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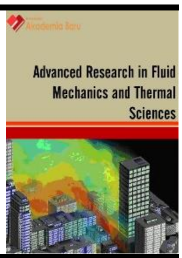

Groundwater Analysis for Unconfined and Clayey Layer by using Response Surface Methodology

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ABSTRACT

Groundwater as a source of water stored in aquifers plays an important role in domestic use. However, excessive and uncontrolled water pump activities have side effects such as soil deposition and groundwater reduction. Therefore, Response Surface Methodology (RSM) is an alternative method to optimize the time and quantity of groundwater pumps based on other wells water level changes. The analysis using Design Expert version 10 involves changing the water level at the main wells $\mathrm{R_1}$ and $\mathrm{R_5}$ with the monitoring of other wells at $\mathrm{R_2}, \mathrm{R_3},$ and $\mathrm{R_4}$ within 245 minutes with 48 samples. Based on 4 hours of pump test in different wells, it shows that groundwater production rates indirectly affect pump power factor, water level change, wells location, pump time, and infiltration of soil. $\mathrm{R_1}$ (1 hp) has a groundwater rate of 28.65 $\mathrm{m^3/day}$, while $\mathrm{R_5}$ (2 hp) with 103.63 $\mathrm{m^3/day}$. The selection of ANOVA Design-Expert model suitable for $\mathrm{R_1}, \mathrm{R_2}, \mathrm{R_3}, \mathrm{R_4}$ and $\mathrm{R_5}$ has been evaluated and shows that optimum time is 116.24 minutes (1 hour 55 minutes) for case 1 and 117.48 minutes (1-hour 57 minute) for case 2. In conclusion, this study provides best and suitable pumping time towards the water balance of groundwater. Hence, the reaction from environment and the influences of other factors play an important role in ensuring the continuous water supplement of groundwater.

Keywords:
Water quantity; Response Surface Methodology; groundwater levels

1. Introduction

According to investigation's statistic, the average water consumption per day of Malaysians in 2013 was 210 litres. However, the average consumption has risen by 2 litres which means 212 litres or about 141 bottles of 1.5 litres per person daily in 2015 [1]. This statistic above shows that the consumption of water is still far beyond the water usage that recommended by the World Health Organization (WHO), which is 165 litres per day. It was expected that the population growth of human

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to be increased to two thirds, where 1.8 million of people live in countries or regions with absolute water scarcity and living under water stress condition on 2025 [3].

The excessive usage of water has increased the stress upon both our land and water resources of earth and resulting water scarcity and water quality risks. Besides, climate change that cause to the trapped heat within the atmosphere, which causing rising sea levels, severe weather events, and droughts that render landscapes more susceptible to wildfires is also a factor to threaten the fresh water on earth [4]. Thus, there are many countries that facing the high stresses in water capacity availability such as water irrigation, water shortage, droughts, land subsidence etc. For example, Mekong Delta which located in Vietnam that underwent excessive groundwater extraction has gradually increased the happening of subsidence [5]. In addition, the failure of unlimited groundwater extraction had made the falling of water tables in China, India and the United States and influence the harvest production [6].

Therefore, groundwater as a water source that can be taken from underground of earth are greatly in concerning to avoid the depletion of water. With the help of gravity, water moves down into the soils and rocks, passing between particles of sand, gravel, or large particle until it reaches an empty space which called aquifer [8]. In Addition, there are more than half of the groundwater withdrawn is for domestic water supplies and globally it provides 25% to 40% of the world's drinking water in other nation [6]. However, suitable water treatment such as filtration, biological, chemical, and physical treatment technologies are needed after extraction. The study of groundwater extraction was conducted at the main campus of Universiti Tun Hussein Onn Malaysia (UTHM) which is at Research Centre for Soft Soil Malaysia (RECESS) that established in order to carry out field experiments as a national centre for soft soil research in Malaysia. The objectives of the study were to determine groundwater extraction capability (m^3/day) after 4 hours of pumping test in RECESS, UTHM and analyse the results from groundwater extraction by using Response Surface Methodology (RSM) from effect of time and volume of groundwater to the water level of existed wells in RECESS, UTHM.

1.1 Aquifer in RECESS

Well was installed vertically to extract the groundwater from underground. There are basically three types of aquifer such as unconfined aquifer, perched aquifer and confined aquifer [9]. In RECESS, an unconfined aquifer was located below the top soil and under a layer of more than 45 meters of fine, sandy, and turf clay as shown in Figure 1.

In Pumped Well (PW), 1 horsepower of submersible pump is installed in well. From a constant rate of 4 hours pumping continuously tests, the capacity of water withdrawal is 40 m^3/day by using only 1 horsepower of pump and the area in RECESS has low hydraulic conductivity below than 9.6 mm/hr [10]. Infiltration rate of top soil is in between of 0.004 to 0.007 mm/s and the soil classification based on particle size is between silt to fine sand [11].

1.2 Well System in RECESS

There are different types of well that used for extraction and functioning on their own purposes. The diverse sizes and depth of the wells are influenced by the water table fluctuations, alongside the groundwater capacity and water storage in the wells [12]. Several matter such as surface and subsurface geologic conditions, site conditions, properties of monitored aquifers, purpose of the well, and duration of monitoring need to be concerned when installation carry out before the groundwater extraction [13].

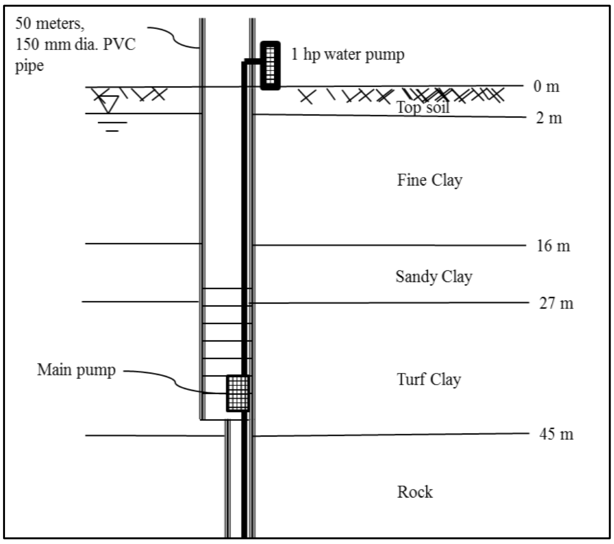


Fig. 1. Soil profile of RECESS [15]

The well system that existed at RECESS, UTHM consists of 4 monitoring well and a pumped well as shown in Figure 2. The construction of wells was designed and constructed by drilling machines and installed with PVC pipe into the ground. The wells are constructed with PVC pipe of diameter 50mm, 100mm and 150mm. The depths of wells are 50 meters for pumped well and monitoring well 1, 42 meters for extracted well and 30 meters for monitoring well 2. Pumped well (also known as recharge well) are the only well that installed with 1 horsepower of submersible pump.

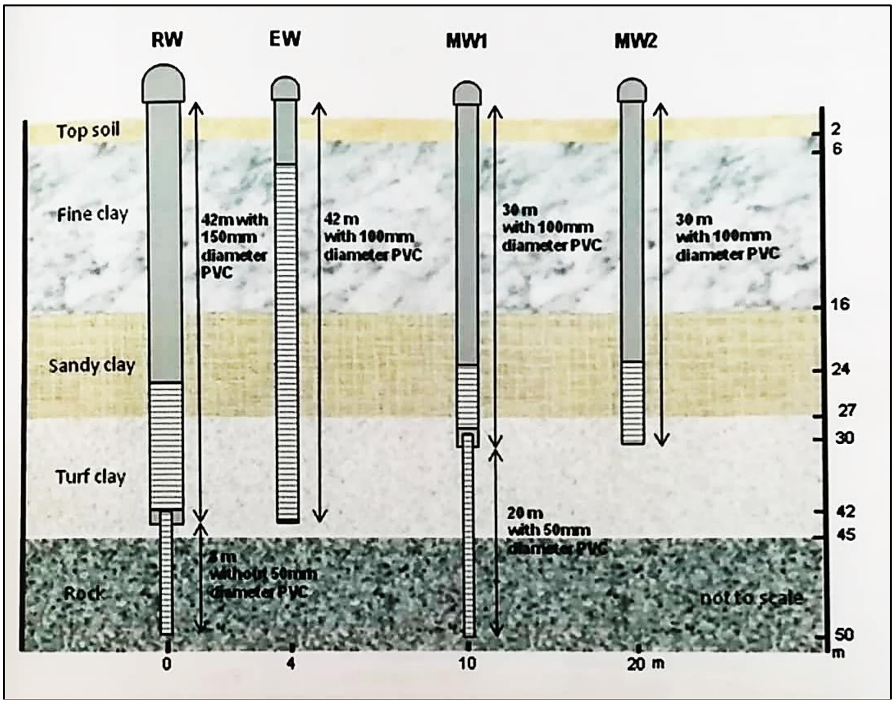


Fig. 2. Cross section wells in RECESS, UTHM (RW = PW, EW = MW1, MW1 = MW2 and MW2 = MW3 for the current study [15]

The wells' length is in 30 meters to 50 meters from top soil until rock layer. There is 60% above of clay soil in RECESS such as fine clay, sandy clay, and turf clay. It was summarized that the layer of clay was varied in thickness from 2 m to 27 m approximately and the layer of Tuff clay was covered up to 18 m of the sub surface to 5 m of hard rock at the bottom.

1.3 Drawdown and Recovery in RECESS

From previous 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 discharged more than 4 hours continuously [10].
The recharge that occurs at RECESS UTHM is natural discharge. Different from artificial recharge, the natural recharge occurs through the process of infiltration where the water percolates from the surface to the bed of the aquifer [14]. After the water from precipitation had reached the ground surface, part of the water will carry out infiltration process and diffuse into the ground. However, the speed of water infiltration is depending on soil moisture and ground's hydraulic characteristics.

However, it is proved that the perforated pipe can act as a well that connected to aquifer and help to reduce the surface runoff of the excess stormwater as well as a flood prevention at the same time can increase the potential of groundwater capacity for water supply and reduce the contribution to channel of drainage system [11]. In this case, excess stormwater is stored in confined layer in subsurface. According this well test that carried out by Musa *et al.,* [15], half of pumping yield was loss by recovery in range 25-26 m in 50 minutes.

2. Methods

The study was carried out at RECESS, UTHM within 245 minutes with the aims of data collection for the analysis of drawdown and the influences of pumping activities to the study area. In this study, two 4 hours pumping tests were carried out at different well which are Pumped well, R_1 and monitoring well 4, R_5. The test was carried out at two different day with same duration. The invert level of pumped well, R_1 and four monitoring wells, R_2, R_3, R_4, R_5 onsite were measured and recorded. There are four monitoring wells and one pumped well existed on the study area as shown in Figure 3. Water levels of wells were recorded from well head of the top soil, before and during pumping test.

2.1 Analysis of Response Surface Methodology (RSM)

In this experiment, Response Surface Methodology (RSM) was carried out with the assist of Design-Expert 10. Design–Expert is statistical software which helps in design of experiments (DOE). Design-Expert 10 is software that consists of two-level factorial screening designs which is known as "manipulation" and "output" [16]. It can help to control and improve water drawdown by identifying unrecognized drops of level, as a process to make breakthrough improvements [2,15,17]. A procedure of RSM was as shown in Figure 4 Before starts the methodology, appropriate knowledge must be studied and identified so that the design of experiments is correct. When factors undergo process, there is the existing of responses [2]. Followed by Empirical Models and ANOVA, contour plots of the experiment can we obtained. Optimization of the experiment will be carried out as last step of RSM to find out the best result and performance among all the trials. Optimization process was carried in last to obtain the desirable expectations results from this study [17,18].

RSM factors and levels were consists of experiment on "Factor A" and "Factor B" and output generated reflected on "Response" to find out relationship between "A" and "B" to achieve optimization of activities carried on "Response" and preservation or extend functionality on "Response".

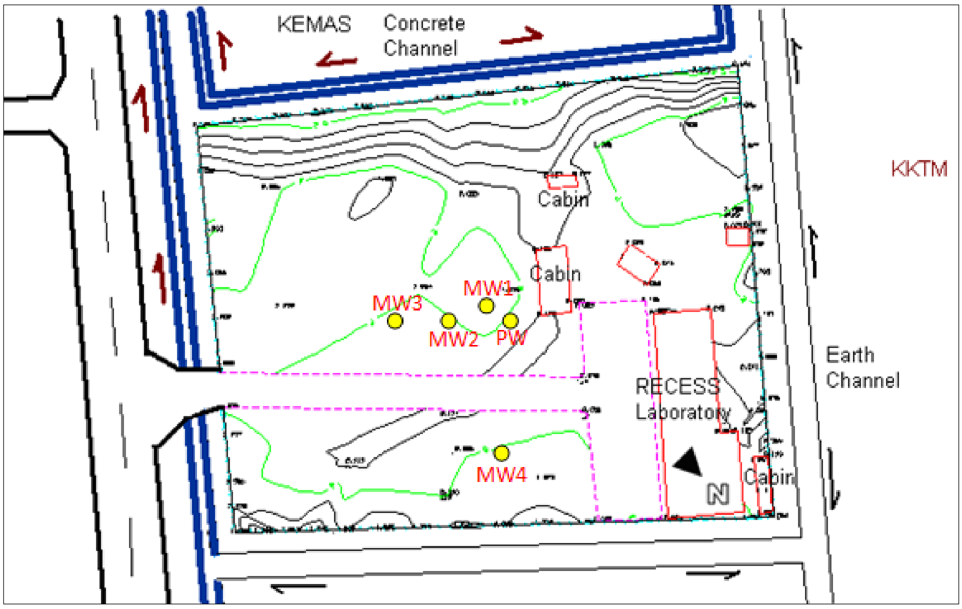


Fig. 3. Plan view of wells was located in RECESS, Parit Raja, Johor [12]

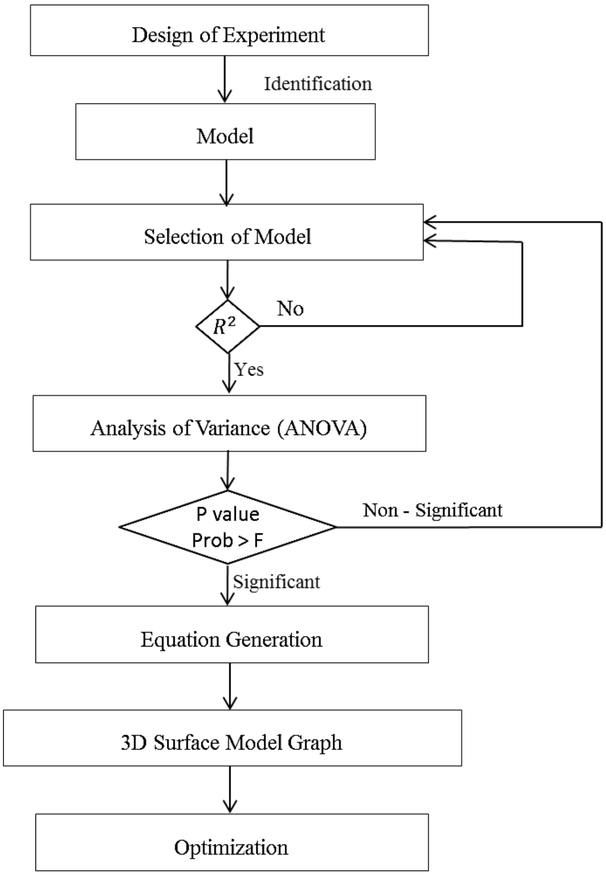
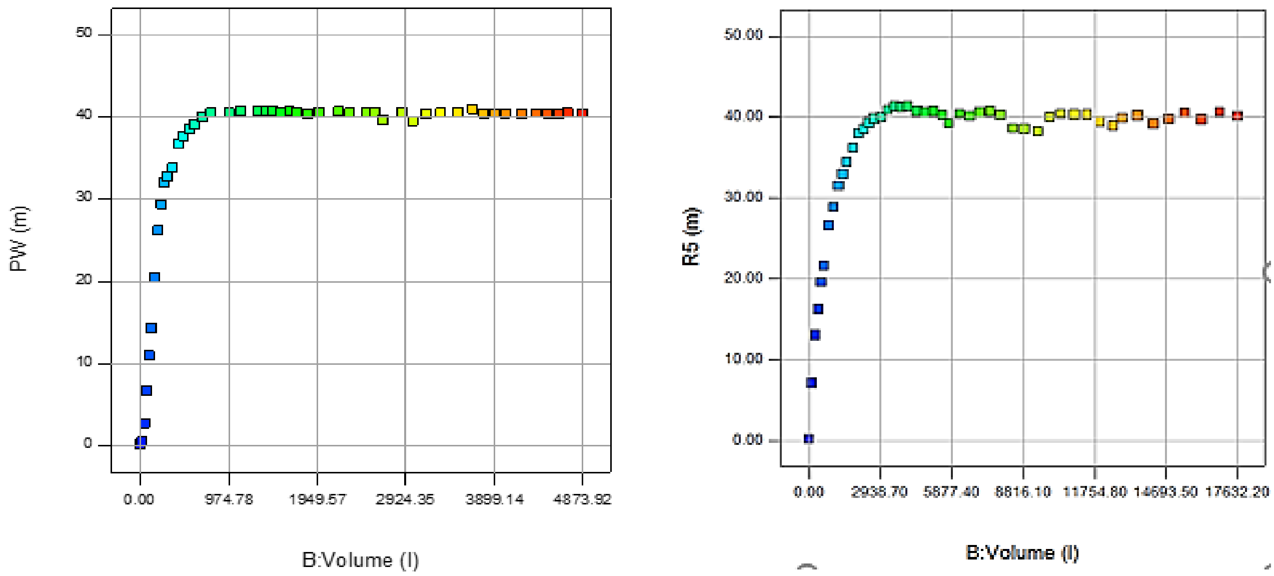


Fig. 4. Model analysis for R_1, R_2, R_3, R_4 and R_5

3. Results

Based on the analysis and results between parameters such as time, volume, and water level of responses, several conclusions were made accordingly to the relationships between Factor A, Factor B and output from optimized value. After carried out the test, data were recorded and re-calculated accordingly to the experiment time. When the time taken for groundwater extraction was longer, the quantity of groundwater was also increasing at the same moment as shown in Figure 5(a) and Figure 5(b).

The maximum reading for Factor A (t, minutes) is 245 while Factor B (v, litres) is 4873.92 and 17632 each. It was concluded that the relationship between R_5 (level of well, m) and Factor B (v, litres) was moderately positive correlation as the correlation reading is positive and both R_1& $R_5$with Factor B are associable and in linear relationship by increasing together. It indicated that graph shows a huge climb and remained steady of well level, m of PW and R5 with range of 39.50m to 40.95m even Factor B was constantly increasing. It was explained that the location of pump is located at level of 41m, therefore the level inside the well maintained at 39.50m to 40.95m.



(a) (b)

Fig. 5. Evaluation R (level of underground well, m) to factor B (volume, litres): (a) R_1(case 1), (b) R_5 (case 2)

It was summarized that groundwater for case 1 was discharged at a constant rate of $28.65\mathrm{m}^3/\mathrm{day}$ and increased by time. However, it was too low compared to case 2 with $103.63\mathrm{m}^3/\mathrm{day}$ of discharge. The lower value in case 1 might happen due to the 1 horsepower of pump that located at level of 40 m inside the well. Besides, it was explained that the location of pump is located at level of 41m, had directly affected to R_1 during 34 minutes to 245 minutes where the water maintained at 39.50 m to 40.95m. Besides, the reason that cause to the insignificant changing of water level was including low infiltration of clay soil between 0.004 – 0.007 mm/s [10]. In addition, the noticeable changing might happen due to the pumping area when pumping had changed the regular course and amount of groundwater flow inside the zone of depression [16]. When two cones of depression overlap, the interference reduces the water available to each well.

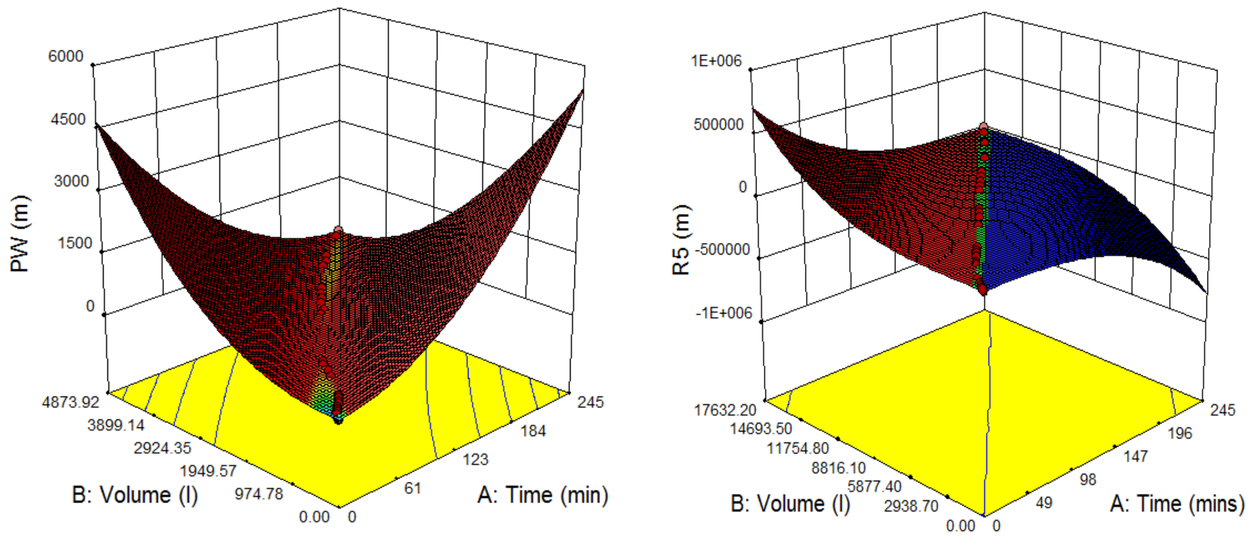
During pumping test in case 2, it was observed that $R_3$and R_4 that located 36m and 40m from R_5 had not changing during the pumping test. The water level remained 0.05m within 245 minutes and pumping test at R_5 had great influences towards the changing of R_1 only. It was explained that the distance is near (35m) and R_1 was located within the cone of depression, and distance of more than

36m was unaffected to pumping activities in RECESS, UTHM. It indicated that the extraction quantity of groundwater does not affect water level of another well in a far distance.

Pumping activities was directly and indirectly affecting the water level of nearby well. For the 48 samples run of pumping experiment within 245 minutes at RECESS UTHM, the changing of invert level by minutes was identified with the optimal value of Factor A and Factor B. Models are used for prediction in order to generate response surface graphs and contour plots. There are significant interactions between volume and time factors, the response surface graphs and contour plots as variation of the process conditions are shown in Figure 6.

When Factor A and Factor B are performing together, R_1 seems unaffected and maintained at the lowest point which formed 'U' shape as shown in Figure 6(a). However, when there was only one Factor performing in test, R_1 was able to reach to the highest point. It shows that the interaction between Factor A and Factor B will give the least expectation on the experiment.

R_5 in Figure 6(b) shows that Factor B (volume) had achieved the biggest increment in graph as the as the point reached highest point on Factor B only. However, Factor A (time) does not affect much on the changing of the water level of R_5. It indicated that R_5 had more influences for itself water level changing from the amount extraction of groundwater. The much and less of extracted volume manipulated on water level of R_5.



(a) (b)

Fig. 6. 3D surface model of $\boldsymbol{R_1}$ and $\boldsymbol{R_5}$: (a) R_1(case 1), (b) R_5 (case 2)

The numerical optimization finds a point that maximizes the desirability function as shown in Table 1. In fact, the goal of the test was to obtain maximize volume extraction with minimum time with the optimal water changing in R_1, R_2, R_3, R_4 and R_5.

Table 1
Desirability specifications of numerical optimization for crossed design from software Design Expert

Name *(factor)*	Goal *(what we want to control)*	Lower Limit (minimum data input)	Upper Limit (in range of data input)
A	minimize	0	Time
B	maximize	0	Volume

Table 2 and Table 3 show that all goals are joined into one desirability function which is based on various responses and factors. The suitable optimum formulation with high desirability of 0.541 and 0.513 were selected.

Table 2
Optimization conditions, prediction changing of level of other well, and desirability of model for R_1

Time, min	Volume, litres	R1, metres	R2, metres	R3, metres	R4, metres	R5, metres	Desirability ratio
116.243	2719.049	40.950	0.195	0.136	0.024	0.275	0.541
115.280	2698.681	40.950	0.195	0.136	0.023	0.274	0.541
117.813	2752.084	40.950	0.194	0.136	0.026	0.277	0.541

Table 3
Optimization conditions, prediction on changing of level of other well, and desirability of model for R_5

Time, min	Volume, litres	R1, metres	R2, metres	R5, metres	Desirability ratio
117.484	8898.361	2.382	0.040	40.778	0.513
118.464	8966.769	2.388	0.040	40.719	0.512
116.419	8824.063	2.375	0.040	40.842	0.512

From the optimization test, it was analysed that 116.243 minutes (1 Hour 55 minutes) to 117.484 minutes (1 Hour 57 minutes) of pumping can performed best in pumping activities to obtain maximize volume extraction with minimum time with the optimal water level changing in other well.

4. Conclusions

Groundwater extraction capability after 4 hours of pumping test in RECESS, UTHM had calculated and identified. In pumped well, $\mathrm{R_1}$, the quantity discharged at $28.65\mathrm{m^3/day}$. However, $\mathrm{R_5}$ had been extracted at rate of $103.63\mathrm{m^3/day}$ which is 3.62 times higher than $\mathrm{R_1}$. The analysis from groundwater extraction by using Response Surface Methodology (RSM) with the assist of Design Expert software was performed. The model formulated from Design-Expert can generate the ideal performance towards each well by formulating the exact changing process of responses based on historical data with the aid of 2D contour and 3D surface graphs during optimization process. It was indicated that in 116.243 minutes (1 Hour 55 minutes) to 117.484 minutes (1 Hour 57 minutes) of pumping activity can performed best in pumping activities to obtain maximize volume extraction with minimum time with the optimal water changing.

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