The impact of river water on groundwater quality in an urban floodplain area, the Lobau in Vienna

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Introduction

River bank filtration is a sustainable means to improve the quality of surface water for drinking water use. It is based on percolation of river water through the ground into the aquifer enhanced by the pumping in drinking water wells close to the river bank. About 60% to 97% of the water supplied by the Lobau drinking water wells is originating from the Danube River. During the percolation processes potential contaminants from the surface water are removed by filtration, adsorption, reduction and biodegradation (Chittaranjan et al. 2002; Tufenkij et al. 2002). The capacity of self-purification depends mainly on flow velocity, hydraulic residence time and the covered distance determined by the permeability and the hydraulic potential in the aquifer.

Especially close to large urban areas drinking water needs lead to an efficient use of existing resources nearby, mainly along the rivers draining the respective areas. Also for Vienna, although supplied to high portion by alpine originated water, river bank filtration along the Danube River is an important source of drinking water. One of these areas is the *Lower Lobau*, a floodplain located along the Danube River in Vienna extending on a length of 8 km and a width of 2-3km. This floodplain provides a wide range of socio-economic and ecological services, including recreational values, flood retention capacity, groundwater recharge and drinking water supply for the metropolitan area Vienna.

Since the major regulation of the Danube River in the late 19th century the floodplain *Lobau* is partly disconnected from the riverine dynamics. So the groundwater became the dominating connection to the river (Griebler & Mösslacher 2003). Only during flooding the area is inundated by back-flooding. Thus, the groundwater recharge is mainly based on bank filtration, which is used for drinking water supply since 1966. The rate of infiltration is controlled by the riverine water levels and the intensity of pumping (Danielopol et al. 1997) Because of this interdependency any changes in the hydrological exchange are thought to affect quantity and quality of groundwater resources.

Thus, the main focus of this work is on processes affecting groundwater quality in the *Lobau*. Therefore, the relationship between groundwater quality and the distance to the main-channel and the respective water level is analysed by multivariate statistics. A general characterization is done by a Principal Component Analysis, based on chemical water quality data of six groundwater monitoring stations in the period between 1992 and 2005. The spatial distribution of quality data along a transect is shown by a Multiple Scatter-Plot comparing

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data from surface water in the Danube River, its backwater and five groundwater monitoring stations in the *Lobau* dependent on different water levels.

Methods

A selection of hydro-chemical data from six groundwater monitoring stations was available in the floodplain *Lower Lobau* (Fig. 1). Five of them were installed close to the drinking water wells between the Danube river bank and the backwater, a former side-arm of the Danube River. The sixth monitoring station was located on the northern bank of the backwater. They all offered a time series of hydro-chemical data with a frequency of four sampling dates a year during the last 13 years. Thus these data comprise a highly representative and statistically comparable data set.

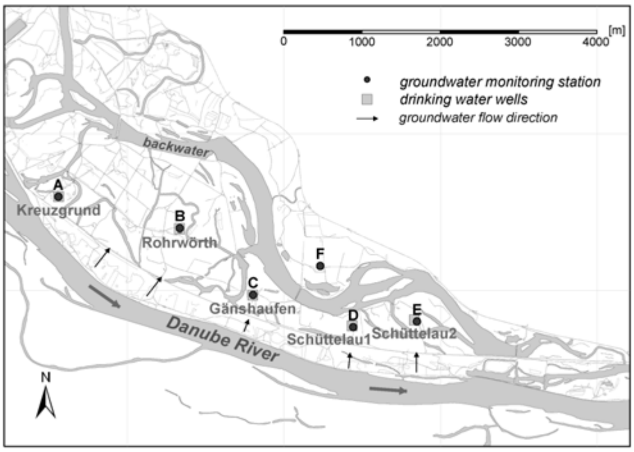

Fig.1: Groundwater monitoring wells floodplain Lobau and the dominant groundwater flow direction

The main flow direction of groundwater infiltrating is indicated by the arrows in Fig. 1 driven by the hydraulic potential between the Danube and the groundwater level.

For an identification of the main factors integrated in the data a Principal Component Analysis (PCA) was used. The PCA concerned twelve parameters to characterise the substantial pattern as a result of diverse exchange processes in the aquifer. The used parameters contained ions (electrical conductivity, HCO_3, Ca, Cl, K, Mg), nutrients (NO_3, PO4), redox parameters (SO_4, Fe, Mn) and dissolved organic carbon (DOC). Other parameters had to be excluded because their data were under the detection limit or had not been sampled frequently.

For the investigation of the bank filtration processes depending on the distance to the Danube, a Multiple Scatter-Plot was used. The data have been pooled in three water level classes (low, medium and high) and the median was calculated for each class. The Scatter Plot contained data from the five groundwater monitoring stations close to the drinking water wells and two surface water monitoring stations; one in the Danube River and one in the backwater.

Results and Discussion

Tab. 1: Matrix of the PCA of groundwater quality data

	1 Major Ions	2 Major Ions	3 Red-Ox Parameters	4 Surface Water Influence
HCO_3	0.93			
Mg	0.77			
Ca	0.76			
NO_3	-0.70			
elec. conduc.	0.64	0.58		
Cl		0.81		
SO_4		0.76		
K		0.50		
Fe			0.75	
Mn			0.73	
DOC				0.73
PO_4				0.57
N=288; measure for sampling suitability according to Kaiser-Meyer-Olkin: 0.68				

The PCA reduced the parameters to four components, which were summarised as three major groups. The first and second component showed an overlap at the parameter electrical conductivity (EC) (Tab. 1). The sampling suitability of 0.68 was adequate according to *Kaiser-Meyer-Olkin (KMO)*. All components together captured 66 % of the total variance of data (Tab. 2).

Tab. 2: Explained variance of the PCA of groundwater quality data

Rotated sum of the squared loadings		
component	**% of captured variance**	**% of captured variance cumulated**
1	**26.54**	**26.54**
2	**18.43**	**44.97**
3	**11.63**	**56.60**
4	**9.46**	**66.06**

Component 1 and 2 captured 45 % of the total variance and can be constituted as *Major-Ions*, because they combined bicarbonate (HCO3), calcium (Ca), magnesium (Mg), chloride (Cl), potassium (K) and electric conductivity (EC). Furthermore nitrate (NO_3) and sulphate (SO_4) were included. Whilst nitrate was loading negatively with the first component, sulphate was loading positively with the second one. The negative correlation of nitrate implied that the concentrations of the major ions and sulphate were increasing whilst nitrate was decreasing during the aquifer passage. The explanation was found in reduction processes. Due to the advancing oxygen consumption in the aquifer nitrate was partly reduced while sulphate was not quantitatively affected by microbial reduction processes. These findings were supported by redox-potential values ranging from 250 to 550 mV in the *Lobau*, which is not enough reduced for a dominant sulphate-reduction (Hölting 1996).

The third component was constituted as *Redox-Parameters* containing iron (Fe) and manganese (Mn), two of the main redox-parameters under anaerobic conditions. They captured 12 % of the total variance. Obviously, redox-processes had not a high but significant relevance in the aquifer. Thus, changing manganese and iron concentrations represent the minor portion of reduction processes in the aquifer whilst nitrate is correlated negatively with the *Major-Ions* concentrations, due to its comparable higher reduction rate.

The last component explained 10% of the total variance and consisted of phosphate (PO_4) and dissolved organic carbon (DOC). Both substances are characteristic for inputs from *Surface Water*. So they represented the substantial influence of surface water of the Danube River and partial the backwater infiltrating and controlling the groundwater quality.

The effects of back-flooding were negligible for groundwater quality. Because of its short-term occurrence it is less relevant for groundwater quality close to the drinking water wells. A direct seeping of flooding water into the considered groundwater–monitoring stations can be excluded for the observed samplings, because there were no significant changes of ground-water quality in times of back-flooding.

On the next step the dependency of groundwater quality on increasing distance from the river bank and changing water levels in the Danube was investigated. To demonstrate the characteristic changes in the substantial pattern from surface water to groundwater the distribution of bicarbonate, dissolved organic carbon and oxygen concentration was plotted from surface to groundwater along an idealised transect (Fig 2.). These exemplary parameters were chosen to show the difference of effects on bio-reactive and chemical-reactive parameters during percolation from the surface water into the aquifer. The three symbols represent the median of quality data at high (▲), middle (●) and low (▼) water levels in the Danube.

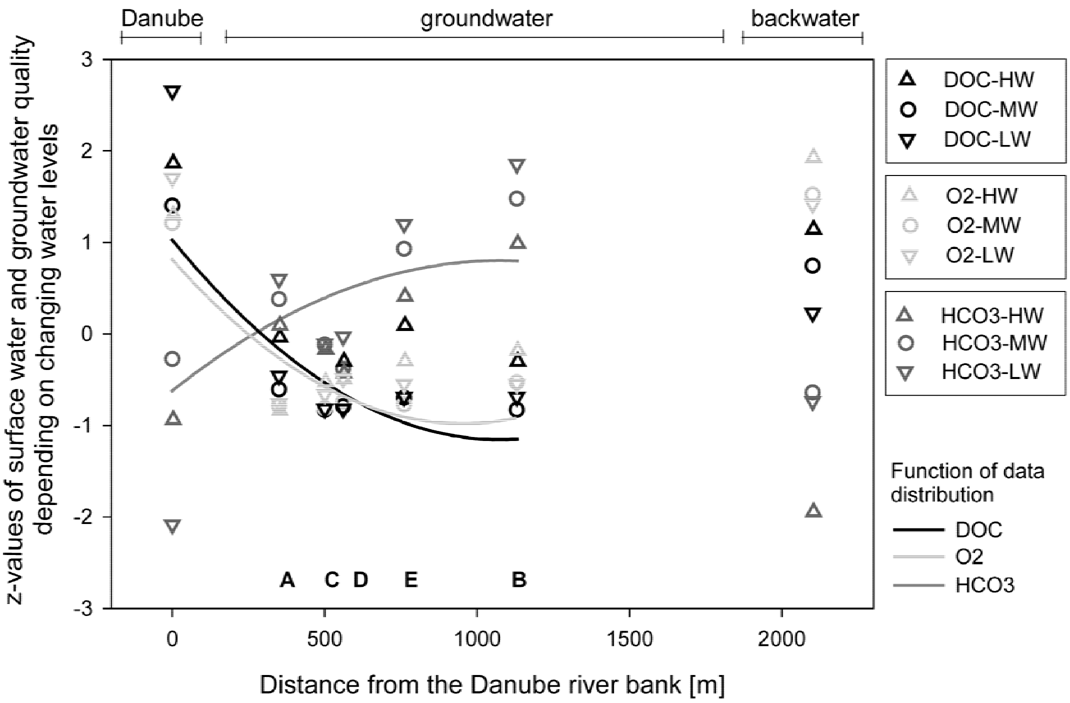

Fig. 2: Distribution of data in surface water and groundwater depending on distance from the Danube river bank and the changing water levels (HW: high water, MW: mean water, LW: low water)

Dissolved organic carbon and oxygen were higher concentrated in surface water than in groundwater, in contrast to bicarbonate. Obviously, the oxygen concentrations were decreasing with the DOC-degradation. The bicarbonate-ion concentration was increasing due to solution processes in the aquifer and decreasing dilution effect of infiltrating surface water. Furthermore, the change in concentration seemed to depend on the chemical characteristics of carbonates in water. Whilst the significant decrease of DOC-concentrations happened on a distance of maximal 400 m from the river bank, the increase in bicarbonate reached at least 1000 m because of the comparable slow carbonate to bicarbonate equilibrium (Fig.2).

The trend of hydro-chemical changes during bank filtration in the Lobau from the Danube to the backwater was described by the following functions:

Whilst *reactive* parameters had been decreasing due to filtering, reduction or biodegradation processes the concentrations of *non-reactive* parameters were increasing in the aquifer and diluted by the infiltration of surface waters (Sánchez-Pérez & Trémolières 2003).

The changing water levels in the Danube River affect the velocity of the groundwater passage and the intensity of processes. At low water-levels the concentrations of ions in groundwater increased, because there was less dilution of infiltrating surface waters (Sánchez-Pérez & Trémolières 2003). Thus, the maximal values of ions in the scatter plot were an effect of low water levels in the Danube (▼). In contrast, nutrients and dissolved organic carbon showed their maximal concentrations in groundwater at high water levels (▲), because of the higher potential of infiltration in the aquifer. Another aspect in the scatter plot is the declining variability in groundwater quality with increasing distance to the surface-waters. Obviously, the influence of surface water on the groundwater quality is decreasing with increasing distance from the river bank (Fig. 2).

Summary

The results of the statistical analysis offer an overview of the main processes being responsible for the characteristics of groundwater quality in the Lobau. The PCA shows that an important factor is the character of the aquifer itself because nearly half of the variation in groundwater quality (45 %) is dependent on the ionic strength in the aquifer. A much smaller amount depends on redox activity represented by manganese and iron (12 %) and organic and nutrient concentration of infiltrating surface water (9 %).

The scatter plot shows the spatial distribution of the groundwater quality compared to surface water quality. Mainly, the groundwater quality close to the river bank of the Danube is affected by quality changes due to bank filtration. On the groundwater flow path the effects of surface water fluctuations decrease with increasing distance from the river bank due to dilution, adsorption, reduction and biodegradation processes. Depending on the chemical properties of the considered parameter, the effects of infiltrating surface water can be measured in varying distances. The reactive parameters like DOC and redox-parameters are reduced quickly in the first few meters in the ground. In contrast the balance between dilution by surface waters and solution in the aquifer of major ions like bicarbonate needs a longer distance from the riverbank.

Furthermore, the variability of the concentrations in groundwater is depending on changing water levels in the Danube, because high water levels lead to high infiltration potentials from the Danube and less time for purification processes due to shorter residence time in the aquifer. In contrast the effects of back-flooding during high water levels are not significant.

So the temporal (residence time) and spatial dimension (distance of flow path) of the aquifer passage is determining the balance in groundwater quality for its use as drinking water. In the *Lower Lobau* groundwater quality is mainly dependent on the aquifer`s material and the quantity and especially quality of the infiltrating surface water from the Danube River.

Acknowledgements

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