Groundwater Responses on Pumping Analysis for Clayey Aquifer

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Abstract. The relationship between water quantity and clayey layer shows that water storage was very limited to an infiltration into the ground layer which is still retains as a surface water during recharge by precipitation. This paper consists of pumping analysis by using AQTESOLV model in a groundwater response for clayey area to identify the capability of water quantity actions during the discharge and recharge flows. Based to pumping analysis, including type of pump used, discharge rate, water table response, recharge rate, type of soil, and remaining time shows that this area was unconfined aquifer with has low hydraulic conductivity below than 9.6 mm/hr. Therefore, this simulation shows that the quantity and capacity of water intake able to withdrawal more than 40 m³/day by using 1hp pump and above with a constant rate after 4 days pumping continuously. The capability of storage and intake should be considered by natural (rainfall) or man-made recharge to show the water balance in the system whiles the process of pumping continuously. Therefore, this analysis able to predicts the capacity of groundwater storage at the clayey characteristics while it needs to improve any strategy to generate more water intake.

1. Introduction
In the area of Sembrong, Johor, sand occurs as isolated layer within the extensive clay layers and has limited capacity as an aquifer. Some other parts of the investigation area have only a few meters thick sandy layers [1]. This situation is a contributor to the cause in conducting the correct investigation in order to find the best solution for the area. This analysis was performed based on recharge well built in system (REWES) model for subsurface model at Research of Soft Soil Centre Malaysia (RECESS) area. This subsurface model consists of recharge and discharge well (RW) and four monitoring well between 4 m to 35 m from RW. There are extra well (EW) at 4 m, monitoring well 1(MW1) at 10 m, monitoring well 2 (MW2) at 20 m and old well (OW) at 35 m distances.

This study area is generally covered by clay that makes up more than 60% of the total layers up to 35 m depth [2]. Sandy layer is limited in the extent both vertically and laterally in layers and it is often admixed with sandy clay. A survey on the sub-surface profile using the resistivity technique at the Universiti Tun Hussein Onn Malaysia (UTHM) campus shows that the sand exists as isolated lenses
within the extensive clay layers and therefore the capacity of aquifer is limited [3]. Therefore, the location of this study indicates that the sand discovery has a wide lateral continuity in the subsurface as its presence is only a few meters thick and almost invisible.

Study on soil permeability has been conducted in the area of UTHM [4]. The top layer of soil in this area mostly consists of silty clay with very low rate of infiltration. Study by [5] shows that most parts in the Sri Gading area are flat (low laying area) and around 1.0 m to 1.5 m above mean sea level. This topographic condition results in the river being unable to drain the surface runoff directly to the downstream or into the sea effectively.

Generally, a top layer of brownish, peaty clay covers most of the area. Below the top covering is a layer of greyey clay, which is frequently mottled and locally contains a lateritic redness. Greenish, shell-bearing clay, probably of marine origin, is also extensive, particularly near the coast. Sand is limited in extent, both vertically and laterally, and is often admixed with a little clay [6].

The report by [7] also shows the similar result of an average 20 m depth of clay and silt cover the top layer. Only two points of the borehole (BH3 and BH10) show a sandy layer on the top surface as shown in Table 1. A total of 48 undisturbed soil samples were obtained from a very soft clayey layer in BH-1, BH-2, BH-4, BH-5, BH-7, BH-8, and BH-9. Nevertheless, this study investigates a deeper recharge well over 40 m deep, which found limestones one of the porous layer at this area as potential groundwater resources [8]. Therefore, meteorological and geo-hydrological/geo-physical information about the catchment area, the existing water table and its fluctuations, water demand, availability of runoff water, and socio-economic condition are considered as fundamental input for aquifer characteristics studies [9]. This investigation in the study area on the subsurface lithological and hydrogeological conditions aims to determine the amount of groundwater available for domestic consumption and/or industrial/agricultural use.

### Table 1. Types of soil for boreholes around study area [3]

| Borehole no. | BH depth (m) | Clay (m) | Silt (m) | Sand |
|--------------|--------------|----------|----------|------|
| 1            | 36.3         | 0.27     | 27.36-30 | -    |
| 2            | 31.93        | 0.23     | 23.31.93 | -    |
| 3            | 39.15        | 1.10-25  | 0-1.10, 28.2-39.15 | 25-28.2 |
| 4            | 34.8         | 0-23.6   | 23.6-34.8 | -    |
| 5            | 34.62        | 0.22     | 22.34.62 | -    |
| 6            | 34.62        | 0.8-24.8 | 0-0.8, 24.8-34.62 | -    |
| 7            | 31.87        | 0.2-4.4  | 24.3-31.87 | -    |
| 8            | 28.65        | 0-21.8   | 21.8-28.65 | -    |
| 9            | 37.77        | 0-23.2   | 23.2-37.7 | -    |
| 10           | 45.3         | 0.8-11.2, 13-19 | 0-0.8, 19.45.3 | 11.2-13 |

### 2. Method analysis

Pump test analysis using software models is usually used to obtain good precision and simulations. The reading results obtained from fieldwork are used as the primary data source for analyzing the findings for the purpose of simulating and predicting a series of data in certain cases. In addition, it is also used to test data and verify the completion of the analysis through relevant derivation in other cases. A solution using AQTESOLV model is suitable for analyzing the situation in a groundwater response and the procedure as summarized in Figure 1. The combination methods between vertical drains (infiltration basins) and REWES models are used to analyze the effectiveness of detecting water contained in the area without disturbing the ecology and the sustainability of the study area.
To run this program, several sets of data are required for the assessment in generating an aquifer parameter output with a minimum error. Table 2 shows the pumped well and the monitoring wells parameters related to the preliminary (set) input data. The model is available to evaluate the well characteristics based on the nearest well requirement by generate the results automatically.

Figure 1. Steps analysis for aquifer characteristics
Table 2. Data set values for wells test

| Parameter                        | RW    | OW    | EW    |
|----------------------------------|-------|-------|-------|
| Head of water level, H           | 0.59m | 0.3m  | 0.44m |
| Depth of aquifer, b              | 45m   | 45m   | 45m   |
| Ratio of hydraulic conductivity, k_v/k_h | 1     | 1     | 1     |
| Coordinate for x direction, x    | 100m  | 62m   | 102m  |
| Coordinate for y direction, y    | 100m  | 90m   | 103.5m|
| Depth of well without screen, d  | 11.5m | 5.7m  | 11.5m |
| Depth of screen well, L          | 30m   | 39m   | 30m   |
| Radius of inside well, r (c)     | 0.074m| 0.074m| 0.049m|
| Radius of outside well, r (eq)   | 0.075m| 0.075m| 0.05m |
| Radius of outside well, r (w)    | 0.075m| 0.075m| 0.05m |
| Transmissivity, T                | 1440 m^2/day | 1440 m^2/day | 1440 m^2/day |
| Storage, S                       | 0.001 | 0.001 | 0.001 |
| Specific yield, S_y              | 0.1   | 0.1   | 0.1   |
| Beta or water compressibility, β  | 0.1   | 0.1   | 0.1   |

Note: RW – recharge well, OW- old well, EW- extra well.

3. Result estimation

The data set for the REWES test is selected during dry and wet (short term) conditions through the pumping process for more than 4 hours. Some outputs for displacement (water level) and discharge flows were produced for this solution.

![Figure 2. Radial flows for pumping and recovery activities.](image)
A RW data test based on this software analysis was conducted to evaluate the type of aquifer in the area which is done by examining radial flow distributions plot. These estimations and simulations were conducted in the aquifer test, which were basically outputs from REWES model. Predictive data is also included in order to be able to predict the discharge record values for long-term needs. Figure 2 shows the confirmation of the assumption of radial flow in an unconfined aquifer with delayed gravity response until 10 minutes. Although the wells in this case was built as penetrate partially, thus, the Moench method [10] was employed to obtain first-cut estimates of aquifer properties.

This pumping analysis showed that the radial flows within 4 hours were achieved around 0.135m with rapid recovery time compared to pumping time. Meanwhile, the water table in this area remains high while the pumping was discharge more than 4 hours continuously.

The second step in choosing the preliminary model is to identify whether a well is a partially or a fully penetrating well and a partially penetrating well, the Moench method is applied. The solution for an unconfined aquifer type was selected based on the required parameters of the program. The visual curve been examined in order to update the initially defined parameter. The match curve is manually drawn on the distribution data to fit the output. The updated parameter on the right side is then verified to determine the suitable values for $S$ nearest to 0.005. This is to ensure the accuracy in the visual curve simulating. Data analysis is continued with matching curve manually with the Neuman (1974) solution for an unconfined aquifer with delayed gravity response as shown in Table 3 as an output validation.

Table 3. Preliminary outputs for testing analysis

| AQTESOLV Analysis | RW Test | RW Simulation |
|-------------------|---------|---------------|
| Method            | Moench  | Moench        |
| Aquifer Model     | Unconfined | Unconfined    |
| Transmissivity, $T$ | 1482 m$^2$/day | 1482 m$^2$/day |
| Storativity, $S$  | 0.557   | 0.004955      |
| Beta or water compressibility, $\beta$ | 0.1 | 0.1 |
| Specific yield, $S_y$ | 0.1 | 0.1 |
| Hydraulic conductivity, $K = T/b$ | 32.93 m/day | 32.93 m/day |
| Specific storage, $S_s = S/b$ | 0.001238 l/m | 0.001101 l/m |
| Alfa, $\alpha$    | $1 \times 10^{-30}$ m$^{-1}$ | $1 \times 10^{-30}$ m$^{-1}$ |
| Radius of outside well, $r(w)$ | 0.075 m | 0.075 m |
| Radius of inside well, $r(c)$ | 0.074 m | 0.074 m |

Preliminary data simulation is employed to fit the selected model. Beta value of 0.1, early time (type A) curve matching for Neuman method is used to find the values of $T$ and the $S_y$, and late time (type B) curve matching is adopted to update $T$ and $S$. This process is repeated until a requirements accurate value are satisfied. The diagnostic details are shown in Table 4.
3.1 Forward Solution.

The discharge evaluation for long-term pumping is shown in Figures 3 and 4 for RW and OW, respectively. Simulation for pumping forecasting was conducted at dry time to ensure that the minimum values (40 m$^3$/day) were produced at the discharge rate. For example, discharge at the RW with 1 horsepower pump was 40 m$^3$/day compared with OW, which was 16 m$^3$/day more (56 m$^3$/day), with twice the horsepower of pump for RW. These values reflect the average for discharges over 40 m$^3$/day for both wells over a seven-day rolling for daily average discharge rate. These forecast values were analyzed to determine the potential or minimum discharge values to forecast for long term pumping activities. Therefore, the quantity and capacity of water intake has shown that this area able to withdrawal more than 40 m$^3$/day with a constant rate after 4 days pumping continuously.

| Table 4. Outputs for RW analysis |
|----------------------------------|
| AQTESOLV                         |
| Diagnostic                       |
| Method / Aquifer Model            | Nueman / Unconfined              |
| T                                | 3.121 m$^3$/day                  |
| S                                | 0.1                              |
| β                                | $1 \times 10^{-5}$               |
| $S_v$                            | 0.5                              |
| $K/K_r$                          | 0.001246                         |
| $K = T/b$                        | 0.06937 m/day                    |
| $S_r = S/b$                      | 0.00222                          |
| Root Sum Square, RSS             | 37.81 m$^2$                      |
| variance                         | 0.5816 m$^2$                     |
| standard deviation               | 0.7627 m                        |

Figure 3. Discharge forecast for recharge well during dry condition in a week-long evaluation.
In response to the wet condition, the flow rate of ground water recharge increases because of the increase in the water table and the mounting pressure. Hydraulic conductivity and discharge also have increased values. For every pumping set, two monitoring wells evaluate the aquifer type in a clay point. Almost all parameters have similar values, except for the anisotropy ratio ($K_z/K_r = \text{ratio of the hydraulic conductivity in horizontal and vertical flows}$) values, which always vary depending on flow movement during discharge time. The anisotropy ratio ($K_z/K_r$) shows the relationship between the aquifer type and the distance from the pumped well effluences the flows during the pumping activities. The ratio become bigger with nearest monitoring well compared to long distance. For example, water withdrawal at RW has an anisotropy ratio of 12.46 at EW, with 4 m of a monitored well, compared with OW, which has an anisotropy ratio of 0.1312 with 35 m from RW for the same values in a condition. Also, response to a pumped well at OW, which is monitored in respective monitor wells, covers a 35 m to 39 m range and a ratio between 0.104 and 0.1312. This ratio shows that flow rate movement is capable of increasing the values based on the nearest distance and water content.

The pumped well from RW, the nearest monitored well is EW with 4 m of distance while pumped well from OW, the nearest monitored well is RW with 35 m of distance. Therefore, the nearest monitored well and analysis more accurate outputs for analysis use. The EW outputs were accepted for available record and use for both conditions for RW and RW are for OW analysis.

3.2 Long term estimation.
One pumping response for 8 hours at RW during the dry condition shows a delayed response in monitoring records after 30 minutes of pumping. The comparison pumping analysis in Figure 5 is a continuous step for long duration was performed to estimate the available capacity at dry condition to support the water supply later. It also available use for evaluate the aquifer characteristics in unconfined type because the observation values has good data recorded and profiles of water level of pumped well and monitored wells. Monitoring level decreased depending on the distance. For
example, at EW located at only 4 m, the level is reduced after 30 minutes of pumping. MW1, located at approximately 10 m, the pumping can reduce the level after 480 minutes of pumping. This natural response is related to coverage width and to the condition of an aquifer. The minimum distance for this clay area was built 4 m from pumped well and maximum distance for monitoring well is 39 m to covers the observations data.

3.3 Clayey responses. In a clayey aquifer, there is delay response to distance. A clayey aquifer also has physical factors that reduce the level in a short period. Monitoring at OW covers 35 m from a pumped well, thus reducing the level after 45 minutes of RW pumping. This condition implies that the accuracy level (same level of construction well) is applicable if the monitoring wells achieve functionality within the aquifer or in the same level as the pumped well.

Figure 6 is plotted based on real site data to formulate functionality of discharge capacity and flow record in the clayey area. Then, the type of soil and flow rate under the ground influences the hydraulic conductivity values. It also depends on the pumping activities, including type of pump used, flow rate of discharge, water table response, recharge rate, type of soil, and remaining time. Equation (1) has good response in order to manage the time constrain to withdrawal capacity for any duration. It means that, the drawdown occurs at 5.7 minutes for 1 m distance of monitoring. However, the actual drawdown for a clayey unconfined aquifer in this area is assumed as:

$$D_t = -0.00001d_m^2 + 0.034d_m + 5.647$$

where;

$D_t$ = Drawdown duration in time (min)

$d_m$ = distance from pumped well (m)
Then, linear concepts are used in the coverage of side effects to predict the affected discharge area. This groundwater extraction needs to be controlled to ensure that its excessive consumption will not contribute to the negative effects of natural hydrology. Extraction flow rate could be controlled based on area level decrease (drawdown) and rate of recharge. Therefore, the water table control can be used in this case based on power of pump flow rate as:

\[ A = 1000 \cdot p_w + 2200 \]  \hspace{1cm} (2)

where:

\[ A = \text{coverage area (m}^2\text{)} \]
\[ p_w = \text{horse power of pump (w)} \]

3.4 Potential and perspective aquifer responses.

Lateral pumping and recovery techniques are widely used to estimate aquifer properties in a simple solution. Many methods are currently used for basic aquifer estimation. The results are very encouraging to the findings of the researcher because of the ability of this technique in identifying the characteristics and types of aquifers. This study also focuses on multi-step of pumping analysis that could be used to obtain the natural response from ground properties and supported factors. Difference steps analyze has real response to the system. These multi-step analyze applied to the system in a clayey aquifer or in an unconfined layer, provide good feedback as well as potential responses to drainage system management.

4. Conclusion

This linearity concept was useful to formulate the estimation capacity and applicable for any power of pump. But, the recovery was limited the water quantity attracted because the clay area has low hydraulic conductivity below than 9.6 mm/hr. Natural (rainfall) or man-made recharge is considered to show the water balance in the system. Recharge quantity in clayey soil is not the same as discharge amount at RW because recharge works in gravity and separately with natural flow in the system, is commonly used in long-term travel, especially in the case of clayey soil. Therefore, this analysis shows that water well can be applied at clayey area for groundwater extraction in terms of domestics and small industries use.
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