Chapter 14 Removal of Iron and Manganese Within the Aquifer Using Enhanced Riverbank Filtration Technique Under Arid Conditions

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Abstract Nowadays, riverbank filtration (RBF) technique is receiving more attention from drinking water suppliers in Egypt. An innovative design has been established to couple RBF and removal of Fe and Mn in situ. A preferential flow has been induced through constructing two sand filters crossing the upper clay layer. Continues monitoring for water quality indicators in RBF wells has revealed the potentiality of the design. The contents of Fe and Mn on average have been reduced with time. Detailed investigations of removal processes for Fe and Mn within the aquifer require long term monitoring. This innovative idea can be transferred along the Nile River where the clay layer exists and the already existing drinking water wells producing water of high iron and manganese contents.

Keywords: Riverbank filtration, Egypt, iron, manganese, water quality

1. Introduction

The population growth and high density of human activities in the Nile valley and Delta have increased the drinking water demand and lead to contamination of surface water sources. This has increased the cost of drinking water treatment with the conventional methods. At present, conventional treatment of surface water in Egypt includes pre-chlorination, coagulation, flocculation, sedimentation, filtration, and post-chlorination disinfection. The currently implemented conventional treatment processes have failed to remove several pollutants (Abdel-Shafy and Aly 2002). Moreover, pollution of source water has reduced the efficiency of sand filters due to accumulation of microorganisms and clogging. An important limitation of sand filtration is the need for high-quality source water (Logsdon et al. 2002). Cost efficient and sustainable techniques are needed to provide safe drinking water in

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sufficient quantity and with high quality in the future. The government has used groundwater sources to supply drinking water to communities in rural areas and cover larger parts of the country with safe drinking water. Nevertheless, after pumping the groundwater into the water distribution system, water turned reddish to black in most of the sites due to the occurrence of iron and manganese in source groundwater (El Arabi 1999).

There is a great potential for the application of riverbank filtration (RBF) along the River Nile and main canals in Egypt. RBF is the naturally occurring inflow of surface water to the groundwater aquifers, via the bed and banks of the surface water body. During its passage, the water quality parameters improve due to microbial, physical and geochemical processes and by the mixing with ambient groundwater quality (Kuehn and Mueller 2000). Typical aquifers used for RBF in Europe consist of sand and gravel deposits that have hydraulic conductivity higher than 8.6 m/day (Grischek et al. 2002). The multi protective barrier concept, of bank filtration, including both natural and technical purification has proven to be a reliable method for drinking water production (Eckert et al. 2006). The natural attenuation of contaminants during bank filtration includes the elimination of suspended solids, particles, biodegradable compounds, bacteria, viruses, and parasites as well as the partial elimination of absorbable compounds (Hiscock and Grischek 2002). Bank filtrate is fairly biologically stable water with a lower disinfection dose thus long term application can decrease water treatment costs (Kuehn and Mueller 2000).

Hydrogeological conditions along the Nile River provide a promising application of RBF. Problems arise if thick clay layer exists at shallow depths that prevent seepage of surface water into groundwater and consume oxygen. Moreover, the redox conditions along the underground passage may lead to iron dissolution in addition to the ambient groundwater has iron concentrations >0.3 mg/L which is the case at many sites in Egypt. An Innovative approach is required to handle such constraints for simple RBF and removal of iron and manganese in the subsurface. A coupling of RBF and subsurface iron removal is used in this study. The objective of this work is to assess the efficiency of the proposed innovative design to enhance RBF and remove the iron and manganese within the aquifer as well as to evaluate the removal efficiency of bacteria and total organic carbon (TOC).

This study has been done in a new RBF site at Cairo along a main branch of River Nile called Al-Rayah Al-Naseri (Figure 14.1). Nevertheless, the hydrogeological conditions were not favorable for simple RBF design and the ambient groundwater quality has high iron (Fe) (0.97 mg/L) and manganese (Mn) (0.87 mg/L) contents. Moreover, surface water quality has high total coliform count (1,800 MPN/100 ml) and contains high amounts of total organic carbon (4.1 mg/L). The main aquifer that is of Pleistocene age and consists of sands and gravel has been targeted. The aquifer is overlaid by clay layer of average thickness (21 m) and upper thin aquifer that is directly connected with the surface water body.

The removal approach shown in this study differs from most other techniques used in Egypt that only investigated the removal using injection of enriched oxygenated water and recovery. It describes the results of the joint use of RBF and subsurface removal of iron and manganese in Nile Delta aquifer. The water quality of the RBF wells has been found suitable for drinking purposes except for Fe and Mn. It has high efficiency in removing coliform bacteria (100%) that is encouraging to apply RBF in similar countries that have high temperature or potential to have high temperature after climatic changes. Sand filters have facilitated the passage of oxygenated river water into the producing aquifer.

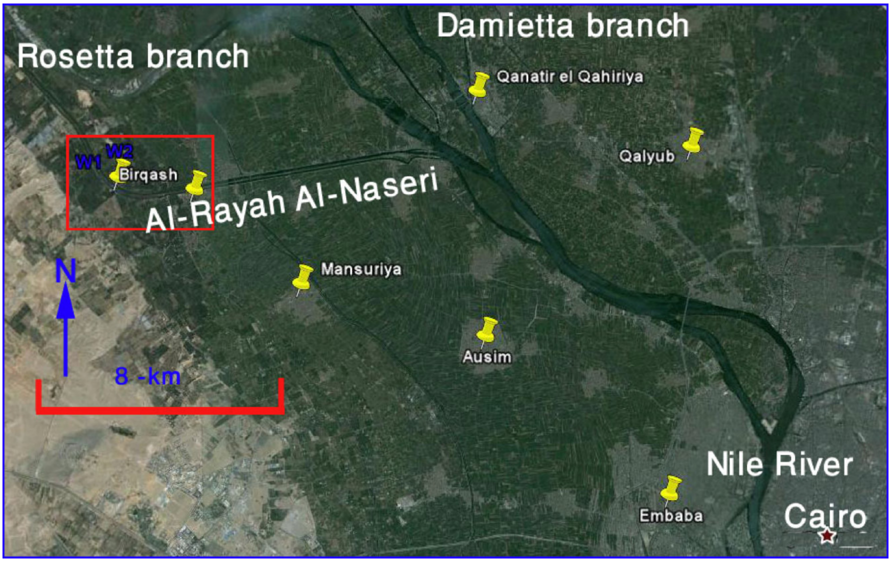

Figure 14.1. General location map for the study area (Birqash site along Al-Rayah Al-Naseri).

2. Iron and Manganese Distribution and Associated Problems in Egypt

Iron is found in natural fresh waters at levels ranging from 0.05 to 50 mg/L. No health-based guideline value is proposed from World Health Organization for iron (WHO 2006). The permissible limit according to Egyptian Drinking Water Standards (law no 458/2007) is 0.3 mg/L. At levels above 0.3 mg/L, iron stains laundry and plumbing fixtures. Anaerobic groundwater may contain ferrous iron at high concentrations without discoloration or turbidity in the water when directly pumped from a well. On exposure to the atmosphere, however, the ferrous iron oxidizes to ferric iron, giving an objectionable reddish-brown colour to the water due to the oxidation of the dissolved Fe(ll) to solid Fe-oxides. Iron also promotes the growth of iron bacteria, which derive their energy from the oxidation of ferrous iron to ferric iron and in the process deposit a slimy coating on the piping and distribution network.

Manganese is naturally occurring in many surface water and groundwater sources, particularly in anaerobic or low oxidation conditions. Occurrence levels in fresh water typically range from 0.001 to 0.2 mg/L, although levels as high as 10 mg/L in acidic groundwater have been reported (WHO 2006). The presence of manganese in drinking water, like that of iron, may lead to the accumulation of deposits in the distribution system (Kohl and Medlar 2007). Guideline value is 0.4 mg/L, concentrations at or below the health based guideline value may affect the appearance, taste or odor of the water, leading to consumer complaints. Upon aeration water turns gray-black due to the oxidation of the dissolved Mn(ll) to solid Mn-oxides. The permissible limit according to Egyptian Drinking Water Standards is 0.4 mg/L.

A baseline national water quality monitoring report (NWRC 2003) indicating a high level of iron and manganese in some observation wells in the Nile Delta and Western Desert aquifers. Iron concentrations exceeded the allowable standard for drinking water in about 51% of the monitored wells in the Nile valley aquifer. While in the Western Desert aquifer; concentrations of manganese exceeded drinking water limit in about 75% of the wells and iron exceeded drinking water standard in up to 100% of the wells (EEAA 2009). The high values of iron and manganese are related to the anaerobic conditions dominant in the aquifers. In a study around Cairo, the percentage of wells exceeding drinking water standard is 80% for manganese (Mn) and 20% for iron (Fe) where the concentrations of Mn were up to 1.5 mg/L and up to 1.0 mg/L for Fe (El Arabi 1999). In a study along the west side of the Nile near the intersection point between the Nile and its Delta, at Giza governorate, the range of Mn concentration is 0.058–2.78 mg/L and Fe concentration value lies within the range of 0.141–1.704 mg/L (Emara et al. 2007). The traditional technology for Fe and Mn removal includes an oxidation-precipitation of the soluble Fe(ll) and Mn(ll) to the insoluble Fe- and Mn-oxides followed by filtration. This can be achieved either above ground (conventional treatment) or in situ groundwater treatment, where Fe and Mn are precipitated within the aquifer.

3. Hydrogeological Conditions of the Nile Delta System

The main aquifer system in the Nile Delta consists of two water-bearing layers. The lower layer is formed of highly permeable alluvial sediments (sand and gravel) of Pleistocene age, and the upper one is formed of the Holocene clay-silt layer of relatively low and very low horizontal and vertical hydraulic conductivities, respectively. The Pliocene clay is the base of the main aquifer system (Idris and Nour 1990). The main aquifer in the Nile Delta is represented by Mit Ghamr Formation (El-Fayoumy 1968) that consists mainly from Pleistocene sand (Figure 14.2). The AQ1 average saturated thickness of the Nile delta aquifer ranges from about 200 m in the South near Qanatir el Qahiriya to about 800 m in the North, with a thickness reduction trend towards the delta fringes and southward to Cairo. The main aquifer is overlaid by a semi confining layer with a thickness ranges between 10 m in the South up to 30 m in the North (Dawoud et al. 2005). The groundwater aquifer underlying the Nile valley and Delta is recharged by seepage losses from the Nile, irrigation canals and deep percolation from irrigated lands (Figure 14.3) (RIGW 1989). Downward groundwater leakage occurs in the southern part of delta. The vertical water movement through the clay cap affects, to a great extent, the groundwater management and the drainage conditions. The existing rate of groundwater abstraction in the Nile valley and Delta regions is about 4.8 billion cubic meters (BCM)/year, which is still below the potential safe yield of the aquifer. Salinity of the Nile Delta aquifers is mainly below 1,500 mg/L. However, the average reported salinity of pumped groundwater lies in the range from 160 to 480 mg/L in the South Delta, 480 to 1,440 mg/L in the Middle Delta and >3,200 mg/L in the Northern Nile Delta (RIGW 1992).

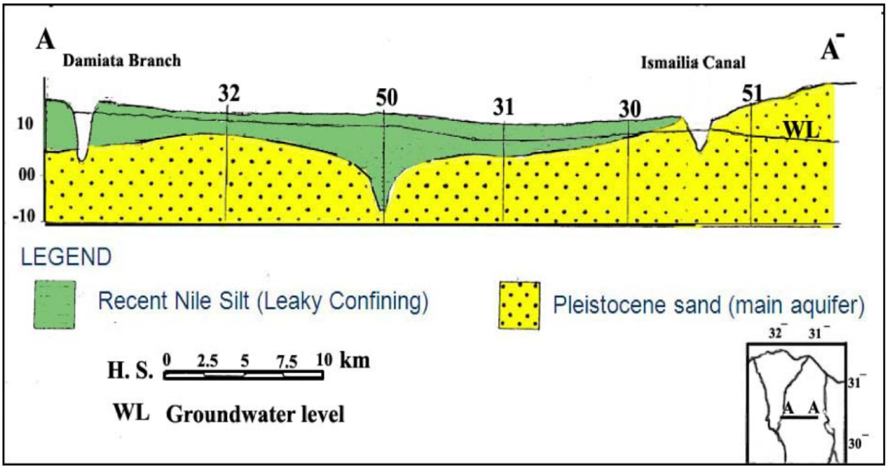

Figure 14.2. Hydrogeological cross-section in the eastern Nile Delta (modified after El-Fayoumy 1968).

4. Research Assumptions, Materials and Methods

Due to the occurrence of shallow clay layer under the surface water courses in the study area, an innovative approach is used. This has included inducing preferential flow through the clay layer and monitoring the quality changes in RBF wells. It is assumed that this innovative design will facilitate the passage of Nile water including oxygen into the producing aquifer and to improve the water quality and remove the Fe and Mn in subsurface. The approach has concentrated on inducing oxygen into the aquifer with bank filtrated water to prevent mobility of Fe and Mn. To test the efficiency of the proposed technique, a continuous water quality monitoring program, for a period of 12 months, was conducted. Water samples were collected from groundwater, surface water and from RBF wells for the determination of the physical, chemical and microbiological (fecal coliform) characteristics. Analyses for about 18 parameters include major ions, trace metals, nutrients, and other organic contaminants (TOC) were done in the laboratories of Geza Water Company and Suez Canal University that follow the American Public Health Association standard methods (APHA 2005). Hydrogeological data were collected for detail investigation. Hydrogeological environment is investigated using the conventional hydrogeological methods. Soil and aquifer materials were investigated and accordingly wells are designed.

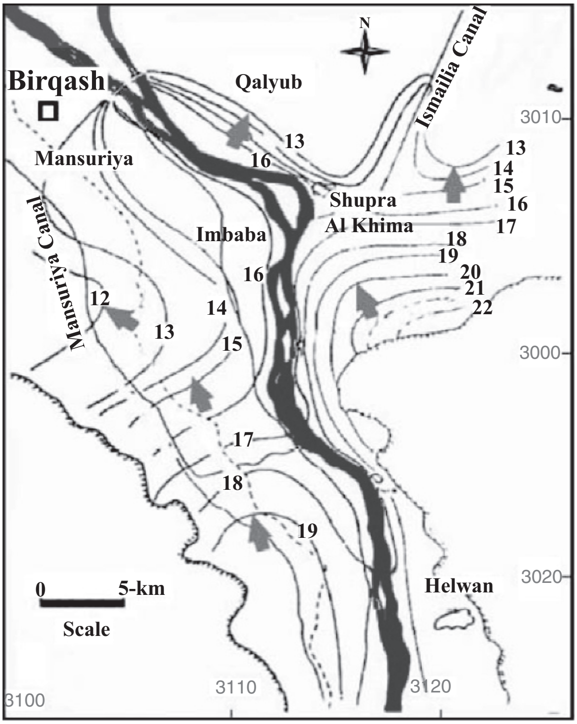

Figure 14.3. Groundwater level map and groundwater flow direction in the main aquifer in the south part of the Nile Delta (modified after RIGW 1989).

5. Design of the Site and Detailed Hydrogeology

The site has been selected in the old cultivated lands of the Nile Delta to be far away from residential areas where local sources of contamination predominate. The site locates along Al-Rayah Al-Naseri at AlSheikh Zayed City water intake that supplies drinking water to the rural residents of Birqash (Figure 14.4). The investigation of drilling cuttings deep to 98 m (Figure 14.5) has shown the presence of clay layer at shallow depth of average thickness 21 m. The upper layer is composed of fine sand and has thin thickness (average 7 m). It has shallow groundwater where water table exists at about 3 m below ground surface. This layer is in direct contact with surface water body. The main aquifer exists below the clay layer and is of Pleistocene age. It is composed mainly from sand and gravel and of average thickness 70 m and is underlain by dense Tertiary clay. Due to the specific constraints in the site that include the presence of thick clay layer at shallow depths and the presence of Fe and Mn in the ambient groundwater an innovative design has been proposed.

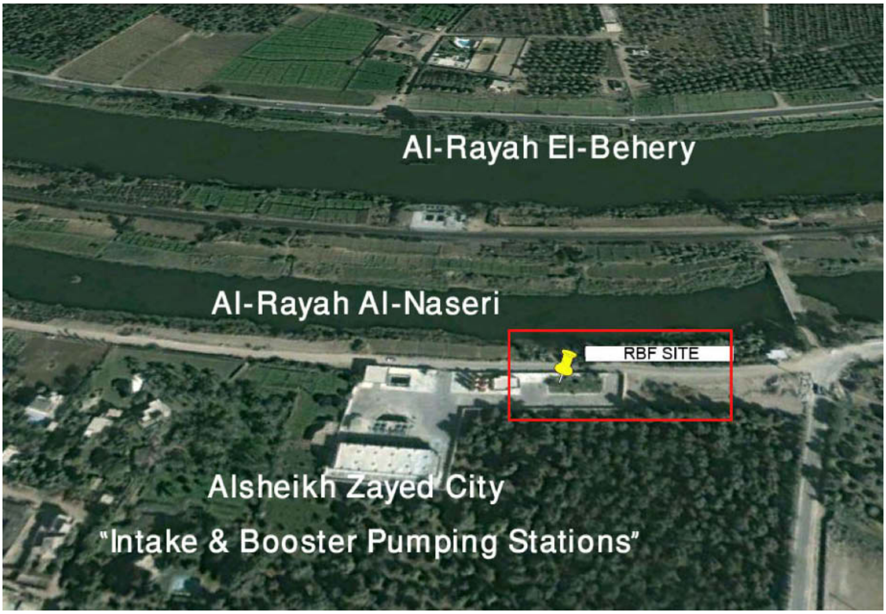

Figure 14.4. Detailed satellite image for the RBF site at Al-Rayah Al-Naseri.

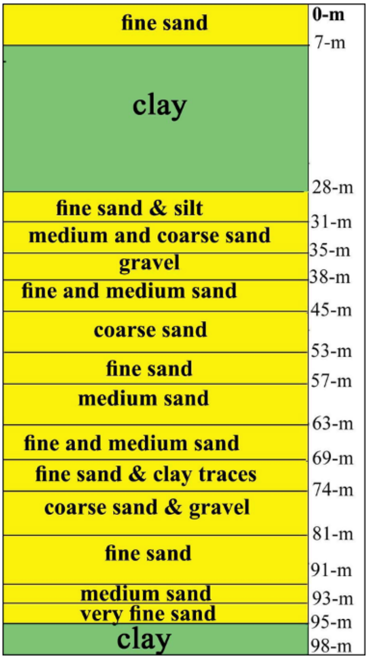

Figure 14.5. Geologic sections in the drilling site.

The site consists of two productive wells placed at 25 m from the surface water bank and two sand filters crossing the clay layer (Figure 14.6). The innovative RBF design has included inducing preferential flow through the clay layer. The two productive wells have been designed to withdraw groundwater from different depth. The well number one is abstracting groundwater from the upper part of the main aquifer (total depth 60 m). In this well, a preferential flow has been induced from the upper layer connected with surface water to the lower one through special design (Figure 14.7). The clay layer has penetrated through the outer annular space of the well and filled with graded sand. Screens were installed at depths range from 30 to 42 and 48 to 60 m below ground surface of total length 24 meters. The well number two is designed in traditional manner to withdraw groundwater from the bottom part of the main aquifer (total depth 90 m). Screens were installed at depths range from 54 to 60 and 66 to 90 m below ground surface of total length 30 m. Moreover, two sand filters crossing the clay layer has been constructed to facilitate the passage of river water and oxygen into the producing aquifer. The design of the sand filters took into consideration the natural geologic section (Figure 14.8). Filters were simply constructed directly on the river bank. Both of them have 0.56 m-inch diameter and 31 m length (crossing clay layer). The normal profile above the clay layer has been recovered and filling coarse sand and gravel instead of clay until reaching the main aquifer.

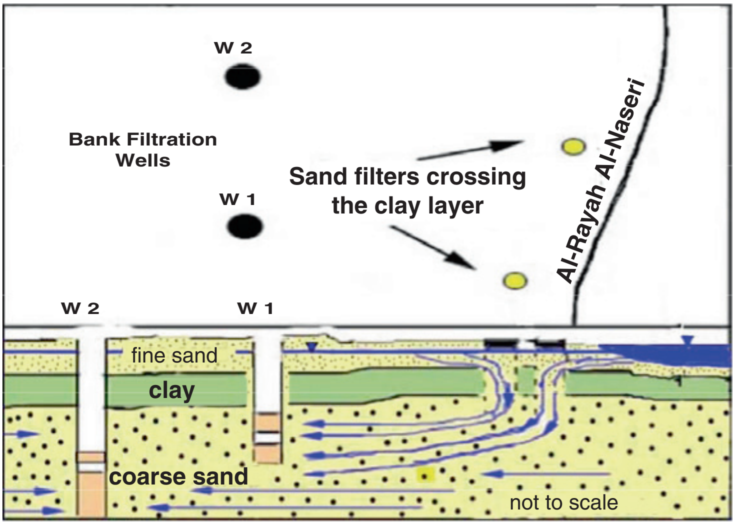

Figure 14.6. Site layout and design (site consists of two productive wells placed at 25 m from the surface water bank and two sand filters crossing the clay layer).

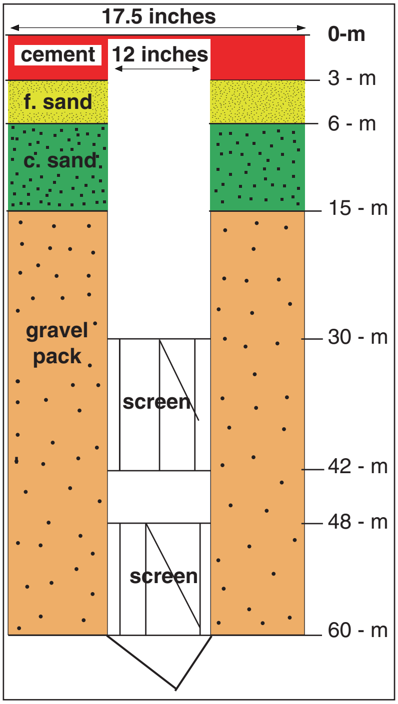

Figure 14.7. Design of RBF well 1 to induce preferential flow through the upper clay layer.

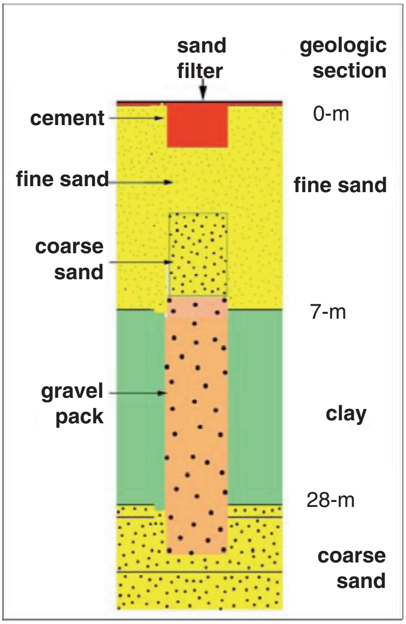

Figure 14.8. Design of sand filters crossing the clay layer (the diameter of the sand filter is 0.56 m).

6. Results and Discussion

6.1. Hydrogeology and RBF Wells Productivity

The main aquifer has high transmissivity where it is estimated about 10,500 m^2/d. It is calculated as the product of average aquifer thickness and hydraulic conductivity (60 m × 175 m/d). The company has targeted the main aquifer at the site to supply the surrounding communities with about 4,000 m^3/day from the two RBF wells. The productivity of the RBF wells (1 and 2) was high; both have average productivity of about 120 m^3/h. The theoretical volume of water that can move downward from the upper aquifer to the well screen through the innovative design that applied to RBF well (1) and the sand filters can be calculated by the Darcy's equation (Driscoll 1986):

$$Q = KIA \tag{14.1}$$

where Q = vertical flow through the pack material, in m^3/day
K = hydraulic conductivity of filter pack, in m/day
I = Hydraulic gradient causing vertical flow in the filter pack
A = cross-sectional area of the filter pack, in m^2.

The hydraulic gradient (I) is measured as the difference between the pumping level in the well and the static water level in the upper aquifer divided on the average distance through which the upper water must move, the distance from the midpoint of the upper aquifer to the top portion of the screen. In the case of the RBF well (1), the amount of water transmitted vertically is about 87 m^3/day. This amount is relatively small in comparison to the total amount of water pumped from the well. The volume of water that can be infiltrated through the two sand filters is about 520 m^3/day.

The proportion of bank filtrate in the RBF wells can be estimated using conservative tracer in the well and in the end-members (surface water and background groundwater). The chloride has been used because it is non-reactive and non-retarding and data about its distribution in the water environment is available. The differences in concentration of the two end-members should ideally be large and concentrations should be stable with time (Appelo and Postma 1993). The percentage of bank filtrate in the well is estimated according to the following equation:

$$X\ [\%] = [(C_w - C_{GW})/(C_{sw} - C_{Gw})]*100 \qquad (14.2)$$

where C is the concentration of chloride in RBF well (C_W), groundwater (C_{GW}) and surface water (C_{WS}). The contribution of bank filtrate is estimated about 100% in the two wells. The area is surrounded by Nile water from all directions. These contributions may be from an old bank filtration. Isotope tracers are recommended to be used in this case.

6.2. Water Quality and Quality Changes

Results for specific quality indicators in surface water, RBF wells and background groundwater relative to Egyptian drinking water standards are shown in Table 14.1. The surface water source (El Rayeh Al Nasery) has fresh water quality where chloride content is ranging from 17 to 34 mg/L with median value 30 mg/L (Table 14.2). Sulfate content is ranging from 9.1 to 24.7 mg/L with median value 17.2 mg/L. The nitrogen species, ammonia, dominate in the source water while nitrate has completely disappeared. Ammonia content is ranging from 0.046 to 0.5 mg/L with median value 0.12 mg/L. The nitrite content is very low with median value 0.0035 mg/L. The average content of ammonia in Nile water at Giza was about 0.32 that comes mainly from domestic sewage (Ahmed et al. 1999). The surface water has relatively high content of TOC. The content of TOC is ranging from 3.9 to 4.9 mg/L with median value 3.9 mg/L while dissolved organic carbon (DOC) is ranging from 3.3 to 4.5 mg/L with median value 3.6 mg/L. The Surface water has relatively high potassium content of median value 5.7 mg/L. Turbidity is ranging from 3.14 to 5.1 NTU with median value 4.25 NTU. The total coliform bacteria were high where it ranges from 1,600 to 1,800 MPN/100 ml with median value 1,700 MPN/100 ml.

TABLE 14.1. Results of water analyses at the investigated site (March 2009) and average groundwater around the site.

	RBF Well 1 (upper part of the aquifer)	RBF Well 2 (bottom part of the aquifer)	El Rayeh Al Nasery	Average groundwater around the site	Egyptian standard (2007)
Odor	Nil	Nil	Nil	Nil	Nil
EC Micro (S/cm)	620	550	376	813	na
TDS (mg/L)	409.2	363	248.2	440	1000
Turbidity (NTU)	1.96	1.74	4.9	na	1.0
pH	7.5	7.5	8.3	7.5	6.5–8.5
NH_3 (mg/L)	0.06	Nil	0.14	Nil	0.5
NO_2 (mg/L)	0.004	Nil	Nil	Nil	0.2
NO_3 (mg/L)	Nil	Nil	Nil	Nil	45
Temperature (°C)	26.4	26	25.8	26	na
O_2 (mg/L)	na	na	10.2	na	na
TOC (mg/L)	1.8	2.0	4.1		na
Total alkalinity (CaCO3) (mg/L)	244	206	148	248	na
Total Hardness (CaCO3) (mg/L)	258	210	138	na	500
Ca^{++} (mg/L)	65.6	55.2	35.2	30	140
Mg^{++} (mg/L)	22.56	17.28	12	26	36
K^+ (mg/L)	na	na	5.7	na	na
Cl^- (mg/L)	24	26	28	70	250
SO_4^{-2} (mg/L)	24.2	32.8	24.69	50	250
Total Fe (mg/L)	0.43	0.5	0.1	1.7	0.3
Total Mn (mg/L)	0.51	0.56	Nil	0.91	0.4
Total coliform (MPN/100 ml)	Nil	Nil	1,600	Nil	<2 units/100 ml

na = not available

TABLE 14.2. Results of monitoring for specific indicators in the investigated site.

Parameter	Date	RBF Well 1	RBF Well 2	El Rayeh Al Nasery
Turbidity (NTU)	6/17/2008	5.09	12.2	5.1
	1/15/2009	1.58	1.7	3.14
	1/21/2009	1.82	1.6	3.6
	3/19/2009	1.96	1.74	4.9
	Median	1.89	1.72	4.25
NH_3 (mg/L)	6/17/2008	0.312	0.158	0.5
	1/15/2009	0.09	0.12	0.1
	1/21/2009	Nil	Nil	0.046
	3/19/2009	0.06	Nil	0.14
	Median	0.09	0.139	0.12
Chlorides Cl^- (mg/L)	6/17/2008	30	25	17
	1/15/2009	26	25	32
	1/21/2009	27	28	34
	3/19/2009	24	26	28
	Median	26.5	25.5	30
Total Iron (Fe) (mg/L)	6/17/2008	0.97	0.486	0.1
	1/15/2009	0.42	0.41	0.08
	1/21/2009	0.54	0.43	0.2
	3/19/2009	0.43	0.5	0.1
	Median	0.425	0.458	0.1
Total Manganese (Mn) (mg/L)	6/17/2008	0.824	0.713	Nil
	1/15/2009	0.64	0.63	0.21
	1/21/2009	0.46	0.41	Nil
	3/19/2009	0.51	0.56	Nil
	Median	0.575	0.595	0.21
Total coliform (MPN/100 ml)	6/17/2008	3	3	1800
	1/15/2009	6	9	1600
	1/21/2009	Nil	Nil	1800
	3/19/2009	Nil	Nil	1600
	Median	4.5	6	1700

The water quality of the RBF wells has been found suitable for drinking purposes except for Fe and Mn and turbidity. The coliform bacteria have disappeared completely from the RBF wells in the last two successive measurements (Table 14.2 and Figure 14.9). The permissible limit of total coliform bacteria according to Egyptian Drinking Water Standards is 2 cfu/100 ml and should not be detected in two successive measurements. It is clear that the applied RBF system has high efficiency in removing total coliform bacteria (100%) (Table 14.3). This result is encouraging to apply RBF in Egypt and similar countries that have relatively high temperature or potentially will have high temperature as expected within the climatic changes. The high removal efficiency of this technique for bacteria was mainly experienced in humid environment under average water temperature of about 10°C (KWB 2005) but the application under high temperature conditions is questionable. In this site, average water temperature is ranging from 15.6 in January to 29.6°C in August; such temperature variation may affect both the infiltration rate (Lin et al. 2003) and redox stage (Greskowiak 2006) and subsequent treatment processes (Hiscock and Grischek 2002). The higher temperature should induce a higher infiltration rate because of the higher hydraulic conductivity value (Eckert and Irmscher 2006). Moreover, under high temperature the redox stages changes and nitrate and manganese reducing conditions generally dominate below river bed (Greskowiak 2006). The passage of water underground can constitute an important treatment step to improve drinking water quality nevertheless it is not capable of removing all relevant contaminants nor is it applicable in all sites (Kuehn and Mueller 2000). The presence of clay layer is an important constraint to RBF.

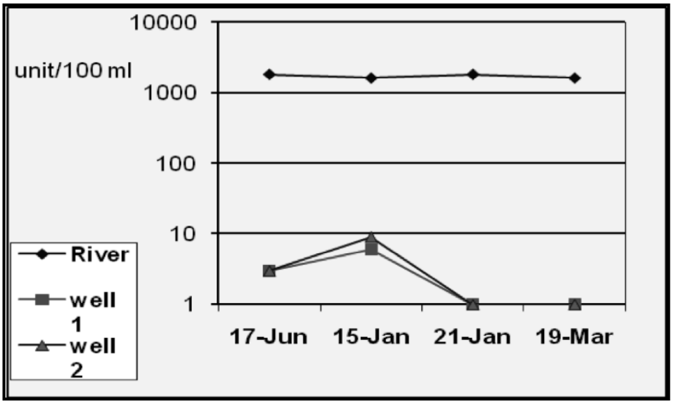

Figure 14.9. Distribution of coliform bacteria (unit/100 ml) in RBF wells and surface water.

TABLE 14.3. System removal efficiency (according to March 2009) for specific indicators.

Parameter	Surface water	Average of RBF wells	RE%
Fecal coliform (MPN/100 ml)	1800	0	100
Turbidity (NTU)	4.9	1.85	62.2
Ammonia NH_3 (mg/L)	0.14	0.03	78.57
Total organic carbon (TOC) (mg/L)	4.1	1.9	53.65

The distribution of ammonia in the RBF wells and surface water is shown in Table 14.2 and Figure 14.10. The removal efficiency of ammonia, turbidity and TOC were 79%, 62%, and 53%, successively (Table 14.3). The permissible limit for ammonia according to Egyptian Drinking Water Standards is 0.5 mg/L. The removal efficiency of ammonia depends on the healthy conditions of the river with respect to organic load and availability of oxygen in the river water. Removal of ammonia is important to keep oxygenated water for further treatment processes and removal of Fe and Mn from well water. RBF is efficient to protect from great variations of turbidity in surface water especially during flood seasons and engineering works in the Nile River. The high turbidity in the beginning is probably due to drilling residue and next almost constant. The TOC content in the surface water is about 4.1 mg/L; this amount is almost reduced by half in the RBF wells. This removal depends on the types (degradable/non-degradable) and prevailing oxic/anoxic/anaerobic conditions where rapid removal of TOC was observed, under oxic conditions whereas slower but continuing removal under both anoxic/anaerobic conditions (Schmidt et al. 2003; Grunheid et al. 2005). This result is of great concern in Egypt as chlorination is used in routine manner for disinfection. The decrease in TOC will reduce the formation of disinfection by-products such as trihalomethanes (THMs) species. The formation of THMs could be minimized by effective removal of organics from source water before chlorination (Reemtsma and Jekel 2006). The discharge of sewage effluent to the Nile River in Egypt should be stopped to recover the oxygen level in the Nile River water and minimize organic pollution.

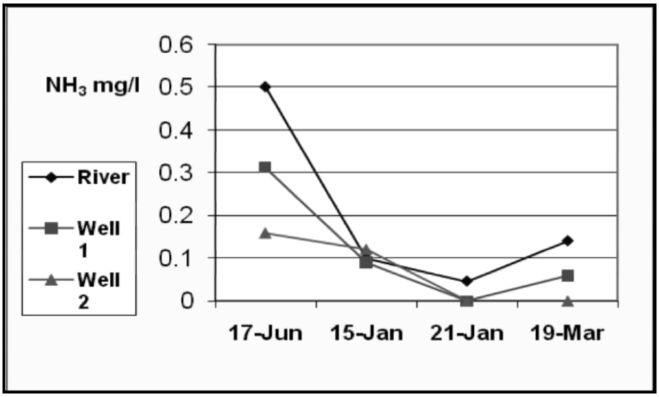

Figure 14.10. Distribution of Ammonia (NH_3 mg/L) in RBF wells and surface water.

The distribution of Fe and Mn in the RBF wells and surface water is shown in Table 14.2 and Figures 14.11 and 14.12. The mobility of Fe and Mn is connected with the redox conditions within the aquifer. After operating the wells under the effect of the new design, the removal efficiency of Fe and Mn were monitored continuously. Fe and Mn contents in the RBF wells range from 0.41 to 0.97 mg/L and 0.41 to 0.82 mg/L, respectively. Average concentrations of Fe and Mn are 0.46 and 0.53, respectively that are slightly above Egyptian drinking water standards. The permissible limit according to Egyptian Drinking Water Standards is 0.3 mg/L for Fe and 0.4 mg/L for Mn. WHO (2006) has no specific standards for iron content but guideline value for Mn is 0.4 mg/L. There is general trend for decrease in Fe content in the upper aquifer (well no. 1) but in the lower aquifer (well no. 2) the trend is not clear (Figure 14.11). The general changes in Mn content in both wells are decreasing (Figure 14.12). This can be explained by the effect of the infiltrated oxygenated water. The redox conditions below the innovative design in Egypt were largely dependent on temperature variations and oxygen content in the surface water. There is not significant difference between surface water temperature (25.8°C) and RBF wells temperature (the upper one has 26.4°C and the lower one has 26°C) in June 2008. The surface water oxygen (O_2) content is about 10.2 mg/L. Generally aerobic conditions prevail at low temperatures of the infiltrated water while anaerobic conditions dominate at high temperature. The Fe and Mn contents on average have been reduced with time. This can be explained by the migration of redox zones further in land. Taking into consideration the limited amounts of oxygenated surface water that could infiltrate through two sand filters of 22-inch diameter, the removal efficiency could be increased by installing two more sand filters. Most Fe removal systems operate on principal of oxidizing the Fe from ferrous, soluble form to ferric or insoluble form, followed by filtration. Coupling RBF and in situ removal of Fe and Mn differs from conventional treatment because removal of Fe and Mn takes place in the underground, in a wide precipitation zone far away from the extraction well. Detailed investigations of removal processes require long term monitoring of specific indicators and applying numerical flow and transport models.

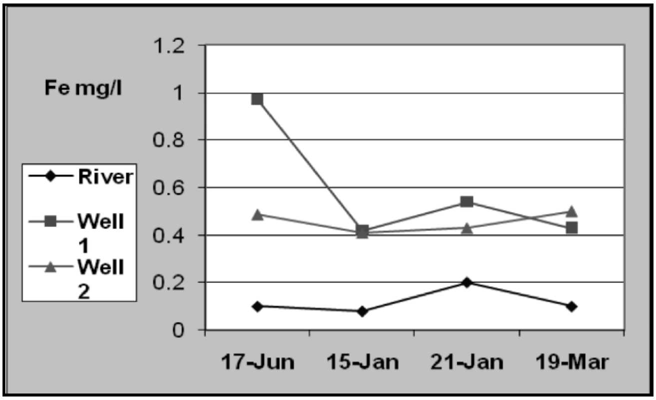

Figure 14.11. Distribution of iron (Fe mg/L) in RBF wells and surface water.

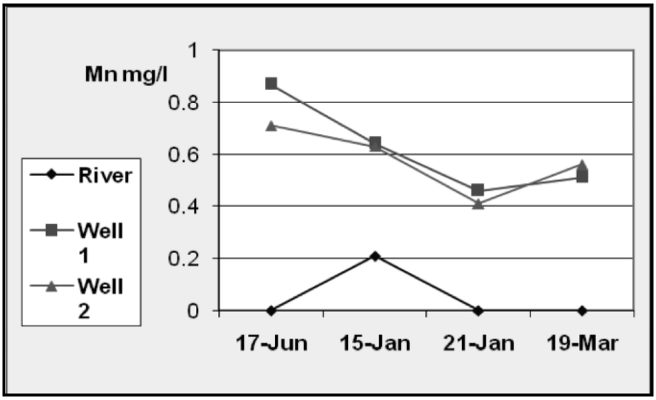

Figure 14.12. Distribution of manganese (Mn mg/L) in RBF wells and surface water.

7. Conclusion

The coupling of RBF technique and in situ removal of Fe and Mn is experimented in Egypt under unfavorable hydrogeological conditions and arid climatic conditions. An innovative RBF design has been installed to induce preferential flow through upper clay layer (21 m) using two sand filters. Sand filters have facilitated the passage of aerobic river water into the producing aquifer. Consequently, the Fe and Mn contents on average have been reduced within time. The mobility of iron and manganese is connected with the redox conditions within the aquifer. However, results suggest that the innovative idea of using sand filters through the clay layer worth further detail monitoring on the long run. The removal efficiency for coliform bacteria has reached 100% that is encouraging to apply RBF technique in similar arid climatic conditions. Total organic carbon has decreased by 53% which decrease the potential formation of chlorination by-products. The discharge of sewage effluent into the Nile River in Egypt should be stopped, otherwise oxygen decrease in the river water. High organic matter and low O_2 in the infiltrating river water would lead to anaerobic condition during RBF. Hence Fe and Mn would be mobilized also within the RBF-streamline, according to the German experience in 1960–1980 (Eckert and Irmscher 2006). For a sustainable use of RBF water protection is essential.

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