River Bank Filtration: A Sustainable Water Supply Option

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Abstract

River bank filtration (RBF) is a water treatment technology that consists of extracting water from rivers by pumping wells located in the adjacent alluvial aquifer. During the under ground passage, a series of physical, chemical and biological processes take place, improving the quality of the surface water, substituting or reducing conventional drinking water treatment. Several mechanisms are responsible for improvement of water quality during RBF. During infiltration and travel through the soil and aquifer sediments, surface water is subjected to a combination of physical, chemical and biological processes such as filtration, solution-precipitation, ion-exchange, sorption-desorption, complexation, redox reactions, microbial biodegradation and dilution that significantly improve water quality. Despite its extensive use in Europe and its emerging use in the United States, there are not much scientific publications related to RBF use in India. The broad objective of this paper is to present the current understanding of the processes and mechanisms of the technique, its benefits and limitations to explore the potential of the technique as sustainable water supply option. The efficiency of RBF depends on local conditions including the hydrology and hydrogeology of the site, the geochemistry of water (from both the river and the aquifer), the geochemistry of microbial populations and associated metabolic activity. This is the reason why it is difficult to define general procedures for identifying appropriate sites to implement the RBF technique, as well as the expected efficiency of the process.

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1. Introduction

River bank filtration (RBF) is defined as the process for producing drinking water, where river water is induced to flow through riverbed to pumping wells located on the banks of the river. During the passage of this water through the riverbed and aquifer, dissolved and suspended contaminants as well as pathogens are removed due to a combination of physical, chemical and biological processes that take place between the surface water, ground water and with the substrate. Bank filtration has been of main importance for the drinking water supply in Germany for many decades. Induced recharge has demonstrated in Europe, in the past 100-150 years, to be a very vital technique of collecting high quality raw water for drinking water preparation, with many advantages (Van der Kooij et al., 1985; Sontheimer, 1991; Ray et al., 2001; Jülich and Schubert, 2001).

The water quality of pumped raw water from bank filtration sites depends to a high degree on the water quality of the infiltrating surface water and the landside groundwater, the mixing portion of both as well as the flow and transport conditions in the aquifer. Since the improvement of river water quality and a drastic decrease in water demand during the last 15 years in Germany, the influence of landside groundwater quality has become more important for the raw water quality of waterworks relying on bank filtration (Grischek et al., 2009).

The reduction of pollution levels is accomplished by a number of processes including physical filtration, microbial degradation, ion exchange, precipitation, sorption and dilution (Ray et al., 2002). Other factors that also contribute to the treatment are: the river water and the ground water quality, the porosity of the medium, the water residence time in the aquifer, temperature and pH conditions of water, and oxygen concentrations (Kuehn and Mueller, 2000).

In drinking water production, river bank filtration has the advantages of dampening peak concentrations of many dissolved components, substantially removing many micro-pollutants and removing, virtually completely, the pathogens and suspended solids. The production aquifer is not only fed by the river bank infiltrate but also by water percolating through covering layers (de Vat et al., 2010). The paper discusses the origin and fate of macro components in river bank filtrate, based on extensive full-scale measurements in well fields and treatment systems of the Drinking Water Company Oasen in the Netherlands. The raw water at the Oasen Drinking Water Company consists of a mixture of two water types, polder water and river bank filtrate, which have distinct differences in composition, related to their redox levels.

Despite the high potential, RBF technology is not being practiced by water utilities in developing countries mainly because the BF system design is site specific and until now designs are based on local experiences. There is lack of knowledge about the mechanisms and processes involved and there are no tools, frameworks or design guidelines available to apply this technology under given local hydrogeological conditions or to transfer the experience from one region to another. Sharma and Amy (2009) described potentials and constraints of promoting river bank filtration technology for water treatment in developing countries based on the results of two feasibility studies conducted in Malawi and Kenya. They have further reported that following activities should be implemented to help in promoting RBF technology for water treatment in developing countries.

- Development of design guidelines, monographs, software, and a decision support system for application of RBF technologies in the developing countries
- Including and officially recognizing RBF as a viable technology for water treatment
- Information dissemination: making design engineers, planners and educators aware of the potentials of RBF technology (training and capacity building; demonstration projects)
- Networking among the professionals involved in RBF (at international, regional and national level) for information sharing and collaborative research.

2. RBF Process Description

In principle, RBF occurs when a well is placed sufficiently close to a river and part of the surface water is induced to flow underground towards the cone of depressions caused by the pumping well (Fig. 1). During ground passage, the water quality parameters change due to microbial and physical-chemical processes (Partinoudi, 2004). After river water infiltration is intercepted by collection wells, the riverbank filtrate requires additional treatment steps before it can be pumped to the distribution system.

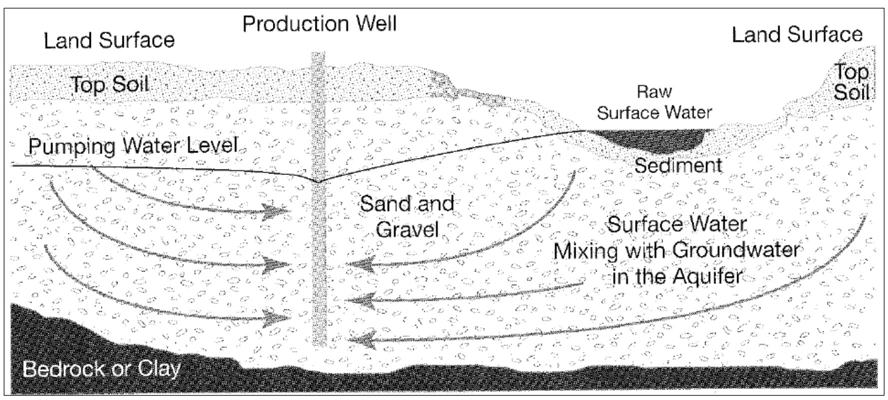

Fig. 1. Generalized Schematic of an RBF System

According to Heij (1989) most contaminants are degraded within the first few centimeters of their path through the subsoil, but others are persistent and mobile and may move over longer distances within the aquifer. Generally, two major areas during subsurface passage can be designated:

- a biologically high-active infiltration and clogging zone, where intensive degrading and sorption processes take place

- the successive subsurface passage, with lower degrading and sorption rates and an increasing impact of dilution processes

The first part of the flow-course within the subsoil passage is the so called clogging zone - a thin layer at the interface between river water and riverbed characterized by intensive physical, chemical, and biochemical processes. Analyses have shown that an immense part of the cleaning capacity takes place here (Grischek, 2003).

Clogging leads to the reduction of the permeability, and thus a decrease in the infiltration rate (Grabs, 1981). Permeability can be increased again by the self-cleaning power of the river itself. The self-cleaning capacity of a river depends chiefly on the runoff regime, characterized by amount, frequency, length, time and rate of change of runoff conditions (Schubert, 2007).

After passing the biologically high-active infiltration zone, surface water mixes with adjacent groundwater. Dilution with ground water improves the infiltrated surface water quality because groundwater is usually a source of higher quality. In addition, dilution compensates for temperature peaks and provides protection against shock loads (Kuehn and Mueller, 2000).

In most cases there is a flow of oxygen-rich surface water into the subsurface environment, but it is common for dissolved oxygen to be completely used up by aerobic microorganisms at some distance from the infiltration zone (Partinoudi, 2004).

Without oxygen, a change from oxidizing to reducing conditions can favor the effect of heavy-metal remobilization of metals such as iron and manganese (Grischek, 2003). On the other hand, anoxic conditions (no dissolved oxygen) help in the removal of river water nitrate through anaerobic microorganisms.

After subsoil passage, the mixture of both groundwater and infiltrated surface water is intercepted by collection wells. The collection wells can employ horizontal laterals or be vertical wells. The laterals may or may not extend under the riverbed, depending on pumping needs, the available budget of the utility and local geohydrological conditions (Partinoudi, 2004).

After extraction, bank filtrate is usually treated depending on the bank filtrate quality, whereby the quality determines the additional treatment steps required in order to produce good-quality drinking water (Kühn, 1999).

At a minimum, RBF acts as a pre-treatment step in drinking water production and, in some cases, can serve as the final treatment just before disinfection (Bourg et al., 2002).

3. Attenuation Processes During RBF

Four attenuation processes are involved in RBF: i) hydrodynamic, ii) mechanical, iii) biological, and iv) physicchemical (Doussan et al., 1998).

Hydrodynamic processes include convective-dispersive transport and dilution. The aquifer acts as a filter for the temporal variation of the pollutant compounds in the river caused by accidental (or intentional) spills, which, due to the connection between the river and the aquifer, represent a risk of contamination to the ground water. As a result, high frequency variations in the surface water quality are reduced in ground water. Beyond smoothing fluctuations in river water quality, dilution takes place when the river water mixes with ground water, which is usually of higher quality, further enhancing the quality of bank filtrate (Doussan et al., 1998).

The most important mechanical processes for the improvement of water quality are those involving the natural filtration of fine sediments, particulate organic matter and pathogens, especially in the first few meters from the river to the well (Doussan et al., 1998; Hiscock and Grischek, 2002).

The biological processes that occur during RBF are directly dependent on the type of microorganisms that inhabit the aquifer (Doussan et al., 1998, Gollnitz et al., 2005). The metabolic processes of these microorganisms mainly determine the final quality of filtered water.

Finally, physic-chemical processes are associated with sorption, precipitation reactions, flocculation, coagulation and redox reactions (Doussan et al., 1998). All these processes govern the removal of particles from the porous media, affecting the concentration and the behavior of metals and other inorganic compounds, thus having implications for the chemical evolution of water.

4. Advantages and Limitations

Advantages with respect to direct surface water treatment are: a) elimination of suspended fine particles with the attached pollutants, b) strong reduction of quality fluctuations, and c) strong quality improvement by elimination of heavy metals, organic micro-pollutants, bacteria and viruses.

Disadvantages are: a) the impossibility of completely impeding the river to infiltrate when this would be episodically desirable because of a bad quality; b) geochemical reactions of the infiltrate with sludge and aquifer materials that raise the concentrations of notably Fe^{2+}, Mn^{2+}, As, NH_4^+, CH_4, Ca^{2+} and HCO_3^-; and c) risks on a cumbersome clogging of the river bed. Another limitation associated with RBF is the obstruction or clogging of the porous media. There are four types of clogging: mechanical, physical, biological and chemical.

5. Conclusion

For quantitative and qualitative management of a river bank filtration system, catchment zone, mixing proportions in the pumped raw water, flow paths and flow velocities of the bank filtrate need to be known. Although water from a properly designed RBF plant has the general advantages of ground water, there are some drawbacks. First of all, persistent micro-pollutants present in the river water eventually reach the production wells, although high concentrations are effectively reduced by adsorption, biological breakdown and residence time variation. The latter applies to peak concentrations in the river water, which are reduced in the well by blending with earlier and later infiltrated water containing lower micro pollutant concentrations. These remaining substances need to be removed by specific techniques in the treatment plant.

The efficiency of RBF depends on local conditions including the hydrology and hydrogeology of the site, the geochemistry of water (from both the river and the aquifer), the geochemistry of microbial populations and associated metabolic activity. This is the reason why it is difficult to define general procedures for identifying appropriate sites to implement the RBF technique, as well as the expected efficiency of the process.

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