Experiences with riverbank-filtration on the Szentendre Island (Danube River, Hungary)

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Abstract: - The objective of this study is to present the benefits and the incidental disadvantages of riverbank-filtration. Our purpose is to describe the hydraulical relationship between the hydrological and water quality parameters of the Danube River and four well-sections (Kisoroszi, Tahi I., Sziget-II., Balpart II.), based on data collected between 1990 and 2006. First, we have compared water quality variables of the river to the hydrological and hydrometeorological parameters (e.g., runoff, water and air temperature). A weak correlation has been observed between runoff and other water quality components, however our results indicate that temperature has a strong effect on water quality. In order to estimate the time it takes for water to get into the wells through the riverbank, we have correlated water quality parameters taken from the river to those measured in wells assuming a retention time of 0-3, 4-7, 8-11, 12-15, 16-20 days. The Sziget II. well-group is the nearest to the river (20-30 m), therefore retention time of water is significantly shorter than in the case of the Kisoroszi wells, which have a distance from the river of about 100 m. We have also observed that the water parameters of Sziget II. wells indicate the shortest transport time (4-6 days), whereas the Kisoroszi reservoir is characterized by the longest flow and transport time (16-20 days).

Key-Words: - riverbank-filtration, river-aquifer interaction, drinking water, water quality

1. Introduction

Infiltration of river water to an adjacent aquifer is a natural phenomenon, which affects the most important source for communal and industrial water supply in some of the densely populated European regions (for instance the Lower-Rhine and the Hungarian Danube-Bend [Fig. 1.]). This is a very cost-effective and the only natural method to remove contaminants from raw river water. The infiltration layer on the boundary of water and riverbed can be characterized as an active biofilm, which has an intensive purifying efficiency. The contaminant removal potential of this layer and the adjacent 10-15 m thick aquifer depends on several factors such as river water quality, hydrological, geological and geochemical conditions. We have paid special attention to these factors in order to extend our knowledge on this very topical theme.

2. General statements

2.1. Significance of riverbank-filtration in drinking water supply

The first water utility in Hungary, which used bank-filtration for water supply, was built in the seventies-eighties of the 19th century – a few decades after the first Western European attempts. These wells are operating even today and are producing drinking water of the finest quality.

Some of the European countries have strong experience in utilizing this process for water treatment (e.g. Germany, France, Switzerland). In regions, such as the ones along the Rhine and the Danube rivers riverbank-filtration is a commonly utilized natural phenomenon. For instance, in the Lower-Rhine-Region of Germany the total amount of bank-filtered water used for public water supply is 250 million m^3/yr. The analogous number for central Hungary is approximately 220 million m^3/yr. This remarkably high value explains how this water source supplies the demand of nearly two million people in Budapest and its vicinity [1,2].

Fig. 1.: Bank-filtration site on Danube River (Kisoroszi, Szentendre Island)

In the rest of the world the technology, based on this natural process, is not well known mainly because other type of surface or ground water of similar quality is more readily available. More studies were carried out in the United States and in Australia (for brackish aquifer) [3,4]. In the Ohio Valley many water utilities exist that use riverbank-filtered water.

2.2. Process of riverbank-filtration

Interaction between the river and the adjacent aquifer is controlled by the constantly fluctuating river level. Under flood conditions the river water percolates through the riverbed into the neighboring aquifer, which typically consists of sand or gravel layers. Under average and low-flow circumstances the infiltration operates only by the extraction of filtered water through wells (Fig. 2.). In this case the pumping of wells produces a cone of depression and the water starts to flow from the river into the aquifer [2].

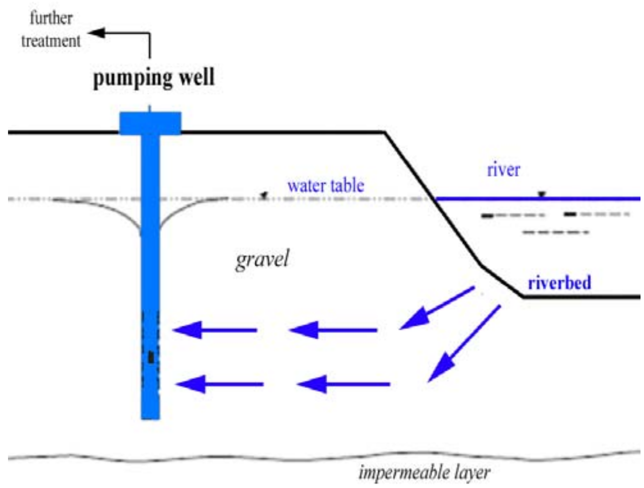

Fig. 2.: Cross-section view of riverbank-filtration [5]

During this infiltration process, contaminants are removed by adsorption on the surface of clay minerals. Another important related phenomenon is the removal of pathogens by the highly active biofilm, which is located on the river-aquifer boundary.

Riverbank-filtration provides several benefits, such as the protection against incidental shock loads, the temperature equalization of river water, and the removal of particles, biological contaminants and biodegradable compounds.

The major problem with riverbank-filtration is the clogging or colmatation of the riverbed. Thin layers of fine sediment often cover the riverbed and aquifer pores can occasionally be clogged by these very fine particles. Although clogged riverbank sediments may increase the efficiency of bank filtration, the loss in permeability can significantly decrease the productivity of the wells [6]. Flood periods of a river can stop the process of clogging because the turbulent flow conditions renew the colmatated layers of the riverbed. Thus, dynamic changes of river water level have not only influence on clogging of the riverbed and transport processes in the aquifer but also on the water quality in production wells. [7]

3. Study site

The approximately 30 km long Szentendre Island is situated North to the Hungarian capital, Budapest (Fig. 3.). Below the island a Mesozoic substrate runs along consisting mostly of limestone and dolomite. The alluvial deposits of the island overlay impermeable Tertiary clay layer. The aquifer consists of Pleistocene sandy gravel sediments and is 7-15 m deep. This zone is capped by a 1-1.5 m thick clay layer above the mean water level of the river [8].

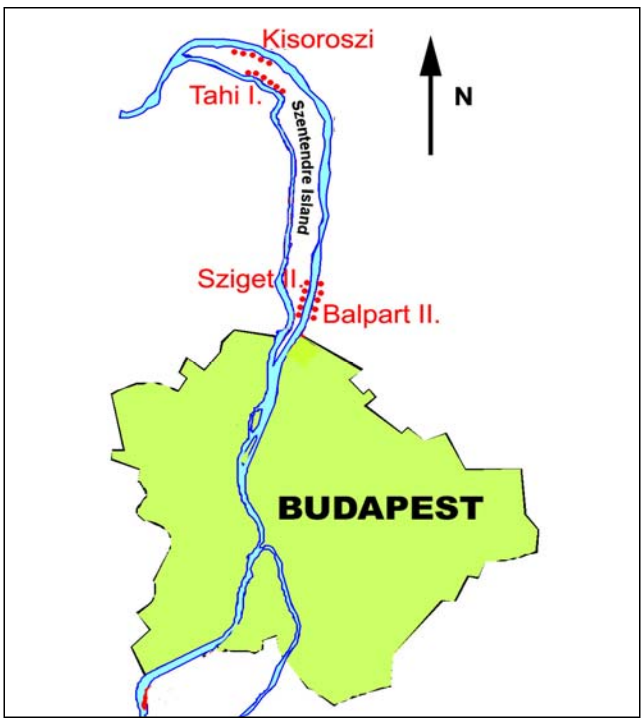

Fig. 3.: Schematic map of the study area: Szentendre Island, Hungary

The mean flow rate of the Danube at Nagymaros is about 2200 m^3/s. The number of the production wells is nearly 600, and the maximal pumping rate is approximately 400 000 m^3/d [1]. At the end of the eighties this value exceeded 700 000 m^3/d. Several different type wells operate on the island. The earliest – so-called „dug wells" – were built 120 years ago and are still operating today (Sziget II., Balpart II.). Water is extracted through lines of drilled, vertical wells (partly Sziget II.), mainly on the western banks of the island, where the natural gravel layers are very thin. The most productive type is that of the horizontal collector wells (Fig. 4.), which has a depth of 15-20 m, depending on the depth of the gravel layer (Kisoroszi, Tahi I.). A typical horizontal well collects water from a large area, and its capacity can reach several thousand m^3/d.

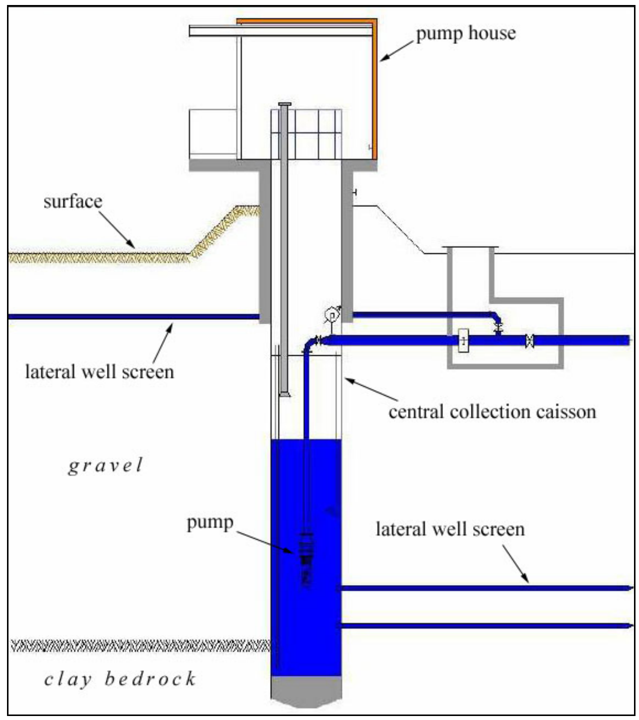

Fig. 4.: Scheme of a horizontal collector well [1]

4. Calculations on the hydrological and water quality parameters of the Danube and the well-sections

This study presents the relationship between the hydrological and water quality parameters of the Danube River and the wells of *Kisoroszi, Tahi I.*, *Sziget-II.* and *Balpart II.* (Fig. 3.), based on data collected from 1990 to 2005. We have examined the duration of the riverbank filtration, the effects of the natural factors in the water quality, as well as relationship between the hydraulical and water quality of the Danube and in the bank-filtered wells.

We have processed databases gathered by several Hungarian Institutes (e.g., Water Resources Research Centre Plc., Water Works of Budapest) in order to generate a 15 years long time series.

4.1. Retention time of bank-filtered water in the aquifer

In a comparison of the water quality parameters (*conductivity, chlorine, nitrate, nitrite, sulfate, phosphate, potassium, iron, manganese, magnesium, sodium, ammonium content; total hardness, pH*) with the river and the four bank-filtered reservoirs we shifted the components of the wells with 0-3, 4-7, 8-11, 12-15, 16-20 days, according to the values measured in Danube water to answer the question, how much time the water needs to get through the riverbank to the wells.

We have analyzed the correlation between parameters at different time shifts. Based on suggestion, it takes more time for a given water molecule to reach wells which are further from the Danube (e.g., Kisoroszi – 16-18 days), than wells which are closer to the Danube (e.g., Tahi I. – 8-10 days, Sziget II. – 4-6 days, Balpart II. – 6-8 days).

The latter three wells are about at the same distance from the Danube. However, the wells of Tahi I. are situated along the Szentendre branch of Danube, which is characterized by small runoff, whereas the other wells are situated along the Danube branch of Vác (the wider one). Therefore, we suggest that the cause of the different durations of riverbank filtration is the difference in distance from the river, runoff and pressure. However, riverbank filtration of longer duration does not always result in a better water quality. We can conclude it from the following calculations, as well.

4.2. Relationship between parameters of water quality and environmental factors

We have contrasted water quality variables of the river and the wells with the hydrological and hydrometeorological parameters (e.g., runoff, water and air temperature). The runoff represents only medium or weak correlation with some water quality components, however temperature has a strong effect on water quality. The conductivity, chemical oxygen demand, total hardness give medium correlation (r=0,5-0,6) the chlorine, sodium, magnesium content give weak relationship (r=0,3-0,4).

The factors of water and air temperature affect with a stronger effect the components of water quality. The highest (r = 0,75-0,85) coherence is between temperature and conductivity, and between the temperature and nitrate content. The correlation is somewhat weaker (r = 0,60-0,75) between temperature and ammonium- and sodium content. The correlation with temperature is even weaker, but recognizable (r = 0,45-0,60) for chlorine-, calcium- and magnesium content. We have estimated the weakest statistical coherence with temperature (r = 0,30-0,45) for sulphate content and pH.

4.3. Comparison of the parameters of average water quality from the Danube and the wells

The conductivity of the bank-filtered water is about 20 percent greater than that of the water of the Danube. In the course of riverbank filtration the water interacts with mineral and pollution substances (sodium, magnesium, chlorine, potassium, nitrate, phosphate, sulfate). This phenomenon occurs in some wells showing individual characteristics. The highest conductivity was measured in the wells of Balpart II. which can be explained by the higher than average chlorine, potassium, sulfate and phosphate pollution and sodium content. These anomalous concentrations are due to the

dissolving of the bedrock and to anthropogenic pollution (agricultural and communal).
The greatest nitrate pollution is measured in the wells of Kisoroszi, which can be the consequence of background chemical fertilizer pollution. Furthermore, the concentration of magnesium is also high. The wells of Tahi I. are different because of the excessive ammonium and calcium content. The previous component can also be accounted for by the fertilization of the background. The shortest time of riverbank filtration can be found in the wells of Sziget II. (90% of the water issues from the Danube), thus the values of the components are low and the conductivity is the smallest among the wells.

5. Conclusion

As the first bank filtration-based water utility in Hungary for water supply was established nearly 120 years ago, it became a well-tried, calculable and low-priced technology. Drinking water of good quality can be produced with minimized need for adding chemicals to remove pathogens and there is no increased risk to human health.
Regarding the connection between river and aquifer the following conclusions are found:

1. Removal potential of the aquifer depends on several factors. The strongest relationship is between temperature and some chemical components. The significant variances of water quality between the different well-groups originate in geological divergences and anthropogenic effects.

2. Retention time of bank-filtered water in the aquifer depends on distances between coastline of the river and production wells. Hydraulical conditions are also major factors of transport time in the aquifer.

Our study focuses on the major, generally occurring chemical components which are present in the river water and filtered water. However, new types of contaminants (e.g. pharmaceuticals, personal care products, radioactive isotopes) have been found worldwide in aquatic environments. These and similar anthropogenic substances are relatively resistant to degradation during bank filtration. This is a very immediate research need in water supply management and can be the next step in our investigations.

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