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An Aquifer Reflections on Deep Clay Conditions for Water Quantity Assessments

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Abstract: This study aims to evaluate the on-site testing of deep clay area through the well response and aquifer reflection analysis. The analysis was conducted using AQTESOLV software on pumping and recovery data to determine the well responses and aquifer characteristics of deep clay area. A simple experimental model was installed at the site using deep well of REWES (Recharge Well System) model assists with four monitoring wells around the model. The monitoring wells were located at 4m, 10m, 20m and 35m from the model. The site has been identified identified to have the unconfined aquifer with deep compacted clay. Due to flatten and low flow, pumping analysis and ground water response were used to evaluate water quantity and potential prospective of circulate water cycle for urban stormwater management. As reflection on water cycle, almost 20% from withdrawal capacity able to refill the ground system with limited space. It was found that the available storage, S and hydraulic conductivity, K of the clayey area are 0.001 and 32 m/day respectively. Therefore, the response on water cycle indicate some potential space to restore and withdrawal at peak time and thus, the water can be used in safely conditions.

Keywords: Well reflection; unconfined aquifer; deep clay; water quantity; storativity

1. Introduction

Clay conditions normally related to low permeability, transmissivity, flow and hydraulic conductivity for groundwater terms. The assessment on pumping records found some requirement parameters on water quantity aspects. This method widely used to analyze the groundwater responses to determine the respectively parameters. Pumping and recovery data set are helpful and often necessary to determine the storativity, safe yield, hydraulic conductivity, transmissivity and others. Another analysis uses simple method to evaluate the parameters from the data set. This method was applied on flatten area (Fig. 1) with a high water table which has underground retention of stormwater management. When recharging the water to deep layers, this potential aquifer provided some storage during the wet season and discharged water efficiently as needed.

However, Sunjoto [1] suggested that infiltration method using a recharge well for water conservation and supply in urban areas is applicable due to limited space. Commonly for the area that has shallow groundwater, the recharge well is not highly efficient due to the small volume of storage available above a shallow water table. However, the evaluating work was conducted on deep well condition where the obtained value potential capacity is significantly high. After evaluating the aquifer transmissivity and permeability using geophysical well log and hydrodynamic parameters, longitudinal conductance is the geoelectric parameter that is the best predictor of aquifer transmissivity [2,3].

The AQTESOLV is an alternative tool for water quantity assessments and it is able to produce good simulation. However, recharge investigation involve variety of approaches, including soil moisture budgeting, well hydrograph analysis, numerical modeling, and catchment water balance [4], also must be defined through site tests. Pumping and recharge activities which were previously conducted by Lewandoski et al. [5] found that groundwater recharge depends on factors such as temperature, vegetation, soil water saturation, and the thickness of the unsaturated zone. In some cases, the use of injection well to funnel stormwater to the underground aquifer has been practiced in Florida for years. In central Florida, up to 40 percent of the aquifer recharge occur through drainage wells. A permit may be required if the department find that the well affect the primary drinking water standards or public health. An existing well may require alteration apart from routine maintenance, or repair work to restore a well to its original condition [6].

This analysis is based on Cooper-Jacob method as AQTESOLV includes Jacob's correction for partial dewatering of water-table aquifers, thereby allowing use of the Cooper and Jacob solution for unconfined aquifers.

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For variable rate pumping tests**,** the implementation of the Cooper and Jacob solution in AQTESOLV is equivalent to the method of [7] which applies the principle of superposition to the Cooper-Jacob approximation of the Theis equation.

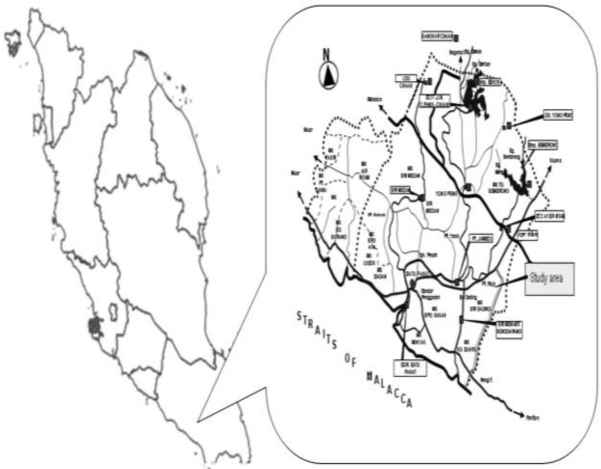


Fig.1 Case study at Johor, Malaysia.

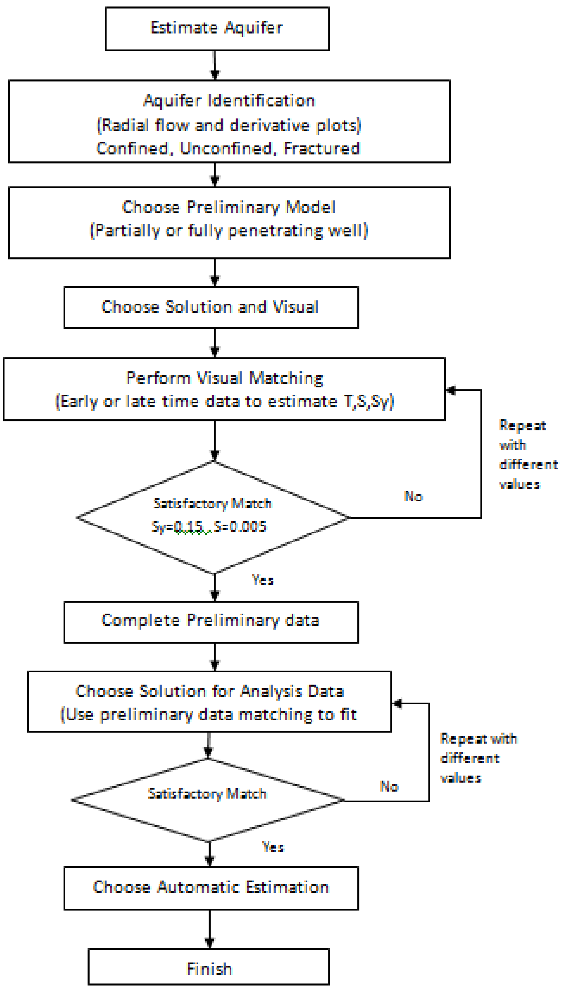


Fig. 2 Steps of analysis conducted.

Pumping and recharge like spreading, pit, induced recharge and well method are practiced. When the well method is used, recharge is fast and has no transit losses or evaporation losses [8]. In other aspects, this indicates that recharge system is a better alternative that supports the open channel system, capturing surface water through infiltration, seepage, leaking, or recharge to the ground by gravity. Before water is taken from an aquifer using wells, the recharge and natural discharge are in balance with the climatic cycle. Recharge must increase or natural discharge must decrease to readjust to the changed situation [9].

When untreated drainage water flows into the lakes, streams, and injection wells, the number of nutrients (nitrogen and phosphorus), solids, bacteria, and viruses increases. Stormwater quality is presented above, along with the rules and regulations by the state agency, documenting the fact that the majority of the pollution load within stormwater is the first flush. Based on this, some means of treatment should be enacted to treat the first half to one inch of runoff, which is already a current requirement. Therefore, water quantity analysis is aparts of water quality treated indirectly. Then, the complicated water evaluation sometimes never ending to solve both of the problems cases at the certain locations.

2. Method Applied

Discharge test is conducted to determine the characteristics of the layered unconfined aquifer under the assumptions that it is homogeneous , anisotropic and of finite extend. The pumping test system consisted of one pumping well located in the bottom layer until 50m and 4 observation wells with different layers and sizes located within the top and bottom layers of the aquifer (30m to 50m) around 4m to 35m coverage area [10]. The distribution data was analyzed using AQTESOLV tool to determine the characters this area.

2.1 Well System and Its Evaluation

The combination of hydrology circular and esthetic values needs to be considered in well design and evaluation. Well tests and evaluation are part of data collection, which determines the characteristics and the values needed for estimation. This paper basically presents discussions on the water quantity evaluation of pumped wells and on laboratory test parameters. Pumped wells were installed with a submersible pump for RW and OW, with 1 horsepower and 2 horsepower pumps, respectively, for pumping purposes. Both pumps were placed 41 m below the surface. The pumps could be used for a short and limited time only because the pumps in the wells function only one at a time. The steps analysis on AQTESOLV is shown in Fig. 2.

3. 3. Result and Discussion

The analysis in this section compares the reactions on the system for different seasons in normal condition. The aquifer test in this section aims to determine the characteristics of different situations but not extremely conditions. In a plot aquifer test, the displacement data and the matching analytical solution include displacement, composite, residual drawdown, and derivative time plots. Different actions are shown in Fig. 3, which exhibit the pumping time record employed to achieve the maximum level. The wet time reaches over 100 minutes to drop to the lowest level because of the quantity of rechargeable water at that time.

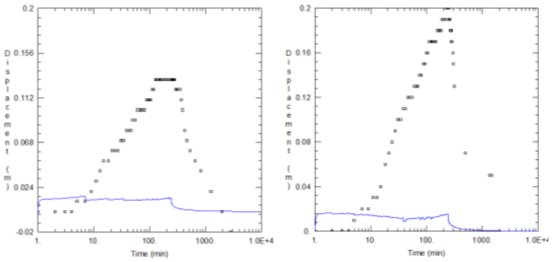


Fig. 3 Displacement-time for two season actions for pumping and recovery

AQTESOLV automatically interpolates or extrapolates a drawdown value when a well does not contain an observation at the time specified for the distance-drawdown plot. Data from the observation well, that is, the EW very close to the RW (pumped well) (4 m only), and some data from the monitored well were used to draw a curve on a distance-drawdown plot for each observation well in the data set. Each curve may vary depending on well construction; for example, under partial penetration on the radial direction from the pumped well (Fig. 4). In a pumped well, the distance-drawdown curve is drawn along the x-coordinate axis. In radial symmetric problems and in observation wells having identical construction, all curves overlay one another.

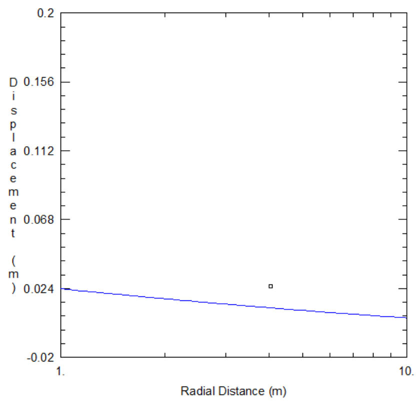


Fig.4 Distance drawdown with radial flow during the seasons for EW from pumped well

However, this observation display for one monitoring well covers 4 m, which shows that a flow occurs at a 1 m radial at a 0.024 m drawdown in dry time. In wet time, a 0.03 m drawdown at a 1 m radial occurs. This situation commonly results from water capacity in a ground circular flow for the same distance that decreases the drawdown deeper in the wet season or when there is high water content. During wet time, there is some difference in the distance-drawdown plot, with many recharges from the surface or the water table, showing a slow recharge with a 0.006 m differential in a long curve distance. These both results at different condition were not showed different value cause by limited flow and events recorded.

Ideally, residual values should not exhibit correlation with the values of simulated displacement. The patterns were the same in the displacement responses in the well test. When residual-simulated data are plotted on linear axes, AQTESOLV fits a straight line to the data, indicating the degree to which the residuals are biased with respect to simulated displacement. Residuals are computed for the current (visual or automatic) curve fit (Fig. 5). A different degree is plotted during a different season. The dry season is more consistent to a discharge drawdown compared with other seasons, in which many recharges occur during discharge time. These recharges increase time drawdown. Water content, based on flow and recharge rates, is always rechargeable during the wet season. Therefore, although the flow is slow, an area still cycles the system during recharge and discharge activities.

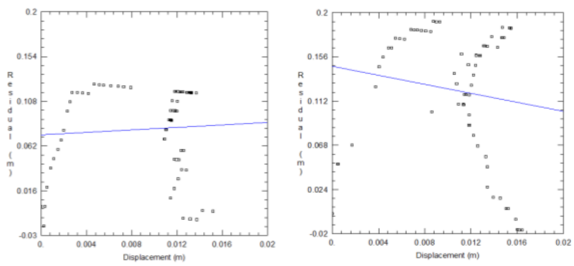


Fig. 5 Residual simulated dry (left) and wet (right) seasons for the well test

Fig. 6 shows a normal probability plot, which displays the standard normal deviates of ranked residuals (residuals sorted from smallest to largest) as a function of the residual values. AQTESOLV fits a straight line to the residuals shown on normal probability axes to measure the degree to which the residuals fit the normality assumption. Deviations from a normal distribution may indicate inadequacy in the fit of the aquifer model to the data. According to the data set, the function almost fits the distribution plot. The same straight line is in both seasons, with more standard normal deviation patterns for the dry season than the wet season. The distribution plots show that the aquifer has slow discharge during wet time. Hence, the aquifer is continuously recharged. The dry response is more effective in rapid discharge flow for a limited recharge time.

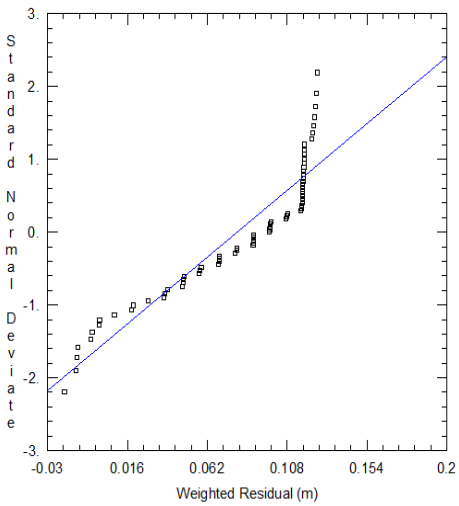


Fig. 6 Normal probability during the dry

The derivative time plots in Fig. 7 provide a useful diagnostic tool for detecting deviations in the rate of displacement change. For example, interpretation of a derivative time plot can help identify wellbore storage, aquifer boundaries, leakage, and delayed gravity response. These well derivatives have similar responses with only slight differentials. In both seasons, derivative values are similar in their responses, with the dry season fluctuating more in its aquifer response. The wet time almost has a flat response, which is nearest to 0 derivatives in a small storage over a short period. Some negative values are found at dry time to store values in delayed time, which means that available storage remains if discharge activities always occur on time. For example, during pumping activities, available storages in an aquifer still remain at certain time discharges. Recovery time is then sufficient to store limited values in the system.

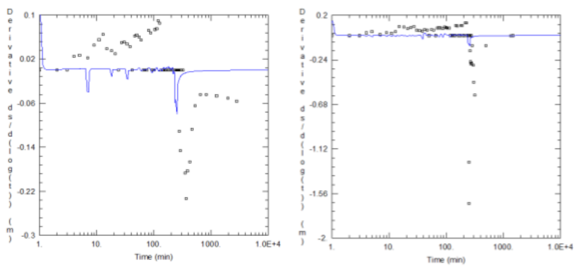


Fig. 7 Derivative –time plots during the dry (left) and the wet (right) seasons for RW

Linear and bilinear flow plots in Fig. 8 are useful diagnostic tools for identifying fracture flow behavior. On log-log axes, these plots do not show any fracture in early-time data, thus exhibiting a unit slope on a linear flow. The plots are indicative of linear flow conditions in a non-single fracture with infinite conductivity.

Radial flow plots, as shown in Fig. 9, can diagnose and identify radial (infinite acting aquifer) flow behavior or wellbore storage. On semi-logarithmic (log-linear) axes, late-time data exhibiting a straight line on a radial flow plot and are indicative of radial flow conditions in an infinite-acting aquifer. This late-time behavior on a semi-log plot is the basis for the Cooper–Jacob straight-line method of analysis. On log-log axes, early-time data exhibiting a unit slope on a radial flow plot are indicative of wellbore storage. One or more observation wells can be found on radial flow plots.

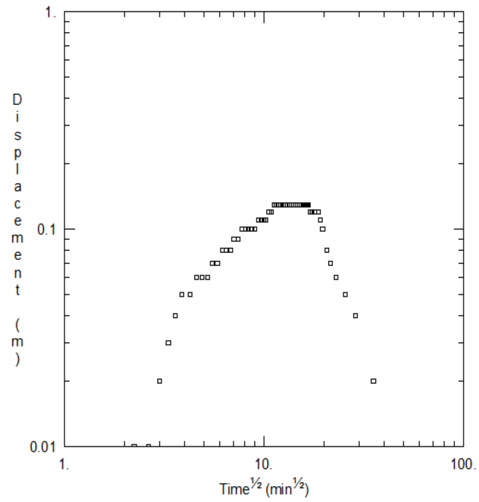


Fig. 8 Linear and bilinear flow plots during dry season at a time different in RW

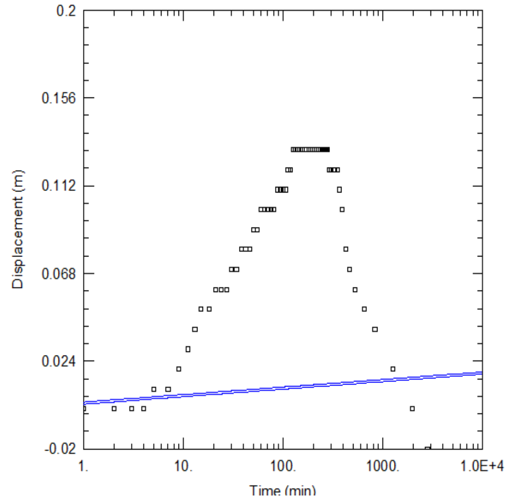
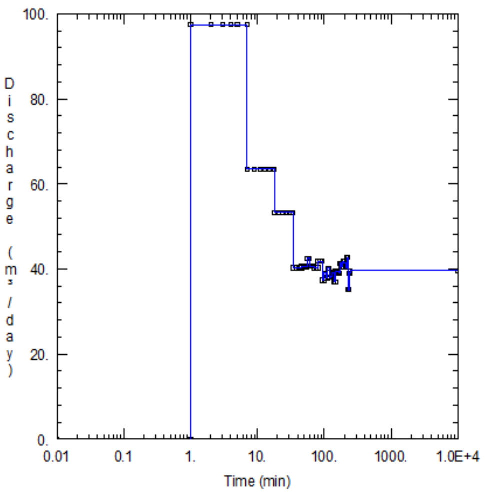


Fig. 9 Radial flows in RW during dry season

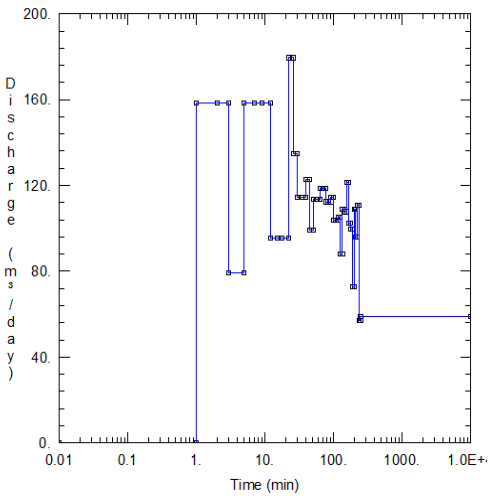
Fitting values are graphical outputs in the matching data test. A single data test at normal time estimates the hydraulic parameters that are nearest the accuracy values, with beta values at 0.1. This simulation allows T to increase to 1920.3, S to 0.04258, and Sy to 0.02175 m^2/day. Moreover, the record for running at different beta values with the same hydraulic parameter output. Applying this technique can help determine the response values of hydraulic characters in an aquifer situation. The selected values and the method used are easy to apply and are user friendly under any condition and with any aquifer type. However, AQTESOLV provides tools for Type A and Type B visual curve matching plus active type curves for the interpretation of delayed yield in a water-table aquifer for future unconfined analysis for Neuman method.

3.1 Forward Solution

The discharge evaluation for long-term forecasting is shown in Fig. 10 for RW and OW, respectively. Simulation was conducted at normal time to ensure that the minimum values were produced at the discharge rate. For example, discharge at the RW with 1 horsepower was 40 m^3/day compared with OW, which was 16 m^3/day more (58 m^3/day), with twice the horsepower of RW. These values reflect the rolling average for discharges over 40 m^3/day for both wells over a seven-day rolling average rate to account for daily reporting variations. The values reflect the recharge and the recovery flow rates with time constraints from the withdrawal rates within the two seasons monitored.



(a)



(b)

Fig.10 Discharge forecast for (a) RW and (b) OW during dry season in a week-long evaluations

In response to the wet season, 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. Table 1 shows the forward solution to withdrawal rates for RW and OW, including their respective monitoring data. 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 (Kz/Kr) values, which always vary depending on flow movement during discharge time. The anisotropy ratio (Kz/Kr) shows the relationship between the aquifer type and the distance from the pumped well. 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 season. Also, response to a pumped well at OW, which is monitored in respective monitor wells, covers a 35 to 37 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.

Table 1 Analysis of two monitoring wells for OW-pumped activities

Analysis	Forward solution - multi well (OW)	
	Dry & Wet season	
Well name	EW	RW
Method	Neuman	Neuman
Aquifer Model	Unconfined	Unconfined
T	1440 m^2/day	1440 m^2/day
S	0.001	0.001
Sy	0.1	0.1
Kz/Kr	0.104	0.1191
K =T/b	32 m/day	32 m/day
Ss =S/b	2.222×10^{-5} 1/m	2.222×10^{-5} 1/m

In other perspective evaluations, some multiple pumping tests are conducted in a layered unconfined aquifer for two seasons. A multi-step pumping test was conducted to determine the characteristic of the aquifer and the physical groundwater flow reaction to the system. Dry and wet seasons were used to evaluate the availability and the efficiency of the system in terms of discharge and recharge activities. During the dry season, evaluation of water supply and water demand was considered based on capacity and rate. However, during the wet season, the effectiveness of the system to store and to recharge the surface water as a drainage system with limited capacity was evaluated. These situations evaluated the capability of the systems based on its respective properties at different periods. At these condition, the equations was found in term of water table responses as:

$$s = h_o - h \quad (1)$$

and

$$\frac{\partial^2 s}{\partial r^2} + \frac{1}{r}\frac{\partial s}{\partial r} + \frac{K_z}{K_r}\frac{\partial^2 s}{\partial z^2} = \frac{S_z}{K_r}\frac{\partial s}{\partial t} \quad (2)$$

where,

s = drawdown
h_o = origin water table
h = water table pumped
r = radius of well
K = hydraulic conductivities
S = storativity
t = time

4. Conclusion

Geological and geo-hydraulic soil characteristics in the studied area are found to have a deep clay layer that has low permeability in the ground and that naturally releases stress caused by surface water runoff and ground water movement in a short time. At the top layer, the water table follows the wet and dry periods, whereas below 2 m, the water content fluctuates, but not dramatically and following gravity potential line.

Many studies such as [11] have contributed to the analysis of surface, open system (ponds, rivers, and man-made detention ponds), and limited well system recharges. Some of these works evaluated the geo-hydraulic characteristics using discharge based analysis on site tests of aquifer systems. However, the records on well system recharges are very limited, perhaps due to complexity and cost of the compilation method and analysis.

The Sri Gading alluvial aquifers, with its shallow depth (<50 m), serve as main sources of potable water in the area [12]. Quality is an important aspect in recycled water, which was diluted with fresh groundwater to release the groundwater stress from daily usage. The relationship between groundwater quantity and quality is more complicated and always integrate for any purposes; the water body impact on the ground and water content in deep layers of the soil must be determined before use.

Therefore, the normal water level at this site stable in both conditions because no lateral flow in the ground system even dry condition. Therefore, drilling and pumping is the reasonable method to channel and flushing the ponding water. The pumping-well method presented that characteristics and behaviors of the aquifer clay acts as stormwater and water supply management was acceptable.

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