



**UNIVERSITI PUTRA MALAYSIA**

***THE SUITABLE DISCHARGE RATE IN DETERMINE THE AQUIFER  
CHARACTERISTIC USING PUMPING TEST***

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FK 2019 84**

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**2018/2019**

## **ACKNOWLEDGEMENT**

**In the name of Allah, The Most Gracious, The Most Merciful.**

**I have taken efforts in this project. However, it would not have been possible without the kind support and help of many individuals. I would like to extend my sincere thanks to all of them.**

**First and foremost, my deep appreciation and gratitude goes to my supervisor, En. Mohamed Azwan Bin Mohamed Zawawi, who expertly guided me through his advice, guidance and encouragement without which this project would not have been possible. His unwavering support kept me constantly focused with my work and engaged on what I had done**

**My sincere appreciation and thanks also towards the Master students, Muhammad Aidil Hakim bin Mhd Ramzam, Muhammad Nazri Bin Ebrahim and Mohd Shahril bin Mislán for their willingness in numerous ways to help and guide me throughout the completion of the project. Thanks to the technician who helped me directly or indirectly in completing my experiment.**

**I would like express my gratitude towards my parents, Mohd Rozali Bin Abdullah, Khatijah Binti Jusoh and all my family members for their kind co-operation and encouragement which help me in completion of this project.**

**My thanks and appreciations also go to my friends and my colleagues in developing the project and people who have willingly helped me out with their abilities.**

## ABSTRACT

Optimum discharge rate demonstrate the suitable flow rate for the well in order to operate at the optimum condition during the pumping activity. However, there is no recent study that have been conducted to clearly determine on how to obtain the optimum discharge value. Meanwhile in Malaysia, the people who working in hydrogeology field run the pumping test based on the presumption on discharge and available pump at the area. This is inappropriate because the test may cause damage to the aquifer and well while giving an error to the analysis of the aquifer characteristic. In this study, a step drawdown test was conducted with 5 increment of discharge rate in order to obtain the specific capacity for the aquifer. The step test was run for 5 hour at 1 hour interval time. The discharge rate started with  $1.90m^3/hr$ ,  $2.55m^3/hr$ ,  $3.0m^3/hr$ ,  $3.85m^3/hr$  and  $5.14m^3/hr$ . Thus, based on graph specific capacity versus discharge rate, optimum discharge rate was obtained which is  $2.96m^3/hr$ . Next, hydraulic conductivity of aquifer was evaluated by conducting the constant rate test using 3 different discharge which is  $1.90m^3/hr$ ,  $2.96m^3/hr$  and  $5.14m^3/hr$ . Analysis of constant rate test was computed by an Aquifer Test software and the aquifer was verified to be a unconfined aquifer. The constant rate test analyzed the hydraulic conductivity of aquifer with  $2.42m/day$  for the optimum discharge while the recovery test analyzed to be  $0.033m/day$ . The hydraulic conductivity of aquifer from optimum discharge rate which  $2.96m^3/hr$  prove that it is the most suitable pumping rate to be used when conducting any pumping test activity in order to correctly analyzed aquifer characteristic.

## ABSTRAK

Kadar pengepaman optimum menunjukkan kadar aliran yang sesuai untuk telaga beroperasi pada keadaan optimum. Walau bagaimanapun, tidak ada kajian terbaru yang dijalankan untuk menentukan dengan jelas bagaimana untuk mendapatkan nilai pengepaman optimum. Sementara itu di Malaysia, orang yang bekerja di bidang hidrogeologi menjalankan ujian mengepam berdasarkan anggapan mengenai pengepaman dan pam yang ada di kawasan itu. Ini tidak sesuai kerana boleh menyebabkan kerosakan kepada akuifer dan memberikan ralat kepada analisis ciri akuifer. Dalam kajian ini, "STEP TEST" dilakukan dengan 5 kenaikan kadar pengepaman untuk mendapatkan kapasiti khusus untuk akuifer. "Step test" dijalankan selama 5 jam pada waktu selang 1 jam. Kadar pelepasan bermula dengan  $1.90m^3/hr$ ,  $2.55m^3/hr$ ,  $3.0m^3/hr$ ,  $3.85m^3/hr$  dan  $5.14m^3/hr$ . Oleh itu, berdasarkan graf keupayaan khusus berbanding kadar pelepasan, kadar pelepasan optimum diperolehi iaitu  $2.96m^3/hr$ . Selanjutnya, kekonduksian hidraulik akuifer telah dinilai dengan menjalankan ujian kadar tetap menggunakan 3 pelepasan yang berbeza iaitu  $1.90m^3/hr$ ,  $2.96m^3/hr$  dan  $5.14m^3/hr$ . Analisis ujian kadar berterusan dikira oleh perisian Ujian Aquifer dan akuifer itu telah disahkan sebagai akuifer tak terkurung. Ujian kadar malar menganalisis kekonduksian hidraulik akuifer dengan  $2.42m/day$  untuk pelepasan optimum manakala ujian pemulihan dianalisis menjadi  $0.033m/day$ . Kekonduksian hidraulik akuifer dari kadar pelepasan optimum yang  $2.96m^3/hr$  membuktikan bahawa ia adalah kadar pam yang paling sesuai untuk digunakan apabila menjalankan apa-apa aktiviti ujian pam untuk dianalisis sifat akuifer yang betul.

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## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 Overview**

A pumping test is a practical and reliable method of estimating well performance, well yield, zone of influence of the well and aquifer characteristics (Agency & Waters, 2006). The test consists of pumping groundwater from a well at a constant rate and measure the water levels in the pumped well or any nearby observation well during and after the pumping activity. (Balasubramanian, 2017)

Pumping test have been used to see the balance between the maximum amount of water that can be pumped out of the well and the amount of water that recharges back into the well from the surrounding groundwater resources. (County, 2003)

In hydrogeology, the optimum discharge rate of pumping test is important to determine the suitable discharge rate for the pumped well. In fact, optimum discharge rate should be known before start any test for the exploration of an aquifer.

## **1.2 Problem Statements**

In pumping test, it is difficult to determine how much water could be extracted from the well. In other words, it is difficult to determine the suitable discharge rate ( $Q$ ) that can be used for the well because in Malaysia, most of the people that run the pumping test literally based on the available pump. (M. Azwan, 2018) This is not good as, if the discharge rate is too high it may cause an error when doing the analysis due to clogging of sand around the screen because of the high entrance velocity through the screen. (Sulaiman, Zawawi, Mohamed, & Selangor, 2015)

There are previous research have been done to determine the aquifer characteristic using the pumping test but there is no specific study highlighted on the procedure where they obtain the value for optimum discharge rate before conducting constant-rate method. This clearly an issues because the result will be affected by the value of discharge rate.

### **1.3 Objectives**

**The main objective of this study is to determine the suitable discharge rate in determining the aquifer characteristic using pumping test.**

**The specific objectives are:**

- 1. To determine the optimum discharge rate for pumping test**
- 2. To determine the hydraulic conductivity using different discharge rate.**
- 3. To analyze the suitable the discharge rate with the hydraulic conductivity from the natural groundwater flow.**

## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.1 Groundwater in Malaysia**

In several parts of the world, groundwater has been used as a reliable supply of water for many purposes such as agricultural, domestic and industry uses. In Malaysia, despite our country uses about 90% of water from the surface water resource, we currently having a problem to maintain the quality of the water and also the cost for the water treatment is high. That is why groundwater is the most realiable alternative to our country other than depends totally on surface water. Therefore, it is important to appropriately manage the groundwater system in order to be able manage this resources.

## 2.2 Aquifer

Groundwater exists everywhere below the ground surface however some parts of the saturated zone contain more water than others. An Aquifer is a groundwater reservoir composed of geological units that are saturated with water and sufficiently permeable to yield water in a useable quantity to wells and springs. Aquifers can transmit the ground water from area of recharge to area of discharge through the hydraulic gradient and provide a storage medium for useable quantities of groundwater (Heath, 1983). The movement of groundwater is affected by the characteristic of the soil at the study area which is the hydraulic conductivity.

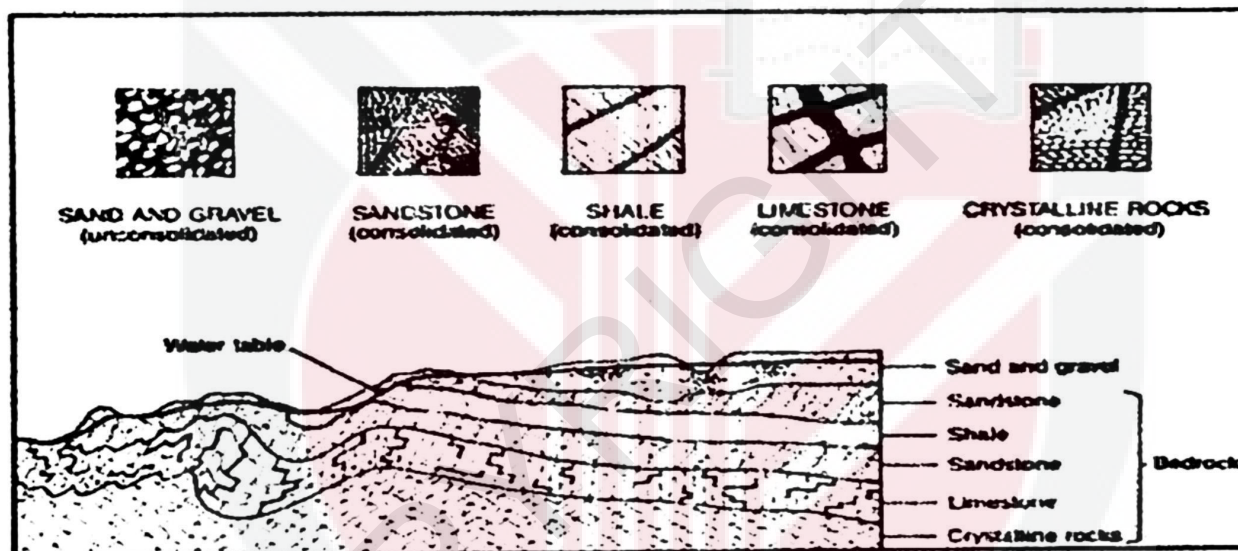


Figure 2. 1 Formation of Groundwater

## 2.3 Types of Aquifers

Aquifers are classified in terms of their structure, hydraulic performance, texture, lithology, and the mobility of their water. (Michigan Environmental Education Curriculum & Groundwater Contamination, 2013) . Types of aquifers are remarkably diverse in geologic structure and there are three general types of aquifer which is confined, unconfined and leaky or semi-confined.

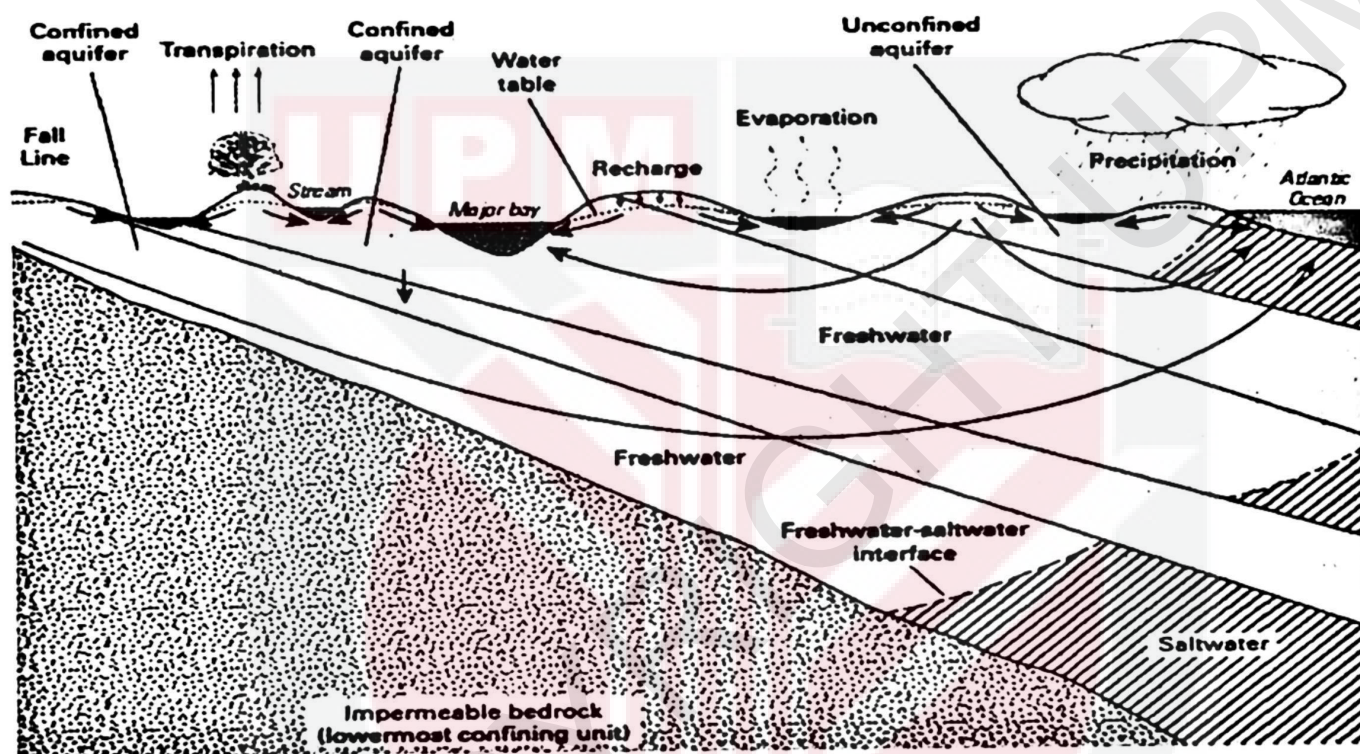
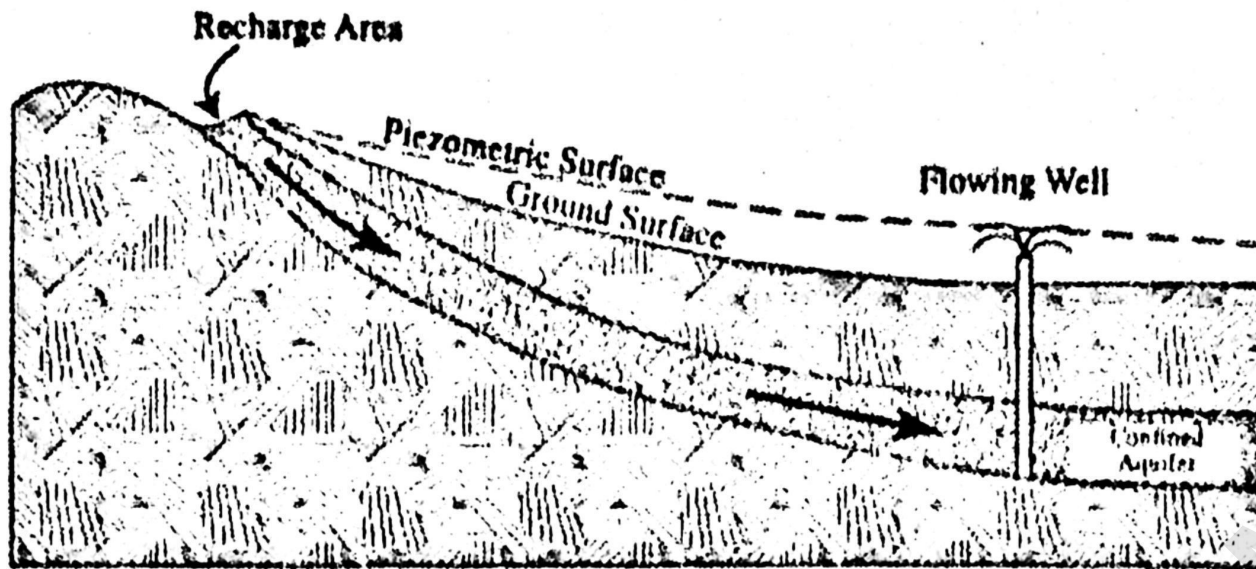


Figure 2. 2 Aquifer types and formation

### 2.3.1 Confined Aquifers

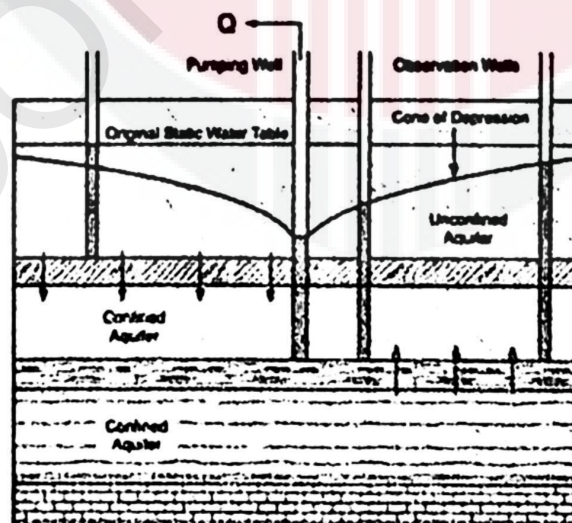
A completely saturated aquifer whose upper and lower boundaries are impervious layers and also known as artesian or pressure aquifers. Groundwater in confined aquifers is under high pressure because of impervious layers.



**Figure 2. 3 Confined Aquifer**

### 2.3.2 Leaky Aquifers

A completely saturated aquifer that is bounded above by a semi-pervious layer and below by a layer that is either impervious or semi-pervious. These are a common feature in alluvial valleys, plains, or former lake basins where a permeable stratum is overlain or underlain by a semi-pervious aquitard or semiconfining layer. Pumping from a well in a leaky aquifer removes water in two ways: by horizontal flow within the aquifer and by vertical flow through the aquitard into the aquifer.



**Figure 2. 4 Formation of leaky aquifers**

### 2.3.3 Unconfined Aquifers

A permeable bed only partly filled with water and overlying a relatively impervious layer. An unconfined aquifer is one in which a water table varies in undulating form and in slope, depending on areas of recharge and discharge, pumpage from wells, and permeability. Its water table free to raise and fall because it not subjected to any pressure other than its own weight.

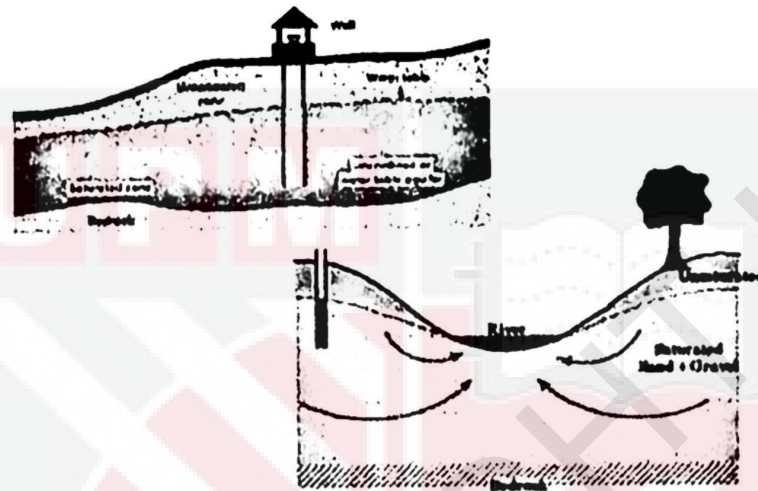
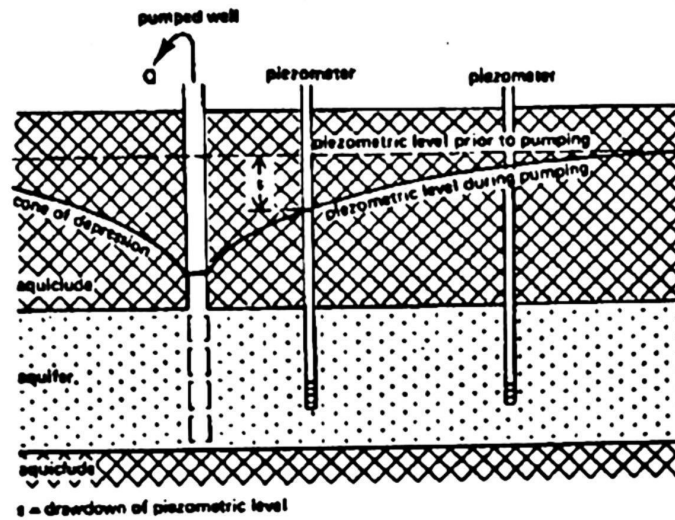


Figure 2. 5 Formation of unconfined aquifers

### 2.4 Pumping Test

The principle of a pumping test is that if we pump water from a well and measure the discharge of the well and the drawdown in the well and in piezometers at known distances from the well, we can substitute these measurements into an appropriate well-flow equation and can calculate the hydraulic characteristics of the aquifer. (Construction Dewatering and Groundwater Control, 2002)



**Figure 2. 6 Drawdown in pumped aquifer**

**i. Discharge rate measurement**

The frequency of measurements depends on the pump, engine power characteristics, the well, and the zone tested. Discharge from electric pumps should be measured and adjusted (if necessary) at 5, 10, 20, 30, 60 minutes, and hourly thereafter. Other types of pumps may require more frequent attention; however, no "rule of thumb" can be set because of the wide variation in equipment response (Stallman, 1983).

**ii. Groundwater level measurement**

The water levels in the well must be measured many times during a test, and with as much accuracy as possible. Because water levels are dropping fast during the first one or two hours of the test, the readings in this period should be made at brief intervals. As pumping continues, the intervals can be gradually lengthened. After the pump has been shut down, the water levels in the well and the piezometers will start to rise rapidly in the first hour, but more slowly afterwards.

### **iii. Duration of Pumping**

Pumping tests commonly last from five hours to five days (Walton, 1962). In some cases, tests may need to be continued until the cone of depression has stabilized and does not expand as pumping continues (e.g., drawdown does not appreciably increase/decrease). Such a steady state or equilibrium can occur within a few hours to weeks or never. According to Kruseman and de Ridder (1990), the average time to reach steady state a leaking ground water zone is 15 to 20 hours. A test of a confined ground water zone should last a minimum of 24 hours. Three days or more should be allowed for tests conducted in unconfined zones because of the slow expansion of the cone of depression. The duration necessary to define the hydraulic parameters depends on the regional and local geologic setting. Plotting drawdown data during tests often reveals anomalies and the presence of suspected or unknown boundaries, and assists in determining test duration.

### **iv. Discharge rate measuring device**

Some discharge measurement techniques are more accurate than others and some allow for a convenient means of adjusting rate. A commercial water meter of appropriate capacity can be utilized. It should be connected to the discharge pipe in a way that ensures accurate reading. The orifice weir is commonly used to measure discharge from high capacity pumps. A manometer is fitted into the discharge pipe. The water level in the manometer represents the pressure in the pipe when the water flows through the orifice. Details on orifice design and interpretation of results can be found in Driscoll (1986). Finally, discharge rate can be obtained by water level measurements taken from weirs and flumes. The rate of flow is determined within known constriction dimensions placed in the discharge channel originating at the well head (Driscoll, 1986).

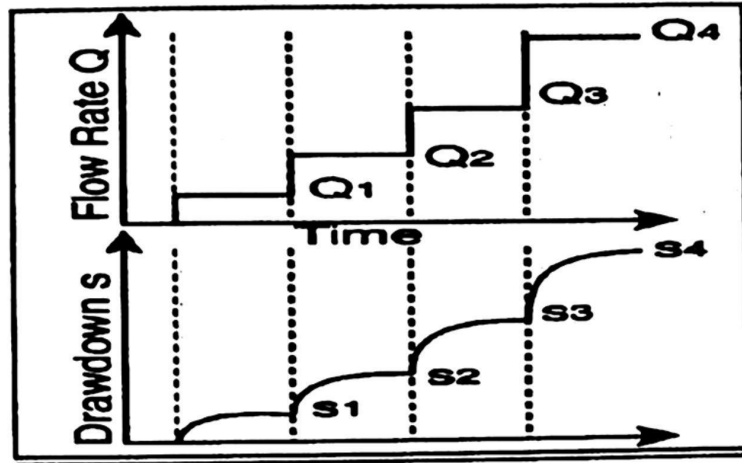
### **2.4.1 Determination of Optimum Discharge Rate**

Before conducting pumping test, optimum discharge rate must be determine to ensure the well and aquifer worked at its best performance. Lee(1915) defined the optimum discharge as the limit to the quantity of water can be extracted regularly and permanently without the depletion of the storage reserve. The high flow rate might damage the screen of well as the water velocity is high that also can leads to clog around the screen. Thus, the hydraulic conductivity decreased and error occurred during the analysis.

#### **I. Step drawdown Pumping Test**

The step drawdown test is conducted in order to provide a range of specific capacities for the well and a reliable method for determining the size of pump and setting (Doh, 2009). A step drawdown test would be recommended to obtain the optimal pumping rate at which the constant rate discharge test should be conducted. But this test will not identify the aquifer information on impermeable boundaries, recharge boundaries or conditions of groundwater under the influence of surface water.

Jacob (1947) introduced the concept of step drawdown test in order to find the impact of well discharge on the drawdown measured in the pumping well. This test provides important information in determining the optimum pumping rate and the depth of pumping based on the yield of the extraction (Bouwer, 1978). The pumping rate in a step drawdown test is consist of short duration of constant discharge rate that run at a progressively higher pumping rate. Initially, the well is pumped at a low constant rate until the well stabilize as it reaching the steady state.



**Figure 2. 7 Principle of Step-drawdown test**

The minimum suggested step drawdown test consists of at least four different pumping rates that conducted at least for 60 minutes (Doh, 2009). It is important to determine the highest flow rate during the pumping in order to ensure the well could operate efficiently. Other than that, the specific capacity of a well also can be used to determine the optimum pumping rate. With higher pumping rates, the specific capacity of the well will decrease due to the well losses.

### 2.4.2 Constant Rate Pumping Test

Constant rate pumping test involve pumping the well at a constant discharge rate and measure the drawdown throughout the test. Depth to water measurement was recorded for pumped well before starting the test in order to determine the static depth to water. The water level was monitored and measured for a certain period.

**Table 2. 1 Range of intervals between water-level measurement in well**

<b>Time since start pumping (minutes)</b>	<b>Time interval (minutes)</b>
0 – 5	0.5
5 – 60	5
60 – 120	20
120 – shutdown of the pump	60

Pumping test is most common method used to determine the hydraulic parameters such as hydraulic conductivity (K) of an aquifer. It frequently used as a tool to characterize systems of aquifers, low permeable layers and flow boundaries. The water discharge by pumping test will stressing the aquifer and result the drawdown of water level at the scale of water usage.

**Table 2. 2 Range of interval between water-level measurement in the pumping well**

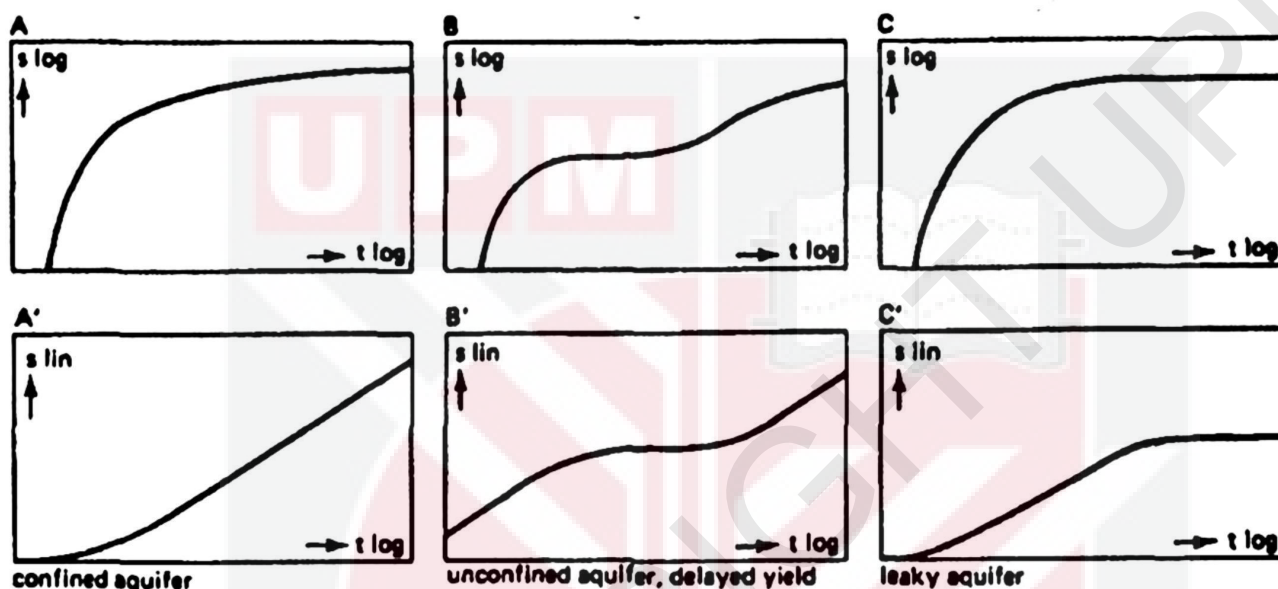
Time since start of pumping	Time intervals
0 – 2 min	10 sec
2 – 5 min	30 sec
5 – 15 min	1 min
15 – 50 min	5 min
50 – 100 min	10 min
100 – 5 hours	30 min
5 – 48 hours	60 min
48 – 6 days	3 times a day
6 days – shutdown of pump	1 times a day

**Table 2. 3 Constant Rate Collection Sheet**

<b>CONSTANT RATE DISCHARGE</b>			
<b>WELL NO</b>		<b>DATE / DAY (START)</b>	12/3/2019
		<b>TIME</b>	4.30pm
<b>LOCATION</b>		<b>DATE / DAY (FINISH)</b>	13/4/2019
		<b>TIME</b>	4.30pm
		<b>STATIC WATER LEVEL</b>	1.1 m
		<b>REDUCE GROUND LEVEL</b>	0
<b>TYPE OF WELL</b>		<b>COLLAR HEIGHT</b>	0.5 m
<b>DEPTH OF WELL</b>	18 m	<b>PUMP POSTION</b>	10 m
<b>SCREEN POSITION</b>	14.0 - 18.0 m	<b>RATE OF PUMPING</b>	1.90 m <sup>3</sup> /hr
<b>PUMPING INTERVAL</b> ( minutes )	<b>WATER LEVEL</b> ( meter )	<b>DRAWDOWN</b> ( meter )	<b>REMARKS</b>
0.00	0.85	0.00	

**i. Time drawdown data interpretation**

Time-drawdown data obtained from pumping test was interpreted with the help of analytical and numerical models. A plot of drawdown and logarithmic derivative of drawdown were used to assist the identification of the model. The best matched model parameters are considered to represent the field parameters but the model becomes true representative of field situation only when the actual field conditions are considered (Singh, 2001).



**Figure 2. 8 Diagnostic plot in hydrogeology**

**ii. Evaluation of aquifer hydraulic parameters**

Kruseman et. Al (1994) described method of aquifer test analysis for several hydrogeologic conditions. Table below showed a common types of pumping test analysis based on aquifer types.

**Table 2. 4 Pumping test analysis based on types of aquifer**

TYPES OF AQUIFER	ANALYSIS
CONFINED	THEIS  $S = \frac{q}{4\pi KD} W(u)$ S = drawdown (m) Q = discharge rate (m <sup>3</sup> /day) KD = transmissivity of aquifer (m <sup>2</sup> /day) W(u) = well function of u

	$U = \frac{r^2 S}{4\pi K D t}$ <p> <math>r</math> = distance from pumping well to observation well  <math>S</math> = dimensionless storativity  <math>T</math> = time since pumping started </p>
UNCONFINED	<p>NEUMAN</p> $S = \frac{q}{4\pi K D} W(uA, uB, \beta)$ <p> <math>s</math> = drawdown (m)  <math>Q</math> = discharge rate  <math>KD</math> = transmissivity of aquifer  Well function of <math>W(uA, uB</math> and <math>\beta)</math> </p> $uA = \frac{r^2 S a}{4\pi K D t}, uB = \frac{r^2 S y}{4\pi K D t}, \beta = \frac{r^2 K v}{D^2 K h}$ <p> <math>r</math> = distance from pumping well  <math>SA</math> = volume of water release  <math>SY</math> = specific yield  <math>Kv</math> = vertical hydraulic conductivity  <math>Kh</math> = horizontal hydraulic conductivity </p>
LEAKY	<p>HANTUSH-JACOB</p> $s = \frac{Q}{4\pi K D} W(u, r/L)$ <p> <math>s</math> = drawdown  <math>Q</math> = discharge rate  <math>KD</math> = transmissivity of aquifer  Well function of <math>r/L</math> obtained from type curve that the best fits the observed data curve by calculating value of </p> $L = \sqrt{Tc}$ <p> <math>L</math> = leakage factor  <math>c</math> = hydraulic resistance of aquitard </p>

### 2.4.3 Recovery Test

Recovery tests (also called residual drawdown tests) involve measuring water level rise after the pump is shut down. These tests provide an independent check on the transmissivity and storativity determined from a pumping test. The results should be used in conjunction with calculations obtained from the pumping phase to estimate the true hydraulic properties of the zone of interest. Results of a recovery test can be more reliable than pumping test results because recovery is not influenced by the erratic fluctuations that can be characteristic of pumping.

As with the early portions of the pumping phase in which water levels drop rapidly, water levels rise rapidly during early portions of the recovery phase and are followed by a decreasing rate of water level rise. It is therefore important to establish the same schedule for obtaining water level measurements during the initial portions of the recovery phase as that used during the pumping phase (Kruseman and de Ridder, 1990)

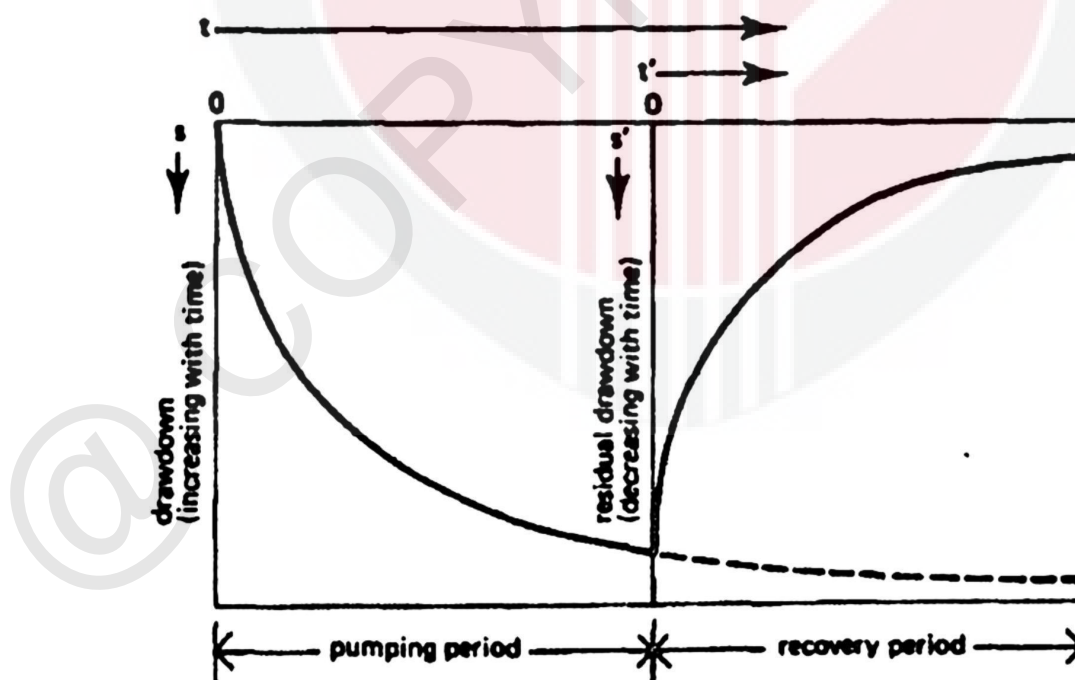


Figure 2. 9 Time drawdown and residual drawdown

**Table 2. 5 Recovery test collection sheet**

<b>GROUNDWATER DEVELOPMENT</b>					
<b>RECOVERY TEST</b>					
<b>WELL NO</b>			<b>DATE/ DAY (START) TIME</b>	13/3/2019 4.30pm	
<b>LOCATION</b>			<b>DATE/ DAY (END) TIME</b>	13/4/2019 4.54pm	
			<b>STATIC WATER LEVEL</b>	1.1 m	
<b>TYPE OF WELL</b>			<b>COLLAR HEIGHT</b>	0.5 m	
<b>WELL DEPTH</b>	18 m		<b>REDUCED GROUND LEVEL</b>		
<b>SCREEN POSITION</b>	14.0 - 18.0 m				
<b>Time after Start of Pumping, t (min)</b>	<b>Time after End of Pumping, t'(min)</b>	<b>t/t'</b>	<b>Residual Water Level (m)</b>	<b>Residual Drawdown (m)</b>	<b>Remarks</b>
1480.00	0.00		2.061	1.214	

**Table 2. 6 Common analysis used for recovery test**

Types Of Aquifer	Analysis
All aquifer	<p>Theis recovery method</p> $s' = \frac{Q}{4\pi KD} \{W(u) - W(u')\}$ $u = \frac{r^2 S}{4KDt} \text{ and } u' = \frac{r^2 S'}{4KDt'}$ <p>when <math>u</math> and <math>u'</math> are sufficiently small, used equation</p> $s' = \frac{Q}{4\pi KD} \left( \ln \frac{4KDt}{r^2 S} - \ln \frac{4KDt'}{r^2 S'} \right)$ <p><math>s'</math> = residual drawdown (m)</p> <p><math>r</math> = distance from well to piezometer</p> <p><math>KD</math> = transmissivity of aquifer</p> <p><math>S'</math> = storativity during recovery</p> <p><math>S</math> = storativity during pumping</p> <p><math>t</math> = time since start pumping</p> <p><math>t'</math> = time since cessation of pumping</p> <p><math>Q</math> = rate of recharge = rate of discharge</p>

## **2.4.4 Data Analysis of Pumping Test Result**

### **i. Analysis Data Using Aquifer Test Software**

Aquifer test software is design to manage hydraulic testing result and provide a selection og the most commonly used solution methods for data analysis. Data can be directly entered in Aquifer Test imported from Microsoft Excel workbook file or imported from any data logger file in ASCII format. In the end of analysis, Aquifer test software could provide the hydraulic characteristic, mapping and countouring on the study area.

### **ii. Aquifer test software support pumping test solution for the following condition**

- 1. Confined aquifer**
- 2. Unconfined**
- 3. Leaky aquifer**
- 4. Fracture flow aquifer**
- 5. Isotropic or anistropic aquifer**
- 6. Constant or variable discharge rates**
- 7. Single or multiple pumping well**

**Table 2. 7 Method to analyze the time drawdown data using aquifer test software**

Pumping Test And Types Of Aquifer	Analysis
Pumping test, Confined aquifer	<p><b><u>THEIS</u></b></p> $S = \frac{Q}{4\pi KD} W(u)$ <p>S = drawdown (m)                      Q = discharge rate (m<sup>3</sup>/day)                      KD = transmissivity of aquifer (m<sup>2</sup>/day)                      W(u) = well function of u</p> $U = \frac{r^2 S}{4\pi KD t}$ <p>r = distance from pumping well to observation well                      S = dimensionless storativity                      t = time since pumping started</p>
Pumping test, Unconfined	<p><b><u>NEUMAN</u></b></p> $S = \frac{q}{4\pi KD} W(u_A, u_B, \beta)$ <p>s = drawdown (m)                      Q = discharge rate (m<sup>3</sup>/day)                      KD = transmissivity of aquifer (m<sup>2</sup>/day)                      Well function of W(<math>U_A, U_B</math> and <math>\beta</math>)</p> $u_A = \frac{r^2 S a}{4\pi KD t}, u_B = \frac{r^2 S y}{4\pi KD t}, \beta = \frac{r^2 K_v}{D^2 K_h}$ <p>r = distance from pumping well                      SA = volume of water release                      SY = specific yield                      Kv = vertical hydraulic conductivity (m/day)                      Kh = horizontal hydraulic conductivity (m/day)</p>

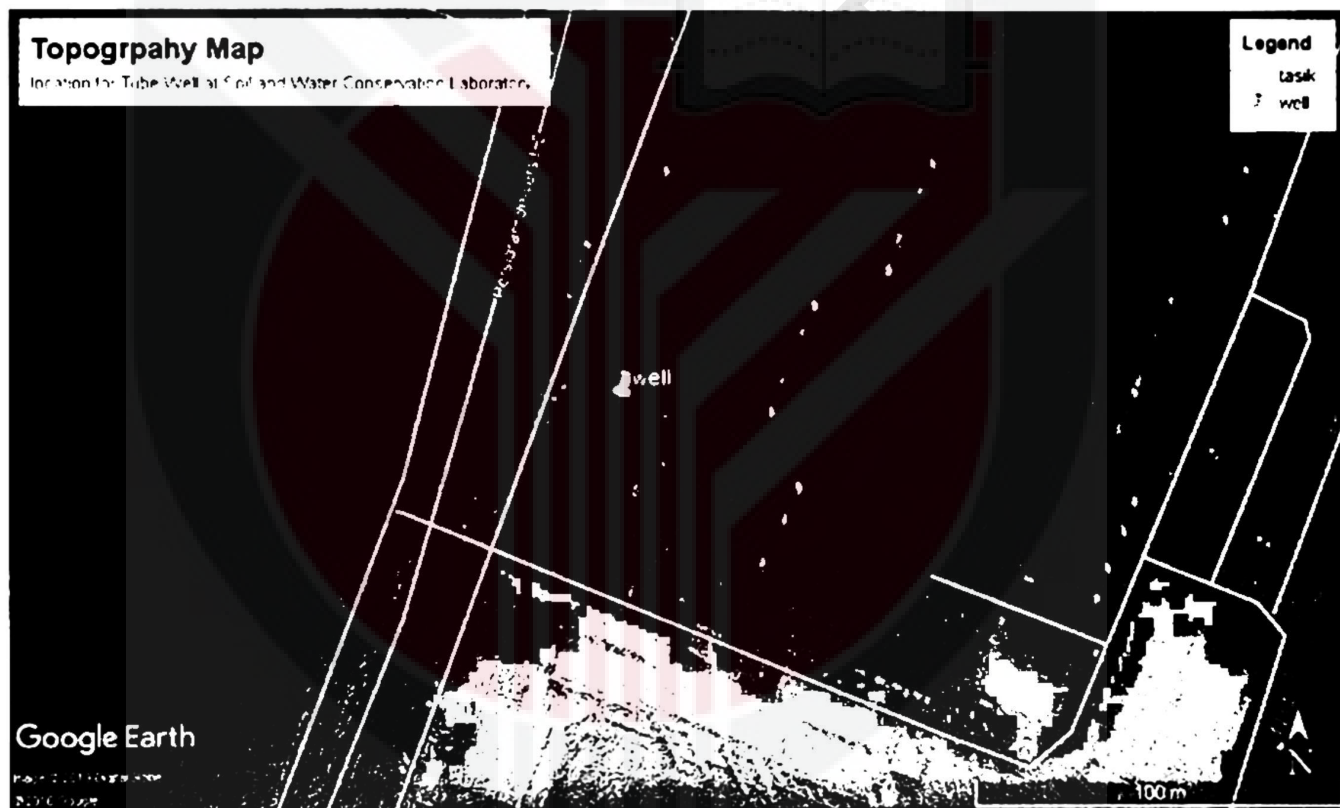
<p><b>Pumping test, Leaky</b></p>	<p><b><u>HANTUSH-JACOB</u></b></p> $s = \frac{Q}{4\pi KD} W(u, r/L)$ <p>s = drawdown (m)  Q = discharge rate (m<sup>3</sup>/day)  KD = transmissivity of aquifer (m<sup>2</sup>/day)</p> <p>Well function of r/L obtained from type curve that the best fits the observed data curve by calculating value of</p> $L = \sqrt{Tc}$ <p>L = leakage factor (m)  c = hydraulic resistance of aquitard</p>
<p><b>Recovery Test, All aquifer</b></p>	<p><b><u>AGARWAL SOLUTION</u></b></p> $S_r = \frac{Q}{4\pi KD} \ln \frac{4Tt_e}{r^2 S}$ <p>S = drawdown(m)  Q = discharge rate(m<sup>3</sup>/day)  KD =transmissivity of the aquifer (m<sup>2</sup>/day)  S<sub>r</sub> = different between head with t<sub>e</sub> the equivalent Agarwal time :</p> $t_e = \frac{tr tp}{tr+tp}$ <p>tr = time since recovery started  tp = total duration of pumping</p>

## CHAPTER 3

### METHODOLOGY

#### 3.1 Study Area

The area of study is located at Soil and Water Conservation Laboratory. The tube well is geographically located at latitude (3.007174 degrees) and longitude (101.720118 degrees) on the map of Faculty Engineering, UPM, Serdang. It is about 180m away from lake at Faculty of Engineering, UPM. The topography map of research area is shown in figure 3.1. This research area cover location for the tested tube well.



**Figure 3. 1 Topography map of Study Area**

This stage will involve site surveying in order to identify the parameters involve in pumping test. All the data collected will be used to determine the appropriate procedure for the aquifer test method. Data needed consist of geological structure of study area, water level measurement, aquifers properties and design information of well.

### 3.2 Experimental Design

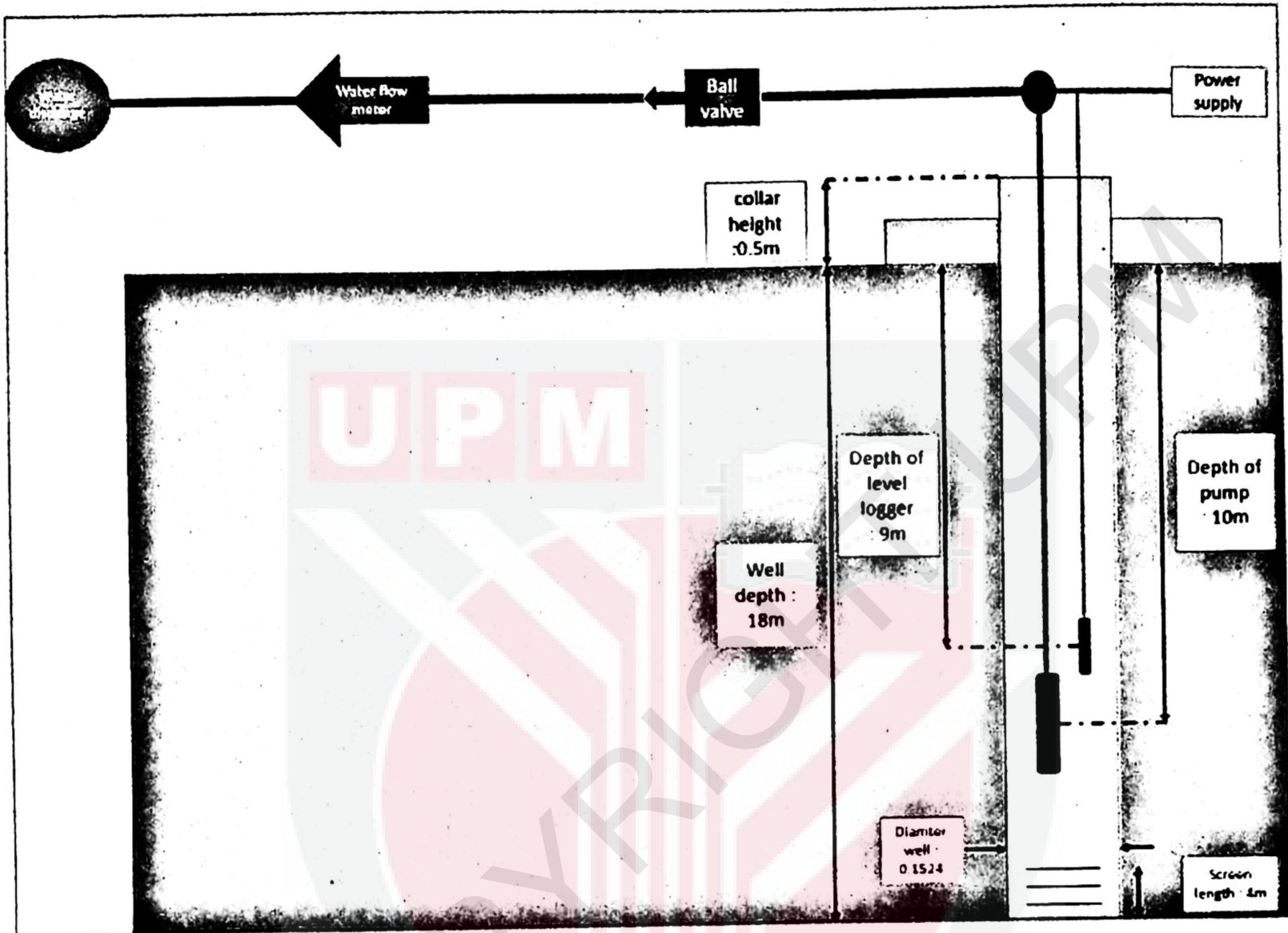
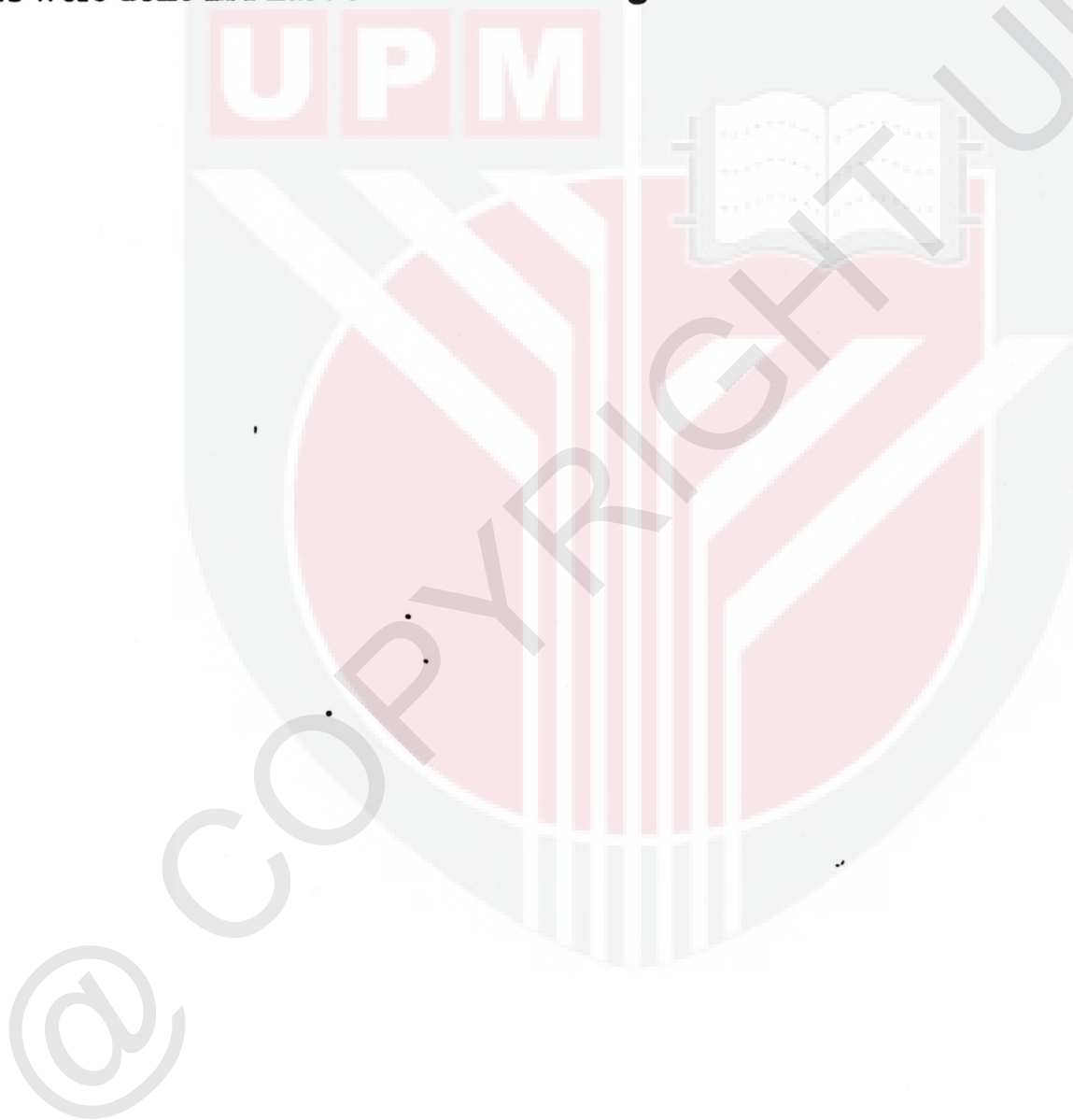


Figure 3. 2 Experimental design for pumping test

### **3.3 Experimental Procedure**

The methodology of this project consist of three main phases. Phase 1 including the site investigation of study area, selection of suitable equipment to be used on the study, determination of well characteristic and geological condition. Phase 2 is the determination of optimum discharge rate to be used in the constant rate test. Three different discharge rate will be selected in order to observe the drawdown pattern. Analysis of drawdown pattern, aquifer types and hydraulic parameters were done in Phase 3. Flow chart in figure 3.3 summarized the methodology discussed below.



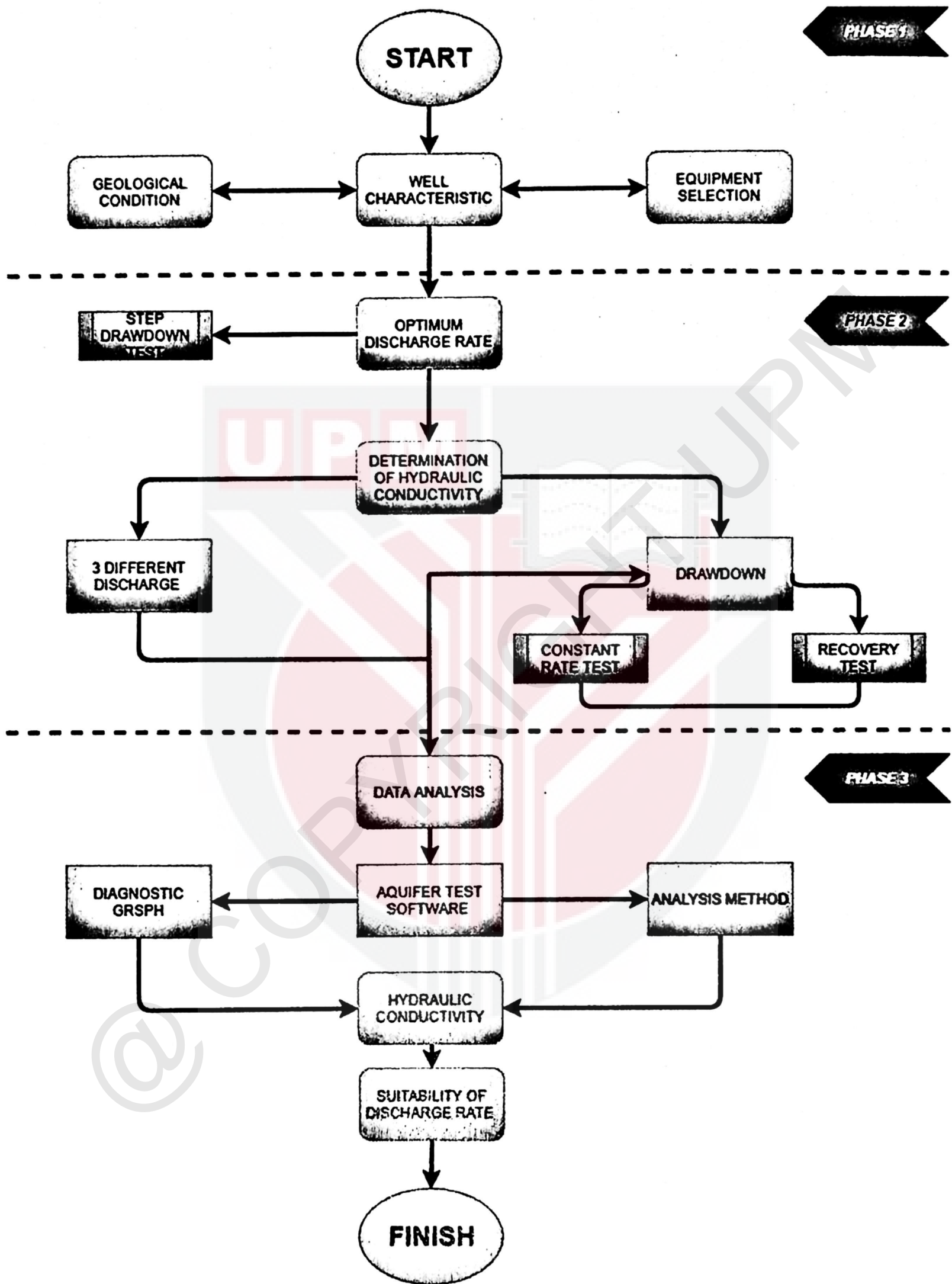


Figure 3. 3 Experimental Procedure for pumping test

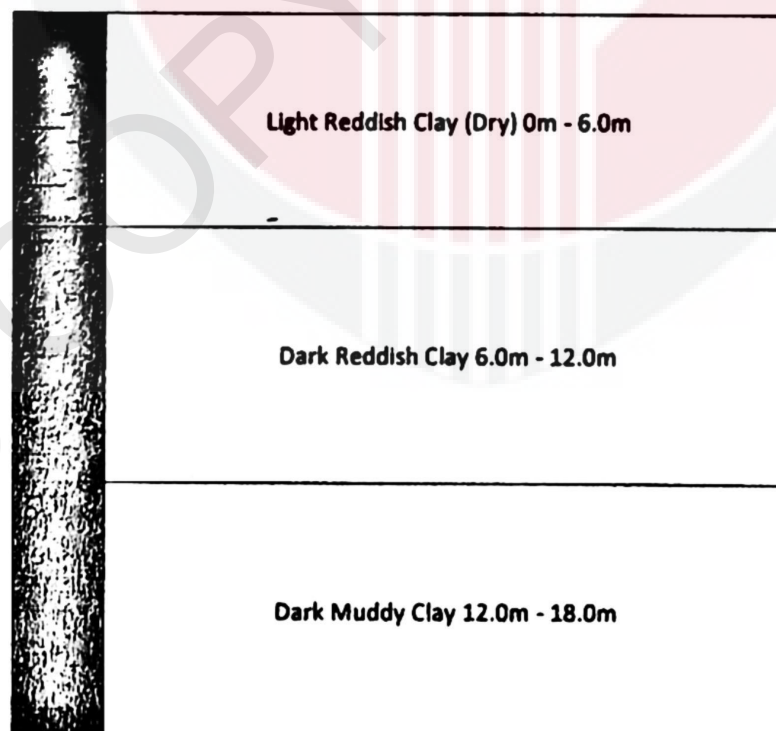
### 3.4 Preparation of Pumping Test System

#### 3.4.1 Well characteristic

In pumping test, it is important to know the information of well in order to select an appropriate equipment to be use when running the test. Besides, it is essential to plan out the work flow so that the preparation can be done properly to ensure the success of the in-situ experiment. The characteristic of the well have been listed in the table 3.1 .

**Table 3. 1 Well information**

Parameter	Tube well	
	North	East
Coordinate	3.007274	101.720118
Depth Of Well	18m	
Location Of Screen	14.0m - 18.0m	
Length Of Collar	0.5m	
Diameter Of Well	0.1524 m	



**Figure 3. 4 Borehole log of well**

### 3.4.2 Selection of equipment

Based on the tube well characteristic, the selected equipment have been listed in preparation for Pumping Test. Table 3.2 shows the list of equipment for the pumping test.

**Table 3. 2 List of equipment used in pumping test**

<b>Equipment</b>	<b>Quantity</b>	<b>function</b>
Submersible pump	1	Extract groundwater from the well
Solinst levellogger	1	Automatically measure the drawdown of water in tube well
Water level indicator	1	Measure the drawdown of water manually
Hoses	2	Drain the discharge water to the drainage to avoid the water enter the aquifer directly
Ball valve	1	Control the discharge of the pump
Water flow meter	1	Automatically measure the discharge of water
Hose clamps	8	Hold the connected hose with equipment
Stopwatch	1	Get the reading at the set interval time

### 3.4.3 Setup of Pumping Test System

The setup of the pumping test systems at the site is important to get the overview about the environment condition and also the equipment. Before the real pumping test is conducted, the test can be run in order to identify the problem that may occur at the site and also to the equipment. Based on the test run, the real problem can be identified. When run the pump for the first time, it is difficult to control the discharge rate by using the ball valve. Figure 3.5 shows the procedure to setup the pumping test equipment.





**Figure 3. 5 Activities of Pumping Test**

### **3.5 Determination of optimum discharge rate**

Determination of optimum discharge rate was done by step-drawdown pumping test that was conducted with variable of discharge for a period of time. Static water level in the pumping well was measured using water level indicator before the testing started. The groundwater drawdown will be monitored and measured throughout the test using level logger.

#### **3.5.1 Step Drawdown Pumping Test**

The information obtained from the Step drawdown test was recorded includes the pump discharges, drawdown in the well and time taken for the test. As for the water level measurement for each step in the well were taken at time interval as shown in table 3.3.

**Table 3. 3 Time interval for the step-drawdown test**

<b>Starting time after pumping</b>	<b>Time intervals</b>
0 – 5 minutes	0.5 minutes
5 – 60 minutes	5 minutes
60 – 300 minutes	30 minutes

The procedure of increasing the pumping rate was repeated for five hour by changes the discharge at every one hour. The test begins with the lowest pumping rate and finished with the highest rate.

The pump discharge are controlled using the ball valve as shown in the figure 3.6 .



**Figure 3. 6 Ball valve and Water flow meter**

The different discharges were determined by the flowmeter (HB2800 SERIES) as shown in figure

3.6. Table 3.4 below indicate the value of discharges at every one hour interval

**Table 3. 4 Discharge rate at every one hour interval**

<b>Time (hr)</b>	<b>Discharge rate (<math>m^3/hr</math>)</b>
1	1.90
2	2.55
3	3.05
4	3.85
5	5.14

The drawdown of well while the test were conducted measured by using two different method as shown in figure 12, figure 13. The In-situ troll level logger will be used to determine the groundwater level during the step drawdown test. It was installed in the depth of 9 meter in the well. Besides that, the water level indicator is the manual method to measure the water level or drawdown.

### 3.6 Determination of Hydraulic Conductivity of Aquifer

#### 3.6.1 Constant Rate Discharge Test

Following the recovery from step drawdown pumping test, the well will be pumped at a constant discharge rate. The discharge rate depends on observation from step drawdown pumping test result. For the constant rate test, there will be three value of discharge rate to be used in the test as shown in the table 3.5.

**Table 3. 5 Discharge rate for three different discharge rate**

No.	Discharge rate
1	Lowest
2	Optimum
3	Highest

For each discharge rate, the test was run for a period of time until achieving stability of drawdown data. The water level measurement was taken in the well at the same time interval during the step drawdown pumping test, as in previous table 3.3.

#### 3.6.2 Recovery Test

Once the pump was shut off, water level measurement in the well immediately recorded corresponding to the same time interval as in table previously. The water level measurement were taken continually until the water level reached at least 80 percent or more of the initial water level.

Recovery phase is also very important because the result can be used to calibrate the result from constant rate pumping test.

### 3.7 Analysis of Hydraulic Conductivity for Each Different Discharge Rate

The data for pumping test will be analyzed using the Aquifer Test Software 2016.1. Aquifer Test software is a software technology for graphical analysis and reporting of pumping and slug test data. This software is useful to calculate the hydraulic properties of an aquifer of an aquifer using the selection of pumping and slug test methods. The data from the constant rate test and recovery test will be transfer from solinst level logger into the computer and create a excel file to manage the data.

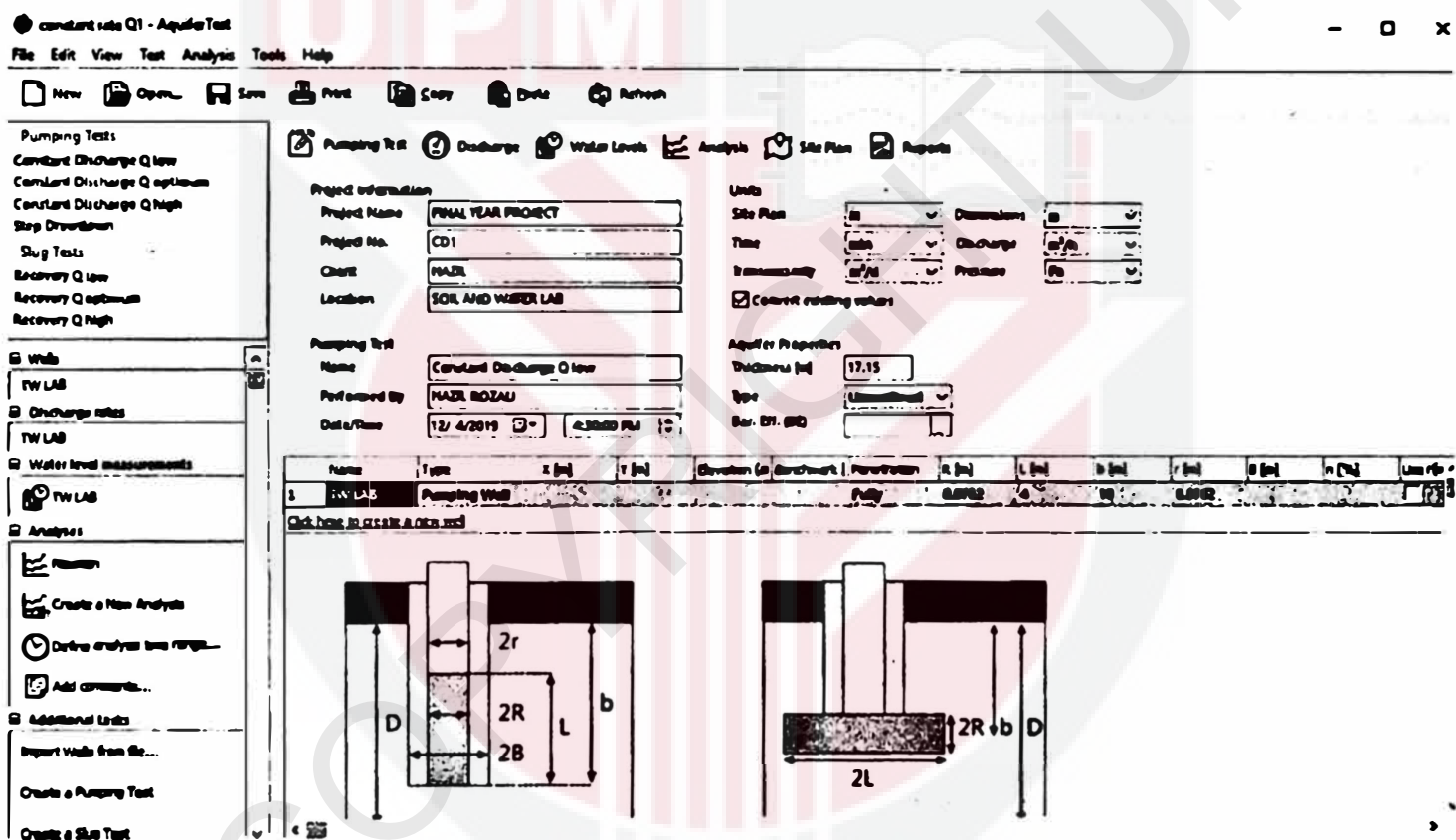


Figure 3. 7 Aquifer Test Software 2016.1

The drawdown pattern was compared with the theoretical models to use the right well test analysis. The theoretical models was known as diagnostic plots which is used to determine the aquifer type and condition before conducting the analysis of the pumping test data.

## CHAPTER 4

### RESULTS AND DISCUSSION

#### 4.1 Optimum discharge rate of pumping test

The optimum discharge rate was obtained by conducting the step drawdown pumping test. The step drawdown pumping test consist of pumping the well with five different discharge started with the lowest discharge rate which is  $1.9m^3/hr$  up to  $5.14m^3/hr$ .

##### 4.1.1 Step drawdown pumping test result

Based on the pumping test activities, the data of groundwater drawdown and discharges are taken.

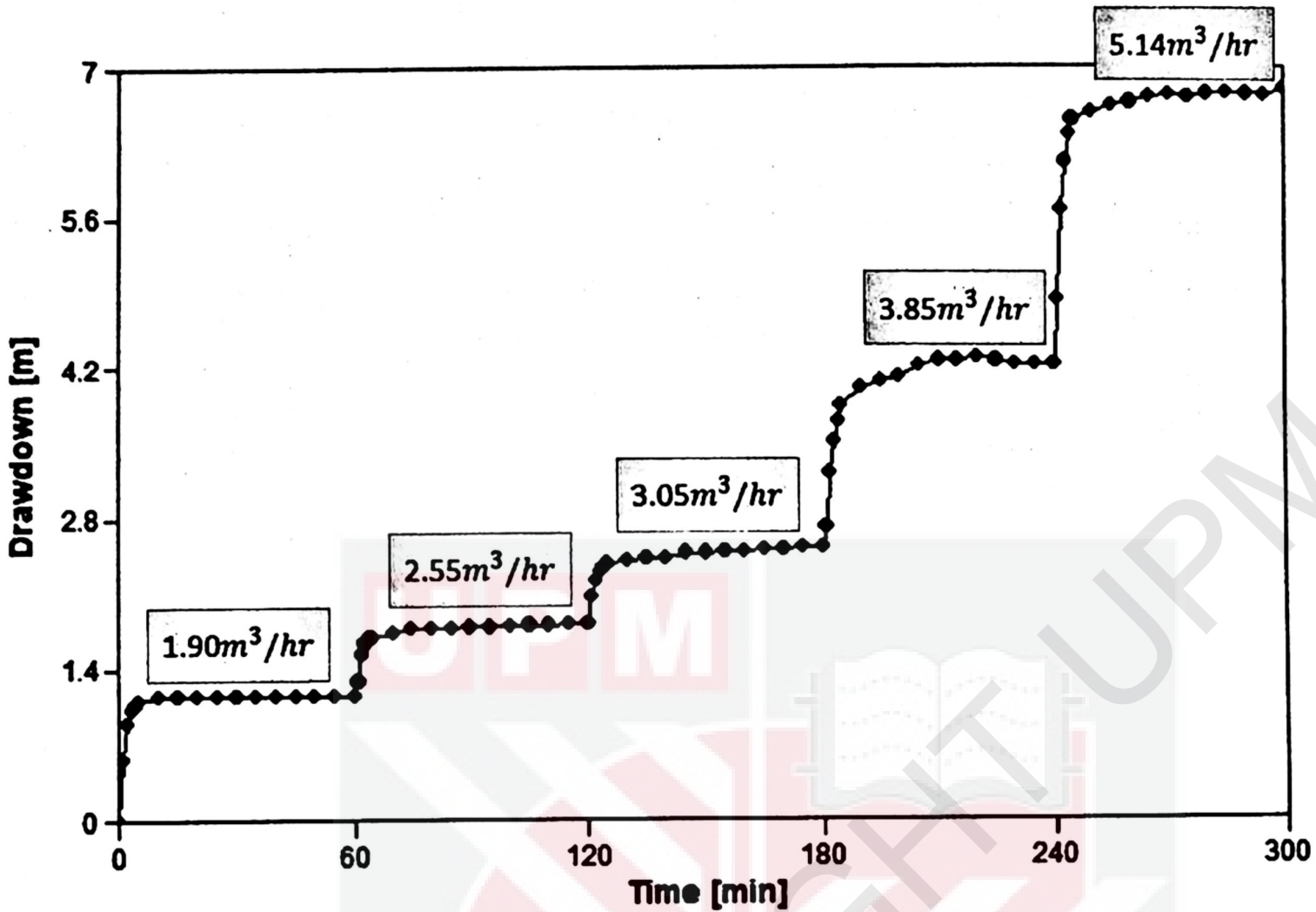
The data are shown in the table 4.1.

**Table 4. 1 Data of Step Drawdown test**

time (min)	Q1 (1.90)			Q2 (2.55)			Q3 (3.05)			Q4 (3.85)			Q5 (5.14)		
	WL	S	ASML	WL	S	ASML	WL	S	ASML	WL	S	ASML	WL	S	ASML
0	1.1	0	41.9	2.248	1.155	40.752	2.915	1.895	40.085	3.624	2.55	39.376	5.331	4.098	37.669
1	1.675	0.575	41.325	2.386	1.286	40.614	3.159	2.059	39.841	3.807	2.707	39.193	5.918	4.818	37.082
2	2.002	0.902	40.998	2.634	1.534	40.366	3.311	2.211	39.689	4.308	3.208	38.692	6.749	5.649	36.251
3	2.124	1.024	40.876	2.732	1.632	40.268	3.391	2.291	39.609	4.593	3.493	38.407	7.206	6.106	35.794
4	2.17	1.07	40.83	2.781	1.681	40.219	3.433	2.333	39.567	4.779	3.679	38.221	7.473	6.373	35.527
5	2.205	1.105	40.795	2.794	1.694	40.206	3.461	2.361	39.539	4.923	3.823	38.077	7.602	6.502	35.398
10	2.244	1.144	40.756	2.839	1.739	40.161	3.494	2.394	39.506	5.093	3.993	37.907	7.662	6.562	35.338
15	2.256	1.156	40.744	2.862	1.762	40.138	3.507	2.407	39.493	5.156	4.056	37.844	7.736	6.636	35.264
20	2.253	1.153	40.747	2.866	1.766	40.134	3.52	2.42	39.48	5.188	4.088	37.812	7.772	6.672	35.228
25	2.248	1.148	40.752	2.874	1.774	40.126	3.562	2.462	39.438	5.299	4.199	37.701	7.822	6.722	35.178
30	2.247	1.147	40.753	2.884	1.784	40.116	3.568	2.468	39.432	5.358	4.258	37.642	7.842	6.742	35.158
35	2.245	1.145	40.755	2.883	1.783	40.117	3.575	2.475	39.425	5.359	4.259	37.641	7.827	6.727	35.173
40	2.243	1.143	40.757	2.891	1.791	40.109	3.586	2.486	39.414	5.387	4.287	37.613	7.849	6.749	35.151
45	2.251	1.151	40.749	2.903	1.803	40.097	3.591	2.491	39.409	5.357	4.257	37.643	7.861	6.761	35.139
50	2.251	1.151	40.749	2.905	1.805	40.095	3.607	2.507	39.393	5.332	4.232	37.668	7.85	6.75	35.15
55	2.248	1.148	40.752	2.909	1.809	40.091	3.618	2.518	39.382	5.327	4.227	37.673	7.835	6.735	35.165
60	2.248	1.148	40.752	2.915	1.815	40.085	3.624	2.524	39.376	5.331	4.231	37.669	7.896	6.796	35.104

From the result obtained, the graph of water level versus time were plotted as shown in figure 4.1.

The graph illustrate the pattern of step drawdown test that started with the lowest discharge to the highest discharge.



**Figure 4. 1 Drawdown versus time**

The static water level of the groundwater in the well is 1.1m. Then, after the test is conducted, water level and drawdown drop according to the increasing of pump discharge rate. At Q1,  $1.90\text{m}^3/\text{hr}$ ; the water level fall from 1.1m to 2.248m, meanwhile the drawdown increase from 0m to 1.148m. At the maximum discharge, Q5,  $5.14\text{m}^3/\text{hr}$ . The water level drop to 7.896m and drawdown is 6.796m. The time range in each step drawdown test is 1 hour. The result illustrate that when the discharge is high, the water level is decrease as the drawdown turn increase. In fact, the well still capable to provide more water even at the maximum discharge of the pump. However, the pump only capable to extract groundwater for  $6.0\text{m}^3/\text{hr}$ . So, the limit discharge is only at  $5.14\text{m}^3/\text{hr}$ .

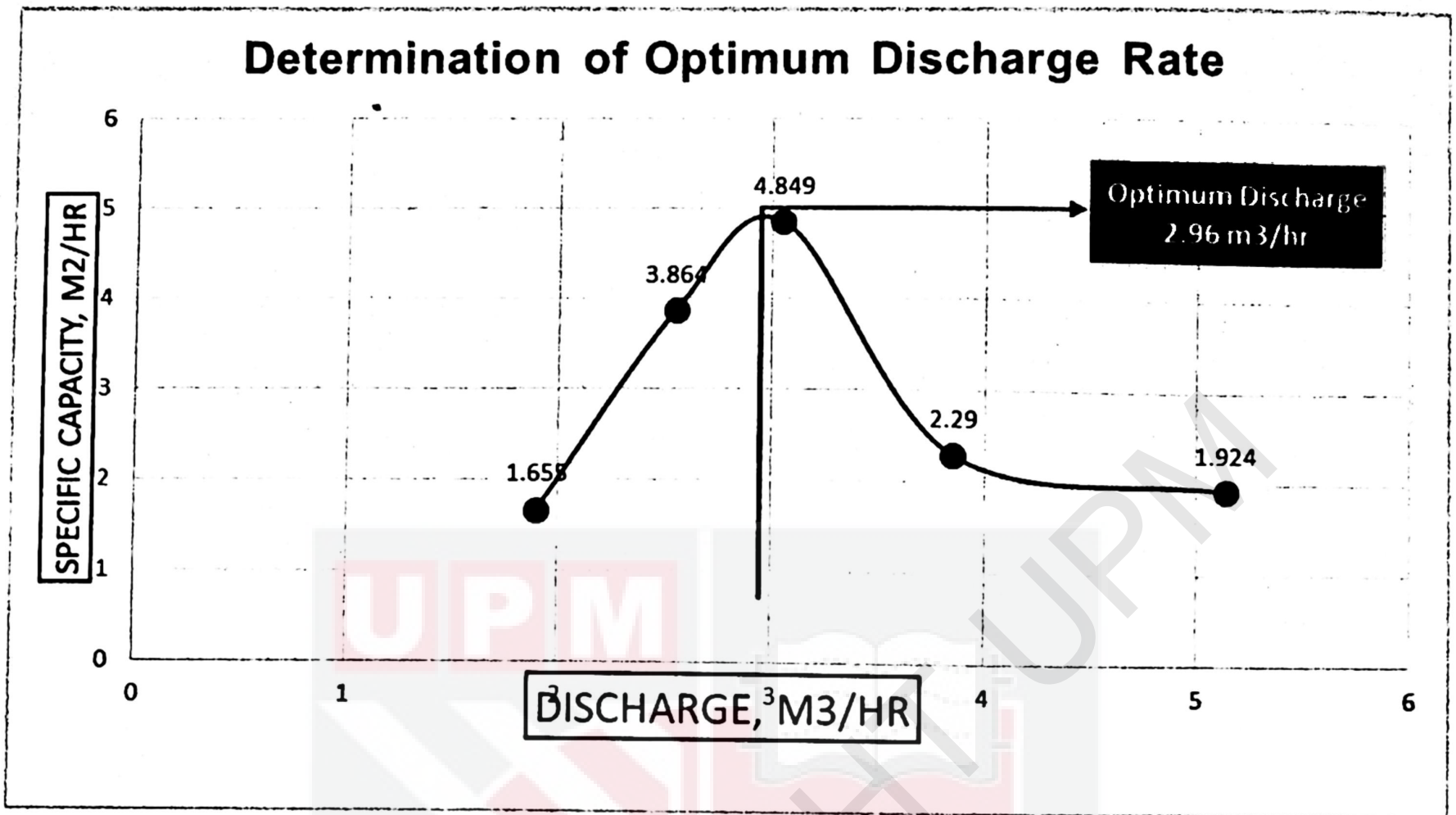
#### 4.1.2 Determination of Optimum Discharge Rate

Based on the result from table 4.1, the different drawdown at each discharge in every hour was shown at the table 4.2 including the specific capacity (Q/S). The graph of specific capacity versus discharge was plotted as shown in figure 4.2

**Table 4. 2 Summary of Step drawdown pumping test data**

<b>Discharge rate (<math>m^3/hr</math>)</b>	<b>Different drawdown (m)</b>	<b>Specific capacity (Q/S)</b>
1.90	1.148	1.655
2.55	0.66	3.864
3.05	0.629	4.849
3.85	1.681	2.295
5.14	2.671	1.924

Drawdown increased up to total of 2.671m after five different steps of discharges. The specific capacity were then analysed to obtain the optimum discharge rate of the well.



**Figure 4. 2 Specific capacity versus Discharge rate**

Figure 4.2 shows the plot of the discharge rate versus specific capacity. Apparently the specific capacity in the pumping well increased when the discharge rate increased gradually. However, there was a point where the specific capacity decreased when the discharge rate increased up to  $5.14\text{m}^3/\text{hr}$ . The drawdown will slowly decreased afterwards even though the discharge rate is still increasing because the well reached its maximum specific capacity based on the pump specification. Therefore, the optimum pumping discharge rate was selected at the maximum specific capacity produced. In this analysis, discharge rate of  $2.96\text{m}^3/\text{hr}$  was selected as the optimum pumping discharge rate for the well.

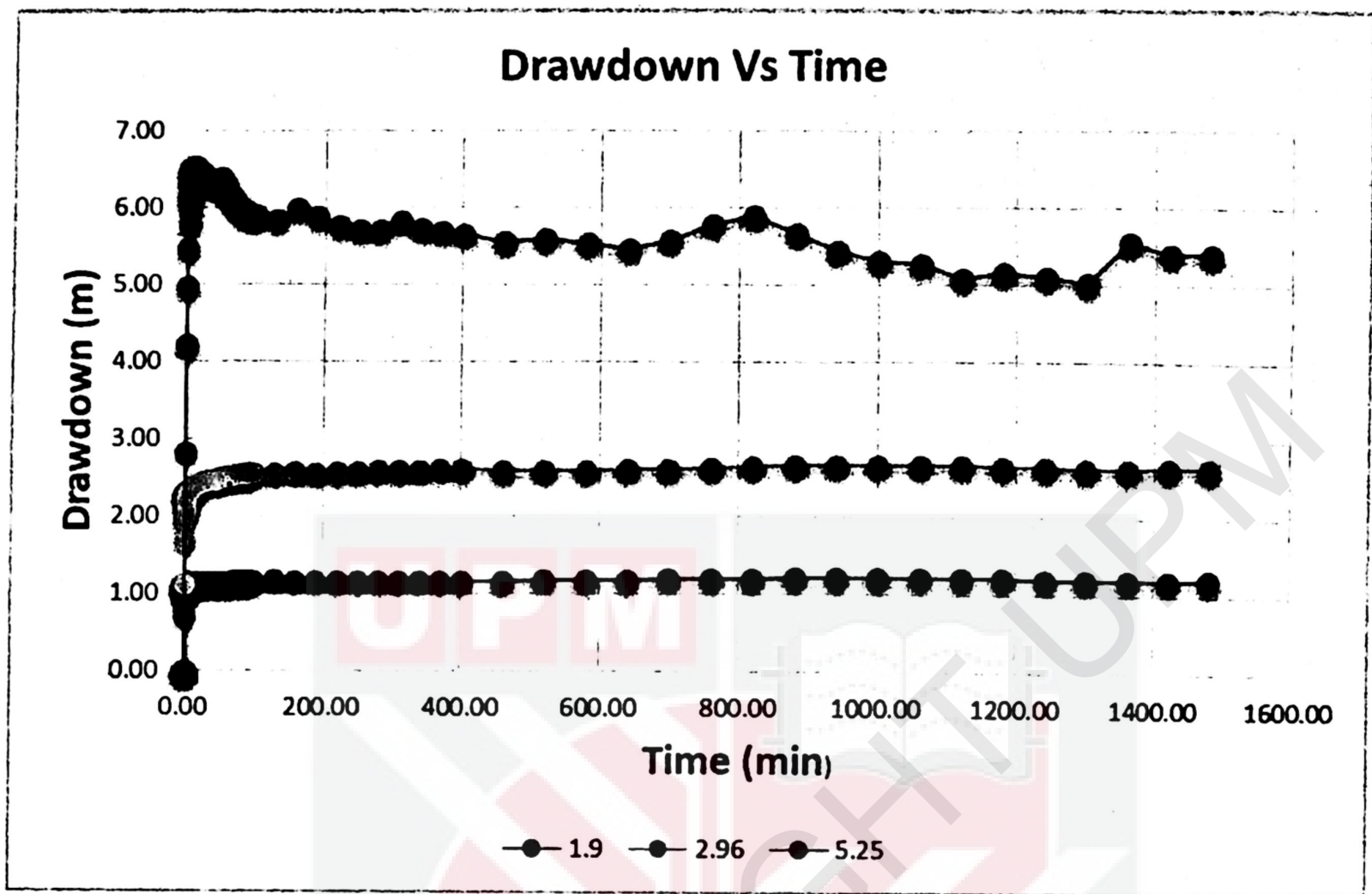
#### 4.2 Evaluation of Hydraulic Conductivity using three different discharge rate

The hydraulic conductivity of aquifer was obtained by conducting the constant rate pumping test. Three different discharge rate was selected consists of the lowest discharge, optimum discharge and the highest discharge rate. The constant rate pumping test was carried out up to 24 hours for each different discharge rate and the summary of result are shown in the table 4.3

**Table 4. 3 Summary of constant discharge rate pumping test**

Discharge, Q ( $m^3/hr$ )	Total Drawdown, S (m)
1.9	1.214
2.96	2.658
5.25	5.402

The initial water level before the constant rate pumping test is 1.1 m and the drawdown was 0 m. The time range for each discharge is 24 hours and the test was started with the lowest discharge rate which is  $1.9m^3/hr$  and continued with  $2.96m^3/hr$  and ended with the highest discharge rate which is  $5.25m^3/hr$ .



**Figure 4. 3 Time drawdown data of constant rate pumping test at different discharge**

The pattern for drawdown versus time for each discharge rate shows in figure 4.3 indicated the increasing of drawdown when the discharge is increase. At the discharge rate of  $5.25\text{m}^3/\text{hr}$ , the drawdown was not stable due to the raining that occur when test was conducted at the site study.

### 4.2.1 Determination of aquifer types

The determination of aquifer types is important in order to determine the analysis to be used for the constant rate pumping test on each different discharge. The diagnostic plot window of constant rate pumping test in Aquifer test software represented in log-log scale and contained two data series consist of the time-drawdown and drawdown derivative data. The right side of the diagnostic plot in Aquifer Test software showed the diagnostic plot templates representing different aquifer conditions and scenarios occurred during the pumping test. The diagnostic plot was compared to a set of typical diagnostic plot templates as shown in the Aquifer Test software in order to identify which model can be used to interpret the data. Figure 4.4, 4.5, 4.6 shows the diagnostic graph for each discharge rate .

#### i) Pumping rate of $1.90 \text{ m}^3/\text{hr}$

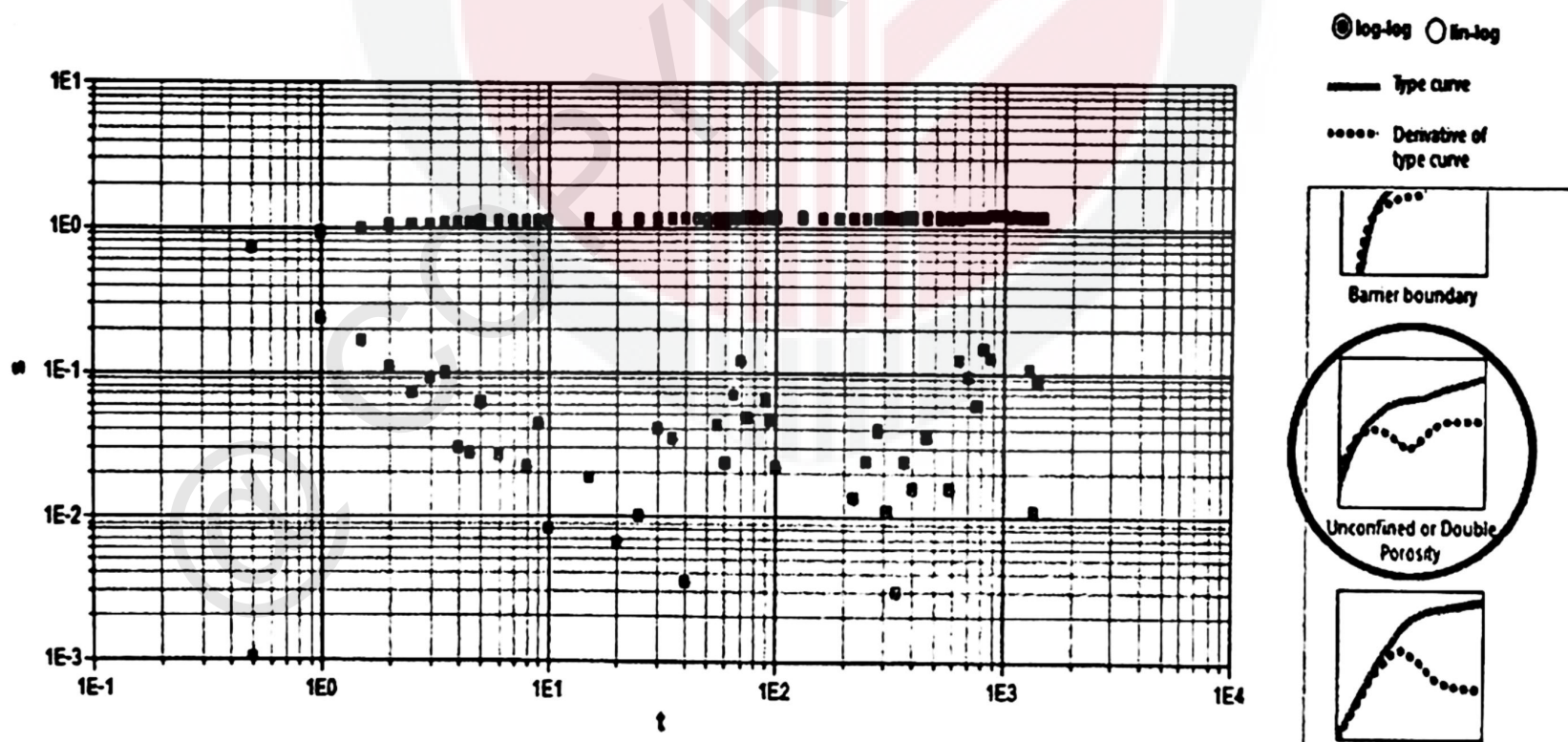


Figure 4. 4 Diagnostic plot of constant rate pumping test for  $1.90 \text{ m}^3/\text{hr}$

ii) Pumping rate of  $2.96 \text{ m}^3/\text{hr}$

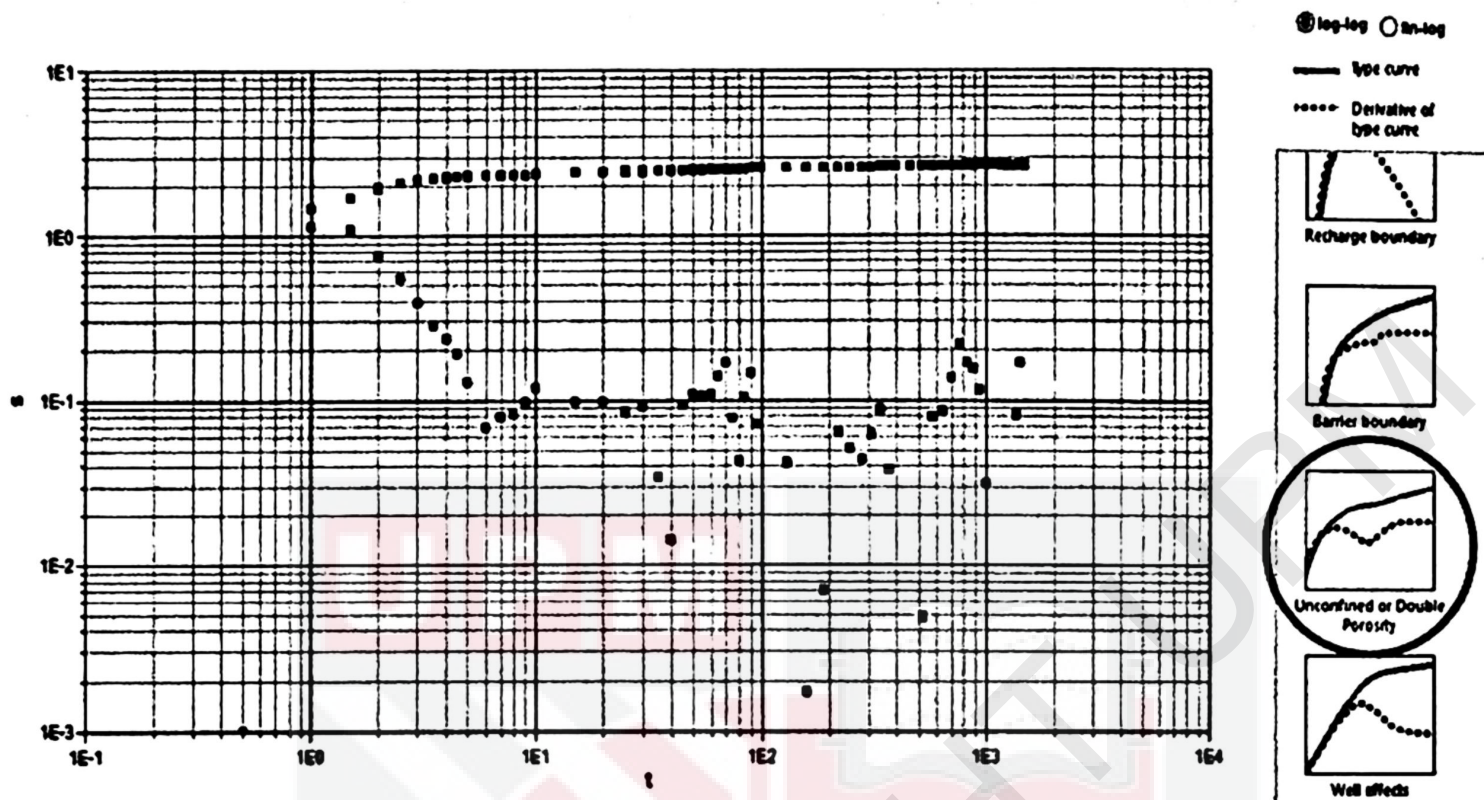


Figure 4. 5 Diagnostic plot of constant rate pumping test for  $2.96 \text{ m}^3/\text{hr}$

iii) Pumping rate of  $5.25 \text{ m}^3/\text{hr}$

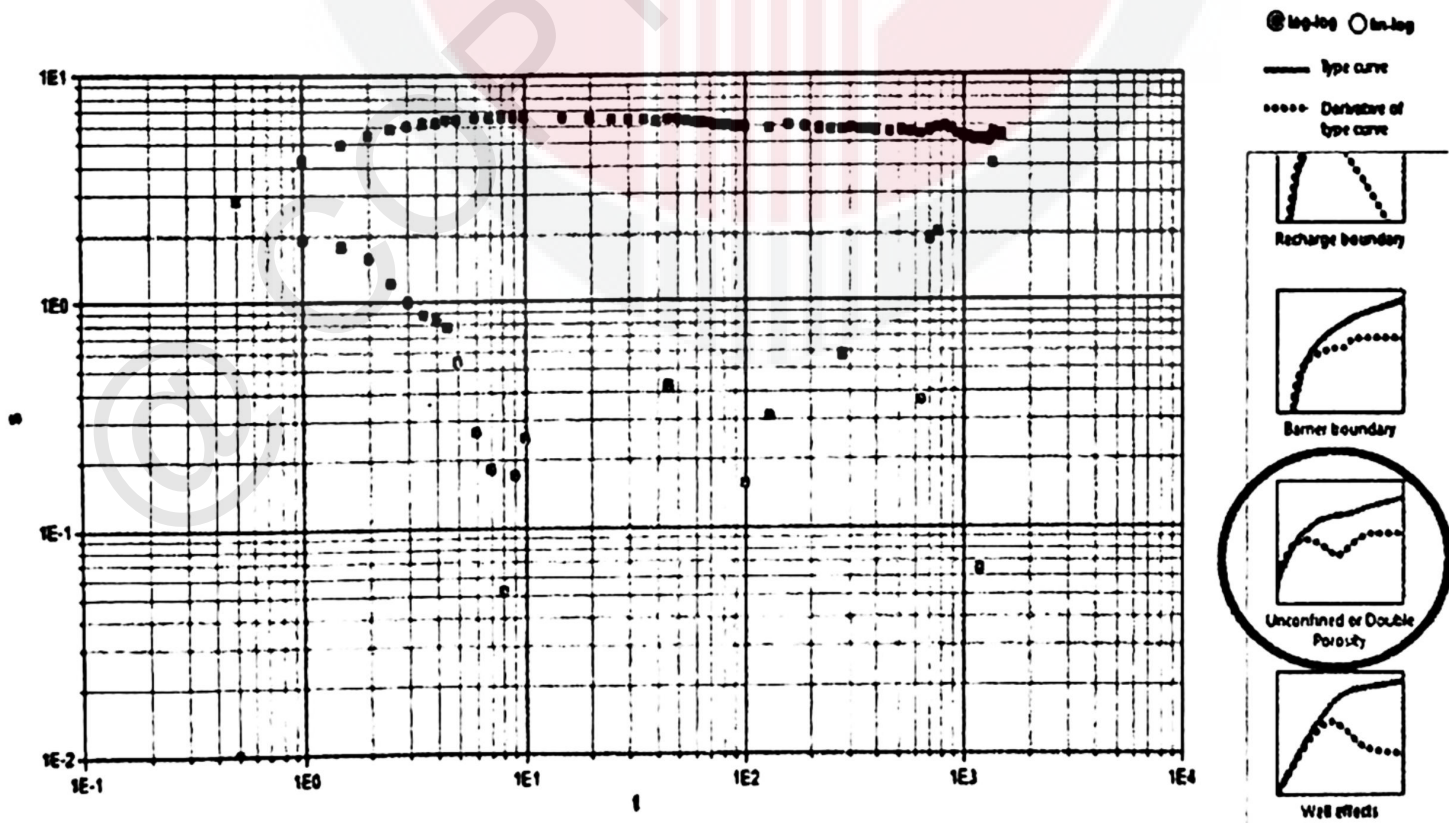


Figure 4. 6 Diagnostic plot of constant rate pumping test for  $5.25 \text{ m}^3/\text{hr}$

Based on the diagnostic plot of time-drawdown data and drawdown derivative data for the three different discharge rate, the curves in all the figure are identical to the typical behavior of unconfined aquifer. Thus, we can use the analysis on assumptions from Neuman method that represent the unconfined aquifer.

#### 4.2.2 Analysis of Hydraulic Conductivity of Aquifer

From the earlier diagnostic plot, the aquifer was identified as unconfined and thus the analysis plot was analyzed using Neuman method in order to determine the corresponding hydraulic conductivity of aquifer. Figure 4.7, 4.8 and 4.9 shows the analysis plot for constant rate pumping rate for each discharge rate.

i) Pumping rate of  $1.90\text{m}^3/\text{hr}$



Figure 4. 7 Analysis plot of constant rate pumping test at  $1.90\text{m}^3/\text{hr}$

ii) Pumping rate of  $2.96 \text{ m}^3/\text{hr}$

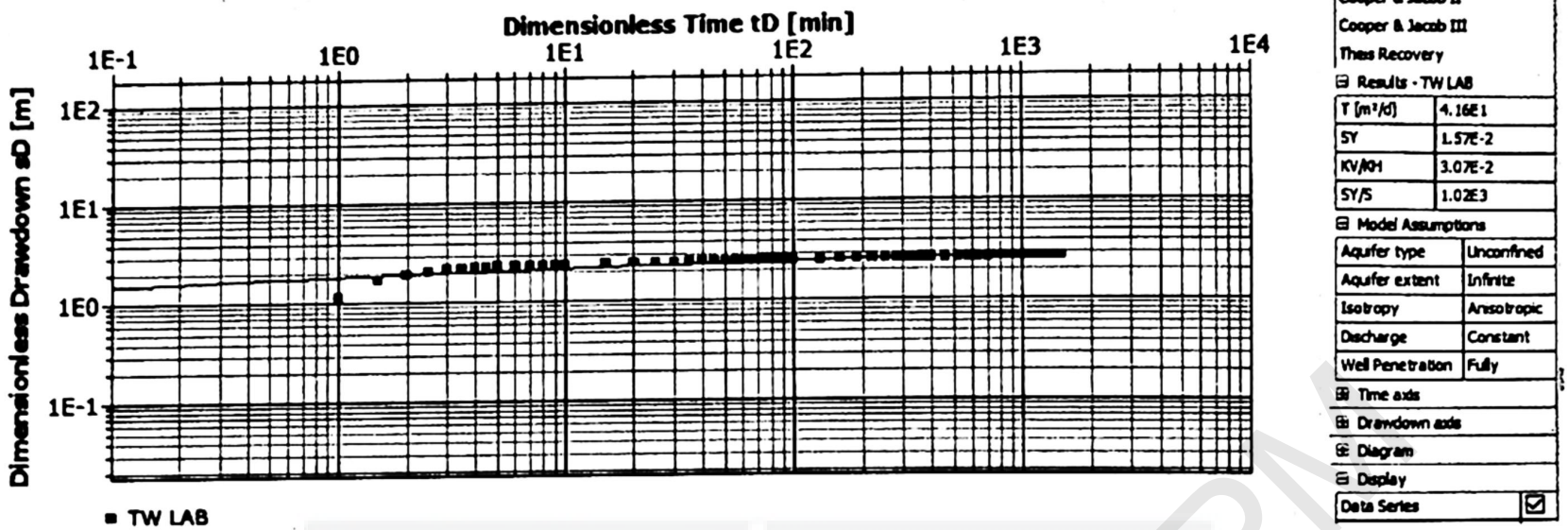


Figure 4. 8 Analysis plot of constant rate pumping test at  $2.96 \text{ m}^3/\text{hr}$

iii) Pumping rate of  $5.25 \text{ m}^3/\text{hr}$

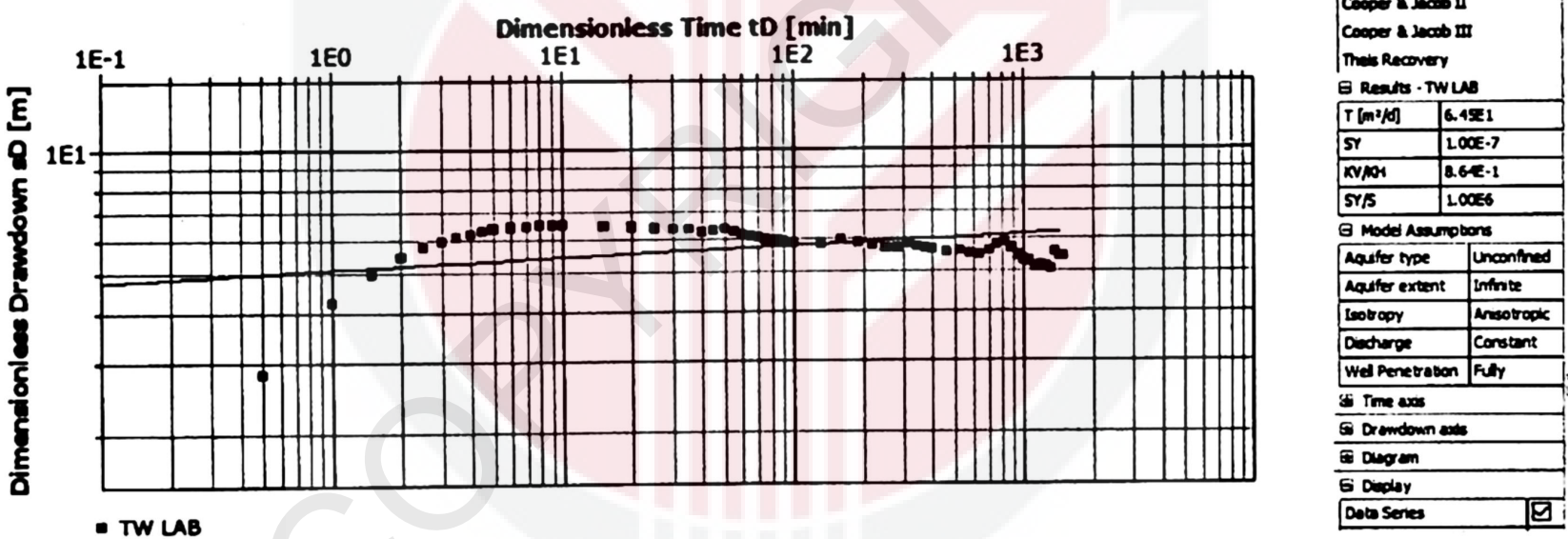


Figure 4. 9 Analysis plot of constant rate pumping test at  $5.25 \text{ m}^3/\text{hr}$

The result of transmissivity;  $T$ , was obtained by the analysis plot for constant rate pumping test at each discharge. Thus, the hydraulic conductivity can be calculated by using the formula as:

$$T = Kb ;$$

$K = \text{hydraulic conductivity (m/day)}$

$b = \text{aquifer thickness (m)}$

The aquifer thickness was considered 17.15m as it was the unconfined aquifer. Table 4.4 shows the result for hydraulic conductivity at each discharge rate.

**Table 4. 4 Hydraulic conductivity obtained from the constant rate pumping test**

Hydraulic parameters	Discharge Rate ( $m^3/hr$ )		
	1.9	2.96	5.25
Transmissivity, $T(m^2/day)$	159	41.6	64.5
Hydraulic conductivity, $K(m/day)$	9.26	2.42	3.76

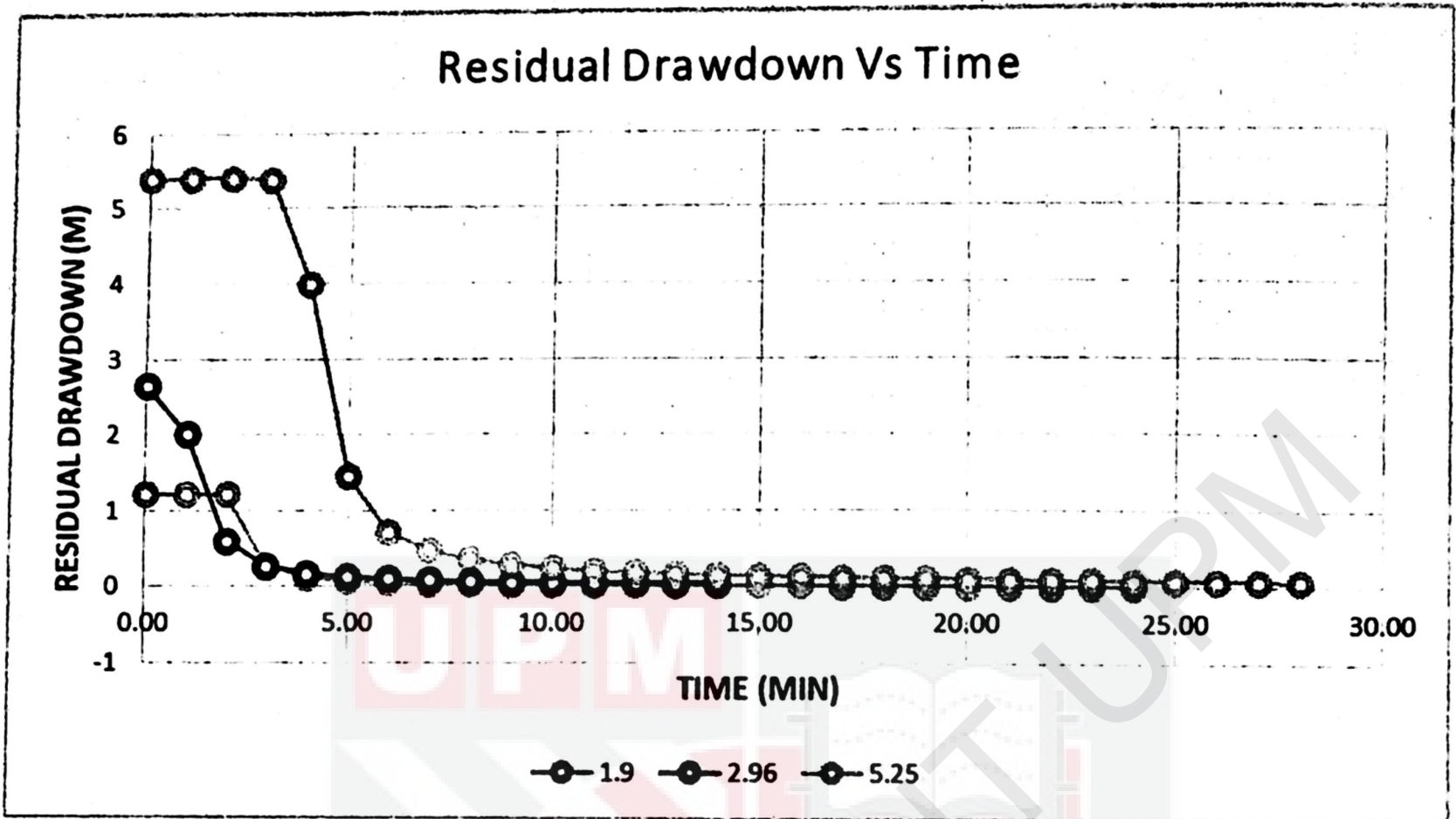
### 4.3 Analysis of Hydraulic Conductivity Using Natural Groundwater Flow

The hydraulic conductivity of aquifer was obtained by conducting recovery test. The recovery test was considered as the most reliable method to measure the hydraulic conductivity of aquifer because the test using the natural groundwater flow. Recovery test was carried out to 30 minutes with the initial water level at 0.85 m and the result was summaries in the table 4.5

**Table 4. 5 Summary of Recovery Test Result**

<b>Discharge (<math>m^3/hr</math>)</b>	<b>Residual drawdown (m)</b>	<b>Recovery (%)</b>
1.9	0.848	99.76
2.96	0.887	104.35
5.25	0.917	107.88

Table 4.5 shows the residual drawdown for each discharge and for  $1.9m^3/hr$ , the residual drawdown was up to 0.848m which indicated 99.76% of recovery of water level. Meanwhile, the residual drawdown for  $2.96m^3/hr$  was up to 0.887m and about 104.35% of recovery and for  $5.25m^3/hr$ , the residual drawdown was 0.917m and 107.88% of recovery of water level.



**Figure 4. 10 Time recovery data for the each different discharge**

The residual drawdown shows the pattern for groundwater to turn into the initial level. The optimum discharge rate was the fastest to achieve the initial water level following with the lowest and highest discharge rate.

### 4.3.1 Analysis of Hydraulic Conductivity using Aquifer Test Software

Figure 4.11, 4.12 and 4.13 shows the analysis plot of recovery test for each discharge rate. Aquifer Test software analyzed the analysis plot using the Bouwer and Rice method. The recovery for each discharge rate were observed and analyzed to determine the hydraulic conductivity of aquifer.

i) Pumping rate of  $1.90\text{m}^3/\text{hr}$

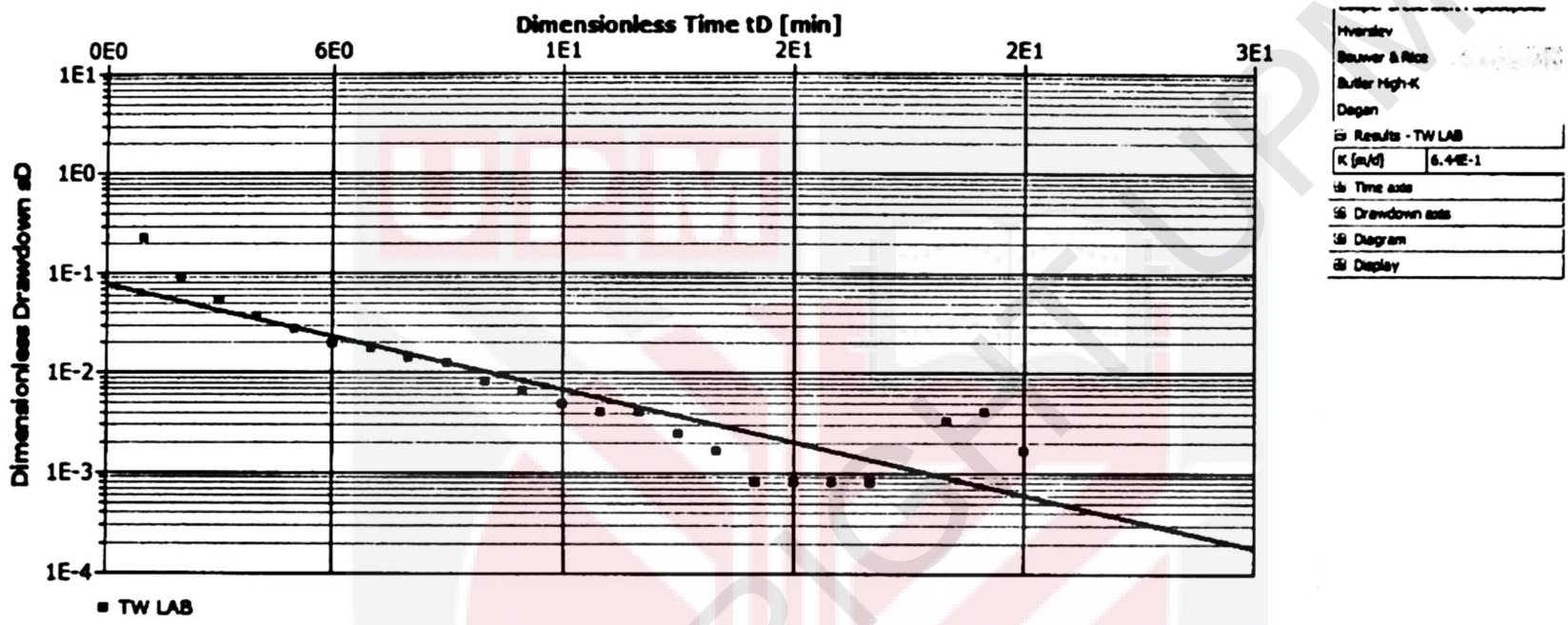


Figure 4. 11 Analysis plot recovery test for  $1.90\text{m}^3/\text{hr}$

ii. Pumping rate of  $2.96\text{m}^3/\text{hr}$

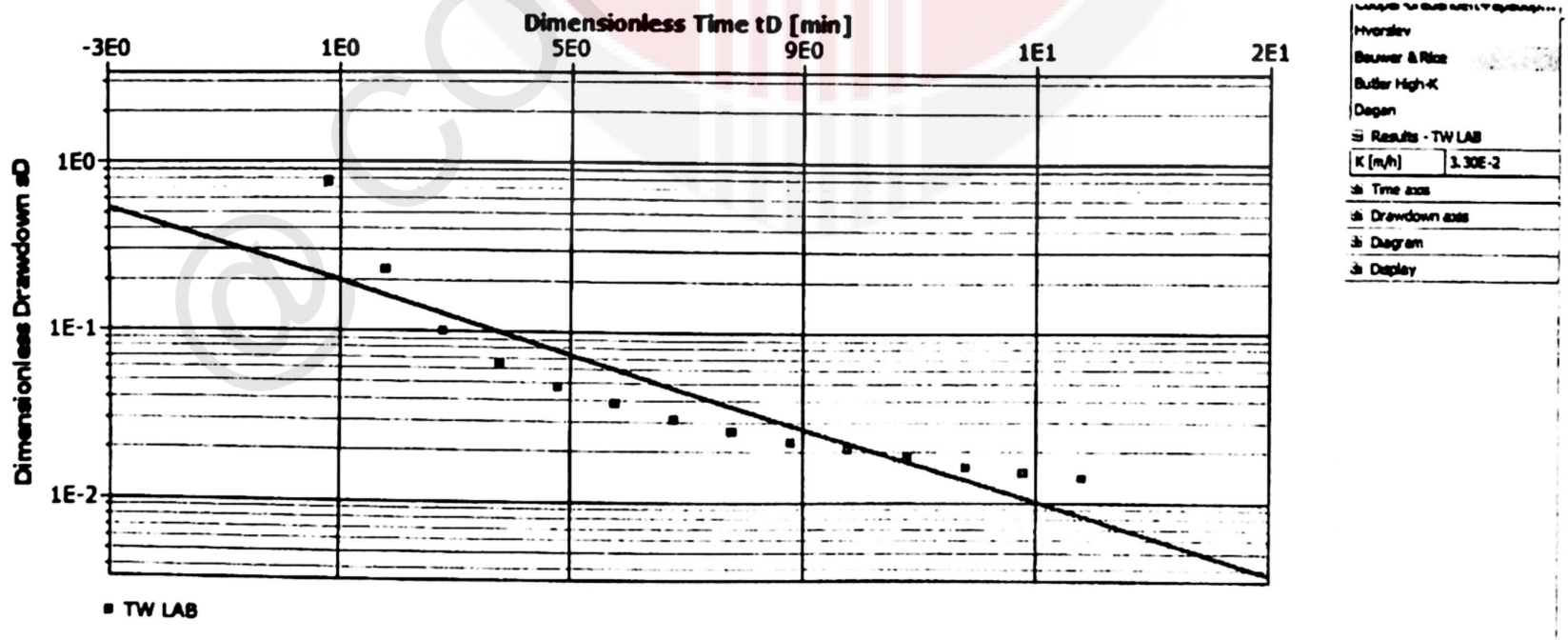


Figure 4. 12 Analysis plot recovery test for  $2.96\text{m}^3/\text{hr}$

iii. Pumping rate of  $5.25\text{m}^3/\text{hr}$

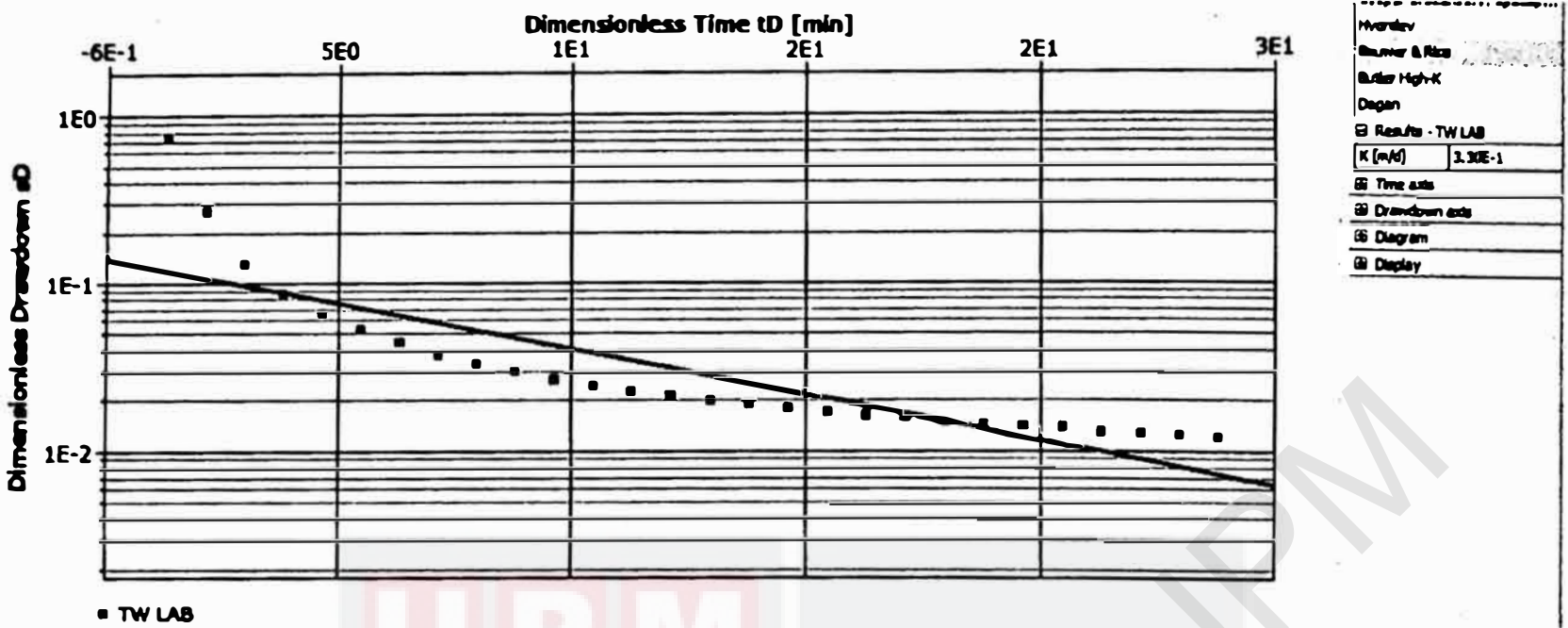


Figure 4. 13 Analysis plot of recovery test for  $5.25\text{m}^3/\text{hr}$

The result of hydraulic conductivity; K was obtained from the Aquifer Test software is shown in the table 4.6.

Table 4. 6 Hydraulic Conductivity obtained from the recovery test

Hydraulic parameters	Discharge Rate ( $\text{m}^3/\text{hr}$ )		
	1.9	2.96	5.25
Hydraulic conductivity, K(m/day)	0.644	0.033	0.330

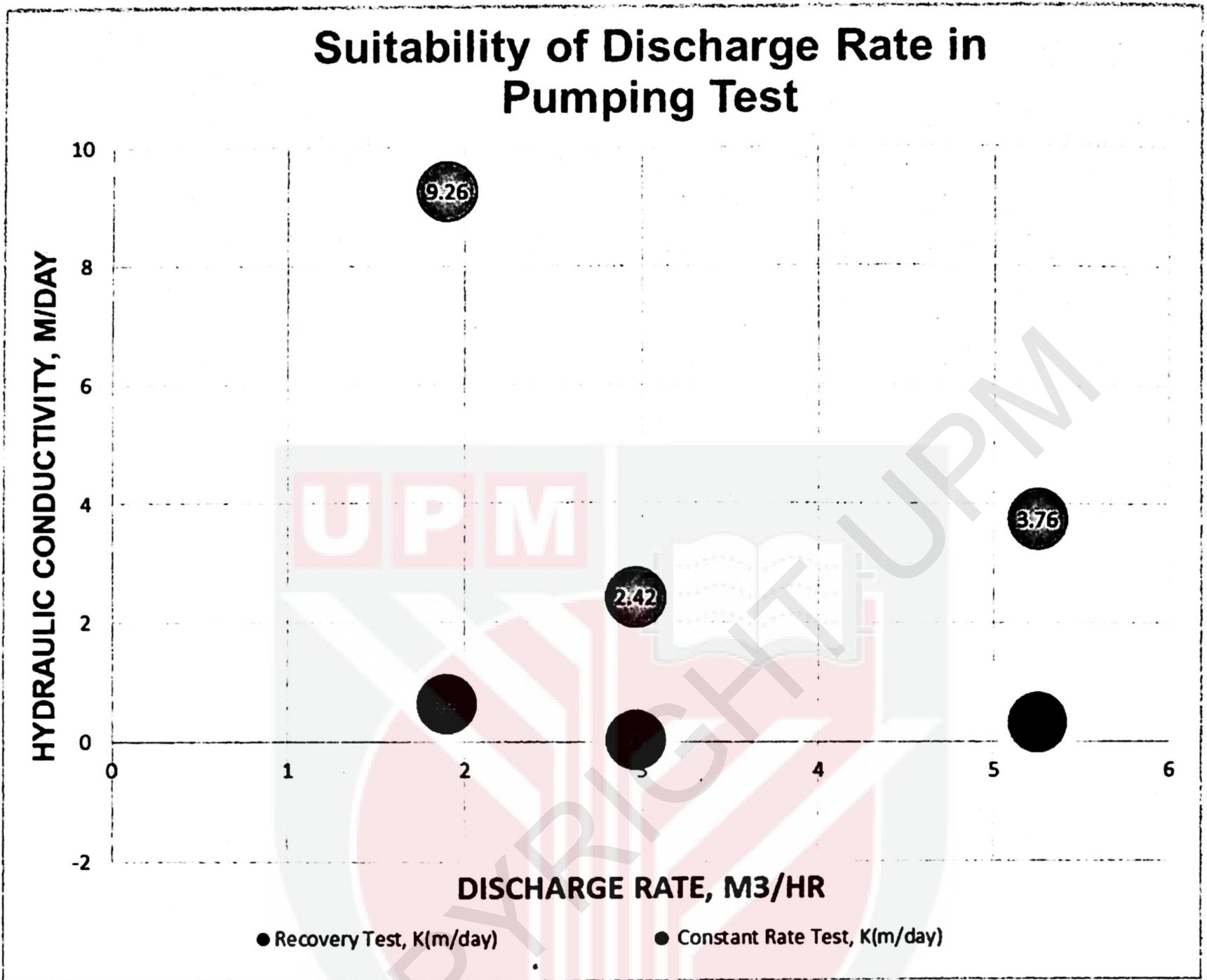
#### 4.4 Suitability of Discharge Rate in Pumping Test

Hydraulic conductivity,  $K$  describe the material's capacity to transmit water throughout the aquifer. The result for  $K$  calculated from the recovery analysis falls into the range of hydraulic conductivity for a mix of sand, clay and silt. Table 4.7 compares the value of hydraulic conductivity obtained from all the test.

**Table 4. 7 Comparison of the hydraulic conductivity of aquifer**

Discharge Rate, ( $m^3/hr$ )	Hydraulic Conductivity, $K(m/day)$	
	Constant Rate Test	Recovery Test
1.9	9.26	0.644
2.96	2.42	0.033
5.25	3.76	0.33

The value of hydraulic conductivity of aquifer from the recovery test will be the constant variable to be compare with the constant rate test as it recovery the groundwater without any tension given to the aquifer. Figure 4.14 shows the closest value of hydraulic conductivity with each different discharge.



**Figure 4. 14 Suitability of Discharge rate in Pumping Test**

The figure 4.14 shows that the value of hydraulic conductivity of aquifer at discharge rate of  $2.96m^3/hr$  between recovery test and constant rate test is the closest compare to other result. Thus, this conclude that the most suitable discharge to be used in pumping test is  $2.96m^3/hr$  which is the optimum discharge rate.

## CHAPTER 5

### CONCLUSION AND RECOMMENDATION

#### 5.1 Conclusion

The main objective of this study is to determine the suitability of discharge rate in determining the aquifer characteristic using pumping test. The test was run at the conventional soil and water laboratory in faculty of Engineering, UPM. The method used to determine the optimum discharge rate was step drawdown test that was run with 5 increment of discharge started with  $1.9\text{m}^3/\text{hr}$ ,  $2.55\text{m}^3/\text{hr}$ ,  $3.05\text{m}^3/\text{hr}$ ,  $3.85\text{m}^3/\text{hr}$  and  $5.14\text{m}^3/\text{hr}$ . Step test was run for 5 hours with 1 hour interval of time for each discharge. The graph of specific capacity versus discharge was plotted and the optimum discharge rate obtained is  $2.96\text{m}^3/\text{hr}$ .

The constant test and recovery test was conducted to determine the hydraulic conductivity of aquifer using 3 different discharge rate which is  $1.9\text{m}^3/\text{hr}$ ,  $2.96\text{m}^3/\text{hr}$  and  $5.14\text{m}^3/\text{hr}$  and the test was run for 24 hours for each discharge. The result of hydraulic conductivity was obtained from the constant test was  $9.26\text{m}/\text{day}$ ,  $2.42\text{m}/\text{day}$  and  $3.76\text{m}/\text{day}$  while as for the recovery test, the result of K was  $0.654\text{m}/\text{day}$ ,  $0.033\text{m}/\text{day}$  and  $0.33\text{m}/\text{day}$ . The collection and analysis of data from both test for each discharge shows that optimum discharge which  $2.96\text{m}^3/\text{hr}$  is the most suitable discharge rate to be used when conducting the pumping test as the value for hydraulic conductivity from constant test is the closest to the value of K from recovery test.

## **5.2 Recommendation**

The recommendations that can be state for further study of optimum discharge rate is the researcher should increase the duration of time more than 1 hours for step test and up to 3 days for the constant test in order to truly obtained steady state drawdown of aquifer. In addition, the submersible pump used should have a greater potential to extract the groundwater as the recharge of aquifer is higher. Next, use the equipment with a higher accuracy to get the more accurate data such as water flow meter, level logger and water level indicator.

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## APPENDIX

### 1. Constant rate test for Q1

<b>PUMPING INTERVAL ( minutes )</b>	<b>WATER LEVEL ( meter )</b>	<b>DRAWDOWN ( meter )</b>
0.00	0.85	0.00
0.50	1.569	0.719
1.00	1.778	0.928
1.50	1.857	1.007
2.00	1.897	1.047
2.50	1.916	1.066
3.00	1.927	1.077
3.50	1.945	1.095
4.00	1.956	1.106
4.50	1.954	1.104
5.00	1.961	1.111
6.00	1.97	1.12
7.00	1.971	1.121
8.00	1.963	1.113
9.00	1.974	1.124
10.00	1.974	1.124
15.00	1.99	1.14
20.00	1.991	1.141
25.00	1.993	1.143
30.00	1.995	1.145
35.00	2.005	1.155
40.00	2.006	1.156
45.00	2.006	1.156
50.00	1.996	1.146
55.00	2.001	1.151
60.00	2.004	1.154
65.00	2.005	1.155
70.00	2.014	1.164
75.00	2.022	1.172
80.00	2.021	1.171
85.00	2.015	1.165
90.00	2.018	1.168
95.00	2.022	1.172
100.00	2.023	1.173

130.00	2.032	1.182
160.00	2.019	1.169
190.00	2.011	1.161
220.00	2.01	1.16
250.00	2.014	1.164
280.00	2.016	1.166
310.00	2.022	1.172
340.00	2.019	1.169
370.00	2.022	1.172
400.00	2.023	1.173
460.00	2.026	1.176
520.00	2.032	1.182
580.00	2.027	1.177
640.00	2.034	1.184
700.00	2.049	1.199
760.00	2.051	1.201
820.00	2.058	1.208
880.00	2.072	1.222
940.00	2.076	1.226
1000.00	2.072	1.222
1060.00	2.067	1.217
1120.00	2.068	1.218
1180.00	2.065	1.215
1240.00	2.047	1.197
1300.00	2.056	1.206
1360.00	2.057	1.207
1420.00	2.057	1.207
1480.00	2.064	1.214

**2. Constant Rate test for Q2**

<b>PUMPING INTERVAL ( minutes )</b>	<b>WATER LEVEL ( meter )</b>	<b>DRAWDOWN ( meter )</b>
0.00	0.85	0
0.50	0.851	0.001
1.00	1.982	1.132
1.50	2.531	1.681
2.00	2.787	1.937
2.50	2.929	2.079
3.00	3.014	2.164
3.50	3.064	2.214
4.00	3.097	2.247
4.50	3.123	2.273
5.00	3.14	2.29
6.00	3.153	2.303
7.00	3.163	2.313
8.00	3.175	2.325
9.00	3.184	2.334
10.00	3.196	2.346
15.00	3.247	2.397
20.00	3.269	2.419
25.00	3.294	2.444
30.00	3.305	2.455
35.00	3.323	2.473
40.00	3.318	2.468
45.00	3.325	2.475
50.00	3.338	2.488
55.00	3.347	2.497
60.00	3.357	2.507
65.00	3.365	2.515
70.00	3.378	2.528
75.00	3.389	2.539
80.00	3.389	2.539
85.00	3.394	2.544
90.00	3.401	2.551
95.00	3.41	2.56
100.00	3.409	2.559

130.00	3.416	2.566
160.00	3.427	2.577
190.00	3.42	2.57
220.00	3.427	2.577
250.00	3.437	2.587
280.00	3.44	2.59
310.00	3.446	2.596
340.00	3.452	2.602
370.00	3.461	2.611
400.00	3.459	2.609
460.00	3.455	2.605
520.00	3.455	2.605
580.00	3.456	2.606
640.00	3.47	2.62
700.00	3.473	2.623
760.00	3.492	2.642
820.00	3.507	2.657
880.00	3.517	2.667
940.00	3.528	2.678
1000.00	3.532	2.682
1060.00	3.532	2.682
1120.00	3.525	2.675
1180.00	3.512	2.662
1240.00	3.499	2.649
1300.00	3.492	2.642
1360.00	3.494	2.644
1420.00	3.499	2.649
1480.00	3.508	2.658

3. Constant rate test for Q3

<b>PUMPING INTERVAL ( minutes )</b>	<b>WATER LEVEL ( meter )</b>	<b>DRAWDOWN ( meter )</b>
0.00	0.85	0
0.50	3.672	2.822
1.00	5.068	4.218
1.50	5.815	4.965
2.00	6.307	5.457
2.50	6.631	5.781
3.00	6.821	5.971
3.50	6.969	6.119
4.00	7.074	6.224
4.50	7.178	6.328
5.00	7.248	6.398
6.00	7.307	6.457
7.00	7.34	6.49
8.00	7.36	6.51
9.00	7.356	6.506
10.00	7.393	6.543
15.00	7.334	6.484
20.00	7.297	6.447
25.00	7.245	6.395
30.00	7.211	6.361
35.00	7.203	6.353
40.00	7.142	6.292
45.00	7.178	6.328
50.00	7.233	6.383
55.00	7.129	6.279
60.00	7.013	6.163
65.00	6.973	6.123
70.00	6.914	6.064
75.00	6.845	5.995
80.00	6.81	5.96
85.00	6.806	5.956
90.00	6.764	5.914
95.00	6.726	5.876
100.00	6.737	5.887

130.00	6.697	5.847
160.00	6.838	5.988
190.00	6.725	5.875
220.00	6.622	5.772
250.00	6.561	5.711
280.00	6.565	5.715
310.00	6.673	5.823
340.00	6.578	5.728
370.00	6.535	5.685
400.00	6.5	5.65
460.00	6.401	5.551
520.00	6.438	5.588
580.00	6.381	5.531
640.00	6.308	5.458
700.00	6.43	5.58
760.00	6.623	5.773
820.00	6.752	5.902
880.00	6.519	5.669
940.00	6.302	5.452
1000.00	6.168	5.318
1060.00	6.122	5.272
1120.00	5.944	5.094
1180.00	6.014	5.164
1240.00	5.957	5.107
1300.00	5.876	5.026
1360.00	6.409	5.559
1420.00	6.264	5.414
1480.00	6.252	5.402

4. Recovery test for Q1

Time after Start of Pumping, t (min)	Time after End of Pumping, t'(min)	t/t'	Residual Water Level (m)	Residual Drawdown (m)
1480.00	0.00		2.061	1.214
1481.00	1.00		1.123	1.212
1482.00	2.00		0.96	1.211
1483.00	3.00		0.914	0.273
1484.00	4.00		0.895	0.11
1485.00	5.00		0.883	0.064
1486.00	6.00		0.874	0.045
1487.00	7.00		0.871	0.033
1488.00	8.00		0.867	0.024
1489.00	9.00		0.865	0.021
1490.00	10.00		0.86	0.017
1491.00	11.00		0.858	0.015
1492.00	12.00		0.856	0.01
1493.00	13.00		0.855	0.008
1494.00	14.00		0.855	0.006
1495.00	15.00		0.853	0.005
1496.00	16.00		0.852	0.005
1497.00	17.00		0.851	0.003
1498.00	18.00		0.849	0.002
1499.00	19.00		0.849	0.001
1500.00	20.00		0.849	-0.001
1501.00	21.00		0.85	-0.001
1502.00	22.00		0.846	-0.001
1503.00	23.00		0.845	0
1504.00	24.00		0.848	-0.004

**5. Recovery test for Q2**

Time after Start of Pumping, t (min)	Time after End of Pumping, t'(min)	t/t'	Residual Water Level (m)	Residual Drawdown (m)
1480.00	0.00		3.501	2.651
1481.00	1.00		2.868	2.018
1482.00	2.00		1.454	0.604
1483.00	3.00		1.116	0.266
1484.00	4.00		1.023	0.173
1485.00	5.00		0.977	0.127
1486.00	6.00		0.952	0.102
1487.00	7.00		0.932	0.082
1488.00	8.00		0.919	0.069
1489.00	9.00		0.91	0.06
1490.00	10.00		0.905	0.055
1491.00	11.00		0.899	0.049
1492.00	12.00		0.893	0.043
1493.00	13.00		0.89	0.04
1494.00	14.00		0.887	0.037

**6. Recovery test for Q3**

Time after Start of Pumping, t (min)	Time after End of Pumping, t'(min)	t/t'	Residual Water Level (m)	Residual Drawdown (m)
1480.00	0.00		6.244	5.402
1481.00	1.00		4.842	5.409
1482.00	2.00		2.297	5.41
1483.00	3.00		1.553	5.394
1484.00	4.00		1.319	3.992
1485.00	5.00		1.204	1.447
1486.00	6.00		1.136	0.703
1487.00	7.00		1.089	0.469
1488.00	8.00		1.051	0.354
1489.00	9.00		1.03	0.286
1490.00	10.00		1.01	0.239
1491.00	11.00		0.993	0.201
1492.00	12.00		0.982	0.18
1493.00	13.00		0.972	0.16
1494.00	14.00		0.965	0.143
1495.00	15.00		0.957	0.132
1496.00	16.00		0.953	0.122
1497.00	17.00		0.947	0.115
1498.00	18.00		0.943	0.107
1499.00	19.00		0.938	0.103
1500.00	20.00		0.936	0.097
1501.00	21.00		0.93	0.093
1502.00	22.00		0.928	0.088
1503.00	23.00		0.927	0.086
1504.00	24.00		0.926	0.08
1505.00	25.00		0.921	0.078
1506.00	26.00		0.92	0.077
1507.00	27.00		0.918	0.076
1508.00	28.00		0.917	0.071