

## **RIVERBANK FILTRATION FOR WATER SUPPLY IN SEMI ARID ENVIRONMENT**

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### **ABSTRACT**

During recent years, Egypt water treatment plants allocated on the banks of River Nile have faced few accidents of hydrocarbon spills into the River which forced the operators to shut down many plants from Aswan to Cairo. Nevertheless, water supply applying the natural and low-cost technique called riverbank filtration "RBF" has been used worldwide. For more than 100 years, RBF that has been used in Europe for public and industrial water supply along Rhine, Elbe, and Danube rivers. In RBF method, the surface water contaminants are removed or degraded as the infiltrating water moves from the river or lake to the abstraction wells. Physical, chemical, and biological treatment processes occur during this technique. In this work, RBF site which is located in east bank of river Nile at Upper Egypt was investigated. This site was established to supply potable water to the construction staff of about 3000 residents, of the new Naga Hammadi Barrage, Qena governorate. It consists of two productive wells of 55 m depth located at 100 m apart from River Nile. No further treatment processes were used except disinfection applying chlorine as calcium hypochlorite. Water samples from abstraction wells were collected for physiochemical and microbiological measurements. Quality analysis of the samples indicates that the produced water using RBF technique complies with allowable standards for drinking purposes. The results have proven RBF effectiveness for water supply from river Nile in Upper Egypt and motivate its integration with tradition plants to secure water supply from Nile during the chemical pollution of Nile.

*Keywords: Water supply, Riverbank filtration, Nile, Groundwater.*

### **1. Introduction**

Demand of high quality of potable water is increasing due to the world's growing population including Egypt. Therefore, water utilities have developed new technologies for treating waters of degraded quality, such as membrane filtration, soil-aquifer treatment, and advanced oxidation. In spite of that, an old method called riverbank filtration "RBF" is increasingly being used because it is a relatively inexpensive and sustainable means to improve the quality of surface waters. The concept of RBF began in 1870's in Germany, and it is a common water production technology in Europe. In the industrial regions of Europe, RBF is used as a pre-treatment technology preceding more advanced treatment operations. In the United States, RBF systems have been operated for about half a century, and often provide the only treatment other than chlorination and fluoridation prior to consumption. According to a conservative estimate, potential exists for 67 million people to be

served by riverbank filtration in the USA [1]. Increasing concern regarding the impact of surface water contamination is driving many utilities to seek a higher quality of source water, and many are investigating riverbank filtration.

Riverbank filtration describes the process of extracting groundwater from wells adjacent to a river, or from horizontal collector wells beneath a river bed or within the banks in order to induce infiltration from the river. The streambed and aquifer materials provide slow rate filtration and the recovered water is of higher and more consistent quality than water drawn direct from the river [2]. Pumping wells are commonly placed in close proximity to riverbanks and lakes to take advantage of this induced infiltration thereby maximizing the water-supply potential of the area. Bank filtration is relatively inexpensive and sustainable to improve the quality of surface waters. Bank filtration is increasingly being used because it has the advantage that it is a natural process and relatively inexpensive. Also, when pumping wells located adjacent to a body of surface water "river or lake" it may, over time, withdraw enough water from the flow system to reverse flow gradients and induce water from the surface source.

RBF is, typically, conducted in alluvial valley aquifers, which are complex hydrologic systems that exhibit both physical and geochemical heterogeneity. During RBF, which is similar to slow-sand filtration, the impurities of river water are attenuated through combination treatment processes. The performance of RBF systems depends upon well type and pumping rate, travel time of surface water into wells, source water quality, site hydrogeologic conditions, biogeochemical reactions in sediments and aquifer, and quality of background groundwater [3]. The processes involved in bank filtration may be physical, biological, and chemical [4]. i) Physical processes such as hydrodynamic "advection, dispersion and diffusion" and mechanical "filtration i.e. trapping of particles in pore spaces". ii) Physio-chemical processes, such as sorption, precipitation, complexation, ion exchange, coagulation, and redox reactions. iii) Biological processes such as degradation of organic matter for metabolic needs and mineralization of secondary substrates. Physical filtration leads to a removal of suspended material, including hydrophobic organic substances adsorbed on suspended solids. Aerobic conditions and a relatively high microbial activity are frequently found in the riverbed at the beginning of the groundwater flow path that can lead to mineralization or transformation of degradable organics. Biodegradation is considered the primary removal process for dissolved organic carbon within the first few meters of infiltration. Adsorption of metals can have a finite lifetime before breakthrough or desorption occurs [2]. The degree of adsorption varies depending on the nature of the compounds and the kind of solid material present. In general, contact with a large surface area and long flowpaths between the river and the wells increase adsorption.

Many researchers reported that RBF process in most cases can completely remove many substances present in surface water including particles, bacteria, viruses, parasites, micropollutants, and organic and inorganic compounds [5-7]. In the first meters of RBF,

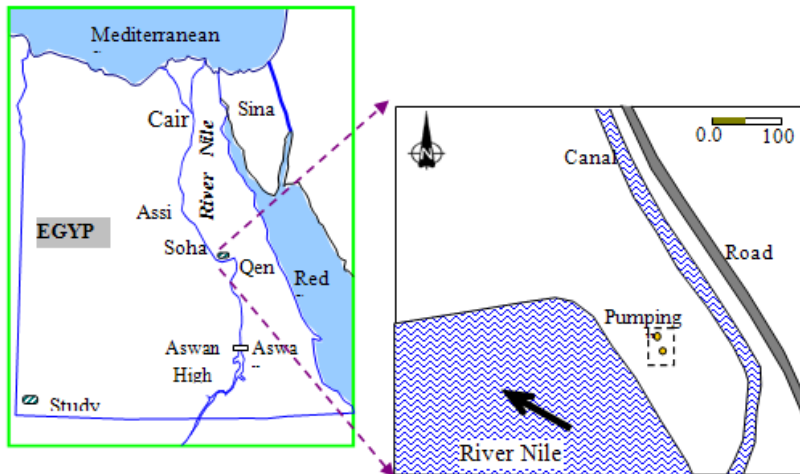
fragrance compounds, such as volatile organic carbons and aromatic hydrocarbons have been reduced to below the detection limit [8]. In addition, RBF can immobilize metals. It has been shown for removing heavy metals, such as chromium and arsenic, by 90% [9]. However, if the surface water is low in dissolved oxygen, conditions during underground passage will likely become anaerobic, which can cause iron and manganese to become soluble and therefore be drawn into the groundwater well [1]. This can lead to the undesirable effect of degrading the water quality to unacceptable drinking water standards. However, under anoxic conditions, nitrates are reduced to nitrogen and thereby provide oxygen for organics removal and ammonia oxidation [9]. Enteric viruses and protozoa, such as *Cryptosporidium* and *Giardia*, are considered critical waterborne pathogens for drinking water protection. Removal of microorganisms by RBF consists of inactivation and adsorption to soil grains, and is primarily dependent on the detention or travel time in the bank, temperature, pH, and soil properties [10]. Although filtrate water quality from RBF systems can vary based on river conditions, appropriate designed systems can serve as pretreatment for high quality water [1-11]. RBF is able to compensate for concentration or temperature peaks and provides protection against shock loads of river.

It is possible that riverbank filtrate can be used as a potable or industrial water source without need to any further treatment processes [10-6-3]. According to Kuehn and Mueller [1], the quality of the surface water is the main factor in determining whether RBF will be an adequate drinking water treatment process. Currently, in Egypt there are economic and quality problems with both surface treatment plants of Nile water and supply wells from natural groundwater [12, 13]. Using RBF technology has the potential to overcome those economic and quality problems. This research work comes as a completion of the previous assessment work for RBF in Upper Egypt [12]. The main goal of current work is to prove the promising effectiveness of RBF technique in removing particulates, dissolved solids, and microbial pathogens in Upper Egypt for potable water supply. The effectiveness of RBF for water supply will expand the treatment options available to Egyptian water utilities and to secure the water supply from Nile in case of any chemical or hydrocarbon pollution.

## **2. Materials and methods**

### *2.1. Environmental setting*

In order to determine whether bank filtration will be a beneficial component of the water supply scheme in Upper Egypt, a thorough site investigation of the target site is required. This full-scale RBF site is important because, it is the only RBF site located on east-bank of Nile in Upper Egypt, Nile Valley. RBF plant site is located in Qena Governorate to supply potable water to the residents of New Naga Hammadi Barrage, about 3000 residents, Fig 1.



**Fig. 1.** Location of the study site at New Naga-Hammadi Barrage, Qena governorate.

This plant was constructed in 2003 to provide drinking water to the construction staff of the project. The abstraction wells are located on the east side of the Nile, Fig. 1. The plant consists of deep pumping wells which provide water into the distribution system with calcium hypochlorite disinfection unit without elevated tank. RBF plant consists of 2-wells, each has 55 m deep. Each well is equipped with submerged pump with horse power of 25 HP. The average production volume of the RBF plant is about 800 m<sup>3</sup>/day. The distance between vertical pumping wells and Nile bank is about 100 m. For this close RBF plant to Nile, it is anticipated that the pumping wells will lower the groundwater table and induces as much as filtrate Nile water towards the abstraction point.

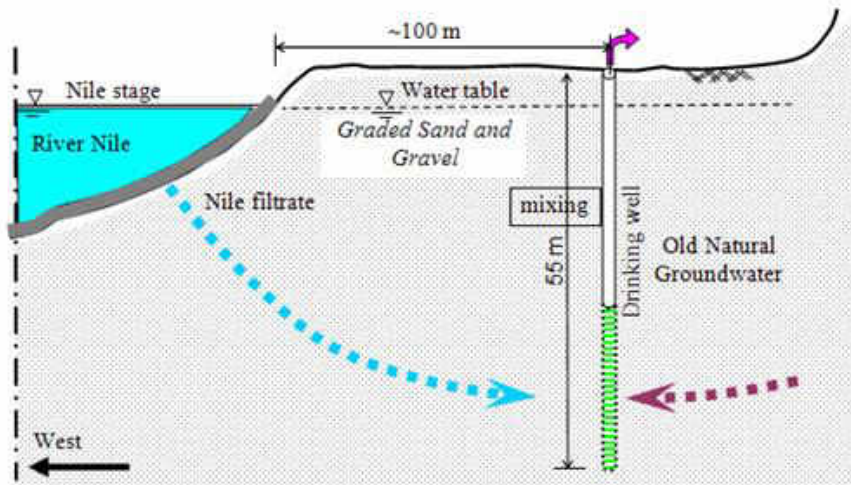
## 2.2. Hydrogeology setting

RBF studied site is located in Upper Egypt. Section of the entire Nile valley is very flat floodplain of about 20Km width [14]. Agricultural activities employ the entire valley except for those areas occupied by buildings and roads. In most alluvial valley aquifers such Nile, sand and gravel predominate with deposit layers of silt and clay in the stratigraphy. Both grain size and distribution of sediments are particularly important characteristics with respect to hydraulic conductivity and filtration efficiency. For example, hydraulic conductivity is low in the upper layers of the riverbed owing to deposition of fine sediment. The riverbank formation at the Nile floodplain can be classified into two units: River Nile alluvium, which comprises the main aquifer and the basement rocks [14]. River Nile alluvium is composed of unconsolidated deposits, which is formed of the erosion of the basement complex in the Upper part of the watershed and subsequent redeposition. River Nile alluvium

represents the aquifer system with variable thickness between 50 and 300m. In the floodplain, the aquifer is formed from Pleistocene graded sand-gravel that is covered by a Holocene silt-clay layer. Thus, the aquifer is semi-confined or leaky aquifer and the basement formation is composed of sandstone and shale of Quaternary age, which act as an impervious boundary. At Naga-Hammadi site there is no such cap layer of silt-clay sediments leading to condition of unconfined aquifer; Fig. 2.

The horizontal hydraulic conductivity of sand-gravel layer is 60 to 110 m/day [14]. Also, the vertical conductivity is 7 to 12 m/day. The water transmitting properties of the sandy aquifer are excellent with transmissivity as high as 12000 m<sup>2</sup> /day in the central part of the valley. In some locations, there are clay lenses interlaced in the main sand gravel aquifer that reduce its hydraulic conductivities. The only significant recharge to the aquifer is the infiltration of irrigation water and seepage from irrigation canals. The recharge into the water table is about 1.0 mm/day [15]. The rainfall is extremely low over the Nile valley, about 20 mm/year. The groundwater table is closely related to the ground surface elevation due to the extensive application of irrigation water. At Naga-Hammadi site, there is very limited recharge into groundwater due to the absence of agricultural activities and eastern side mountain. Groundwater surface is about 6 m under the ground surface at the study site. In Nile valley, the regional piezometric head indicates that groundwater movement is generally towards the river Nile, which acts as a major natural drain. In fact, after the construction of High Aswan Dam, there are small variations in the seasonal fluctuations of Nile surface water. The generic flow paths of natural groundwater and bank filtrate into at the study sites are illustrated in Fig. 2. The most important layer is the biologically active surface layer responsible for much of the effectiveness of RBF systems is located at the Nile bed, about 1000m width.

Typical surface water parameters of concern include: total coliforms, E-coli, nutrients "nitrite/ nitrate, phosphate, and sulfate", calcium, magnesium, sodium, turbidity, and pH. Particles measured as turbidity is a typical general water quality parameter for most surface waters and is a useful measurement tool for water quality analyses. Collected samples from RBF wells at three times in August and September 2009 were analyzed using a Hach DR2000 Spectrophotometer for physio-chemical measurements [16]. Other meters for pH and TDS measurements were used. Instrument startup and analysis were carried out as detailed in the operating manual and each measurement was made in duplicate. Microbial measurements for pathogens were carried out at the laboratories of Ministry of Health in Egypt. The results of riverbank filtrates at abstraction wells were compared with those of Egyptian standards for drinking water. The effectiveness of the RBF process is evaluated based on this comparison.



**Fig. 2.** Schematic hydrogeological cross section of RBF study site, new Naga-Hammadi Barrage.

### 3. Results and discussions

For Naga-Hammadi RBF site, water quality analysis at one sampling location was carried out. This location is the pumping water from the two drinking wells. Important water quality parameters of the abstraction water at the study site are listed in Table 1. Total dissolved solids "TDS", pH, turbidity, other chemical concentrations, and bacteriological parameters "total coliform and E-Coli" are given for the monitoring period, three times in 2009.

#### 3.1. Water quality

All measured physio-chemical and bacteriological quality of pumped RBF wells are under the allowable limits for drinking purposes according to WHO or Egyptian standards. Actually, Fig. 2 shows that the wells water is a mixture of Nile water and background natural groundwater. The main recharge of the aquifer is the infiltration and seeping water from irrigation water system. In general, there are many chemical and biogeochemical transformations that happen for Nile water during its flow path to production bank wells. According to Shamrukh and Abdel-Wahab [10] and Attia [17], natural background groundwater in Nile valley has higher concentrations than Nile water for most of chemical constituents and TDS. In the current RBF site is that the pumping wells are very close to desert fringes. In the desert fringes, there is limited groundwater recharge due to limited agricultural activities. Most of the groundwater at those desert fringes is palaeowater which is characterized with higher

salinity and TDS. In addition, groundwater in the floodplain and desert fringes has problems nitrate increasing due to infiltration and recharge of irrigation water system [15-17].

**Table 1.**

Water quality at the investigated RBF wells and the opposite sampling point in the River Nile (average values).

Parameter "mg/L or mentioned"	Concentrations RBF wells	Concentrations Nile water
pH	7.7 - 7.8	7.6 - 7.7
Turbidity "NTU"	0.1	6.1 - 6.8
TDS	340 - 360	175 - 185
Fe	0.02 - 0.3	0.0 - 0.1
Mn	0.08 - 0.10	0.05 - 0.07
Cl	28 - 35	17 - 20
Ca	51 - 63	32 - 38
Mg	32 - 36	22 - 27
Na	34 - 39	19 - 22
K	10 - 11	8 - 10
NO <sub>3</sub>	8 - 11	2 - 5
PO <sub>4</sub>	0.9 - 1.2	0.5 - 0.7
SO <sub>4</sub>	38 - 43	24 - 27
Alkalinity "CaCO <sub>3</sub> "	292 - 311	122 - 148
Hardness "CaCO <sub>3</sub> "	260 - 282	126 - 131
Total coliform /100ml	2- 4	800 - 1080
Escherichia coli "E. coli"/100ml	0	88 - 120
Colony count 22°C /ml	5	not measured
Colony count 37°C /ml	1	not measured

In general, the quality of pumped water at Naga Hamada site has higher concentrations for most of chemicals. Chemical contents of the pumped water at this RBF site are higher than the previous investigated RBF site, Sidfa, located on the western side of Nile [10]. Moreover, there are small amounts of nitrate, phosphate and chloride and moderate amounts of manganese, sulfate, and total dissolved solids. Manganese concentration in the Naga-Hammadi RBF site is higher than Sidfa RBF site. On the other hand, microbiological quality of the current RBF water is better than those measured at Sidfa site. However, quality results presented in Table 1 indicate that the quality parameters of Naga-Hammadi RBF site are under the allowable Egyptian standards for drinking purposes.

### 3.2. RBF performance

In RBF, the production water is a mixture of background groundwater and Nile water with many transformation processes for the filtered Nile water. Figure 2 indicates that filtrated Nile water plays the key element to dilute the background groundwater moving into production wells. Due to about 100 m distance of pumping wells from Nile, it is anticipated that the pumped water will has natural groundwater characteristics more than filtered Nile water. Chloride, bromide and iodide are believed to be among the most conservative constituents of groundwater and therefore reflect water origins with less ambiguity than other dissolved species [18]. In this work, chloride "Cl" amounts could be used as conservative constituent to estimate the percentage of Nile water into wells water. Reported values for chloride from [19-20] for the natural groundwater and the Nile water at closed locations to the study site were used to estimate the percentage of the Nile water in the pumping one. At Sidfa RBF system, the estimated Nile filtrated to pumping wells, applying mass conservation principal is about 51%.

Natural groundwater in the desert fringes at Naga-Hammadi RBF site has more values of most chemical constituents. Previous works have showed that there are significant reductions in river impurities by RBF in many sites [3]. The significant chemical changes are connected with microbiologically mediated redox processes [4]. Inducing of background groundwater with more values of the chemical species, into bank wells, may be balance or alter reduction through biochemical reactions of bank filtration. From current measurements, induced Nile water, about 51%, has the main impact on this RBF, 100 m from the river. Results indicate that Nile filtered water has diluted the natural groundwater. The outcome of this dilution is the significant quality improvements especially water salinity of palaeowater groundwater [12].

Another aspect of water quality is the microbiology criteria. However, microorganisms such bacteria and viruses of surface Nile water were effectively removed in Naga-Hammadi RBF plant. The two sampled wells showed that significant removal of microorganisms through RBF plant. This microbiology removal maybe due to filtration processes and impact of travel time of RBF system. The current finding is in agreement with other results of previous works [3 -21-22]. To give a detailed picture of RBF in Nile valley, more research works are needed to measure quality parameters along the pathway from Nile to production wells. Also, there is a need to get detailed information about biogeochemical reactions and aquifer conditions either aerobic or anoxic.

## 4. Conclusions

A full-scale RBF plant located in the eastern bank of Nile River at Naga-Hammadi in Upper Egypt was observed. Physical, chemical and microbial measurements have proven the effectiveness of RBF system to treat Nile water in Upper Egypt. Monitoring values of turbidity, chemical species, alkalinity, hardness, and TDS were



significantly reduced. All measured quality parameters at the RBF site are under the allowable limits for potable water. For microorganisms, the removal efficiency of Naga-Hammadi RBF site is remarkable. Nile filtrated water was estimated to contribute about half the abstracted RBF water. As the RBF is natural process, its capital and operating costs compared to conventional water treatment plant are much lower. These advantages of RBF in Egypt Nile valley make it as a proven method for water supply without requiring any further treatment except chlorine or as pre-treatment for higher water quality. RBF might be integrated with the tradition treatment plants allocated on Nile banks to secure water supply during the crises of River oil spills. Further work is needed to delineate the treatment processes occurring during the RBF in Nile valley. Furthermore, guidelines for design considerations such as distance from Nile bank and the pumping rate of wells are needed.

### **Acknowledgment**

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## طريقة الترشيح الطبيعي عبر ضفة النهر للإمداد بمياه الشرب في المناطق شبه الجافة

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### الملخص:

خلال السنوات الأخيرة واجهت مصر حوادث عدة لتلوث مياه نهر النيل من بقع بترولية مما أدى إلى إغلاق محطات تنقية مياه الشرب الواقعة على ضفة النهر على فترات متفاوتة من أسوان إلى القاهرة. وعموما فإن الإمداد بمياه الشرب باستخدام تكنولوجيا طبيعية ورخيصة التكلفة تسمى الترشيح عبر ضفة النهر تستخدم حاليا على نطاق دولي واسع. ففي أوروبا تستخدم هذه الطريقة لأكثر من 100 سنة لاستعمالات مياه الشرب والصناعة من انهار الراين والدانوب والألب. خلال هذه الطريقة الطبيعية يتم ترشح وإزالة الشوائب من مياه الأنهار خلال سريانها إلى آبار السحب بجوار الضفة حيث تتم المعالجة الطبيعية والكيميائية والبيولوجية للمياه السطحية. في الدراسة الحالية تم بحث موقع ترشيح طبيعي على ضفة النيل الشرقية في صعيد مصر. هذه المحطة أنشئت لإمداد العاملين بمشروع قناطر نجع حمادي الجديدة بمحافظة قنا من خلال آتئين من الآبار الرأسية عمقهما 55 متر وعلى بعد 100 متر من النيل شرقا. لم يتم استخدام أي معالجة إضافية للمياه المستخرجة ما عدا التطهير بالكلور. تم أخذ عينات مياه من الآبار وأجريت التحاليل الكيميائية والبكتريولوجية لها والتي كانت نتيجتها أن المياه المستخرجة بهذه الطريقة هي مطابقة لمواصفات مياه الشرب. نتائج هذه الدراسة تثبت أن طريقة الترشيح الطبيعي عبر ضفة النهر هي طريقة فعالة لتنقية مياه النيل من الشوائب ولإمداد بمياه الشرب من نهر النيل في صعيد مصر وايضا يمكن دمج هذه الطريقة مع المحطات القائمة لتأمين إمدادات مياه الشرب في حالة تلوث النهر بمواد كيميائية أو بترولية.