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title: **Optimizing a monitoring concept for a Riverbank Filtration Site**

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INTRODUCTION

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 behavior 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 maximum safety as well as efficiency in well field and treatment plant operation.

At an existing RBF site an extensive monitoring program which was executed in the past 15 years was analyzed. The main purpose of this work was to identify potentials for reducing effort and costs while assuring a level of information that satisfies legal requirements as well as demands for risk and operation management. The general concept of the monitoring program at this site is to treat the catchment as a part of the multi-barrier system in the drinking water production process. The potential of the soil and the surface water body to remove or reduce undesired substances from water present barriers and monitoring can be considered as a tool to manage the function of these barriers. This concept was retained. However, the analysis of the existing data led to a re-evaluation of sampling frequencies and parameters of the monitoring system and, eventually, to adjustments. To guarantee a high level of objectivity, statistical methods were applied where possible.

SITE DESCRIPTION

The waterworks Torgau-Ost is located at the River Elbe in Saxony, Germany. Its catchment, consisting of 42 vertical wells, stretches over a length of about 6 kilometres along the southwest bank of the river (Fig. 1).

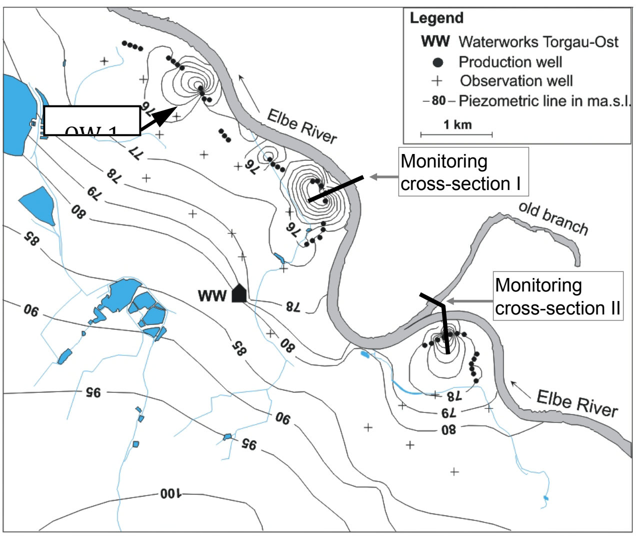

Figure 1. Catchment of the waterworks Torgau-Ost (Grischek, 2003).

The average distance between the wells and riverbank is 300 m. The aquifer with an average total thickness of 50 metres is formed by Pleistocene deposits overlain by Holocene river gravels and covered by a top layer of meadow loam (Grischek et al., 1998). It can be considered as a three-layered aquifer with varying geohydraulic properties. The hydraulic conductivities of the rather thin upper and lower aquifers are significantly higher than the conductivity of the dominating middle aquifer (Fig. 2).

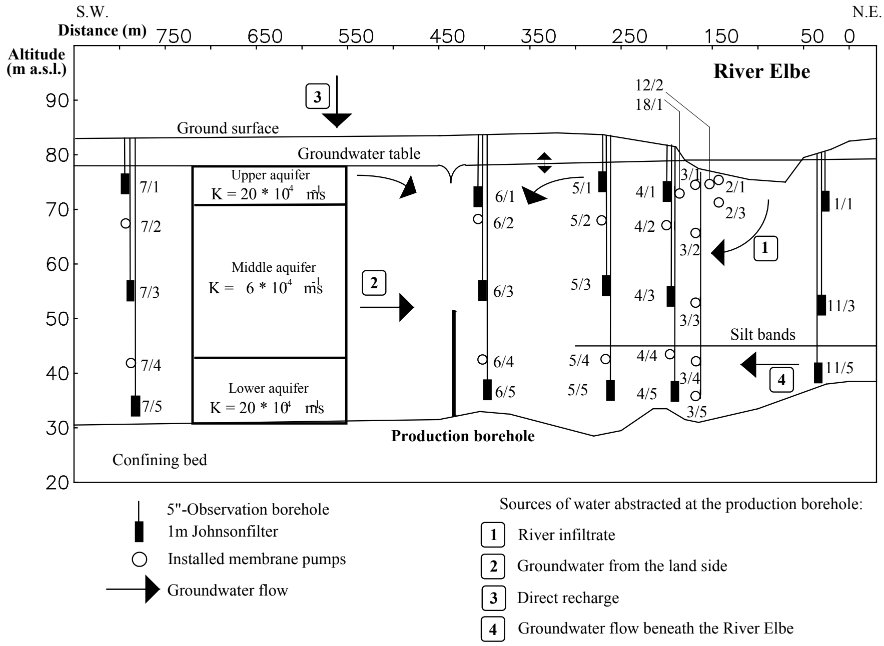

Figure 2. Monitoring cross-section 1 (Grischek et al., 1998).

Overall production rates of the waterworks usually vary within the range of 50000–80000 m^3/d with single well abstraction rates of approximately 150 m^3/h. The maximum production capacity exceeds 100,000 m^3/d. Depending on operational regime and river stage, bank filtrate can account for 20 to 60 % of the abstracted raw water. A significant groundwater flow beneath the river also has been found in field investigations and by numerical groundwater flow modeling as well.

MONITORING DATABASE

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 120 observation wells had been installed across the entire catchment area (Fig. 1 and 2) on both sides of the river Elbe. Among these two monitoring cross-sections to observe the flow of bank filtrate (Fig. 2) allows for depth-oriented water sampling. During the past 15 years a substantial database has been generated. Data resulted from regular measurements of water table and in-situ parameters, water 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.

GENERAL MONITORING CONCEPT

The general concept of monitoring at this RBF site was designed according to the monitoring principles as applied at contaminated sites. Its structure is shown in Fig. 3.

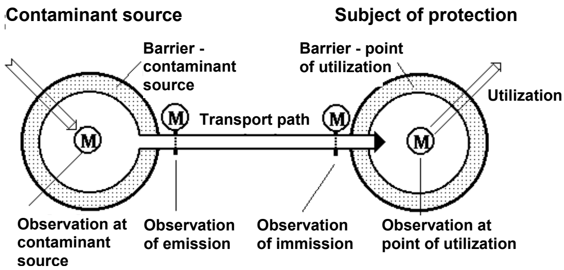

Figure 3. General structure of the monitoring of a potential endangering contaminated site (Nestler, 1999).

At a RBF site there exist basically two potential sources of endangering contaminations, namely diffuse and point contamination sources on the land-side and the river as a linear source for constant or temporary highly concentrated contamination. On the land-side the covering loam meadow and the aquifer itself act as barriers, whereas the topsoil is substituted by the river and its capacity for self-cleaning, dispersion and dilution processes on the bank filtrate side of the catchment. For the abstracted water the treatment in the waterworks presents the final barrier in drinking water production. The refinement of the elements of the monitoring structure, as presented in Fig. 3, lead to a modified structure for a RBF site as given in Fig. 4.

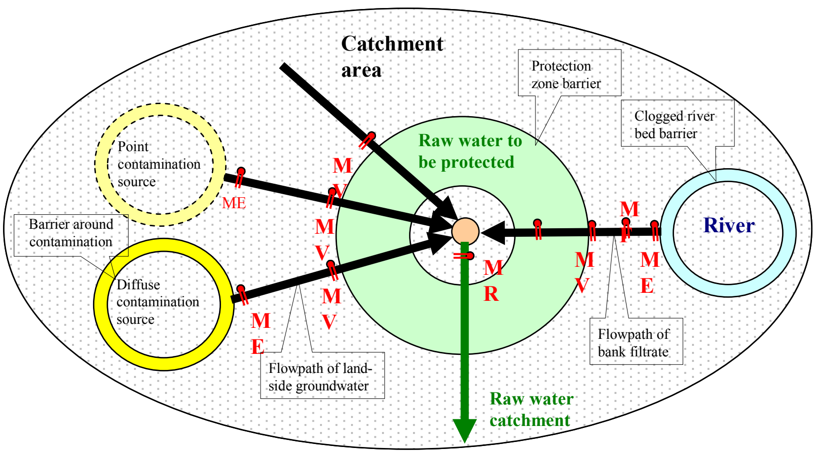

Figure 4. Structure of the monitoring of a RBF site (Grischek et al., 2010).

The observation points, as named in Fig. 4, are distinguished according to their relevance for the water supplier:

- MR — observation of abstracted raw water,
- MV — observation for early warning at boundary of protection zone of catchment,
- ME — observation at point of emission of contaminant,
- MF — observation of impact of operational actions on raw water quality.

DATA ANALYSIS

A 3-D groundwater flow model for the catchment of the waterworks Torgau-Ost was provided by the water company and used to determine the residence times of groundwater from each observation well to the production wells for average abstraction rates. Based on the residence times and considering a minimum advance warning time of 1 year, as well as a minimum sampling frequency of 2 years for maintenance reasons, sampling frequencies could be enlarged. Existing data sets were used to prove the sufficiency of longer sampling intervals. Trends derived from total sets of data (all samples included) for significant parameters were compared to the trends which result from a decreased number of samples, considering only the samples that would have been taken when applying the newly defined sampling intervals. No significant deviations were found. An example is given in Fig. 5.

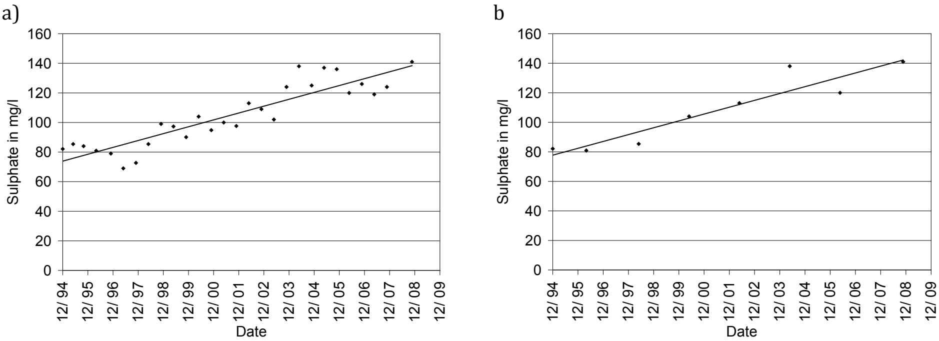

Figure 5. Trend for sulphate concentration in observation well OW 1 (see Fig. 1) from a) all samples; b) decreased number of samples.

Descriptive statistical parameters, mean and median value, standard deviation, minimum, maximum, and 10% and 90% percentile were used to identify parameters which showed constantly negligible or acceptable concentrations. For these parameters low input and/or sufficient protection by the mentioned barriers can be assumed. Hence, they were removed from the parameter spectrum for the regular monitoring and will be checked only randomly.

For the parameters nitrate, sulphate, DOC and iron a linear regression analysis was conducted to identify significant linear trends at a 95 % level of significance. Furthermore, trends were evaluated visually to classify them according to the trends shown in Fig. 6. Both procedures served the purpose of identifying trends which require further attention due to unexplainable behaviour or strongly increasing concentrations.

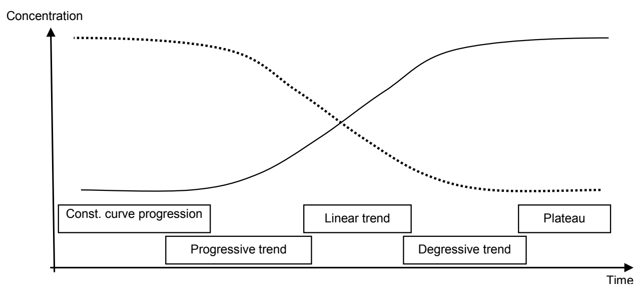

Figure 6. Schematical trend curves.

The two existing monitoring cross-sections (Fig. 1) were compared and tested for supplementary information with regard to the aims of the optimized monitoring program. For observation points at comparable distances to the riverbank, concentration curves of significant parameters and curves of in-situ parameters, such as temperature and electric conductivity, were compared to evaluate residence times of the bank filtrate and degradation rates. It was shown that additional information derived from the second monitoring cross-section was not relevant for monitoring purposes. Thus, the second cross-section, which was built for RBF research, could be excluded from regular monitoring.

Table 1. Example of results (significantly decreasing trends and visual evaluation).

Observation well	Depth	Parameter	Mean M [mg/l]	Standard deviation s [mg/l]	Annual decrease [% of M]	Visual evaluation of trend
G_506	upper	Sulphate	259	78.4	–5.0	Linear
	medium	DOC	3.0	0.24	–1.2	Linear
G_508	upper	Sulphate	297	80	–5.1	Degressive (decreasing, Plateau: 200 mg/l)
G_512	medium	Iron	3.76	2.65	–9.7	Degressive (decreasing, Plateau: 3 mg/l)

MONITORING OF TEMPORARY RIVER POLLUTION

The possible case of a contamination of the river water due to accidents requires special consideration. Because of the short residence times of the riverbank filtrate of < 100 days in the upper layer of the aquifer, spills present the highest potential risk for the catchment. That is why a monitoring and evaluation strategy was developed, including additional experiments and modeling to be conducted to support the risk evaluation based on monitoring results (Grischek, 2003). The basis of this concept is an event-based sampling of the water beneath the riverbed using membrane pumps (see 2/1, 2/3, 12/2 in Fig. 2).

CONCLUSIONS

The multi-barrier concept has been demonstrated to be a useful base for a monitoring program at a RBF site. Groundwater flow modeling and statistical data analysis are essential tools for an objective evaluation of an existing monitoring program. At the waterworks Torgau-Ost, a significant reduction of monitoring effort and costs was achieved and the sufficiency of information gained was proven. Furthermore, an action plan for the case of river water pollution was developed to provide efficient monitoring and evaluation of the impacts on the catchment. The modification of the monitoring program does not lead to a static schedule of sampling but must be considered as a dynamic process. Monitoring results will be continuously reviewed and in case of divergent tendencies, the monitoring program modified.

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