Jurnal Teknologi

Full Paper

RIVERBANK FILTRATION: EVALUATION OF HYDRAULIC PROPERTIES AND RIVERBANK FILTERED WATER AT JENDERAM HILIR, SELANGOR

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Article history
Received
24 April 2015
Received in revised form
4 May 2015
Accepted
9 May 2015

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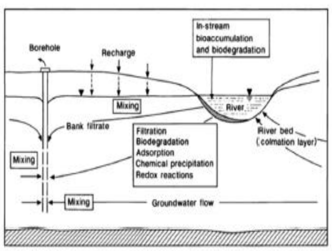
Graphical abstract



Abstract

Riverbank filtration (RBF) is a natural process where river water is induced to flow through riverbed soils to pumping wells located on the banks. It is a well-established and proven natural water treatment technology. Improvement of water quality is achieved by a series of chemical, biological and physical processes during subsurface passage. This paper aims at evaluating the hydraulic properties of the aquifer and bank filtered water at the RBF study area located in Kg. Jenderam Hilir, Selangor. The pumping well was able to produce 142.21 m^3/hour of water with a drawdown of 2.17 m. Transmissivity (T) and hydraulic conductivity (K) were 59.15 m^2/hour and 4.41 m/hour respectively. Turbidity and color from the range of 52.1 to 62.3 NTU and 9 to 44 PtCo were reduced to 0.27 to 0.55 NTU and 7 to 12 PtCo respectively.

Keywords: Riverbank filtration, hydraulic conductivity, pumping test, turbidity, color

Abstrak

Kaedah penapisan tebing sungai (RBF) adalah proses semulajadi di mana air sungai menyusup ke dalam tebing sungai dan mengalir ke telaga pengepaman yang terletak berhampiran tebing. Ia adalah teknologi rawatan air yang mantap dan telah terbukti keberkesanannya. Peningkatan kualiti air sungai dicicapai melalui stau siri proses kimia, biologi dan fizikal yang berlaku sepanjang laluan air di kawasan sub-permukaan. Kajian ini bertujuan untuk menilai sifat-sifat hidraulik akuifer dan air telaga yang telah ditapis di tapak kawasan kajian yang terletak di Kg jenderam hilir, Selangor. Telaga pengepaman mampu menghasilkan sejumlah 142.21 m^3/jam dengan kadar penurunan paras air sebanyak 2.17 m. Nilai transmisiviti, T dan kadar resapan,K masing-masing adalah 59.15 m^2/jam dan 4.41 m/jam. Bagi kadar kekeruhan dan warna yang mempunyai nilai masing-masing 52.1-62.3NTU dan 9-44 PtCo telah berkurangan sebanyak 0.27- 0.55 NTU dan 7-12 PtCo.

Kata kunci: Penapisan tebing sungai, kadar resapan, ujian pengepaman, kekeruhan, warna

1.0 INTRODUCTION

Malaysia is one of the developing countries that experienced rapid industrialization, urbanization and the growth of population. Due to that, it has caused an increasing demand of water supply, especially in industrial, domestic and agricultural areas. As Malaysia is located in the tropics, it is blessed with abundant rainfall with an annual precipitation of 250 centimeters (98 in) and a total volume of 990 km^3.

Most of the water supply in Malaysia originates from rivers and streams, while ground water contributes only 1% of the water required [1].

According to the Malaysia Water Industry Guide (2011), 96.8% and 90.1% of the urban and rural population enjoyed clean water supply respectively. Total water consumption for domestic and non-domestic at the end of 2010 was 9164 MLD. The country's water requirement is expected to increase by 60% to 18 billion cubic meters in 2050 compared to 11 billion cubic meters in 2000. In order to obtain a sustainable water use, riverbank filtration (RBF) offers a good practice to treat and protect the surface water as well as groundwater.

Riverbank filtration (RBF) is defined as the process, where the river water is induced to flow through a riverbed to pumping wells located on the bank at a certain distance from the river. Pumping well or collector well will create a pressure head difference between the river and aquifer, which induces the water from the river to flow downward through the porous media into the pumping wells. In the RBF system, two different water resources are used. These are the surface water from the river percolates towards the well and groundwater of the surrounding aquifer [2]. It is widely applied in the European countries including of Germany, Netherlands, France, Switzerland, and Hungary. In Germany, RBF has been used along the Rhine River for many decades and it is the main important source for the drinking water supply. Riverbank filtration constitutes nearly 16% of drinking water production in Germany [3]. Riverbank filtration is applied in the United States as a treatment technology due to its removal efficiency and cost-effectiveness in drinking water treatment [4].

Riverbank filtration is a natural process using alluvial aquifers to remove contaminants and pathogens in river water for the production of drinking water. According to the previous study, RBF is effective in reducing turbidity, total coliform, microbial contaminants, natural organic matter and organic contaminants [5]. Several authors reported that RBF has the capability in reducing the risk of *Cryptosporidium* and *Giardia* contamination from drinking water when flow path length and filtration time are sufficient [6, 7]. Singh *et al*. [8] reported that microbial monitoring of different RBF systems in Ohio, Missouri and Wabash Rivers revealed occasional presence of *Cryptosporidium* and *Giardia* in river waters but never in any sample from the wells.

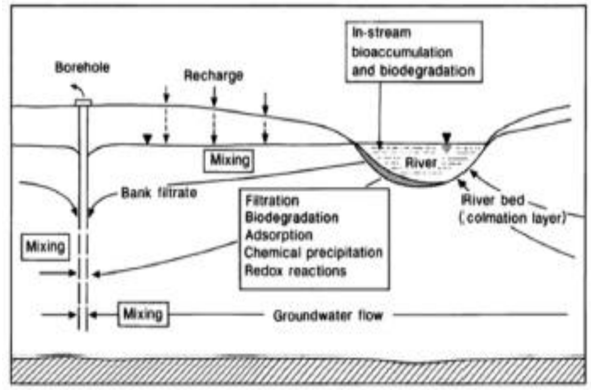


Figure 1 Basic scheme of riverbank filtration and main attenuation processes [7]

The reduction of pollution levels is accomplished by a number of processes, including physical filtration, microbial degradation, ion exchange, precipitation, sorption, and dilution as shown in Figure 1. Marcela *et al*. [9] reported there are other factors that also contribute to the treatment include the river water and the groundwater quality, the porosity of the medium, the water residence time in the aquifer, temperature and pH conditions of water, and oxygen concentrations. The quality of bank-filtered water is affected by the riverbed sediment, the aquifer media, the infiltration velocity, and the residence time in the aquifer [10]. The most important aspect when evaluating the potential of RBF site is the hydrogeological characteristics. Thickness and hydraulic conductivity of the aquifer and available drawdown are an important part of hydrogeological condition when evaluating the potential of pumping for a significant volume of water from the well. This study area was chosen due to the high water demand in the area and high pollution level of the river. The objectives of this paper are to study the hydraulic properties of the aquifer in the study area and the bank filtered quality during the pumping test.

2.0 EXPERIMENTAL

2.1 Site Description

The study site is located at Jenderam Hilir, Dengkil in the southwest state of Selangor within the Langat Basin. It is approximately 4 km to the south of raw water intake of SYABAS water treatment plant. It is located between latitude 2° 53′28.56″N to 2° 53′39.75″ and longitude 101° 42′03.78″E to 101° 44′14.58″E. The Langat river basin is an important water supply source in the Klang Valley. The use of Langat River is not only limited to water supply, but also for other purposes such as recreation, fishing, effluent discharge, irrigation and even sand mining. Figure 2 shows the location of the study area.

The study area is drained by 3 major tributaries which include the main Langat River, Semenyih River and Jenderam Hilir River. The main tributary, Langat River, flows about 182 km from the upper reach of the main range (Banjaran Titiwangsa) at the Northeast of Hulu Langat District in south-southwest direction and finally drains into the Straits of Malacca. There are two reservoirs built in the study area, namely Sungai Langat Dam and Sungai Semenyih Dam. Along the Langat river basin, there are eight water treatment plants. This study site was chosen due to the high water demand in the area and RBF is seen as an alternative source with very high potential to be developed as a supplementary source to meet the high public water supply demand.

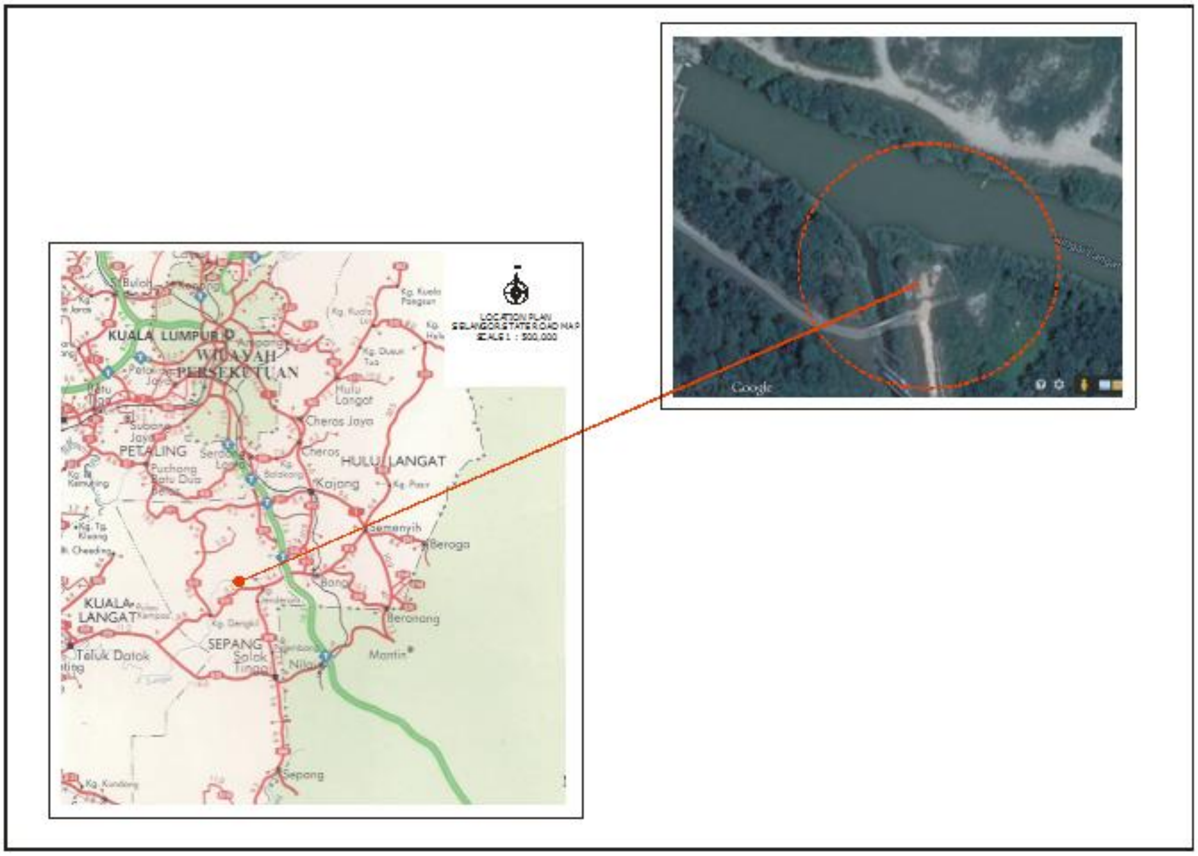


Figure 2 Location of the study area

2.2 Construction of Wells and Soil Sampling

The pumping well in the study area was constructed by NAHRIM (National Hydraulic Research Institute of Malaysia) in 2009 and it is used to determine the hydraulic parameters of the aquifer and the well itself. According to the data provided by NAHRIM, the well was drilled using a semi-mechanized bangka (percussion method). The construction of the exploration alluvium tubewell consists of 255 mm diameter PVC screen from 11.4 m to 17.4 m below ground water level, followed by blank PVC pipe of the same diameter. A 1 m length blank PVC pipe was installed at the bottom of the screen as a sand-trap. The annular pace between the borehole and PVC screen was then gravel-packed with 3-6 mm size gravel. The bottom of the sand-trap was then installed with a PVC end-cap. Six monitoring wells were constructed surrounding the pumping well. The average depth of the monitoring wells was between 10 m to 25 m. The wells were assembled with PVC pipe with 1-3 m screens at the end with diameter 50 mm. Soil samples for this study were taken during the drilling work of the monitoring wells. For soil characteristic, soil samples were collected from borehole MW2 which was located 4.7 m from the pumping well. The borehole was drilled at 26 m depth. The samples were collected at every meter depth of the borehole and placed in the plastic bag and were then transported to USM. The soil samples were characterized in order to understand the classification and the type of the soil using grain size analysis and constant head permeability test.

2.3 Soil Samples Analysis

2.3.1 Grain Size Analysis

This test is performed to determine the percentage of different grain sizes contained from borehole MW2. The mechanical or sieve analysis is performed to determine the distribution of the coarser, larger-sized particles, while the hydrometer method is used to determine the distribution of the finer particles. This analysis was performed based on British Standard 1377: Part 2:1990.

The initial mass of the soil in the container was measured and then it was soaked in distilled water for 24 hours. After that, the soil was washed using 63µm sieve until the water was clear. The remaining soil on that sieve was dried in the oven for 24 hours. The dried soil was weighed again and started with sieve analysis. The sieves were fixed in the order of 14 mm, 10 mm, 6.3 mm, 5.0 mm, 3.35 mm, 2.0 mm, 1.18 mm, 600 µm, 425 µm, 300 µm, 212 µm, 150 µm and 63 µm. The weight of the soil that was retained on each sieve was measured after completing the shaking process in 10 minutes. The soil that passed through the finest sieve (63 µm) was collected and undergone for hydrometer test. The hydrometer test was conducted using the measuring cylinder (1000 ml) and sodium silicate (Na2SiO3) as a dispersing agent. The test was performed using British Standard 377: Part 2:1990:9.6.

2.3.2 Permeability Test

Permeability is a measure of the ability of soil to transmit fluids. Permeability or hydraulic conductivity refers to the ease with which water can flow through a soil. Hydraulic conductivity is the necessary parameter to estimate the travel time at different depths [11]. This test is performed based on ASTM D 2434-Standard Test Method for Permeability of Granular Soils (Constant Head). The soil was first oven-dried for 24 hours before placing in the column. The column with and without soil sample was weighed using electronic balance. The soil sample, then poured into the column. The flexible tube from the tail of the column was connected to the bottom outlet of the permeameter and the valve on the top of the permeameter was kept open. Water was allowed to flow constantly. Figure 3 shows the schematic diagram of the test. A quantity of water was collected from the outlet using measuring cylinder for a given time interval (30 s).

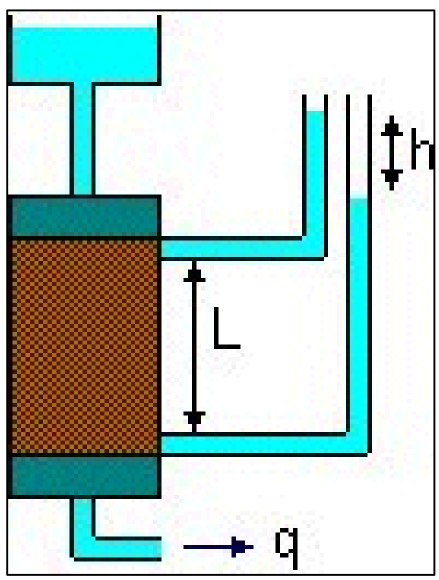


Figure 3 Schematic diagram of permeability test

2.4 Pumping Test

The pumping test program for exploration test well (PW) consists of a Step Drawdown Test, a 72 hour Constant Discharge Test and Recovery Test. It was started on 18 July 2013 until 24 July 2013 for test well (PW) and 6 monitoring wells which were MW1, MW2, MW3, MW4, MW5, and MW6. The test was carried using a DT 95-10 Dynatech submersible pump. The submersible pump was installed using a crane to a depth of 9.5 m below ground level and 125 mm diameter GI riser pipes was connected to the submersible pump. A 125 mm diameter gate-valve was connected to the riser pipe to regulate the flow rate. The riser pipe was then directed to a 90° V-notch tank to measure the flow rate. After the installation of the pump and all other necessary set-up were completed, a calibration test was carried out for 2 hours to determine the capacity of the exploration test well and also to determine the pumping rates for the Step Drawdown Test. The Step Drawdown Test was done on 20 July 2013 with five discharging steps, with step 1 to step 4 for a duration of 90 minutes, while step 5 was carried out for a duration of 120 minutes. A short Recovery Test was conducted then, after the final step for 60 minutes. The Constant Discharge Test was done in duration of 72 hours started on 21st July 2013 and Recovery Test was carried out on 24th July 2013. The measurement of groundwater levels was performed using dip-meter. The recovery test was then carried out immediately after the Constant Discharge Test was completed. It was done in 2 hours. The water discharge from the 90° V-Notch through the pumping test was diverted into the nearby river in order to prevent soil erosion of the river banks as part of the environmental awareness.

2.5 Water Samples and Water Quality Analysis

For the study of water quality, water samples from the pumped well and river water were collected. The samplings were carried out for every 12 hours started at 3 pm on 21st July until 3am on 24th July 2013. Samples from the river were collected at varying depth 1.5 m to 3 m while samples from the test well (PW) were collected via the tap that has been installed at the riser pipe. The samples were collected in a clean polyethylene bottle. The parameters that have been tested were included turbidity, salinity, pH, temperature, conductivity, colour and iron. The samples were tested using YSI Proplus meter and DR2800 Spectrophotometer. All tests were conducted on site during the constant discharge rate test. The sampling method and analysis were in accordance to [12].

3.0 RESULTS AND DISCUSSION

3.1 Soil analysis

A sieve analysis was done for every meter of the soil sample. The values of D_{10}, D_{30}, and D_{60} were obtained from the particle size distribution, the range of D_{10} is 0.075 mm to 0.7 mm, D_{30} is 0.1 mm to 1.3 mm and the D_{60} is 0.15 mm to 1.9 mm.

From the particle size analysis of the soil samples, the majority of the soil particles in the borehole MW2 fall under fine sand to fine gravel. Figure 4 shows the particle size distribution of the soil samples. In order to sort out the type of soil, two classification system was used as an indicator which are U.S Department of Agriculture (USDA) and the British Standards of Soil Classification System (BSSCS). Based on the two systems, the soil samples were classified as clay, silt, silty clay loam, clayey sand and silty sand or clayey silt. According to the grain size analysis results, the thickness of the aquifer ranges from 5 to 20m and it can be locally heterogenous because the presence of beds of fine to coarse-grained sand. The bedrock is located at a depth of 20m.

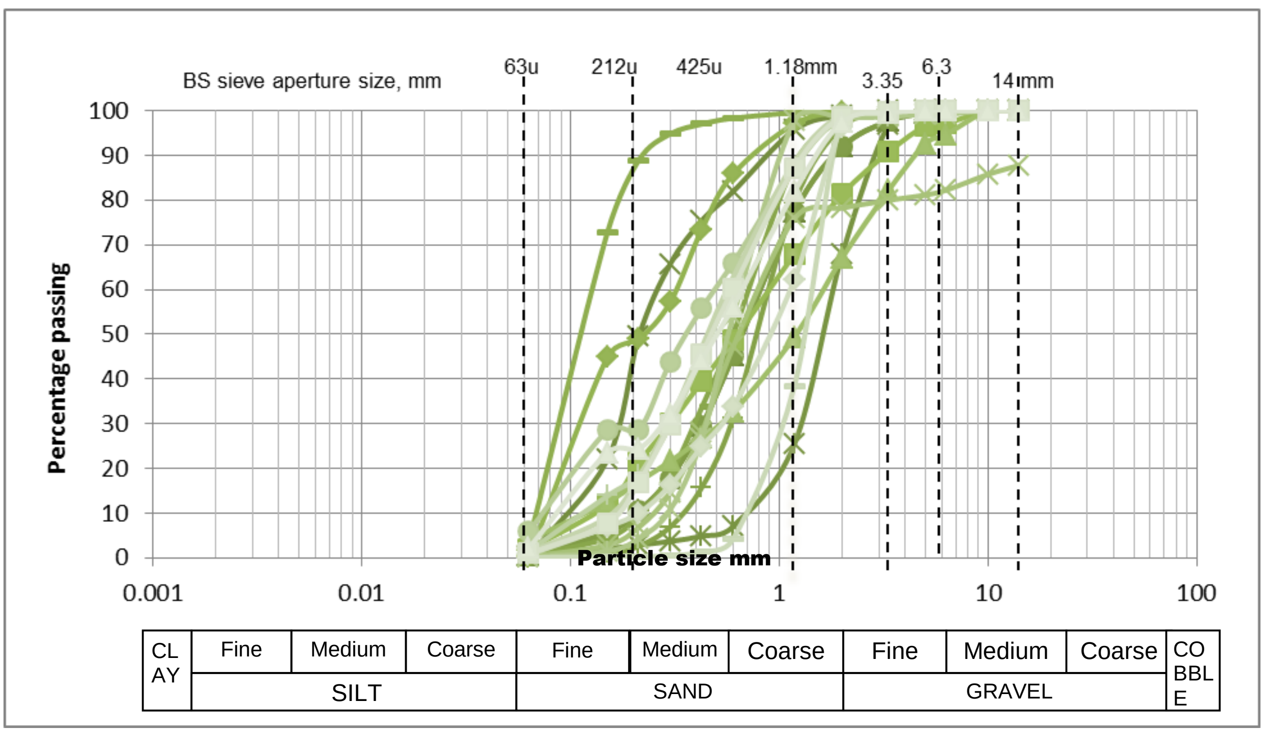


Table 1 shows the results of permeability. From the constant head permeability test, the result showed that the permeability of the soil was in the range 10^{-1} cm/s to 10^{-3} cm/s. This indicated permeability of the soil in the aquifer is high and has a good drainage capacity. From the permeability result, the soil is classified as gravel and clean sand which is the same as the result obtained from the USDA and BSSCS system. Based on the characteristics obtained, it could be concluded that the aquifer in the study area has a potential for riverbank filtration, (RBF).

Table 1 Permeability result from constant head test

Depth, m	Permeability, cm/s
8-14 (Excluded 9 and 10)	3.0×10^{-2}
15-17	7.0×10^{-3}
18-19	3.6×10^{-1}
20-22	7.0×10^{-3}
23-24	6.3×10^{-2}
24-25	6.1×10^{-2}

3.2 Pumping Test Results

Step Drawdown Test was carried out with pumping rate of 28.44 m^3/hour, 56.88 m^3/hour, 85.33 m^3/hour, 113.77 m^3/hour and 142.21 m^3/hour. The initial static water level before the test was 5.10 m below ground level and the final water level was at 6.83 m below ground water level. From the Step Drawdown Test it could show the well efficiency of the test well (PW) for step 1 until step 5. Table 2 shows the well efficiency results. The results indicate that test well (PW) has the efficiencies of 90.59% , 82.80%, 76.24%, 70.64% and 65.81% for step 1 to step 5 respectively. The total drawdown (Sw) is very low which 1.08m at step 5. It could be concluded that this well has a very high efficiency due to the presence of sandy gravel in the aquifer which has high porosity and transmissivity. It also shows that the test well (PW) is capable of yielding a significant volume of water.

Table 2 Well efficiency of the test well

Step	Q (m^3/hr)	Δs (m)	S_w (m)	S_w/Q	W_e (%)
1	28.44	0.23	0.23	0.00809	90.59
2	56.88	0.27	0.50	0.00880	82.80
3	85.33	0.17	0.67	0.00791	76.24
4	113.77	0.17	0.84	0.00748	70.64
5	142.21	0.24	1.08	0.00764	65.81

Abbreviation, Q is discharge, Δs is drawdown, S_w is total drawdown, W_e is well efficiency

According to the results of the Step Drawdown Test, the Constant Discharge Test was selected based on step 5 which is at 142.21 m^3/hour. The flow rate was kept constant throughout the test for a duration of 72 hours. Thus the overall rate for the production well is 3.413 million liters per day. The initial static water level was at 5.14 meters below ground level and the final water level after 72 hours of continuous pumping was at 7.31 meters below ground level. The drawdown was very low with only 2.17 meters. The transmissivity (T) and hydraulic conductivity (K) were 59.15 m^2/hour and 4.41 m/hour (105.84 m/day) respectively. Recovery Test was then carried out immediately after the Constant Discharge Test ends. The Recovery Test was carried out for 2 hours. After 2 hours of the test, water level recovered to 5.51 meters below ground level, with a residual drawdown of 0.37 meters. The recovery after 2 hours was 82.95%, with a transmissivity value (T) of 144.58 m^2/hour and hydraulic conductivity value (K) of 10.79 m/hour (258.96 m/day). Table 3 shows the data of T and K values. From the data it shows that the drawdown value is very low. It proved that the test well (PW) has an ability to produce much higher amounts of water.

Goldschneider *et al*. [13] stated that suitable sites for RBF are sand and gravel aquifers with hydraulic conductivities $k_f > 10^{-4}$m/s, a minimal thickness of 5 m and a good hydraulic connection to the adjacent surface water. Kühn and Müller [14] reported that RBF sites in Germany have a hydraulic conductivity in the ranges 0.005 to 0.5 m/s. According to the previous studies, the thickness of some existing RBF sites ranges from a minimum of 3–5 m at Böckingen by the Neckar River to a maximum of 40–55 m at Torgau-Ost by the Elbe River in Germany, with hydraulic conductivities in the range $1 \times 10^{-2} - 7.5 \times 10^{-5}$ m/s [15]. Based on the soil analyses and pumping test results it indicates that the study area has a potential as a to be developed as a RBF site.

Table 3 Result of pumping test for the value of transmissivity, T and hydraulic conductivity, K

Test	Date	Well	Drawdown (m)	Transmissivity, T (m^2/h)	Hydraulic Conductivity, K (m/h)
Constant Discharge	21st July 2013-24th July 2013	PW	2.17	59.15	4.41
Recovery	24th July 2013	PW	0.37	144.58	10.79

3.3 Water Quality Analysis

Department of Environment of Malaysia (DOE) has monitored the water quality of river in Malaysia based on the water quality index (WQI) to evaluate the water quality status and river classification. The water quality in the Langat River Basin has been deteriorating over the years, as evidenced from the water quality database compiled for 15 years. The recorded WQI ranged from 58.1 to 75 which corresponds to pollute (WQI 0-59) and moderately polluted (WQI 60-80) [16]. Figure 5 shows the comparison between samples from the Langat River and the pumping well during the pumping test. The water samples were taken from pumping well and river at 12, 24, 36, 48, 60 and 72-h interval during the pumping test. Water quality sampling conducted at intervals of 12 hours is to monitor changes in water quality during the day and evening, but there is no significant difference between the results. Turbidity, which indicates the cloudy or muddy appearance of water, is caused by the presence of suspended and dissolved matter such as clay, silt finely divided organic matter, plankton and other microscopic organisms, organic acids, and dyes. The color of water, whether as a result of dissolved compounds or suspended particles, could affect the turbidity measurement. As the river water passes through the aquifer, most contaminants are attenuated and diluted. Therefore, most of the turbidity and organic pollutants can be removed by the bank side material and diluted with groundwater. The table shows that water samples from the river have high turbidity which is exceeding the Malaysia Drinking Water Standard (2010). For six consecutive samplings, the turbidity of river water was in the range of 52.1 to 62.3 NTU which is against the Malaysia Drinking Water Standard value of 5 NTU. However, the values of water samples from pumping well were in the range of 0.27 to 0.55 NTU, which proves that RBF can significantly reduce the turbidity of the river water at the study area. The percentage removal of turbidity was in the range of 98.9% to 99.6%. Figure 6 shows the results of turbidity. The result of color also shows a slight decrease from the range 9 to 44 PtCo in the river to range 7 to 12 PtCo. The percentage removal of color was in the range of 22.2 to 72.7%. Total dissolved solid, (TDS) content was also significantly reduced from 149.5 to 137.2 mg/l in the river water to a range of 43.6 to 83.9 mg/l. Figure 7 shows the results of TDS. The high TDS concentration in the rivers is attributed to the presence of extreme anthropogenic activities along the river course and runoff with high suspended matter [17]. Electrical conductivity (EC) depends on temperature, ionic concentration, and types of ions present in the water. The EC of the river water in the study area varies from about 163.5 to 249.8 µS/cm, and a lower electrical conductivity was observed for the pumping well which range from 135.47 to 141.3 µS/cm. Figure 8 shows the results of electrical conductivity. However, result of iron was increased for water samples in the test well (PW) and also exceeded the permissible limit of the Malaysian Drinking Water Standard. The limit for Fe was only 0.3mg/l. The Fe concentration in the well ranges from 0.88 to 2.08 mg/l, while in the river water, it ranges from 0.17 to 0.58mg/l. Figure 9 shows the comparison of iron for Langat River and Pumping Well. Grischeck and Hisock [18] studied that water quality change depends mainly on the redox reactions. When the surface water is low in dissolved oxygen, the condition during underground passage will likely become anaerobic, which can cause iron and manganese to become soluble and therefore be drawn into the groundwater well. This can lead to the undesirable effect of degrading the water quality to unacceptable drinking water standards [3]. From the pumping test data sets, the percentage removals widely vary for the different substances, ranging from 0 to 99.6 %; an increase in concentration during infiltration can be observed for Fe which reached concentration levels that are exceeded the permissible limit. Therefore, post-treatment is needed to target a wide range of substances.

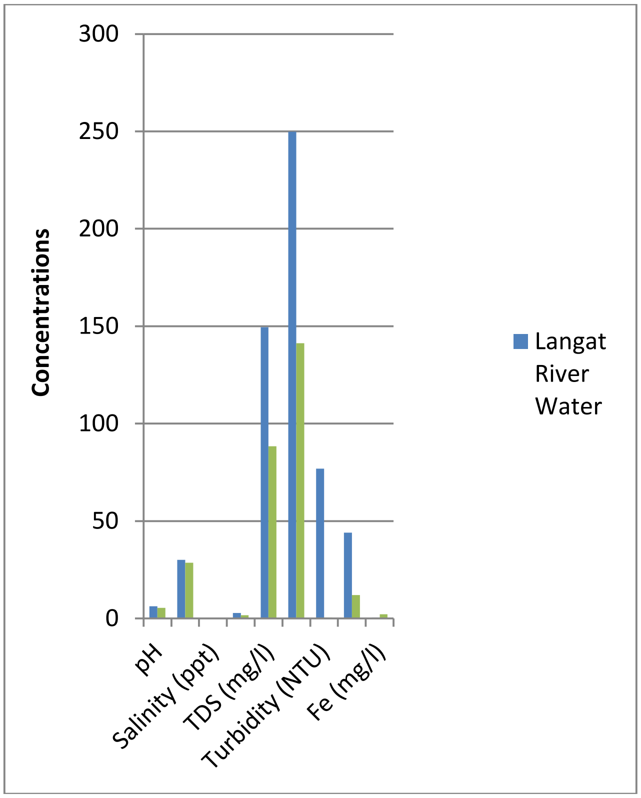


Figure 5 Comparison of Langat river water and pumping well, during the pumping test

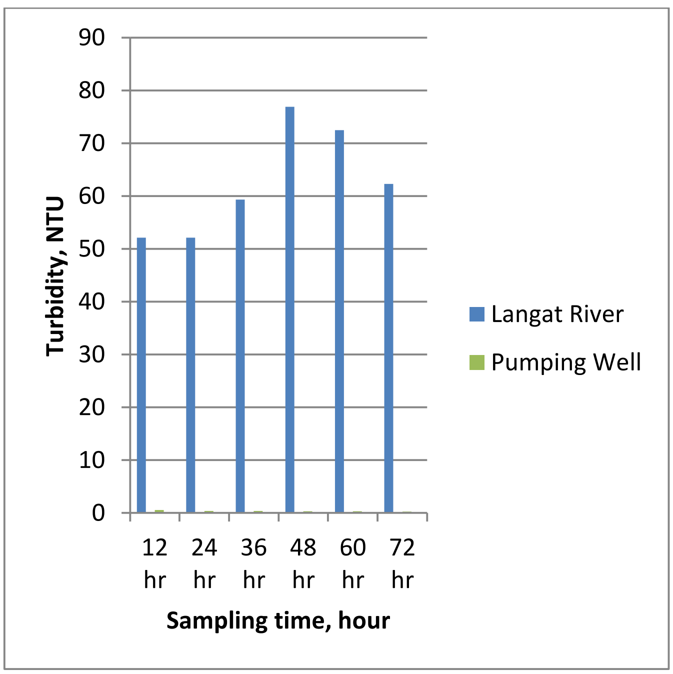


Figure 6 Value of turbidity for Langat river and pumping well

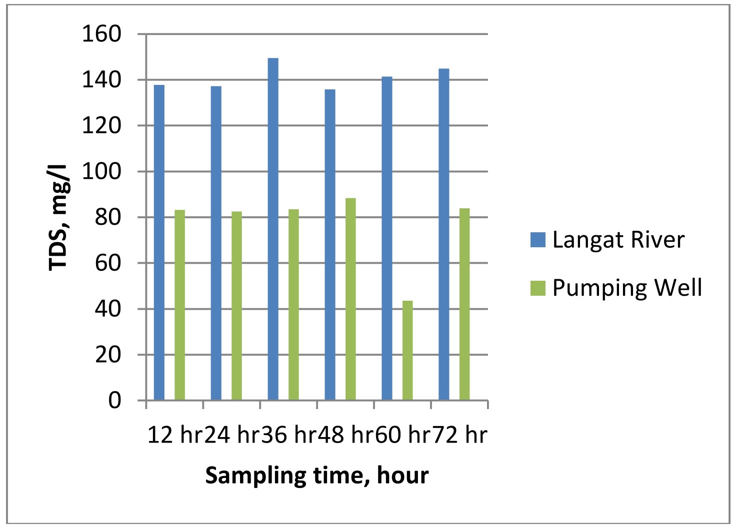


Figure 7 Value of TDS for Langat river and pumping well

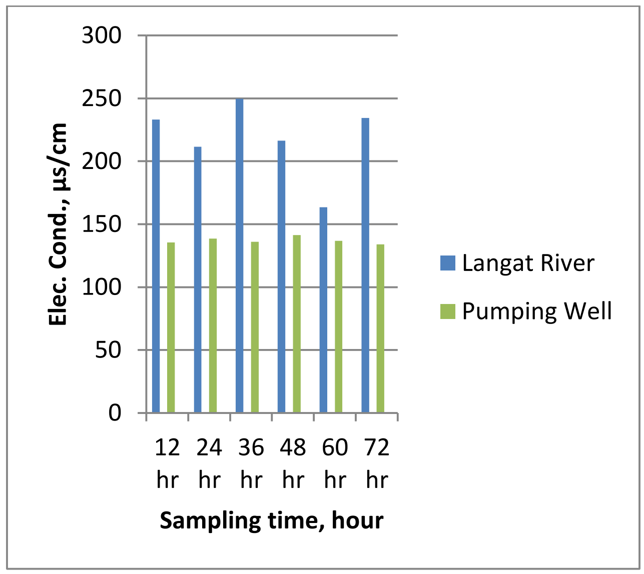


Figure 8 Electrical conductivity value for Langat river and pumping well

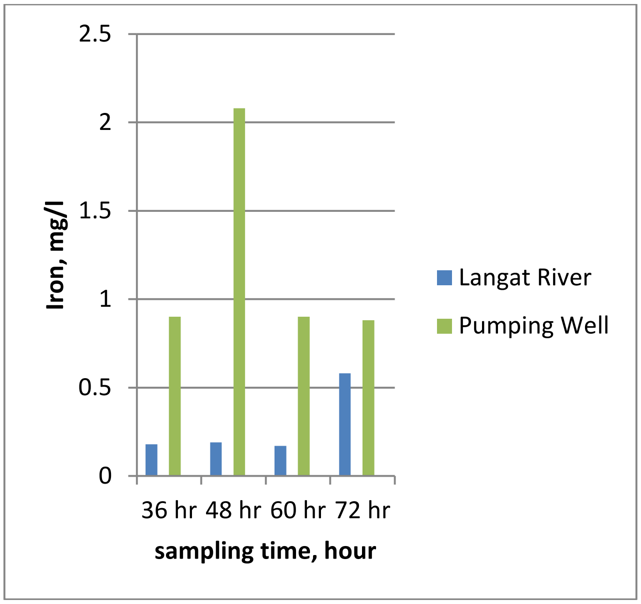


Figure 9 Comparison of iron between Langat river and pumping well

4.0 CONCLUSION

This study was undertaken to evaluate the effectiveness of RBF technology in the study area. Based on the pumping test results, the test well (PW) was capable to produce 142.21 m^3/hour of water (3.413 MLD) with the drawdown 2.17m. The transmissivity value (T) and hydraulic conductivity value (K) was 59.15 m^2/hour and 4.41 m/hour (105.84 m/day) respectively. From the results, it clearly shows that RBF is capable to reduce turbidity and color. Turbidity was reduced from the range 52.1 to 62.3 NTU in river water to 0.27 to 0.55 NTU in the test well (PW). The result of color also shows a slight decrease from the range 9 to 44 PtCo in the river to range 7 to 12 PtCo in pumping well. According to that, the implementation of RBF at this study area is suitable and will be able to produce enough quantity of drinking water for the population of Langat Basin, Selangor

Acknowledgement

The authors would like to acknowledge Ministry of Education Malaysia for providing LRGS grant No. 203/PKT/6726001-Riverbank Filtration for Drinking Water Source Abstraction to fund this research.

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