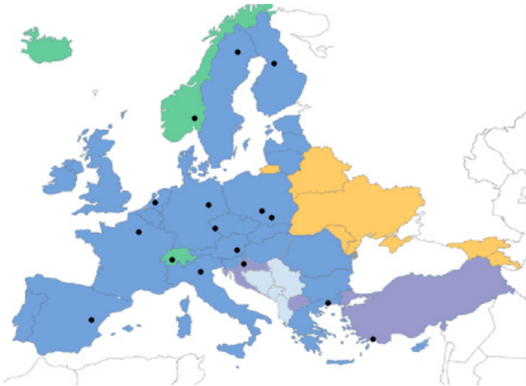

Figure 1. Locations of the test sites examined within the GENESIS project

Moreover, possible gaps with respect to the Water Framework Directive (WFD) and the GWD are discussed. Finally, a general overview of modeling approaches used and their purposes with a specific focus on model requirements and data availability and needs is put together.

IMPACTS AND THREATS ON GROUNDWATER DYNAMICS, RECHARGE AND WATER BALANCE OF GROUNDWATER SYSTEMS

First analyses show that three major reasons can be identified that significantly influence groundwater recharge and the water balance of groundwater systems. The most obvious cause of all is overexploitation, typically related to the use of groundwater for agricultural irrigation. At one test site the observed drawdown between the starting of the pumping period in May and the end in September reaches 20 m. Furthermore, infiltration from a connected river and a lake into the subsurface are induced (which was not the case before), diminishing an important source of water for the wetland system. Another threat is the intrusion of seawater into the wetland area. At the Spanish site a maximum decline of 100 m of groundwater levels has been reached in 30 years of exploitation. As a consequence, the streamflow of an interacting river becomes depleted leading to direct effects for groundwater dependent ecosystems.

The next group linked to disturbance of natural subsurface conditions summarizes more general kinds of land use like gravel mining activities, increased sealing of ground surfaces due to urbanisation and industrialization and artificial groundwater recharge (washing sites, drinking water purpose). An important component within this group is the regulation of rivers that interact with groundwater which may lead to riverbed erosion (potentially changing a feeding into a gaining river), the reduction of areal recharge from flooding due to embankments and the prevention of any water exchange due to the colmation of water reservoirs that were built for hydro power generation. Drainage ditches significantly influences groundwater systems in Finland and the Netherlands.

Finally, climate change and with it the modification (or reduction) of seasonal water availability will potentially influence groundwater systems in the future, especially in mountain regions. In the Swiss karst aquifer some pumping wells were abandoned after the dry summer of 2003, because their yield became insufficient. In addition, during the dry autumn of 2009, the spring discharge (and hence the river discharge) was too low for hydroelectrical production and likely had also some detrimental affect on the river ecosystem.

IMPACTS AND THREATS OF SUBSTANCES LEACHING TO GROUNDWATER AQUIFERS DUE TO DIFFERENT LAND-USES

A common threat to groundwater quality is linked to the non-point source pollution of nitrate leaching from the soil through the unsaturated zone into the groundwater body. The nitrate mass often derives from disproportionate use (i.e. amount and timing of application) of fertilizers in agriculture. This situation is present in many of the test sites, as for example in Spain, where nitrate contents of 125 mg/l have been observed, in Greece, where nitrates in some boreholes were detected in much higher concentrations compared to the EU limits, or also in Austria.

Cold climates represent a special condition in this context since findings of several pesticides from grain and potato production demonstrate that slowly degradation of pesticides can contribute to the deterioration of groundwater resources. Due to the rapid infiltration into the subsurface after the frozen soil has thawed the use of pesticides on such areas might represent an additional threat to the groundwater quality.

Moreover, groundwater pollution may be linked to an entire mixture of emission sources comprising leaky sewage systems, municipal landfills, illegal waste depositories (containing all kind of chemical wastes like sludge or ashes), non-authorized gravel pits and also industrial plants, that partly discharge waste water in uncontrolled manner. High concentrations of pollutants like nitrates, atrazine, heavy metals and chlorinated hydrocarbons in groundwater confirm the influence of these sources. Furthermore, in situ transformation (e.g. reductive dechlorination) of these substances can be observed.

Leaching of substances into groundwater is not only related to excessive pollution but can also be favoured by hydrogeologic conditions. The Swiss Karst aquifer (due to its general hydraulic characteristics) has only limited buffer capacity and the Polish site barely shows any soil cover.

IMPACTS AND THREATS ON GROUNDWATER DEPENDENT ECOSYSTEMS INTERACTING WITH SURFACE WATER

Most often threats to groundwater dependant ecosystems may have a quantitative background, are related to a water quality issue or are a combination of both. Due to surface streams or shallow groundwater that may contain significant concentrations of nutrients the risk of eutrophication of connected ecosystems exists in such different environments as coastal lagoon systems (e.g. nutrients coming from waste water discharge) and shallow weathered bedrock aquifers (e.g. nutrients coming as leachate from agricultural fertilizer). At the latter site (Czech Republic) the situation is even worsened because of acid athmospheric depositions influencing the natural pH and the seepage of mine waters containing a variety of heavy metals. These elements have a direct toxic or inhibit effect on the fluvial biota as the riverbed sediments are incrusted by iron and manganese oxides to a depth of about 10–15 cm.

Equilibrium shifts in freshwater bodies as a result of nutrient loading have been reported at the Dutch test site. Water bodies once characterised by clear water, macrophytes and predator fish have been replaced by turbid water systems dominated by algae and freshwater bream. In strongly regulated rivers (e.g. for power production) the discharge patterns are completely changed. Thus, riparian zone processes are also altered leading to retention of chemical elements that induce the production of diatom in stored water (Swedish test site).

The application of tracers has proven a powerful tool in exploring the dynamics and time scales of groundwater exchange and in assisting to build good conceptual models, which are the basis for corresponding numerical modeling efforts. At the Polish site, impacts of long-term changes of water balance (including the delineation of climate change impact) and anthropogenic pollution on the ecosystem functioning have been studied by these methods.

POSSIBLE GAPS WITHIN THE WFD AND GWD

With respect to the Water Framework Directive and the Groundwater Directive possible gaps have been identified as unconsidered processes, non-existing tools for particular conditions (e.g. spreading patterns of pesticides in areas with winter climate), missing thresholds and the negligence of uncertainty bounds as well as implementation deficits (e.g. incomplete definitions of protection zones).

Climate change is not directly covered in the WFD or the GWD. However, the changed water availability could lead to an imbalance between water availability and water use, violating Art. 4 of the WFD, which imposes to ensure equilibrium between withdrawal and renewal of water. Definition of threshold values and environmental indices should also consider the needs of wetland ecosystems and provide means to account for uncertainties since otherwise difficulties in assessing environmental and resource costs might occur.

For some of the test site countries national River Basin Management Plans (RBMP) already exist, for others they will be published in the near future. In general, these plans are based on large river catchment areas and discuss the quantitative and qualitative status of the water systems. Within the RBMPs also the most important threats to groundwater are presented and corresponding measures are suggested to preserve or improve aquifer conditions. However, the proposed measures sometimes are of basic nature and their quantitative impact is difficult to assess. If feasible the suggestions will be adapted to the specific conditions present at the test sites and evaluated within the groundwater systems management scenarios.

CURRENT MODELING APPROACHES

The investigated test sites strongly vary regarding the already existing use of modelling approaches. At some sites a lot of modelling experience already exists in diverse aspects of saturated groundwater flow, thus future aims comprise extension, further refinement or improved characterization of particular processes (e.g. surface water–groundwater interaction). Moreover, bridging the gap from the plot to the regional scale in the field of combined modelling of unsaturated water movement and substances (e.g. nitrate) fate and transformation is pursued by several groups applying different codes that are validated against field experiments.

The coupling of yet individual models is also applied in the framework of linking climate models to integrated hydrologic models (e.g. SWAT). At the Spanish site the development of a socio-hydro-economic modelling framework goes even further since it allows selecting sustainable cost-efficient measures and management strategies to achieve a good quantitative and chemical groundwater status in an uncertain environment. In this model chain agronomic simulation is linked to numerical representation of groundwater flow and pollutant transpsort and optimization algorithms. In order to limit computational time also stochastic methods are used that offer a wide range of specific implementations. For the Dutch test site a discrete number of realizations for extreme events is defined within an integrated hydrological model and the results are evaluated in terms of frequency distributions.

For the sites with no present numerical model applications, clear visions exist about initial model uses including verification of conceptual models, improvement of process understanding and providing the basis to predict the impact of various land management practices on groundwater conditions. Additionally, the modelling of in situ biochemical attenuation processes is of strong interest to compute the evolution of plumes at large uncontrolled landfills. It that case collection of further field data is often needed to infer corresponding degradation parameters.

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