Subsurface Conditions with Geo-hydraulic Properties: Empirical Evidence from Parit Raja, Johor

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Abstract

Problems in surface runoff management in the study area will eventually involve the subsurface and its layer conditions. The effects highlighted by the media were “pond” flooding and water demand. The study area was covered by peat with an acidic wet top layer. The subsurface was defined by deep layers of compacted clay with low groundwater flow in the ground. A number of surveys and investigation records were found, serving as evidence for these stated problems. To evaluate and define the actual properties of subsurface conditions, this study relates these conditions and property evidence based on *in situ* and laboratory tests. Geological tests and soil analyses were considered to elaborate on the evidence in the relationship with real site conditions. Portions of the subsurface, limited to a depth of 1.5 m to 30 m, were sampled. Basic geotechnical tests were conducted, and the samples were defined by soil classification, moisture content, and permeability. Onsite tests were conducted to determine the geo-hydraulic parameters on the subsurface interactions according to the onsite physical model of wells. Pumping-and-recovery tests were conducted to determine the subsurface properties related to the storage, transmissivity, drawdown, and flow rate of the aquifer system. All parameters were sandwiched to analyze the subsurface area problem and its geo-hydraulic interactions with storm water management during wet season. With empirical evidence, useful parameters may be able to implement alternative ways to manage surface runoff and local water demand.

Keywords: Subsurface conditions, geo-hydraulic interaction, flood, clay layer.

1. Introduction

Sri Gading is historically renowned in local records for meeting water demand [1]. A number of studies and surveys on it involve top and subsurface scopes. Data from the well obtained through pumping and recovery tests are limited in defining the records in this area. The project involves effective planning, and it is costly to construct and design.

An investigation using geological surveys was conducted in the area, revealing that most of the study area sits on compacted clay over 30 m deep. This condition affects this study and thus needs to be investigated properly. Proper investigations can determine suitable solutions for problems in this area [2]. In addition, exploratory drilling [3] indicates that the subsurface is predominantly clayey in nature. A number of the drilled boreholes penetrate an entirely clayey sequence. The occurrences of sandy water-bearing layers are limited both vertically and laterally. Sand is limited in extent, both vertically and laterally, and is often admixed with minor amounts of clay [3]. The failure of the top layer to distribute the total runoff infiltrates to the layers further complicates the situation. This study aims to determine the essential properties of the layers according to subsurface lithological and hydro-geological conditions in the area. The empirical determination of the useful amount of groundwater can be obtained for domestic, industrial, or agricultural use.

1.1 Fluctuation of Water Levels

A previous study [9] on water table fluctuation in the old well (OW) 150 mm in diameter and more than 30 m deep and in a borehole (B1) 50 mm in diameter and 30 m deep indicates that the water level is approximately 1 to 2 m under the mean sea level. The layer under the ground presents a high water table. Based on the observation on the water level, the fluctuation in the OW reveals that precipitation affects the water recharge/discharge into the well. However, the recorded B1 does not exhibit a similar response to the underground flow. The different sizes and depth of the wells are affected by the water table fluctuations, along with the storage and capacity of the wells. OW is properly designed with a filter and casing underground to accommodate recharge/discharge activities, whereas B1 only contains a bore log without any filter unit or underground casing. The bore log's failure to record the groundwater fluctuation indicates that the weakness of wells in the RECESS (Research Centre of Soft Soil Malaysia) areas is their unsuitable locations and their role in determining good groundwater reflection. According the results of the complex configuration of the water table, individual surface bodies in the terrain with low permeability can be recharged and discharged in areas for closed local flow systems or be discharged in areas for local, intermediate, and regional groundwater flow systems [11]. These phenomena indicate the relationship between these two wells in the subsurface layers, which do not continuously connect with each other.

1.2 Surface Conditions

Topsoil analysis using basic geotechnical testing on soil classification methods was conducted. Surface studies using the infiltration test were conducted near the study area to determine the soil surface properties. Ten stations were selected: Parit Raja Town, Parit Daun, Parit Sempadan, Parit Resipan, Parit Hj. Rais, Parit Jelutong, Parit Karjo, the new campus, the old campus, and the RECESS area. These tests were handled onsite at RECESS and in the Water Resources and RECESS's laboratory in the Universiti Tun Hussein Onn Malaysia (UTHM).

Based on Figure 1, Parit Jelutong had predominantly more access to infiltration than did the other stations. Parit Karjo, Parit Sempadan, and Parit Haji Rais exhibited limited runoff capacity, each below 2 cm^3 in volume. Results from the area of Parit Raja Town to the UTHM campus indicate that the area is drier with a high ground level compared with Parit Karjo, Parit Sempadan, and Parit Haji Rais. The upgraded origin level was observed in town, and similar levels nearby caused the increased development of safety levels.

The surface results in Table 1 illustrate similar types of soil from different method analyses. The clay-loam category was defined in this area. The 10 locations also determined the average infiltration rate at approximately 11.3 mm/hour, indicating that the low land area exhibited a wetted surface condition with low infiltration capacity. These records were compiled during the dry season with minor rainfall. Therefore, the surface area of the peaty-loam area was limited in quality in terms of recharge and the proposed water distribution. Moreover, subsurface conditions with deep clay encountered difficulties involving infiltrate surface runoff with high capacity during the wet season.

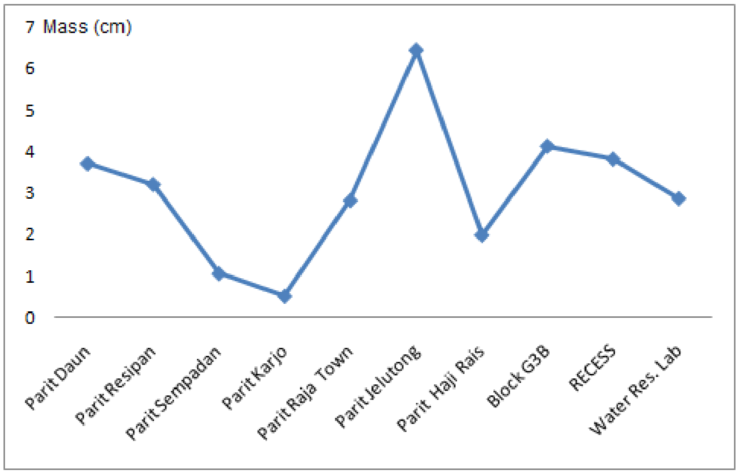
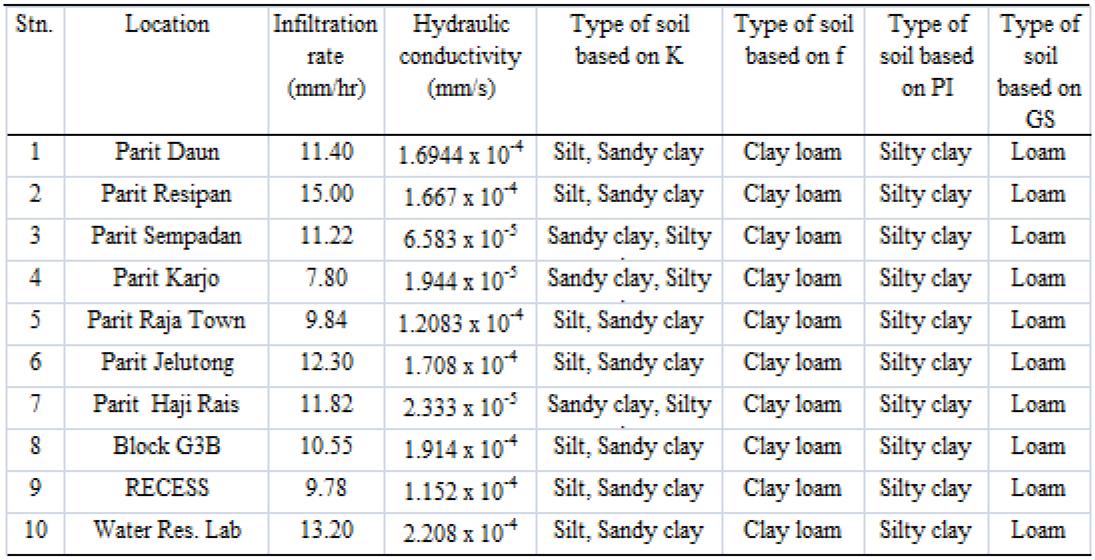


Figure 1 Different capasities of water entering the Sri Gading area

Table 1 Examples of surface evidences in the selected stations at Sri Gading conditions



Stn.	Location	Infiltration rate (mm/hr)	Hydraulic conductivity (mm/s)	Type of soil based on K	Type of soil based on f	Type of soil based on PI	Type of soil based on GS
1	Parit Daun	11.40	1.6944 x 10^{-4}	Silt, Sandy clay	Clay loam	Silty clay	Loam
2	Parit Resipan	15.00	1.667 x 10^{-4}	Silt, Sandy clay	Clay loam	Silty clay	Loam
3	Parit Sempadan	11.22	6.583 x 10^{-5}	Sandy clay, Silty	Clay loam	Silty clay	Loam
4	Parit Karjo	7.80	1.944 x 10^{-5}	Sandy clay, Silty	Clay loam	Silty clay	Loam
5	Parit Raja Town	9.84	1.2083 x 10^{-4}	Silt, Sandy clay	Clay loam	Silty clay	Loam
6	Parit Jelutong	12.30	1.708 x 10^{-4}	Silt, Sandy clay	Clay loam	Silty clay	Loam
7	Parit Haji Rais	11.82	2.333 x 10^{-5}	Sandy clay, Silty	Clay loam	Silty clay	Loam
8	Block G3B	10.55	1.914 x 10^{-4}	Silt, Sandy clay	Clay loam	Silty clay	Loam
9	RECESS	9.78	1.152 x 10^{-4}	Silt, Sandy clay	Clay loam	Silty clay	Loam
10	Water Res. Lab	13.20	2.208 x 10^{-4}	Silt, Sandy clay	Clay loam	Silty clay	Loam

These results agree with a study [4] on a lowland area, suggesting that floodplain flooding did not occur during a one-year period. However, studying the infiltration rate is more important to surface water than to aquifers. The return period of flooding had, for a long time, occurred over a period of more than five years. Low and flattened land presented difficulties in channeling or in the water's direct return to rivers. Thus, researchers have commonly concluded that no recharge/discharge condition occurs during the wet season. Furthermore, scientists have assumed that no flow (storage/capacity) or recharge occurs in the ground with a minimal flow of groundwater. Planning and valuable properties were determined in the investigation, which used the methods in a drainage exchange system to forecast the flow model in the ground and the recharge estimated in a vertical system.

2. Methods Applied

This study, which focuses on subsurface records, was conducted using on-site and experimental studies. The assessment work was performed based on subsurface exploration using the resistivity test, the investigation of soil through the drilling method, geo-hydraulic tests on pumping, and recovery tests and conclusion of the empirical analysis. The study area was conducted at the RECESS station representing the Sri Gading situation.

2.1 Subsurface Exploration Study

The leveling survey revealed that the study station was lower than the surrounding area at 1.589 m to 2.119 m (average of 2.0 m) above the mean sea level. The interpretation survey on geological sections using the geo-electrical resistivity survey is shown in Figure 2. Using *Wenner_L* and *Wenner_S* Protocols, we were able to interpret up to a depth of 61.1 m with maximum length of the survey tools. The three-line survey was conducted to evaluate the soil properties of the deep layers.

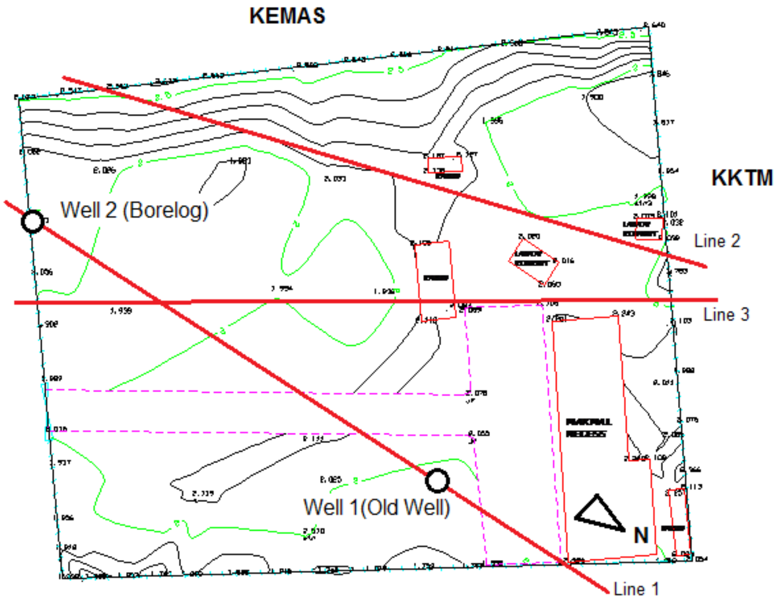


Figure 2 Line survey at the RECESS area and its leveling

The inverse model indicates that the clay layer with minor portions of sandy line ranged at 3 ohm-m to 5 ohm-m in the dark-green area (white sandy). The layer shows that the line was less than 10 m thick and was composed of sandy soil with clayey portions. The interpreted image of this line layer was sandwiched between clay and turf. In the literature [5], the aquifer layer is evaluated based on the interpreted values between 11 ohm and 20 ohm, which is unsuitable for use as the sandy layer because the study location (Banting, Selangor) is near the sea. However, the surface area exhibited similar conditions with this area. The defined lines 2 and 3 show the sandy layer at a depth of 16 m and 20 m, respectively, with the dark-green section denoting the compacted clay and hard rock layers.

A comparison of the drilling conditions revealed assumptions on the ground layer textures. Using the conventional method, sampling and laboratory tests were conducted to determine the real character of soil properties layer by layer. The detailed soil investigation was analyzed through geotechnical tests, including moisture content, plastic index, sieve analysis, permeability, and soil resistivity, as interpreted in Line 1 in Figure 3. A similar sandy layer, which was less than 10 m thick, presented at a depth of more than 22 m. Lines 2 and 3 (Figure 4) show valuable data based on the bore log and survey line 1. The clay on the top layer, which was more than 22 m thick, was discovered, with a bottom layer of sediment/turf layer (hard layer).

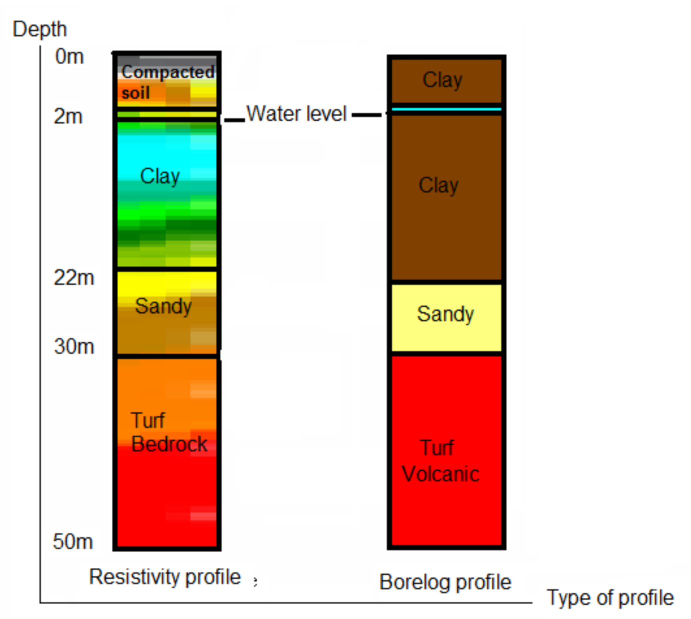


Figure 3 Profile of the Line 1 survey with bore log in the OW

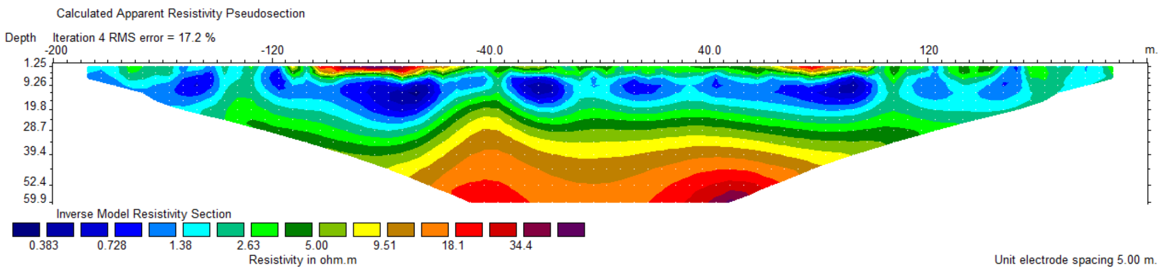


Figure 4 Psedusection at Line 3 in the onsite model

2.2 Soil Resistance Test

The drilling method in the new wells near the OW, located approximately 30 m in the RECESS area, revealed a similar assessment of the soil properties. Soil tests on resistances were taken for every 1.5 m of sample. Using limited undisturbed samples, the resistances of soil were determined using Formula 1. The scatter data revealed that the moisture content (percentage) exhibited a relationship between the resistance values (ohm-m). The water content decreased to a depth layer along with the resistances, as the bottom is usually harder in terms of depth, with narrow fluctuations of water retained in the depth (Figure 5).

$$m = 75.5R^2 - 238R + 209.8 \qquad (1)$$

where m = moisture content (%) and R = resistance value (ohm-m). This test analysis is useful in interpreting a new survey in a similar area, with the assumption of using limited parameters.

Furthermore, this method is required to monitor future studies on quantitative and qualitative controls for groundwater requirement.

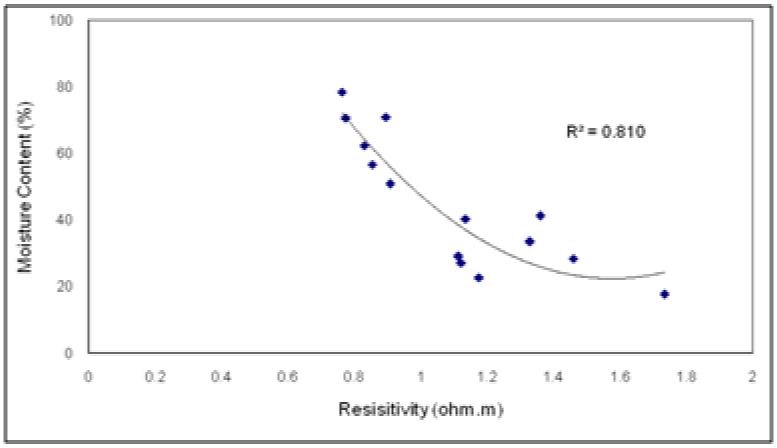


Figure 5 Polynonial new well resistances in the layers

Distribution sizes were obtained via the CILAS 1180 liquid caused by particles; these are very small. The laser tracer method applied to the sample passed 300 mm with dilution in water. Figure 6 indicates that the samples from the depths of 6 m were finer than those were from 18 m, passing 69% and 13% at 60 µm, respectively. At 18 m, a white sandy layer was found with minor clay content. This state should be considered a storage layer for the recharge/discharge groundwater movement.

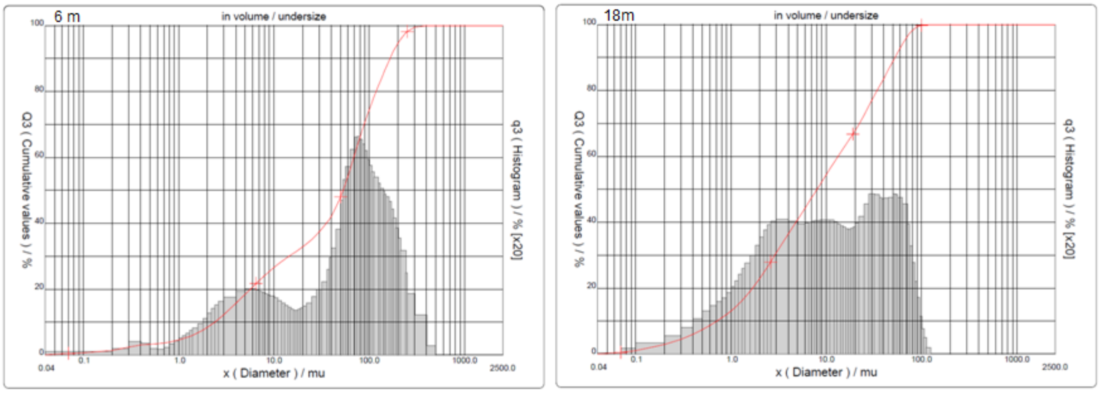


Figure 6 Different soil sizes at different levels

2.3 Aquifer Properties

The aquifer test was conducted in an OW in the study area and was used to determine the aquifer parameters, such as storage coefficient, transmissivity (T), hydraulic conductivity, drawdown, and discharge rate. The identification of aquifer parameters plays an important role in assessing and managing the groundwater resources. The constant flux-pumping test is commonly applied to identify the aquifer parameters from the measured drawdown data [6]. Conventionally, these test parameters were estimated through pumping-and-recovery tests, rainfall depth, runoff from the roof, and water level records. Drawdown records presented a number of other parameters. The difference in depth is the drawdown, and the discharge drawdown is an estimate of the specific capacity of the well [7]. The yield (m^3/day) equation is defined as follows:

$$Yield\ capacity = \frac{Discharge\ x\ 1000}{60\ x\ 60\ x\ 24} \qquad (2)$$

Using the aquifer formula (unconfined), the T values related to the saturated thickness of the aquifer, b, and the hydraulic conductivity value were obtained. Storativity (dimensionless) was also used, as it is volumetric in storage and related to specific storage and specific yield (Sy). The valuable Sy property produced an unconfined aquifer release per unit decline of the water table (0.001 to 0.47). These properties were determined in the following ranges:

$$S = \rho g b(\alpha + n\beta) = Ssb \qquad (3)$$

$$Ss = \rho g(\alpha + n\beta) \qquad (4)$$

where; ρ = mass density of water, g = acceleration due to gravity, α = compressibility material of fluid property, and β = compressibility of water.

The data set was verified using the **AQTESOLV** software for aquifer analysis. A simple simulation was applied using the Neuman method (unconfined) solution for this case. Table 2 indicates that the output was used to estimate future groundwater behavior in a similar area used for study and modeling. Water quality is an important aspect in monitoring the recharge/discharge of subsurface groundwater movement. It affects the water body and handles standard water demand.

Table 2 Different analysis with pumping record for well test (OW)

Parameters of well test	Manual	AQTESOLV	
	Cooper Jacob	Test data	Fit data
Yield (Q)	144.029 m^3/day	144.029 m^3/day	144.029 m^3/day
Coefficient of transmissivity (T)	1.076 m^2/day	1.071 m^2/day	0.5064 m^2/day
Coefficient of storativity (S)	0.189	0.1672	0.2702
Specific capacity (Sc)	3.45 m^3/day/m	-	-
Hydraulic conductivity (K)	0.0826 m/day	23.79 x 10^{-3} m/day	11.31 x 10^{-3} m/day
Specific Yield (Sy)	-	0.1	0.1
Spesific Storage (Ss)	-	3.716 x 10^{-3} 1/m	6.091 x 10^{-3} 1/m
Beta	-	0.1	0.1

The characteristics of unconfined aquifer were detailed in an analysis using the Neuman method (1972, 1974), which derives an analytical solution for unsteady flow to a fully or partially penetrating well in a homogeneous and anisotropic unconfined aquifer with delayed gravity response [8]. According to the AQTESOLV analysis, the set data well test approximately produced Neuman parameters in the aquifer for the unconfined layer. The running data set further defined the single boundary depth layer of 45 m (b) in the ground (Figure 7).

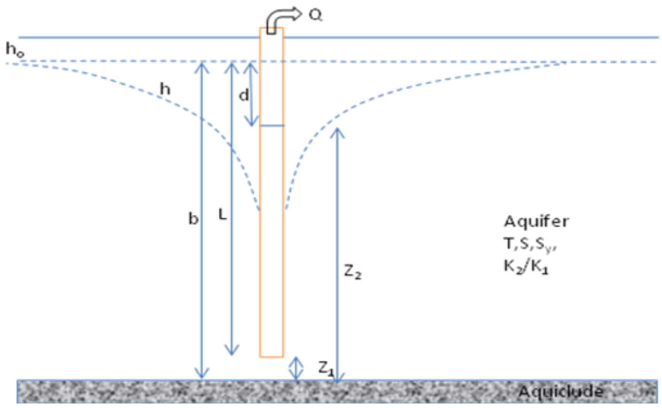


Figure 7 Basic comcept of the single well test for an old well

Figure 8 shows the pumping response on the displacement and the derivative, establishing the parameters for evaluating the aquifer characteristics. This level was limited and recorded at a depth of 41 m; however, the character line produced infinite temporal displacement. The derivative plot indicates a flow in an infinite unconfined aquifer with late time, which began to flatten, suggesting the influence of a recharge boundary or leakage. Furthermore, the plot determined additional aquifer characteristics, such as pumping rate, well storage, aquifer boundaries, and leakage and delayed gravity response. This aquifer responded to the late time and soil type. The clay soil capability exhibited low flow with temporal travel. The accuracy data were defined in the clay overall layer with limited leakage. Therefore, the formulation can determine well properties, as defined in the original site. Using values and Formulas 2 to 4, we can identify the actual conditions.

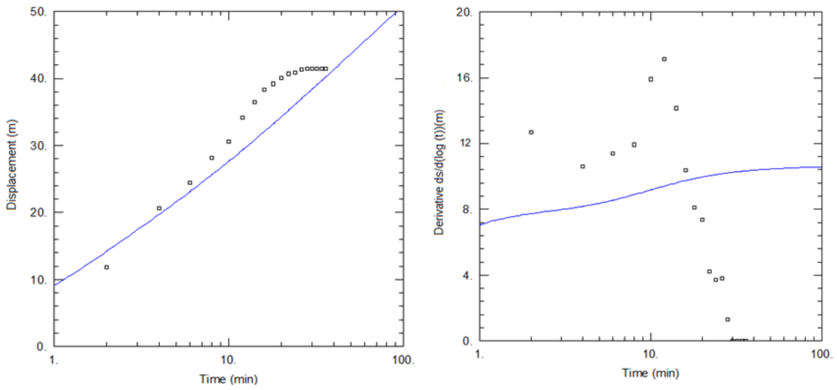


Figure 8 Identification of aquifer characteristics in the layers

2.4 Recharge Responses

Three days of recharging tests were conducted in the OW with different intensities and results [9]. Figure 9 indicates that low intensity, which more effectively recharges storage, was achieved two times more than the high intensity situation. In other instances, the well could hold three times more rainwater with high intensities and more than seven times during rainfall events with low intensity. The ability of the storage well could then be increased for long periods with low intensity to separate the subsurface. This direct dilution method is useful in reducing groundwater quality. Moreover, this method is a more effective in economic practice, reducing 10% to 50% of contamination in the water supply for daily use [10].

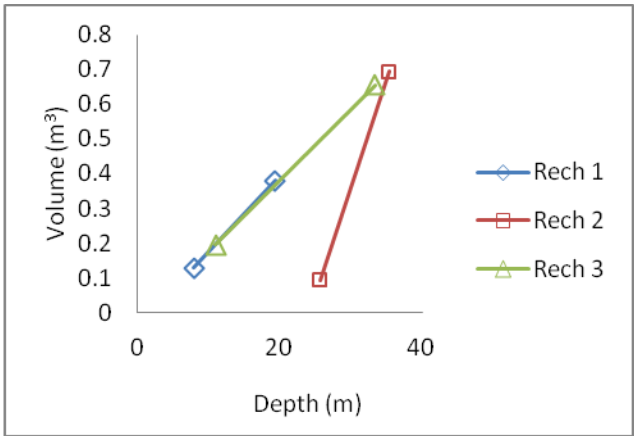


Figure 9 Capability of recharges volume on the subsurface at different intensities

3. Conclusion

The study on subsurface indicates limited research on certain problem areas. These studies do not accurately define the layers. Real records with empirical solutions may be able to verify the data in the location and the soil characteristics. Therefore, the majority of the parameters collected from the subsurface conditions can be used as asset data, guidelines, and standardized values. Values for cluster soil analysis in the ground were recorded without using complicated or conventional methods. These methods can be used to interpret a wide range of surface survey data and can be implemented in areas similar to the current area of study, especially in Malaysia or other countries in Asia.

Acknowledgment

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