Assessing sewer-groundwater interaction at the city scale based on individual sewer defects and marker species distributions

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Abstract: Combining a sewer defect database and hydrogeological information it has been attempted to assess sewer-groundwater interaction at the scale of the city Rastatt (SW-Germany). Comprehensive hydrochemical samplings including a series of new marker species have been conducted in the urban aquifer and used to prove sewage exfiltration.

Key words: Urban groundwater, sewer system, sewer defects, marker species.

Introduction

Global population growth and changing climatic conditions result in water scarcity in many areas worldwide. Especially big cities are growing fast and are often located in unfavourable places. While urban aquifers are often perceived as being of lesser relevance for the drinking water supply it is on the contrary a fact that over 40% of the water supply of Western & Eastern Europe and the Mediterranean region are coming from urban aquifers. Indeed, in many regions they are the only natural resources for drinking water supply. In addition to the temporary and single event contaminations caused by spillages and accidents also leakages from defect sewer system provide a continuous source of contaminant input. The Handbook of the EU-WFD (von Keitz, 2002) is citing figures derived from Dohmann (1999) according to which exfiltration rates for the former Western Germany are in the range of 31 to 445 million cubic meters per year from public sewers. A significant plus to this figure is expected from defect private sewers. The exfiltration of wastewater can lead to raise levels of sodium, chloride, nitrogen compounds and sulphate in the aquifer (Eiswirth & Hötzl, 1997). Likewise also contaminants illegally discharged into the sewer system (e.g. trichlorethene) can enter the groundwater. In order to assess the problems of sewer-groundwater-interaction at the scale of the city Rastatt it has been attempted to use a known spatial distribution of sewer defects together with the hydrogeological boundary conditions for the estimation of the sewer-groundwater interaction. In order to validate the calculations comprehensive hydrochemical samplings including a series of new marker species have been conducted in the urban aquifer.

In this work the city of Rastatt is serving as study area. Rastatt has approximately 50.000 inhabitants and is located 30 km south of Karlsruhe in the Upper Rhine Valley, SW-Germany. The aquifer most used for drinking water supply and industrial processes is the Upper Gravel Layer beneath the urban area. Its quaternary sediments are made up of unconsoli-

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dated sand and gravel with occasional silty lenses. The aquifer is tapped downstream of Rastatt for the drinking water supply and the northern area of the city lies within the groundwater protection zone of the local water works. Recharge takes place mainly through direct infiltration, infiltration from surface water bodies (River Murg, River Rhine, numerous smaller creeks), flows from the mountain ridge of the black forest and water mains losses under the city.

RESULTS AND DISCUSSION

Infrastructure and hydrogeological boundary conditions

The evaluation of the CCTV-inspection results via the sewer defect database showed that there are a large number of defects in the sewer system through which interaction with the groundwater is possible. Within a length of 208 km sewer system (combined and separate), a total number of 31006 defects have been noticed. In detail the defects consist of 13646 damaged or improperly installed house connections, 7363 joint displacements, 4109 cracks, 2100 obstacles, 1584 root intrusions, 1563 corrosion problems and 641 other defects. While citing this information, it has to be emphasized that the city of Rastatt has an exceptionally good rehabilitation department and that these figures are describing a rather well maintained sewer network. In order to produce an environmental risk assessment of these defects it is necessary to describe the boundary conditions for groundwater-sewer interaction in detail: 1) Leak size, 2) Leak position inside the sewer (e.g. bottom or top), 3) Flow regime in the sewer, 4) Vertical position of the sewer in relation to variable groundwater level, 5) Soil or rock type in the immediate sewer surrounding and 6) Clogging and self sealing of the leaks.

Based on the individual leaks detected, an exfiltration area of 0.96 m^2 for a 475000 m^2 part of the city center has been estimated. Applying exfiltration rates from own studies as well as from VOLLERTSEN & HVITVED-JACOBSEN (2002), first approximations of the recharge to the urban aquifer are in the range of 2.88 mm a^{-1} to 5.06 mm a^{-1}. These recharge rates will be further influenced by groundwater level as a constraint for wastewater exfiltration. A significant number of sewers are located beneath the water table even in summer. For September 2001 about 13 % of the sewers were actually below the groundwater table. However these calculations have many uncertainties and can only be taken as a first guess. Much work remains to be done on the estimation of leak sizes and the exfiltration rate itself which is a strongly time transient parameter, mainly depending on the condition of the clogging layer at the leak.

Marker species distributions

For an independent direct assessment of the sewage exfiltration comprehensive hydrochemical samplings of potential marker substances in the groundwater of Rastatt have been conducted. Besides major ions also microbiological parameters, rare earth elements, DOC, boron and pharmaceutical residues were analysed.

Among the major cations Na, K, Mg and Ca none showed a pattern corresponding to the extension of the city area, where the effects of sewage exfiltration should be pronounced. The concentrations are mainly controlled by different aquifer lithology, the influence of infiltrating surface water bodies (esp. the river Murg) and different soil types which affect recharge composition. The same situation could be found for the major anions.
Elevated concentrations in the groundwater below the Rastatt city center have been found for Boron with concentrations of 60-150 µg/l while concentrations outside the city range between 11-36 µg/l. Boron has been widely used in detergents in the past and is only slowly replaced by other substances. Concentrations in the sewage range between 690 µg/l and 2066 µg/l.
Pharmaceutical residues had been found widespread in German rivers and locally also in groundwater (SACHER, 2001). However, in none of the groundwater samples in Rastatt pharmaceutical residues could be found although significant loads were present in the wastewater (s. Tab. 1). One soil water sample taken from a suction cup (SK7) beneath a sewer leak showed bezafibrate concentrations of 440 ng/l but the groundwater of observation well GWM 6 in a distance of 4 m to the suction cup showed no concentrations above the detection limit. It is reasonable to assume that the pharmaceutical residues have been subject to microbiological decomposition and adsorption effects on their passage through the unsaturated zone. Another explanation might be that the leakage rate is too small and the dilution with the unaffected groundwater is lowering concentrations below the detection limits.
In contrast to the pharmaceutical residues the iodated x-ray contrast media proved to be useful thanks to their high persistivity (BAUS, 2002, TERNES & HIRSCH, 2000) in the aquatic environment and to the uniqueness in their use. Elevated concentrations in the Rastatt city center have been measured for the iodated contrast media amidotrizoic acid (66 ng/l) and iothalamic acid (72 ng/l). At the inflow of the wastewater treatment plant to concentrations of 610 – 930 ng/l iothalamic acid and 840-1200 ng/l amidotrizoic acid were measured in the wastewater. Considering that the natural concentration of iodated X-ray contrast media in groundwater is zero and assuming that iodated X-ray contrast media are conservative this would indicate a percentage of wastewater in the groundwater in the range between 5 and 12 %. However the concentrations of iodated X-ray contrast media in the sewer close to the groundwater observation well might be significantly higher than at the wastewater treatment plant and some natural background might be given from infiltration of anthropogenic influenced river water.

CONCLUSIONS

The combined infrastructural and hydrogeological risk assessment of the sewer system in the case study city Rastatt has shown significant potential for sewer-groundwater-interaction. CCTV-observations have been used for the assessment of the exfiltration potential based on individual defects. It has to be noted that CCTV inspections cannot directly assess the water tightness of the sewer and can lead to an underestimation of leaks. The hydrogeological constraints on sewage exfiltration have been identified and stored within a geographical information system. The acquired database now allows better positioning of

groundwater observation wells, which is essential for assessing the hazard potential of sewer leakages. It is recommended for each city using CCTV inspections to store the results in similar databases, which link infrastructure and environmental information.
A variety of marker species has been tested for their applicability in the urban aquifer of Rastatt. While the rare earth element gadolinium and pharmaceutical residues produced no hints on major sewage exfiltration in Rastatt it was possible to analyze iodated x-ray contrast media in 5 of 8 groundwater wells with maximum concentrations of 66 ng/l amidotrizoic acid and 72 ng/l iothalamic acid. Compared with concentrations in the sewage this points to a percentage of approximately 5-12 % sewage in the groundwater at this spot. Elevated concentrations of boron in the city center further corroborate these findings.
Future research must lead to more precise estimations of exfiltration rates, quantification of leak sizes from CCTV-inspections and more extensive sets of marker species data.

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