A study on the soil characteristic and properties of riverbank soil samples from Sungai Perak, Kota Lama Kiri, Kuala Kangsar, Malaysia

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Abstract. Riverbank filtration (RBF) technology is new in Malaysia and only a few efforts have been made to understand the RBF mechanisms and processes. Soil characteristics and properties play important roles in determining the suitability of the site for the RBF application. A research has been carried out in Kota Lama Kiri, Kuala Kangsar, Perak, Malaysia to identify the characteristics of the riverbank soil for different layers of the pumping well (PW) and three adjacent monitoring wells namely MW2, MW3, and MW5. Particle size distributions and hydraulic conductivities of the soils were obtained from sieve analyses and constant head permeability tests. The subsurface soils of the study site consisted of medium sand, fine sand, coarse sand and gravel but the medium sand was highest in percentage over the other types of soil. The aquifer extended down to 8 m. The highest hydraulic conductivity value for the PW was 0.91 cm/s and obtained for sample taken from 6 m deep. The highest hydraulic conductivity value for the monitoring wells was 5.03 cm/s and obtained for sample taken from 2.20 to 3.20 m of MW5. The overall well production capacity determined from the pumping test was 112.10 m$^3$/hr.

1. Introduction

RBF is a natural first-step process of water treatment. The technology is commonly employed in alluvial aquifers with complex hydrologic system that exhibits both physical and geochemical heterogeneity. Alluvial aquifers that are hydraulically connected to surface water bodies have been used for water production throughout the world. Sites have been selected because of the significant amount of groundwater that can be extracted at shallow depths [1]. River water flowing through the riverbed on its way to the underlying aquifer and subsequently to the production wells can undergo RBF. Riverbed and aquifer material act as filter media to the contaminants [2]. During the process, various contaminants such as trace organic pollutants, bacteria, viruses, and inorganic compounds can be removed [3].

The design of a RBF system usually requires detailed hydrogeological site investigation and knowledge about the hydrological characteristics of the catchment. The hydrological characteristics such as hydraulic conductivity, transmissivity, storage coefficient, and dispersivity affecting groundwater flow and contaminant transport can be characterized by various laboratory and field tests such as column tracer tests, grain size analyses, pumping tests, slug tests, and field tracer tests [4]. Alluvial aquifers near a river are typically multilayered due to the deposition processes resulting in
vertical heterogeneities in hydraulic properties [5,6,7,8]. A suitable site for a RBF would involve sand and gravel aquifers with hydraulic conductivity, $k_f > 10^{-4}$ m/s, a minimal thickness of 5 m and a good hydraulic connection to the adjacent surface water [9]. Studies on the characteristics of a feasible bank filtration site based on examples from Europe and North America would mention the relevance aquifer thickness, hydraulic conductivity, flow velocity gradient, river discharge, and clogging of the riverbed [10,11,12]. The thicknesses of some existing RBF sites in Germany range from 3-5 m at Böckingen, by the Neckar River to 40–55 m at Torgau-Ost, by the Elbe River, with hydraulic conductivity ranging between $1 \times 10^{-2}$ and $7.5 \times 10^{-5}$ m/s [10].

The RBF technology is very new in Malaysia. The characteristics of the alluvial soils need to be identified in determining the suitability of a site. The aim of this study was to describe the characteristics of the alluvial soils of the selected site in Perak and evaluate the suitability of the site for RBF application. This paper focuses on soil classification, particle size distribution (PSD), and hydraulic conductivity values.

2. Materials and methods

2.1 Study area

The study area is located in Kg Kota Lama Kiri, Kuala Kangsar, Perak. Kuala Kangsar site was selected for RBF application after considering the soil profile near the Sungai Perak. Figure 1 shows the location of the study site at Kota Lama Kiri, Kuala Kangsar, Perak, Malaysia. As shown in Figure 1, the distance from the MW1 to the river was 10 meter. The distance between MW1 and MW2 was 8 meter, where the distances were applied similar to all of the monitoring wells, except for MW5 and MW6. The distance of MW5 from the PW was 25 meter, and 50 meter for the MW6, respectively. This paper will focus on the investigation of the soil samples from pumping well (PW) and the adjacent monitoring wells including MW2, MW3 and MW5.

![Figure 1. Location of the study site with boreholes](image)
2.1. Soil sampling and soil investigation
Soil samples were collected during the construction and development of the PW and MW’s in Kuala Kangsar, Perak. The coordinate of the PW is 04°48’08.5’’N and 100°57’06.9’’E. The samples were collected for each meter depth as the drill penetrates deep into the ground. The soils sample in each layer were collected and labeled. The maximum depth was 8.20 meters. Figure 2 shows the borelog and schematic well design of PW. The soil samples were transported to the Geotechnical Engineering Laboratory in School of Civil Engineering, Universiti Sains Malaysia (USM) for the soil characteristics investigation.

![Diagram of borelog and schematic well design of PW](image)

**Figure 2.** Borelog and schematic well design of PW

2.3. Sieve analyses
The sieve analysis was performed with reference to British Standard 1377: Part 2:1990. Sieve analyses were conducted by using a mesh wire woven sieve size of 14.00 mm at the top and
Soil samples were oven dried at 105 °C for 24 hours. 100g of soil samples were washed through the sieve size 0.063 mm. The soil sample must be washed carefully to avoid losing the soil material. Washed sample will be used for the mechanical sieving and the washed samples were oven dried at 105 °C for 24 hours. The dry samples were weighed again and were put on the top sieve having the largest opening which is 14.00 mm. The mechanical shaker was set to operate for 10 to 15 minutes. The soils retained on top of each sieve were weighed using the balance readable to 0.01g.

2.4. Permeability (Constant Head Test)
The constant head test was done in accordance with British Standard 1377: Part 1-9:1990. Permeability of a soil is a measure of its capacity to allow the flow of the water through the pore spaces between solid particles. The degree of permeability is determined by applying a hydraulic pressure gradient in a sample of saturated soil and measuring the flow rate of the water. The ancillary apparatus were prepared in the Geotechnical Laboratory. The internal diameter the of the permeameter cell were measured and recorded. The length and the weight of the specimen were also measured. The permeameter were placed at the test equipment and the water valves were opened. The water was allowed to flow for several minutes to let all of air out from the permeameter. A measuring cylinder was placed under the outlet of permeameter and the timer was started simultaneously. The levels of the water in the manometer tubes which is H1 and H2 were recorded. The quantity of water collected in the cylinder was measured. The temperature of the water was recorded.

2.5. Pumping test
The pumping test was carried using a DT 95-10 Dynatech Submersible Pump. A Submersible Pump was installed using a crane and 125 mm diameter GI riser pipe 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 of pumping. After the installation of the pump and all other necessary setup was completed, a calibration test was carried out for 2 hours to determine the capacity of the pumping wells, and also to determine the pumping rates for the Step Drawdown Test. The pumping test program consists of step drawdown and a 72 hours constant discharge test and recovery test.

3. Results and discussions
3.1. Sieve analyses for soil samples
Grain size analyses were carried out in the Geotechnical Engineering Laboratory, School of Civil Engineering, Universiti Sains Malaysia (USM). From particle size distribution (PSD), the types and class of the soil can be determined. Gravel, coarse sand, medium sand, fine sand, silt and clay can be found within soil sample. D10 represents the 10% of the particles are finer and 90% of the particles are coarser than that particular size of D10. D30 means 30% of the particles are finer and 70% of the particles are coarser than that particular size of D30. The uniformity coefficient, termed as Cu, is the ratio of D60 to D10. Cc is another measurement of gradation, which is coefficient of gradation. Table 1 shows the classification of the soil samples within PW, MW2, MW3 and MW5 at different depth. Table 2 shows the result of sieve analyses for PW, MW2, MW3 and MW5.

Table 1 and table 2 show the results of sieve analyses for PW, MW2, MW3 and MW5 for different depths. Table 1 indicates the proportions of clay, silt, fine sand, medium sand, coarse
sand, and gravel for the PW as 0 %, 0 %, 16.77 to 72.70 %, 45.12 to 77.90%, and 0.06 to 10.20 %, respectively, thus the medium sand has the most percentage. Soil samples of MW2, MW3, and MW5 indicate presence of medium sand ranging from 30.16 to 59.35 %, 0.70 to 54.51 % and 0.32 to 81.34 %, respectively. Table 2 indicates that the soils from PW had D10 ranging from 0.15 to 0.38 mm, D30 ranging from 0.40 to 0.75 mm, and D60 ranging from 0.60 to 1.50 mm. For MW2, MW3, and MW5, the D10, D30, D60 had ranged from 0.30 to 4.00 mm, 0.45 to 11.00 mm, and 0.60 to 15.00 mm, respectively. The coefficient of uniformity, Cu, for PW, MW2, MW3 and MW5 ranged from 2.0 to 14.0 while the coefficient of gradation, Cc, ranged from 0.05 to 2.75. The grain size distributions of soils from PW, MW2, MW3, and MW5 are given in Figures 3, 4, 5, and 6.

The grain size distributions for PW indicate that down to a depth of 8 m, the soils have a high percentage of medium sand, fine sand, coarse sand and gravel; and more gravel beyond the 8 m depth, thus making it suitable for the purpose of a pumping well. Nevertheless, the main aquifer was considered to reside above the 8 m mark due to the general presence of bedrocks at 8 m. The soils of MW2, MW3 and MW5 were predominantly medium and fine sands from surface down to 4.8 m. There was no silt or clay found in the soil samples of all boreholes.

Table 1. Soil Classification for PW, MW2, MW3 and MW5

| Boreholes | Depth (m) | Gravel (%) | Coarse Sand (%) | Medium Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) |
|-----------|-----------|------------|-----------------|----------------|--------------|---------|---------|
| PW        | 0.0-1.0   | 6.81       | 18.98           | 45.12          | 21.85        | 0       | 0       |
|           | 1.0-2.0   | 10.20      | 16.60           | 51.27          | 21.32        | 0       | 0       |
|           | 2.0-3.0   | 2.14       | 14.23           | 66.42          | 16.77        | 0       | 0       |
|           | 3.0-4.0   | 2.42       | 9.40            | 55.70          | 31.45        | 0       | 0       |
|           | 3.0-5.0   | 0.63       | 12.03           | 66.20          | 20.58        | 0       | 0       |
|           | 4.0-5.0   | 0.06       | 1.18            | 64.82          | 33.16        | 0       | 0       |
|           | 5.0-8.0   | 0.92       | 4.09            | 63.73          | 72.70        | 0       | 0       |
|           | 7.0-8.0   | 0.92       | 4.09            | 63.73          | 72.70        | 0       | 0       |
| MW2       | 0.0-1.0   | 6.56       | 16.46           | 53.63          | 22.03        | 0       | 0       |
|           | 1.0-3.0   | 4.72       | 41.59           | 47.56          | 6.10         | 0       | 0       |
|           | 3.0-4.0   | 6.10       | 33.34           | 59.35          | 1.19         | 0       | 0       |
|           | 4.0-4.5   | 22.01      | 47.49           | 30.16          | 0.92         | 0       | 0       |
| MW3       | 0.0-1.0   | 34.11      | 30.76           | 11.19          | 2.07         | 0       | 0       |
|           | 1.0-2.0   | 1.85       | 30.78           | 54.51          | 12.75        | 0       | 0       |
|           | 2.0-3.0   | 12.96      | 15.46           | 36.55          | 3.03         | 0       | 0       |
|           | 3.0-4.8   | 51.27      | 10.03           | 7.86           | 0.11         | 0       | 0       |
|           | >4.8      | 32.94      | 6.23            | 0.70           | 0.30         | 0       | 0       |
| MW 5      | 0.0-1.0   | 15.59      | 14.63           | 51.36          | 9.04         | 0       | 0       |
|           | 1.0-2.2   | 40.89      | 16.46           | 38.27          | 4.31         | 0       | 0       |
|           | 2.2-3.2   | 0.12       | 37.97           | 55.18          | 6.64         | 0       | 0       |
|           | 3.2-4.0   | 0.061      | 10.76           | 81.34          | 7.73         | 0       | 0       |
|           | >4.0      | 52.18      | 4.36            | 0.32           | 0.04         | 0       | 0       |
Table 2. Sieve analyses results for PW, MW2, MW3 and MW5

| Boreholes | Depth (m) | D10 (mm) | D30 (mm) | D60 (mm) | Cu | Cc | Types of samples            |
|-----------|-----------|----------|----------|----------|----|----|-----------------------------|
| PW        | 0.0-1.0   | 0.15     | 0.50     | 1.50     | 10 | 1.11 | Well -graded                |
|           | 1.0-2.0   | 0.25     | 0.50     | 1.10     | 4.4 | 0.91 | Poorly/uniformly graded    |
|           | 2.0-3.0   | 0.35     | 0.55     | 1.10     | 3.14 | 0.79 | Poorly/uniformly graded    |
|           | 3.0-4.0   | 0.30     | 0.40     | 0.80     | 2.67 | 0.06 | Poorly/uniformly graded    |
|           | 3.0-5.0   | 0.25     | 0.40     | 0.60     | 2.40 | 0.07 | Poorly/uniformly graded    |
|           | 4.0-5.0   | 0.38     | 0.70     | 1.20     | 3.16 | 0.15 | Poorly/uniformly graded    |
|           | 5.0-8.0   | 0.30     | 0.55     | 0.85     | 2.83 | 1.19 | Poorly/uniformly graded    |
|           | 6.0       | 0.37     | 0.75     | 1.30     | 3.52 | 0.16 | Poorly/uniformly graded    |
|           | 7.0-8.0   | 0.20     | 0.40     | 0.75     | 3.75 | 0.14 | Poorly/uniformly graded    |
|           | 8.0-8.5   | 0.60     | 0.80     | 1.20     | 2.00 | 0.89 | Poorly/uniformly graded    |
|           | 13.0      | 0.69     | 1.0      | 2.0      | 2.90 | 0.35 | Poorly/uniformly graded    |
| MW2       | 0.0-1.0   | 0.30     | 0.50     | 1.50     | 5.00 | 0.05 | Poorly/uniformly graded    |
|           | 1.0-3.0   | 0.56     | 1.40     | 2.30     | 4.10 | 0.48 | Poorly/uniformly graded    |
|           | 3.0-4.0   | 0.55     | 1.40     | 2.00     | 3.63 | 0.54 | Poorly/uniformly graded    |
|           | 4.4-4.5   | 1.20     | 2.00     | 3.40     | 2.83 | 1.41 | Poorly/uniformly graded    |
| MW3       | 0.0-1.0   | 0.55     | 2.80     | 6.00     | 10.91| 0.72 | Poorly/uniformly graded    |
|           | 1.0-2.0   | 0.45     | 0.80     | 1.80     | 4.00 | 0.16 | Poorly/uniformly graded    |
|           | 2.0-3.0   | 0.68     | 1.20     | 10.00    | 14.00| 0.10 | Poorly/uniformly graded    |
|           | 3.0-4.8   | 0.50     | 0.55     | 0.60     | 1.20 | 0.25 | Poorly/uniformly graded    |
|           | >4.8      | 4.00     | 11.00    | 15.00    | 3.75 | 2.75 | Poorly/uniformly graded    |
| MW 5      | 0.0-1.0   | 0.41     | 1.20     | 2.00     | 4.88 | 0.30 | Poorly/uniformly graded    |
|           | 1.0-2.2   | 0.48     | 0.80     | 5.10     | 10.63| 0.06 | Poorly/uniformly graded    |
|           | 2.2-3.2   | 0.60     | 1.40     | 2.00     | 3.33 | 0.59 | Poorly/uniformly graded    |
|           | 3.2-4.0   | 0.41     | 0.45     | 1.10     | 2.69 | 0.08 | Poorly/uniformly graded    |
|           | >4.0      | 0.00     | 0.00     | 8.50     | -    | -    | Poorly/uniformly graded    |

Figure 3. Graph of grain size analysis for soil samples at PW borehole
Figure 4. Graph of grain size analysis for soil samples at MW2 borehole

Figure 5. Graph of grain size analysis for soil samples at MW3 borehole
Permeability test for soil samples

Constant head permeability test were conducted for all the soil samples within PW and MW’s in the Geotechnical Engineering Laboratory, School of Civil Engineering, Universiti Sains Malaysia (USM). Permeability or hydraulic conductivity, \( k \) was a measurement of flow within a soil sample. Table 3 shows the results of permeability of the soil samples.

Table 3. Permeability test results for soil samples within PW, MW2, MW3 and MW5

| Boreholes | Depth (m) | Hydraulic conductivity, \( k \) (cm/s) |
|-----------|-----------|--------------------------------------|
| PW        | 3.0-4.0   | 0.15                                 |
|           | 3.0-5.0   | 0.15                                 |
|           | 5.0-8.0   | 0.26                                 |
|           | 6.0       | 0.91                                 |
|           | 7.0-8.0   | 0.10                                 |
| MW2       | 1.0-3.0   | 1.90                                 |
|           | 3.0-4.0   | 0.90                                 |
|           | 4.0-4.5   | 4.70                                 |
| MW3       | 0-1.0     | 0.53                                 |
|           | 2.0-3.0   | 0.47                                 |
|           | 3.0-4.8   | 1.47                                 |
| MW5       | 1.0-2.0   | 0.38                                 |
|           | 1.0-2.2   | 0.43                                 |
|           | 2.2-3.2   | 5.03                                 |
|           | 3.2-4.0   | 1.15                                 |
The table indicates that the hydraulic conductivity, k, of soil samples from the PW range between 0.10 and 0.91 cm/s. The values of k for MW2, MW3 and MW5 ranged between 0.38 and 5.03 cm/s or between \(3.8 \times 10^{-3}\) and \(5.03 \times 10^{-2}\) m/s. The literature indicates that an alluvial aquifer near a river such as the Rhine River often have a hydraulic conductivity of \(10^{-3}\) to \(10^{-2}\) m/s [13,14]. In previous RBF application, the hydraulic conductivity, k, of Illinois River, USA had ranged between \(2 \times 10^{-3}\) and \(3 \times 10^{-3}\) m/s. The Ohio River in Louisville, Kentucky, USA had a k value of \(6 \times 10^{-4}\) m/s, while the value for Great Miami River in Cincinnati, USA ranged between \(8.8 \times 10^{-4}\) and \(1.5 \times 10^{-3}\) m/s [15].

These result shows that hydraulic conductivity at field site and k obtained from constant head permeability test were quite similar with the natural materials from Sungai Perak, Kota Lama Kiri, Kuala Kangsar, Perak. Based on the screen depth between 5.00 to 8.00 metre within PW, soil samples hydraulic conductivity of 0.26 cm/s, 0.91 cm/s, 0.10 cm/s for depth 5.00 to 6.00 metre, 6.00 to 7.00 metre, 7.00 to 8.00 metre, respectively, and the result of pumping test 112.10 m³/h, it can be inferred that the average value of hydraulic conductivity of 0.42 cm/s, has the possibility to yield the abstraction of 112.10 m³/h.

3.3. Pumping test
Pumping test was conducted from 27 September 2013 to 30 September 2013 for 72 hours. Constant discharge rate for PW was 112.10 m³/h. The recovery percentage for PW was 84.67% for duration time of 180 minutes. The static water level within PW before conducting the pumping test was 2.60 metre. The measuring drawdown during pumping test was 0.79 metre.

4. Conclusion
A typical aquifer of a riverbank alluvial deposit considered for RBF application was investigated for the characteristics of its soil samples. The grain size analysis of PW, MW2, MW3 and MW5 showed that soils consisted of medium sand, fine sand, coarse sand and gravel with the medium sand having the highest percentage. The percentages of medium sands at various depths of PW, MW2, MW3, and MW5 were 45.12 to 77.90, 30.16 to 59.35, 0.70 to 54.51, and 0.32 to 81.34 respectively. The aquifer extended down to 8 meter deep. The maximum hydraulic conductivity for the PW was 0.91 cm/s at 6 m deep. The highest permeability, k was 5.03 cm/s, which is for the depth of 2.20 to 3.20 m of MW5. The constant discharge pumping rate of 112.10 m³/h verified the suitability of the site for RBF application.

References
[1] Hiscock KM and Grischek T 2002 Attenuation of groundwater pollution by bank filtration *Journal of Hydrology* **266**:139–144
[2] Samuel M and Jonathan L 2010 Using temperature modeling to investigate the temporal variability of riverbed hydraulic conductivity during storm events *J Hydrol* **388**: 321-334
[3] Ray C, Melin G, Linsky RB 2002a Riverbank filtration improving source-water quality Kluwer Academic Publishers, Fountain Valley, CA, USA; 364
[4] Vandenbohede A, Lebbe L 2003 Combined interpretation of pumping and tracer tests: theoretical considerations and illustration with a field test. *J Hydrol* **277**:134–149
[5] Kim J-W, Choi H, Lee J-Y 2005 Characterization of hydrogeologic properties for a multi-layered alluvial aquifer using hydraulic and tracer test and electrical resistivity
survey Environ Geol 48:991-1001
[6] Pickens JF and Grisak GE 1981 Scale dependent dispersion in a stratified granular aquifer Water Resource 17:1191–1211
[7] Mas-Pla J, Yeh T-CJ, McCarthy JF, Williams TM 1992 A forced gradient tracer experiment in a coastal sandy aquifer, Georgetown site, South Carolina Ground Water 30:958–964
[8] Thorbjarnarson KW, Mackay DM 1997 A field test of tracer transport and organic contaminant elution in a stratified aquifer at the Rocky Mountain Arsenal (Denver, Colorado, USA) J Contam Hydrol 24:287–312
[9] TZW 2006a Exportorientierte F&E auf demGebiet der Wasserver-und–entsorgung, Teil II: Trinkwasser, Leitfaden, Publisher: DVGW Technologie ZentrumWasser (TZW), Karlsruhe, Germany; 249 p
[10] Grischek T, Schoenheinz D, Ray C 2002 Sitting and design issues for river bank filtration schemes. In: Riverbank filtration: improving source water quality. Ray C et al (eds) Kluwer, Dordrecht, The Netherlands; 291–302
[11] Ray C, Grischek T, Schubert J, Wang JZ and Speth, TF 2002 A perspective of riverbank filtration Journal of American Water Works Association 94:149–160
[12] Schubert J 2002 Hydraulic aspect of river bankfiltration-field studies J Hydrol 266:145–161
[13] Schubert J 2006 Experience with riverbed clogging along the Rhine River In: Bank filtration Hydrology – Impacts on system capacity and water quality Hubbs, S.A. (eds) NATO Science Series IV Earth and Environmental Sciences 60:221-242
[14] Price ML, Flugum J, Jeane P, Tribbet-Peelen L 1999 Sonoma County finds groundwater under direct influence of surface water depends on river conditions. In: Proceedings Int. Riverbank Filtration Conf., National Water Research Institute, Fountain Valley, CA, USA; 25–27
[15] Dash RR, Mehrotra I, Kumar P, Grischek T 2008 Lake bank filtration at Nainital, India: water quality evaluation Hydrogeol J, 16:1089–1099. DOI: 10.1007/s10040-008-0295-0

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