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GROUNDWATER POTENTIAL IN THE SARAWAK COASTAL ZONES

Nur Afnie Faryisha Bt Mohamad Hamsah

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Title	: GROUNDWATER POTENTIAL IN THE SARAWAK COASTAL ZONES
Name	: NUR AFNIE FARYISHA BT MOHAMAD HAMSAH
Metric no	: 8880

Has been read and approved by:

PROFESSOR SALIM SAID

Project Supervisor

12/6/06

Date

GROUNDWATER POTENTIAL IN THE SARAWAK COASTAL ZONES

NUR AFNIE FARYISHA BT MOHAMAD HAMSAH

This project is submitted in partial fulfillment of
the requirements for degree of Bachelor of Engineering with Honors
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2006

Dedicated to my beloved family

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ABSTRACT

The knowledge of groundwater resource in Sarawak is sparse. This is probably due to the abundance of surface water resulting from the heavy precipitation, which amounts to more than 3000mm/year. Consequently, the demand for groundwater is very low. Despite this, research groundwater potential need to be done especially at the coastal zones in Sarawak, where the surface water supplies are unable to cope with the demand for fresh water during the drier months of the year. Realizing this, two coastal zones namely Belawai and Kabong were selected as study areas. The type of aquifer identified in these areas is unconfined aquifer. Studies in the both areas were done by analysing reports available in Minerals and Geoscience Department. Analysis on the type of soil bounded the areas and groundwater qualities were done including the pumping test results in both areas. In order to determine the hydraulic properties, the pumping test results were analysed using the steady state method. Based on the study, both study areas are bounded with sand and clay. Due to the existence of peat and silt in Kabong, the permeability of the soil is lower. This explained the lower value of hydraulic conductivity K in Kabong (0.65 mh^{-1}) compared to Belawai (1.81 mh^{-1}). Meanwhile, transmissivity, T of aquifer in Belawai (62.42 m^2h^{-1}) is larger compared to the transmissivity, T of aquifer in Kabong (4.56 m^2h^{-1}). This is the reason why drawdown, s of pumping test conducted in Belawai (4.43m) was slightly higher than that in Kabong (4.01m). The greater value of drawdown leads to greater value of discharge, Q during pumping. Based on the results, a conclusion was made that Belawai has the higher groundwater potential compared to Kabong. Furthermore, pH of groundwater in both areas are in natural range of around pH 7 and the chloride content in groundwater of both areas are low with no salt water intrusion. Furthermore, the groundwater quality in both areas meets the WHO standards; thus the fresh groundwater in both areas is safe to be supplied to the public communities along the coastal zones.

ABSTRAK

Maklumat berkenaan dengan sumber air tanah di Sarawak adalah sedikit. Ini mungkin disebabkan oleh lebihan jumlah air di permukaan bumi yang diperoleh daripada jumlah taburan hujan sebanyak 3000mm setahun. Kesannya, permintaan air bawah tanah adalah rendah. Walau bagaimanapun, kajian berkenaan air tanah perlu dijalankan terutamanya di kawasan persisiran pantai di Sarawak. Ini adalah kerana jumlah air yang dibekalkan di kawasan berkenaan adalah tidak mencukupi terutamanya pada musim kemarau. Menyedari hakikat ini, dua kawasan persisiran pantai yakni Belawai dan Kabong telah dipilih sebagai kawasan kajian untuk projek ini. Akuifer yang terdapat di kawasan ini adalah jenis akuifer tak terkurung. Kajian ini telah dijalankan dengan menganalisa data-data yang terdapat di arkib Jabatan Minerals dan Geoscience. Kajian berkenaan dengan lokasi kawasan kajian termasuk jenis tanih yang terdapat di kawasan tersebut termasuk kualiti air bawah tanah juga dijalankan. Tabahan pula, sifat-sifat hidraulik akuifer-akuifer berkenaan didapati melalui penganalisaan keputusan ujian pengepaman bagi kawasan berkenaan dengan menggunakan kaedah penyelesaian aliran seragam. Hasil daripada kajian, kedua-dua kawasan ini didapati diliputi dengan tanih jenis pepasir dan tanah liat. Walaubagaimanapun, kehadiran tanah gambut dan lodak di Kabong telah menyebabkan kawasan itu menjadi kurang telap berbanding di Belawai. Ini telah dibuktikan melalui hasil pengiraan keberkonduksian hidraulik akuifer K di kedua-dua kawasan. Hasil telah menunjukkan bahawa nilai K bagi Kabong (0.65 mh^{-1}) adalah lebih rendah berbanding di Belawai (1.81 mh^{-1}). Tidak hairanlah jika terusan akuifer, T di Belawai (62.42 m^2h^{-1}) adalah lebih tinggi berbanding di Kabong (4.56 m^2h^{-1}). Ini menjelaskan mengapa nilai kadar surutan, s di Belawai (4.43m) adalah lebih tinggi berbanding di Kabong (4.01m). Nilai kadar surutan yang tinggi s, akan menyebabkan kadar luahan perigi, Q menjadi tinggi. Dengan itu dapat disimpulkan di sini bahawa Belawai mempunyai potensi air bawah tanah yang lebih tinggi. Tambahan pula, kualiti air tanah di kedua-dua kawasan kajian memenuhi kehendak piawaian WHO dan mempunyai potensi untuk dibekalkan kepada penduduk kampung..

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LIST OF ACRONYMS AND SYMBOLS

B.O.D	Biochemical Oxygen Demand
D.I.D	Drainage of Irrigation Department
W.H.O	World Health Organization
PWL	Pumping Water Level
SWL	Static Water Level
n_T	Total porosity
V_v	Volume of voids
V_s	Volume of solids
V_T	Total volume
Q	Flow from the observation well
K	Hydraulic conductivity of aquifer
r	Radial distance from pumping well centre
D	Height of aquifer (m)
dh/dr	Hydraulic gradient (slope of piezometric head, h at distance r from the pumped well)
h	Height of groundwater level
s	Drawdown or drop of water level during pumping test.
T	Transmissivity
u	Dimensionless parameter
$W(u)$	Well function

H	Aquifer height at full thickness
S	Storage coefficient

CHAPTER 1

INTRODUCTION

1.1 General

The main aim of this project is to study the groundwater potential along the coastal zones in Sarawak. Firstly, results of previous pumping tests of the study areas were collected from the Minerals and Geoscience Department in order to determine some basic hydraulic properties of the aquifer. Then, studies on the hydraulic properties including the groundwater quality were performed.

1.2 Introduction of groundwater

According to Carter (1988), groundwater can be defined as subsurface water that occurs beneath the water table in soils and geologic formations that are fully saturated. Bouwer (1987) reported that portion of water beneath the surface can be collected with wells, tunnels or drainage galleries. For some countries, groundwater has become an important source of water supply since ages. This is proven in the Al-Quran , surah Yusoff verses 10:

“Said one of them “Slay not Yusoff, but if ye must do something, throw him down bottom of the well; he will be picked up by some caravan or travellers”

The word “well” mentioned by Allah proofs that groundwater has been discovered and was a source of water supply for the Arabs since thousands years ago. In fact, dug well can be found along wadis of Middle East, the cradle of our civilizations (Bouwer, 1987).

In Malaysia, groundwater investigation has been carried out systematically since year 1975. Kiat (1983) reported that the first hydrological map on Peninsular Malaysia was published on scale of 1: 500 000. Hydrological map is important for understanding the occurrence of groundwater in the country. Based on the map, detailed investigation before well construction can be done easier. Thus, water supplement for current, future and emergency needs will be able to be carried out under a properly developed policy and strategy. However, up till today, there is no hydrological map published yet in Sarawak.

Johari (1980) reported that investigations in Sarawak were carried out in particular areas only when there are immediate needs for groundwater to be used as source of water. The investigations were carried out in the rural areas especially at the coastal zones where there is a lack of surface source of fresh water. Through the research, quality of the groundwater reported varied from place to place and four areas reported the existence of chloride content below the highest limit (350ppm). These are Belawai, Kabong, Kuala Lawas and Bako.

In engineering aspects, exploration of groundwater is done in order to fulfill the current increment in water demand. Furthermore, most rural areas in Sarawak are still depends on the groundwater source. This project aims to establish the potential of groundwater utilization in the coastal zones in Sarawak

1.3 Project Background

Data available in the Minerals and Geoscience Department are obtained to reach the objectives of this project, which are stated as follows:

- Analysing previous reports to determine the types of soils bounded in the study areas.
- Analysing the pumping test data to determine the hydraulic properties of the study areas
- Analysing previous reports to determine the quality of groundwater in the study area.

The outlined of the project report is as described below:

Chapter 1: Presents the general, introduction of groundwater, background and objective of the project.

Chapter 2: Concerns on a literature review of the characteristics and properties of groundwater and the behaviour in the coastal zones.

Chapter 3: Mainly about the investigation conducted in the present study. This section indicates the data that need to be analysed including detailed on the location and equations involve in interpreting the pumping test data. Data that needed to be analysed are, the types of sediments bounded in the study areas and the groundwater quality

Chapter 4: Presents the results and discussion of the experimental investigation outlined in Section 3.

Chapter 5: Contains an outlined of the conclusions drawn in the project and the recommendations for further development of the present work for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 General

Sarawak is the largest state in Malaysia with an area of 125 000 km^2 and have a smaller population compare to Peninsular Malaysia (Johari, 1980). Sarawak located in the humid tropics between longitudinal $109^0 30'$ and $115^0 45'$E and latitude $0^0 50'$ and 50^0N. Sarawak has uniform high humidity throughout the year with the temperature of 25.6^0C. Most of the areas in the state have a mean annual rainfall of about 3050-4050 mm (Johari, 1980). This is much higher than the average annual rainfall for the whole of Malaysia which is only 2500 mm. Based on this; Yogeswaran (1983) made a statement that Sarawak is full with abundance of surface water. However, the knowledge of groundwater resources in Sarawak is sparse.

2.2 Formation of Groundwater

Basically, groundwater is recharged by precipitation. Precipitation or amount of water that falls on the earth's surface; infiltrates or seeps downward into the subsurface and trapped on the impermeable layer to form an aquifer.

According to Schwartz and Zhang (2002) this is the source of recharge to groundwater

The rapidity of infiltration depends on the permeability and porosity of soil. During infiltration, water will move downwards (due to gravity force) and fill the voids. In permeable soil i.e. sandy and alluvial soil, water infiltrates faster due to its higher volume of voids. Compared to impermeable soil i.e. clay and silt, small pore spaces retard infiltration. Otherwise in permeable soil, infiltration happens continuously and only stops once the voids in the ground are full with water (Bell, 1993). However, if the amount of water surface exceeds the amount which the soil can infiltrate, this can result to flood.

2.3 Aquifers Properties

According to Canter (1988), groundwater can be defined as subsurface water that occurs beneath the water table in soils and geologic formations that are fully saturated. This geologic formation is commonly known as aquifer. Physically, an aquifer can be defined as any geologic material, e.g., sand, gravel, alluvial, etc., that has open spaces, such as voids or fractures, and these open spaces are filled with water.

From the functional perspective, aquifer must sufficiently permeable to yield water that meets the supply needs. According to Schwartz and Zhang (2002), an aquifer is defined formally as a geologic unit that is sufficiently permeable to supply water to a well.

According to Todd (1980), aquifers may consist of an entire geologic unit, such as a saturated sand deposit, they may consist of a part or parts of a larger geologic formation, for example several different water-bearing gravel layers in an alluvial formation, or of different rock types that are connected hydraulically. This means that if a well is continuously drilled, different water-bearing units or depths of the same aquifer might be encountered (Fig.2.1). These different depths encountered in aquifers are classified as either confined or unconfined.

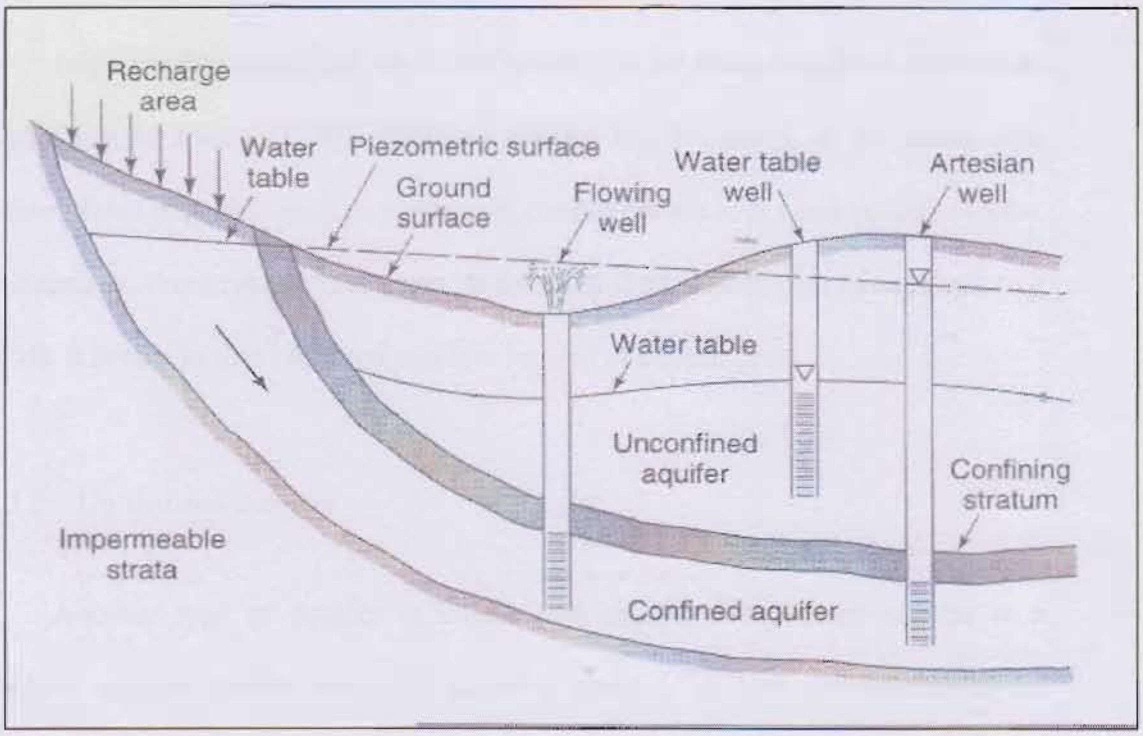

Fig.2.1: Location of unconfined and confined aquifers. (Karanth, 1987)

2.3.1 Confined Aquifer

Confined aquifers tend to be separated from the surface by confining layers or impermeable strata (Fig. 1.1). According to Canter, Fairchild and Knox (1987), confined aquifer is water or bearing formation between two confining layer. Thus, the location of confined aquifer always predicted to be located at way down beneath the earth. It consists of low permeability layer or confining stratum beneath the aquifer that is capable of storing water and transmitting water between adjacent aquifers (Schwartz and Zhang, 2002).

Impermeable strata can be found mostly in the areas that have hard rock. According to Johari (1980), confined aquifer can be found in the areas with consolidated materials such as sandstone, conglomeratic rocks and volcanic rocks. In Sarawak, these types of rock can be found at the northern part of Sarawak (e.g Miri). It is rare to find confined aquifers located at coastal zone.

2.3.2 Unconfined Aquifer

Another type of aquifer is unconfined aquifer. Unconfined aquifer is a shallow aquifer. Unlike confined aquifers, there is no low permeability layer beneath the aquifer (Fig. 2.1). Based on research done by Johari (1980), unconfined aquifer usually can be found in sand layer, which normally located at the costal area of Sarawak.

2.4 Shallow Coastal Sand Aquifer

Shallow coastal sand aquifers in Sarawak have been exploited for water supplies for many years. However, there is no systematic groundwater investigation done. Up till today, investigation only has done when there is demand.

The shallow coastal aquifers are important as they formed source of water for the coastal community especially during drought months (April to September). The groundwater in the aquifer is sufficient enough to be used even in drought seasons. According to Yogeswaran (1984), the shallow coastal aquifers are recharged by rainwater and to lesser extent by rivers and backwaters. The rainfall infiltrate directly into the aquifer and the amount of water infiltrate represents the maximum possible volume of water available for extraction.

In 1984, Yogeswaran discovered the aquifer in most parts along the coastal zone of Sarawak namely Rambungan, Beliong, Sambir, Kabong, Belawai, Matu, Daro, Igan, Oya, Judan, Penipah, Kuala Lawas and Kampung Awat-Awat.

Generally, the aquifers in the coastal zone are unconfined aquifers. However, Yogeswaran has classified the type of aquifer according to the geology and physiographic of the coastal sands and hydrochemistry of the aquifers. Based on the discovery area of Rambungan, Belawai and Kabong were selected as the study area for this project. However, due to missing data and incomplete report, study on Rambungan was cancelled.

2.5 Saline Water Intrusion

Eventually, aquifers located at the coastal zones are in a risk of having saline water intrusion. Saline water intrusion is the phenomenon when sea water intrudes into the fresh water supply. According to Karanth (1987), the boundary between salt and fresh water moves towards a fresh water zone when a hydraulic gradient is established from the saline water zone, as a result of groundwater development or by rise in the head of saline water relative to that of fresh water, e.g. during high tide.

Intrusion of salt water into heavily exploited aquifers is a serious problem faced in coastal zones and not suitable for domestic used.

2.6 Physical Characteristic

2.6.1 Porosity

Porosity is the property of a rock to contain interstitial pore spaces (Karanth, 1987). The rapidity of water that seeps into the ground is based on the opening sizes of the pore spaces. According to Schwartz and Zhang (2002), total porosity of a rock or soil is defined as the ratio of void volume to the total volume of material:

$$nT = \frac{V_v}{V_T} = \frac{V_T - V_s}{V_T} \qquad 2.1$$

Whereby n_T is the total porosity, V_v is the volume of voids, V_s is the volume of solids, and V_T is the total volume. From this equation, it is shown that porosity depends on the volume of voids and the volume of solids Porosity is classified into two, namely primary porosity and secondary porosity. Primary porosity refers to the original interstices which formed at the same time the material did i.e. voids (Fig. 2.2 (a), (b), (c) and (d)), meanwhile secondary porosity is referred as the open spaces formed later than the material due to joints, cracks etc. i.e. (Fig. 2.2 (e) and (f)). (Schwartz and Zhang, 2002). According to them again, in sediments such as alluvium, e.g. river sands and gravels, the pore spaces are primary, occurring as openings between individual grains. In an igneous rock such as granite or basalt, the openings are generally secondary, occurring as individual fractures that have developed after the rock crystallized from a molten state.

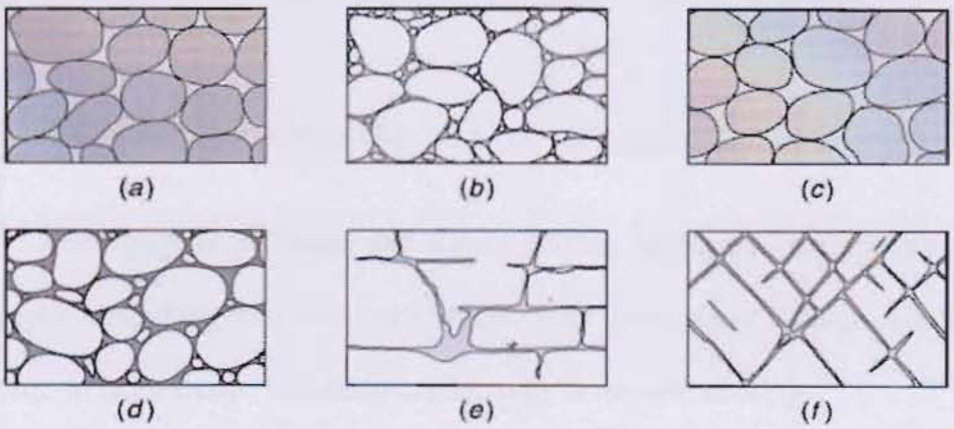

Fig. 2.2: Types of porosity texture. (Todd, 1980)

Theoretically, the greater amount of voids, the greater is the porosity of the material.

2.6.2 Safe Yield

According to Bouwer (1978), the safe yield of an aquifer is the rate at which groundwater can be withdrawn without causing a long-term decline of water table Thus, safe yield of an aquifer need to be determined in order for efficiency and economical development of groundwater exploration.

2.7 Hydraulic Properties of Groundwater

Groundwater flow is controlled by the hydraulic properties. Hydraulic properties, which are hydraulic conductivity K, transmissivity T, and storage coefficient S are useful in determining the velocity of water movement into, through and out of subsurface material and how piezometric surface or water tables are affected (Bouwer, 1978).

2.7.1 Hydraulic Conductivity (K)

According to Schwartz and Zhang (2002), hydraulic conductivity is a parameter describing the ease with which flow take place through a porous medium. In other words, hydraulic conductivity is the permeability

Permeability of a soil is interconnected to the porosity of a soil. Permeability increases with the increment of porosity. In other words, hydraulic conductivity was found larger in coarser soil.

Hydraulic conductivity can be affected by temperature, ionic composition of the water and presence of entrapped air (Bouwer, 1978). Based on his research, K can be affected by the temperature on water viscosity. According to him, K increases with the increment of the temperature. Higher temperature normally is due to lower viscosity of the water.

The ionic composition of the water has an effect on K if porous material contains clay and if the cations in the water are not yet equilibrium with the cations in the double layer of the clay particles (Bouwer, 1978).

Entrapped air in soil or aquifer material physically blocks pores causes K to be less than when the material is completely saturated (Bouwer, 1978). Entrapped air can occurred due to the rise of the water table. Based on research done by Bouwer (1978), K for sandy soil at unsaturated condition maybe only about one-half the K value at complete saturation.

2.7.2 Transmissivity

Todd (1980) defines tranmissivity as the rate at which water of prevailing kinematics viscosity is transmitted through a unit width of aquifer under a unit hydraulic gradient. Transmissivity of confined and unconfined aquifers usually is evaluated from pumping test of the well. The method used to determine transmissivity in both aquifers are different.

2.7.3 Storage Coefficient or Specific Yield

According to Cherry and Freeze (1979), storage coefficient is defined as groundwater that yields from the aquifer under a unit decline in hydraulic head. For unconfined aquifers, the storage coefficient can be called specific yield, which is the volume of water released from a unit volume of saturated aquifer mineral drained by a falling water table (Bouwer, 1978). The declination involves water table as the datum. Storage coefficient of unconfined aquifers may yield from a few percent for fractured rock to as much as 30% for unconsolidated materials of uniform particle size. The S value of confined aquifers are relatively small and often in the rage of 0.01 to 0.00005.

2.8 Pumping Test

The project focuses on investigating ground water potential at some areas in Sarawak. Method used was pumping test. Pumping test is done by pumping a well to the constant rate and observe the drawdown of the piezometric surface or water table in observation wells at some distance from the pumped well (Bouwer, 1978). Piezometric surface is the initial static water level (SWL) before pumping started while drawdown is the difference between the initial static water level (SWL) before pumping started and the pumping level (PWL) at any given time during pumping.

Based on The Minerals and Geoscience Department Malaysia manual, the pumping test procedure is divided into three stages, which are the background monitoring, constant-rate pumping test and recovering monitoring.

During the background monitoring, groundwater levels in both the pumping test well and neighbouring wells were measured before the pumping test started. Next, the test well was pumped and the rate of pumping was monitored. It is important to keep the rate of pumping constant throughout the test. During the process, the rate of discharge was measured using an office meter or accurate calibrated flow meter. The rate of discharge was kept constant to an accuracy of 50 %.

During the pumping test, water level measurements at pumped well plus the nearby water resource (e.g. streams, springs, etc.) should be taken every minutes for the first 10 min, once in every 5 min in the next 10-30 min, once in every 10 min in the next 30-60 min, once in every 30 min in the next 1-6 hr, once in every hour in the next 6-24 hr, and once every 2 hr thereafter. The changes or recovery in water levels were monitored.

2.9 Interpreting Pumping Test Data

Pumping test data is analyzed to determine hydraulic properties of an aquifer. Analysis in confined aquifer is different to unconfined aquifer. During analysis, the type of groundwater flow from observation wells towards pumping well should be taken into account. The type of flow will be either steady flow or transient flow.

2.9.1 *Steady Flow*

During pumping test, a cone of depression will expand into an area of recharge or discharge after long period of pumping. At this state, groundwater will flow at steady state from the aquifer to the well.

Data collected during the pumping test can be interpreted using steady state method. In this method, equations involved in confined and unconfined aquifers are different.

In confined aquifers, the flow in the aquifer, which comes from a distance, will flow in a form of imaginary cone surface, in the aquifer at the radius of r from the pumped well. This flow can be calculated using the equation below:

$$Q = K2\pi rD\left[\frac{dh}{dr}\right] \tag{2.2}$$

Where

Q = pumping rate $\left({m^3}/{day}\right)$

K = hydraulic conductivity of aquifer *(m/day)*

r = radial distance from well center *(m)*

D = height of aquifer (m)

${dh}/{dr}$ = hydraulic gradient (slope of piezometric head, h at distance r from the pumped well)

However, in unconfined aquifer, the well flow will be calculated as below:

$$Q = \frac{[2\pi T(h_2 - h_1]}{\ln \frac{r_2}{r_1}} \tag{2.3}$$

Where T = transmissivity

In unconfined aquifer, the height of the water table (h) above the boundary of aquifer is used instead of the height of aquifer (D) in equation above thus producing equations below:

$$Q = 2\pi r h K \left[\frac{dh}{dr} \right] \tag{2.4}$$

When two points of different well involves, the well flow will be calculated as below:

$$Q = \left[\frac{\pi K \left(h_2{}^2 - h_1{}^2 \right)}{\ln \frac{r_2}{r_1}} \right] \tag{2.5}$$

2.9.2 Transient Flow

Transient prior to the point at which a cone of depression reaches equilibrium we monitor the time - drawdown of a pumping aquifer we can estimate aquifer parameters. Transient of unconfined aquifer will not be focused due to difficulties of T changes with t and r as the water table drops during the pumping. For confined aquifer, transmissivity can be calculated using Theis Method and Jacob Method.

Theis Method

Transmissivity of the aquifer can be estimated using Theis equation below:

$$T = \frac{Q[W(u)]}{4\pi(h_0 - h_1)} \tag{2.6}$$

Where Q = pumping rate (Which keep constant during the test)

W (u) = the well function of u

u = dimensionless parameter

Whereby u can be determined by:

$$u = \frac{\left(r^2 S\right)}{4Tt} \tag{2.7}$$

Where t = time since beginning of pumping.

S = storage coefficient

The well function of u is the exponential integral:

$$W(u) = -\int\left(\frac{e^{-u}}{u}\right)du \tag{2.8}$$

$$= -0.5772 - \ln(u) + u - \frac{u^2}{2.2!} + \frac{u^3}{3.3!} - \ldots \tag{2.9}$$

Cooper and Jacob Method

Cooper and Jacob method is applicable for small u (u<0.01) through their equation below

$$s = \left(\frac{Q}{4\pi T}\right)\ln\left(\frac{2.25Tt}{r^2 S}\right) \tag{2.10}$$

However, Theis Method and Jacob Method will not be implemented in this study as the type of aquifer exists in coastal zone of Sarawak is unconfined aquifer.

2.10 Groundwater Quality

Determining groundwater quality is as much important as determining the hydraulic properties of a groundwater. According to Karanth (1990) The study of groundwater quality involve field investigation regarding the source and environment of groundwater occurrence, sources of pollution and other aspects having a bearing on the quality of the groundwater. The result will be recorded based on the bacteria quality, chemical quality and physical quality.

2.10.1 Bacteria Quality

Bacteria and micro organisms present in groundwater can only be seen through microscope. Some of the bacteria are harmless while some are dangerous and has the potential of causing disease.

An indirect index of presence of these micro organisms in groundwater is the biochemical oxygen demand (BOD), which is the amount of oxygen required to cause the biological decomposition of organic matter and water (Karanth, 1990). When oxidation is complete and no oxygen is required, B.O.D is zero. The small value of B.O.D is a sign of excessive presence of micro organism.

2.10.2 Chemical Quality

Chemical analysis on groundwater samples normally is done in the lab whereby the content of dissolved constituents such as iron; chloride, manganese and other chemical constituents including the pH value of groundwater are determined. The high amount of these constituents is not suitable for domestic used and if it is not well treated, it might lead to fatal once the groundwater is used for drinking purpose.

2.10.2 Physical Quality

Unlike water surface, groundwater is generally clean, colourless and odourless. However, the presence of colour and odour in groundwater may impart the presence organic material or certain chemical constituent. For example, the colour of yellowish may impart the presence of iron.

CHAPTER 3

METHODOLOGY

3.1 General

Studies on groundwater potential at coastal zones in Sarawak were done by analysing recent hydrological investigation reports done by the Minerals and Geoscience Department of Sarawak. The study focuses on the areas along coastal region in Sarawak that bounded by South China Sea on the western side. The study is focusing along the coastal areas due to the lack of surface water sources. The select locations are Belawai and Kabong. The objective of selecting two different areas is for the comparison of the groundwater potential in each area.

The geology of the areas was studied using data available in the Minerals and Geoscience Department. Then, the results of the pumping test data were analysed to determine the hydraulic properties and groundwater quality of the aquifers in the areas. Finally, the results in each area were compared. This project is merely focusing on analysing recent hydrological report and there were no fieldwork done since there was no ongoing project on groundwater exploration that involves pumping test done by the Mineral and Geoscience Department.

3.2 Location of Study Areas

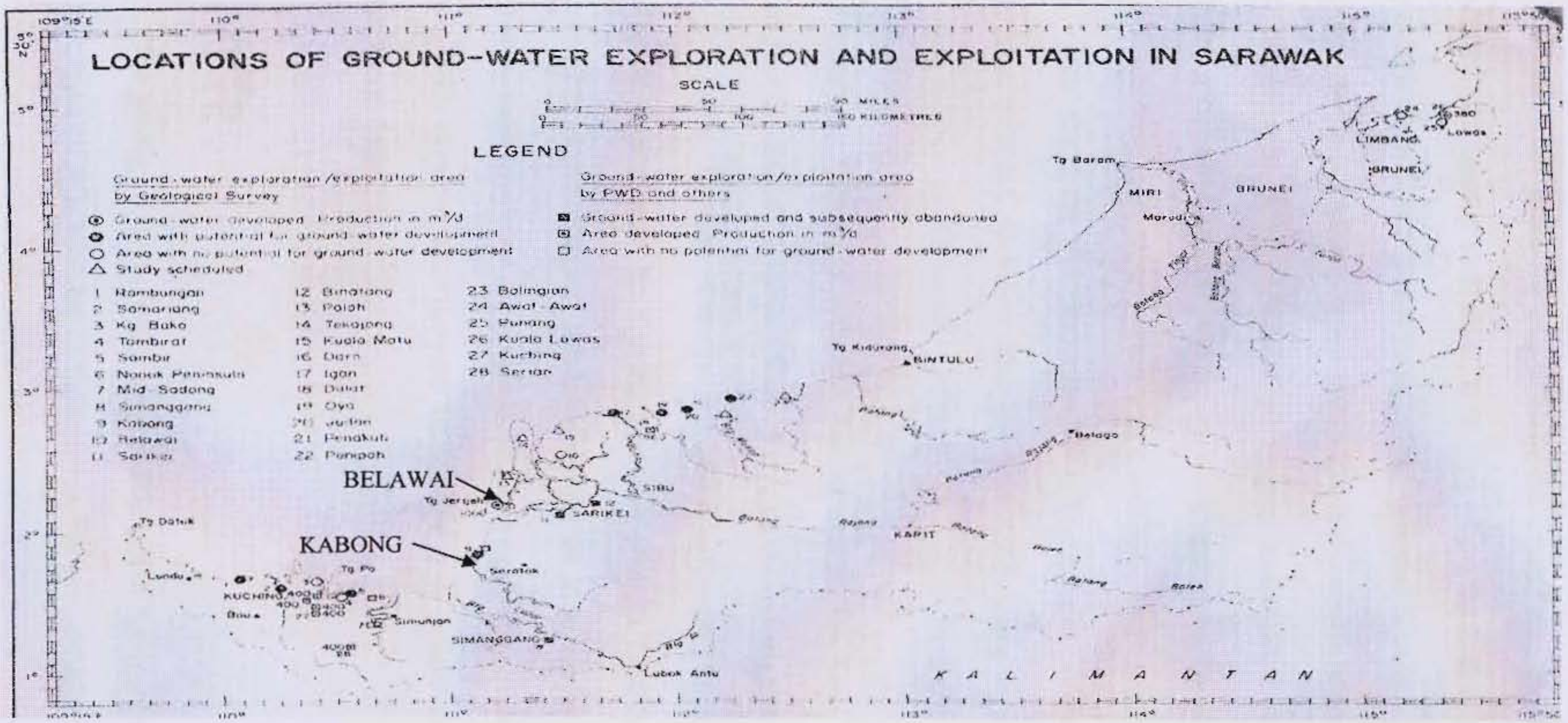

Figure 3.1: Location of the study areas, Belawai, and Kabong (Tan, 1983)

Selected study areas are located along the coastal area of Sarawak.Belawai is a district that located in Sarikei. It is situated on the Rajang Delta about 65 kilometres west of Sibu (Yogeswaran, 1978). It is mainly built up of marine and estuarine sediments with sub recent beaches, which extends inland for up to two miles (Yogeswaran, 1978). The first hydrological investigation was done in 1978 by Yogeswaran Mailvaganam. A pumping test was done during the investigation. In 1980, the first well point system was constructed in Belawai (Yogeswaran, 1980). Ever since, the well was monitored. The progress of the groundwater quality was recorded. However after the year 1995, there is no groundwater monitoring progress report found.

Meanwhile, Kabong is a district that located 90 km from Kuching. It is situated near the Seblak River and Krian River on the eastern side (Yogeswaran, 1980). It is mainly built up of marine and deltaic sediments (Yogeswaran, 1980). Hydrological investigation on Kabong was also done in 1980 by Yogeswaran Mailvaganam. A pumping test was done during the investigation. A well point system was constructed and the progress on the groundwater quality was carried out until 1995. However after the year 1995, there is no groundwater monitoring progress report found.

3.3 Geology

The geology and the results on pumping test of the areas are analyzed to determine types of soils bounded on the aquifers. The properties of the soil are important to estimate the physical properties of the aquifer in terms of the porosity and permeability of the soil.

Based on the geology type of the area, the porosity and permeability of the soil can be estimated. The approximate range of porosity and permeability is listed as below.

Table. 3.1: Types of soil that are sorted according to their porosity and permeability (Bouwer, 1978)

<table>
<tr><td>Types of Sediments</td><td rowspan="9">Permeability and porosity increase</td></tr>
<tr><td>Clay</td></tr>
<tr><td>Silt</td></tr>
<tr><td>Very fined sand</td></tr>
<tr><td>Fined sand</td></tr>
<tr><td>Medium sand</td></tr>
<tr><td>Coarse sand</td></tr>
<tr><td>Very coarse sand</td></tr>
</table>

3.4 Analyzing Pumping Test Data

In analyzing pumping test, a few terminologies should be understood. The pumping test data is useful for determining the flow behaviour of the groundwater including its hydraulic properties.

In determining the flow behaviour of the aquifer, three types of graphs were plotted which are graph on changes of water levels in pumping wells and observation wells, the changes of drawdown levels and the changes of drawdown levels in log scale.

Changes of water levels in pumping wells and observation wells were plotted to determine the behaviour of the groundwater flow from observation well towards the pumping well.

Meanwhile drawdown graphs were plotted to determine the changes of drawdown level during pumping test. Drawdown is important in estimating the energy needed to pump out the groundwater. According to Price (1996), the greater the drawdown, the more energy is needed.

Based on the graph, changes of water level and drawdown during pumping test can be seen clearly.

3.6 Hydraulic Properties

Groundwater flow is controlled by the hydraulic properties which are hydraulic conductivity K, transmissivity T, and storage coefficient S. They are useful in determining the velocity of water movement into, through and out of subsurface material and how groundwater levels (h) are affected (Bouwer, 1978). The pumping test data is also useful in determining the hydraulic properties of the aquifer. The type of aquifer exists in Belawai and Kabong are unconfined aquifer. Thus, interpreting data was done based on the equations used in analysing unconfined aquifer. The method used in this analysis is steady state method. Geometry and symbol used in steady state method is illustrated in Fig. 3.2.

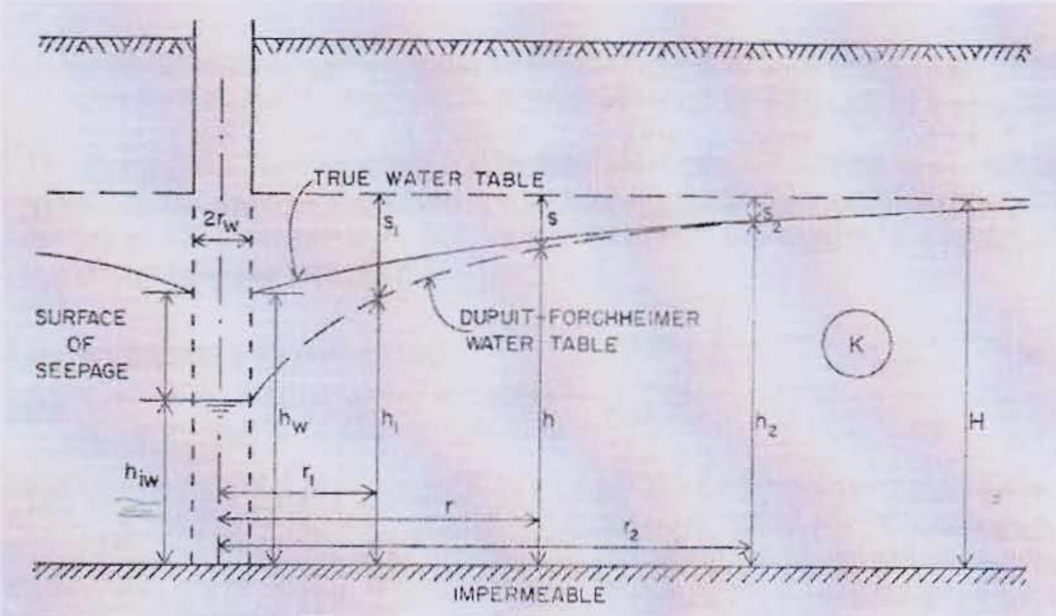

Figure 3.2: The geometry and symbols for pumped well of an aquifer. (Bouwer, 1980)

The geometries involved are

h = height of water level

s = drawdown or drop of water level during pumping test.

r = observation wells distance from pumping well.

3.6.1 Hydraulic Conductivity of Unconfined Aquifer

Basically, steady state method was discussed in chapter 2 under interpreting pumping test topic. The general steady state method equation used in interpreting the pumping test result of an unconfined is as mentioned in is Eq. 2.5.

Meanwhile, drawdown, s is defined as the total head loss (the distance between the pumping water level and the static water level). Its equation is written as

$$h = H - s \tag{3.1}$$

Where

H = initial water level (m)

h = height of water level (m)

s = drawdown

The factor *h* in Eq. 2.5 is replaced with Eq. 3.1, yielding

$$Q = \frac{\pi K(2H - s_1 - s_2)(s_1 - s_2)}{\ln(r_2 / r_1)} \tag{3.2}$$

Where

Q = pumping rate (m^3s^{-1})

K = hydraulic conductivity (ms^{-1})

r = observation wells distance from pumping well (m)

To determine the hydraulic conductivity, Eq. 3.2 is rearranged into

$$K = \frac{Q \ln(r_2 / r_1)}{\pi(2H - s_1 - s_2)(s_1 - s_2)} \tag{3.2}$$

Based on the K value, the type of soils bounded the area can be estimated based on Table. 3.2.

Table. 3.2: Orders of magnitudes for hydraulic conductivity (K) for granular materials. (Bouwer, 1978)

Types of soil	K(m /day)	K (m/hr)
Clay soils (surface)	0.01-0.2	4.17^{-4}-8.33^{-3}
Deep clay beds	10^{-8}-10^{-2}	4.17^{-10}-4.16^{-4}
Loam soil (surface)	0.1 - 1	4.17^{-3}-0.042
Fine Sand	1 - 5	0.042-0.208
Medium sand	5-20	0.21-0.83
Coarse sand	20 – 100	0.833 - 4.17
gravel	100- 1000	4.17-41.67
Sand and gravel mixes	5-100	0.208-4.17
Clay, sand and gravel mixes	0.001-0.1	4.17^{-5}-4.17^{-3}

3.6.2 Transmissivity of Unconfined Aquifer

Basically, the general equation used in determining transmissivity is Eq. 2.3. The factor *h* in Eq. 2.3 is replaced with Eq. 3.1, yielding

$$T = \frac{2H}{2H - s_1 - s_2} \frac{Q \ln(r_2 / r_1)}{2\pi(s_1 - s_2)} \tag{3.3}$$

Where

T = tranmissivity (m^2s^{-1})

Q = pumping rate (m^3s^{-1})

H = aquifer at full thickness (m)

s = drawdown (m)

r = observation wells distance from pumping well (m)

Then, the results of both areas are compared.

3.7 Goundwater Quality

Data on the groundwater quality progress of both areas available in Groundwater Progress Reports are obtained. Based on the data, the progress of chloride content and pH of the groundwater is analyzed.

Unit used to quantify the chloride content is ppm. According to Karanth (1990), concentration of one part per million means that one part by weight of dissolves matter is present in one million parts by weight of solution. The unit is also equal to the weight of dissolved matter in milligrams in one litre (mg/l). Chloride content has strong connection to salt water intrusion.

Meanwhile, pH value of the groundwater is useful to monitor the alkalinity and acidity of the groundwater. The data on the groundwater quality of the study areas than were compared to the WHO International standard drinking water quality.

Table. 3.3: Standards for physical and chemical quality of drinking water. (Karanth, 1990)

Quality	W.H.O. International Standards, 1971		Indian Standards Institution, 1983	
	Highest desirable	Maximum permissible	Highest desirable	Maximum permissible
1	2	3	4	5
Physical				
Turbidity (JTU units)	5	25	10	25
Colour, Hazen-units (on platinm cobalt scale)	5	50	5	50
Taste and odour	Unobjectionable	—	—	Unobjectionable
Chemical				
pH	7.0-8.5	6.5-9.2	6.5-8.5	6.5-9.2
Total dissolved solids (mg/l)	500	1500	500	1500
Total hardness as $CaCO_3$ (mg/l)	100	500	300	600
Calcium (mg/l)	75	200	75	200
Magnesium (mg/l)	$\leq$ 30 if SO_4 is 250 mg/l, up to 150 mg/l if SO_4 is less than 250 mg/l	150	30	100
Iron (as Fe) (mg/l)	0.05	1.5	0.3	1.0
Manganese (as Mn) (mg/l)	0.1	1.0	0.1	0.5
Copper (as Cu) (mg/l)	0.05	1.5	0.05	1.5
Zinc (as Zn) (mg/l)	5.0	15.0	5.0	15.0
Chloride (mg/l)	200	600	250	1000
Sulphate (mg/l)	200	400	150	upto 400 if Mg does not exceed 30 mg/l

CHAPTER 4

RESULTS AND DISCUSSION

4.1 General

Based on the analysis of the data obtained, aquifers that exist along the coastal region in Sarawak are mainly unconfined aquifers. Thus, the calculation involved in the analysis is merely related to unconfined aquifers.

In this section, analysis on the types of soil bounded the study areas; the behavior of changes in water levels and drawdown; the hydraulic properties of aquifers in both areas; groundwater quality; and saline intrusion are done. Principally, the analysis was done based on the pumping test results, which are obtained from the Mineral and Geoscience Department.

4.2 Types of Soil

The types of soil in the study areas are summarized in Table. 4.1.

Table. 4.1: Lithology of Belawai and Kabong

Area	Types of soil
Belawai	Clay, sand
Kabong	Clay,silt peat and sand

4.2.1 Belawai

Belawai is located at coastal region where the deposit of sand appears to be dominant. According to Yogeswaran (1978), only minor part of Belawai is layered with clay deposits. He reported again that the area will generally completed flooded by brackish water at spring tide. The existence of brackish water or slightly salty water is probably due to the salt water intrusion.

4.2.2 Kabong

According to Yogeswaran (1980), the sand towards the top of the beach ridges in Kabong is overlain by silt and clay. Based on the geology map available in Geoscience and Minerals Department, Kabong is located at coastal region where the area is covered with unconsolidated quaternary sediments of marine and deltaic origin. Normally, sediments that bounded the deltaic origin are silt, clay, peat and sand.

4.2.3 Comparison

Both areas are located at sandy beach along the coastal area and over layered by clay. However, unlike in Belawai, some area in Kabong is overlain by peat and silt.

4.3 Analyzed on Pumping Test Data

4.3.1 Belawai

Pumping test result on Belawai is obtained from the Hydrological Survey in Belawai report dated 1978. The survey was done by late Mr. Yogeswaran Mailvaganam.. Before pumping test starts a pumping well of 19.5 m depth was constructed (Yogeswaran ,1978). The location of pumping well and observation wells are shown in Fig. 4.1.

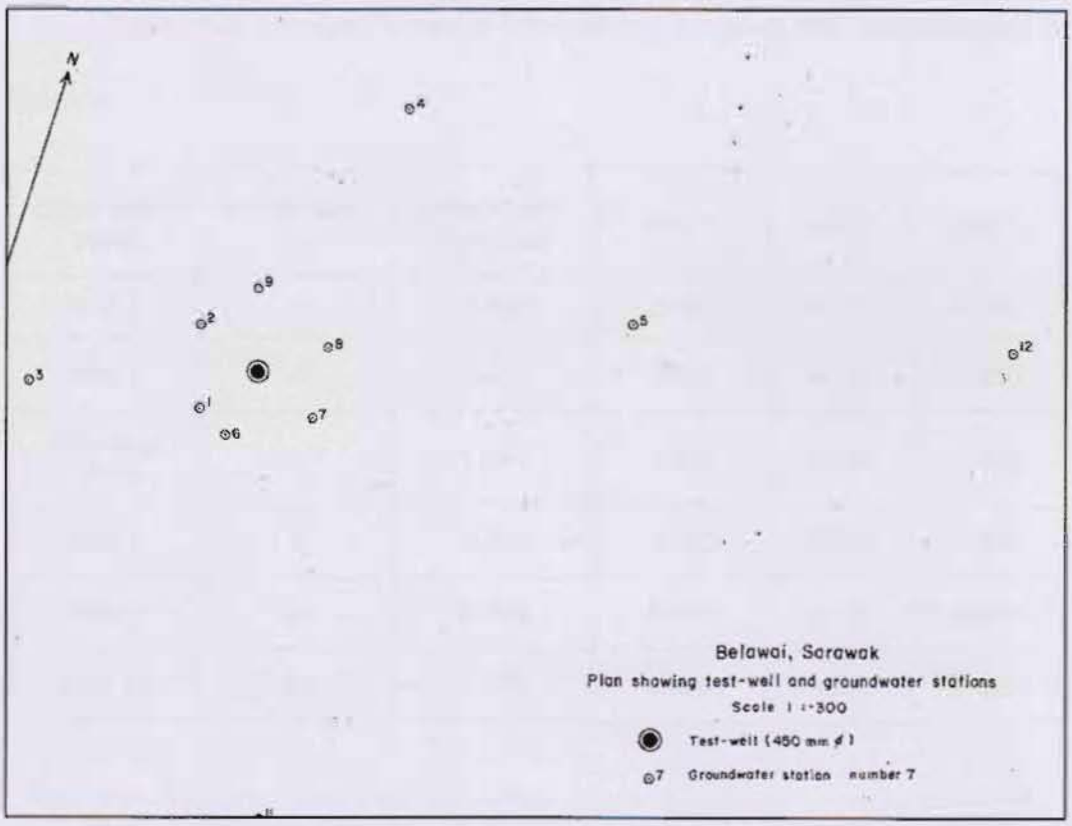

Figure 4.1: Location of pumping well and observation wells in Belawai.

(Yogeswaran ,1978)

According to Yogeswaran (1978), the pumping test was done using centrifugal pump. The pumping test took about three days (27.10.1977 to 29.10.1977) and the result of the pumping test is attached in Appendix 1. Steady flow of $9.1m^3 h^{-1}$ was reached after 1 hour 12 minutes of pumping. Yogeswaran (1978) reported that the aquifer is about (H) 200m depths. The changes of water level during pumping test are summarized in Table. 4.2.

Table. 4.2: Changes in water level during pumping test concentrating in Belawai.

Observation Wells	Well distance (m)	Initial Water Level (m)	Day 1	Day2	Day 3
Well 3	-15	0.230	0.380	0.165	0.250
Well 1	-5	0.410	0.920	0.535	0.430
Pumping Well	0	1.190	5.620	5.790	1.260
Well 8	5	0.590	1.160	0.580	0.570
Well 5	25	0.490	0.580	0.110	0.510
Well 12	50	0.570	0.600	0.570	0.580

The highest water level reported occurred on day 2 in pumping well with the value of 5.7 m. The initial water level in pumping well was 1.19 m. However, the water level increased drastically after day 1. On day 3, the water level decreased approximately to the initial water level. The same changes occurred in most of the observation wells. Basically, the water levels are decreasing as they are approaching to the pumping well. These changes can be clearly seen in Fig. 4.2.

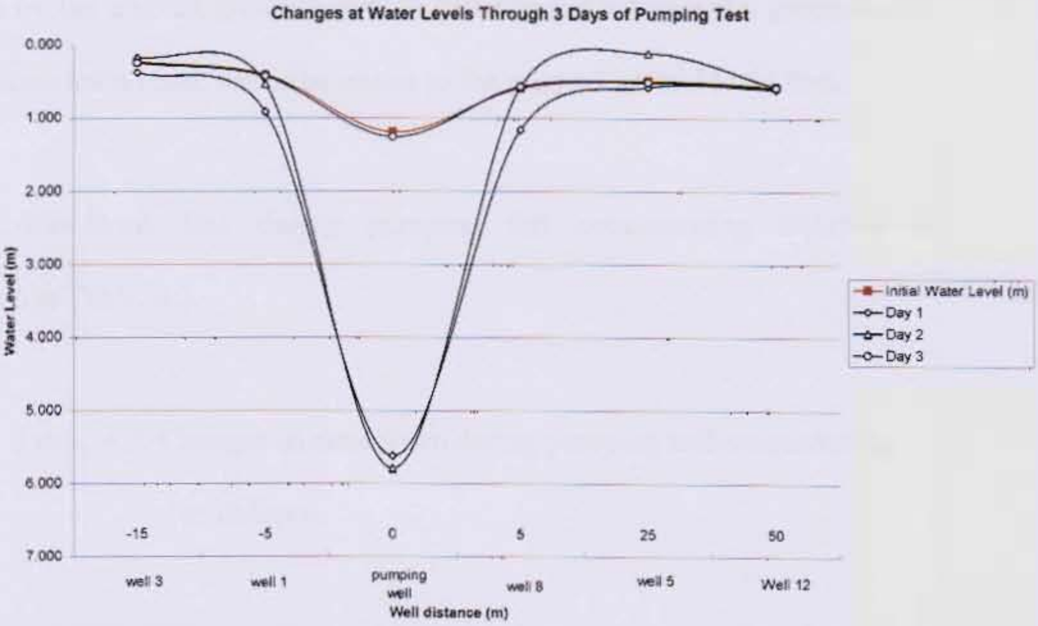

Figure 4.2: Changes of water levels through 3 days of pumping test in Belawai.

In unconfined aquifer, withdrawal of water means the water level is lowered, and the saturated thickness of the aquifer is reduced (Price, 1996). In other words, water level around pumping well declined rapidly once pumping starts. Based on Fig. 4.2, the water level in each well decreased respectively and recovered to the initial water level on day 3.

Theoretically, the water levels in each observation wells should not higher than the initial water level in pumping test. However, water level on day 2 (28.10.1977) is slightly higher than the initial water level. This is probably due to rainfall, high water tide or groundwater level not horizontal. DID (1977) reported that it was raining in Belawai on the second day of pumping test dated 28 October 1977 with 9.3 mm rainfall. Meanwhile, there is no water tide record in 1970s. The defect may be also due to groundwater level that is not horizontal, which is influenced by the uneven ground level. In order to get a horizontal groundwater level, the drawdown result has to be minus to the original ground level first.

The drawdown data during pumping test concentrating Belawai is summarized in Table. 4.3.

Table. 4.3: Changes in drawdown during pumping test concentrating in Belawai.

Drawdown (m) end of day			
Observation Wells	Day 1	Day 2	Day 3
Pumping Well	4.43	0.07	0.02
Well 1	0.51	0.02	0.01
Well 3	0.15	0.02	0.02
Well 5	0.09	0.02	0.02
Well 8	0.57	0.02	0.02
Well 12	0.03	0.00	0.01

Based on the table, the highest drawdown occurred in pumping well with drawdown of 4.43 m. The highest drawdown in observation well reported occurred in observation well 8 with the value of 0.57 m. The graphical changes of drawdown in Belawai are illustrated in Fig. 4.3.

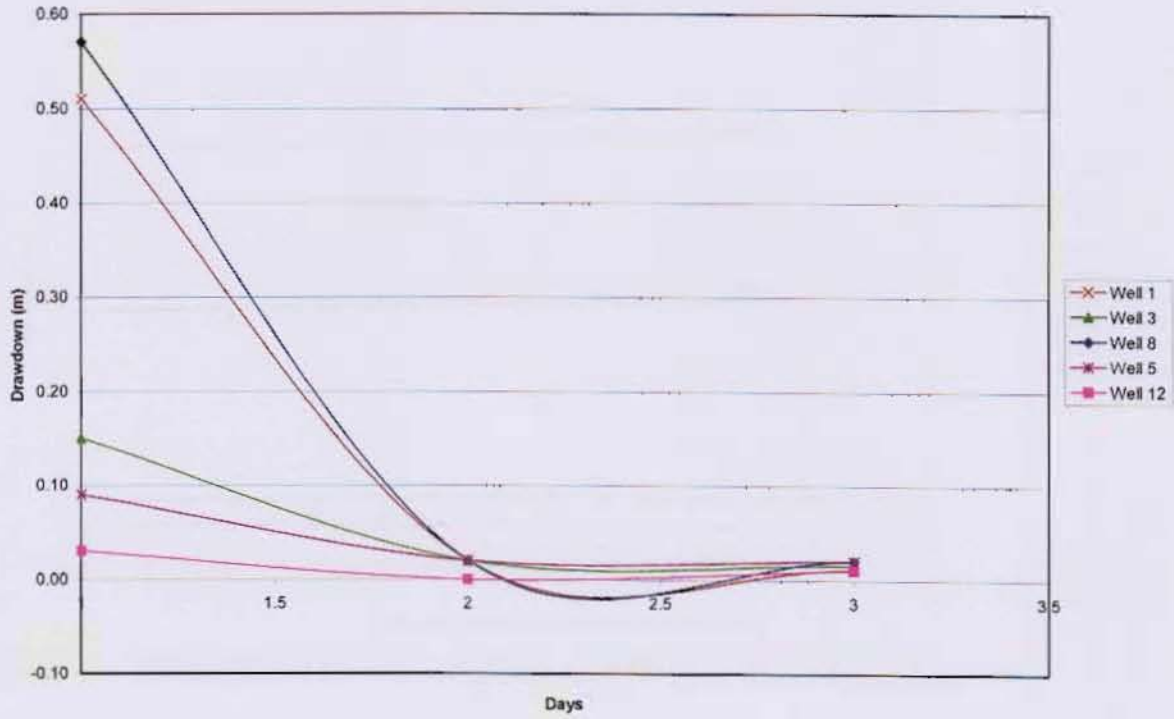

Figure 4.3: Changes of drawdown through three days of pumping test in Belawai.

Based on the graph, the value of drawdown in each well decreased respectively. According to Price (1996), the greater the drawdown, the more energy is needed. On the first day, drawdown levels in most observation wells are high. This is because the pump must impart energy to the water in order to lift the groundwater to the surface. However, the drawdown levels reach a constant value of 0.015m after three days of pumping.

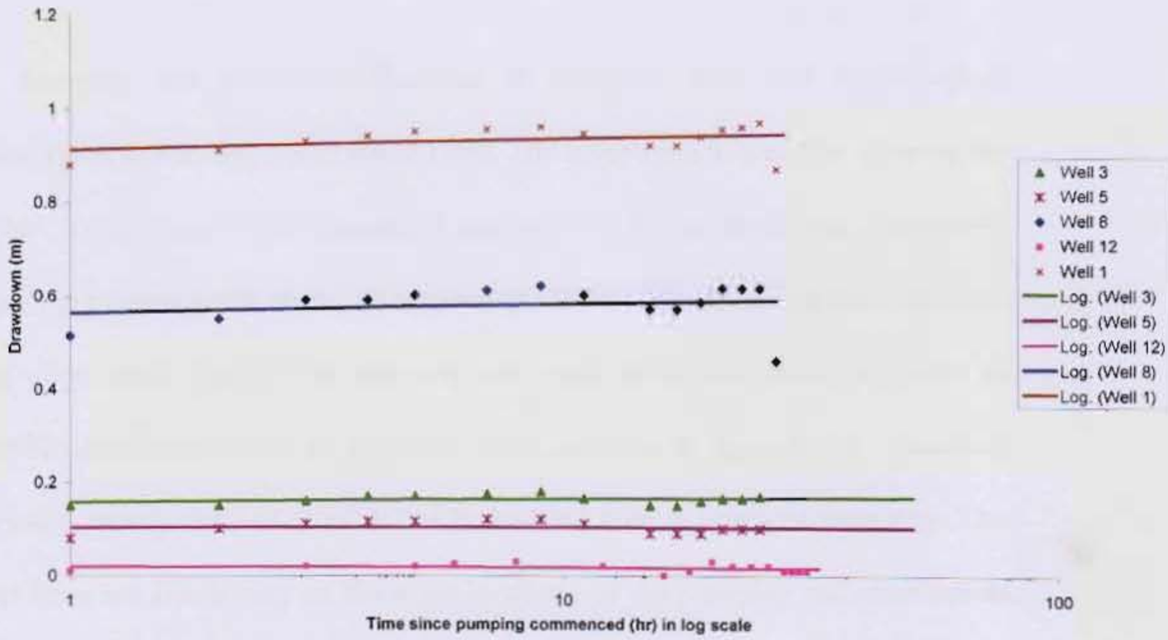

Figure 4.4: Graph time vs drawdown of each well for three days of pumping test in Belawai. (log scale)

Fig. 4.4 shows the different of drawdown levels in each well. The difference inversely related to the distance from the pumping well. The observation well that located nearest to the pumping well has the greatest drawdown. Based on Fig. 4.4, the nearest observation well is well 1, which was located 5 m from the pumping well. The farthest observation well is well 12, which was constructed 50 m from the pumping well (Table. 4.2). The locations of the wells are shown in Fig. 4.1.

4.3.2 Kabong

Pumping test result on Kabong is obtained from the Hydrological Investigation in Kabong report dated 1980. The investigation was also done by the late Mr. Yogeswaran Mailvaganam. A test well of 8.1 m depth was constructed before the pumping test starts, (Yogeswaran, 1980). The pumping test was done using centrifugal pump. The pumping test took about five days (4.2.1980 to 8.2.1980) and the result of the pumping test is attached in Appendix 2. Based on the result, steady flow of 8 $m^3 h^{-1}$ was reached after 8 hours of pumping. The report does not attach map on the exact locations of the pumping and observation wells. Thus, the locations of the wells were predicted based on Fig. 4.7. The prediction location is illustrated in Fig. 4.5. The water level data during pumping test pumping test is summarized in Table. 4.4.

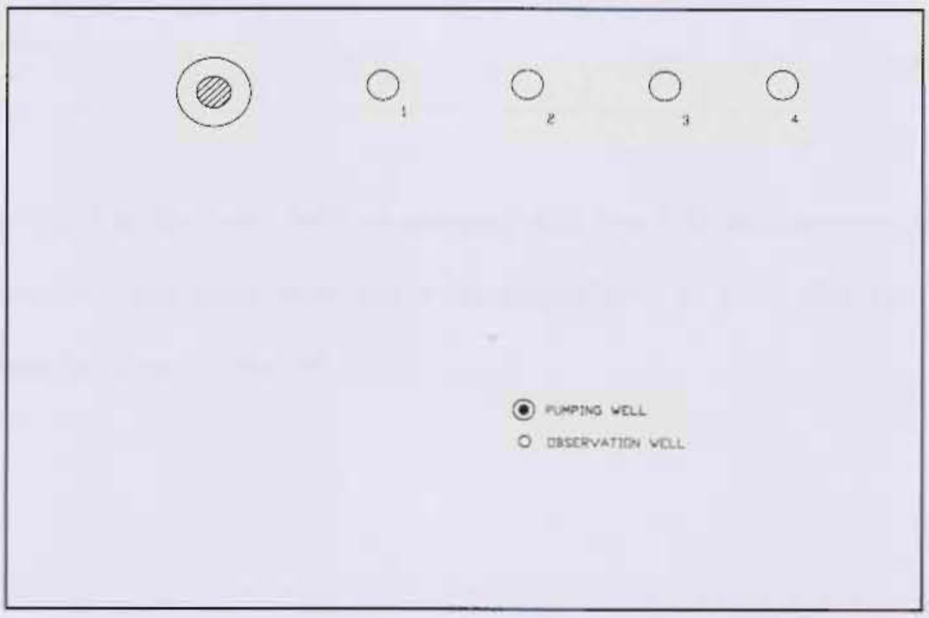

Figure 4.5: Predicted location of pumping and observation wells constructed in Kabong.

The changes of water level during pumping test pumping test is summarized in Table. 4.4.

Table. 4.4: Changes in groundwater level during pumping test concentrating in Kabong.

Wells	Well distance (m)	Groundwater Level (m)					
		Initial groundwater Level (m)	Day 1	Day2	Day 3	Day 4	Day 5
Pumping Well	0	0.82	4.2	4.01	0.71	0.75	0.75
Observation well 1	5	0.39	1.44	1.28	0.25	0.32	0.32
Observation well 2	10	0.69	1.37	1.2	0.56	0.61	0.62
Observation well 3	18.7	0.63	1.09	0.9	0.51	0.53	0.52
Observation well 4	27.7	0.85	1.11	0.92	0.73	0.79	0.78

The initial groundwater level in pumping well was 0.82 m. However, the groundwater level increased drastically to the highest level of 4.2 m after day 1. The changes are shown in Fig. 4.6.

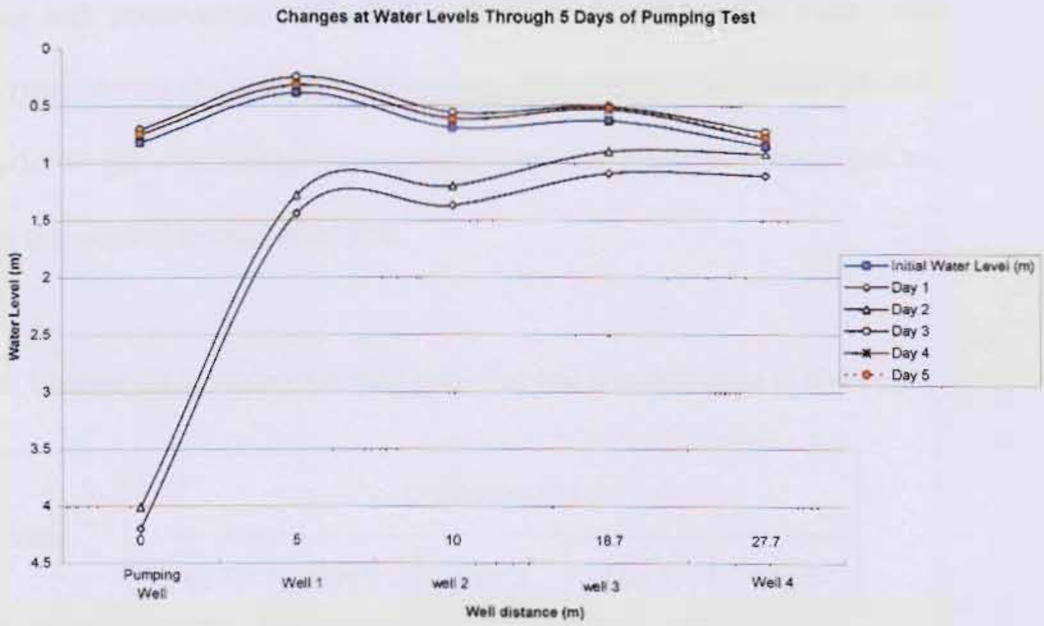

Figure 4.6: Changes in groundwater levels through five days of pumping test in Kabong.

Based on Fig. 4.6, the groundwater level in each well lowered respectively and recovered to the initial groundwater level on day 5. The same changes occurred in most of the observation wells. Theoretically, the groundwater levels in each observation wells should not higher than the initial groundwater level in pumping test. However, groundwater level on day 3 (6.2.1980) is slightly higher than the initial groundwater level. This is probably due to rainfall, groundwater level not horizontal or high tide. However, DID (1980) reported that there was no rainfall on the third day of pumping test (6 February 1980). Heavy rainfall was only reported on the day before (5.2.1980) with the amount of 83.1 mm. The rainfall on day 2 might cause surface runoff and some of the rainwater percolate into the subsurface causing the groundwater level on day 3 increased higher then the initial groundwater level. However, this statement is not concrete. Meanwhile, there was no tidal height data in Kabong recorded in 1980. Data on ground level of pumping and observation wells did not attach to the report. Thus, the drawdown result during the pumping test may be influenced by the uneven ground level. In order to get a horizontal groundwater level, the drawdown result has to be minus to the original ground level first.

Table. 4.5: Changes in drawdown during pumping test concentrating in Kabong.

Wells	Drawdown (m)				
	Day 1	Day 2	Day 3	Day 4	Day 5
Pumping well	3.38	3.19	0.11	0.07	0.07
Observation well 1	1.05	0.89	0.14	0.07	0.07
Observation well 2	0.68	0.51	0.13	0.08	0.08
Observation well 3	0.46	0.27	0.12	0.10	0.11
Observation well 4	0.26	0.07	0.12	0.06	0.07

The highest drawdown that occurred in observation well reported occurred in observation well 1 with the value of 1.05 m. The drawdown graph of Kabong is shown in Fig. 4.7.

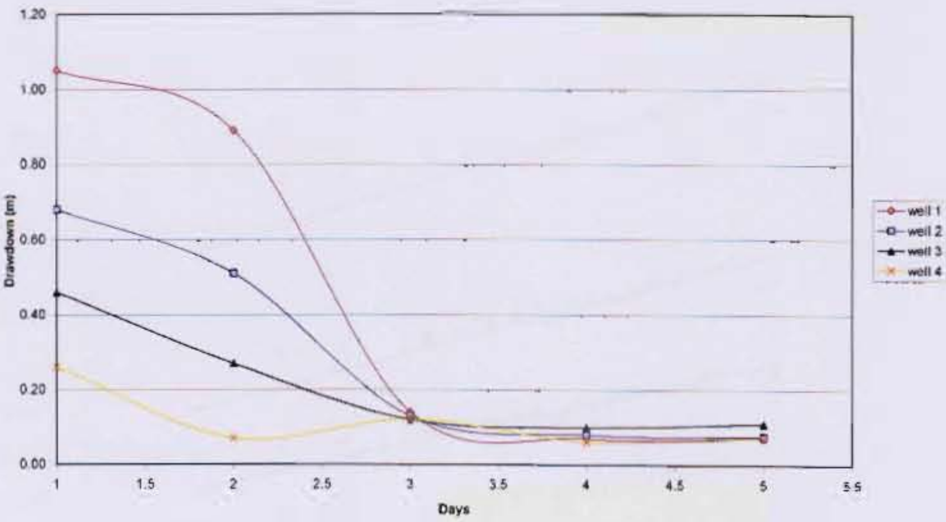

Figure 4.7: Changes of drawdown through five days of pumping test in Kabong.

Based on the graph, the drawdown level reached constant after five days of pumping. The values remain constant even after five days of pumping. Based on the graph, the value of drawdown in each well decreased respectively. On day 1, drawdown levels in most observation wells are high. This is because the pump must impart energy to lift the groundwater to the surface. However, the drawdown levels reach a constant value of 0.015m after three days of pumping

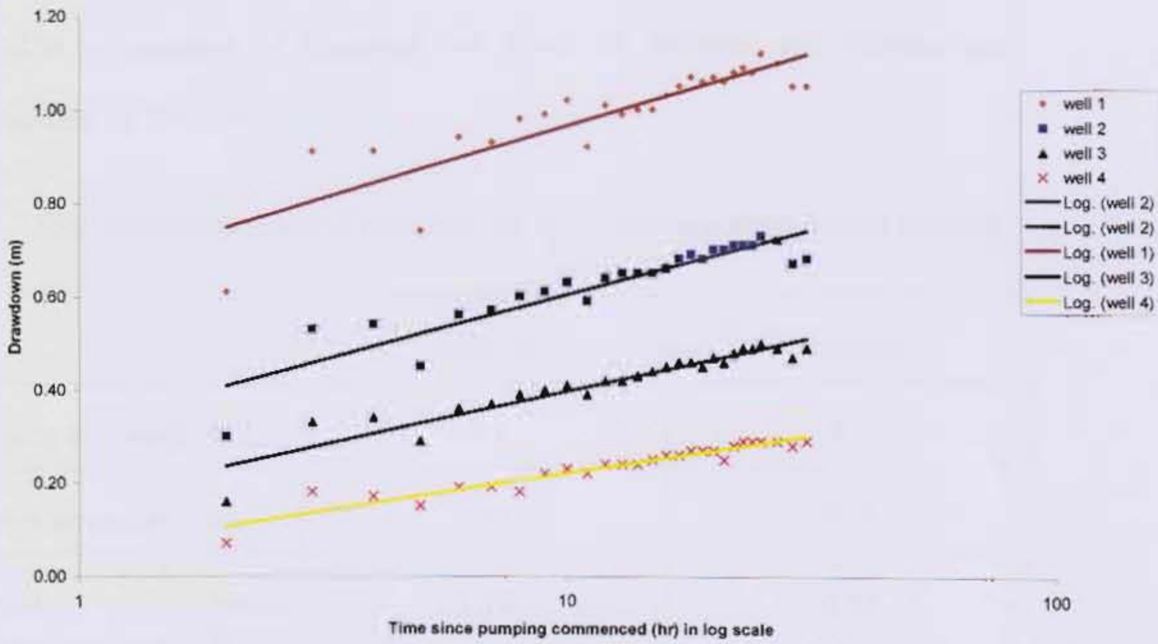

Figure 4.8: Time vs drawdown of each well for five days of pumping test in Kabong (log scale).

Fig. 4.8 shows the different of drawdown levels in each well. The difference inversely related to the distance from the pumping well. The observation well that located nearest to the pumping well has the greatest drawdown. Based on Table. 4.5, the nearest observation well is well 1, which was located 5 m from the pumping well. The farthest observation well is well 4, which was constructed 27.7 m from the pumping well (Fig. 4.5).

4.3.4 Comparison

The comparison of pumping test result of Belawai and Kabong are summarized in Table. 4.6.

Table. 4.6: Comparison of pumping test result between Belawai and Kabong

	Belawai	Kabong
Pumping discharge $m^3 h^{-1}$	9.1	8.0
Highest drawdown (m)	4.43	4.01
Highest initial groundwater level (m)	1.19	0.82

Based on Table. 4.6, the results of both areas are not much difference. Basically, the drawdown of pumping test in Belawai is slightly higher than that in Kabong. According to Price (1996), the greater the drawdown, the more energy is needed. Thus, greater discharge was needed during pumping test in Belawai. With the greater energy, a greater initial groundwater level was reached.

4.4 Hydraulic Properties

Results of the hydraulic properties in the study areas are summarized in Table. 4.7.

Table 4.7: Hydraulic properties of aquifers in the study areas.

Study Areas	Average Value of Transmissivity m^2h^{-1}	Average Value of Hydraulic Conductivity $m\ h^{-1}$
Belawai	9.85	1.93
Kabong	1.52	0.57

4.4.3 Transmissivity

Transmissivity of aquifer in Belawai is larger compared to the transmissivity of aquifer in Kabong. Based on the comparisons made between results in Table 4.7 and Table 3.1, the type of sand bounded in Belawai is coarser compared to the sand that bounded in Kabong. This shows that groundwater of aquifer in Belawai moves easier compared to the groundwater of aquifer in Kabong.

4.3.2 Hydraulic Conductivity

The results in Table 4.1 show that the hydraulic conductivity of aquifer in Kabong is lower than the hydraulic conductivity of aquifer in Belawai. In other words, the porosity and permeability of soil in Kabong is lower compared to the soil in Belawai. This is due to the existence of peat and silt, which are impermeable soil (Table. 4.1).

Compared to Table 3.2, permeability and porosity of silt and clay are lower compared to sand. The existence of silt causing the value of hydraulic conductivity in Kabong larger compared to the hydraulic conductivity in Belawai. The presence of low permeability sediments retards infiltration causing greater amount of surface runoff. This might be the reason to the occurrence of the flood reported, which was mentioned earlier.

4.5 Groundwater Quality

In determining the quality of groundwater in both areas, data on the monitoring progress reports of both areas was studied.

4.5.1 pH

In determining the pH values, two type of groundwater are analyzed which are raw and treated groundwater. Raw groundwater is fresh groundwater that is not yet treated. Treated groundwater is groundwater that is ready for domestic used. Table 4.8 show the pH progress of groundwater in Belawai and Kabong from year 1988 to 1995.

Table. 4.8: Summarized of groundwater pH in Belawai and Kabong

		pH value in				
		Feb-88	Jan-89	Jan-90	Sep-94	Feb-95
Belawai	Raw	7.54	7.6	7	7.2	7.2
	Treated	7.58	7.2	7.4	7.6	7.3
Kabong	Raw	8	7.6	7.6	6.9	7.3
	Treated	7.2	7.2	7.2	7.3	7.1

Figure 4.9: Graph of groundwater pH reading concentration in Belawai.

Fig. 4.9 shows the changes in pH value of groundwater in Belawai. Result shows that the pH value of groundwater in Belawai is in the range of natural (pH 7.0-7.54).

pH value of raw groundwater reaches the highest in year 1989 with pH 7.6. However, the value fall approaching pH 7 towards year 1990 and slightly increase to pH 7.2 in year 1994 and the value maintain until year 1995.

Meanwhile, there are no drastic changes on pH values in treated groundwater. The values maintain around pH 7 throughout the years. In conclusion, the pH changes in both raw and treated groundwater should not be a concern as the pH value meets the WHO standards (pH7-pH 8.5) as shown in Table. 3.3.

Figure 4.10: Graph of groundwater pH reading concentration in Kabong.

Fig. 4.10 shows the changes in pH value of groundwater in Kabong. Result shows that there are drastic changes in pH values of groundwater in Kabong.

pH value of raw groundwater reaches the highest in year 1988 with pH 8.0. However, the value fall approaching pH 6.8 towards year 1994. Based on the hydrological investigations done by Yogeswaran (1980), ferrous iron content in Kabong was 0.75 ppm-11.60 ppm. The readings did not meet the WHO standards in Table. 3.3. With pH of 6.3, the groundwater is considered slightly acidic. The high content of iron derived from peat bogs can lowered the pH value (Karanth, 1990). The drastic change from alkaline to acidic was due to the high existence of ferrous iron in the nearby peat soil. However, the value reaches natural in year 1995 with the value of pH 7.1.

Meanwhile, there are no drastic changes on pH values of treated groundwater. The values maintain around pH 7 throughout the years. Based on the W.H.O International standard shown in Table 3.3, groundwater with pH 7 is in the highest desirable.

4.5.3 Chloride Content

Results of the chloride content in the study areas are summarized in Table. 4.9.

Table. 4.9: Summarized of chloride content in groundwater at Belawai and Kabong.

		Chloride content (ppm) in				
		Feb-88	Jan-89	Jan-90	Sep-94	Feb-95
Belawai	Raw	144	410	132	42	30
	Treated	34	57.4	86	48	32
Kabong	Raw	179.2	580	360	62	132
	Treated	34	34	96	58	114

Figure 4.11: Graph of chloride content in groundwater at Belawai.

Fig. 4.11 shows the changes in chloride content in groundwater in Belawai. The highest chloride reading in raw groundwater was reported in 1989. This is probably due to the high water tide in January thus increase the interface level.

This leads salt water intrusion that cause to high value of chloride (410 ppm) in raw groundwater. This value is less desirable for drinking purpose. However, towards year 1995, the value of chloride content is decreasing to 30 ppm, which approaching the same value of chloride content in treated groundwater.

Even though the chloride content in raw groundwater is slightly high in 1988, the chloride content in treated groundwater was decreased to 34 ppm. The value was maintained in a range of 34 ppm to 86 ppm, which is still meets the WHO requirement (Table. 3.3).

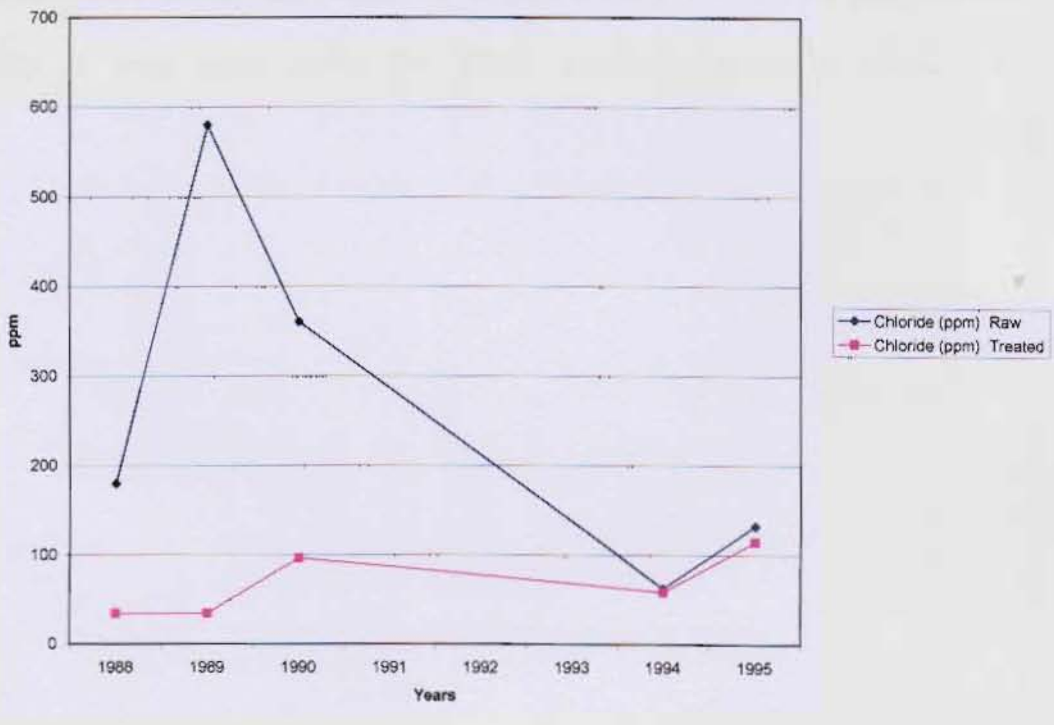

Figure 4.12: Graph of chloride content in groundwater at Kabong.

Fig.4.12 shows the changes in chloride content in groundwater in Kabong. The highest chloride of 580 ppm reading was reported in 1989. This is less desirable for drinking purpose. However, the value is still below the WHO maximum permissible standard (Table. 3.3). However, the valued decreased approaching 30 ppm towards the year 1994.

The chloride content in treated groundwater was reported stable in the range of 30 ppm to 150 ppm. The value meets the WHO standards (Table. 3.3).

4.5.4 Comparison

The chloride content in groundwater of both areas does not show any signs of salt-water intrusion. This is probably due to the existence of low permeability sediments such as clay that retards the original salinity. Overall, the groundwater quality in both areas meets the WHO standards shown in Table. 3.3.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This project can be concluded as below:

- The study areas are bounded with sand and clay. The existence of clay and silt sediments decreases the permeability of the soil.

- Drawdown of pumping test conducted in Belawai (4.43m) was slightly higher than that in Kabong (4.01m). According to Price (1996), the greater the drawdown, the more energy is needed. Thus, greater discharge was needed during pumping test in Belawai.

- Hydraulic conductivity of aquifer in Belawai (1.81 mh^{-1}) is larger than the hydraulic conductivity of aquifer in Kabong (0.65 mh^{-1}) due to the presence of silt.

- The tranmissivity of aquifer in Belawai (62.42 m^2h^{-1}) is larger compared to the transmissivity of aquifer in Kabong (4.56 m^2h^{-1}).

- Aquifer located at Belawai has better potential compared to the aquifer located at Kabong.

- pH of groundwater in both areas are in natural range of around pH 7.

- Based on the study, the chloride content in groundwater of both areas are low. A conclusion is made that there is no salt-water intrusion in aquifers at both areas.

- The groundwater quality in both aquifers meets the WHO standards (Table. 3.3).

- The fresh groundwater in both areas has the potential to be supplied to the public.

5.2 Recommendations

Based on the project, groundwater exploration in Sarawak is still using the conservational method, which is more complicated compared to the up to date methods, which ear easier. It is recommended of shifting the pumping test method to the Electrical Resistively method. This method that is more efficient in sensing the areas that predicted to have high yield of groundwater storage might be in a good attempt.

The major problem arose during completing the project was dealing missing data. The existence data is recommended to be digitalized and computerised for the sake of future use.

Hopefully, this project shall be preceded for further research with a proper or better procedure and equipment for analysing the process in order to obtain the best method and problem solving in determining groundwater potential along the coastal area in Sarawak.

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APPENDIX

APPENDIX 1-BELAWAI

Pumping test result in Belawai

Day	Time (hr)	test well			Time (hr)	Observation well 1, r_1 = 5m		Observation well 3, r_3 = 15m		Observation well 5, r_5 = 25m	
		Drawdown (m)	Groundwater Level (m)	Discharge $m^3 h^{-1}$		Drawdown (m)	Groundwater Level (m)	Drawdown (m)	Groundwater Level (m)	Drawdown (m)	Groundwater Level (m)
Day 1	0	0	1.19	12.2	0	0	0.41	0	0.23	0	0.49
	1	4.02	5.21	12.2	1	0.47	0.88	0.15	0.38	0.08	0.57
	2	4.17	5.36	12.2	2	0.5	0.91	0.15	0.38	0.1	0.59
	3	4.3	5.49	12.2	3	0.52	0.93	0.16	0.39	0.11	0.6
	5	4.41	5.6	12.2	4	0.53	0.94	0.17	0.4	0.115	0.605
	6	4.47	5.66	12.2	5	0.54	0.95	0.17	0.4	0.115	0.605
	8	4.54	5.73	12.2	7	0.545	0.955	0.175	0.405	0.12	0.61
	10	4.6	5.79	10.6	9	0.55	0.96	0.18	0.41	0.12	0.61
	12	4.56	5.75	10.6	11	0.535	0.945	0.165	0.395	0.11	0.6
end of day 1	16	4.43	5.62	10.6	15	0.51	0.92	0.15	0.38	0.09	0.58

<u>Continue: Pumping test result in Belawai</u>

Day	Time (hr)	test well			Time (hr)	Observation well 1, r_1 = 5m		Observation well 3, r_3 = 15m		Observation well 5, r_5 = 25m	
		Drawdown (m)	Groundwater Level (m)	Discharge $m^3 h^{-1}$		Drawdown (m)	Groundwater Level (m)	Drawdown (m)	Groundwater Level (m)	Drawdown (m)	Ground water Level (m)
Day 2	18	4.39	5.58	10.6	17	0.51	0.92	0.15	0.38	0.09	0.58
	20	4.55	5.74	9.1	19	0.53	0.94	0.16	0.39	0.09	0.58
	22	4.7	5.89	7.8	21	0.545	0.955	0.165	0.395	0.1	0.59
	24	4.725	5.915	9.1	23	0.55	0.96	0.165	0.395	0.1	0.59
	26	4.71	5.9	9.1	25	0.56	0.97	0.17	0.4	0.1	0.59
	27	4.75	5.94	9.1	27	0.46	0.87	0.1	0.33	0.06	0.55
	28	0.34	1.53	9.1	28	0.08	0.49	0.04	0.27	0.03	0.52
	29	0.27	1.46	9.1	29	0.06	0.47	0.03	0.26	0.025	0.515
	31	0.2	1.39	9.1	31	0.05	0.46	0.03	0.26	0.025	0.515
	33	0.16	1.35	9.1	33	0.04	0.45	0.03	0.26	0.02	0.51
	37	0.09	1.28	9.1	37	0.02	0.43	0.02	0.25	0.02	0.51
	39	0.08	1.27	9.1	39	0.02	0.43	0.02	0.25	0.01	0.5
end of day 2	41	0.07	1.26	9.1	41	0.02	0.43	0.02	0.25	0.02	0.51

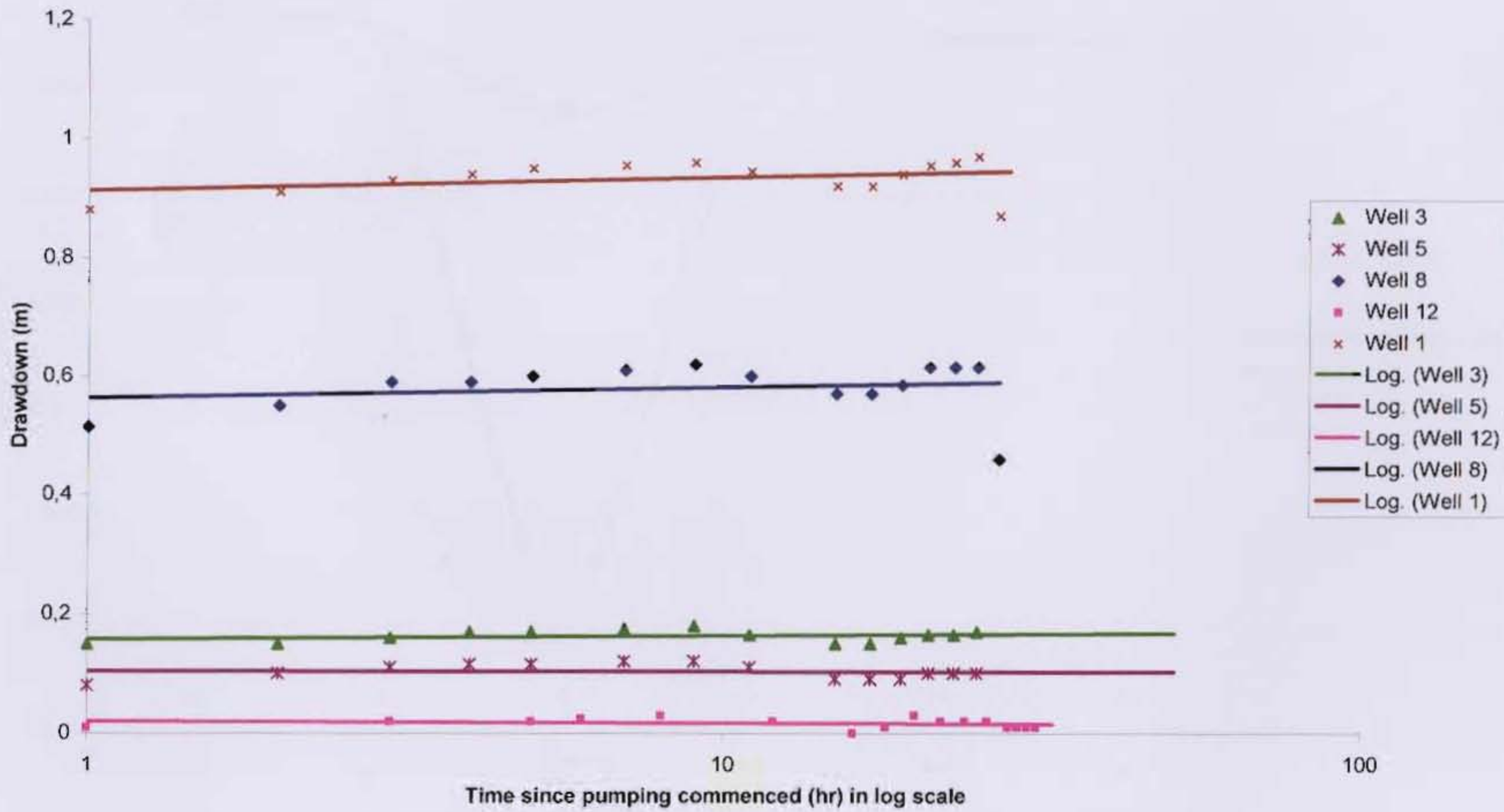
Continue: Pumping test result in Belawai

Day	Time (hr)	test well			Time (hr)	Observation well 1, r_1 = 5m		Observation well 3, r_3 = 15m		Observation well 5, r_5 = 25m	
		Drawdown (m)	Ground water Level (m)	Discharge $m^3 h^{-1}$		Drawdown (m)	Ground water Level (m)	Drawdown (m)	Ground water Level (m)	Drawdown (m)	Ground water Level (m)
Day3	43	0.055	1.245	9.1	43	0.01	0.42	0.01	0.24	0.01	0.5
	45	0.05	1.24	9.1	45	0.01	0.42	0.01	0.24	0.01	0.5
	47	0.04	1.23	9.1	47	0.01	0.42	0.02	0.25	0.01	0.5
	49	0.025	1.215	9.1	49	0.01	0.42	0.01	0.24	0.015	0.505
end of day 3	51	0.02	1.21	9.1	51	0.01	0.42	0.015	0.245	0.02	0.51

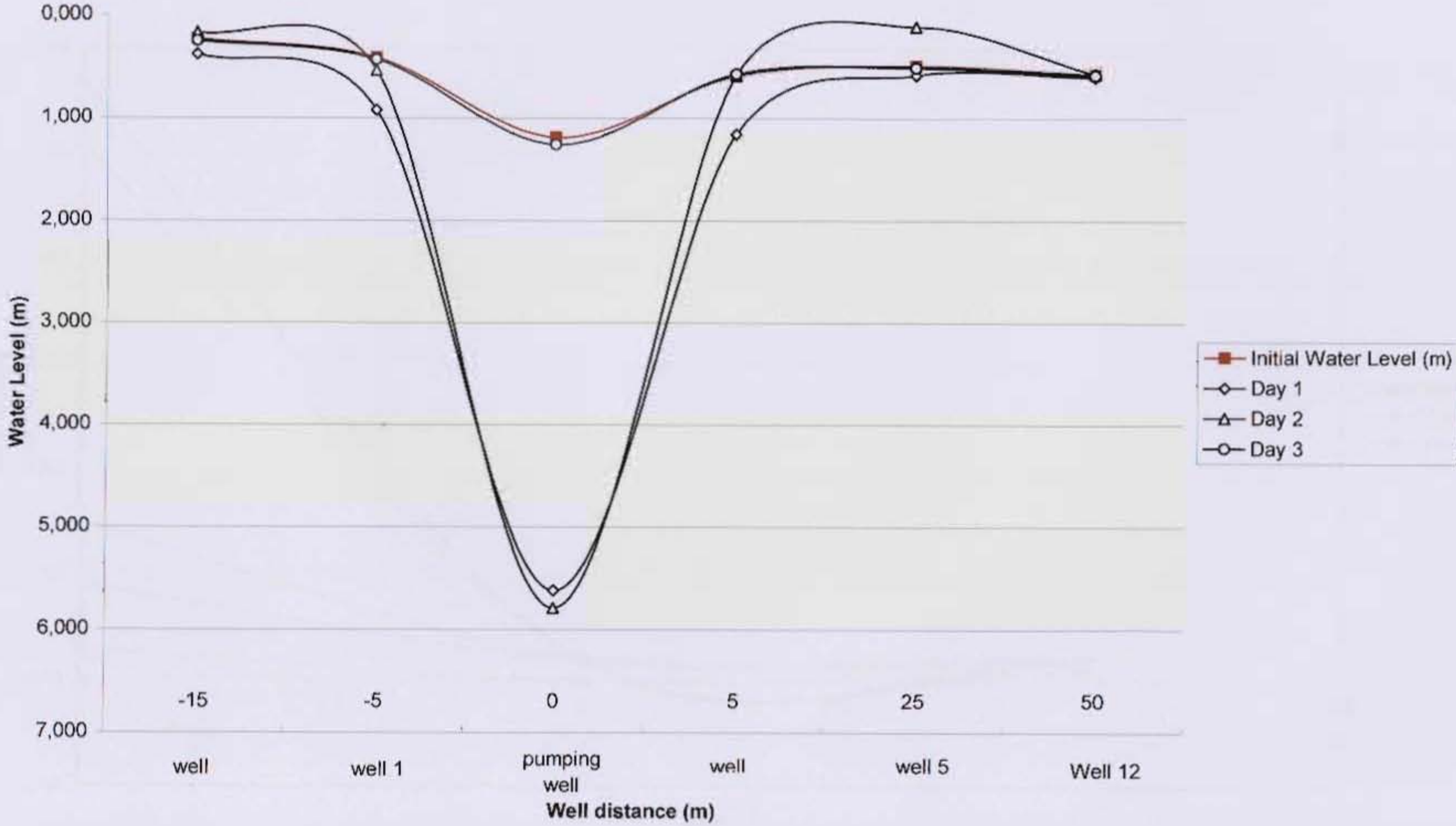
Appendix 1.1: Hydraulic conductivity and transmissivity result in Belawai.

Time (hr)	Hydraulic Conductivity m^2h^{-1}		Transmissivity $m\ h^{-1}$	
	Groundwater movement from observation well 1 and 3 toward the left side of the pumping well	Groundwater movement from observation well 8 and 12 toward the right side of the pumping well	Groundwater movement from observation well 1 and 3 toward the left side of the pumping well 1	Groundwater movement from observation well 8 and 12 toward the right side of the pumping well
0	0.00	0.00	0.00	0.00
1	0.37	0.26	7.30	6.77
2	0.36	0.24	7.06	6.20
3	0.34	0.23	6.63	6.03
4	0.34	0.23	6.70	6.03
5	0.34	0.22	6.56	5.87
7	0.33	0.22	6.50	5.87
9	0.28	0.22	5.54	5.10
11	0.29	0.22	5.64	5.10
15	0.30	0.23	5.75	5.24
17	0.30	0.23	5.75	5.24
19	0.25	0.22	4.79	4.38
21	0.20	0.22	3.95	3.66
23	0.24	0.22	4.61	4.21
25	0.24	0.21	4.61	4.16
27	0.30	0.23	5.91	4.48
28	2.00	2.05	38.97	39.90
29	3.42	2.73	66.74	53.16
31	7.98	4.09	155.66	79.72
33	0.00	8.17	0.00	159.40
37	0.00	0.00	0.00	0.00
39	11.96	0.00	233.28	0.00
41	0.00	0.00	0.00	0.00
43	11.96	0.00	233.28	0.00
45	11.96	0.00	233.28	0.00
47	11.96	-8.17	233.28	-159.24
49	23.93	0.00	466.61	0.00
51	0.00	-16.33	0.00	-318.43

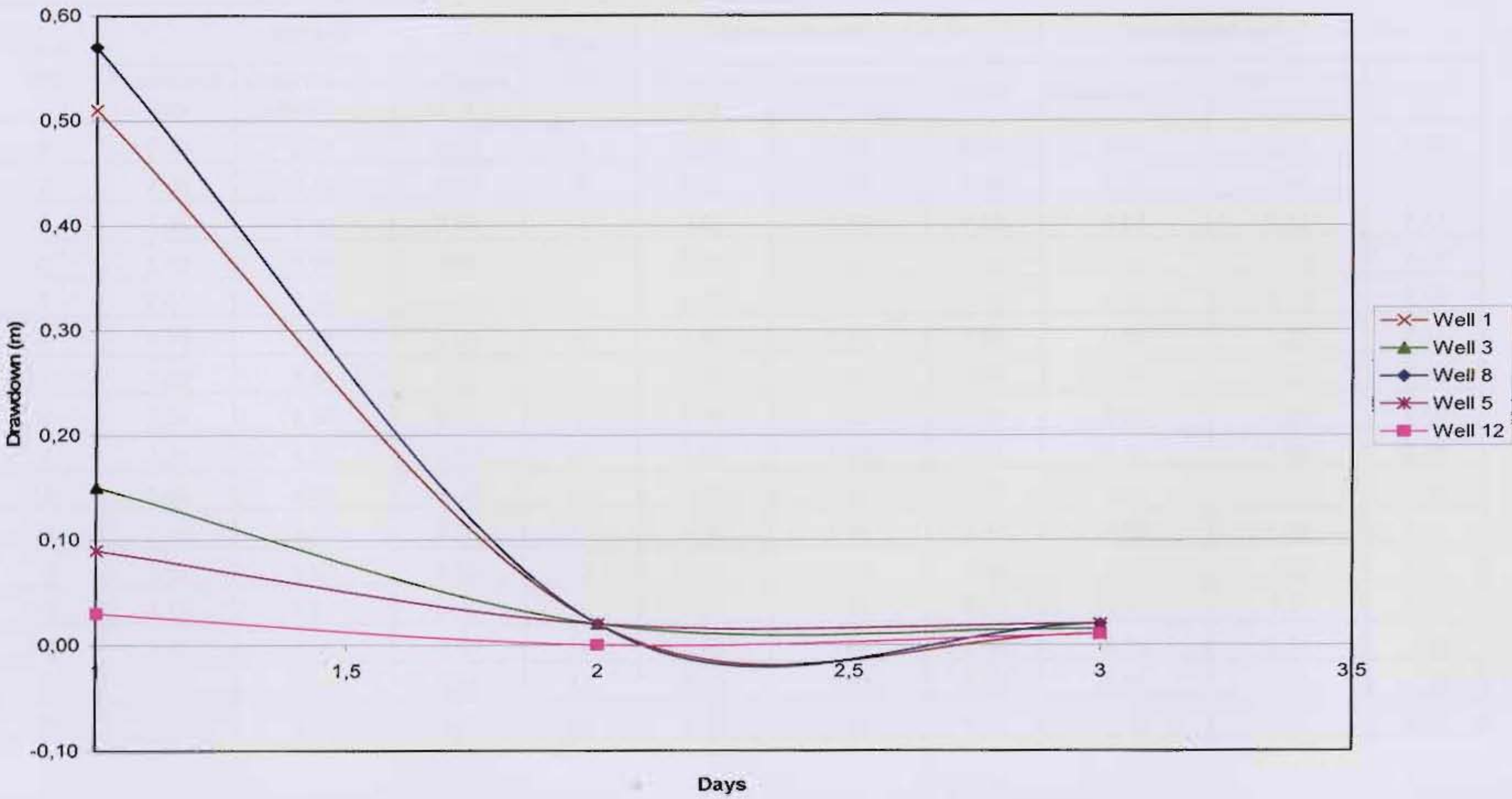
Appendix 1.2: Graph time vs drawdown of each well for three days of pumping test located at Belawai (log scal)



Appendix 1.3: Changes at water levels through 3 days of pumping test in Belawai.



Appendix 1.4: Changes of drawdown through three days of pumping test in Belawai.



APPENDIX 2-KABONG

Pumping test result in Kabong

Time (hr)	test well			Time (hr)	Observation well 1, r_1 = 5m			Observation well 2, r_2 = 10m		
	Drawdown (m)	Groundwater Level (m)	Discharge $m^3\ h^{-1}$		Drawdown (m)	Groundwater Level (m)	h_1 (m)	Drawdown(m)	Groundwater Level (m)	h_2 (m)
0	0.00	0.82	9.60	0	0.00	0.39	8.00	0.00	0.69	8.00
2	2.60	3.42	9.60	2	0.61	1.00	7.39	0.30	0.99	7.70
3	3.08	3.90	9.60	3	0.91	1.30	7.09	0.53	1.22	7.47
4	3.12	3.94	9.60	4	0.91	1.30	7.09	0.54	1.23	7.46
5	2.41	3.23	8.50	5	0.74	1.13	7.26	0.45	1.14	7.55
6	3.16	3.98	9.00	6	0.94	1.33	7.06	0.56	1.25	7.44
7	3.02	3.84	9.00	7	0.93	1.32	7.07	0.57	1.26	7.43
8	3.26	4.08	9.30	8	0.98	1.37	7.02	0.60	1.29	7.40
9	3.28	4.10	9.00	9	0.99	1.38	7.01	0.61	1.30	7.39
10	3.40	4.22	9.00	10	1.02	1.41	6.98	0.63	1.32	7.37
11	2.95	3.77	9.00	11	0.92	1.31	7.08	0.59	1.28	7.41
12	3.25	4.07	8.80	12	1.01	1.40	6.99	0.64	1.33	7.36
13	3.19	4.01	9.50	13	0.99	1.38	7.01	0.65	1.34	7.35
14	3.18	4.00	9.60	14	1.00	1.39	7.00	0.65	1.34	7.35
15	3.19	4.01	9.60	15	1.00	1.39	7.00	0.65	1.34	7.35
16	3.30	4.12	9.00	16	1.03	1.42	6.97	0.66	1.35	7.34

Continue pumping test result in Kabong

Time (hr)	test well			Time (hr)	Observation well 1, r_1 = 5m			Observation well 2, r_2 = 10m		
	Drawdown (m)	Groundwater Level (m)	Discharge $m^3 h^{-1}$		Drawdown (m)	Groundwater Level (m)	h_1 (m)	Drawdown(m)	Groundwater Level (m)	h_2 (m)
17	3.38	4.20	9.30	17	1.05	1.44	6.95	0.68	1.37	7.32
18	3.35	4.17	8.60	18	1.07	1.46	6.93	0.69	1.38	7.31
19	3.36	4.18	9.00	19	1.06	1.45	6.94	0.68	1.37	7.32
20	3.36	4.18	8.50	20	1.07	1.46	6.93	0.70	1.39	7.30
21	3.35	4.17	8.80	21	1.06	1.45	6.94	0.70	1.39	7.30
22	3.38	4.20	8.50	22	1.08	1.47	6.92	0.71	1.40	7.29
23	3.31	4.13	9.20	23	1.09	1.48	6.91	0.71	1.40	7.29
24	3.31	4.13	9.00	24	1.08	1.47	6.92	0.71	1.40	7.29
25	3.44	4.26	8.60	25	1.12	1.51	6.88	0.73	1.42	7.27
27	3.33	4.15	8.00	27	1.10	1.49	6.90	0.72	1.41	7.28
29	2.94	3.76	9.00	29	1.05	1.44	6.95	0.67	1.36	7.33
31	3.08	3.90	8.40	31	1.05	1.44	6.95	0.68	1.37	7.32
33	2.93	3.75	8.40	33	1.07	1.46	6.93	0.68	1.37	7.32
35	3.30	4.12	8.60	35	1.05	1.44	6.95	0.68	1.37	7.32
37	3.13	3.95	8.70	37	0.87	1.26	7.13	0.49	1.18	7.51
39	3.19	4.01	9.10	39	0.89	1.28	7.11	0.51	1.20	7.49
41	3.24	4.06	9.60	41	0.91	1.30	7.09	0.53	1.22	7.47

Continue pumping test result in Kabong

Time (hr)	test well			Time (hr)	Observation well 1, r_1 = 5m			Observation well 2, r_2 = 5m		
	Drawdown (m)	Groundwater Level (m)	Discharge $m^3 h^{-1}$		Drawdown (m)	Groundwater Level (m)	h_1 (m)	Drawdown(m)	Groundwater Level (m)	h_2 (m)
43	3.15	3.97	9.00	43	0.88	1.27	7.12	0.51	1.20	7.49
45	3.10	3.92	9.20	45	0.79	1.18	7.21	0.34	1.03	7.66
47	3.01	3.83	9.20	47	0.75	1.14	7.25	0.34	1.03	7.66
49	3.08	3.90	9.00	49	0.77	1.16	7.23	0.35	1.04	7.65
50	0.06	0.76	9.00	50	0.09	0.30	7.91	0.16	0.53	7.84
51	0.11	0.71	9.00	51	0.12	0.27	7.88	0.14	0.55	7.86
52	0.12	0.70	9.00	52	0.13	0.26	7.87	0.15	0.54	7.85
53	0.13	0.69	9.00	53	0.13	0.26	7.87	0.15	0.54	7.85
54	0.13	0.69	9.00	54	0.13	0.26	7.87	0.14	0.55	7.86
55	0.13	0.69	9.00	55	0.13	0.26	7.87	0.14	0.55	7.86
56	0.13	0.69	9.00	56	0.13	0.26	7.87	0.13	0.56	7.87
57	0.13	0.69	9.00	57	0.12	0.27	7.88	0.13	0.56	7.87
58	0.13	0.69	9.00	58	0.14	0.25	7.86	0.13	0.56	7.87
59	0.12	0.70	9.00	59	0.14	0.25	7.86	0.13	0.56	7.87
60	0.12	0.70	9.00	60	0.13	0.26	7.87	0.13	0.56	7.87
61	0.12	0.70	9.00	61	0.13	0.26	7.87	0.13	0.56	7.87

Continue pumping test result in Kabong

Time (hr)	test well			Time (hr)	Observation well 1, r_1 = 5m			Observation well 2, r_2 = 5m		
	Drawdown (m)	Groundwater Level (m)	Discharge $m^3 h^{-1}$		Drawdown (m)	Groundwater Level (m)	h_1 (m)	Drawdown(m)	Groundwater Level (m)	h_2 (m)
62	0.11	0.71	9.00	62	0.13	0.26	7.87	0.13	0.56	7.87
63	0.12	0.70	9.00	63	0.13	0.26	7.87	0.13	0.56	7.87
64	0.11	0.71	9.00	64	0.14	0.25	7.86	0.13	0.56	7.87
65	0.12	0.70	9.00	65	0.14	0.25	7.86	0.12	0.57	7.88
66	0.12	0.70	9.00	66	0.13	0.26	7.87	0.12	0.57	7.88
67	0.11	0.71	9.00	67	0.13	0.26	7.87	0.11	0.58	7.89
68	0.11	0.71	9.00	68	0.12	0.27	7.88	0.11	0.58	7.89
69	0.11	0.71	9.00	69	0.12	0.27	7.88	0.11	0.58	7.89
70	0.10	0.72	9.00	70	0.12	0.27	7.88	0.11	0.58	7.89
71	0.10	0.72	9.00	71	0.09	0.30	7.91	0.11	0.58	7.89
72	0.10	0.72	9.00	72	0.09	0.30	7.91	0.11	0.58	7.89
73	0.09	0.73	9.00	73	0.09	0.30	7.91	0.11	0.58	7.89
74	0.09	0.73	9.00	74	0.09	0.30	7.91	0.10	0.59	7.90
76	0.08	0.74	9.00	75	0.08	0.31	7.92	0.09	0.60	7.91
78	0.07	0.75	9.00	76	0.06	0.33	7.94	0.07	0.62	7.93
80	0.07	0.75	9.00	77	0.06	0.33	7.94	0.08	0.61	7.92

Continue pumping test result in Kabong

Time (hr)	test well			Time (hr)	Observation well 1, r_1 = 5m			Observation well 2, r_2 = 5m		
	Drawdown (m)	Groundwater Level (m)	Discharge $m^3 h^{-1}$		Drawdown (m)	Groundwater Level (m)	h_1 (m)	Drawdown(m)	Groundwater Level (m)	h_2 (m)
82	0.06	0.76	9.00	78	0.05	0.34	7.95	0.04	0.65	7.96
84	0.08	0.74	9.00	79	0.06	0.33	7.94	0.06	0.63	7.94
86	0.07	0.75	9.00	80	0.07	0.32	7.93	0.08	0.61	7.92
88	0.07	0.75	9.00	81	0.06	0.33	7.94	0.08	0.62	7.93
90	0.07	0.75	9.00	82	0.07	0.32	7.93	0.07	0.62	7.93
92	0.05	0.77	9.00	83	0.08	0.31	7.92	0.12	0.57	7.88
94	0.06	0.76	9.00	84	0.07	0.32	7.93	0.08	0.61	7.92
96	0.07	0.75	9.00	85	0.07	0.32	7.93	0.08	0.62	7.93

Continue pumping test result in Kabong

Time (hr)	Observation well 3, r_3 = 18.7m			Observation well 4, r_4 = 27.7m		
	Drawdown (m)	Groundwater Level (m)	h_3 (m)	Drawdown (m)	Groundwater Level (m)	h_4 (m)
0	0.00	0.63	8.00	0.00	0.85	8.00
2	0.16	0.79	7.84	0.07	0.92	7.93
3	0.33	0.96	7.67	0.18	1.03	7.82
4	0.34	0.97	7.66	0.17	1.02	7.83
5	0.29	0.92	7.71	0.15	1.00	7.85
6	0.36	0.99	7.64	0.19	1.04	7.81
7	0.37	1.00	7.63	0.19	1.04	7.81
8	0.39	1.02	7.61	0.18	1.03	7.82
9	0.40	1.03	7.60	0.22	1.07	7.78
10	0.41	1.04	7.59	0.23	1.08	7.77
11	0.39	1.02	7.61	0.22	1.07	7.78
12	0.42	1.05	7.58	0.24	1.09	7.76
13	0.42	1.05	7.58	0.24	1.09	7.76
14	0.43	1.06	7.57	0.24	1.09	7.76
15	0.44	1.07	7.56	0.25	1.10	7.75
16	0.45	1.08	7.55	0.26	1.11	7.74
17	0.46	1.09	7.54	0.26	1.11	7.74
18	0.46	1.09	7.54	0.27	1.12	7.73
19	0.45	1.08	7.55	0.27	1.12	7.73
20	0.47	1.10	7.53	0.27	1.12	7.73
21	0.46	1.09	7.54	0.25	1.10	7.75
22	0.48	1.11	7.52	0.28	1.13	7.72
23	0.49	1.12	7.51	0.29	1.14	7.71
24	0.49	1.12	7.51	0.29	1.14	7.71
25	0.50	1.13	7.50	0.29	1.14	7.71
27	0.49	1.12	7.51	0.29	1.14	7.71
29	0.47	1.10	7.53	0.28	1.13	7.72
31	0.49	1.12	7.51	0.29	1.14	7.71
33	0.48	1.11	7.52	0.29	1.14	7.71
35	0.50	1.13	7.50	0.27	1.12	7.73
37	0.23	0.86	7.77	0.05	0.90	7.95
41	0.27	0.90	7.73	0.09	0.94	7.91
43	0.23	0.86	7.77	0.10	0.95	7.90

Continue pumping test result in Kabong

Time (hr)	Observation well 3, r_3 = 15m			Observation well 4, r_4 = 20m		
	Drawdown (m)	Groundwater Level (m)	h_3 (m)	Drawdown (m)	Groundwater Level (m)	h_4 (m)
45	0.15	0.78	7.85	0.06	0.79	7.94
47	0.12	0.75	7.88	0.10	0.75	7.90
41	0.27	0.90	7.73	0.09	0.94	7.91
49	0.14	0.77	7.86	0.06	0.79	7.94
50	0.14	0.49	7.86	0.17	0.68	7.83
51	0.14	0.49	7.86	0.17	0.68	7.83
52	0.14	0.49	7.86	0.17	0.68	7.83
53	0.14	0.49	7.86	0.17	0.68	7.83
54	0.15	0.48	7.85	0.15	0.70	7.85
55	0.14	0.49	7.86	0.15	0.70	7.85
56	0.14	0.49	7.86	0.15	0.70	7.85
57	0.13	0.50	7.87	0.14	0.71	7.86
58	0.13	0.50	7.87	0.14	0.71	7.86
59	0.13	0.50	7.87	0.13	0.72	7.87
60	0.12	0.51	7.88	0.12	0.73	7.88
61	0.12	0.51	7.88	0.12	0.73	7.88
62	0.12	0.51	7.88	0.12	0.73	7.88
63	0.13	0.50	7.87	0.12	0.73	7.88
64	0.12	0.51	7.88	0.12	0.73	7.88
65	0.11	0.52	7.89	0.11	0.74	7.89
66	0.11	0.52	7.89	0.11	0.74	7.89
67	0.11	0.52	7.89	0.10	0.75	7.90
68	0.10	0.53	7.90	0.09	0.76	7.91
69	0.10	0.53	7.90	0.08	0.77	7.92
70	0.10	0.53	7.90	0.10	0.75	7.90
71	0.10	0.53	7.90	0.09	0.76	7.91
72	0.10	0.53	7.90	0.09	0.76	7.91
73	0.10	0.53	7.90	0.09	0.76	7.91
74	0.09	0.54	7.91	0.08	0.77	7.92
76	0.09	0.54	7.91	0.07	0.78	7.93
78	0.08	0.55	7.92	0.07	0.78	7.93
80	0.07	0.56	7.93	0.06	0.79	7.94

Continue pumping test result in Kabong

Time (hr)	Observation well 3, r_3 = 18.7m			Observation well4, r_4 = 27.7m		
	Drawdown (m)	Groundwater Level (m)	h_3 (m)	Drawdown (m)	Groundwater Level (m)	h_4 (m)
82	0.06	0.57	7.94	0.05	0.80	7.95
84	0.10	0.53	7.90	0.06	0.79	7.94
86	0.10	0.53	7.90	0.06	0.79	7.94
88	0.08	0.55	7.92	0.05	0.80	7.95
90	0.08	0.55	7.92	0.05	0.80	7.95
92	0.11	0.52	7.89	0.06	0.79	7.94
94	0.11	0.52	7.89	0.06	0.79	7.94
96	0.11	0.52	7.89	0.07	0.78	7.93

Appendix 2.1: Hydraulic conductivity and transmissivity result in Kabong

Time (hr)	Hydraulic Conductivity m^2h^{-1}	Transmissivity $m\,h^{-}$
	Groundwater movement from observation well 1 and 2 toward the right side of the pumping well	Groundwater movement from observation well 1 and 2 toward the right side of the pumping well
0	-0.42	-3.40
2	-0.36	-2.87
3	-0.37	-2.95
4	-0.46	-3.70
5	-0.36	-2.88
6	-0.38	-3.04
7	-0.36	-2.90
8	-0.36	-2.90
9	-0.35	-2.84
10	-0.42	-3.32
11	-0.37	-2.99
12	-0.41	-3.25
13	-0.40	-3.16
14	-0.40	-3.16
15	-0.38	-3.00
16	-0.38	-3.01
17	-0.37	-2.94
18	-0.37	-2.93
19	-0.38	-3.02
20	-0.39	-3.10
21	-0.38	-3.02
22	-0.37	-2.94
23	-0.38	-3.02
24	-0.36	-2.88
25	-0.37	-2.95
27	-0.37	-2.93
29	-0.38	-3.01
31	-0.36	-2.86
33	-0.38	-3.01
35	-0.36	-2.86
37	-0.36	-2.86
39	-0.36	-2.87

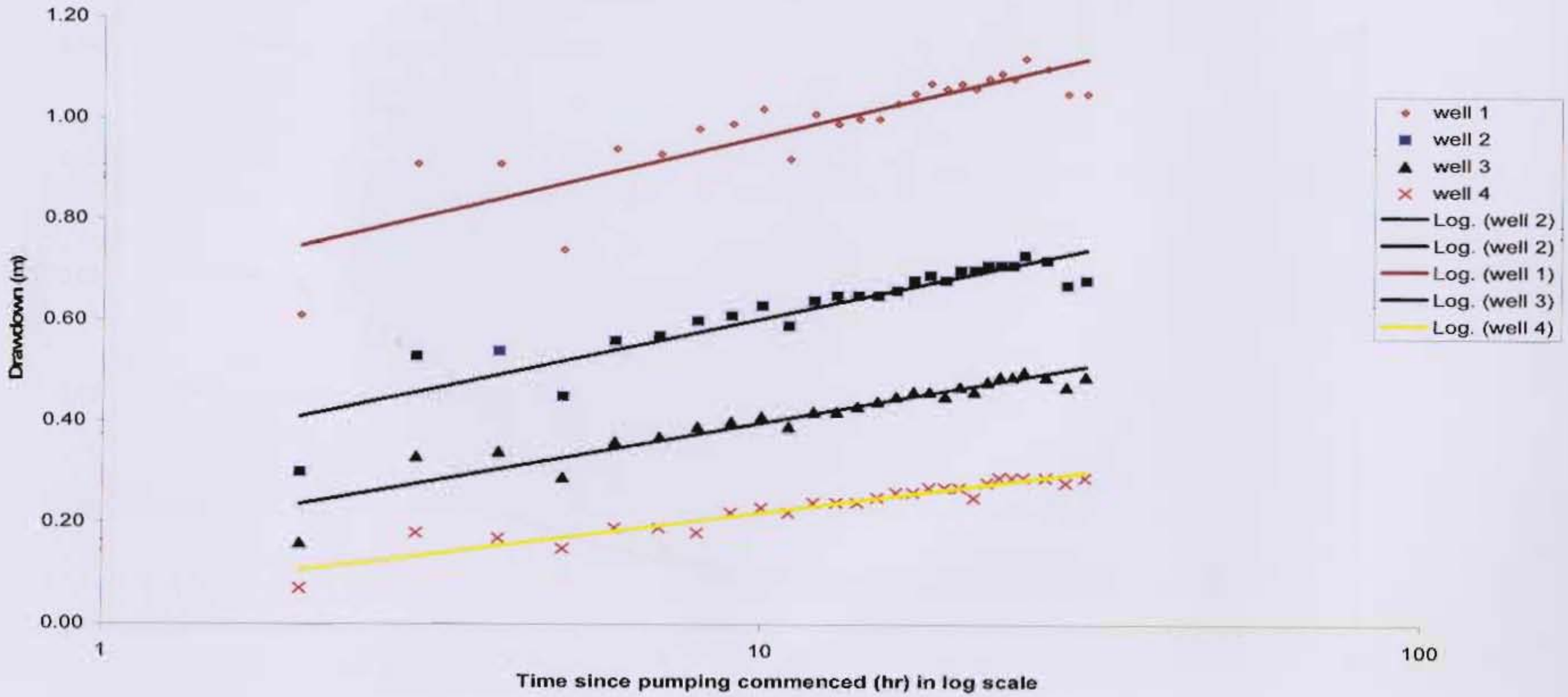
Appendix 2.1Hydraulic conductivity and transmissivity result in Kabong

Time (hr	Hydraulic Conductivity m^2h^{-1}	Transmissivity m h^-
	Groundwater movement from observation well 1 and 2 toward the right side of the pumping well.	Groundwater movement from observation well 1 and 2 toward the right side of the pumping well.
41	-0.37	-2.94
43	-0.30	-2.37
45	-0.32	-2.60
47	-0.32	-2.54
49	1.80	14.41
50	6.31	50.46
51	6.32	50.53
52	6.32	50.53
53	12.62	100.99
54	12.62	100.99
55	0.00	0.00
56	12.61	100.86
57	-12.62	-100.99
58	-12.62	-100.99
59	0.00	0.00
60	0.00	0.00
61	0.00	0.00
62	0.00	0.00
63	-12.62	-100.99
64	-6.31	-50.46
65	-12.61	-100.86
66	-6.30	-50.40
67	-12.59	-100.73
68	-12.59	-100.73
69	-12.59	-100.73
70	6.28	50.27
71	6.28	50.27
72	6.28	50.27
73	12.56	100.48

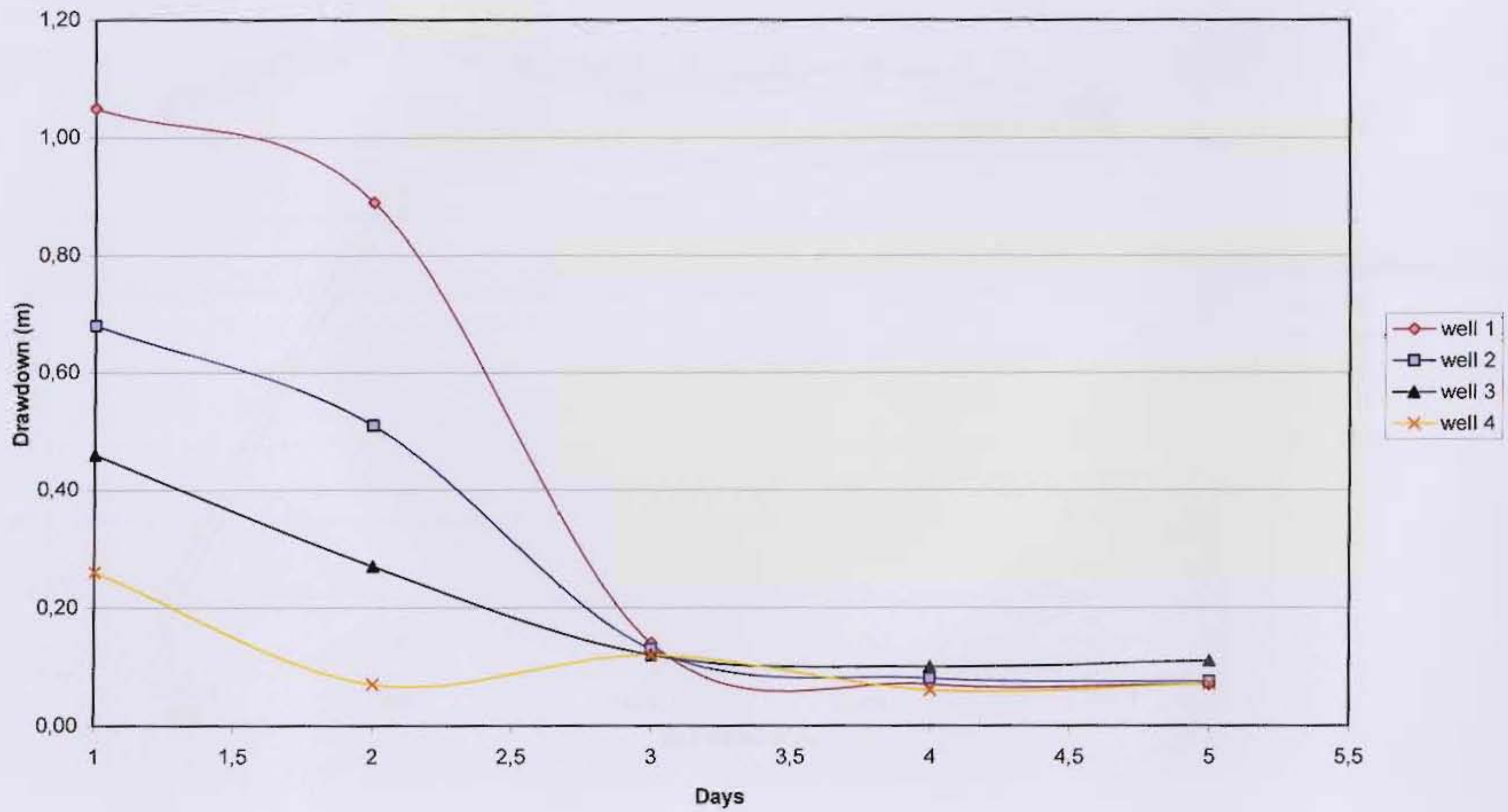
Appendix 2.1: Hydraulic conductivity and transmissivity result in Kabong

Time (hr	Hydraulic Conductivity m^2h^{-1}	Transmissivity m h^-
	Groundwater movement from observation well 1 and 2 toward the right side of the pumping well	Groundwater movement from observation well 1 and 2 toward the right side of the pumping well
74	12.54	100.35
76	12.51	100.10
78	6.26	50.08
80	-12.48	-99.85
82	0.00	0.00
84	12.53	100.23
86	6.26	50.08
88	0.00	0.00
90	3.14	25.14
92	12.53	100.23
94	12.53	100.23

Appendix 2.2: Time vs Drawdown of each well for five days of pumping test located at Kabong (log scale).



Appendix 2.3:Changes of drawdown through five days of pumping test in Kabong.



Appendix 2.4: Changes at water levels through 5 days of pumping test in Kabong.