Concepts for transboundary groundwater management in a region of extensive groundwater use and numerous contaminated sites

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ABSTRACT

The Rhine gravel aquifer in the Basel area (northwestern Switzerland) extends to both France and Germany. Since Basel developed into a major center for the chemical and pharmaceutical industry in the 19th century, vast areas in this region were or were likely to have been contaminated. In addition, there are abandoned sites of small enterprises and numerous areas (fillings of former gravel pits) on adjacent French and German territory which are probably also contaminated. The aquifer is used by numerous municipal and industrial water suppliers. Two case studies are presented that illustrate the need for transboundary groundwater management concepts in the region. Whereas the first case study illustrates short-term impacts on groundwater resources during a major suburban development project, the second case study shows long-term changes of groundwater flow regimes and the regional distribution of contaminants. For both case studies it is shown that river-groundwater interaction along the Rhine is an important element of the regional groundwater flow regime. It further can be demonstrated that considerable risk, with regards to the mobilization of contaminants, can be caused by changes in regional scale groundwater flow regimes together with changed hydraulic boundary conditions. The change in groundwater flow regimes and the reversal of flow lines may lead to the contamination of areas that were formerly not or only weakly polluted. These areas suddenly may lie within the capture zones of municipal or industrial groundwater wells or within the groundwater drainage of construction sites. Such risks of contamination require the development of concepts and methods for groundwater protection and management. A prerequisite for groundwater protection and management is a good knowledge of the spatiotemporal processes of regional scale groundwater flow regimes, which requires appropriate modeling and monitoring. This allows the evaluation of the impacts of planned changes at an early stage and to develop suitable groundwater management systems.

Key words: urban groundwater management; contaminated sites, management concepts

1. INTRODUCTION

Open space in urban areas is very rare and new infrastructures are increasingly extended into the subsurface. However, these areas often had the status of non-productive terrains and were historically used for industry settlements, transport systems and for the deposition of different types of waste. The "Trinational Euro District Basel", including mainly the cities of Basel (CH), Lörrach (DE) and St. Louis (FR), is located at the southern end of the Rhinegraben aquifer system. Here, non-productive areas are becoming increasingly valuable resources for future urban development

However, urban development can impact regional groundwater flow regimes and new constructions (subsurface traffic lines or large buildings) may affect urban groundwater systems temporarily during construction as well as permanently after completion. Potential impacts can include a reduction of the cross-section for groundwater flow and a decrease of aquifer storage volume. Some of these impacts are permanent, while others, such as construction site drainages, only affect the groundwater flow regime temporarily during the construction period.

In order to predict, mitigate or prevent environmental problems across national and legislative borders and to assure the supply of groundwater for municipal and industrial users, integrated multi-disciplinary adaptive groundwater management approaches have to be chosen. An approach is presented which includes the integration of geological and hydrological data, and results in the setup of a groundwater management system comprising (1) groundwater monitoring, (2) the development of a data-base application, facilitating the interpretation of geological and hydrogeological data, (3) geostatistical analyses of the aquifer heterogeneity, as well as (4) regional and local scale high resolution groundwater modeling.

The approach presented is illustrated by two examples. The first case study discusses strategies to understand and predict the cumulative effects of the numerous single impacts on groundwater resources during a major suburban development project. Focus is placed on a construction phase that was associated with considerable changes in groundwater flow regimes resulting in the reversal of flow lines and a shift of groundwater divides. In the second case study the development of groundwater pollution during the last decades in a heavily industrialized groundwater protection area is analyzed. This includes the illustration of long-term changes to a groundwater body due to changed hydraulic boundary conditions.

2. INSTITUTIONAL ASPECTS OF TRINATIONAL COOPERATION

Transboundary cooperation in environmental issues in the Basel area has made considerable progress. Primarily because of the activities of local groups, such as the "Trinational Euro District Basel", whose aim is to cooperate in the three countries in the domain of urban planning, healthcare and traffic infrastructure, as well as the "Regio Basiliensis" (initiation and cooperation in transboundary projects) and the support of international organizations, such as the "Council of Europe", the Upper Rhine Valley and other European border regions have succeeded in voicing their interests in a fairly cohesive manner. However, concerning environmental issues, the continued emphasis of national governments on sovereignty and national interests has prevented international border regions from achieving such basic goals as infrastructure integration and harmonization of environmental policy.

There are several institutions which are in charge of the transboundary cooperation in the Upper Rhine area in the domain of groundwater encompassing politicians and environmental scientists. An important board is the groundwater expert panel of the French-German-Swiss conference of the Upper Rhine. This board supported the several initiatives of INTERREG projects in the groundwater domain ranging from the transboundary compilation of hydrogeological data (Wagner et al., 2001) to the development of tools, that allow to predict the groundwater quality with respect to changes in agriculture policy in the three countries (i.e. MoNit, 2006). The legal aspects are still matter of the three countries, which requires a certain effort of harmonization.

3. CONCEPTS AND METHODS

In order to develop concepts and methods for the sustainable use of groundwater resources in urban areas, environmental impact assessments not only have to incorporate above ground vitiations but also such concerning negative impacts on groundwater flow regimes. Together with various possible sources of groundwater pollution observed in urban environments, urban development may interfere with a previously balanced urban groundwater flow regime and change groundwater quality also across national borders.

Many decisions concerning impacts on urban groundwater flow regimes are typically taken at the level of the individual project. However, it is the sum of all impacts, and their interaction in time and space, that has to be considered. In the context of interferences of subsurface constructions and ancient polluted industrial sites it is of particular interest to know, which hydrogeological data are required to understand the changes in groundwater flow and transport. To accomplish this, it is necessary to develop instruments that facilitate the quantification of the consequences of the cumulative effects of numerous decisions concerning groundwater flow regimes and groundwater quality. At the same time, system profiles must be identified together with the delineation of boundaries and specific targets that lead to defined overall goals for specific groundwater areas. These instruments form part of groundwater management systems, comprising among others, the setup of groundwater observation systems, high resolution numerical groundwater modeling, and the development and evaluation of scenarios. Numerical methods greatly facilitate the consideration of the multitude of impacts in a complex environment. They allow evaluating and comparing changing boundary conditions, constructional alternatives and groundwater management strategies as well as ensuring an adequate protection of groundwater resources (Epting et al., 2008).

4. SETTINGS

The two case studies are located in northwestern Switzerland and extend to both Germany and France (Fig. 1). In both areas the shallow unconfined upper aquifer mainly consists of late Pleistocene gravels deposited by the Rhine. The gravel depositions are intercalated with fine-grained flood-plain sediments that result in variable permeability within the aquifer. The thickness of the aquifer ranges between 15 and 35 m and is underlain by an aquiclude consisting of mud to clay rich sediments, Oligocene in age. In the area illustrated in the second case study the aquifer system is more complex due to a lower karst aquifer.

River-groundwater interactions along the Rhine are an important element in the regional groundwater flow regime. The groundwater table fluctuates phase-delayed and with reduced amplitude in response to the river level fluctuations of the Rhine. Depending on the hydrological constraints, the river can be a source or sink for groundwater.

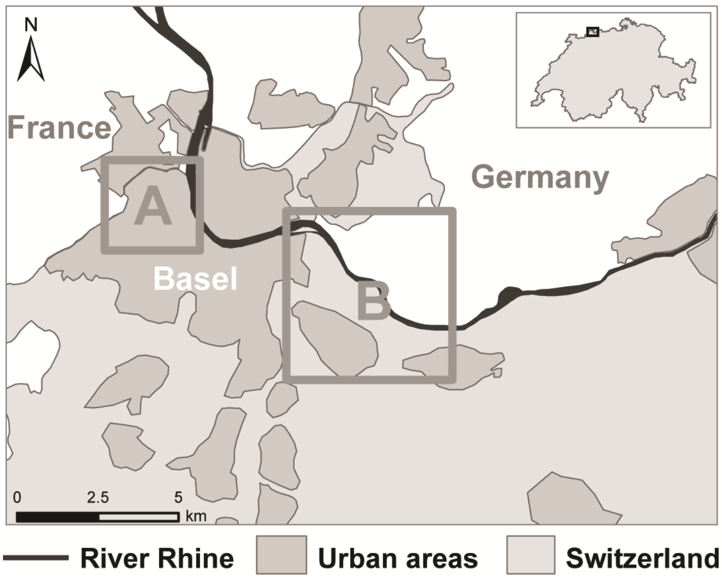

Fig. 1: Location of case studies.

Since Basel developed into a major center for the chemical and pharmaceutical industry in the 19th century, large areas in the region of Basel were or are likely to have been contaminated. In addition, there are abandoned sites of small enterprises and sites with municipal or multicomponent waste (fillings of former gravel pits) on adjacent French and German territory. The aquifer is presently used by numerous municipal and industrial water suppliers. Due to changing activities the groundwater flow regime changed several times, both at the local and the regional scale.

4. EXAMPLES OF TRANSBOUNDARY GROUDWATER ISSUES

To define the specific profiles of groundwater systems, high-resolution groundwater models are applied that have been transiently calibrated with groundwater head data and river stages as well as extraction and recharge rates. In the presented examples, the strongly transient character of groundwater flow regime and/or river-groundwater-interactions in urban areas is illustrated. Scenarios were developed to assess the consequences of decisions and to optimize particular measures such as channel widening and their influence on groundwater quality.

A Transboundary groundwater management during highway construction

The highway construction outlined as the first example is located in the northern part of Basel on the western bank of the river Rhine (Fig. 2). The tunnel highway connection has a total length of 3.2 km. About 87 % of the tunnel construction are situated in the gravel deposits. The remaining 13 % are covered by the bridge across the Rhine and the various tunnel entrances. For the tunnel either methods based on mining techniques or the cover-and-cut construction method were employed. The large scale groundwater model is described in detail by Huggenberger et al. (2004) and Epting et al. (2008). Progressive adaptations were made throughout the various construction phases. In total 44 observation wells were instrumented with automated water-level loggers that continuously measure the hydraulic head, 21 observation wells were regularly sampled for groundwater quality measurements. Furthermore, the extractions to be supplied to the industrial groundwater users and to the settling tanks on the construction sites are sampled at regular intervals.

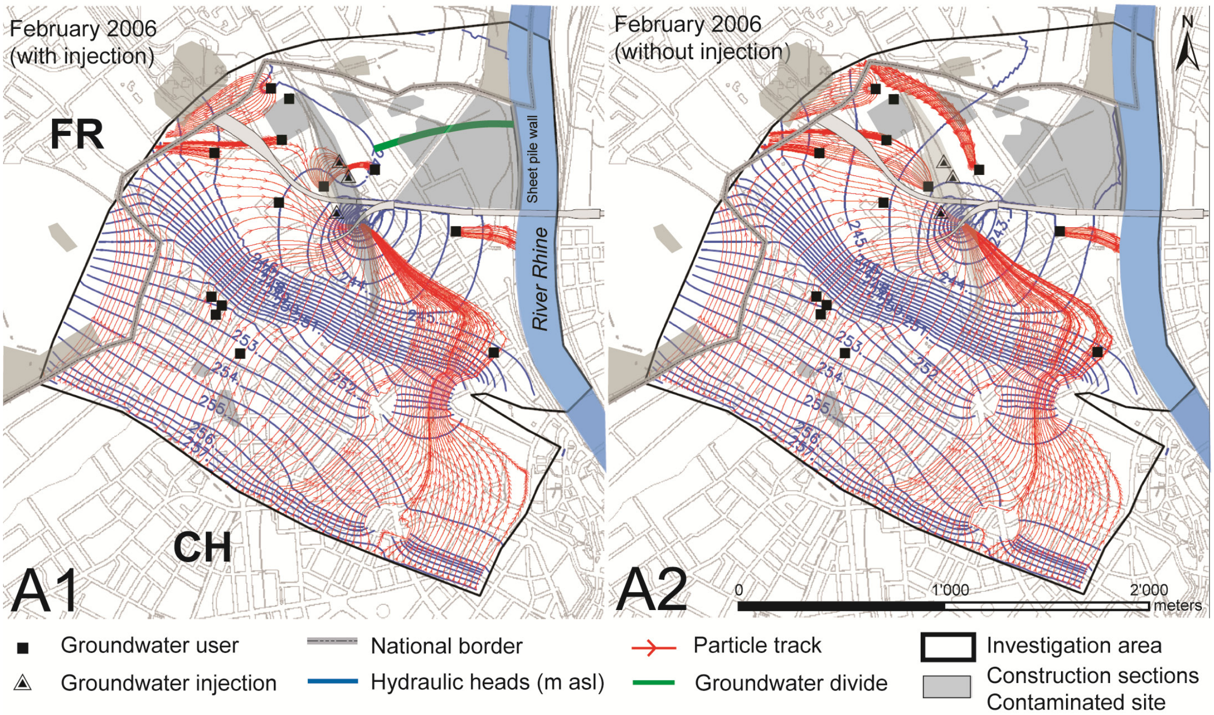

Fig. 2: Groundwater flow regimes for case study A. A1: with groundwater injection. A2 without groundwater injection.

During the entire construction period, the groundwater flow regime was affected by the movement of construction sites requiring different groundwater management systems. Depending on the mining techniques, the degree of complexity for groundwater drainage varied and was either realized as open sump drainage, the dewatering of residual groundwater in areas enclosed by sheet pile walls, or a combination of both. The groundwater extracted from the construction site was generally either discharged into surface waters, into the sewage system or recharged back to the groundwater. In all cases, the discharged water has to satisfy the specific quality standards.

A considerable change in the local groundwater flow regime in the northern industrial area was expected by the open sump drainage in 2006. With the known polluted sites on both sides of the national borders (FR and CH), in the vicinity of the construction site, there was a considerable risk for mobilization of contaminants resulting from groundwater extractions and drawdown of the groundwater table. Contaminated areas may have suddenly lain in the capture zones of the industrial groundwater users or within the groundwater drainage areas on the construction site. As a consequence, positions of groundwater recharge and required recharge rates were evaluated in order to maintain the groundwater flow regime to the north and to minimize remobilization or deviation of contaminated groundwater (Fig. 2).

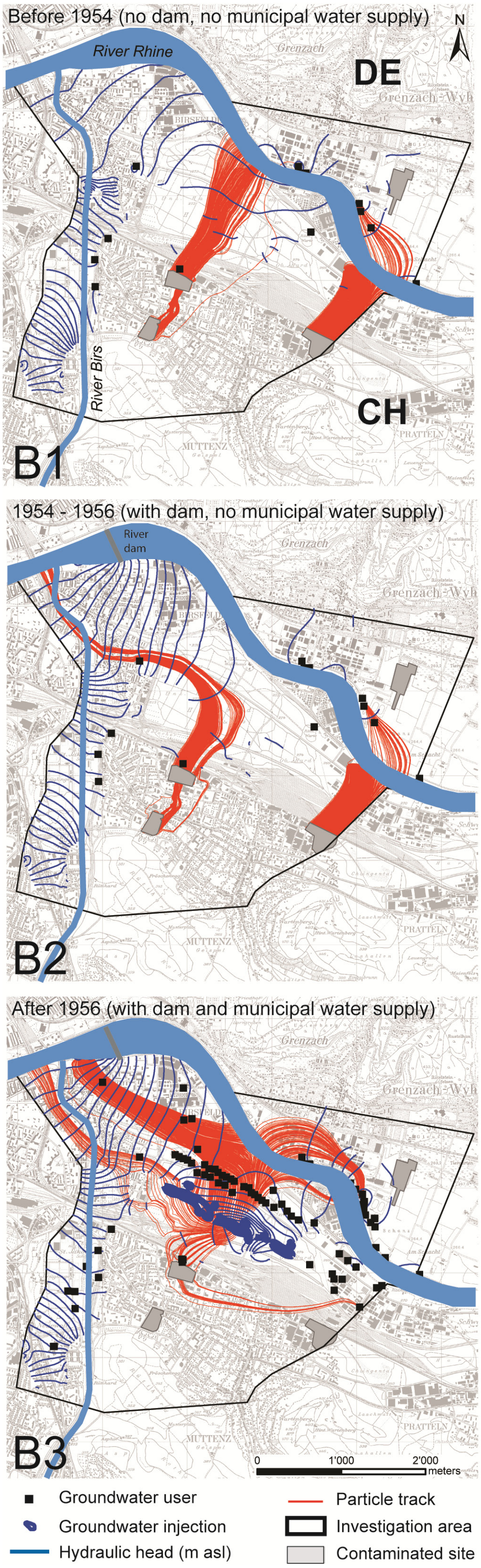

Fig. 3: Groundwater flow regimes for case study B. B1: Situation before construction of the river dam. B2: Situation with river dam and before installation of the water supply. B3: Situation with river dam and water supply.

The management system was continuously adapted, based on the progress achieved on the various construction sections or risk profile in the case of old contaminated sites. The interpretation of changes observed in groundwater quality measurements together with the modeling results allowed an optimal localization of new observation wells. The extended knowledge of groundwater flow regimes could lead to a reduction and minimization of negative effects during the various construction phases and result in a sustainable development concerning use and management the groundwater resource.

B Ancient contaminated industrial sites

In the area of the second case study important drinking water production is located in the vicinity of several contaminated sites. Aware of the risks and due to measurable pollution, the drinking water production was protected by the infiltration of filtrated Rhine water, creating a hydraulic gradient towards the known contaminated sites and towards infiltrating surface waters from the river Rhine.

A total of 72 wells, 30 of them used for industrial use and 42 as drinking water wells were integrated into a 3D numerical groundwater model. Continuous monitoring of the hydraulic head was accomplished by a total of 121 observations wells. The model was used to determine the capture zones of drinking water production wells and downstream of the most important polluted sites for different time periods with changing boundary conditions. Figure 3 shows the development of the groundwater flow regime before construction of the river dam and before the development of the water supply (B1), after construction of the river dam and the hydropower plant in the Rhine resulting in changed hydraulic gradients (B2) and after the development of a municipal water supply in the mid 19th century (B3). For each time period it is likely that part of the contaminants were retained in the subsurface according to the compound specific physico-chemical conditions. This process actually explains the large spreading of contaminants still measurable at many different locations at relatively low concentration, but sometimes with signals above the required quality standards of the drinking water guidelines. In addition the models illustrate the transboundary character of the different groundwater flow regimes over the last fifty years. It also clearly documents the fact, that in future a change of production of one key-player would likely lead to changes in water quality for other groundwater users.

As a consequence groundwater management in this area has to include all the partners across the national borders (DE and CH).

5. CONCLUSIONS

Two case studies of transboundary groundwater projects illustrate the problems of urban groundwater management. As environmental problems generally do not stop at national boundaries, the exchange of information about mayor impacts to the groundwater flow regime requires communication between the neighboring countries.

Extending current protection concepts with process-based approaches that include the consideration of nature and location of contamination in urban areas, as well as the interaction between surface and subsurface waters could enhance the sustainable development of groundwater resources. Knowledge of the composition of groundwater quality, including the consideration of variable hydrologic boundary conditions and fluctuations of contaminant loads in rivers, is therefore of great importance. Key factors in investigating contaminant transport are the relevant boundary conditions as well as their development and origin, in particularly the depth and nature, of relevant substances. Modeling results indicate that flow paths and velocities can vary considerably for the various simulated layers.

Management strategies for groundwater are confronted with enormous implementation barriers. Confidence in their success is often low, and conventional and more expensive approaches, like extensive drillings and analytical programs, are preferred. Applied and problem-oriented fields should fulfill the requirements for a more sustainable management of groundwater resources in a sensitive urban environment. The illustrated approaches can help to meet challenges posed in a sensitive transboundary urban environment. This includes the evaluation of contaminated sites, risk assessment for waste disposal as well as the parameterization of numerical groundwater models. While some of this work may be specific to these case studies, it is expected that the overall conceptual approach and the methodologies will be directly transferable to other urban and transboundary areas. Thus, this is one step towards the application of new findings to complex practical problems.

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