Attenuation of River Contaminant using River Bank Infiltration in Jenderam Hilir, Dengkil, Selangor

Mohd Khairul Nizar Shamsuddin[1,*], Saim Suratman[1] and Mohamad Faizal Tajul Baharuddin[2]

[1]Geohydrology Research Centre,
National Hydraulic Research Institute of Malaysia, Lot 5377, Jalan Putra Permai, 43300 Seri Kembangan, Selangor, MALAYSIA.
[2]Department of Water and Environment,
Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja 86400 Batu Pahat Johor, MALAYSIA.

Abstract: Bank infiltration (BI) refers to the process of surface water seeping from the bank or bed of a river to the groundwater production wells. During the water's passage through the ground, its quality changes due to microbial, chemical and physical processes, as well as mixing with groundwater in the aquifer. The BI study in Jenderam Hilir, Selangor is a pilot project to develop a better and sustainable source of water, and will provide a good platform to introduce this method in Malaysia. BI has been successfully implemented in many Asian and European countries. This site was chosen due to the high water demand in the area and groundwater is seen as one of the source with very high potential to be developed as supplementary source to meet the high public water supply demand. The objective of this study is to determine the effectiveness of BI and improving the quality of river water, and to determine the effective rate of water extraction from the alluvium aquifer in the study area. Twenty five (25) monitoring wells and 2 test wells were constructed at the study site and pumping tests have been carried out on these two test wells. The pumping tests shows that DW1 and DW2 were able to produce more than 15.9 m^3/hr (0.3816 MLD) and 128m^3/hr (3.072 MLD) during the duration of 72 hours pumping tests with drawdown for DW1 was 4.17 m and DW2 was 2.63 m respectively. The distance between the river and the test well is more than 18 m and the shortest travel time is 10 days. The river water was filtered through a 16 m thick silty sand for DW1 and 13 m thick gravelly sand for DW2. Both wells are located in confined aquifer adjacent to the Sungai Langat. Water quality analyses were carried out and the results shows a decreasing trends in turbidity, nitrate, aluminium and sulphate in groundwater which were very high in the Sungai Langat. Microorganism count (*E. coli*, total coliform, *Cryptosporidium* and *Giardia*) were also carried out. the microorganism counts were significantly reduced during the passage in BI which is capable to achieve more than 99.9 % removal of *E. coli*, total coliform and *Giardia*. The study on the effectiveness of BI method is a proactive effort of NAHRIM to improve surface water quality as a source for domestic water of the modern urbanised area.

Keywords: groundwater, quality, river, microorganism

1. Introduction

Population growth, rapid industrialization, urbanization and infrastructure development in Malaysia has increases the usage of the water and simultaneously increase the demand of the water supply for domestic, industrial and agricultural sectors. However, the possible impact of climate change such as long dry season or drought, and increased in pollution has reduced the availability of clean water. Pollution of river water has made many river water unsuitable for source of raw water, thus, required an extensive treatment before ita can be used. It is known that most surface water sources in Malaysia are polluted to a certain extent by various pollutants coming from point sources such as landfills, industrial wastes and non-point sources of agricultural related activities and there is a risk for human consumption unless they are extensively treated [14]. The water operator incurred higher costs of water treatment particularly when using conventional sedimentation treatment plant in which higher concentrations of pollutants requires higher volumes of chemicals. At the same time, the volume of disinfection by-product (DBPs) is also high.

Constructing a new reservoir may damage the natural ecology and upset the balance in nature. Existing dams can no longer cope with such high demand whereas building new dams will increase the government expenditure and affect the environment in long term. Thus, there is a need to use groundwater as second sources of water supply to guarantee clean and permanent water supply in Selangor.

*Corresponding author: nizar@nahrim.gov.my

penerbit.uthm.edu.my/ojs/index.php/ijie

In order to supply safe drinking water and avoid disruption due to pollution, bank infiltration (BI) is one of the best methods to provide water from both river and groundwater. BI is known to effectively remove microorganism and pollutant when surface water flows through aquifer materials [15]. BI refers to the process of surface water seeping from the bank or bed of a river or lake to the production wells of a water treatment plant. During the water's passage through the ground, its quality changes due to microbial, chemical and physical processes, and due to mixing with groundwater in aquifer. BI can be accomplished through natural seepage into receiving ponds, shallow vertical or horizontal wells placed in alluvial sand and gravel deposits adjacent to surface waters, and infiltration galleries. Infiltration of river water to the aquifer cleans the water through physical and microbiological processes. BI is a low-cost and efficient treatment method for potable water applications and has been successfully implemented in many Asian and European countries. BI does not require chemical additives, is simple to operate, and requires minimal maintenance. BI can reduce concentrations of many pollutants including disinfection by-products (DBPs) through a combination of natural processes including filtration, biodegradation and dilution. Other advantages of BI include its ability to attenuate contaminant shock loads and reduce water temperature fluctuation [15]. Hence, the proper use of an alluvial aquifer could benefit water usage and water management [8]. The BI study in Jenderam Hilir, Selangor is a part of Managed Aquifer Recharge (MAR) system. This is a pilot project to develop a better quality and sustainable source of water, and provide a good platform to introduce this method in Malaysia. Hence, R&D work is being carried out on BI method as a form of natural treatment to increasing the quality of water sourced for public water supply.

Other than availability of flowing river, the hydrogeological characteristics are the most important aspect when evaluating potential BI sites. Aquifer thickness of the alluvium is part of hydrogeological conditions that are important factors in determining the availability of water of BI. Hydraulic conductivity of the aquifer and available drawdown in the well are major hydrogeological conditions to be taken into consideration when evaluating potential of pumping significant volume of water from well. The key factors in selecting and developing suitable BI sites are the extent of alluvial aquifer and thickness of the aquifer. The main goal of current work is to evaluate the proven effectiveness of BI technique in removing particulates, dissolved solids, and microbial pathogens from one of the Malaysia longest rivers, the Langat River. In particular, this work focuses on potable water supply in Langat Basin. The demonstration that BI system is an effective approach to treat the Langat River will expand the treatment options available to Malaysia water utilities.

2. Materials and method

2.1 Bank Infiltration site

The study area at Jenderam Hilir is located downstream of confluences of the Langat River and the Semenyih River. This area is a former tin mining area, where the lake at this old mining site has been used as water reservoirs. The Langat River river bank area at the Jenderam Hilir some 5 km south of the city of Putrajaya was chosen to test the effectiveness of BI at the Langat River. Jenderam Hilir is located in the southwest state of Selangor within the Langat Basin. It extends between 20 53' 28.56" N and 20 53' 39.75" N and 1010 42' 03.78" E and 1010 44' 14.58"E, covering an area of 10 km^2 (Fig. 1). The geology of the study area consists of phyllite, schists, slate and sandstone layers alternating of the Kenny Hill Formation with some conglomerates overlain by alluvium consisting of sand, gravel, clay and silt. The bedrock geology of the study area consists of meta sediments like mudstone, sandstone and shale of the folded Kenny Hill Formation. The Kenny Hill Formations overlies the schists of Hawthorden graphite,

2.2 Geophysical Investigation

Geophysical method was used to investigate the subsurface geology area as well as to determine the depth and thickness of the potential aquifer in the Jenderam Hilir. The principal geophysical technique used was multi-electrode resistivity profiling using the Lund Imaging System ES464 with an ABEM TSAS4000 Terra-meter. Eight resistivity survey lines ranges from 400-1200 m long were carried out using Schlumberger electrode arrangement with a total length of 6,040 m, employing 10 m electrode spacing. RES2DINV and DESIGNER ® were used to process the data.

2.3 Construction of Monitoring Wells and Test Wells

Eight (8) wells were drilled using YBM rotary drilling machine employing wash boring method and 17 holes were drilled using a motorized auger to a depth of 2-3 m below the existing water table. The drilling work was conducted in May 2009 to establish the subsurface geology and the depth of the water table in identified locations around the study area. A total of 25 monitoring wells (MW) were then constructed at the drilled locations, focusing to the downstream area of the Semenyih River and the Langat River (Fig. 2). The wells were constructed using PVC 50 mm or 75 mm outside diameter complete with 1 m long slotted screen.

Based on the exploration and geological information the diameter of the well from DW1 and DW2 is 255 mm with a depth of 19.0 and 18.40 m respectively. These wells were constructed for the purpose of determining the hydraulic parameters of wells and the aquifer

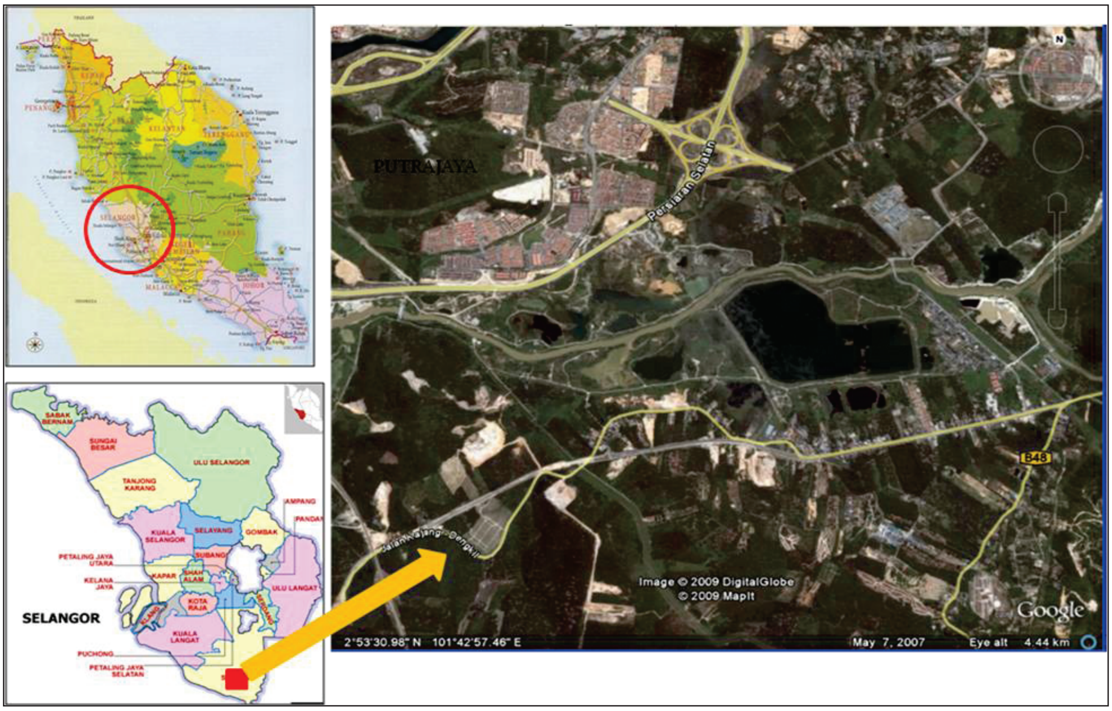

Fig. 1 Location of study area

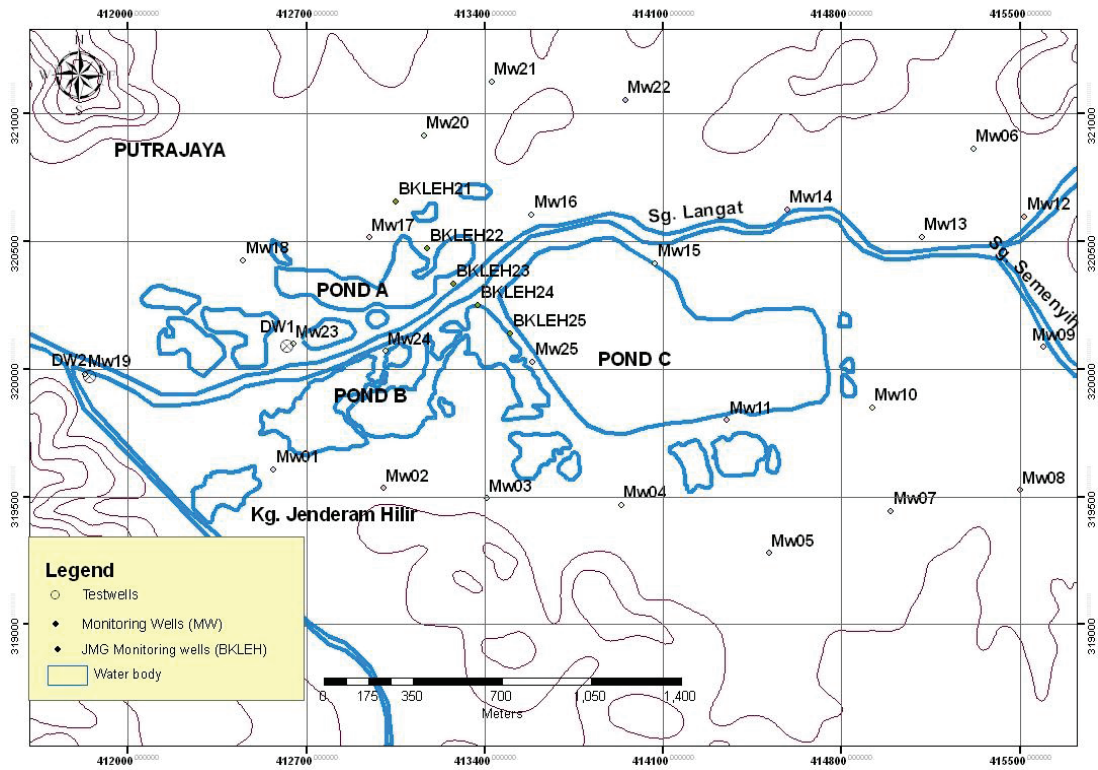

Fig. 2 Location of 25 monitoring wells (MW), test wells (DW) and JMG monitoring well (BKLEH) in Jenderam Hilir, Selangor

characteristics. The test well has been drilled using with a semi-mechanised bangka percussion drill. Grain size analysis for the aquifer materials was carried out at selected intervals to a depth of 15 m for all the 27 boreholes.

2.4 Pumping test

A step-drawdown test (five steps), and a 72 hours constant discharge test and recovery test were done on the 22 October 2009 for DW1 and 5 December 2009 for DW2 using a Groundfos 45-7 submersible pump. During the pumping tests, pumping rates were measured using a V-notch weir. The measurement of groundwater levels was performed using automatic data logger placed in the test wells. Because of the potential of higher yield and low drawdown rate for DW2, another pumping test was conducted again to study the aquifer characteristics. The constant discharge was conducted on the 22 April 2010 for 168 hours (7 days) followed by a recovery test. The long duration of constant rate pumping test was undertaken to ascertain the impact of pumping on the surrounding area especially the nearby lakes. Groundfos SP 60-7 submersible pump was used for the pumping test for DW2 to measure high potential of the aquifer. For the DW2, another 72 hours constant discharge test and recovery test was carried out on the 9 October 2010 to ascertain the capacity of the well. No step-drawdown test was carried out. The pumping test was carried out using a DT 95-10 Dynatech submersible pump. The submersible pump was installed to a depth of 9.5 m below ground level with 125 mm diameter galvanized (GI) riser pipe connected to the submersible pump. A 125 mm diameter gate-valve was connected to the riser pipe to regulate the flow rate. A flow meter was installed at the riser pipe to measure the flow rate. The riser pipe was then directed to a tank complete with 900 V-Notch weir to also measure the flow rate. After the installation of the pump and all other necessary set-up was completed, a calibration test was carried out for 2 hours to determine the capacity of the test well. The recovery test was then carried out immediately after the constant discharge test was completed.

2.5 Water Samples

For water quality, 6 groundwater samples for DW2 and 2 surface water samples (upstream and downstream of the Langat River) were collected. During the constant discharge test for production well DW2, groundwater samples were collected at 24, 48 and 72 hours. Method of collection and analysis of water samples followed APHA [2]. All samples from surface and groundwater were collected in 2l capacity polyethylene bottles of raw water samples and 1l of the acidified sample with 50 % strength nitric acid (HNO_3) to a pH of less than 2 so as to keep the iron and manganese in solution, and were filtered and split in different polyethylene bottle for subsequent analysis of cations and anions. All the analysis was performed in the Geochemical Laboratory, Technical Services Divison, Minerals and Geoscience Department (JMG), Ipoh.

2.6 Microorganisma Counting

For the analysis of Cryptosporidium and Giardia concentrations in the water itself, 3 water samples were collected; upstream (SW1), downstream (SW2) of the Langat River and one sample from the tube well (DW2). USEPA method 1623 (USEPA, 2005) was used for testing purposes. An absolute porosity filter (Whatman Cryptest®) was used to collect debris from 10 l of water. If the water was too turbid to allow filtration of 10 l, a lesser volume was filtered. The filter was eluted through back flushing and the debris was collected and centrifuged to concentrate it. The concentrate was subjected to immuno magnetic separation (IMS) that specifically retains the Cryptosporidium oocysts and Giardia cysts, and allows the background debris to be removed. The IMS part of the sample was placed on a well slide and stained with fluorescein-tagged antibodies to Cryptosporidium and Giardia and a vital dye stain (DAPI) that specifically delineates the nuclei within the organisms. The slides were examined microscopically, and organisms that were identified as Cryptosporidium and Giardia were counted.

Total coliform and E. coli concentrations were determined using the most-probable number (MPN) method from Colilert™ at NAHRIM's Laboratory. Colilert™ is a commercially available liquid medium (Idexx Corporation, Westbrook, Maine) that allows the simultaneous detection of total coliforms and E. coli. The MPN method is facilitated by the use of a specially designed disposable incubation tray called the Quantitray. To perform the analysis, two enzyme substrates are reacted in Colilert™-a chromogen that reacts with the enzyme found in total coliforms (galactosidase), and a fluorogen that reacts with an enzyme found in E. coli (glucuronidase). After 24 hours of incubation at 35°C, a total coliform-positive reaction turns the medium yellow, while an E. coli-positive reaction causes the medium to fluoresce under a long-wave ultraviolet light (366 nm).

3. Results and Discussion

3.1 Geophysical Result

According to the result of geophysical investigation, the area is characterized by clay or silt subsurface layer with the thickness ranges from 0-5 m and the resistivity values ranges between 12-17 Ωm. Below this layer, to a depth of 20 m, there is a medium to coarse grained sandy aquifer layer, partly with some gravel with resistivity values between 32.3-57.9 Ωm (Fig. 3). The resistivity measurements shows that the geological strata dominated by schist bedrock or weathered schist and graphite schist zones below the depth of 20 m which have high resistivity values (200-600 Ωm).

Table 1 Results of step-drawdown test wells for DW1 and DW2.

Step-Drawdown DW1	**Q (m^3/h)**	**Δs(m)**	**S_w(m)**	**S_w/Q**	**W_e**
1	4.4	0.60	0.60	0.136	48.2%
2	6.6	0.39	0.99	0.15	38.28%
3	9.1	0.53	1.50	0.165	31.03%
4	12.2	1.02	2.52	0.207	25.13%
5	15.9	4.17	6.69	0.421	20.48%

Step-Drawdown DW2	**Q (m^3/h)**	**Δs(m)**	**S_w(m)**	**S_w/Q**	**W_e**
1	25.1	0.29	0.29	0.01155	99.85%
2	30.7	0.08	0.37	0.01205	86.34%
3	36.9	0.09	0.46	0.01246	84.02%
4	43.9	0.1	0.56	0.01276	81.55%
5	51.6	0.12	0.68	0.01318	78.99%

Table 2: Result of pumping test analyses for value of Transimitivity (T) and Hydraulic conductivity (K) based on Thesis equation

Date	Pumping hours	No. Well	Q (m^3/h)	Drawdown (m)	T Constant discharge	T Recovery	K m/h Constant discharge	K m/h Recovery
22/9/2009	72	DW 1	12. 20	4.16	3.18	27.90	0.29	2.54
7/12/2009	72	DW 2	51.60	0.75	33.73	94.43	2.52	7.05
22/04/2010	168	DW 2	90.20	2.02	55.02	82.50	4.11	6.16
10/10/2010	72	DW 2	128.00	2.63	52.50	117.12	3.92	8.74

*abbreviation, T is transimitivity (m^2/h), K is Hydraulic Conductivity (m/h), Q is discharge, Δs is drawdown, S_w is total drawdown and W_e is wells efficiency

3.2 Aquifer System

The aquifer system in the study area consists of alluvial deposits of sand, silt and gravel which form shallow aquifer. The unsaturated zone sits on the aquifer consists of clay. The thickness of this clay layer is about 1-3 m (Fig. 4). The aquifer is mostly of fine to coarse grained sand with mixture of gravel. The thickness of aquifer layer ranging from 5-20 m (Fig. 5). It can be locally heterogeneous due to the presence of beds of fine to coarse-grained sand. Based on drilling information, gravelly sand or sandy gravel aquifer layer are overlain by a layer of clay, while other areas are overlain by a layer of low permeability of fine sand or silt which make the aquifer classified as confined or semi confined aquifer which closely depends on the locations. Meanwhile, bedrock is located at the depth of 20 m.

Recharge to the aquifer is from rain water and river water that infiltrates through the aquifer which show the interdependence between groundwater and river water. Due to the presence of sandy gravel which has high porosity and transimitivity, and connection to the river, during high river flow, water from the river recharged the aquifer. During the river low flow, depending on location of the study area, groundwater discharged into the river. The schematic diagram of Jenderam Hilir hydrogeological cross section A-A', B-B' and E-E' based on 25 piezometers and 2 test wells borehole logs shown in Fig. 6.

3.3 Pumping Test Result

From the step-drawdown pumping test, it can be concluded that well DW1 is not efficient as the well efficiency (We) is less than 48%. Low efficiency is affected by the finer composition of the aquifer materials which consist of 54% silt and 38% sand. The drawdown (Δs) for DW1 is 4.4 m at the step 1 with control discharge (Q) at 4.4 m^3/hr. At the step 5, the total drawdown (Sw) increased to the 4.2 m from initial static of 4.05 m during step 1. In comparison, the results of DW2 show higher drawdown about 0.15 m and the well efficiency is very high. The low drawdown in DW2 explains that the river is significantly contributing water to the well.

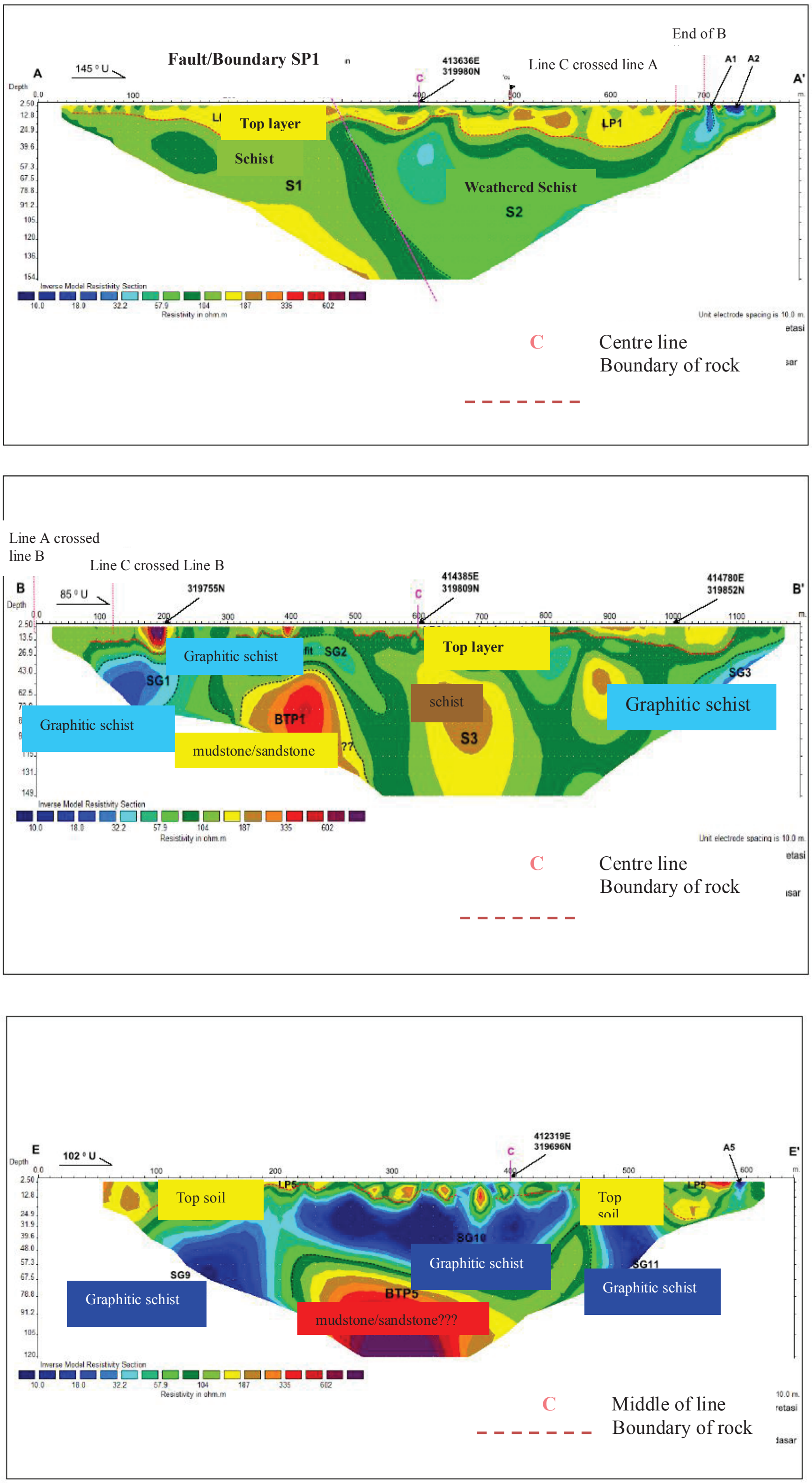

Fig. 3 Resistivity profile line, A-A', B-B' and E-E' in Jenderam Hilir, Dengkil, Selangor

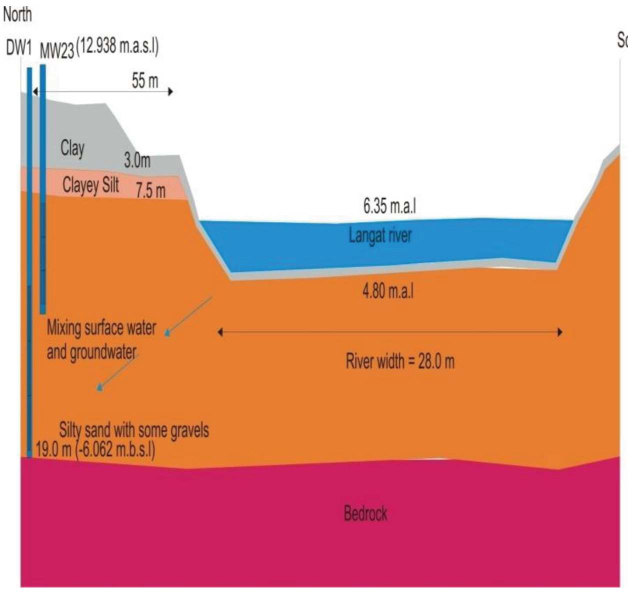

Fig. 4 Cross-sections of across the test well DW1 site

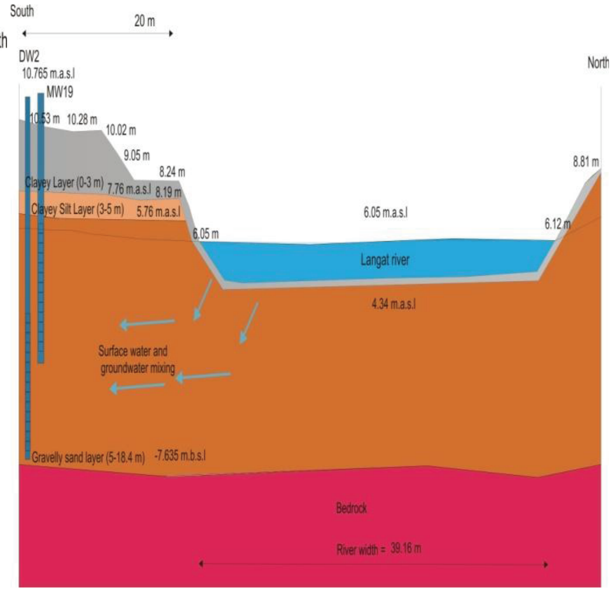

Fig. 5 Cross-sections of across the test well DW2 site

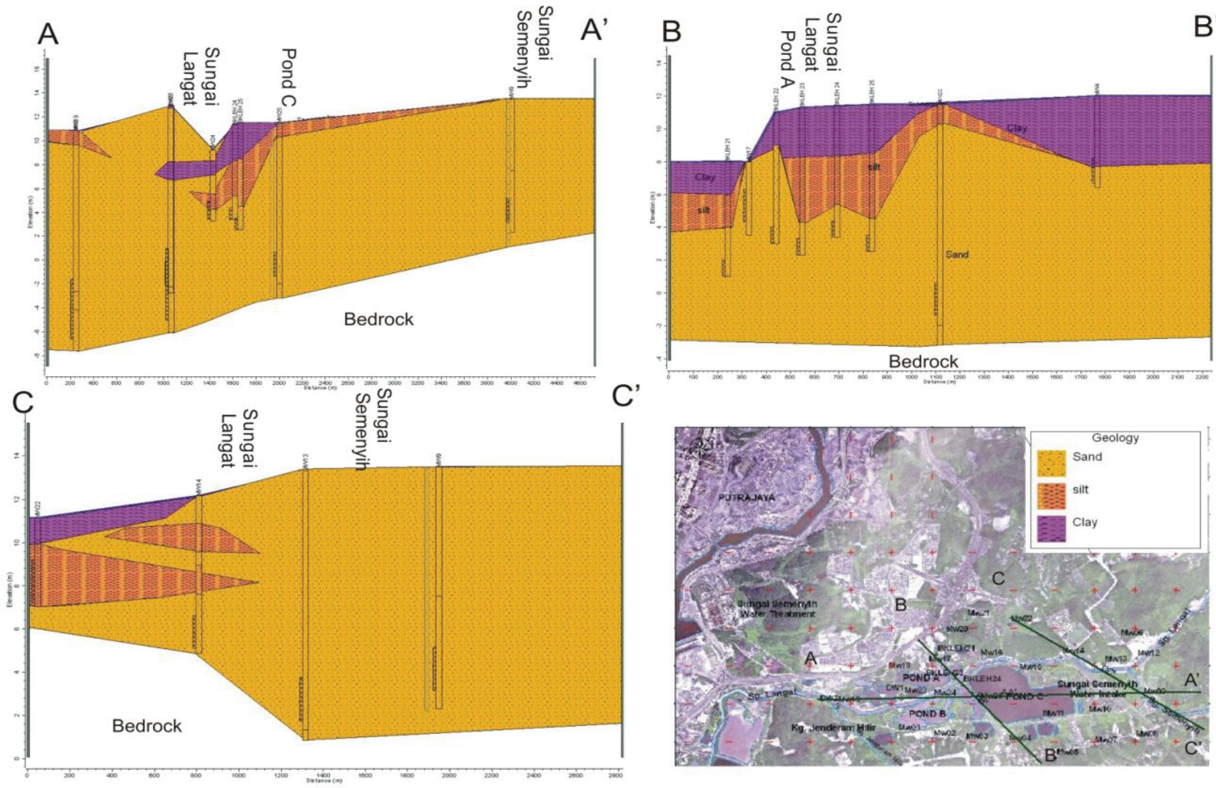

Fig.6 The schematic hydrogeological cross section A-A', B-B' and C-C' illustrating the aquifer system in Jenderam Hilir

The pumping test at DW2 was started at a rate of 51.6 m^3/h show the static water level of 4.19 m below top of casing (TOC). The pump was set at a depth of 9 m from TOC. The flow rate was constant throughout the test is 51.6 m3/h. The total drawdown at the end of the one day pumping test was 4.94 m. Table 1 show the result of step-drawdown pumping test for DW1 and DW2. The static water level for DW2 was 4.36 m and the final water level was 6.30 m (drawdown was only 2.02 m). The transmissivity (T) and hydraulic conductivity (K) value were 31.48 m^2/hour and 2.35 m/hour (56.4 m/day) respectively for DW2. Recovery test was carried out immediately after the constants discharge test ends of the residual drawdown was 0.29 m. The transmissivity and hydraulic conductivity value of 47.22 m^2/hour and 3.52 m/hour (78 m/day) were obtained respectively.

The third DW2, another 72 hours constant discharge test and recovery test was carried out for the on the 9 October 2010. The constant discharge test was carried out with a pumping rate of 128 m^3/hour. The static water level was 4.05 m and the final water level was 6.68 m below ground level. The drawdown was only 2.63 m. The T and K values were 52.05 m^2/hour and 3.88 m/hour (93.12 m/day) respectively.

The recovery was completed in 4 hours, and the residual drawdown was 0.50 m. The recovery after 4 hours was 80.99%, with T and K values of 117.12 m^2/hour and 8.74 m/hour (209.76 m/day) respectively. The pumping test data is shown in Table 2. The drawdown of DW2 was very low, this shows that the well is capable of producing much higher amount of water. According to this aquifer test, the range of travel time from river water to recharge the aquifer is 3-11 days. The travel time was estimated by dividing K in m/day with distance measured from the river to the well. The test well DW2 has successfully shown that well constructed along the river banks is capable of yielding significant volume of water with very much better quality.

3.4 Water Quality

Based on the water quality results, it clearly shows that the river water has high turbidity value (Appendix 1, Table A). However, the water quality after the BI has show a great improvement where the turbidity value has reduced from 328 NTU to 14.0 NTU. This proved that the BI has been able to reduce the turbidity of the river water significantly. On the other hand, total dissolved solid values also was reduced significantly from 206~370 mg/l in the river water to 84~140 mg/l in the groundwater. The sulphate was reduced from 10-15 mg/l in the river water to 1.89-6.00 mg/l in groundwater. The nitrate levels in the river water is greater than the 5 mg/l but has significantly reduced to 1.0 mg/l in groundwater. Although during the pumping test using the high capacity of pumps, the water quality of BI is still reduced the concentration of river water.

Based on the results, it also clearly revealed that the nitrate levels are four to six times lower in wells adjacent to the river. Water quality changes in Jenderam Hilir explained using redox reactions. These reactions involved oxidized inorganic species such as Fe (III) and nitrate, and reduced organic carbon can strongly influence the levels of both organics and of Fe (II) in groundwater [6]. Natural filtration was able to remove contaminants and provide cleaner raw water which not required extensive treatment.

3.5 Removal of Microorganism

Analysis results shows that the water taken from the Langat River contained *Giardia cyst* with the concentration of 0.1-2.9 cysts/l, while no *Giardia cyst* in groundwater was found (Table 3). In Malaysia, it is very common that the river water was polluted with *Giardia cyst*. Farizawati [5] has reported that the concentration of *Giardia cyst* in her study area is range from 0.7-12,780.0 cysts/l. However, to date there is still no reported disease outbreak in Malaysia in relation to water borne *giardiasis*. *Giardia cyst* can be eliminated in temperature more than 65°C but conventional chlorine concentration that is used for water treatment could not kill *Giardia cyst*. Ozonation is effective but expensive. Therefore, it is important to make sure that *Giardia cyst* concentration is being reduced through filtration process.

Samples from the Langat River and test well DW2 were analyzed for total coliform and *E. coli* concentrations. The result of this study shows that water samples taken from the the Langat River were positive for total coliform and *E. Coli*. Total coliforms and *E. coli* were not detected in groundwater (DW2) samples (Table 4).

3.6 Performance of BI

Shamrukh and Abdel-Wahab [1] in their study has used equation 1 to estimate the proportion of surface water into bank infiltration:

$$B = \frac{C_{bi} - C_{gw}}{C_{rw} - C_{gw}} \, x \, 100 \qquad (1)$$

Where;

B percentage of bank infiltration in production well %,
C_{bi} conservative concentration in the production well,
C_{rw} conservative concentration in the river water,
C_{gw} conservative concentration in the groundwater.

Produced water in BI in Jenderam hilir is a mixture of the Langat River water and background groundwater with many transformation processes for infiltrating the Langat River water were using this equation to calculate the proportion of surface water in BI system in study site. 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 [3]. BI study at Jenderam Hilir, concentration of chloride (Cl) was used as to estimate the percentage of the Langat River water infiltrate into wells.

Table 3 Occurrence of Cryptosporidium and Giardia in river water and groundwater sample in Jenderam Hilir, Dengkil, Selangor

Station No	Sampling Site	Date collected	Sampled volume (liter)	Parasitological Analysis		
				Concentrated volume (ml)	Giardia cycts/l	Cryptosporidium oocysts/l
SW1	Langat River	20/4/2010	10	10	2.9	0
SW2	Langat River	20/4/2010	10	10	0.1	0
DW2	Test well	20/4/2010	10	10	0	0

Table 4 Occurrence of total coliform and *E. coli* in river water and groundwater samples in Jenderam Hilir, Dengkil taken in May 2010

Samples	Bacteria Analysis-Analysis Quantitative	
	Total Coliform	*E. Coli*
Langat River	>2420 MPN/100 ml, 35.5$\pm$ 0.5^{0}C/24 h	488 MPN/100 ml, 35.5$\pm$ 0.5^{0}C/24 h
DW1	<1.0 MPN/100 ml, 35.5$\pm$ 0.5^{0}C/24 h	<1.0 MPN/100 ml, 35.5$\pm$ 0.5^{0}C/24 h
DW2	<1.0 MPN/100 ml, 35.5$\pm$ 0.5^{0}C/24 h	<1.0 MPN/100 ml, 35.5$\pm$ 0.5^{0}C/24 h

The percentage of infiltrated water from the Langat River plays a key role in evaluating the BI performance of installed well in study area. The water quality parameters indicates that the Langat river water was seep through the aquifer and was dilute with the local groundwater and moving to test wells during pumping activity. According to previous research by Ray [11], the BI techniques have proven that it has many similarities between slow sand filtration processes. Turbidity of BI in water has been removed by more than 85%. The concentration of other parameters such as turbidity, Nitrate, Ammonium, Aluminium, and Sulfate were also effectively reduced through the BI process. These results show an agreement with the previous results reported in literature [1, 8]. Fig. 7 shows that Nitrate, Ammonium, Aluminium, and Sulfate are significantly reduced to small concentration in produced BI. Previous works also shows that there are significant reductions in river impurities by BI in many sites worldwide. Hiscock and Grischek [6] show that the chemical properties are changing during the filtration process. This clearly explains that the process has a close connection with microbiologically mediated through redox processes.

Generally, microbial metabolism and degradation processes require both electron donators and acceptors and depending on the site inherent boundary conditions. In BI of Jenderam Hilir, NO_3, Mn, Fe and SO_4 can work as electron acceptors for microorganisms in the mentioned sequential order. Organic matter of both infiltrating water and solid phase can work as electron donors. In previous biogeochemical reactions NO_3, Mn, Fe, and SO_4 has decreased in river filtrated water. Current measurements of these parameter indicated that Mn and

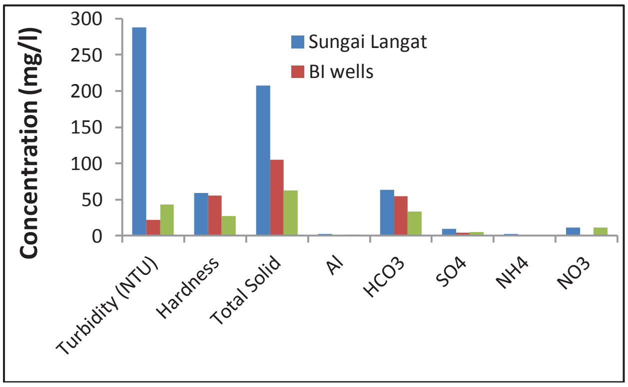

Fig.7 Comparison of water quality for the Langat River, Groundwater , and BI system at Jenderam Hilir

Fe in BI are higher than in Langat river water. This condition was due to mixing of groundwater with elevated values of these chemical species [13]. From current measurements of infiltrated Langat River water, about 70% of water has influence on quality of BI, 60 m for DW1 and 20 m for DW2 from the river. The filtered river water was diluted with the natural local groundwater. This dilution led to significant quality improvements of production water. The last important aspect of BI performance is the microbiological water quality. Based on the analyses, it clearly shows that the microorganisms were effectively removed and the water quality has achieved Malaysia drinking water standard. Analysis of BI water showed that the number of microorganisms for both total coliform and fecal coliform or specific count plate is less (MPN/100 ml) than Malaysia drinking water standard. From this study, it can conclude that the factors which influence the microbiology removal efficiency are the condition of the aquifer and travel time of BI system. This finding shows a good agreement with previous works [14, 15]. On the other hand, detailed study at Jenderam Hilir area is needed to measure quality parameters along the pathway from the Langat River to nearby pond and production wells.

4. Conclusion

The comprehensive study to evaluate the effectiveness of BI technique in Jenderam Hilir was carried out. BI site located at Jenderam Hilir, was monitored for 3 years with several tests were conducted such as physical and chemical of water quality parameters and microorganism's counts have been used to determine effectiveness of BI system. Based on the results, it clearly shows that the concentration of monitored parameters such as turbidity, hardness and TDS were significantly reduced to allowable limits for potable water. While, for microorganism number, the removal efficiency of microorganism though BI is 100%. As a conclusion, BI effectiveness are very much depends on the state of the hydrogeology of the aquifer characteristics (hydraulic conductivity, saturated depth, transmissivity, porosity, lithology, storage coefficient and travel time).

The travel time from river to the tube well is more than 10 days. Hence, the water treatment using bank infiltration (BI) methods can be applied to reduce pollutant concentration originated from the river water. Based on the analyses conducted, the water quality in tube well is considered sufficient and significant improve.

The thickness of the aquifer is more than 5 m consisting of more than 80% gravely sand. This condition is very suitable and promising aquifer in removing the concentration of turbidity and number of microorganism. From the results, it clearly shows that turbidity concentration has reduced to more thatn 85% turbidity and coliform bacteria, *Giardia and Cryptosporidium* was 100% removed. BI not only suitable for water treatment but also can be applied to increase discharge rate. Based on the constant pumping test with 254 mm diameter test well DW2 is able to produce 128 $m^{3/}h$ (3.072 MLD) with a drawdown of 2.63 m. The BI facility in Jenderam Hilir is also expected to be able to provide clean and safe drinking water to the people living in Langat Basin, Selangor. Therefore, is great potential in developing BI technologies for water treatment in developing countries such in Malaysia.

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Appendix 1

Table A Measured water quality of Langat River, BI wells and background groundwater at Jenderam Hilir site (derived from 2009 to 2012 water quality monitoring events)

Parameter (mg/l or mentioned)	**Langat River**	**BI wells**	**Back ground groundwater**
	Average	**Average**	**Average**
pH	6.83	6.73	6.65
Turbidity (NTU)	287.86	22.33	42.98
E.Conductivity (uS/cm)	88.86	95.33	64.75
Total Solid	207.43	104.67	63.00
TDS	64.86	77.33	35.50
Hardness	59.40	55.50	27.33
Fe	3.34	10.63	18.55
Mn	0.36	0.97	0.40
Na	6.17	2.77	3.50
Ca	13.47	16.93	3.10
Mg	1.07	2.43	2.20
K	4.13	5.93	3.40
Cl	10.29	3.75	7.75
Al	2.77	0.08	1.98
P	0.30	0.32	0.41
SIO_2	15.51	18.60	15.70
HCO_3	63.86	54.67	33.25
SO_4	9.57	3.88	5.38
NO_3	10.94	0.50	11.30
NH_4	2.4	0.90	0.93
Total coliform MPN/100ml	335.00	0.00	0.00
E.coli MPN/100ml	60.00	0.00	0.00

Table B Water quality in Jenderam Hilir sample during the pumping test, for period of 30 minutes, 24 hours, 48 hours and 72 hours

Parameter	**unit**	**Langat River Upstream**	**Langat River Downstream**	**DW2 (30 minutes)**	**DW2 (24 hours)**	**DW2 (48 hours)**	**DW2 (72 hours)**
pH		6.3	6.7	7.1	5.26	5.26	5.27
Colour	H.U.	5	5	5	3.5	5.6	8
Turbidity	N.T.U	52.0	328.0	14.0	57	61	60
Conductivity	µS/cm	161	94	211	141	135	130
silica (SiO_2)	mg/l	7.7	22.0	6.2	14.2	14.9	13.8
Tot. Solid	mg/l	206	370	140	92	99	84
Diss. Solid	mg/l	88	54	120	90	86	83
CO_3	mg/l	<1	<1	<1	<1	<1	<1
HCO_3	mg/l	41	23	99	38	39	39
Cl	mg/l	11	7	7	1.6	1.5	0.8
SO_4	mg/l	15	10	6	2.61	1.89	3.8
NO_2	mg/l	0.01	0.011	0.015	1.12	0.46	0.75
NO_3	mg/l	16.0	9.1	1.0	0.007	0.009	0.009
F	mg/l	<0.5	<0.5	<0.5	0.2	0.2	0.15
P	mg/l	0.79	0.81	0.76	0.05	0.04	0.05
NH_4	mg/l	<0.5	<0.5	<0.5	0.71	0.86	0.86
Ag	mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Al	mg/l	2.5	11.0	<0.1	0.63	0.65	0.78
As	mg/l	0.03	0.01	0.06	0.016	0.012	0.018
Ba	mg/l	<0.1	0.1	0.2	<0.05	<0.05	<0.05
Ca	mg/l	24.0	11.00	32.0	11.3	11.9	12.63
Cd	mg/l	<0.01	<0.001	<0.001	<0.001	<0.001	<0.001
Co	mg/l	<0.05	<0.05	<0.05	<0.01	<0.01	<0.01
Cr	mg/l	<0.01	<1	<0.01	<0.03	<0.03	<0.03
Cu	mg/l	<0.1	<0.1	<0.1	<0.01	<0.01	<0.01
Fe	mg/l	3.4	7.9	15.0	7.93	8.93	8.74
Hg	mg/l	<1	<1	<1	<0.001	<0.001	<0.001
K	mg/l	4.6	4.8	8.3	3.37	3.48	3.68
Mg	mg/l	1.4	1.5	3.0	3.1	3.11	3.3
Mn	mg/l	<0.1	0.2	0.8	0.59	0.62	0.65
Na	mg/l	9.5	5.4	3.8	2.88	2.94	3.12
Ni	mg/l	<0.1	<0.1	<0.1	<0.01	<0.01	<0.01
Pb	mg/l	<0.01	0.05	<0.01	<0.01	<0.01	<0.01
Se	mg/l	<0.01	<0.01	<0.01	<0.01	<0.001	<0.001
Sr	mg/l	0.03	0.03	0.03	0.03	0.03	0.03
Zn	mg/l	<0.1	<0.1	<0.1	0.06	0.07	0.04
Carbonate Hardness	mg/l	66	34	92	39	42.4	44