ลักษณะทางอุทกธรณีวิทยาของชั้นน้ำบาดาลบริเวณศูนย์ศึกษาการพัฒนาห้วยทรายอันเนื่องมาจากพระราชดำริและบริเวณใกล้เคียง อำเภอชะอำ จังหวัดเพชรบุรี

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ปีการศึกษา 2554

HYDROGEOLOGIC CHARACTERISTICS OF AQUIFERS IN HUAY SAI ROYAL DEVELOPMENT STUDY CENTER AND ADJACENT AREAS, AMPHOE CHA-AM, CHANGWAT PHETCHABURI

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A REPORT IN PARTIAL FULFILLMENT OF THE REQUIREMENT
FOR THE DEGREE OF THE BACHELOR SCIENCE
DEPARTMENT OF GEOLOGY, FACULTY OF SCIENCE
CHULALONGKORN UNIVERSITY
2011

Date of submit......./...../.....

Date of approval......./...../.....

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(Dr.Srilert Chotpantarat)

Senior Project Advisor

ลักษณะทางอุทกธรณีวิทยาบริเวณศูนย์ศึกษาการพัฒนาห้วยทรายอันเนื่องมาจากพระราชดำริและบริเวณใกล้เคียง อำเภอชะอำ จังหวัดเพชรบุรี

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บทคัดย่อ

พระบาทสมเด็จพระเจ้าอยู่หัวภูมิพลอดุลยเดชมหาราชทรง พระราชทานพระราชดำริให้จัดตั้งศูนย์ศึกษาการพัฒนาห้วยทรายอันเนื่องมาจากพระราชดำริ เพื่อเป็นแบบอย่างในการพัฒนาพื้นที่เสื่อมโทรมในภาคตะวันตก อย่างไรก็ตาม ปัญหาในด้านการขาดแคลนน้ำใช้ในการอุปโภคบริโภคยังคงมีอยู่ โดยเฉพาะในฤดูแล้ง

พื้นที่ศึกษาอยู่ในพื้นที่ตำบลสามพระยา ตำบลห้วยทรายเหนือและตำบลไร่ใหม่พัฒนา อำเภอชะอำ จังหวัดเพชรบุรี วัตถุประสงค์ของการศึกษาในครั้งนี้คือ เพื่อสำรวจและศึกษาลักษณะทางอุทกธรณีวิทยาของชั้นน้ำบาดาล ตลอดจนสร้างแบบจำลองเชิงมโนทัศน์ในพื้นที่ศึกษา จากการศึกษาพบว่า มีชั้นน้ำที่มีความสามารถในการให้น้ำบาดาลจำนวน 3 ชั้น ได้แก่ ชั้นน้ำที่ราบลุ่มน้ำหลากและตะกอนเศษหินเชิงเขา (Qfd), ชั้นน้ำหินตะกอนกึ่งแปร อายุเพอร์เมียน-คาร์บอนิฟอรัส (PCms)และชั้นน้ำหินแกรนิต (Gr) ชั้นน้ำที่ราบลุ่มน้ำหลากและตะกอนเศษหินเชิงเขา และชั้นน้ำหินตะกอนกึ่งแปรอายุ เพอร์เมียน -คาร์บอนิ เฟอรัส มีทิศทางการไหลจากทางทิศตะวันตกเฉียงใต้ไปยังทิศตะวันออกเฉียงเหนือ บางบริเวณแสดงการลดระดับน้ำรูปกรวย (Cone of depression) เนื่องจากการสูบใช้น้ำเพื่อการเกษตรกรรมในปริมาณมาก บริเวณภูเขาทางด้านตะวันตกและตะวันออกของพื้นที่ศึกษาเป็นบริเวณเติมน้ำ (Recharge zone) ส่วนพื้นที่ราบลุ่มตอนกลางเป็นพื้นที่สูญเสียน้ำ (Discharge zone) จากข้อมูลสูบทดสอบ วิธีของนิวแมน (Neuman Method) เหมาะกับชั้นน้ำ ชั้นน้ำที่ราบลุ่มน้ำหลากและตะกอนเศษหินเชิงเขา ส่วนวิธีของไทส์ (Theis Method) เหมาะกับชั้นน้ำหินตะกอนกึ่งอายุแปรเพอร์เมียน -คาร์บอนิเฟอรัสและชั้นน้ำหินแกรนิต จากการวิเคราะห์ค่าสัมประสิทธิ์การจ่ายน้ำ (Transmissivity) ชั้นน้ำตะกอนที่ยังไม่แข็งตัว (มีค่า 61.300-91.400 เมตร ^{2} /วัน) มีศักยภาพในการให้น้ำบาดาลสูงกว่า ชั้นน้ำหินตะกอนกึ่งแปร อายุเพอร์เมียน -คาร์บอนิ เฟอรัส (มีค่า 1.840-9.520 เมตร ^{2} /วัน) และชั้นน้ำหินแกรนิต (มีค่า 0.218-10.000 เมตร ^{2} /วัน) น้ำบาดาลที่พบจัดเป็นน้ำบาดาลประเภทแคลเซียม-ไบคาร์บอเนต ($Ca-HCO_3$) โซเดียม-ไบคาร์บอเนต ($Na-HCO_3$) แคลเซียม-โซเดียม-ไบคาร์บอเนต ($Ca-Na-HCO_3$) และแคลเซียม-โซเดียม-ไบคาร์บอเนต-คลอไรด์ ($Ca-Na-HCO_3-Cl$) น้ำบาดาลดังกล่าวมีความกระด้างที่ไม่เกินมาตรฐานสำหรับการบริโภค แต่ควรทำการต้มเพื่อปรับปรุงคุณภาพ

HYDROGEOLOGIC CHARACTERISTICS OF AQUIFERS IN HUAY SAI ROYAL DEVELOPMENT STUDY CENTER AND ADJACENT AREAS, AMPHOE CHA-AM, CHANGWAT PHETCHABURI

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ABSTRACT

His Majesty King Bhumibol Adulyadej initated to establish Huay Sai Royal Development Study Center as a demonstrated area of deteriorated western area. However, the area still faces lack of water in drought season.

The study area is located in Tambon Sam Phraya, Tambon Huay Sai Nua and Tambon Rai Mai Phattana, Amphoe Cha-am, Changwat Phetchaburi. The aims of this study were to explain the hydrogeologic characteristics of aquifers and to create the conceptual model of groundwater and hydrogeologic systems. The results showed that there are three types of aquifer in the study area: floodplain deposits aquifer (Qfd), Permo-Carboniferus metasedimentary aquifer (PCms) and granitic aquifer (Gr). Main groundwater direction of both of aquifers (Qfd and PCms) flow from south-western to north-eastern area. Some areas are found cones of depression due to intensive pumping for agricultural purposes. As a result, the mountainous area in western and eastern areas are the recharge zone and central floodplain is discharge zone. From pumping test analysis, Neuman Method is consistent with Qfd aquifer and Theis Method is consistent with PCms and Gr aquifers. According to transmissitvity, yield potential in Qfd aquifer (ranged from 61.300-91.400 m^2/d) is better than both of PCms (ranged from 1.840-9.520 m^2/d) and Gr aquifers (ranged from 0.218-10.000 m^2/d). Furthermore, water types in study area are calcium-bicarbonate ($Ca\text{-}HCO_3$), sodium-bicarbonate ($Na\text{-}HCO_3$), calcium-sodium-bicarbonate ($Ca\text{-}Na\text{-}HCO_3$) and calcium-sodium-bicarbonate-chloride ($Ca\text{-}Na\text{-}HCO_3\text{-}Cl$) due to the ion dissolution in Qfd, PCms and Gr Aquifers. The hardness of water is not over than consumption standard, but the water should be treated by boiling.

ACKNOWLEDGEMENTS

This senior project could not be successfully completed without the helping and support from everyone. First and foremost, I would like to express my gratitude to my senior project advisor, Dr.Srilert Chotpantarat, who gave all helpful helping and excellent advice since the project started until successfully completed for almost one year.

My heartiest to Mr.Jaturon Kornkul who heartily helped and suggested me for all Technical Program. Furthermore, I would like to thank Dr.Santi Pailoblee in teaching me for using a program sincerely. The special thanks to Ms.Pobporn Settaprueksa who provided a lot of data from Department of Groundwater Resources' fieldwork, and good advice as well.

Many thanks to all village headmen and officers at Tambon Sam Phraya, Tambon Huay Sai Nua and Tambon Rai Mai Phattana, Amphoe Cha-am, Changwat Phetchaburi, who navigated my team for accession all study area in fieldwork and also Mr.Wanpob from Hauy Sai Royal Development Study Center.

I would like to express my deeply sincerity to all my friends, who gave me all cheerful support and helping, and always be at my side no matter my success or failure.

Finally, my achievement would not be completed without best wish from my family, Mr.Chaiwat Rojborwornwittaya, Mrs.Nittaya Rojborwornwittaya and also Mr.Wassawat Rojborwornwittaya, who gave me all support and cheerful encouragement, not only my senior project, but also all my university time.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

Page

CHAPTER I

INTRODUCTION

1.1 Introduction

Huay Sai was an abundant and plentiful area. There were the forest, river source and water resource for people. Later, the area was intruded and forest was damaged and contaminated by intensively applying agro-chemical substances. The area rapidly deteriorated within a few years. These have caused effects on ecosystem, for examples deteriorated soil, adversely affect on plant growth, lack of rain as a shadow rain area. His Majesty King Bhumibol Adulyadej came in this area to visit people in April 26, 1983. The King had known the trouble in this area and said that "If the area is left, it may finally become a desert. Hence, the King initiated to establish Huay Sai Royal Development Study Center as a regulation of western deteriorated area.

Huay Sai Royal Development Study Center was located in Tambon Sam Phraya, Amphoe Cha-am, Changwat Phetchaburi. The operated area is located in Tambon Sam Phraya, Tambon Huay Sai Nua and Tambon Rai Mai Phattana, Amphoe Cha-am, Changwat Phetchaburi. The project aims at three objectives as following: 1) natural resources restoring, 2) water resources development and 3) people's life quality development.

Although Huay Sai Royal Development Study Center was established to solve the problems, the area still faces with lacking of water, especially in a drought season. Hence, groundwater is an essential and optional source for both of consumption and agricultural purpose. In some areas, groundwater is used instead of surface water. Some areas use groundwater with surface water. However, groundwater supply is less than water demand in such area. This problem should be clarified by explaining geologic and hydrogeologic characteristics accounting for hydraulic properties of aquifers, hydraulic conductivity, transmissivity of aquifers of groundwater basin underneath this area. In addition, groundwater levels of each aquifer have been measured to describe groundwater flows, which will be used for interpretation groundwater potential. As mentioned, the studying of such characteristics is very significant used as a guideline for alleviation and water resource management.

This project focuses on studying hydrogeologic characteristics of aquifers in Huay Sai Royal Development Study Center and adjacent areas, Amphoe Cha-am, Changwat Phetchaburi by using geologic, topographic, hydrogeologic data to explain the concept model, of hydrogeologic systems. The results will be applied further for developing appropriate guidelines for sustainable resource management.

1.2 Objectives

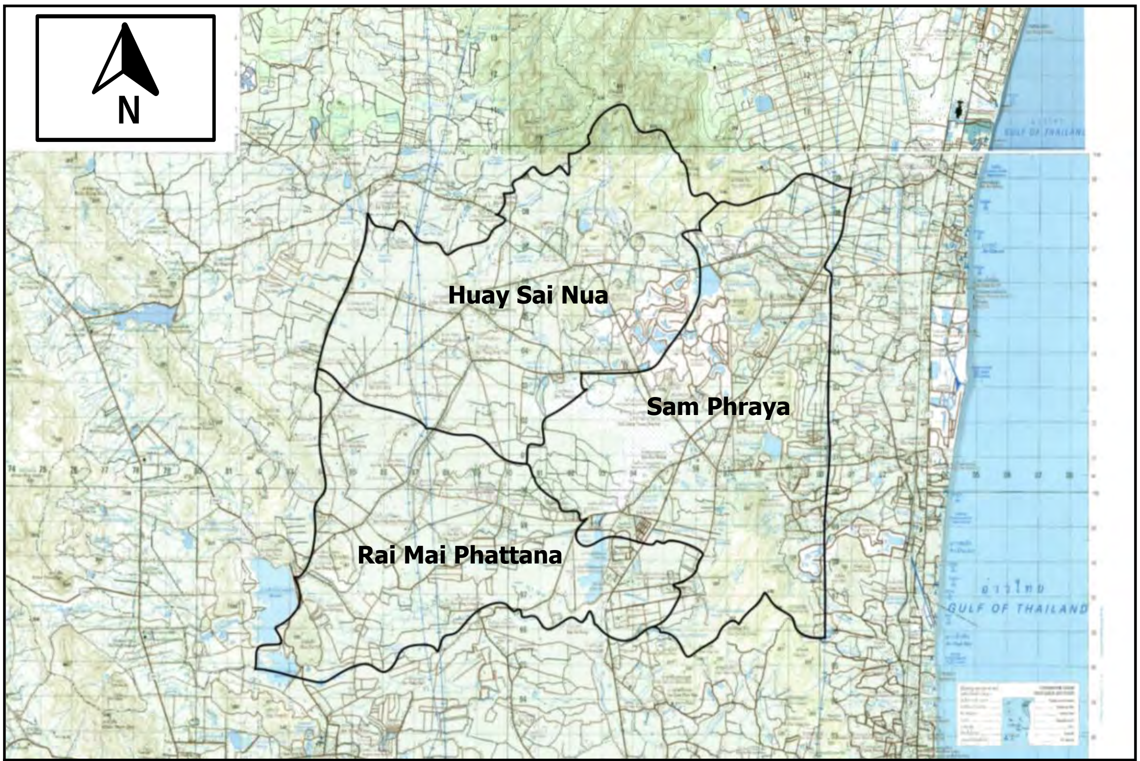
1. To explain the hydrogeologic characteristics of aquifers in Huay Sai Royal Development Study Center and adjacent areas, Amphoe Cha-am, Changwat Phetchaburi.
2. To construct the conceptual model of groundwater and hydrogeologic systems in Huay Sai Royal Development Study Center and adjacent areas, Amphoe Cha-am, Changwat Phetchaburi.

1.3 Scope of Work

1. Geologic data and groundwater level, which derived from the measurement, were used to develop the hydrogeologic conceptual model.
2. Pumping test data, collected by Department of Groundwater Resources (DGR), was used to evaluate aquifers' properties in Huay Sai Royal Development Study Center and adjacent areas, Amphoe Cha-am, Changwat Phetchaburi.

1.4 Study Area

Huay Sai Royal Development Study Center and adjacent areas cover Tambon Sam Phraya, Tambon Huay Sai Nua and Tambon Rai Mai Phattana, Amphoe Cha-am, Changwat Phetchaburi, or approximately 205 square kilometers. The area is located in topographic map scale 1:50,000, series L7018, map sheet 4934 I, 4934 II and 4934III.



Derived from THAILAND 1:50,000 WGS 84
SERIES L 7018 SHEET 4934 I, 4934 II, 4934 III

Figure 1.1 Study area map

1.5 Expected Outputs

1. Hydrogeologic characteristics of aquifers in Huay Sai Royal Development Study Center and adjacent areas, Amphoe Cha-am, Changwat Phetchaburi.
2. The conceptual model of aquifers in Huay Sai Royal Development Study Center and adjacent areas, Amphoe Cha-am, Changwat Phetchaburi.

CHAPTER II

LITERATURE AND THEORY

2.1 Literature Review

Department of Groundwater Resources and GMT Corporation Limited (2001) studied and published a user manual of groundwater map of Phetchaburi province on 1:100,000 scale. According to this study, three types of aquifers were found as follow: unconsolidated, semi-consolidated and consolidated aquifers, in Phetchaburi Province.

I. Unconsolidated Aquifers can be divided into two hydrogeologic units.

- Beach Sand Aquifer of Quaternary Age (Qbs) which has a depth of 5-8 meters from surface and mostly found in the coast of Amphoe Cha-am.

- Floodplain Deposits and Colluvial Deposited Aquifer of Quaternary Age (Qfd) which has a depth of 24-50 meters from surface and mostly found in the east of Phetchaburi.

II. Semiconsolidated Aquifers consist of Tertiary Rocks which has a depth of 18-24 meters from surface and slightly distribute in the southern Phetchaburi.

III. Consolidated Aquifers can be divided into three hydrogeological units.

- Permian Limestone Aquifer (Pc) which has a depth of 18-24 meters from surface and mostly found in the south-east of Amphoe Kaeng Krachan.

- Permian-Carboniferous Metasedimentary Aquifer (PCms) which has a depth of 20-35 meters from surface and mostly found in Phetchaburi.

- Granitic Aquifer (Gr) which has a depth of 25-30 meters from surface and mostly found in the western and eastern mountain.

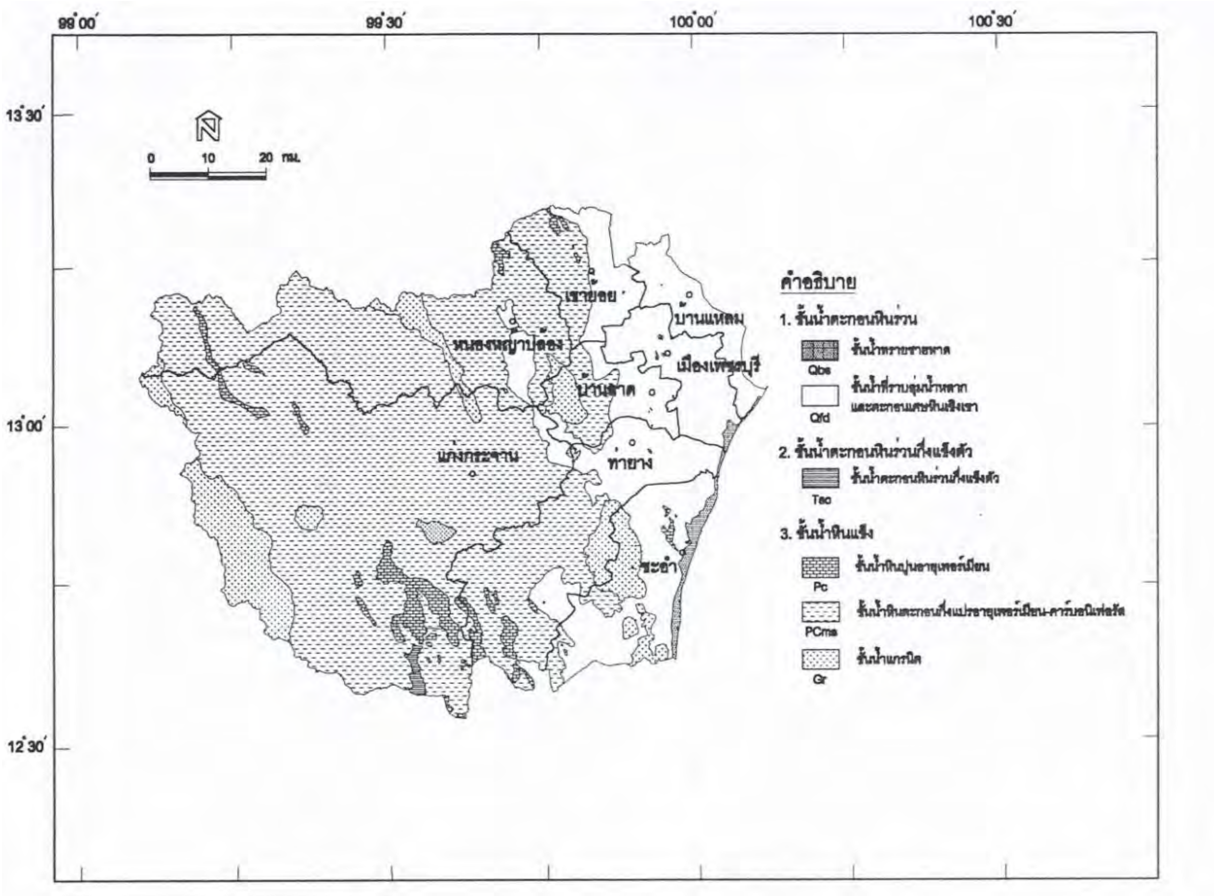


Figure 2.1 Groundwater Map of Phetchaburi Province (DGR and GMT Co.Ltd., 2001)

Jiamjarasrangsi (2010) studied hydrogelogic and hydrogeochemical characteristics of aquifers in Amphoe Phankratai, Changwat Kampangphet by using borehole logging, geophysics data, pumping test data and hydrogeochemical properties of groundwater. All of data were analyzed and proceeded to construct conceptual model in the area. From interpretation, the model showed that aquifer classification can be divided into three main aquifer units as below:

I. Younger Terrace Deposits Aquifer (Qyt)

II. Old Terrace Deposits Aquifer (Qot)

III. Silurian-Devonion Metamorphic Aquifer (SDmm)

From the aquifers classification, two hydrogeologic cross-sections were created

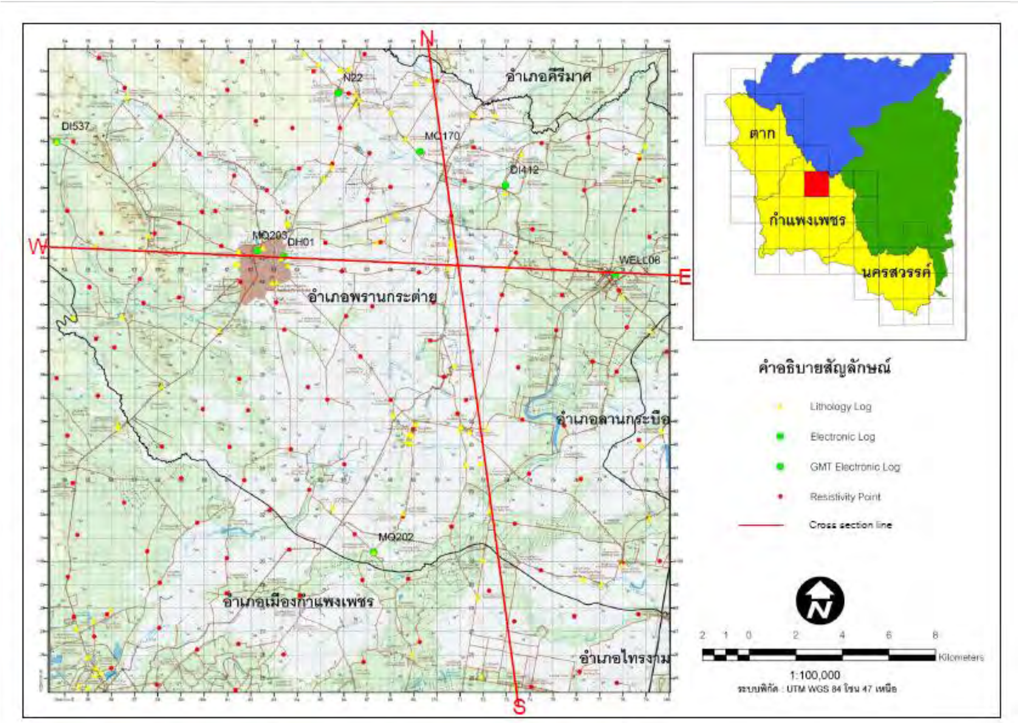


Figure 2.2 Hydrogeologic cross-sections along Amphoe Phankratai (Jiamjarasrangsi, 2010)

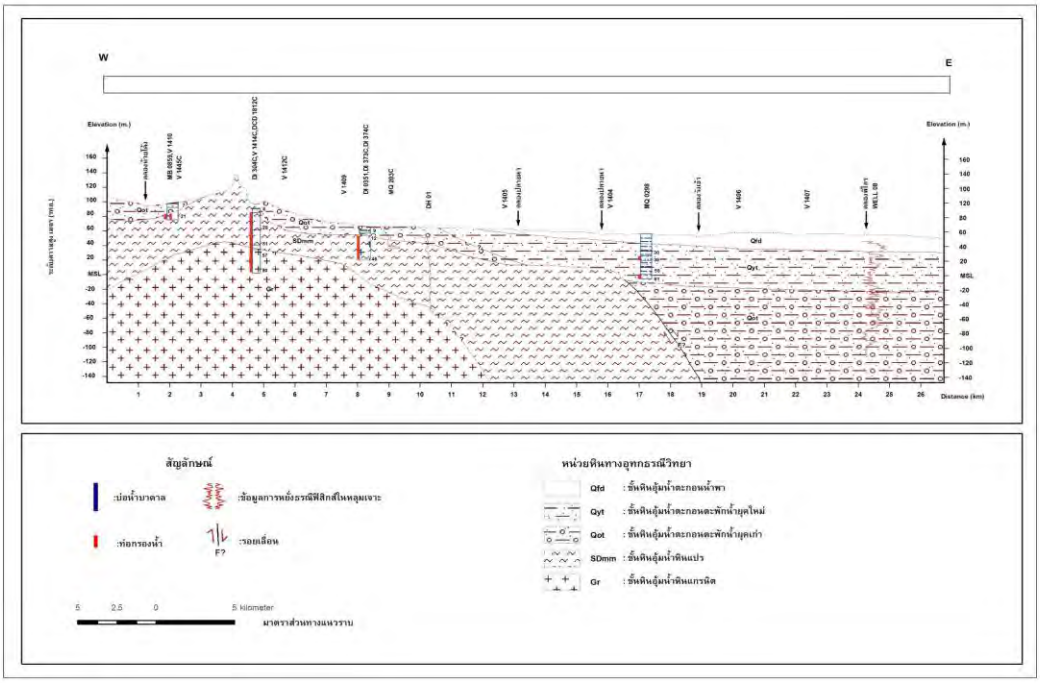


Figure 2.3 Hydrogeologic cross-sections along the western-eastern line (Jiamjarasrangsi, 2010)

Moreover, pumping test analysis was carried out. The groundwater level of pumping wells and observation wells were used, associated with pumping rates, time and recovery level. The analysis proceeded with Aquifer Test Program (Version 2.5). There are various methods to analyze pumping data, such as Theis, Cooper-Jacob, Hantush method and Theis Jacob Recovery method. After processing, the program provided Transmissivity (T), Hydraulic conductivity (K) and coefficient of storage (S). The results were applied to appropriately develop groundwater management plan.

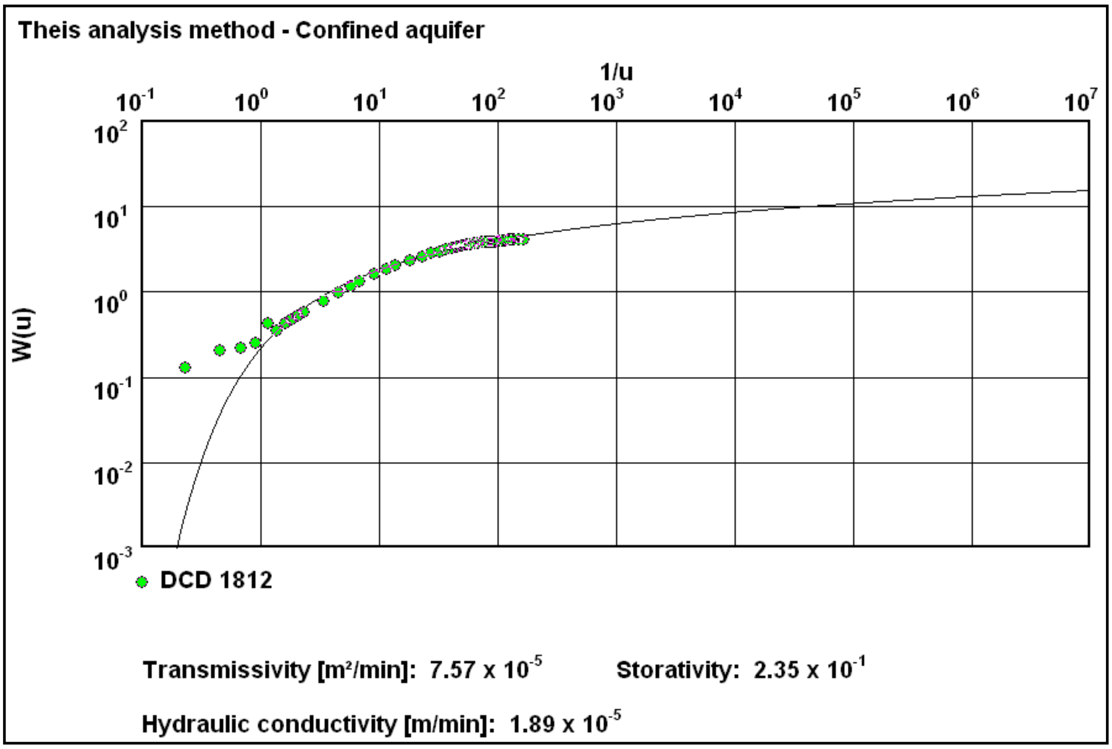


Figure 2.4 Theis analysis Method of Confined aquifer by using Aquifer Test Program, Version 2.5 (Jiamjarasrangsi, 2010)

Jarurat (2008) studied about groundwater in Chiang Mai Basin by processing resistivity survey, rock cutting, bore hole logging and pumping test analysis, associated with geology and background data of Chiang Mai Basin. There are thirteen resistivity lines, thirty-six drilling data and twenty-eight pumping stations for analysis. From interpretation, aquifers in the area can be divided into three units as follow: Chao Phraya Aquifer (Qcp), Chiang Rai Aquifer (Qcr) and Chiang Mai Aquifer (Qcm). These lithologic data is the key of creating hydrogeologic cross-sections, especially borehole logging. The cross-sections were created along Chiang Mai Basin for twelve lines (as showed below). After the evaluation of the pumping test data, the guideline was developed for planning sufficiently and sustainable consumption in the future.

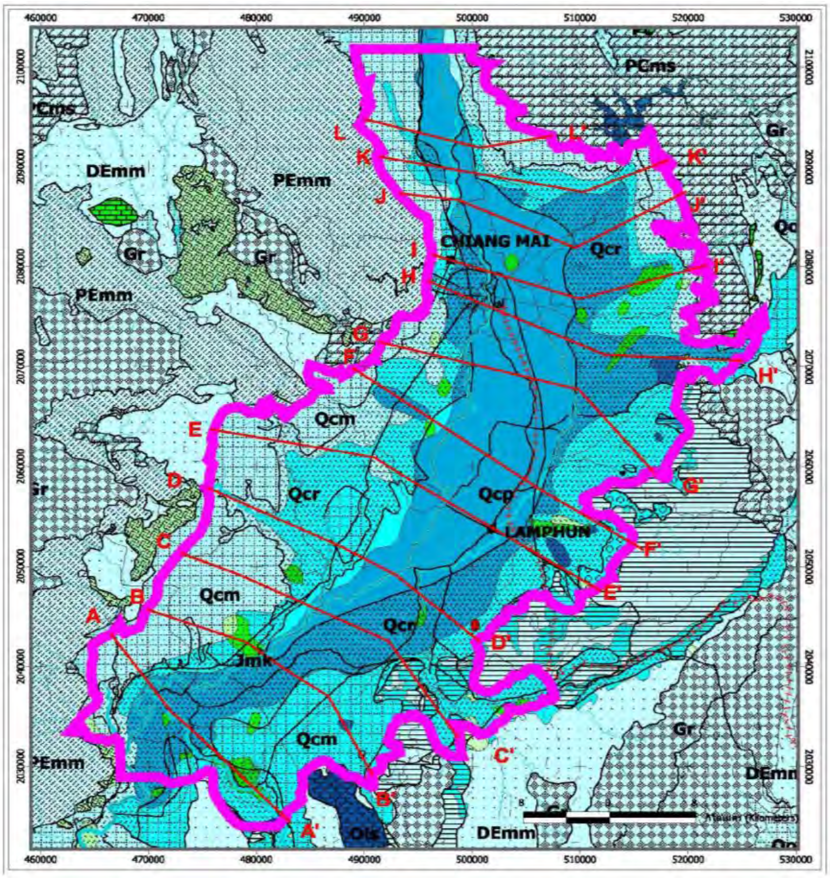


Figure 2.5 Hydrogeologic cross-sections along Chiang Mai Basin (Jarurat, 2008)

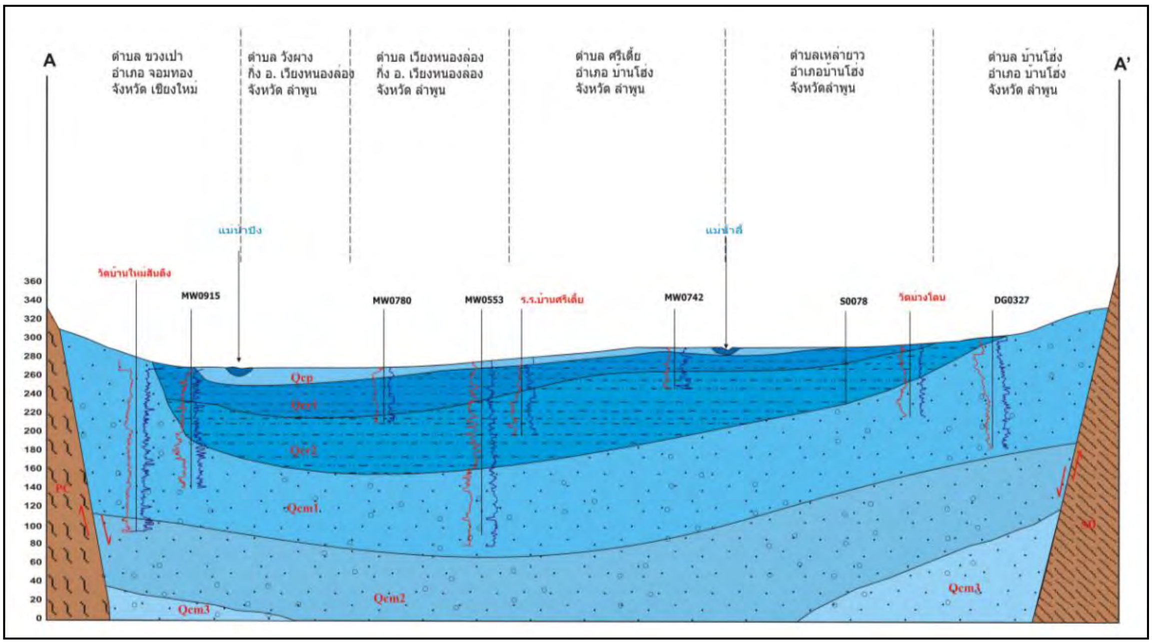


Figure 2.6 Hydrogeologic cross-sections along A-A’ Line (Jarurat, 2008)

Hsieh (2004) studied aquifers classification at Shui-Lin in Taiwan by using bore hole logging and analysis with Fuzzy Lithology System. The system based on mathematics information and mathematic functions. The system also used with general information of the area, geology and geophysics data to provide rocks classification. The results showed that this method can provide better aquifers classification than the others and the accuracy is higher than 95%. If the system is used with borehole logging, the results will be very well.

Krasny and Sharp (2007) studied hydrogeologic characteristics of large-scale fracture, specific characteristic fracture. Also, evaluating hydraulic properties of the fracture from analysis parameters, transmissivity, hydraulic conductivity and permeability. The results showed that the fracture in rocks is a major of groundwater source, yield large quantity of groundwater, also based on climate and geomorphology factors in the area.

Khan (2008) evaluated increased use of groundwater consumption at Indus Basin in Pakistan, for developing and studying guideline for sufficiently and sustainable water consumption. Studied and created groundwater flow direction model of aquifers, found that aquifer in the area are unconfined aquifer. Furthermore, applied the model to explain the relationship between groundwater and surface water, Rechna Doab River. The results also showed the balance of water cycle and were used to develop guideline for conjunctive uses between, groundwater and surface water.

Lachaal (2011) studied hydrogeologic characteristics of complex aquifers at Zeramdine and Mahdia–Jebeniana blocks in the eastern Tunisia. The area related to the geotectonics processes, which effected to the complexity in the area. The studying used geophysics data, seismic data and borehole logging, and created geometric model. The model identified groundwater flow direction of aquifers and Piezometric Surface. All results can also used to apply with the development of people’s quality life.

2.2 Theory

Pumping test

Pumping test is a way to study hydraulic properties of aquifer. In general, pumping test provides hydrogeologic characteristics as follow:

- Hydraulic properties of aquifer as Hydraulic Conductivity (K), Transmissivity (T) and Storativity (S). These mentioned properties are significant for water consumption’s planning and management in the future.
- Efficiency of pumping well, in term of Yield-drawdown characteristics, for choosing the most appropriate pump.
- Effect from groundwater pumping to groundwater system in the area.

There are several methods to analyze pumping test. In general, the important methods are Neuman Method, Theis Method, Cooper&Jacob Method.

1. Neuman Method

$$h_0 - h = \frac{Q}{4\pi T} W(u_A, u_{B,} T) \qquad (2.1)$$

$(h_0 - h) =$ Drawdown ($L; m$ or ft)

$Q =$ Constant pumping rate ($L^3/T; m^3/d$ or ft^3/d)

$T =$ Aquifer transmissivity ($L/T^2; m^2/d$ or ft^2/d)

$r =$ Radial distance from the pumping well ($L; m$ or ft)

$S =$ Aquifer storativity (Dimensionless)

$S_y =$ Aquifer specific yield (Dimensionless)

$t =$ Time since pumping began ($T; d$)

2. Theis Method
   - Create a graph between drawdown $(h_0 - h)$ and time (t). Compare the graph with Type curve graph (graph between $W(u)$ and $1/u$). Choose match point of the graphs (always choose at $W(u)$ and $1/u = 1$).
   - Calculate the result in a formula below.

$$T = \frac{Q}{4\pi(h_0 - h)} W(u) \qquad (2.2)$$

$T =$ Aquifer transmissivity ($L/T^2; m^2/d$ or ft^2/d)

$S =$ Aquifer storativity (Dimensionless)

$Q =$ Constant pumping rate ($L^3/T; m^3/d$ or ft^3/d)

$(h_0 - h) =$ Drawdown ($L; m$ or ft)

$W(u) =$ Well function of u (Dimensionless)

$t =$ Time since pumping began ($T; d$)

$r =$ Radial distance from the pumping well ($L; m$ or ft)

$u =$ Dimensionless constant

3. Cooper&Jacob Method

- Create a graph between drawdown $(h_0 - h)$ and time (t). Choose drawdown with Log cycle of time (always choose time at 10 and 100).
- Calculate the difference of drawdown ($\Delta(h_0 - h)$). Then, calculate the result in a formula below.

$$T = \frac{2.30Q}{4\pi\Delta(h_0 - h)} \qquad (2.3)$$

$T =$ Aquifer transmissivity ($L/T^2; m^2/d$ or ft^2/d)

$Q =$ Pumping rate ($L^3/T; m^3/d$ or ft^3/d)

$\Delta(h_0 - h) =$ Drawdown per log cycle of time ($L; m$ or ft)

$S =$ Storativity (Dimensionless)

$r =$ Radial distance to the well ($L; m$ or ft)

$t_0 =$ Time, where the straight line intersect the zero drawdown axis (T; days)

4. Hantush Method

$$h_0 - h = \frac{Q}{4\pi T} W(u, r/B) \qquad (2.4)$$

$Q =$ Pumping rate ($L^3/T; m^3/d$ or ft^3/d)

$(h_0 - h) =$ Drawdown ($L; m$ or ft)

$T =$ Aquifer transmissivity ($L/T^2; m^2/d$ or ft^2/d)

$W(u, r/B) =$ leaky artesian well function

$r =$ Radial distance from the pumping well ($L; m$ or ft)

$S =$ Aquifer storativity (Dimensionless)

$t =$ Time since pumping began ($T; d$)

Piper Diagram

Piper Diagram is a diagram which is used for hydrogeochemical characteristics analysis. The parameters are Sodium ion (Na^{+}), Magnesium ion (Mg^{2+}), Potassium ion (K^{+}), Chloride ion (Cl^{-}), Sulfate ion (SO_4^{2-}), Nitrate ion (NO_3^{-}), Bicarbonate (HCO_3^{-}) and Carbonate (CO_3^{2-}). These parameters are separated into two groups, cations and anions, and are calculated in percent of milliequivalent per litre. Then, the value will be plotted in the diagram. In the diagram, there are 9 zones of water based on the study of Galloway and Kaiser (1980). The diagram provides type of water as below.

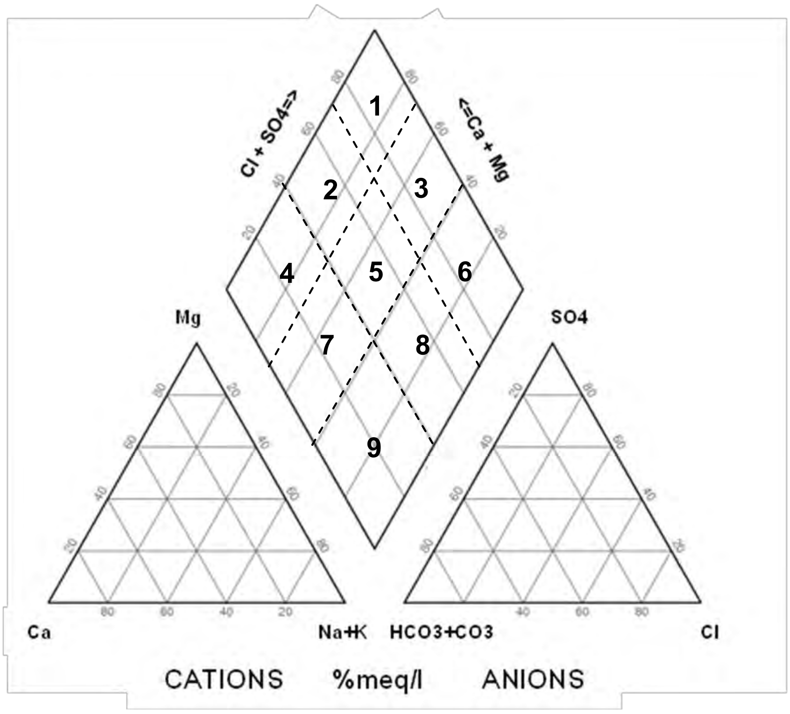


Figure 2.7 Piper Diagram, based on the study of Galloway and Kaiser (1980)

Legends

1 = Calcium Chloride (CaCl)

2 = Calcium Bicarbonate Chloride ($CaHCO_3Cl$)

3 = Calcium-Sodium Chloride (CaNaCl)

4 = Calcium Bicarbonate ($CaHCO_3$)

5 = Calcium-Sodium Bicarbonate Chloride ($CaNaHCO_3Cl$)

6 = Sodium Chloride (NaCl)

7= Calcium-Sodium Bicarbonate ($CaNaHCO_3$)

8 = Sodium Bicarbonate Chloride ($NaHCO_3Cl$)

9 = Sodium Bicarbonate ($NaHCO_3$)

CHAPTER III

METHODOLOGY

3.1 Methodology

1. Review and study previous study and related data

    1.1 Review fundamental information about Huay Sai Royal Development Study Center and adjacent areas, Amphoe Cha-am, Changwat Phetchaburi.

    1.2 Study of literature about principle and methodology of the hydrogeologic characteristics of aquifers' analysis.

2. Review and study geology of the area

    2.1 Collect geologic data from lithologic well logs.

    2.2 Collect geology of the area from geological map.

    2.3 Collect additional data from the other sources, topographic map, land uses map and manual of groundwater map in Changwat Phetchaburi.

3. Fieldwork for data collecting

    3.1 Measure groundwater level by using groundwater level measurement.

    3.2 Locate the position of groundwater wells by using GPS (Global Positioning System).

4. Analysis and process data

    4.1 Analysis and process data from fieldwork, associated with geologic characteristics of study area.

    4.2 Construct the conceptual model.

5. Evaluating hydraulic properties of aquifers from pumping test data.
6. Evaluating hydrogeochemical properties of water by plotting piper diagram.
7. Discussion and conclusion
8. Report writing and presentation

Methodology

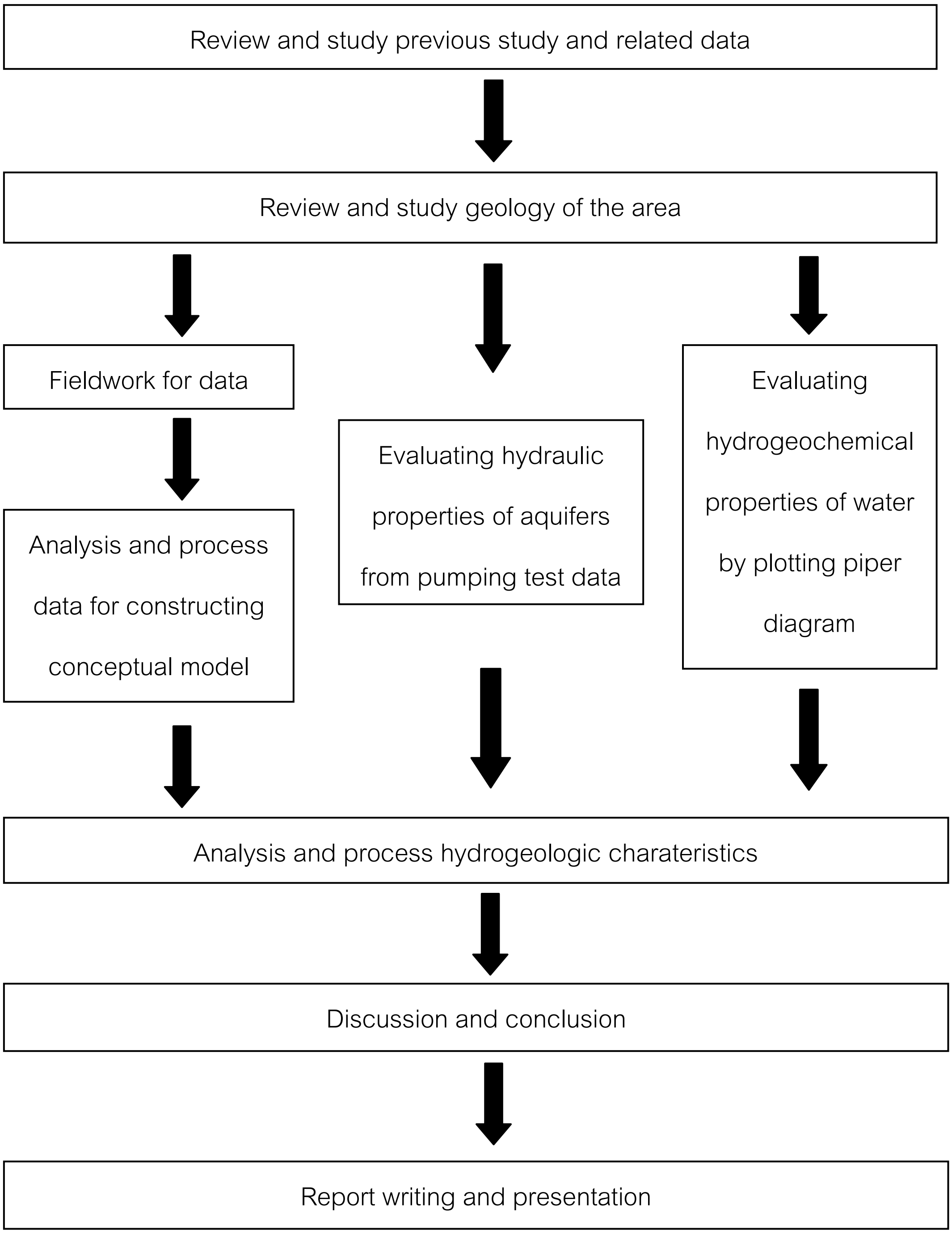


Figure 3.1 Methodology

3.2 Data Acquisition

Data were derived from related literature, geological map, topographic map and land uses map. The lithologic well logs, pumping test data and hydrogeochemical of water sample were derived from Department of Groundwater Resources. Besides, groundwater level data was collected from fieldwork as shown below.

- Data from Department of Groundwater Resources

1. Lithologic well logs which based on cutting analysis
    - There are 120 wells in the study area.
2. Pumping test data which is long-term pumping test, 72 hours.
    - There are 12 wells in the study area.
3. Hydrogeochemical of water contained total dissolved solids (TDS), Sodium ion (Na^{+}), Magnesium ion (Mg^{2+}), Potassium ion (K^{+}), Chloride ion (Cl^{-}), Sulfate ion (SO_4^{2-}), Nitrate ion (NO_3^{-}), Bicarbonate (HCO_3^{-}) and Carbonate (CO_3^{2-}).
    - There are 29 wells in the study area.

- Data from fieldwork

  Groundwater level data from fieldwork

  - Data collected on August 8, 2011 from Tambon Sam Phraya, Tambon Huay Sai Nua and Tambon Rai Mai Phattana Area, there are 20 wells.

  - Data collected on August 9, 2011 from Tambon Huay Sai Nua and Tambon Rai Mai Phattana Area, there are19 wells.

  - Data collected on August 10, 2011 from Tambon Rai Mai Phattana Area, there are 35 wells.

  - Data collected on August 11, 2011 from Tambon Sam Phraya Area, there are 12 wells.

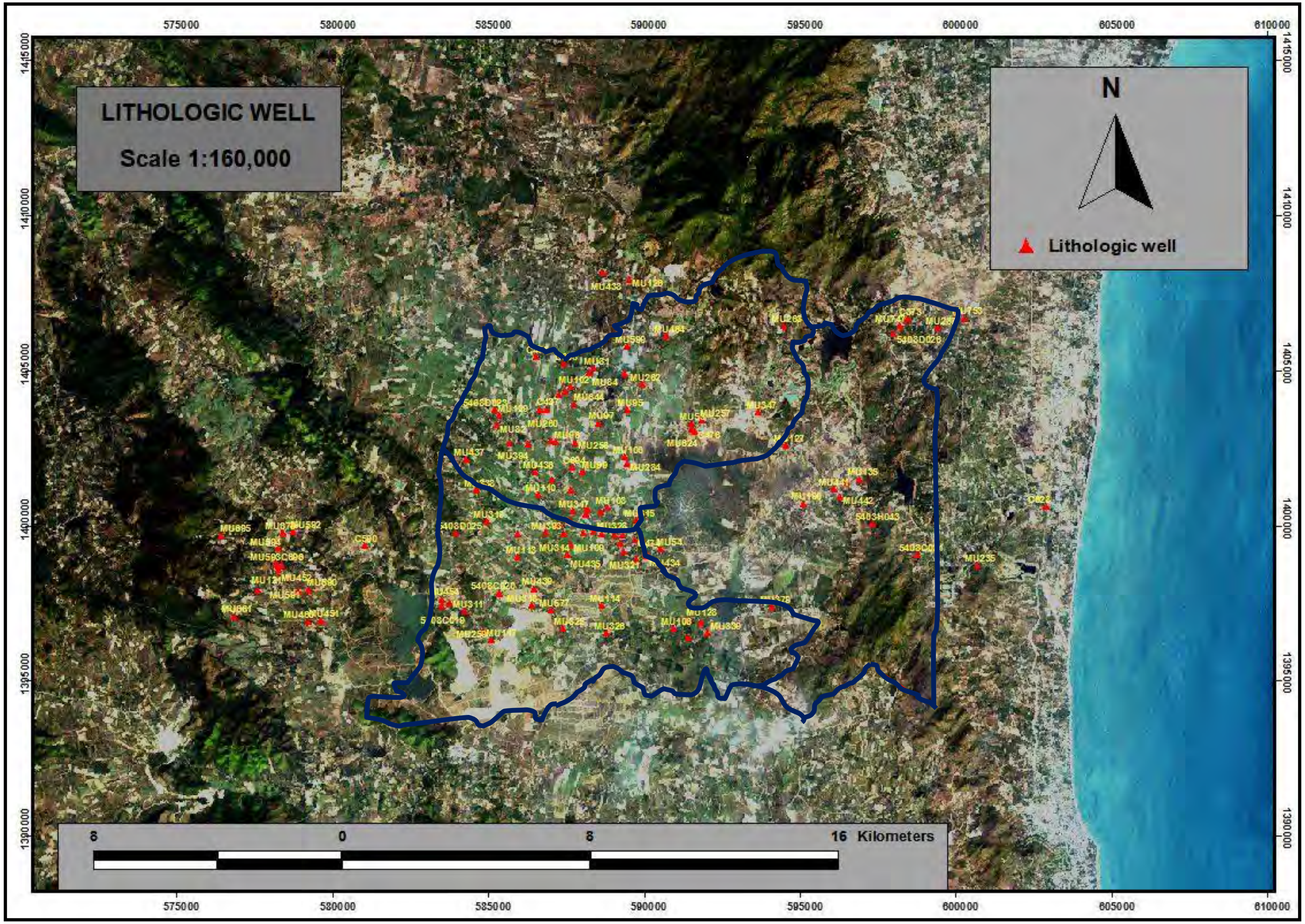


Figure 3.2 Lithilogic well logs map

3.3 Analysis

1. Classify aquifers in the study area by using lithologic well logs, associate with geological map, topographic map and geology of the area and then create hydrogeologic cross-section in several lines. From the cross-sections, aquifers will be divided and the aquifers' distribution will be identified
2. Analyze groundwater level from fieldwork, separate different aquifers and check the accuracy between the cross-sections and the groundwater level. Stimulate groundwater level contour by using Surfer 8 Program.
3. Analyze the cross-sections and groundwater level contour. Then, determine groundwater direction in each aquifer. Furthermore, recharge and discharge zones were identified. Constructing conceptual model by using:
    1. Microsoft Office Visio 2007 Program for two dimensions display.
    2. RockWorks 15 Program for three dimensions display.
4. Evaluate hydraulic properties of each aquifer. The parameters are transmissivity (T) and hydraulic conductivity (K), by using pumping test data associate with Aquifer Test Program (Version 2.5).
5. Evaluate hydrogeochemical of water, based on Sodium ion (Na^{+}), Magnesium ion (Mg^{2+}), Potassium ion (K^{+}), Chloride ion (Cl^{-}), Sulfate ion (SO_4^{2-}), Nitrate ion (NO_3^{-}), Bicarbonate (HCO_3^{-}) and Carbonate (CO_3^{2-}). Then, create piper diagram by using AquaChem 2011.1 Program. Compare the diagrams with Galloway and Kaiser (1980) diagram to identify water type.

CHAPTER IV

RESULTS AND INTERPRETATION

From review of related literature and collect geological map, topographic map, land uses map, lithologic well logs, pumping test data and hydrogeochemical of groundwater samples, the hydrogeologic characteristics of aquifers were interpreted as below:

1. Results and interpretation from lithologic well logs, geological map, topographic map and geology of the area. Hydrogeologic cross-sections were created based on stratigraphic correlation principle. There are four lines: A-A’, B-B’, C-C’ and D-D’. The cross-sections are showed below

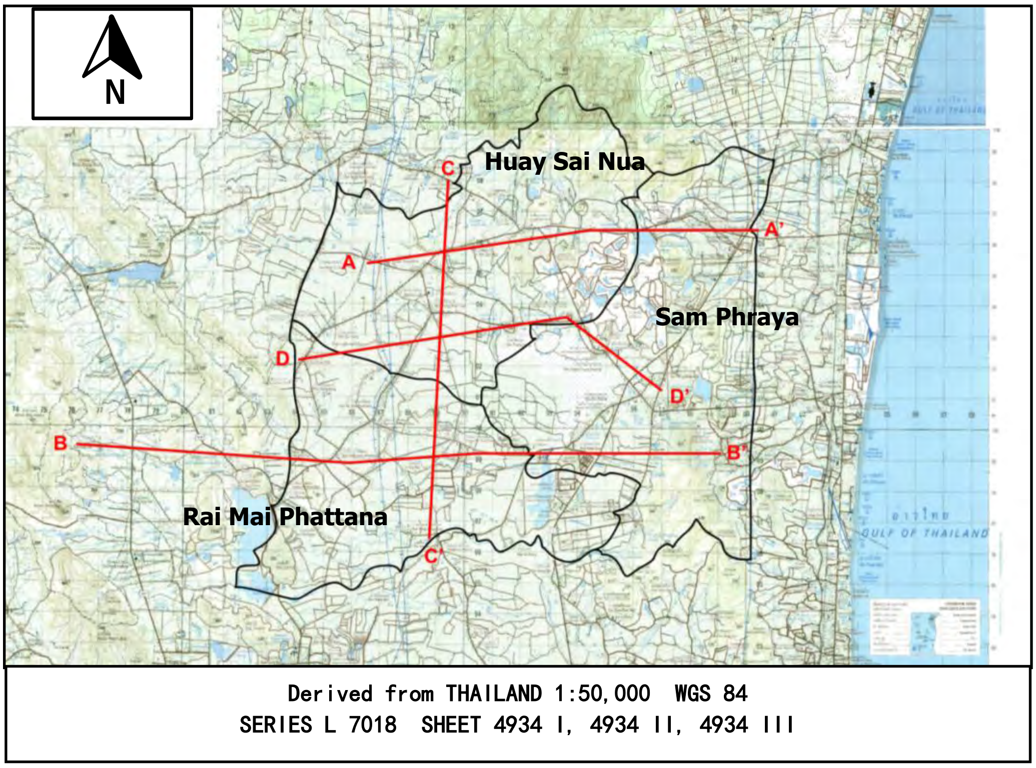
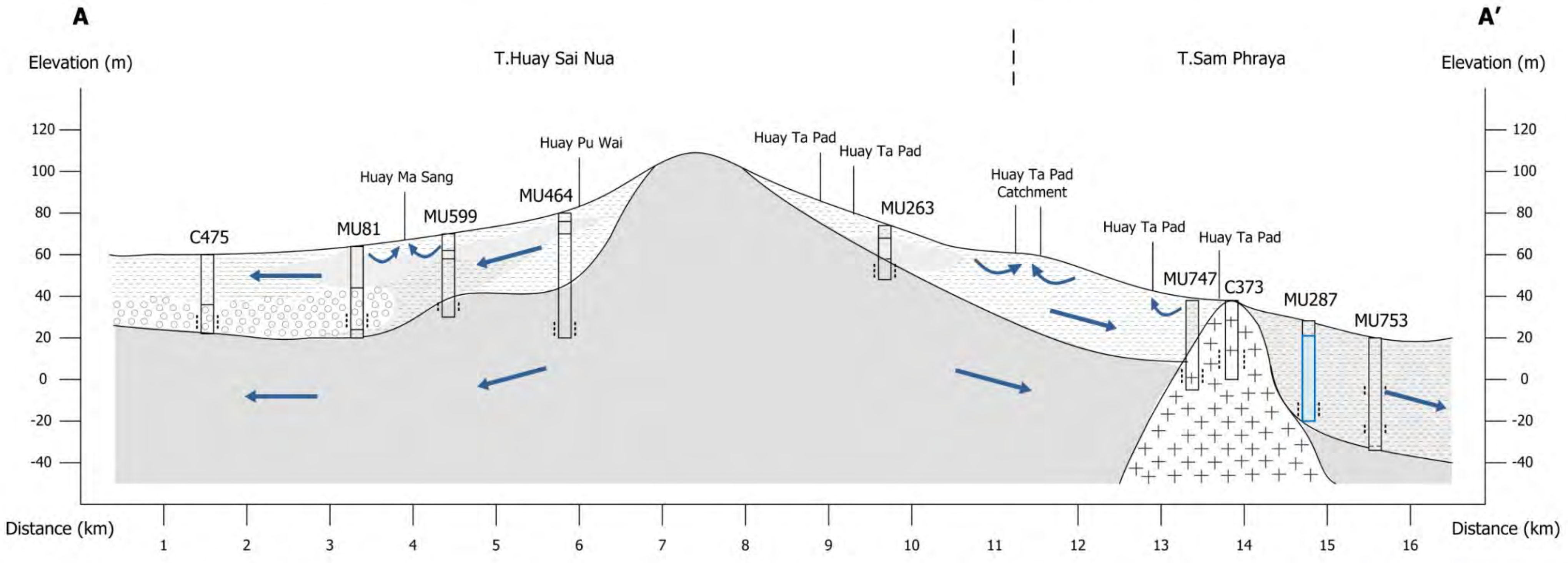
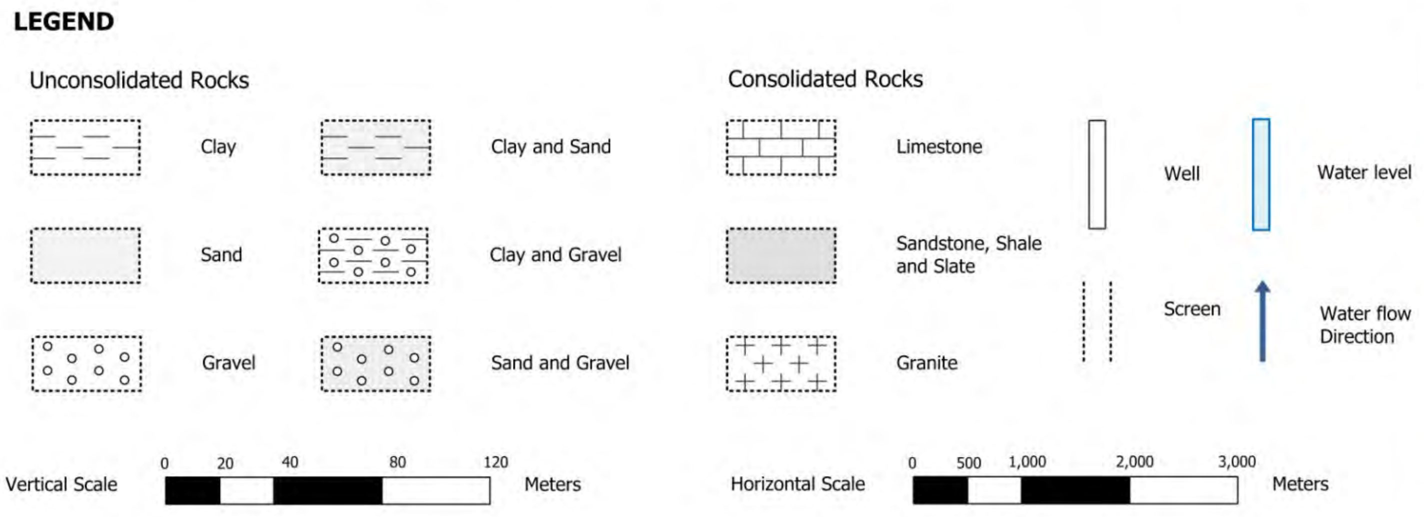


Figure 4.1 Hydrogeologic cross-sections, four lines

Hydrogeologic Cross-Section along A-A' Line, Tambon Huay Sai Nua-Tambon Sam Phraya





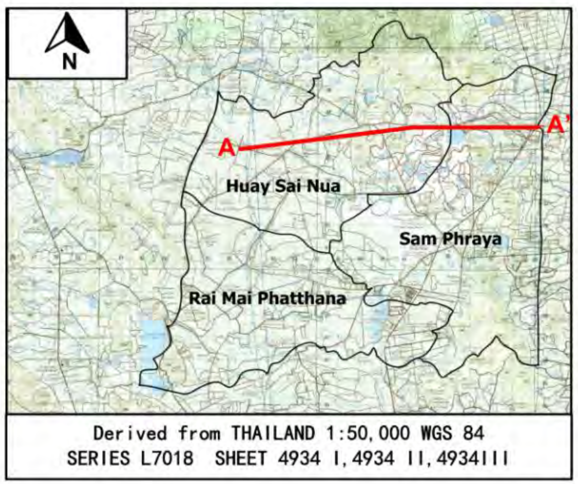


Figure 4.2 Hydrogeologic cross-section along A-A' Line, Tambon Huay Sai Nua-Tambon Sam Phraya

Hydrogeologic Cross-Section along B-B′ Line, Tambon Rai Mai Phatthana-Tambon Sam Phraya

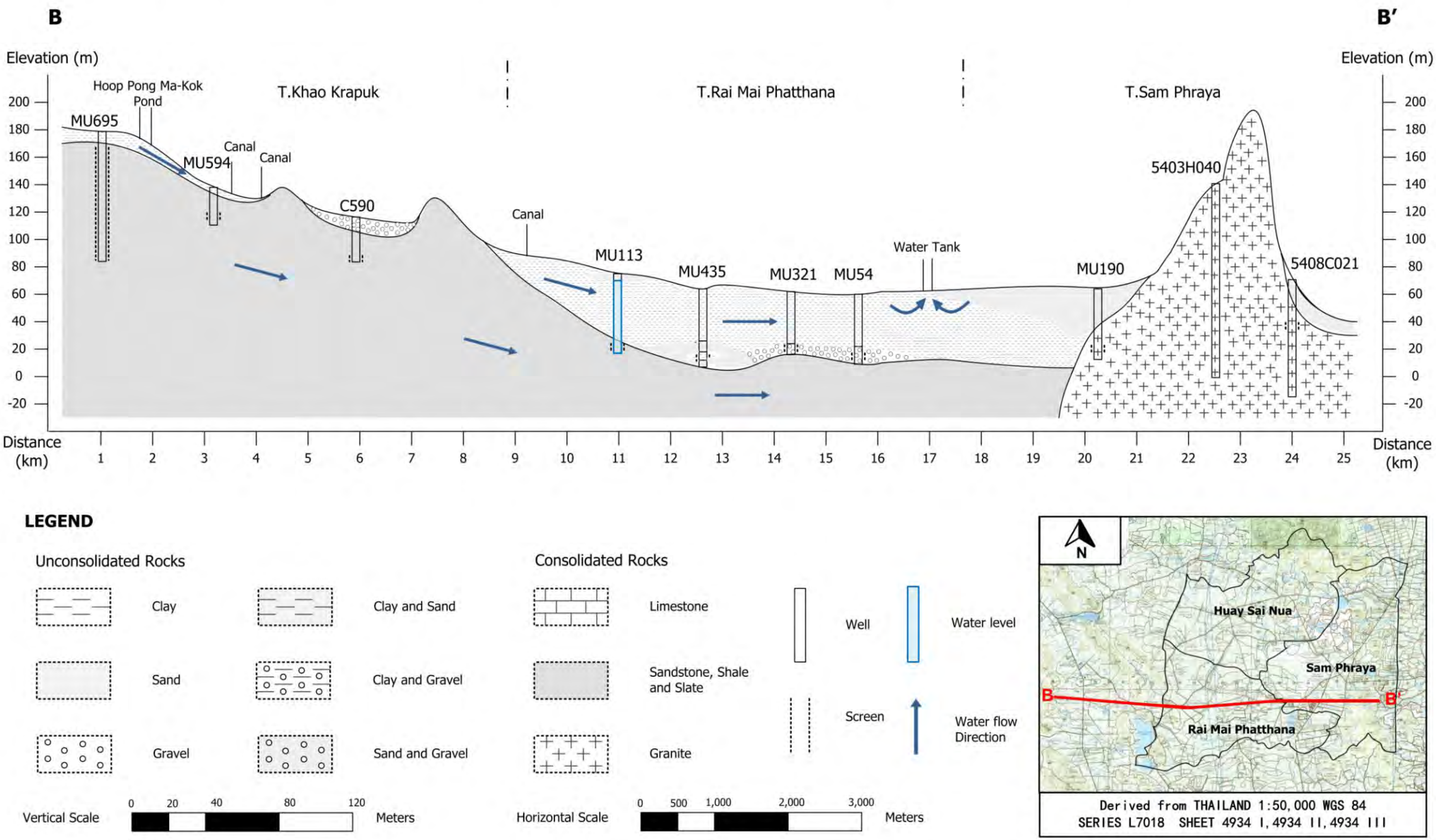


Figure 4.3 Hydrogeologic cross-section along B-B' Line, Tambon Rai Mai Phattana-Tambon Sam Phraya

Hydrogeologic Cross-Section along C-C′ Line, Tambon Huay Sai Nua-Tambon Rai Mai Phatthana

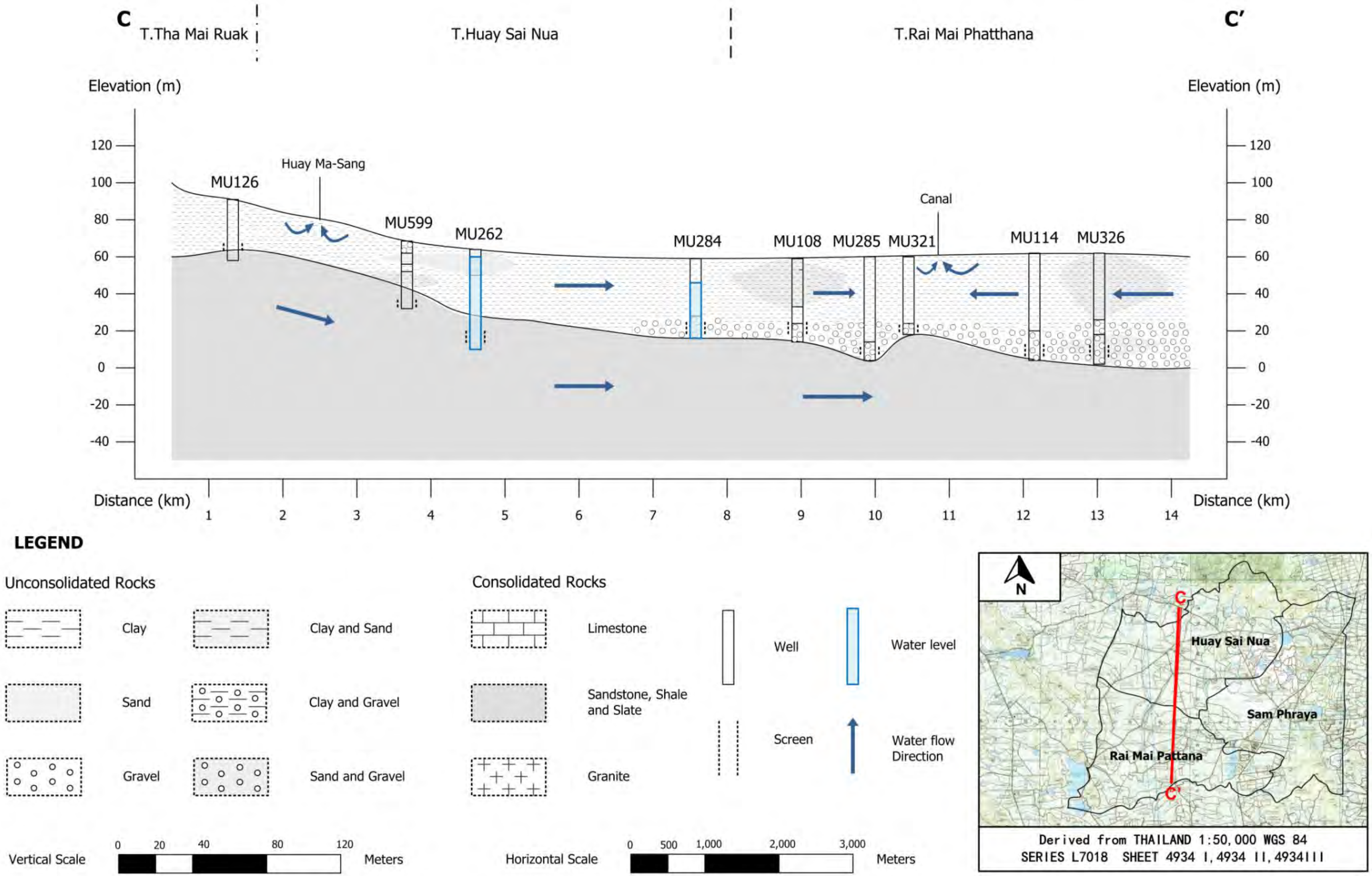


Figure 4.4 Hydrogeologic cross-section along C-C' Line, Tambon Huay Sai Nua-Tambon Rai Mai Phattana

Hydrogeologic Cross-Section along D-D' Line, Tambon Rai Mai Phatthana-Tambon Huay Sai Nua-Tambon Sam Phraya

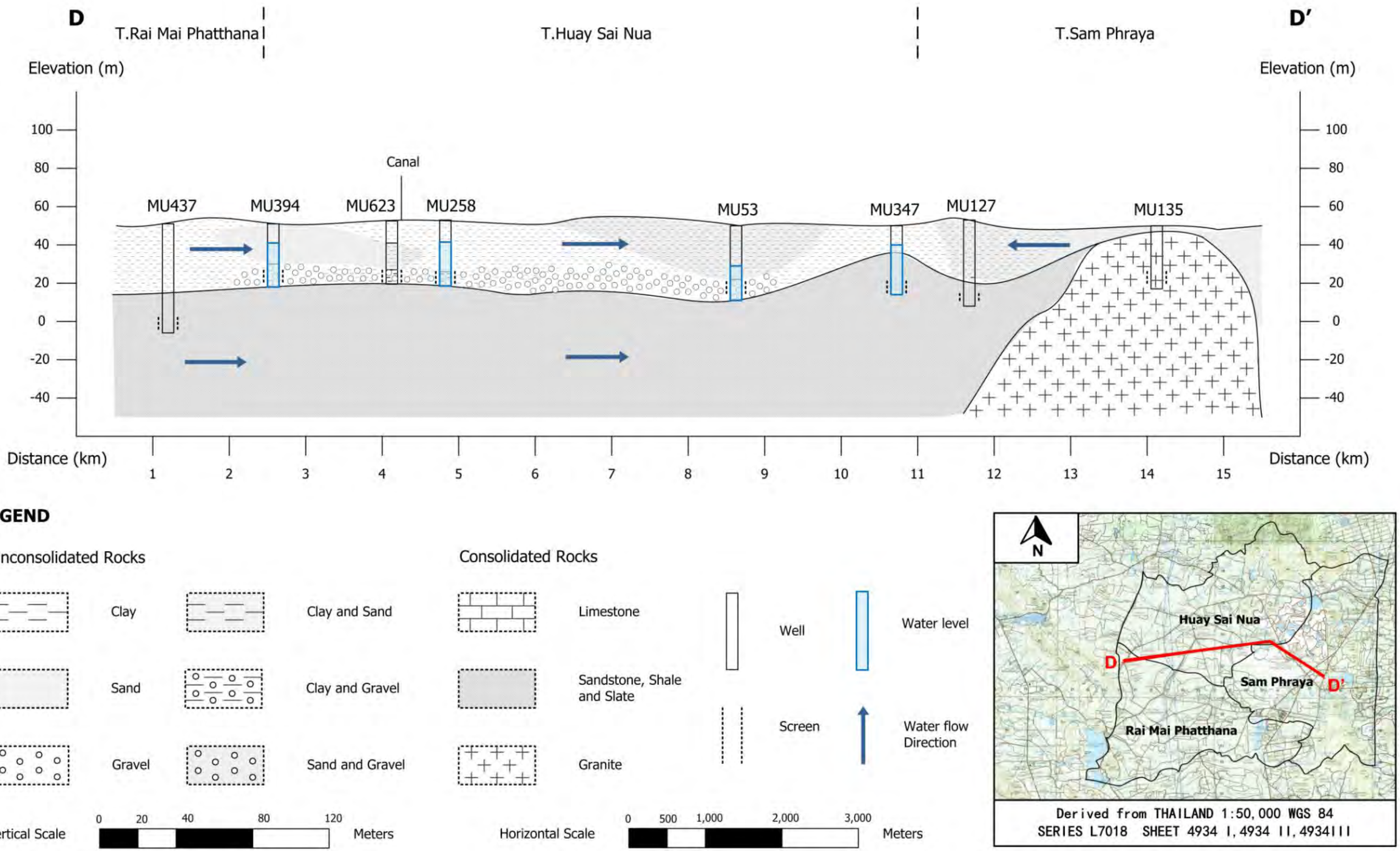


Figure 4.5 Hydrogeologic cross-section along D-D' Line, Tambon Rai Mai Phattana-Tambon Huay Sai Nua-Tambon Sam Phraya

According to results of cross-sections, there are three types of aquifer in the study area, which conforms with the study of Department of Groundwater Resources and GMT Corporation Limited (2001), as follow:

1.1 Floodplain deposits aquifer (Qfd)

1.2 Permo-Carboniferous metasedimentary aquifer (PCms)

1.3 Granitic aquifer (Gr)

The floodplain deposits aquifer is Quaternary-age deposit. The Permo-Carboniferous metasedimentary aquifer is found in the western area and the granitic aquifer of various periods, which is younger than Permian-Carboniferous age, is mainly found in the eastern area.

2. The groundwater level from the fieldwork was showed as the table below.

Table 4.1 Number of groundwater wells observed during August 8-11, 2011

Date	Number of groundwater wells
August 8, 2011	20
August 9, 2011	19
August 10, 2011	35
August 11, 2011	11
Total	**85**

The groundwater level which derived from fieldwork were analyzed and calculated, compared with mean sea level (MSL). Then, groundwater level contour proceed and displayed by using Surfer 8 Program.

The data was separated into two groups.

2.1 Groundwater level in the floodplain deposits aquifer

2.2 Groundwater level in the metasedimentary aquifer

** Remark: Groundwater flow in the granitic aquifer was not analyzed because there was not enough data.

The groundwater level contour showed that both of the two aquifers flow from south-western area to north-eastern area. However, some areas showed cones of depression characteristic due to intensive pumping.

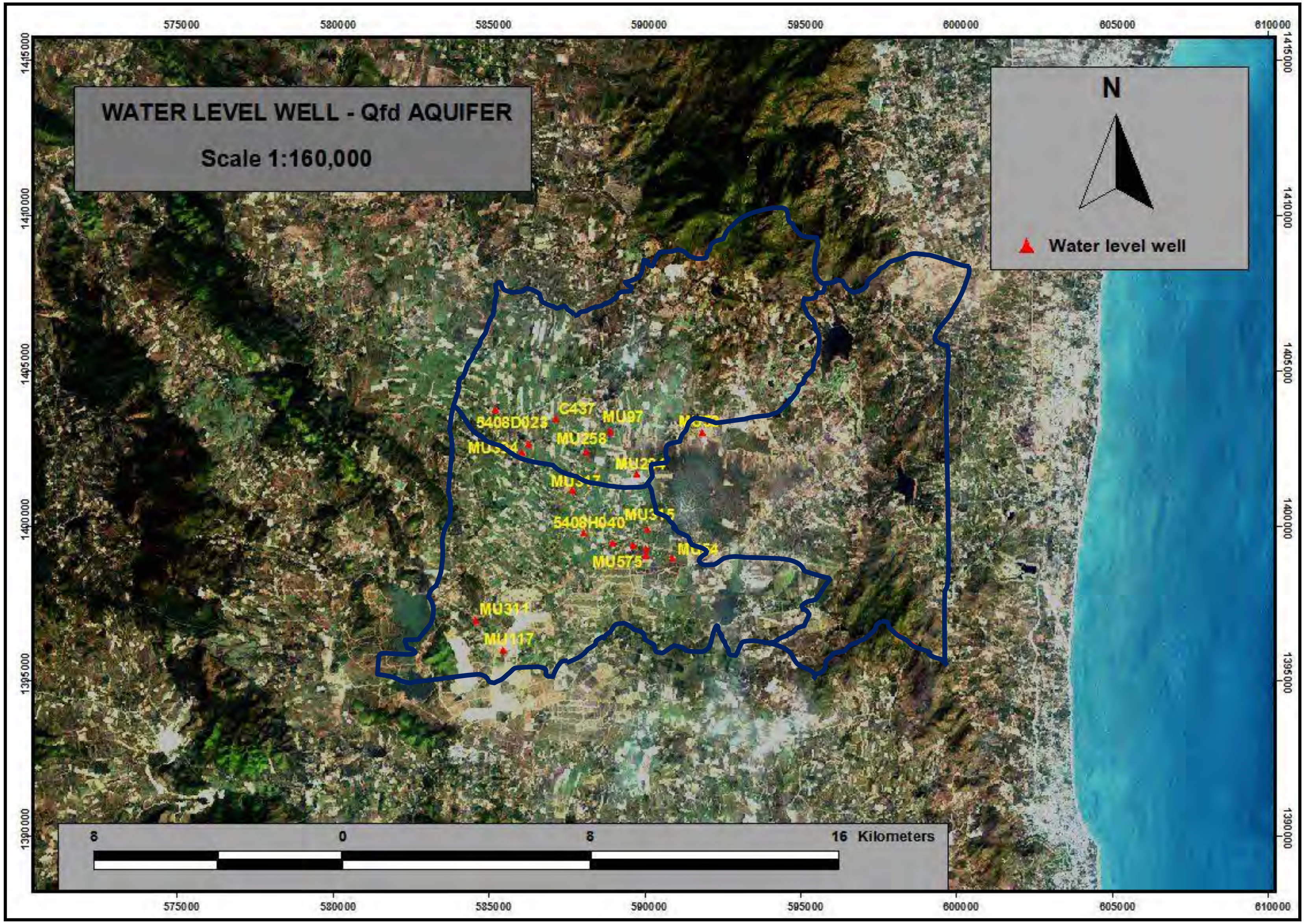


Figure 4.6 Water level well map from fieldwork

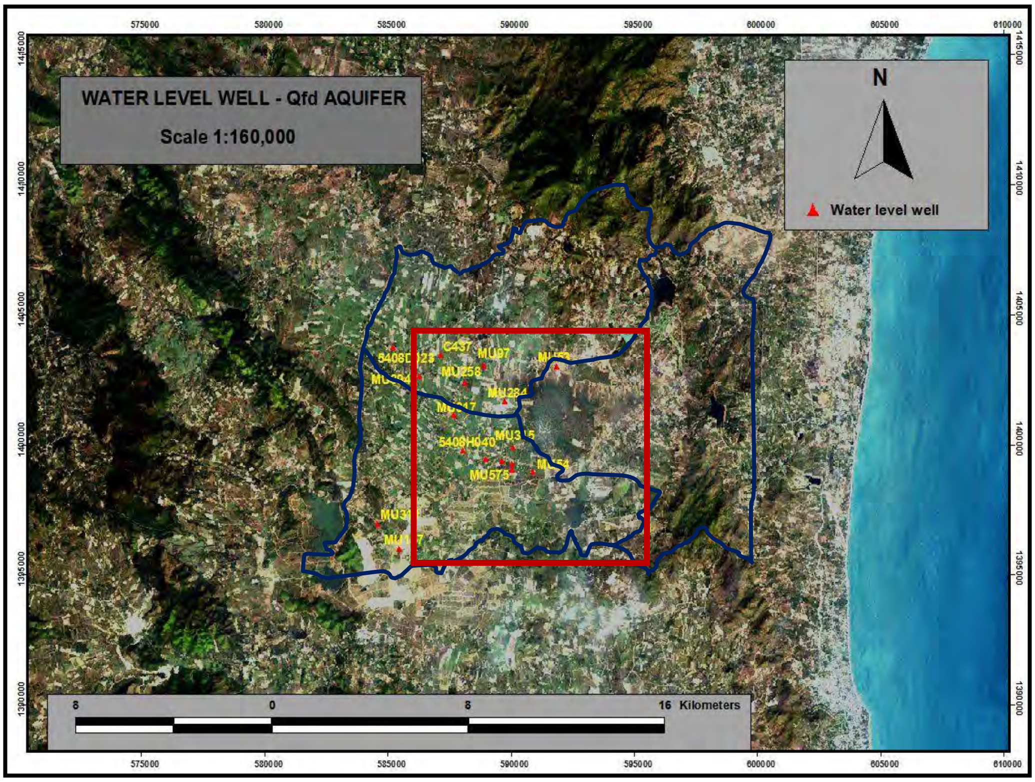


Figure 4.7 Water level well map from fieldwork

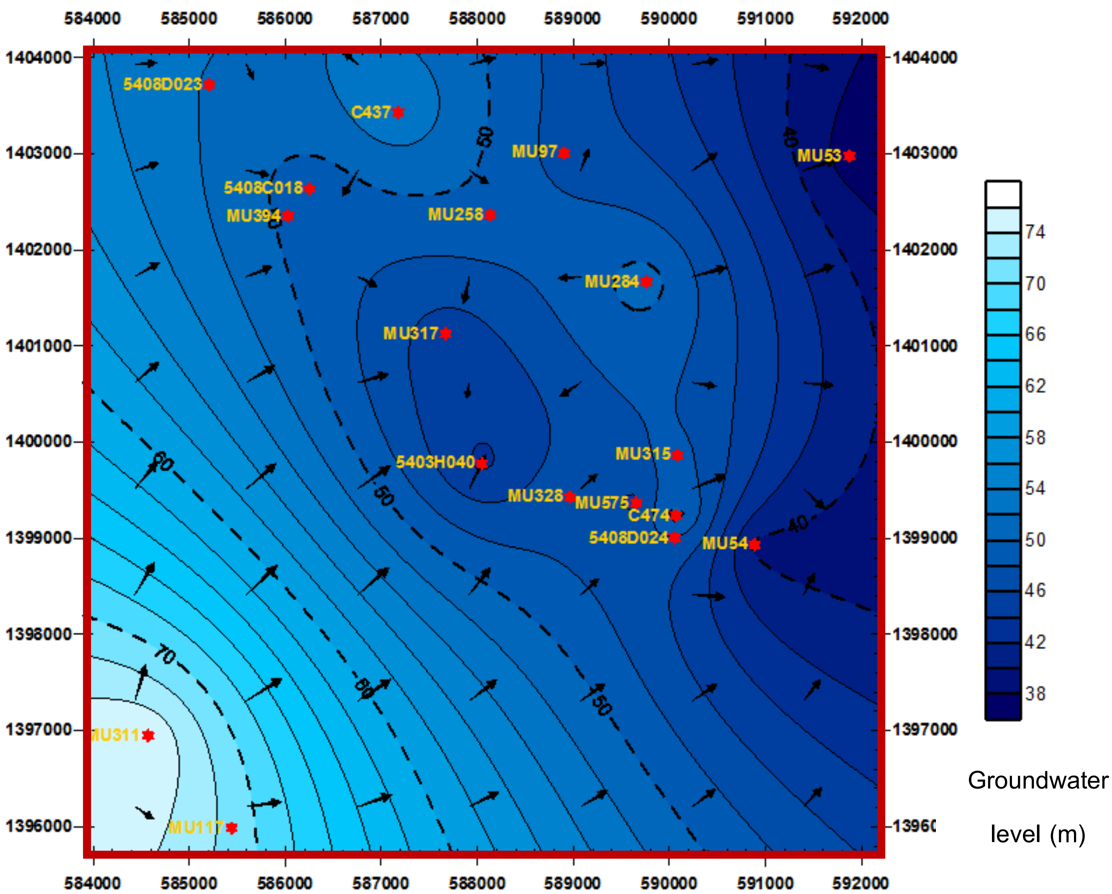


Figure 4.8 Contour of groundwater level in the floodplain deposits aquifer (Qfd)

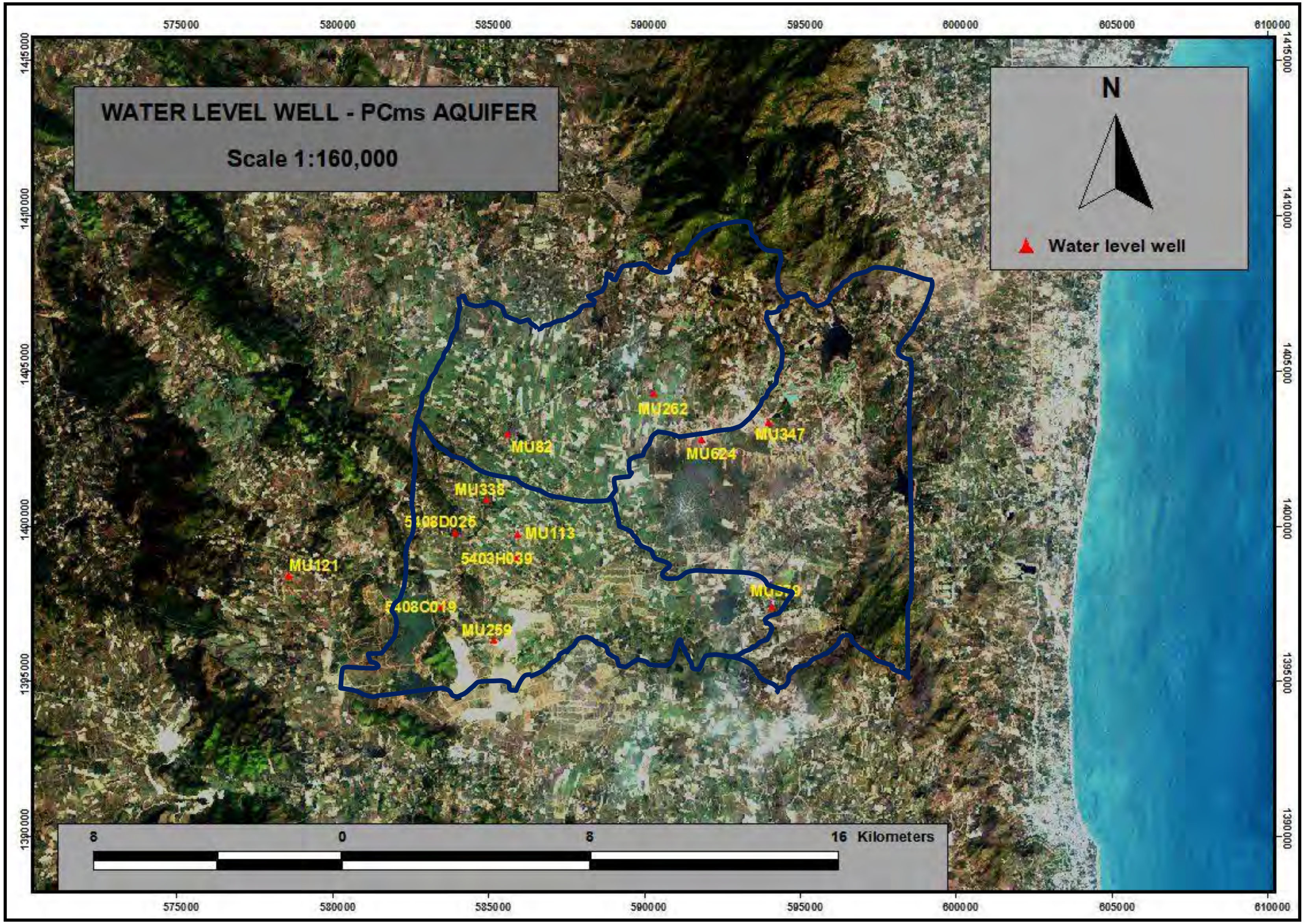


Figure 4.9 Water level well map from fieldwork

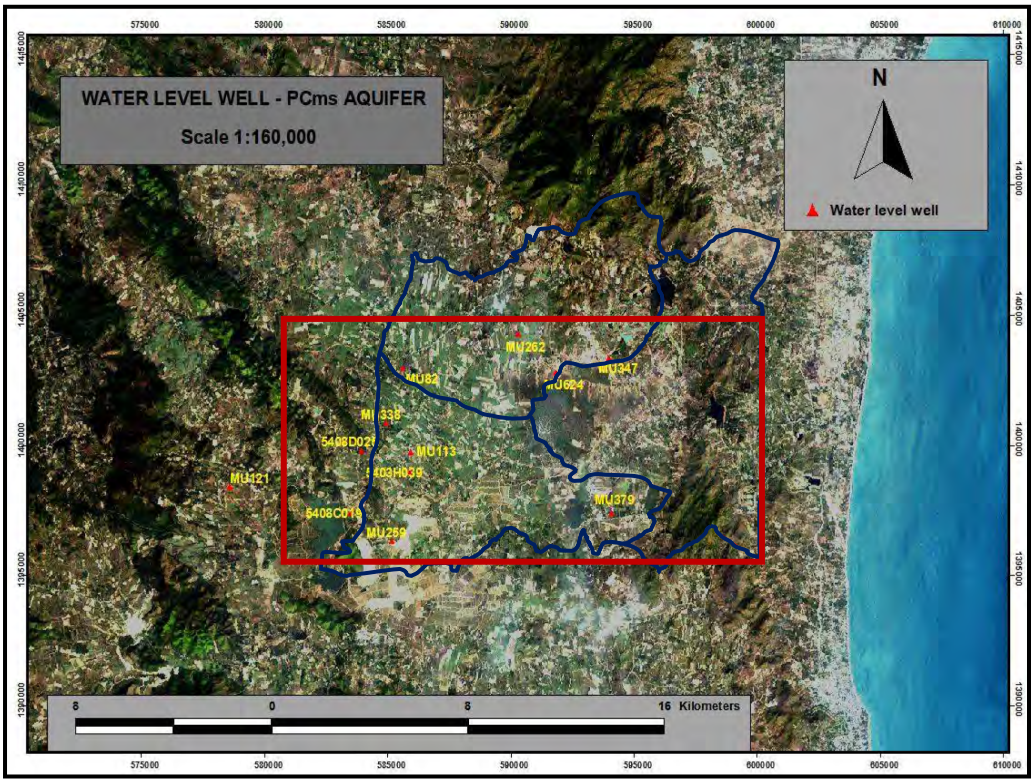


Figure 4.10 Water level well map from fieldwork

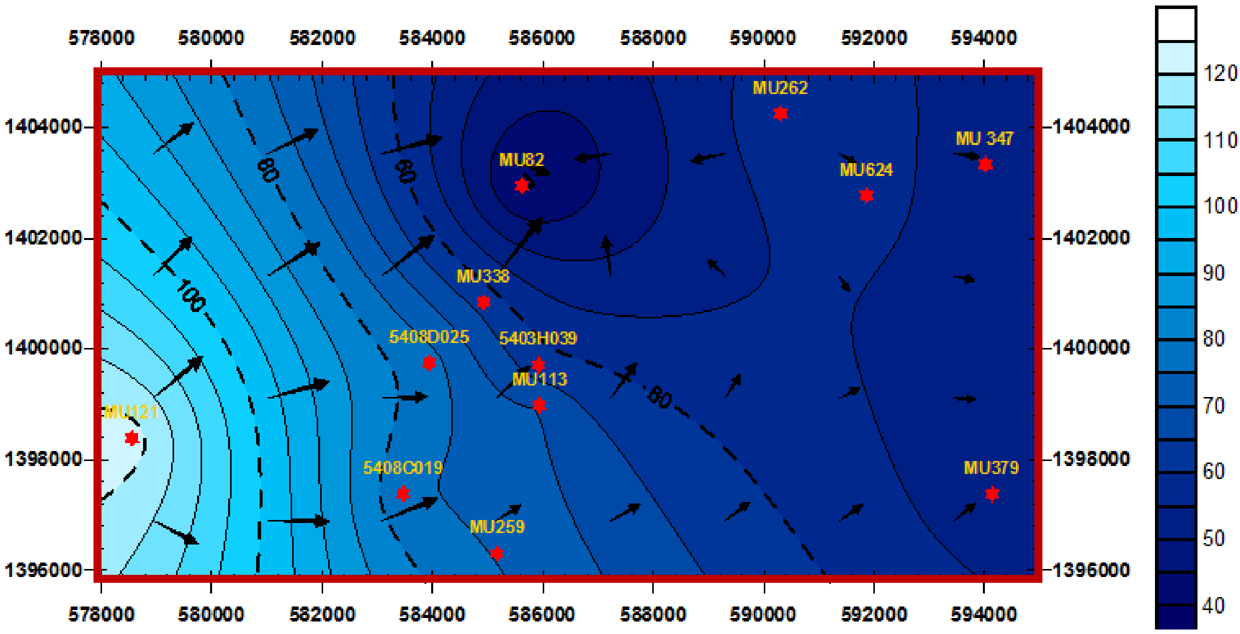


Figure 4.11 Contour of groundwater level in the metasedimentary aquifer (PCms)

From the hydrogeologic cross-sections and groundwater level contour, conceptual models were constructed as:

- Two dimensions display by using Microsoft Office Visio 2007 Program.
- Three dimensions display by using RockWorks 15 Program.

The floodplain deposits aquifer is on the top and distribute in Tambon Huay Sai Nua, Tambon Rai Mai Phattana and Tambon Sam Phraya. The average thickness of the aquifer is 30-40 meters.

The metasedimentary aquifer is under the floodplain deposits aquifer and distribute in Tambon Huay Sai Nua, Tambon Rai Mai Phattana and of Tambon Sam Phraya. The average thickness of the aquifer is more than 100 meters.

For the granitic aquifer, intrude through the floodplain deposits aquifer and the metasedimentary aquifer. The intrusion was in the eastern area, which is Tambon Sam Phraya and the average thickness is more than 80 meters.

Generally, groundwater direction of both of the floodplain deposits aquifer and the metasedimentary aquifer in the area flow from south-west to north-east. If analyze with topographic characteristics, groundwater flow from higher place (mountain) to lower place or act as floodplain or basin. Hence, the mountainous areas are recharge zone and floodplain is discharge zone.

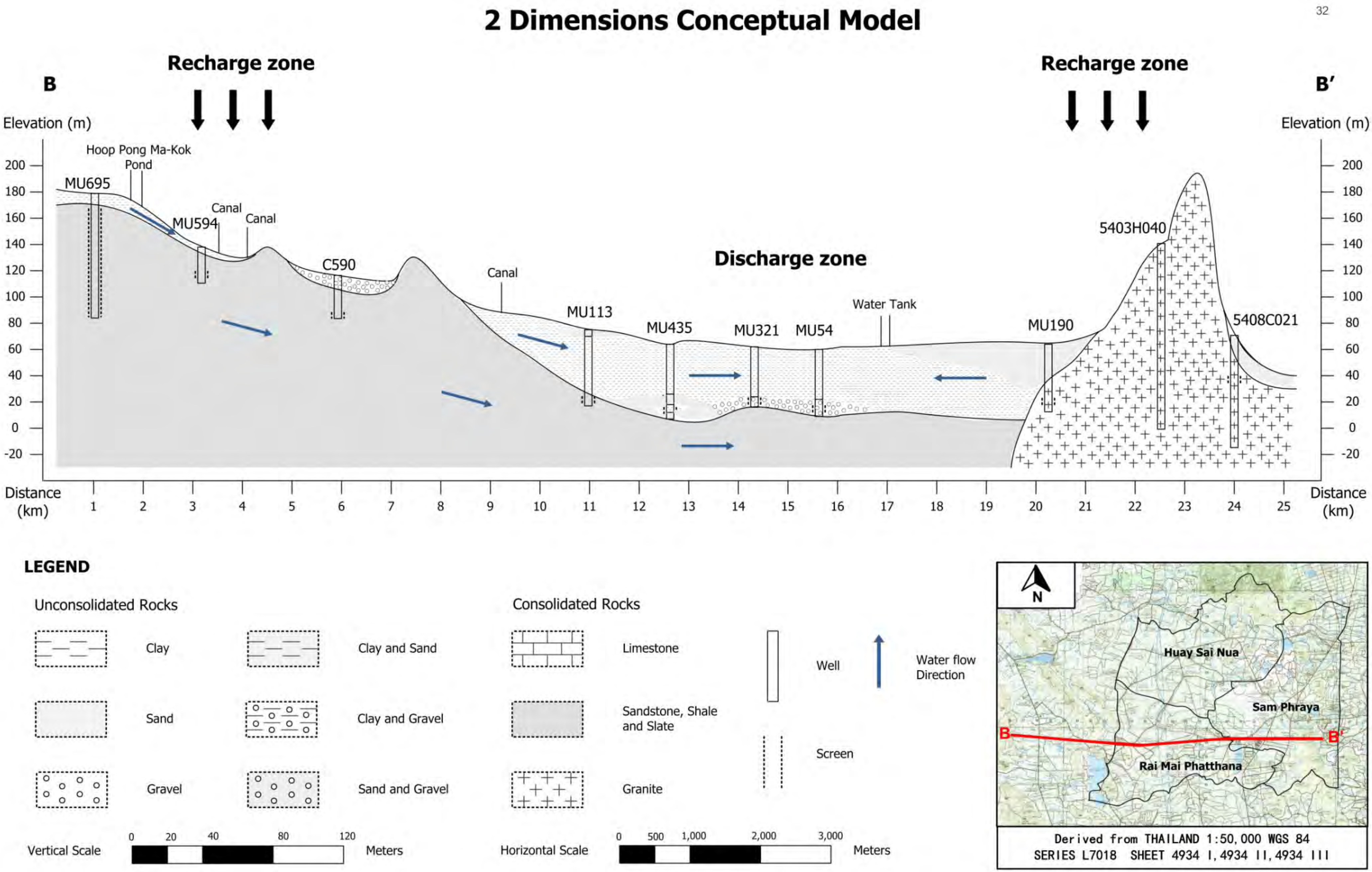


Figure 4.12 Two dimensional conceptual model hydrogeological setting

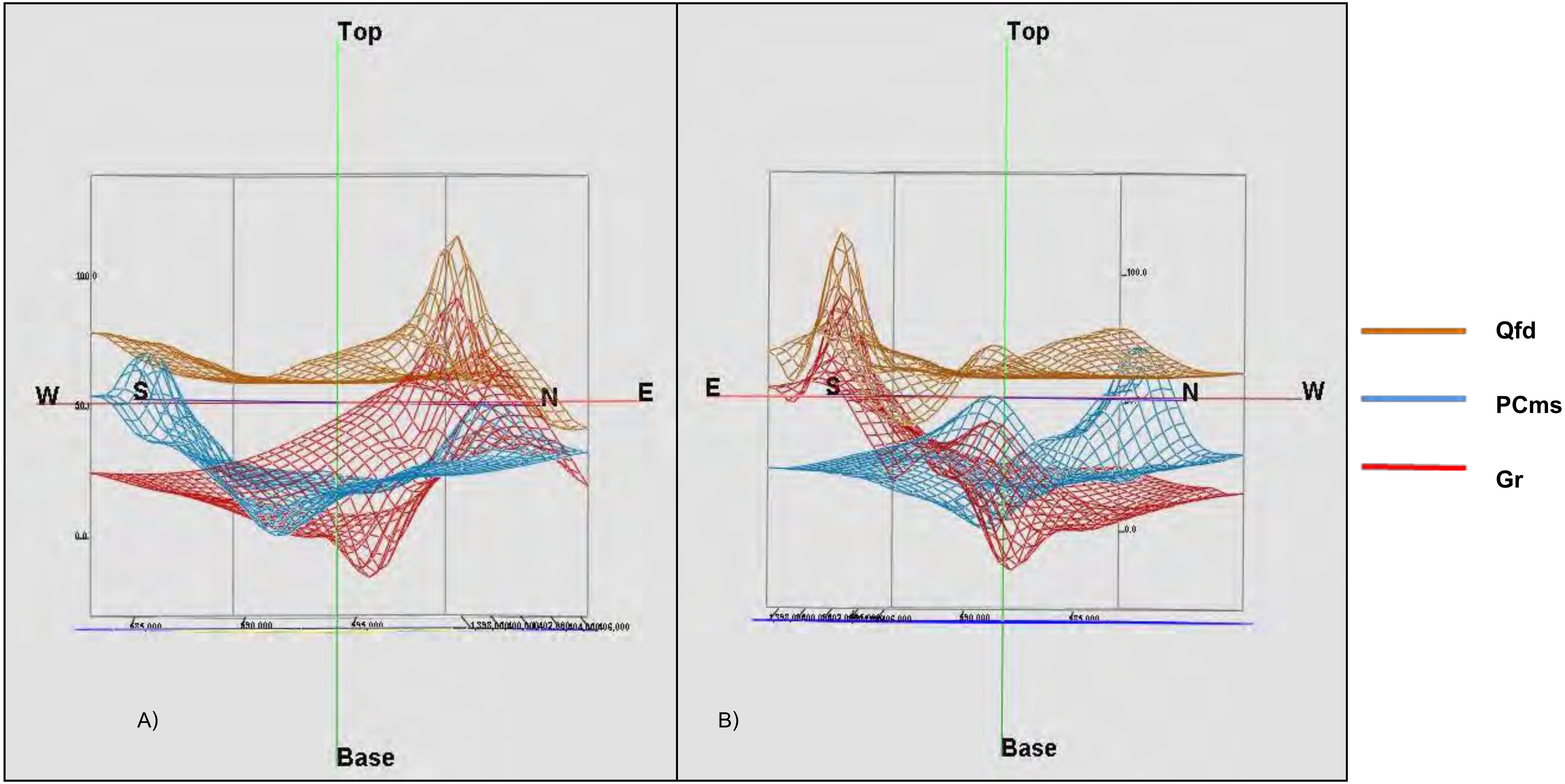


Figure 4.13 Three dimensions conceptual model of hydrogeological setting

A) South-east direction B) North-east direction

3. From the pumping test data, Aquifer Test Program (Version 2.5) was used as a tool to analyze the data. There were 12 wells that operated the pumping test, all of them are pumping wells. In pumping well cases, credible values from calculating are Transmissivity (T) and Hydraulic Conductivity (K). Storativity (S) value is incredible and not used.

The methods, which were used for analysis, were showed below. Each methods were consistent with different type of aquifers.

- Neuman Method - Unconfined Aquifer
- Theis Method - Confined Aquifer
- Cooper&Jacob Method - Confined Aquifer
- Hantush Method - Leaky Confined Aquifer

The confined aquifers in the study area were analyzed in threes methods, Theis Method, Cooper&Jacob Method and Hantush Method. The result showed that the valued from Theis Method were similar to Cooper&Jacob Methods. For Hantush Method, the data weren't fit with the graph, mean that there is no leaky aquifer in the area or very small amount of leak.

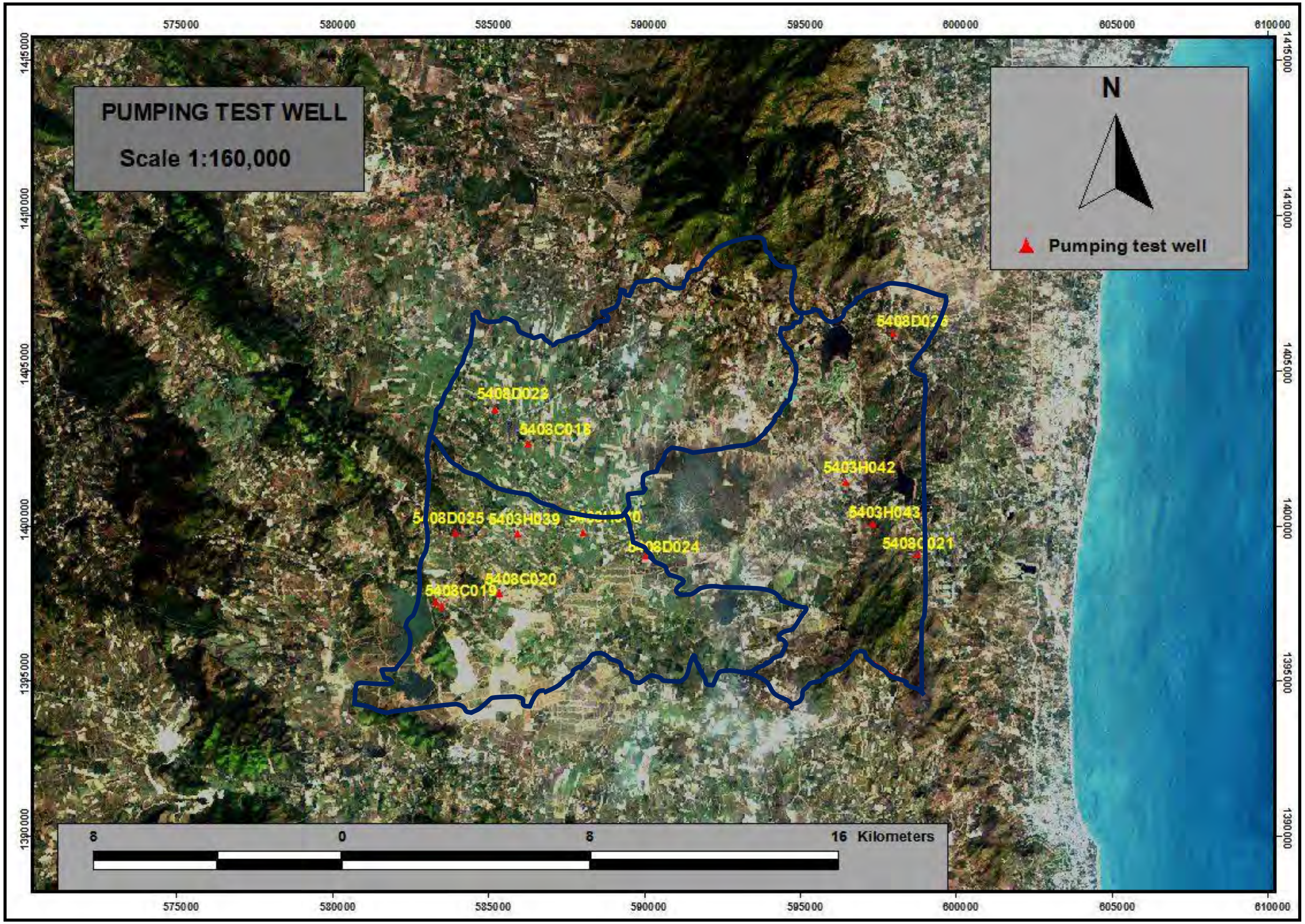


Figure 4.14 Pumping test well map

3.1 Well 1 (5408D023)

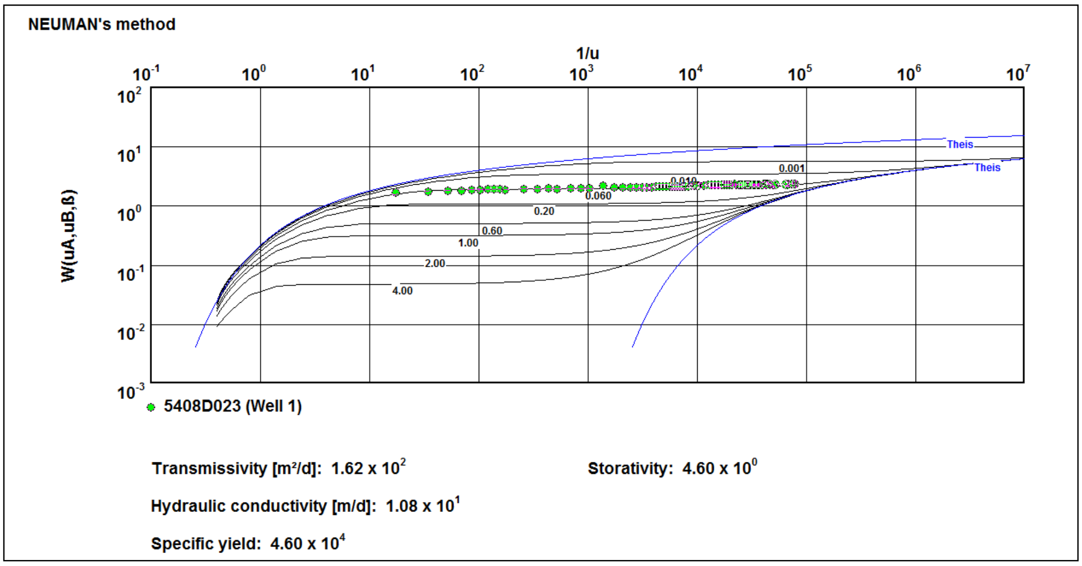


Figure 4.15 Neuman Method graph of Well 1 (5408D023)

3.2 Well 2 (5408C018)

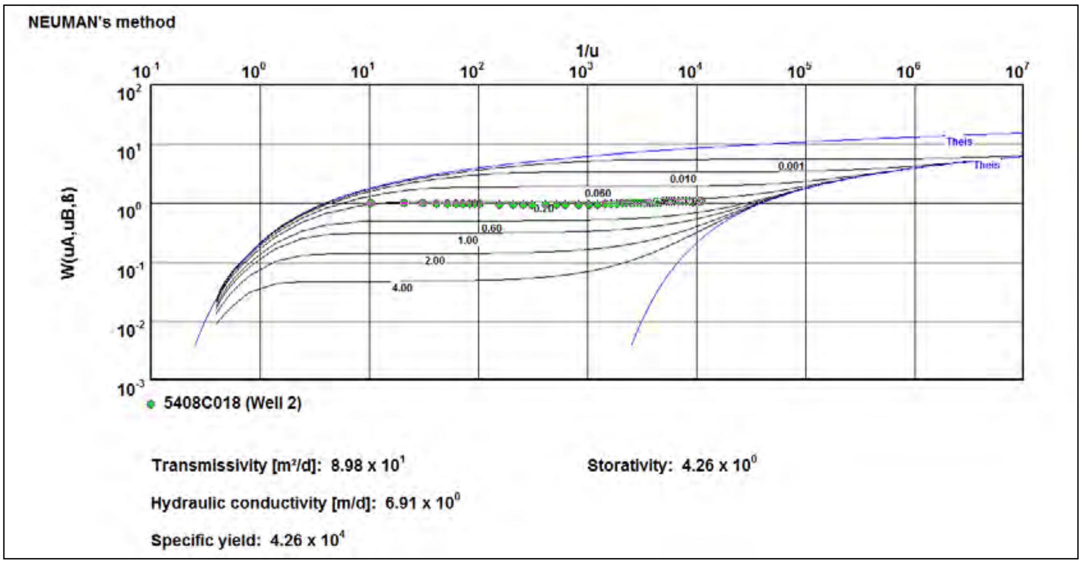


Figure 4.16 Neuman Method graph of Well 2 (5408C018)

3.3 Well 3 (5408C019)

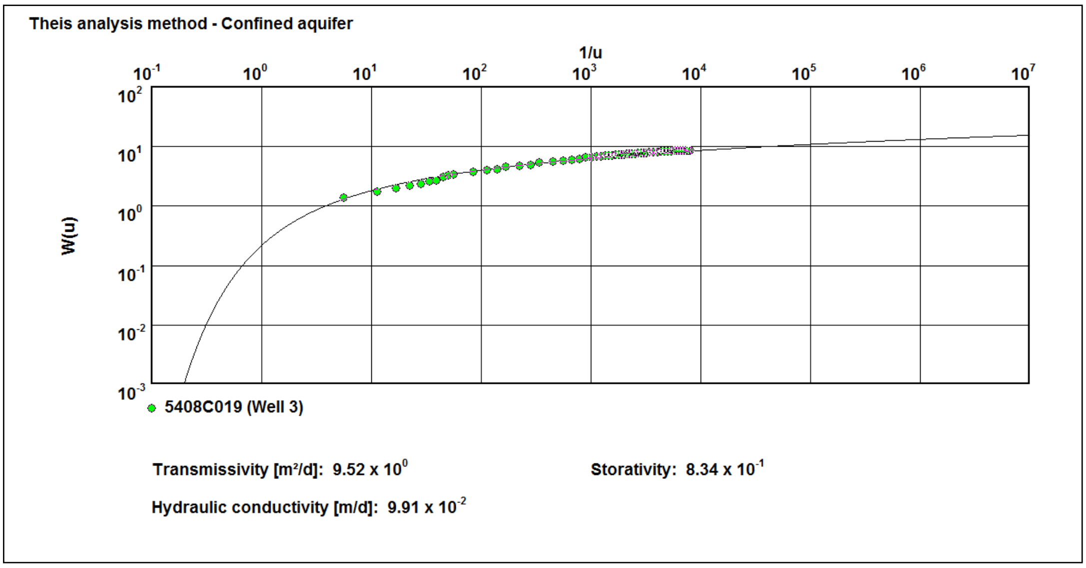


Figure 4.17 Theis Method graph of Well 3 (5408C019)

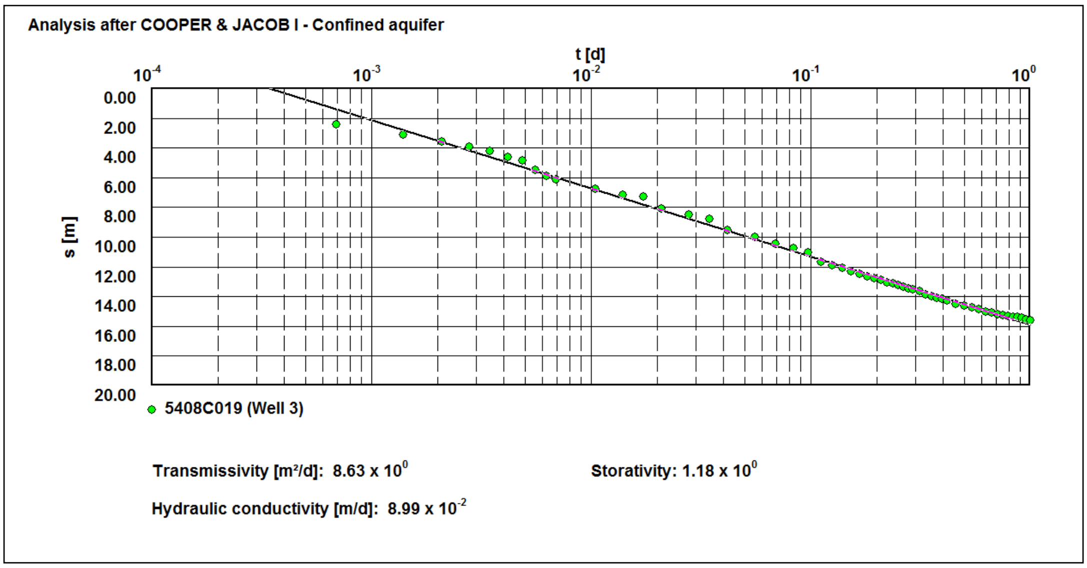


Figure 4.18 Cooper&Jacob Method graph of Well 3 (5408C019)

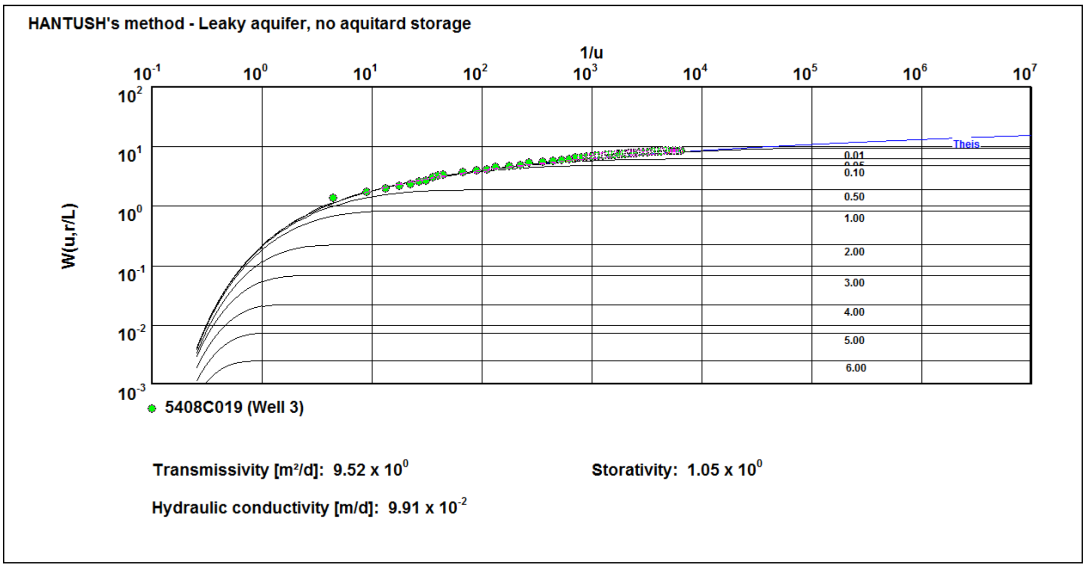


Figure 4.19 Hantush Method graph of Well 6 (5403H040)

3.4 Well 4 (5408D026)

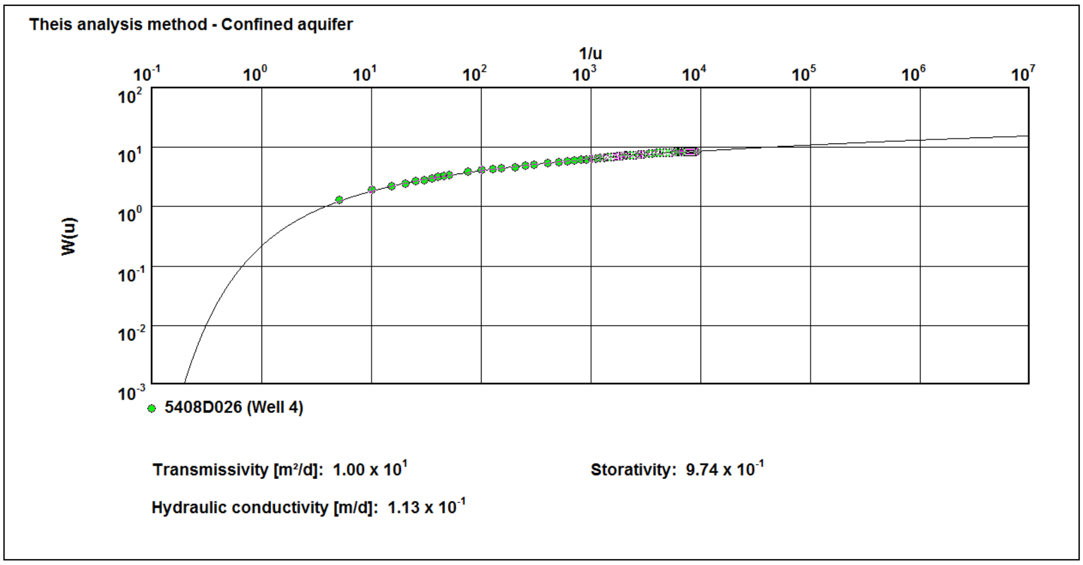


Figure 4.20 Theis Method graph of Well 4 (5408D026)

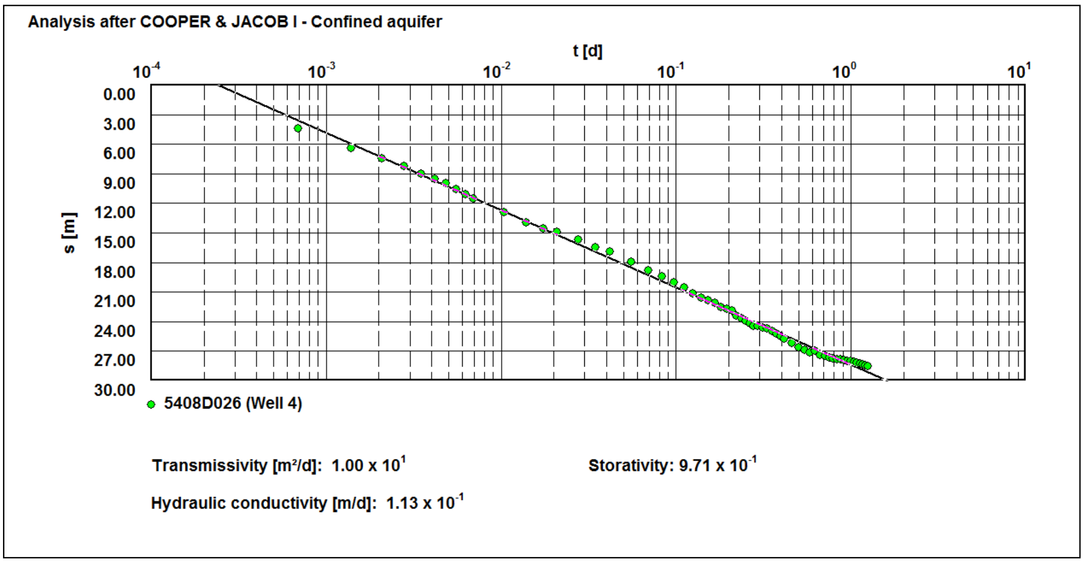


Figure 4.21 Cooper&Jacob Method graph of Well 4 (5408D026)

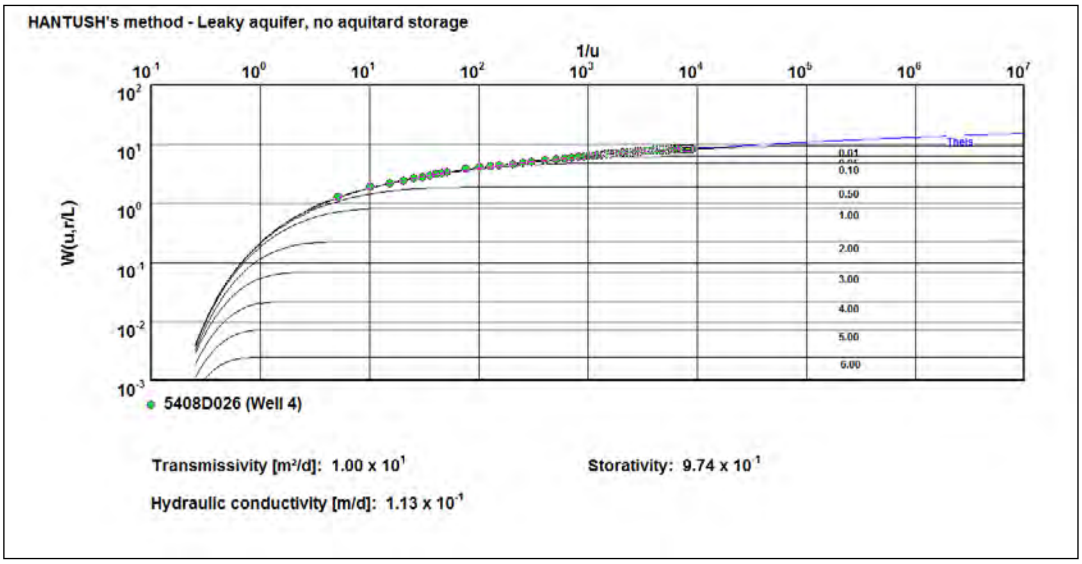


Figure 4.22 Hantush Method graph of Well 4 (5408D026)

3.5 Well 5 (5403H039)

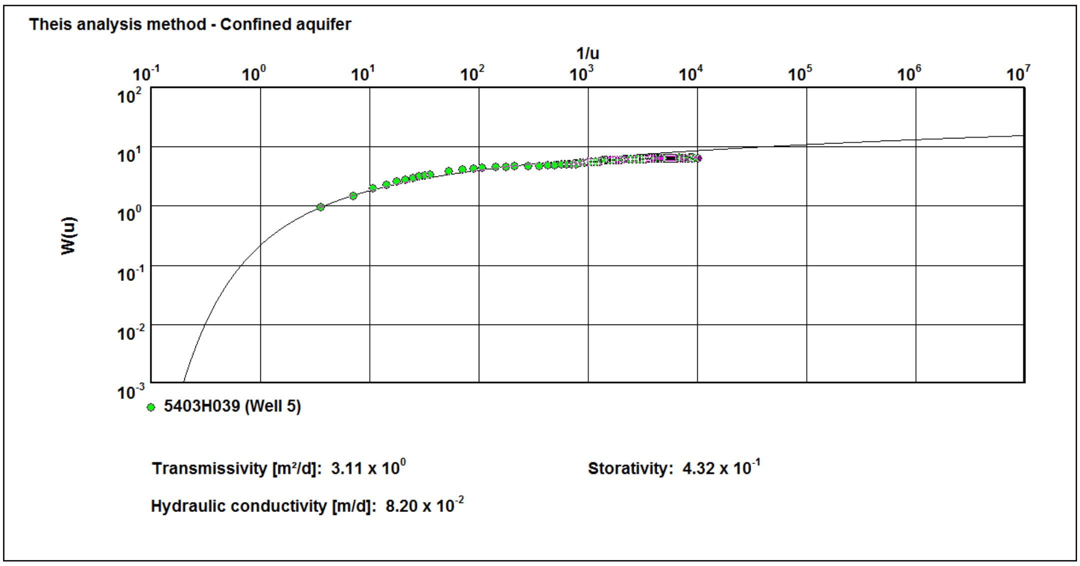


Figure 4.23 Theis Method graph of Well 5 (5403H039)

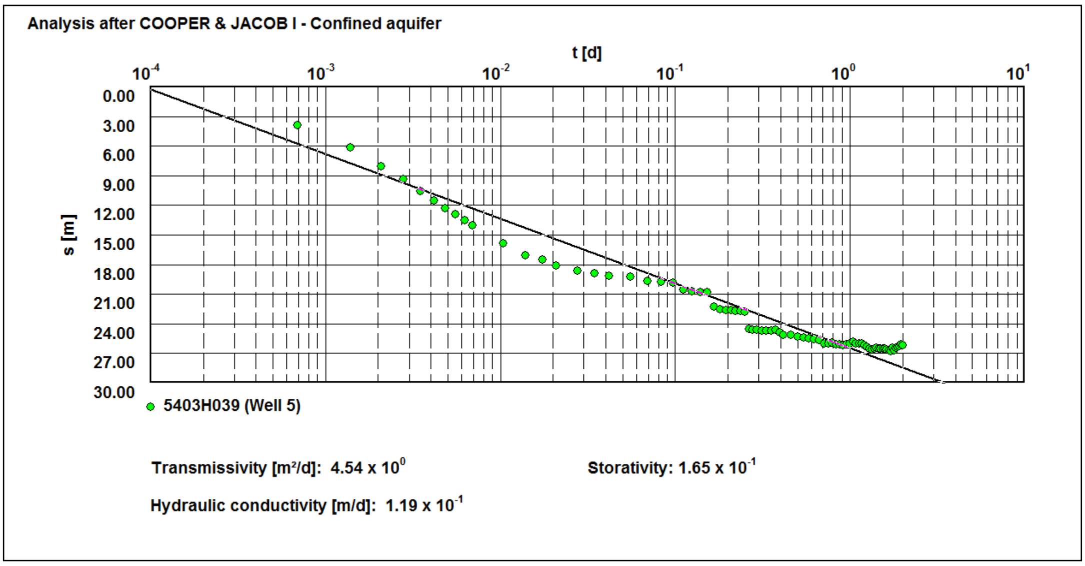


Figure 4.24 Cooper&Jacob Method graph of Well 5 (5403H039)

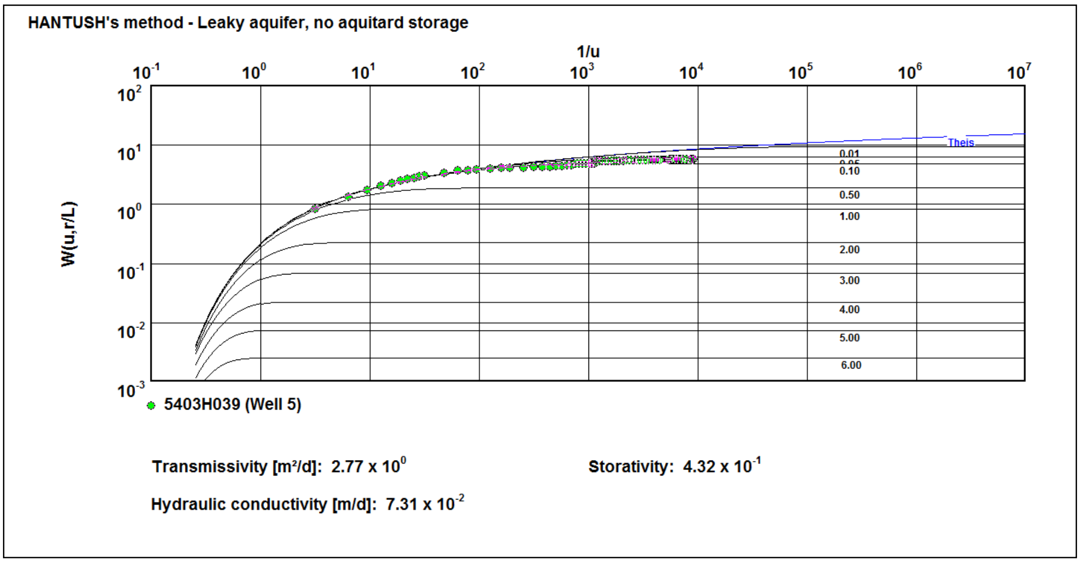


Figure 4.25 Hantush Method graph of Well 5 (5403H039)

3.6 Well 6 (5403H040)

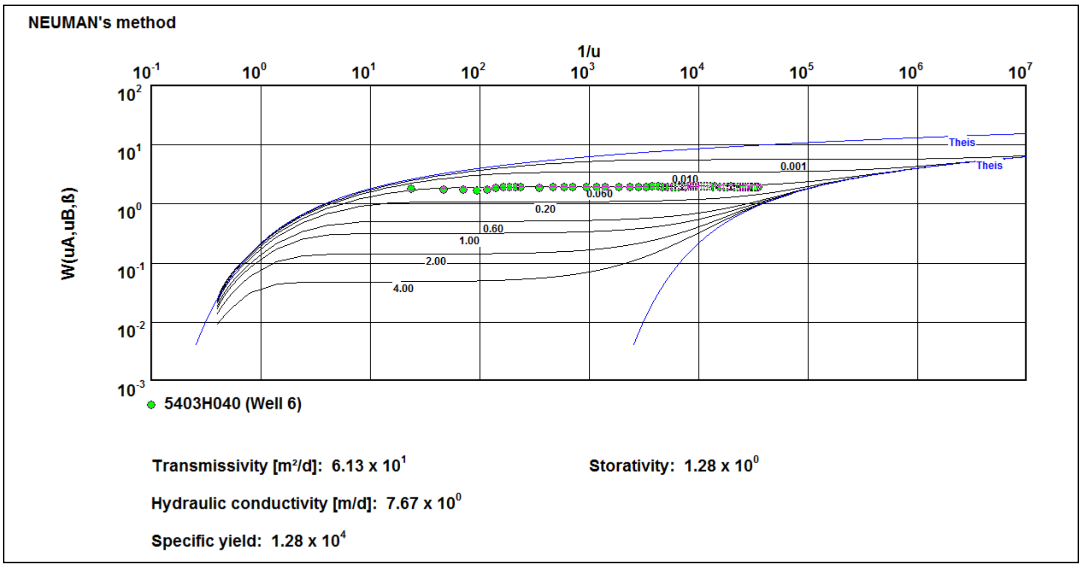


Figure 4.26 Neuman Method graph of Well 6 (5403H040)

3.7 Well 8 (5403H040)

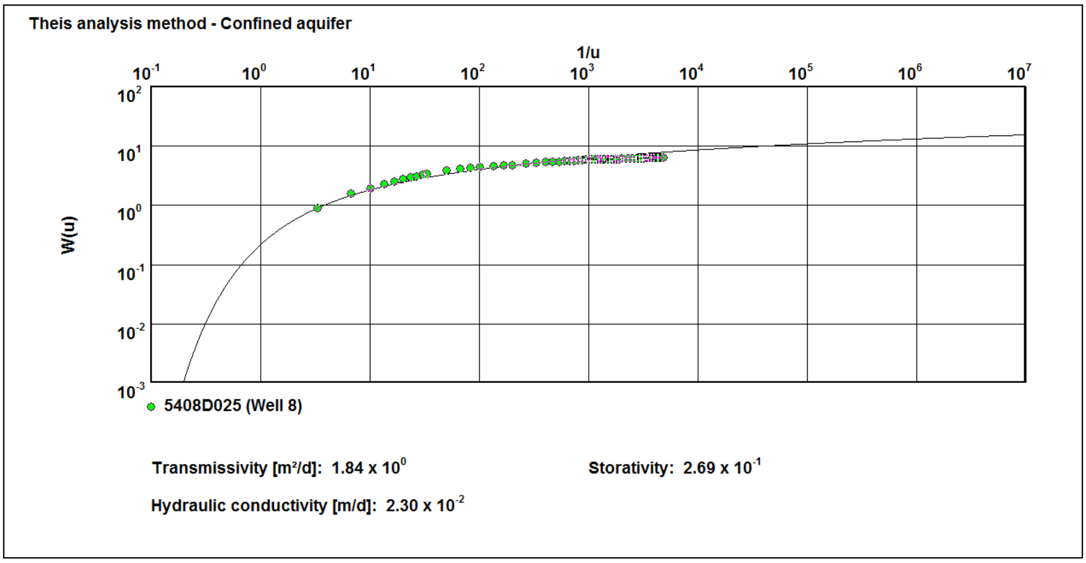


Figure 4.27 Theis Method graph of Well 8 (5403H040)

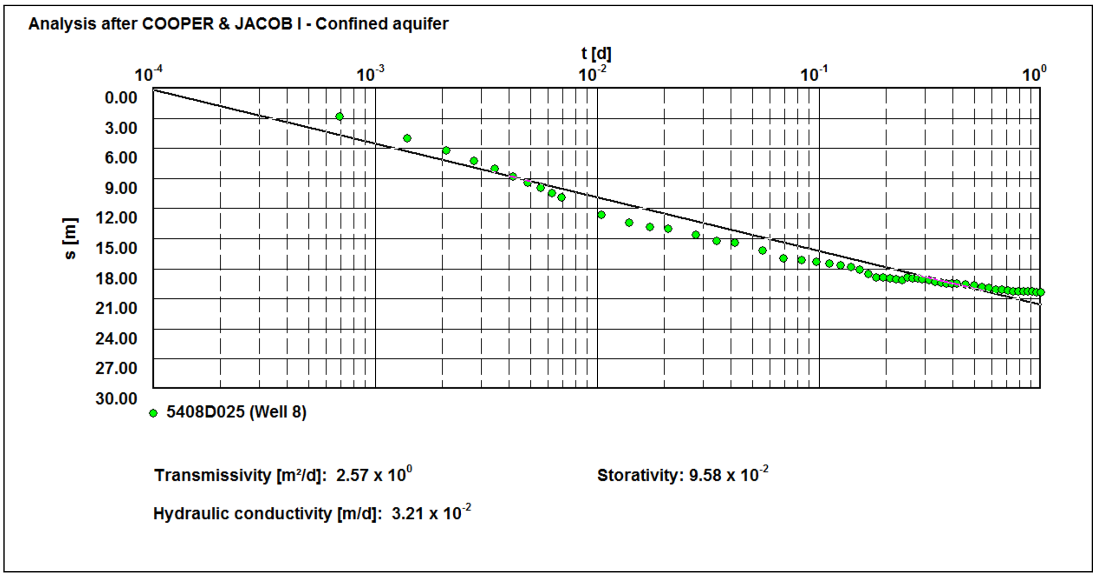


Figure 4.28 Cooper&Jacob Method graph of Well 8 (5403H040)

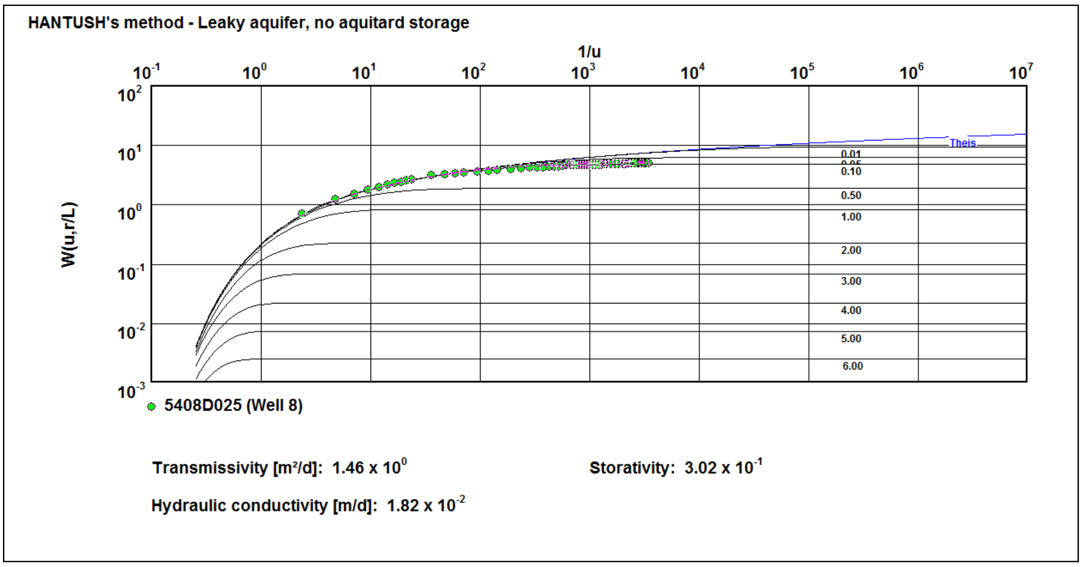


Figure 4.29 Hantush Method graph of Well 8 (5403H040)

3.8 Well 9 (5403H042)

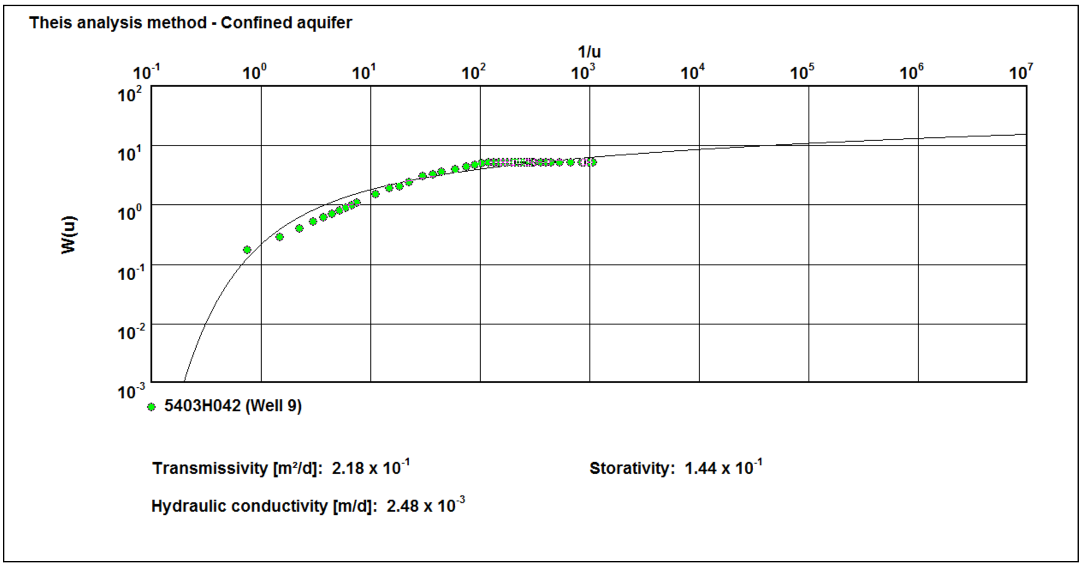


Figure 4.30 Theis Method graph of Well 9 (5403H042)

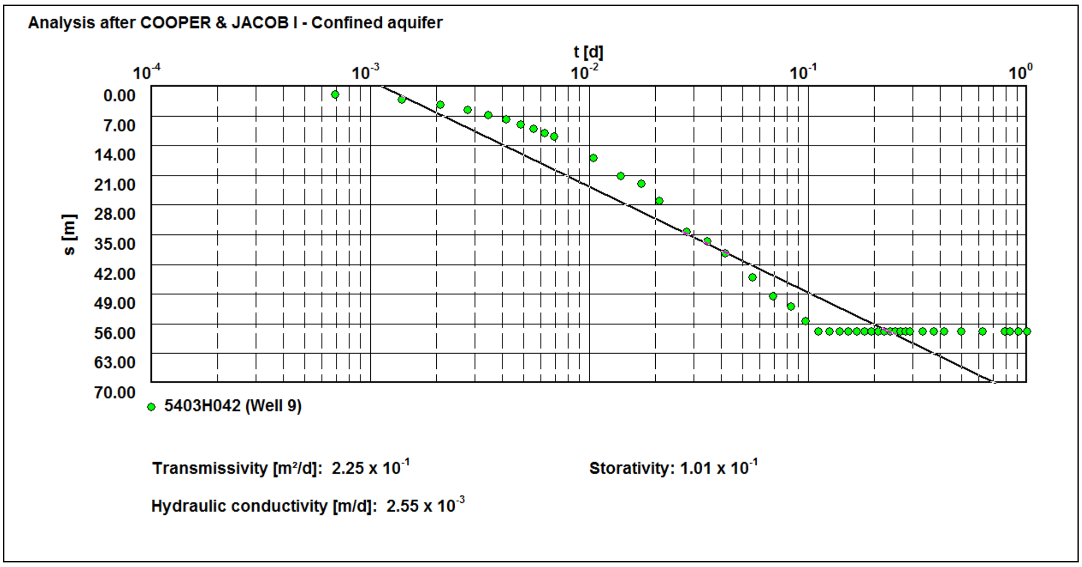


Figure 4.31 Cooper&Jacob Method graph of Well 9 (5403H042)

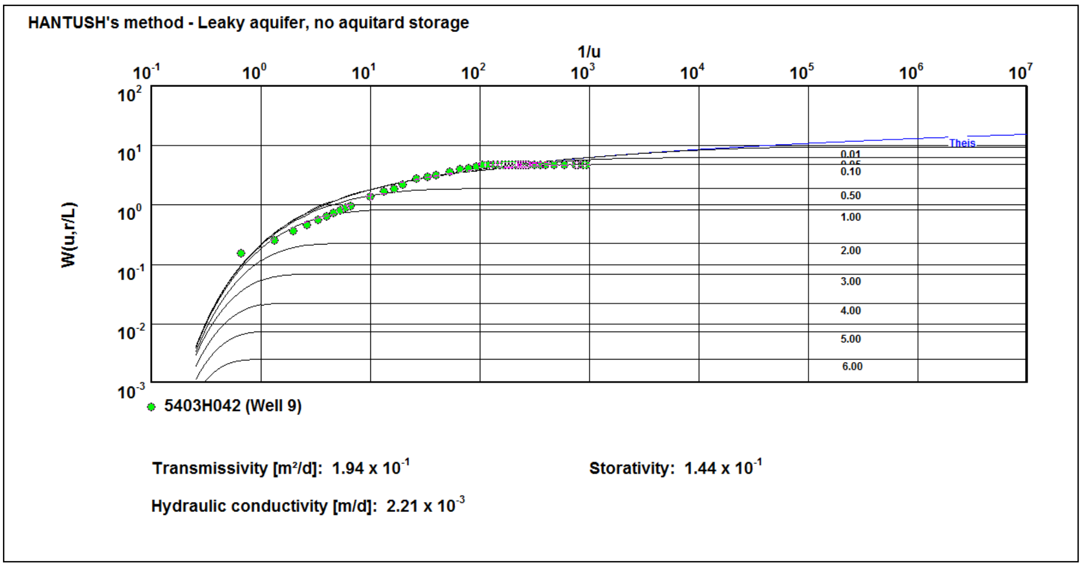


Figure 4.32 Hantush Method graph of Well 9 (5403H042)

3.9 Well 10 (5408C021)

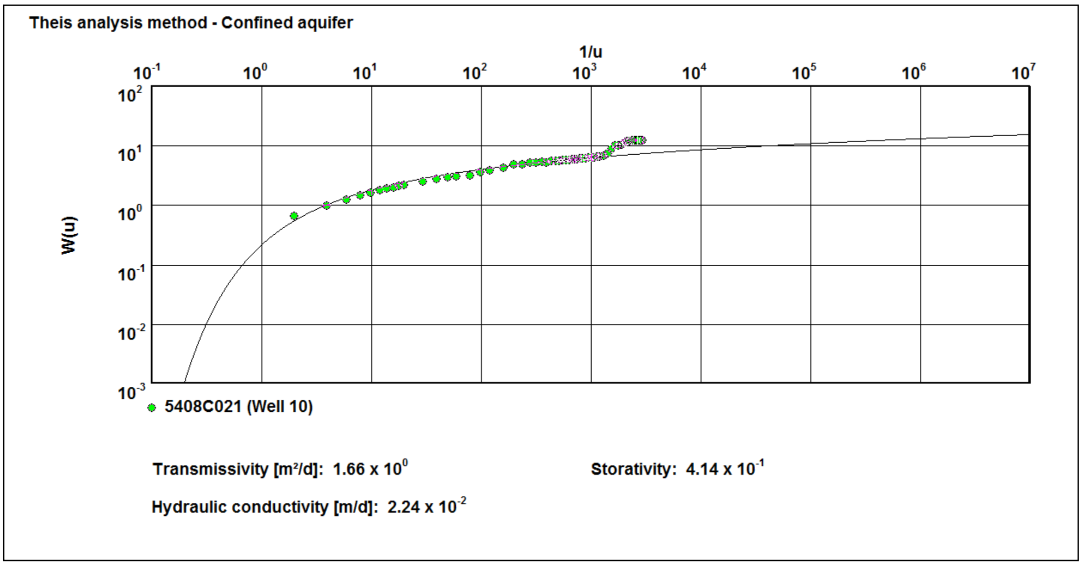


Figure 4.33 Theis Method graph of Well 10 (5408C021)

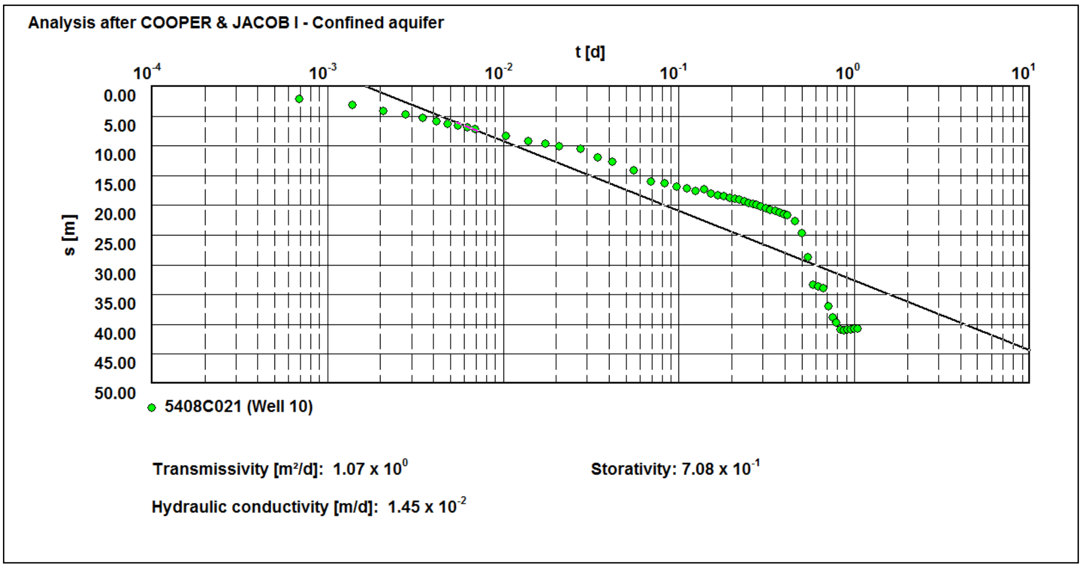


Figure 4.34 Cooper&Jacob Method graph of Well 10 (5408C021)

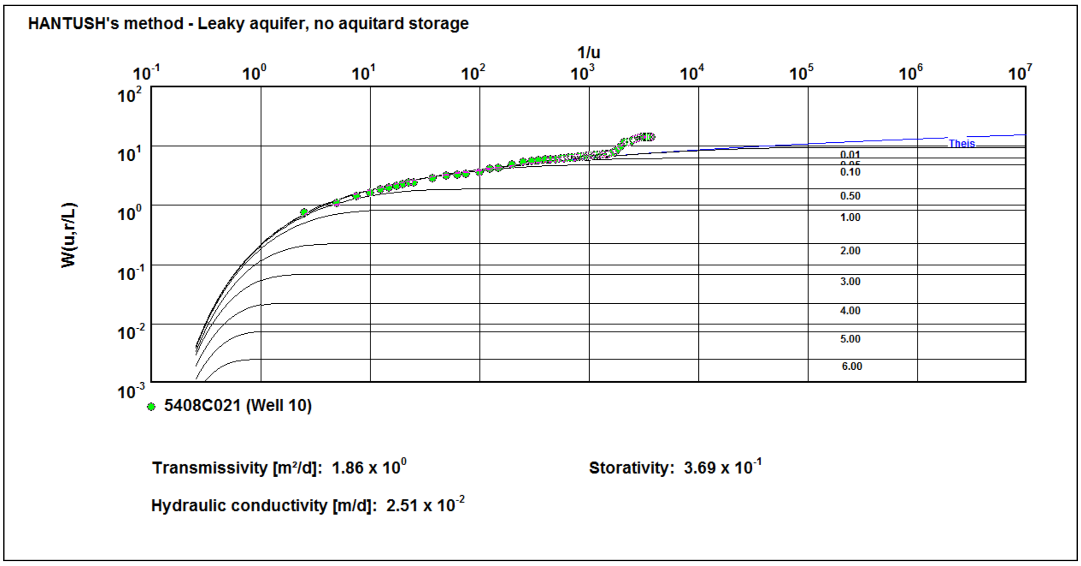


Figure 4.35 Hantush Method graph of Well 10 (5408C021)

3.10 Well 11 (5408C021)

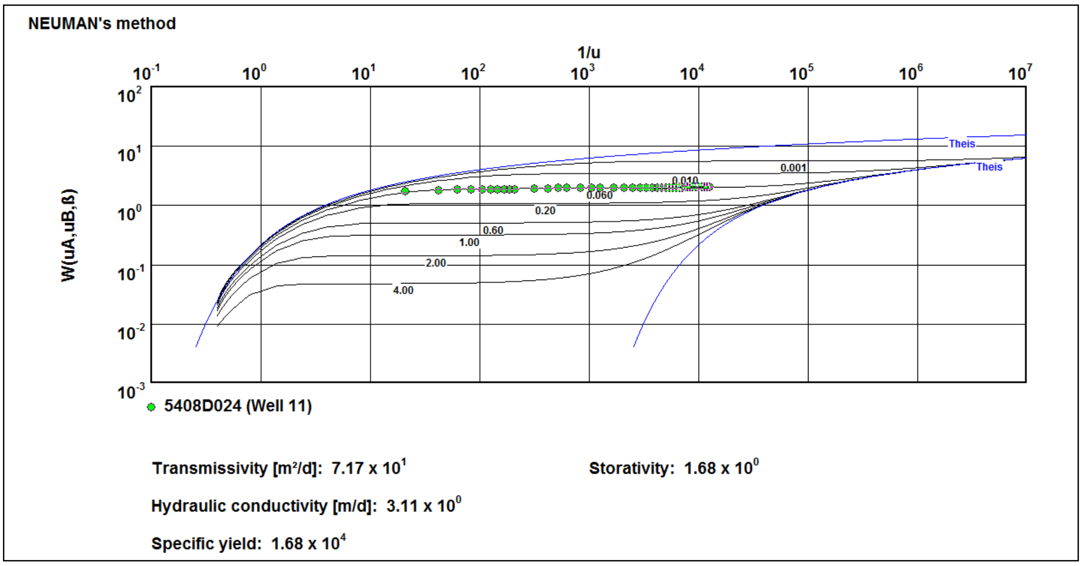


Figure 4.36 Neuman Method graph of Well 11 (5408C021)

3.11 Well 12 (5403H043)

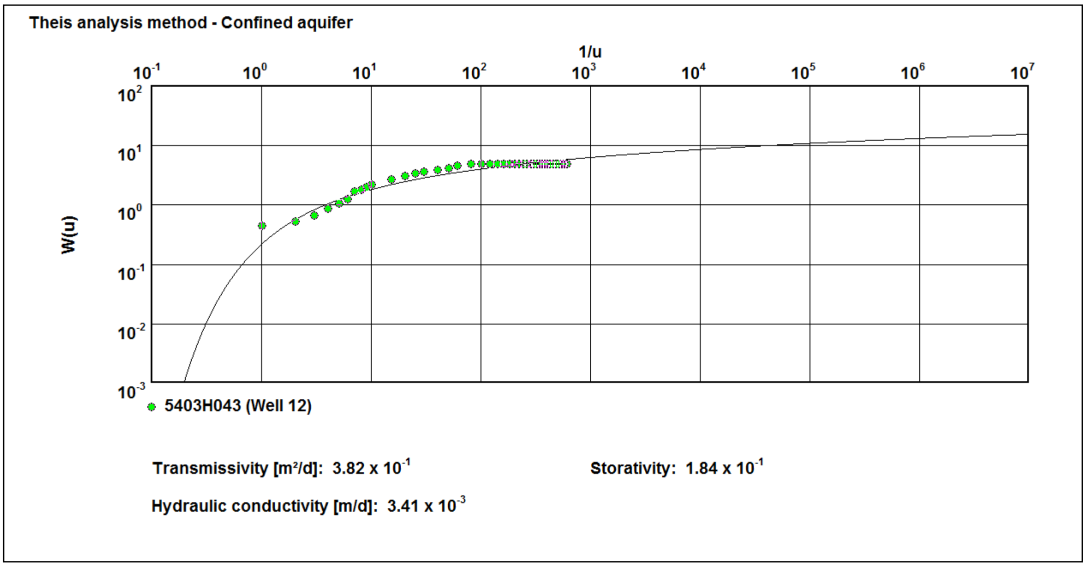


Figure 4.37 Theis Method graph of Well 12 (5403H043)

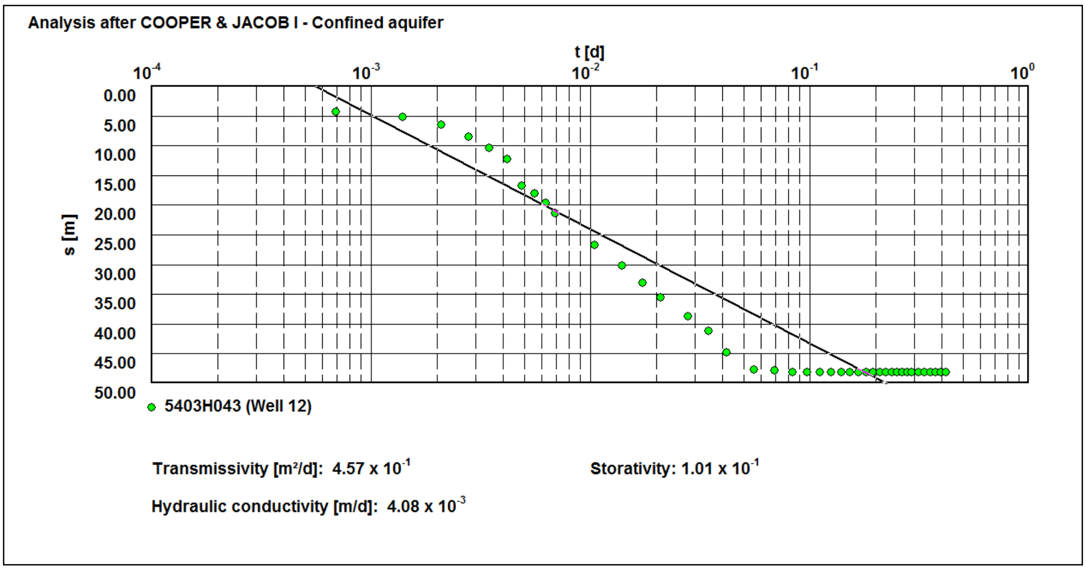


Figure 4.38 Cooper&Jacob Method graph of Well 12 (5403H043)

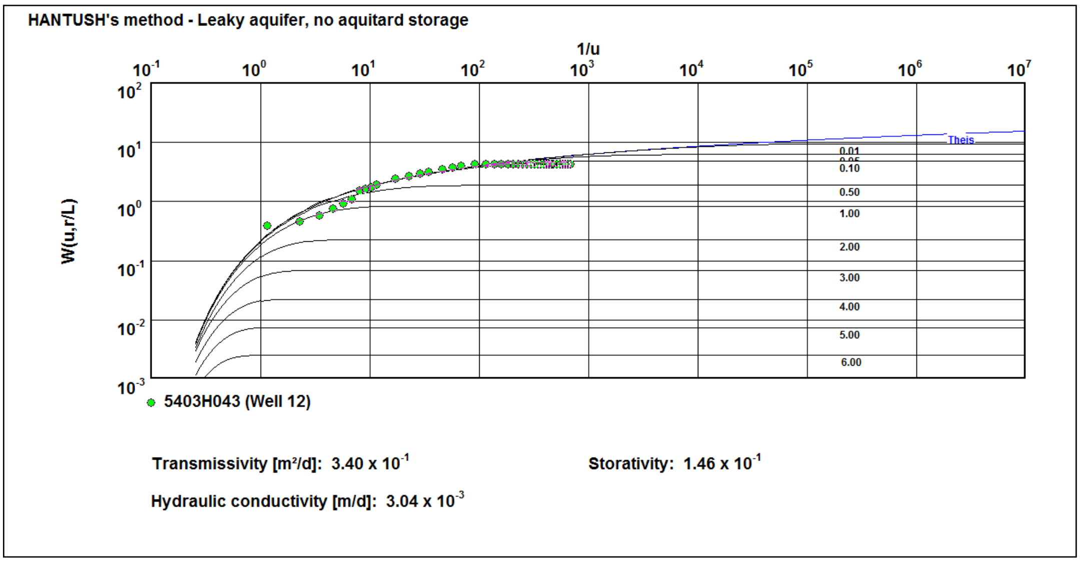


Figure 4.39 Hantush Method graph of Well 12 (5403H043)

** Remark: Well 7 (5408C020) was not analyzed because screens opened in two aquifers.

Neuman Method quit explained pumping data of floodplain deposits aquifer in study area were analyzed. The data were quite fit with the graph. Transmissivity and Hydraulic Conductivity values were showed in the Table 4.2.

Table 4.2 Conclusion of Transmissivity and Hydraulic Conductivity values in the floodplain deposits aquifer

Well No.	Aquifer Type	Neuman Method	
		Transmissivity (m^2/d)	Hydraulic Conductivity (m^2/d)
Well 1	Qfd	91.400	6.090
Well 2	Qfd	89.800	6.910
Well 6	Qfd	61.300	7.670
Well 11	Qfd	71.700	3.110

The confined aquifers in the study area, the metasedimentary aquifer and the granitic aquifer, were analyzed in threes methods as follow: Theis Method, Cooper&Jacob Method and Hantush Method. The result showed that the valued from Theis Method were similar to Cooper&Jacob Methods. For Hantush Method, the data were not fit with the graph, mean that there is no leaky aquifer in the area or very small amount of leak. Transmissivity and Hydraulic Conductivity values were showed in the table below.

Table 4.3 of Transmissivity and hydraulic conductivity values of the metasedimentary and the granitic aquifers derived from Theis, Cooper&Jacob and Hantush Methods.

Well No.	Aquifer Type	Theis Method		Cooper&Jacob Method		Hantush Method	
		Transmissivity (m^2/d)	Hydraulic Conductivity (m^2/d)	Transmissivity (m^2/d)	Hydraulic Conductivity (m^2/d)	Transmissivity (m^2/d)	Hydraulic Conductivity (m^2/d)
Well 3	PCms	9.520	0.099	8.630	0.089	9.520	0.099
Well 5	PCms	3.110	0.082	4.540	0.119	2.770	0.073
Well 8	PCms	1.840	0.023	2.570	0.032	1.460	0.018
Well 4	Gr	10.000	0.113	10.000	0.113	10.000	0.113
Well 9	Gr	0.218	0.002	0.225	0.002	0.194	0.002
Well 10	Gr	1.660	0.022	1.070	0.014	1.860	0.025
Well 12	Gr	0.382	0.003	0.457	0.004	0.340	0.003

4. Hydrogeochemical characteristics of water were analyzed and plotted Piper Diagram by using AquaChem 2011.1. The parameters were Sodium ion (Na^{+}), Magnesium ion (Mg^{2+}), Potassium ion (K^{+}), Chloride ion (Cl^{-}), Sulfate ion (SO_4^{2-}), Nitrate ion (NO_3^{-}), Bicarbonate (HCO_3^{-}) and Carbonate (CO_3^{2-}).

The data were separated into three groups, based on aquifer types

4.1 Groundwater in the floodplain deposits aquifer (Qfd)

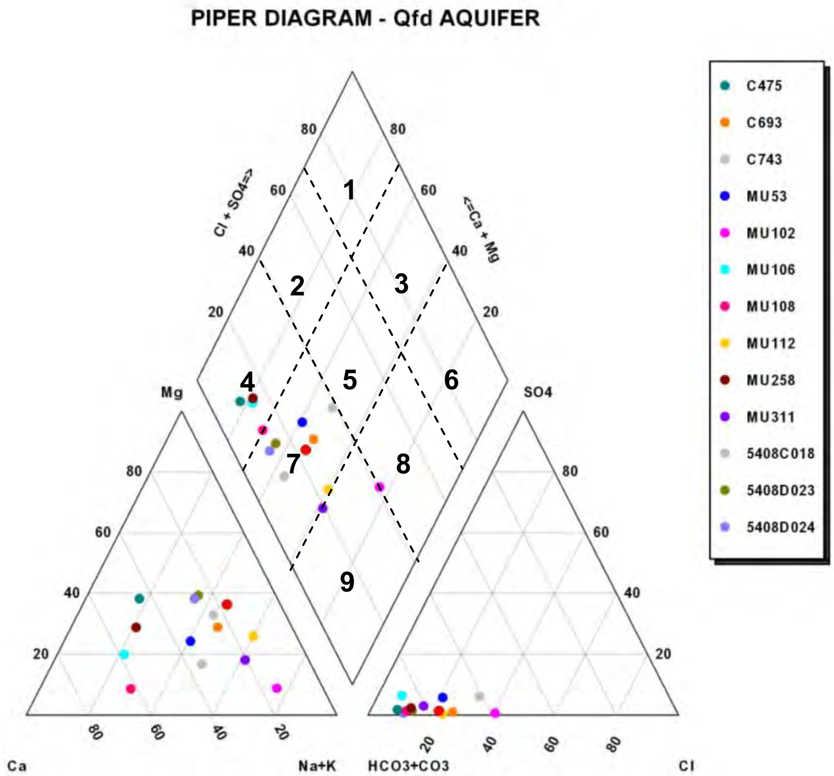


Figure 4.40 Piper Diagram of the floodplain deposits aquifer (Qfd)

Groundwater types of the floodplain deposits aquifer are in 4, 7 and 9 Zone, which are Calcium-Bicarbonate (Ca-HCO_3), Calcium-Sodium-Bicarbonate (Ca-Na-HCO_3) and Sodium-Bicarbonate (Na-HCO_3), respectively.

4.2 Groundwater in the metasedimentary aquifer (PCms)

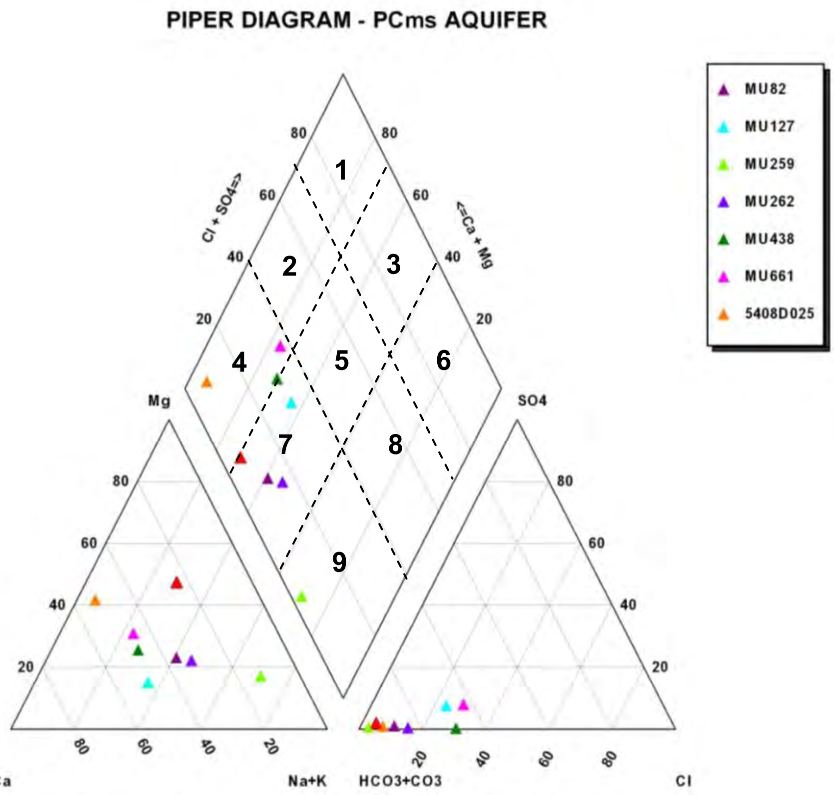


Figure 4.41 Piper Diagram of the metasedimentary aquifer (PCms)

Groundwater types of the metasedimentary aquifer are in 4, 7 and 9 Zone, which are calcium-Bicarbonate (Ca-HCO_3), Calcium-Sodium-Bicarbonate (Ca-Na-HCO_3) and Sodium-Bicarbonate (Na-HCO_3), respectively.

4.3 Groundwater in the granitic aquifer (Gr)

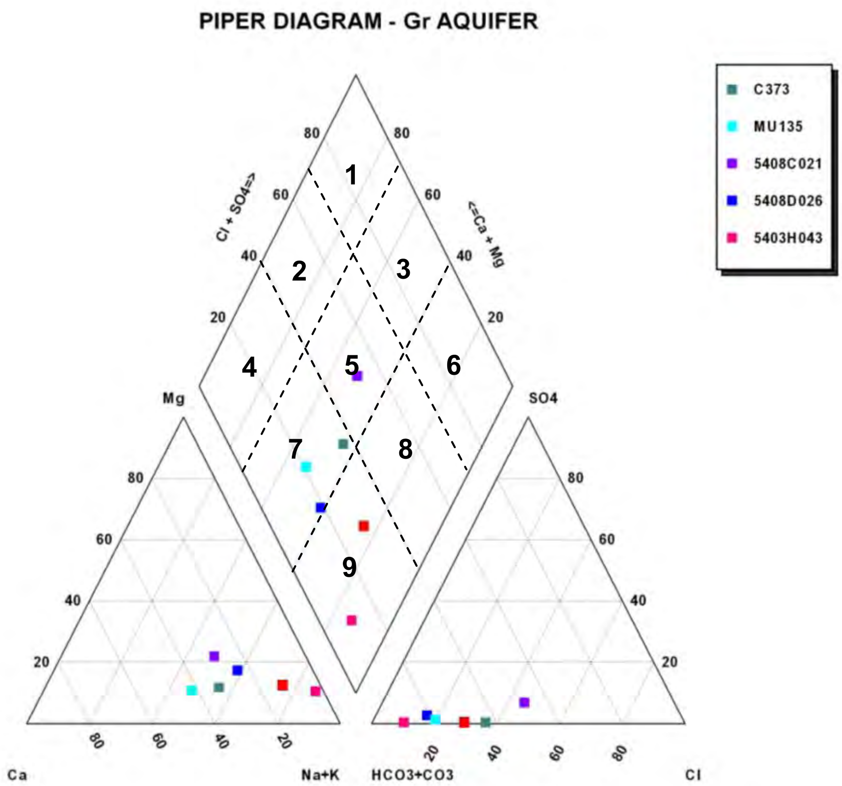


Figure 4.42 Piper Diagram of the granitic aquifer (Gr)

Groundwater types of the granitic aquifer are in 5, 7 and 9 Zone, which are Calcium-Sodium-Bicarbonate-Chloride (Ca-Na-HCO_3-Cl), Calcium-Sodium-Bicarbonate (Ca-Na-HCO_3) and Sodium-Bicarbonate (Na-HCO_3), respectively.

CHAPTER V

DISCUSSION AND CONCLUSION

5.1 Discussion and Conclusion

In Huay Sai Royal Development Study Center and adjacent areas, Amphoe Cha-am, Changwat Phetchaburi, there are three types of aquifers: 1) Floodplain deposits aquifer (Qfd) 2) Metasedimentary aquifer (PCms) 3) Granitic aquifer (Gr). The floodplain deposits aquifer and metasedimentary aquifer distributed in Tambon Sam Phraya, Tambon Huay Sai Nua and Tambon Rai Mai Phattana. The granitic aquifer was found in Tambon Sam Phraya, eastern part of study area. Groundwater in the floodplain deposits and the metasedimentary aquifers mainly flow from south-western area to north-eastern area.

As mentioned in Table 4.2 and 4.3, the floodplain deposits aquifer (Qfd) yield the highest groundwater potential, which associated to values of Transmissivity (T) and Hydraulic Conductivity (K). Moreover, transmissivity of three aquifers are in the following order: the floodplain deposits aquifer yields (ranged from 61.300-91.400 m^2/d) > the metasedimentary quifer (ranged from 1.840-9.520 m^2/d) > the granitic aquifer (ranged from 0.218-10.000 m^2/d). However, cones of depression were found in some areas as a result of intensive pumping for agricultural purposes.

Most of groundwater types in the study area are Calcium-Bicarbonate (Ca-HCO_3), Sodium-Bicarbonate (Na-HCO_3), Calcium-Sodium-Bicarbonate (Ca-Na-HCO_3) and Calcium-Sodium-Bicarbonate-Chloride (Ca-Na-HCO_3-Cl) due to the ion dissolution in Qfd, PCms and Gr Aquifers. The hardness of water is not over than consumption standard (500 mg/L), but the water should be boiled in order to make it safe for drinking.

5.2 Recommendation

1. Request Data from the Department of Groundwater Resources took a very long time because of the complicated process and flooding hazard in Bangkok.

2. Although, there were a lot of lithologic well logs, the data were lack of some values and data reliability. The data needed to be classified carefully, associated with the others data.

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APPENDICES

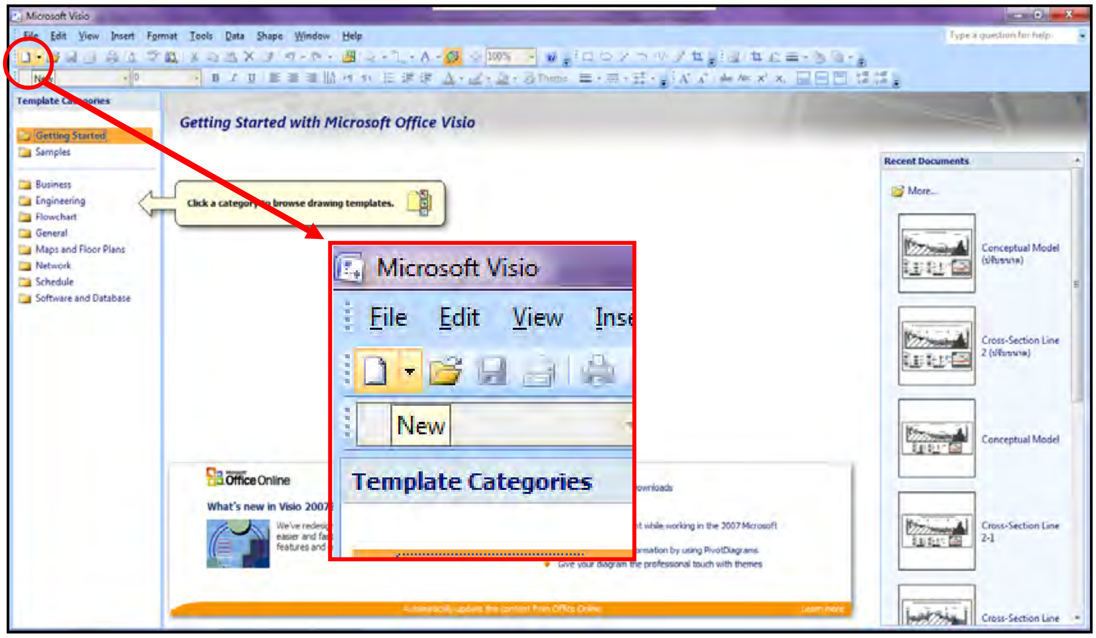
APPENDIX A

Microsoft Office Visio 2007

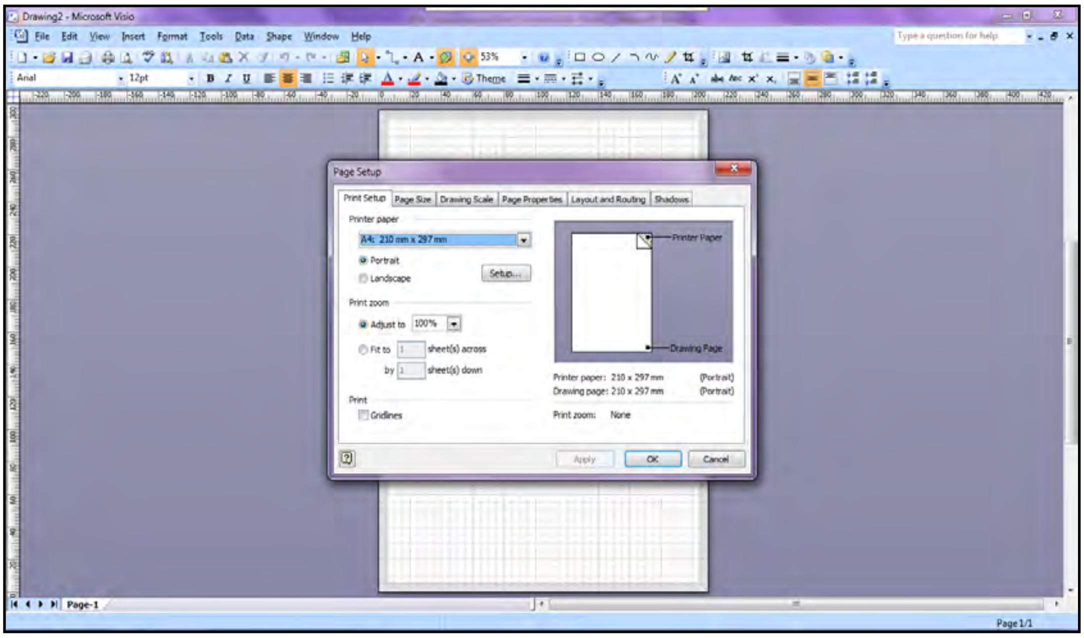
Microsoft Office Visio 2007 is one of program in Microsoft Office 2007. It helps in creating diagrams for understanding, documenting, and analyzing information, data, systems, and processes. It is used easily because all functions are similar to Microsoft Office Word 2007 or Microsoft Office PowerPoint 2007, which are used worldwide.

For the senior project, this program is used for creating hydrogeologic cross-sections in 2 dimensions display. The principle is to copy pattern from draft and establish the picture. There are the easy steps as follow.

1. Draw hydrogeologic cross-section as a draft, then scan it into computer. Graph paper is recommended to use in this case.
2. Open Microsoft Office Visio 2007 and click New to create a new work.

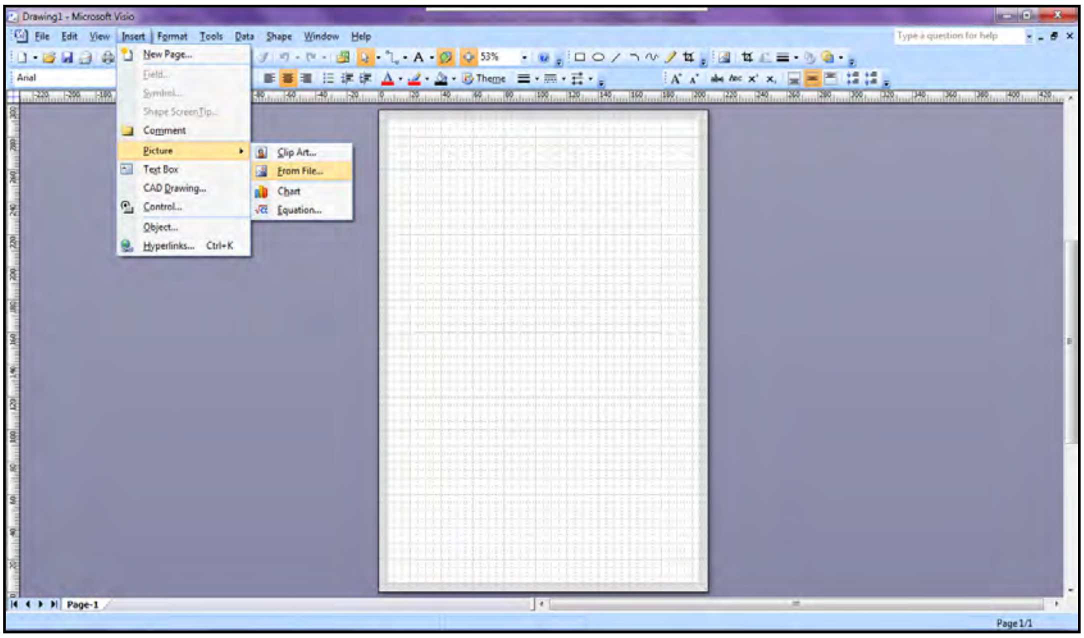


3. Click File> Page setup to adjust paper size and positioning of paper, if desire.

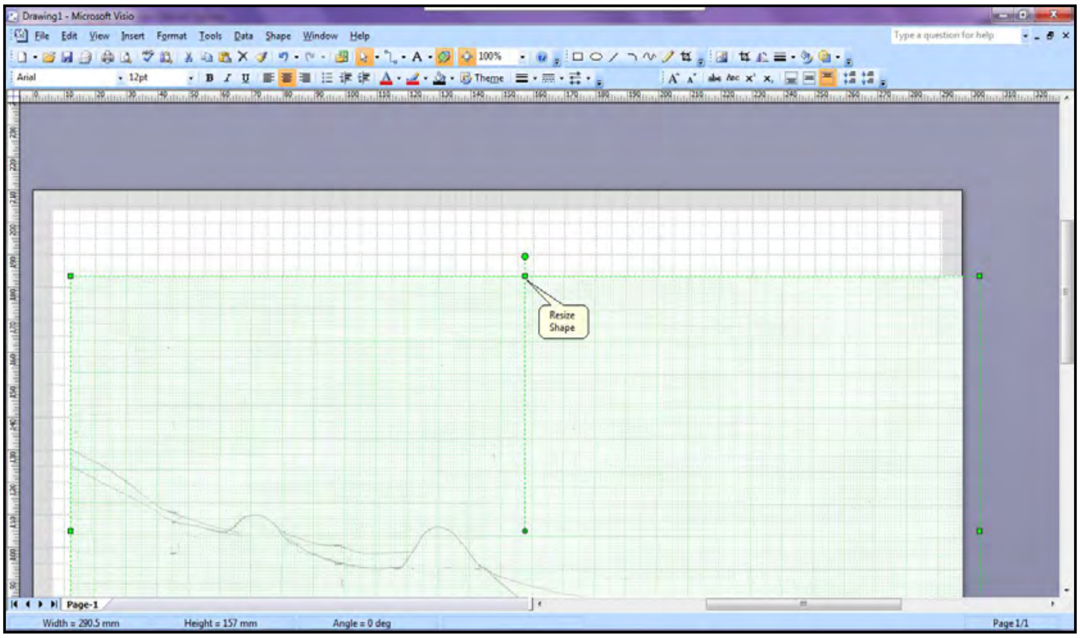


4. Insert a cross-section draft that is scanned by click Insert> Picture> From file…>

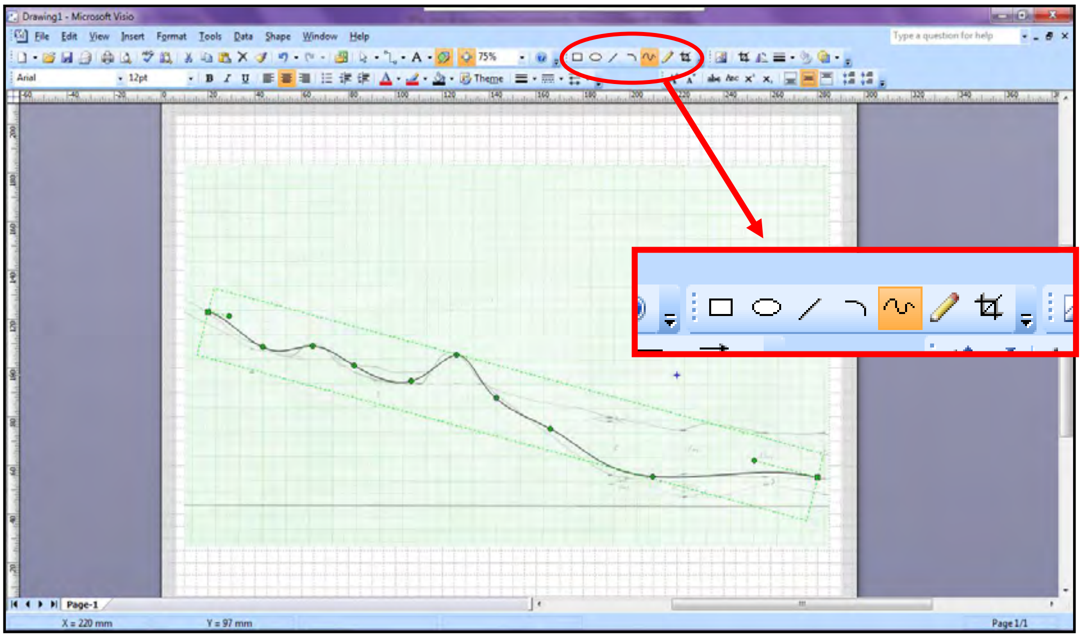
Choose source of file> Open.



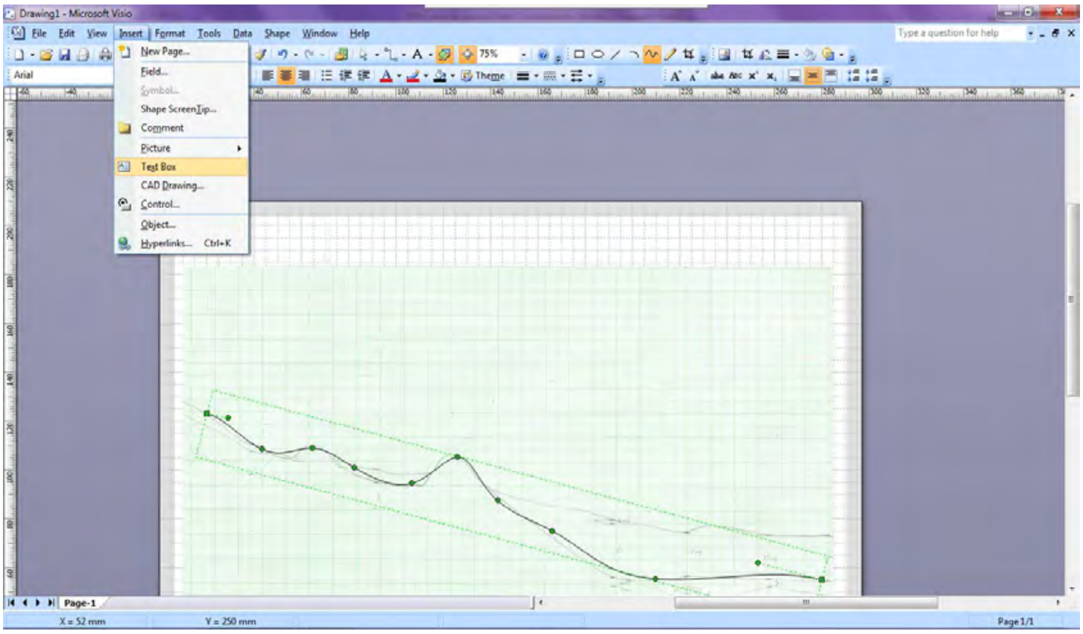
5. Adjust scale in graph paper to match with scale in the program, by resizing shape or rotating shape at the edge of picture.



6. Copy pattern by using tools bar, copy picture as a draft.

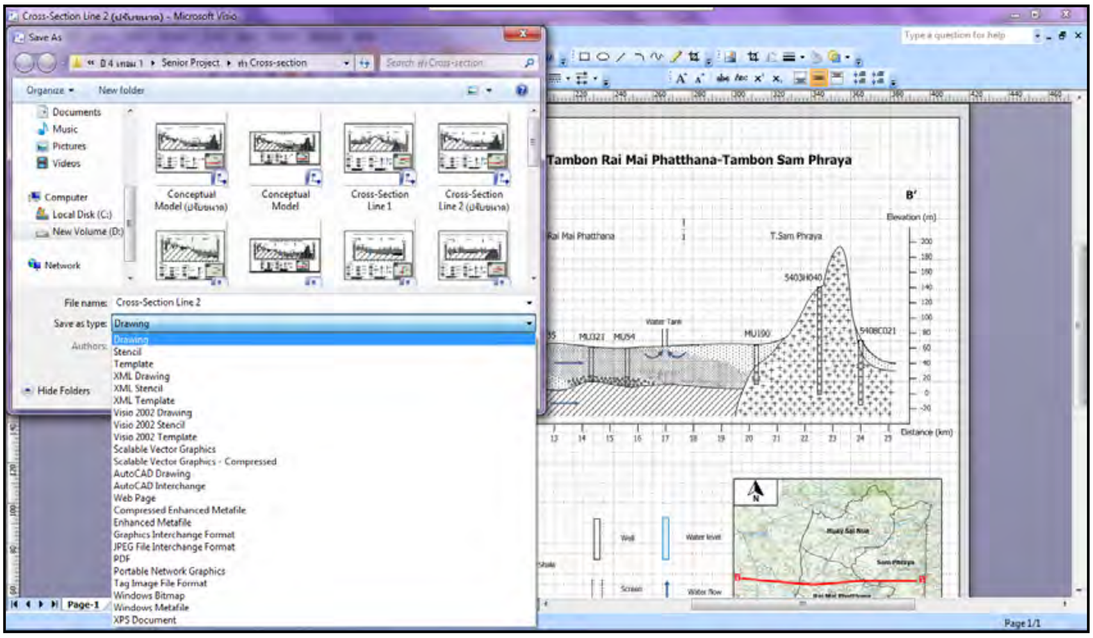


7. Create text by click Insert> Text box> Type words.



8. All lines and texts can be colored or size adjusted as same as Microsoft Office Word 2007 or Microsoft Office PowerPoint 2007.

9. After work is done, delete draft paper and save file. Click File> Save as…> Choose folder, give file name and file type as desire: drawing, JPEG, PDF or TIF are available.

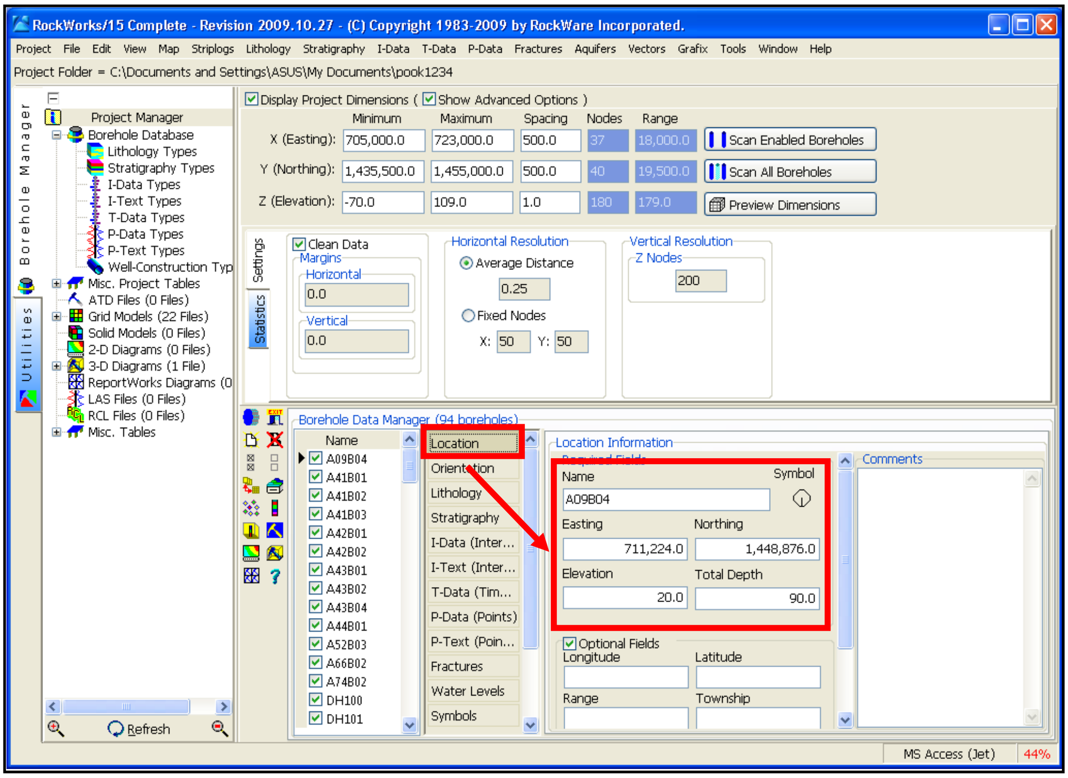


<u>RockWork 15</u>

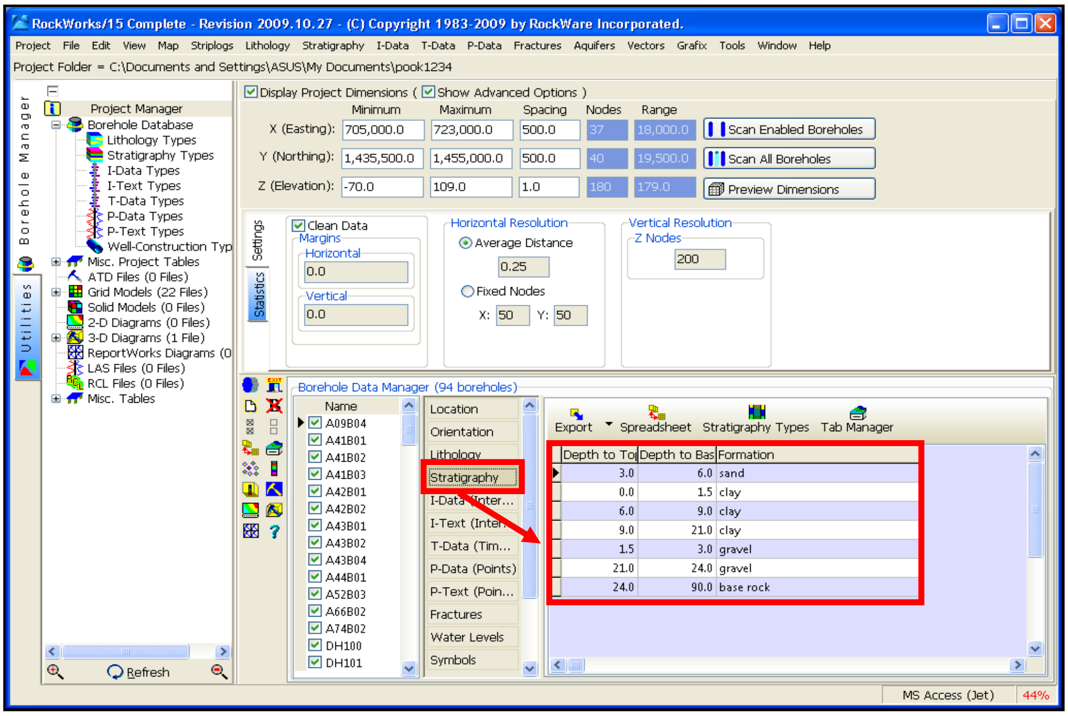
RockWork 15 is a program that is used in the petroleum, environmental, geotechnical and mining industries for subsurface data visualization for a long time. The program can construct various type of display: map, log, cross-section, fence diagram, solid model and volumetric.

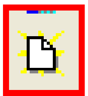
For the senior project, this program is used for creating hydrogeologic cross-sections in 3 dimensions display. There are the several steps as follow.

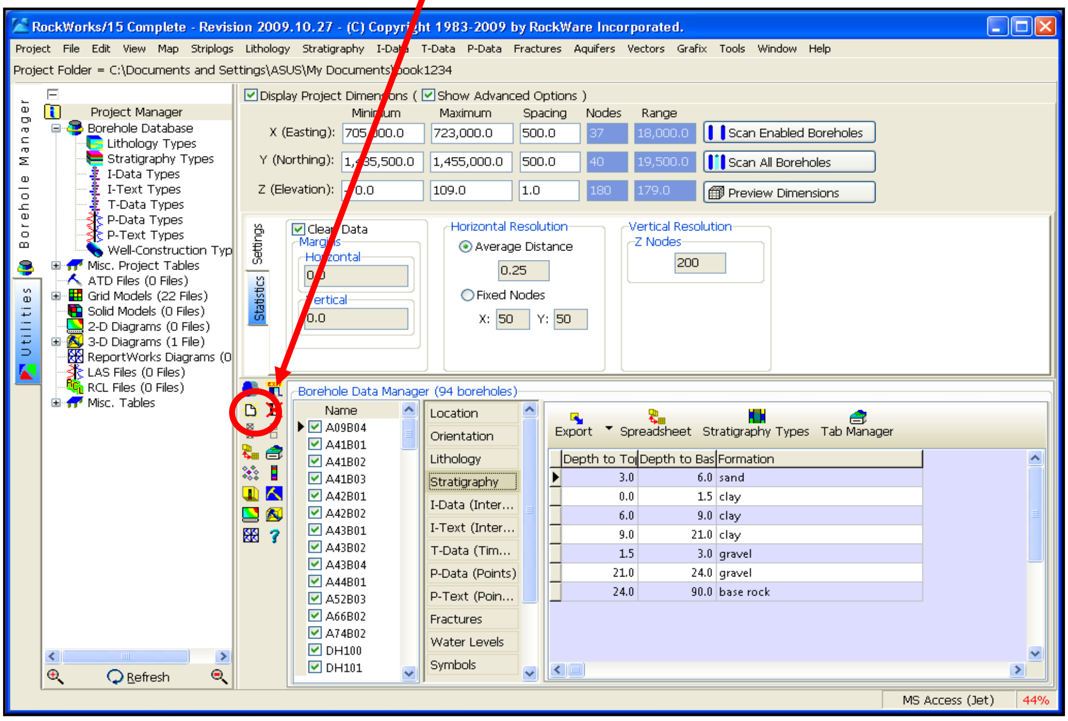
1. Open RockWork 15 Program> click Location Topic> Type Name, Eating, Northing, Elevation, Total Depth



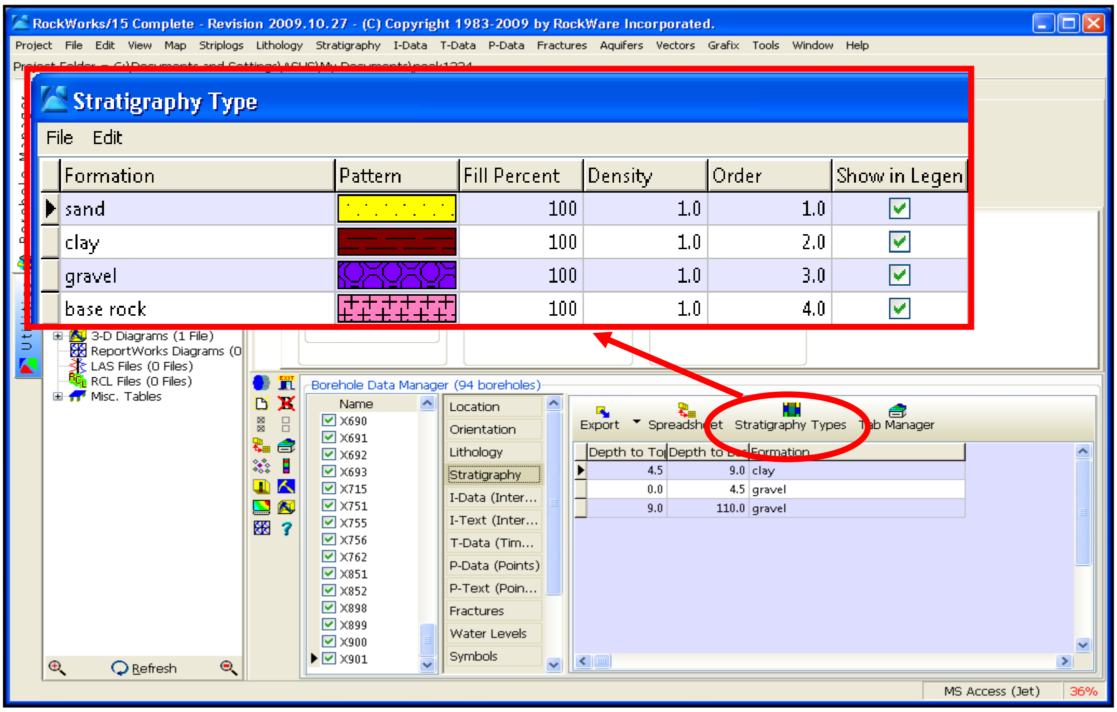
2. Click Stratigraphy Topic> Fill out lithologic data: Depth to Top, Depth to Bottom and Formation Type



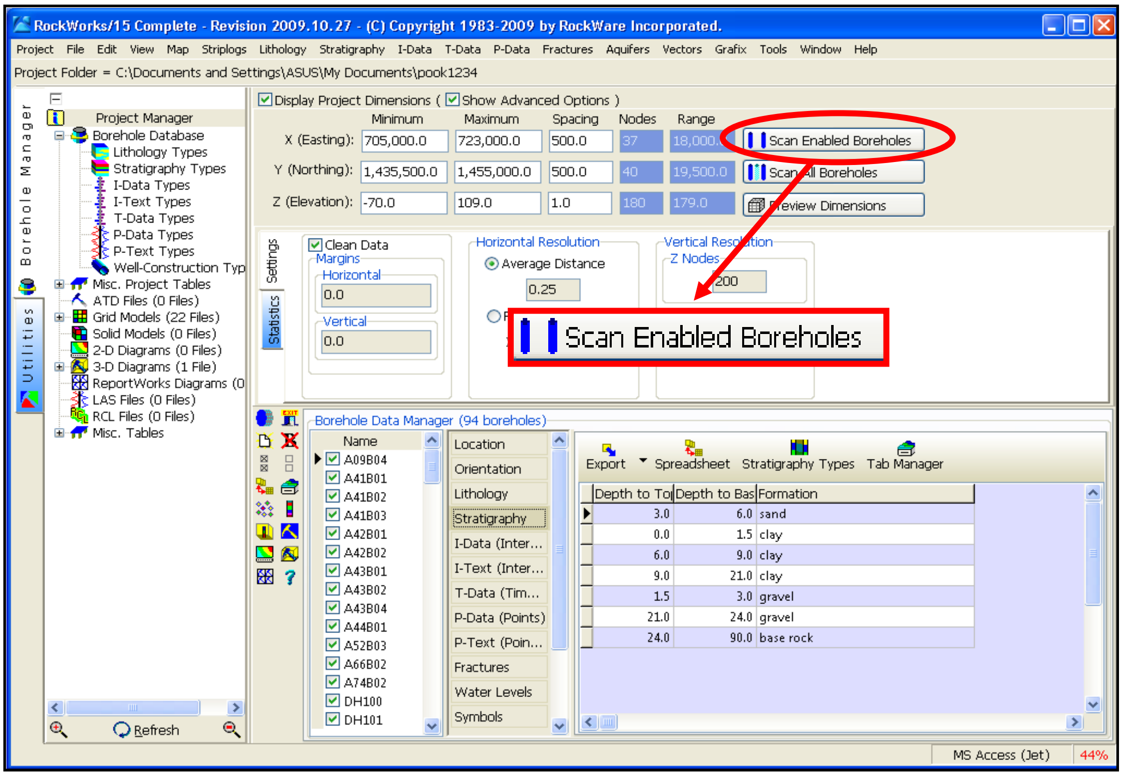
3. Fill out all lithologic data, click  icon to insert a new well



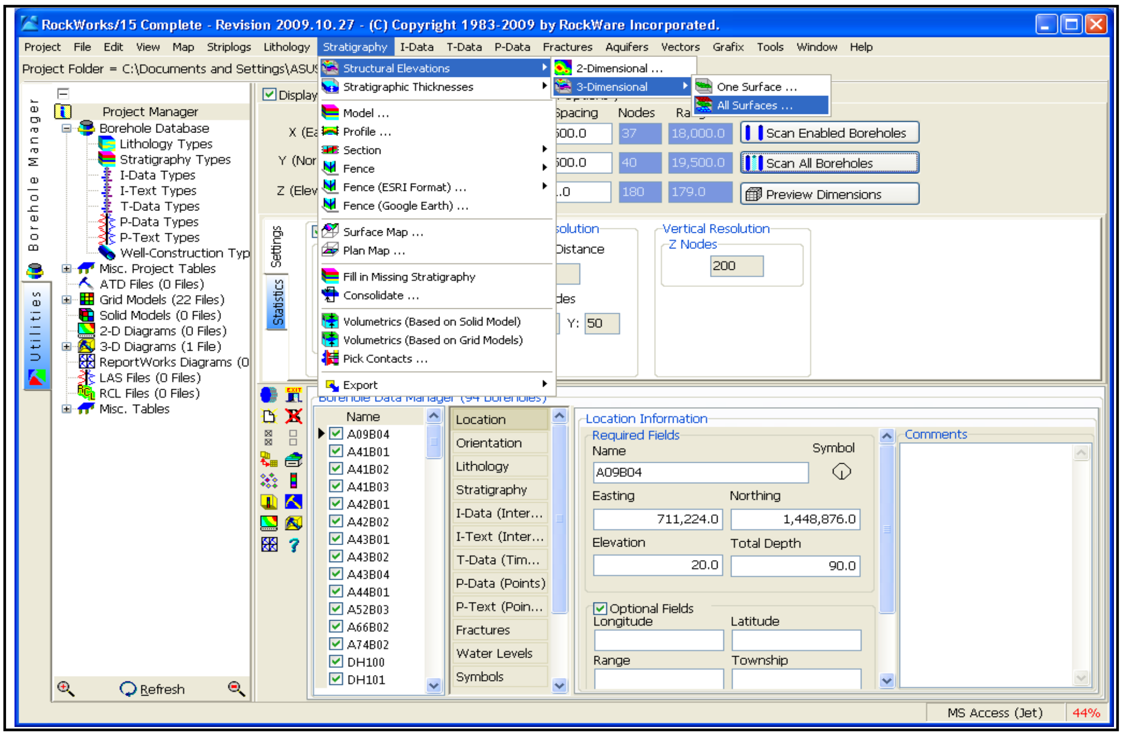
4. Double click Stratigraphy Types to change symbol, if desire.



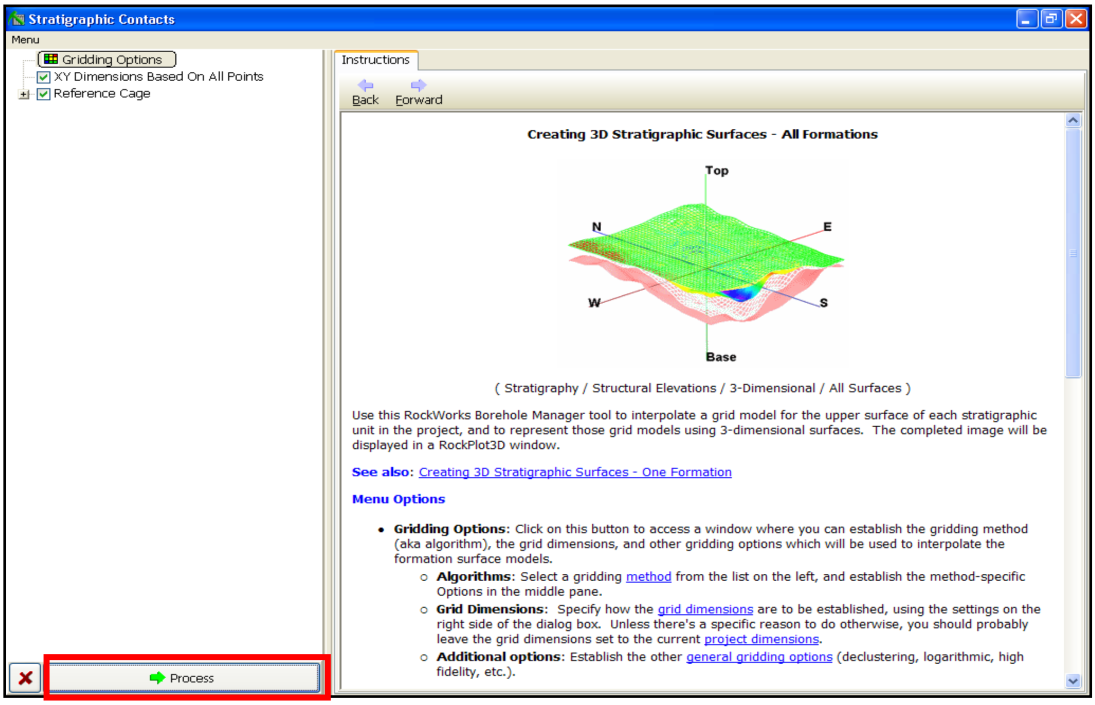
5. After fill out all data click Scan All Boreholes



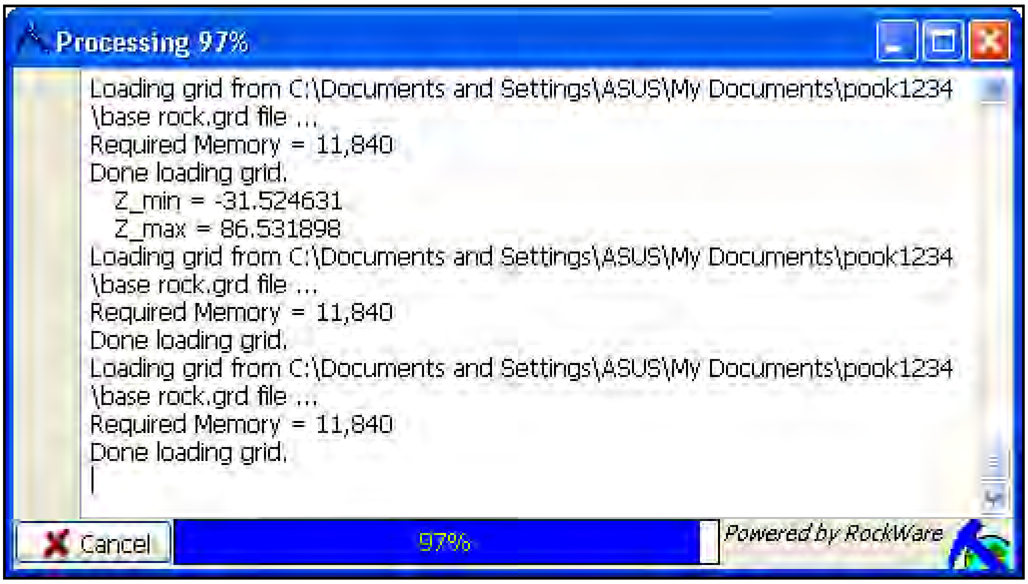
6. Click Stratigraphy> Structural Elevations> 3Dimensional> All Surfaces

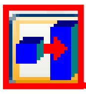


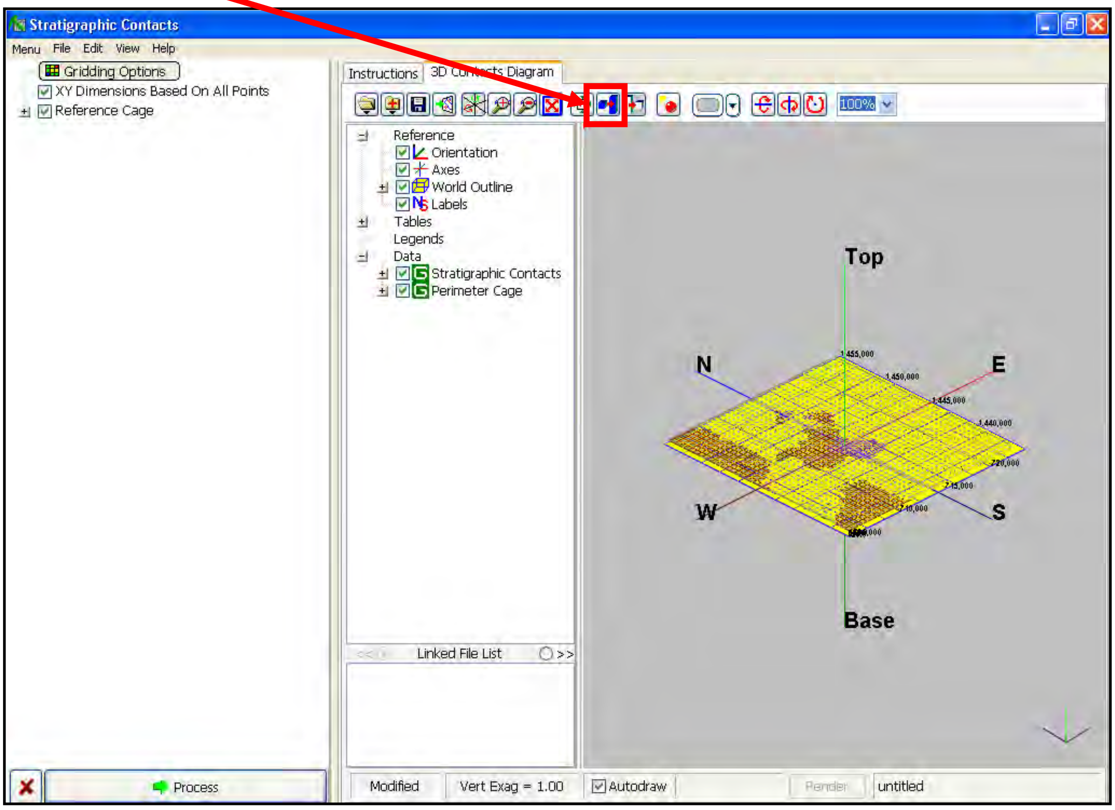
7. Stratigraphic Contacts window will appear> click Process



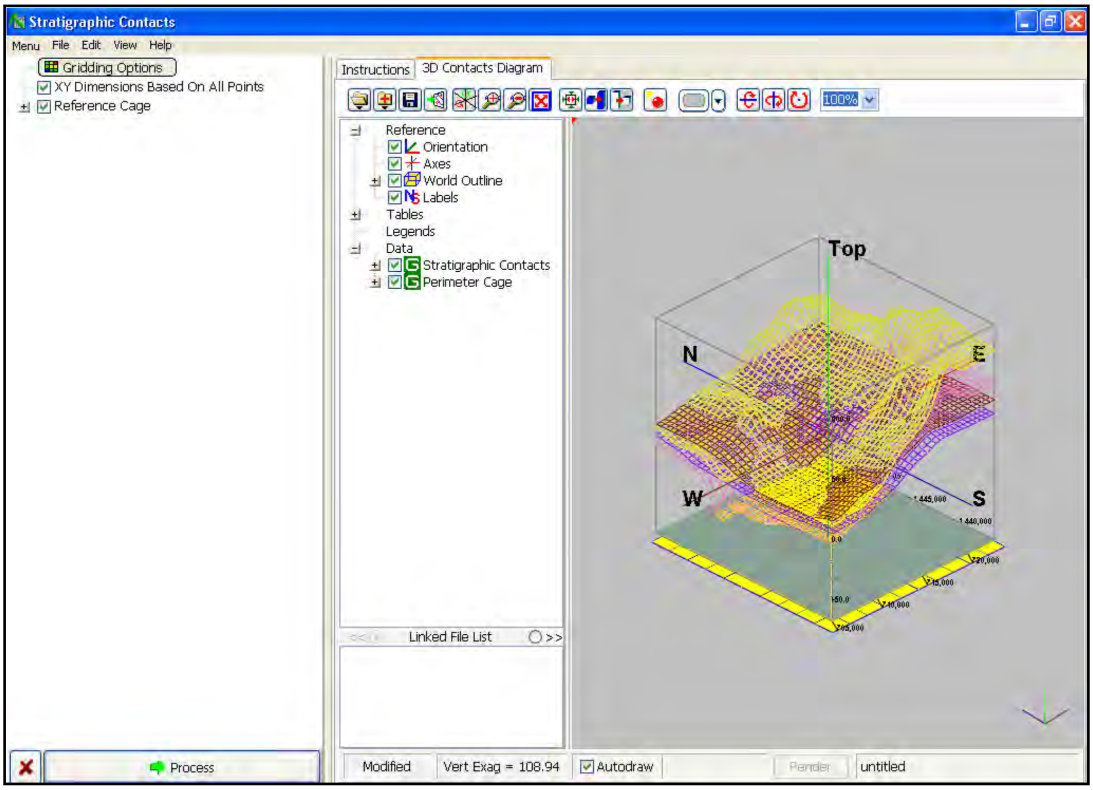
8. Processing window will appear, wait for a while.



9. Click  icon to maximize the 3D model



10. The model can be rotate 360° by click at the model and move a mouse as desire.

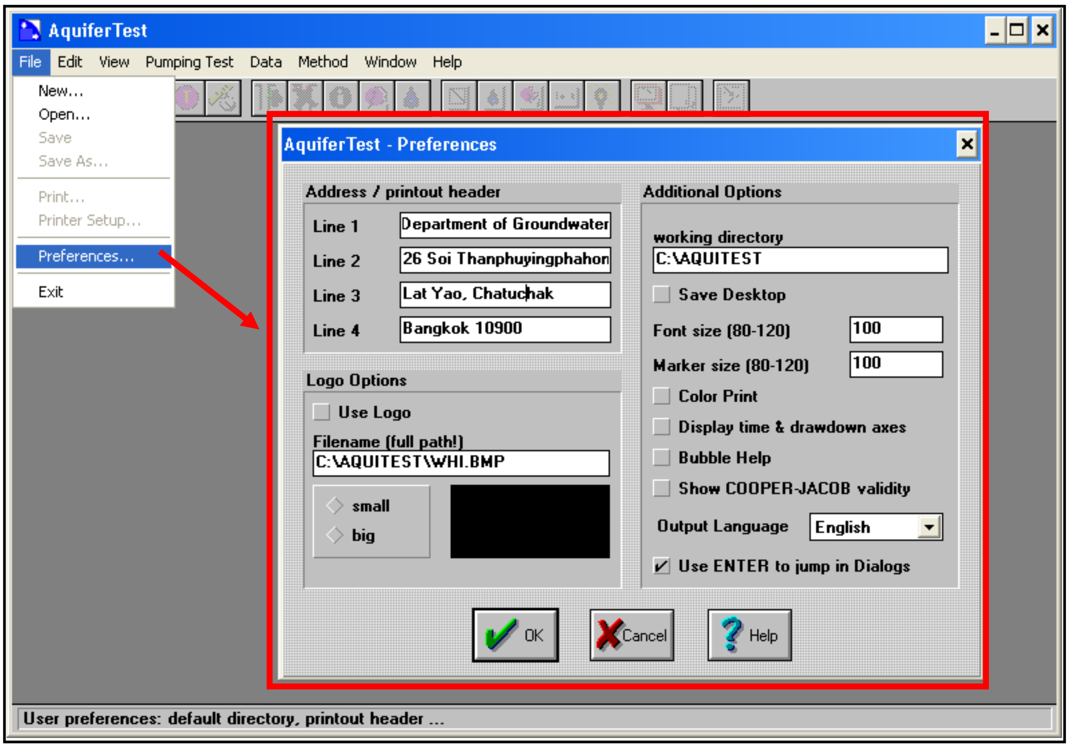


AquiferTest Version 2.5

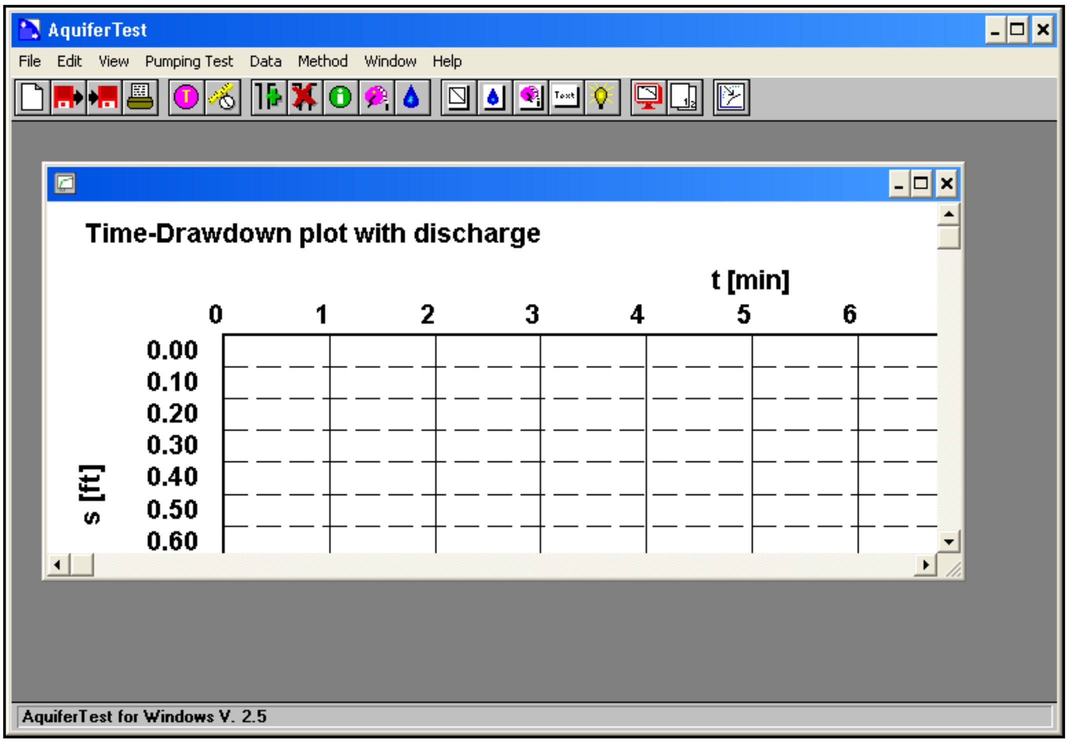
AuiferTest Version 2.5 is a software for pumping test analysis. There are many method for analysis, such as Theis Method, Cooper&Jacob Method, Neuman Method, Hantush Method which is proper with different aquifers.

For the senior project, there are four methods as mentioned above which are used for analysis. There are several steps as follow.

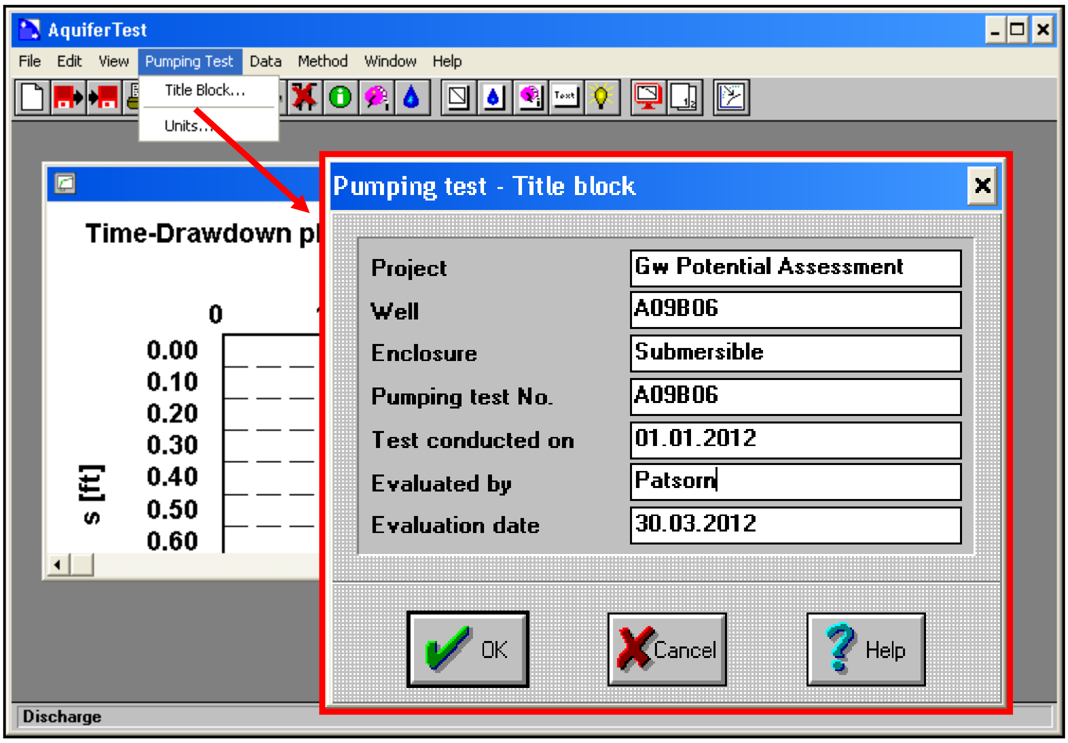
1. Prepare raw data in Microsoft Office Excel. The data should cover time (minute) in the first column and water level (m) in the second column.
2. Open AquiferTest Version 2.5 Program, click File> Preferences…> Fill out address of data owner> OK



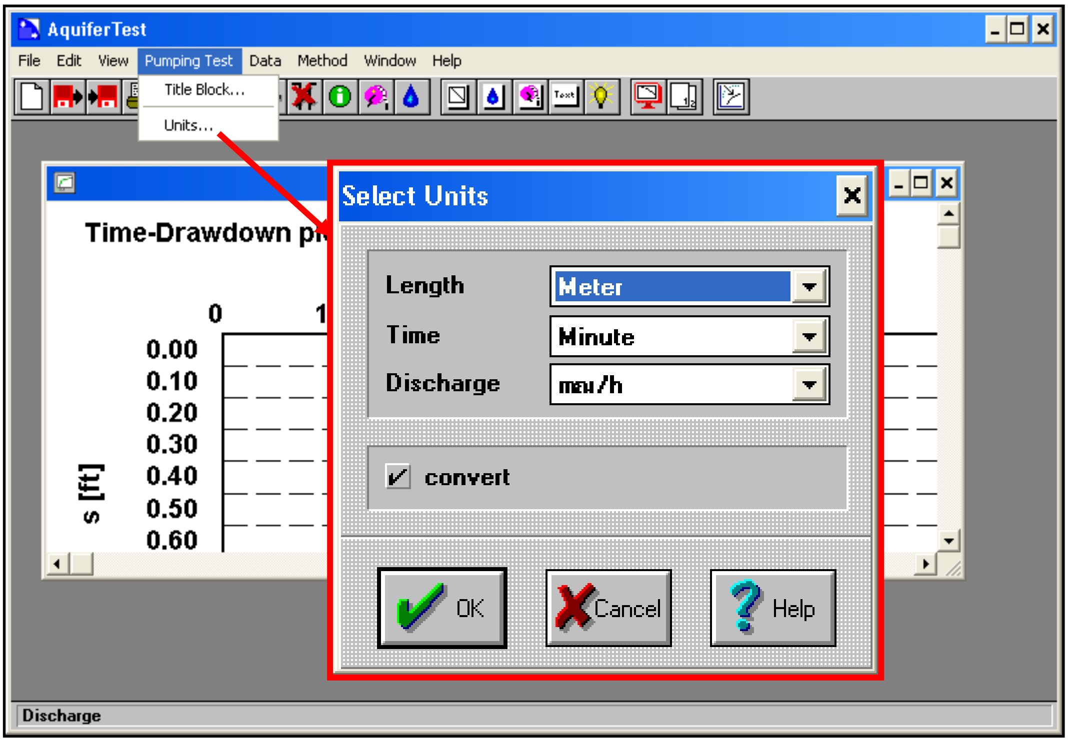
3. Click File> New… to create new work



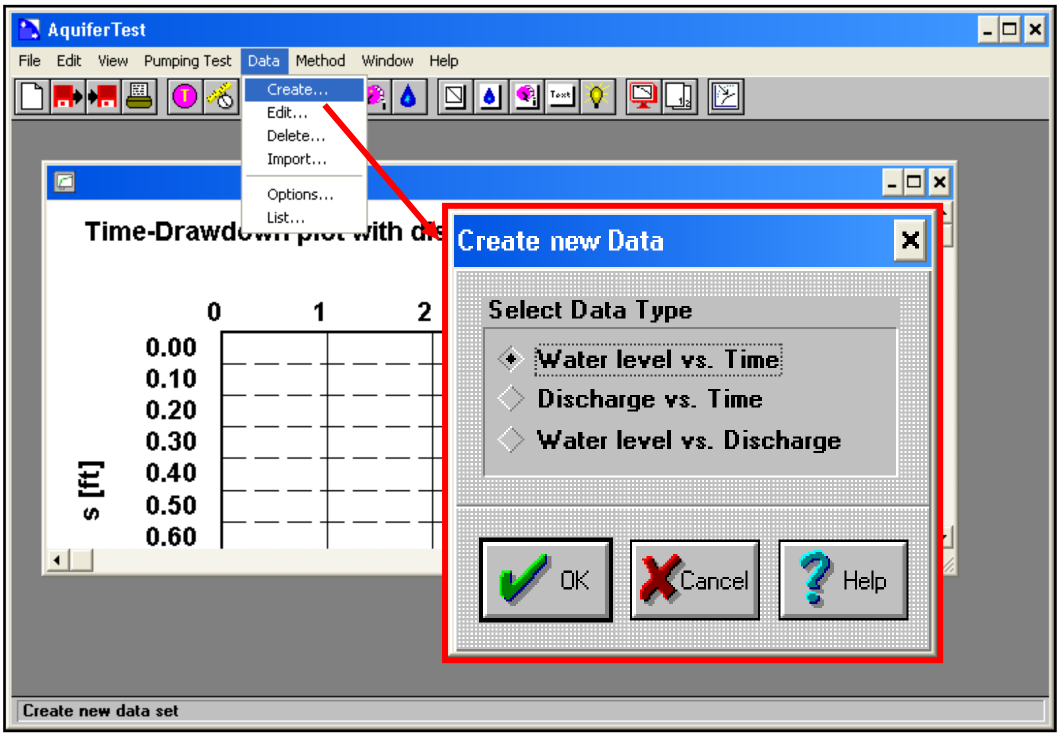
4. Click Pumping Test> Title Block…> Fill out well's detail> OK



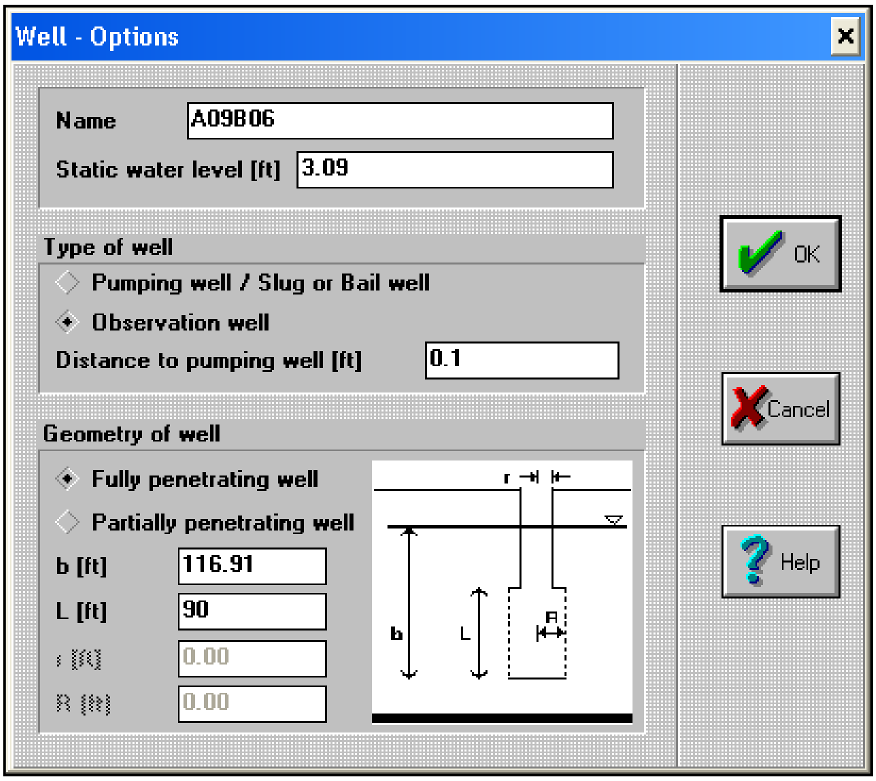
5. Click Pumping Test> Units…> change unit as below> OK



6. Click Data> Create…> choose Water level vs. Time> OK



7. Well-Options will appear automatically, fill out well detail as below.



b (m) = Well depth-Static water level

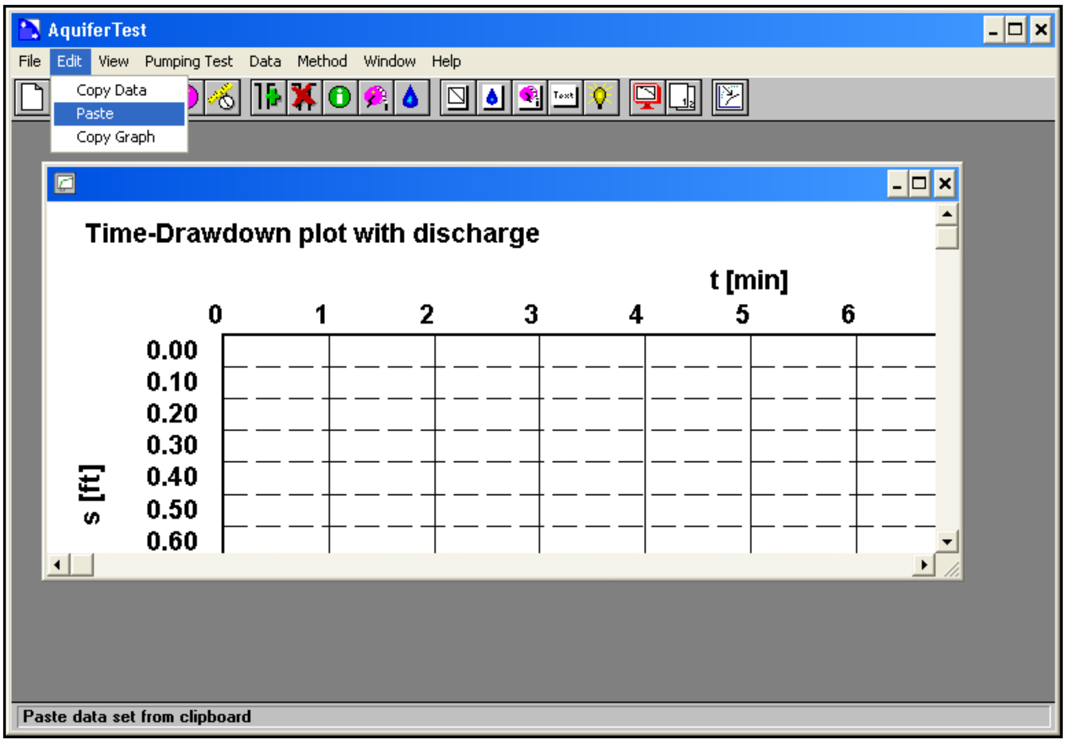
L (m) = Aquifer thickness or screen thickness

Click OK

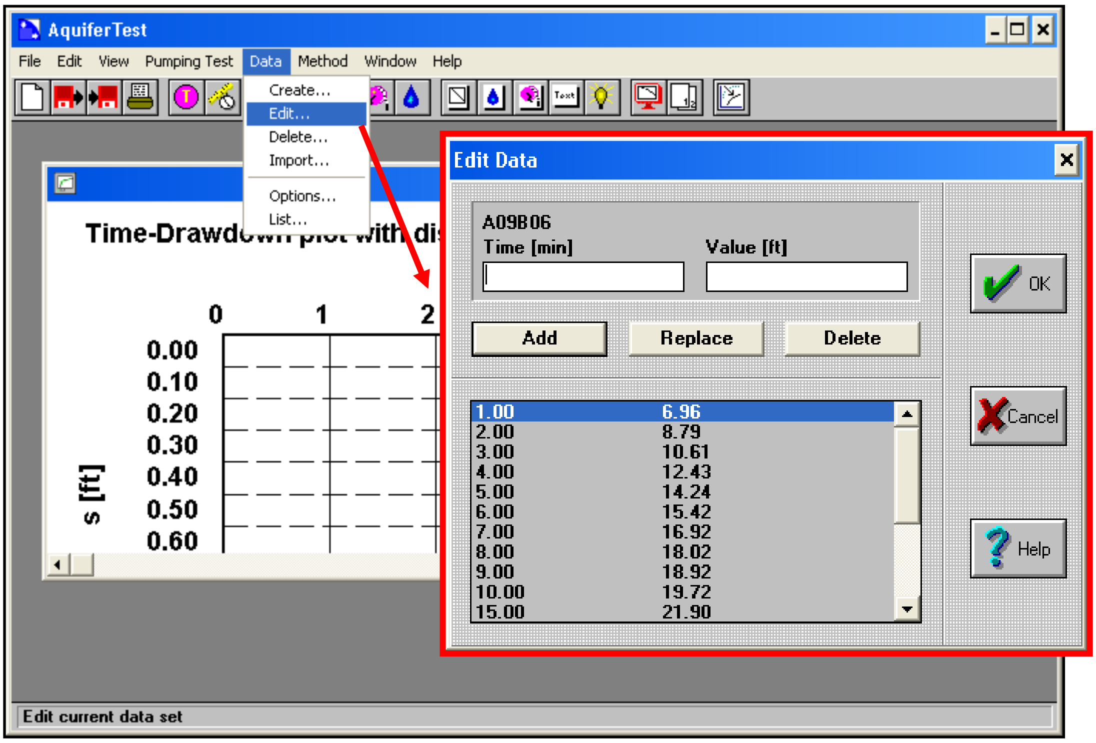
8. Edit Data window will appear, click Close

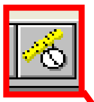
9. Open Excel file from step 1, darken both of two column, then copy.

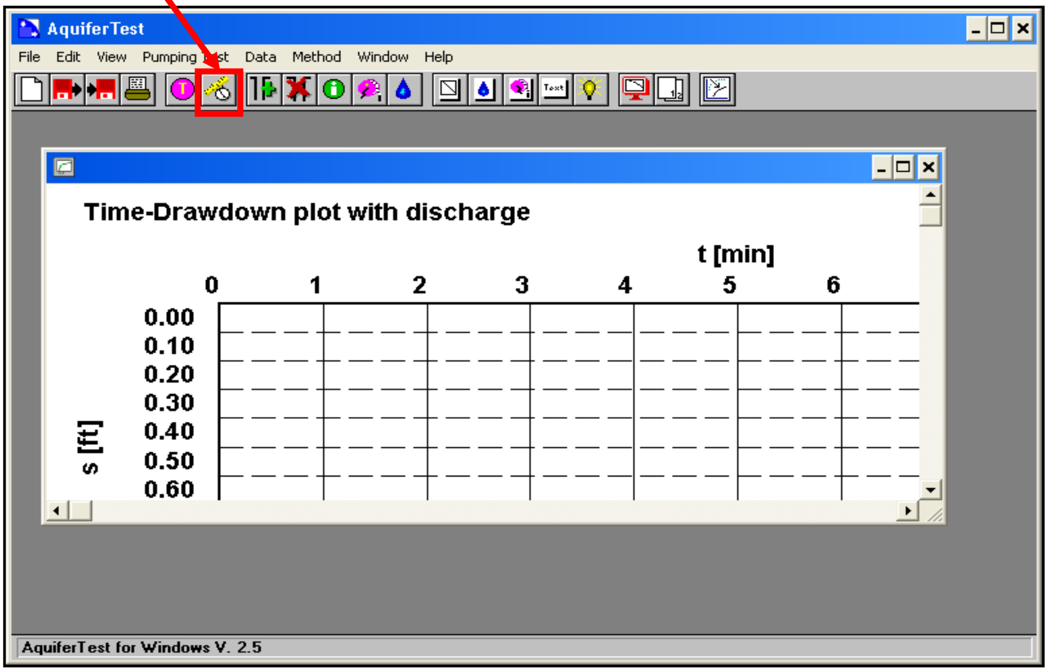
10. Open Aquifer Test window again, click Edit> Paste



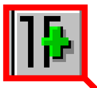
11. Click Data> Edit…> check imported data and click OK

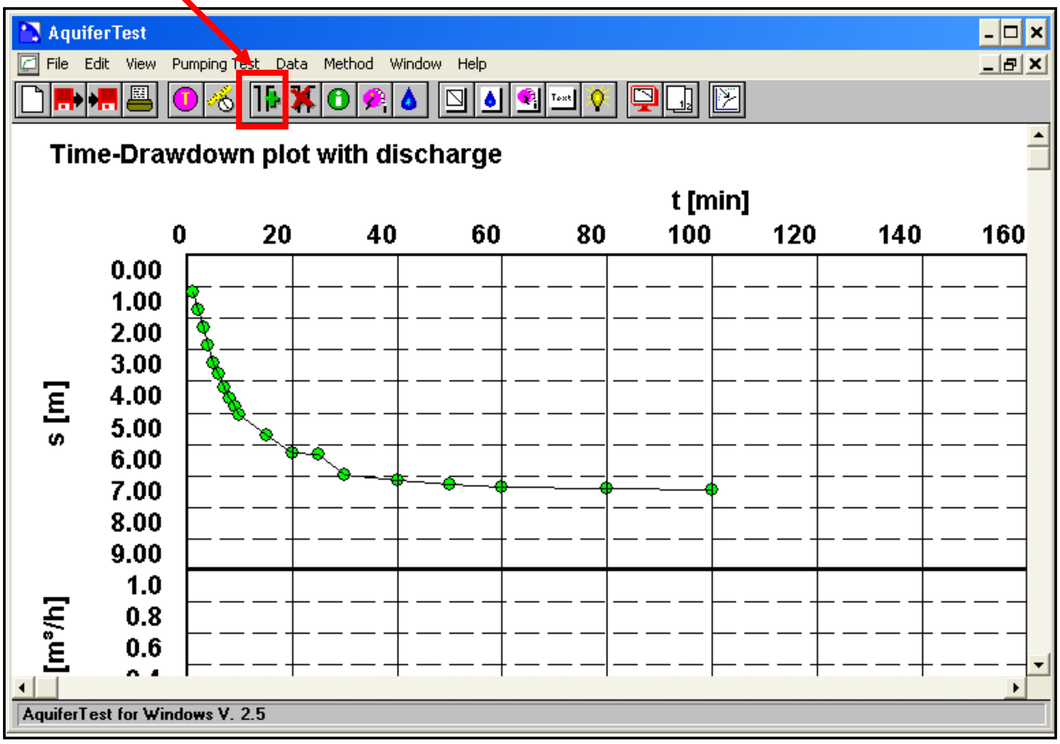


12. Click  icon to transfer numerical data to be a graph.

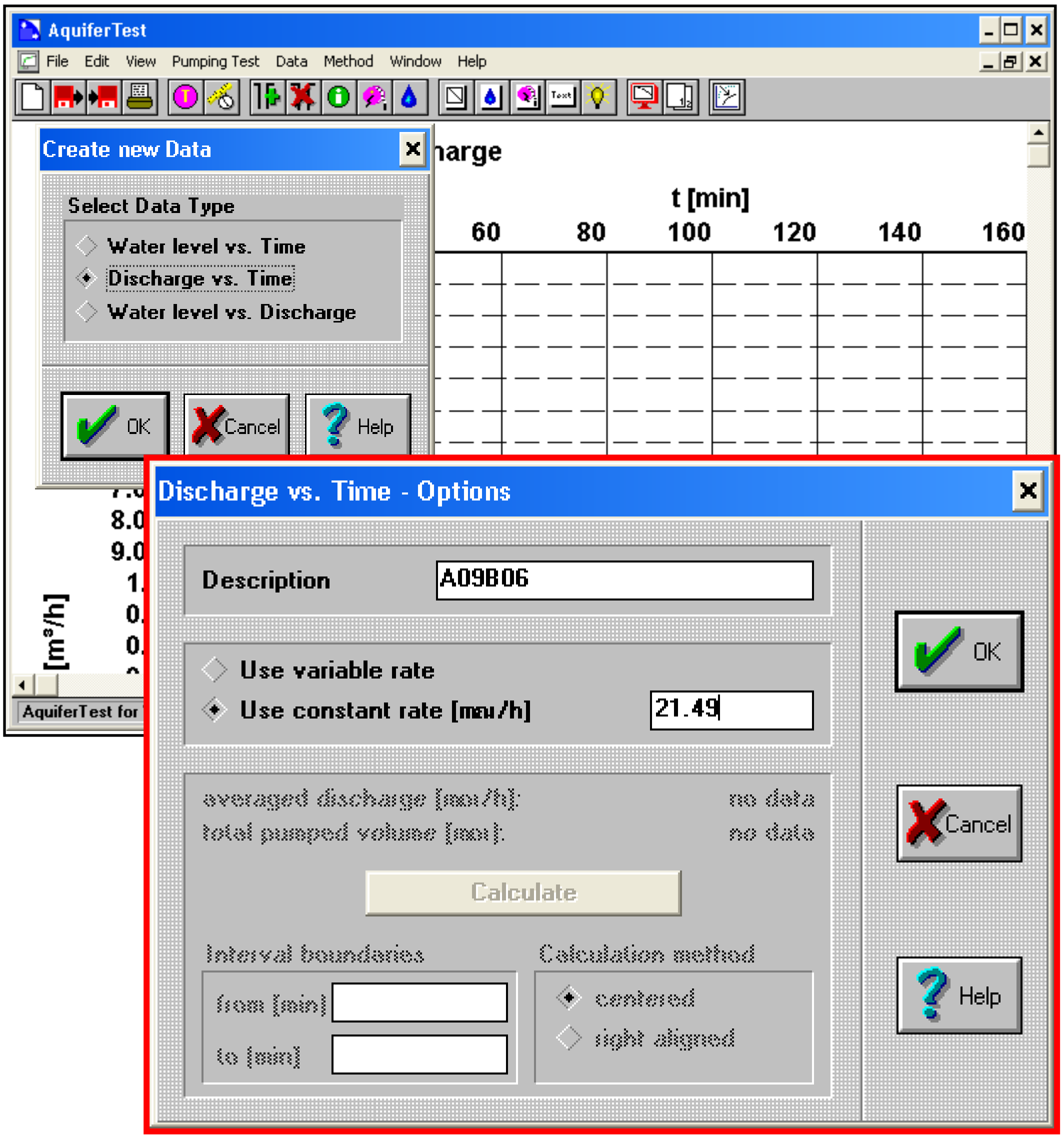


13. Unit window will appear again, check unit and click OK

14. Click  icon to input pumping rate data



15. Create new Data will appear, choose Discharge vs. Time> OK> fill out pumping rate as below> OK



16. Next step is to choose method of analysis. There are several methods which are proper with different. In this study, there four methods which were used as below.

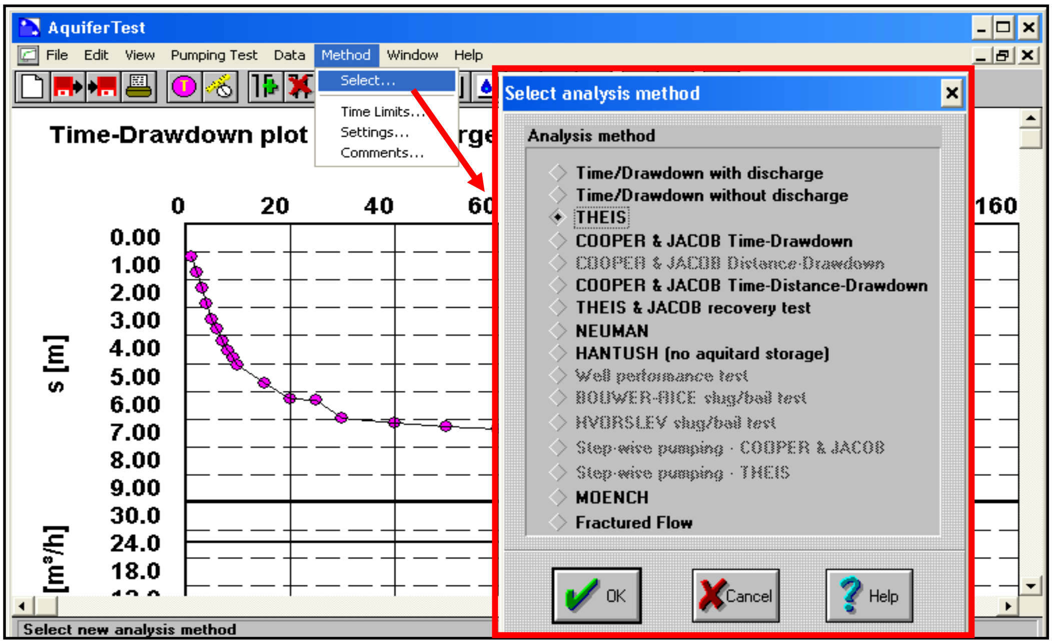
16.1 Neuman Method - Unconfined aquifer

16.2 Theis Method - Confined aquifer

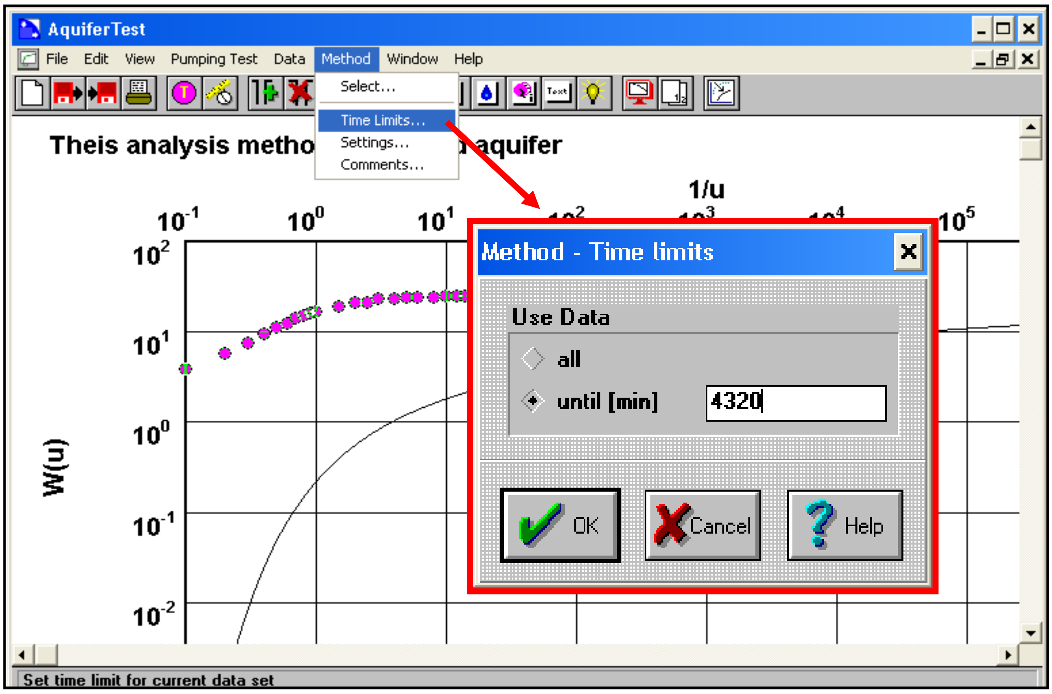
16.3 Cooper&Jacob Time-Drawdown Method - Confined auifer

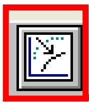
16.4 Hantush Method - Leaky auifer

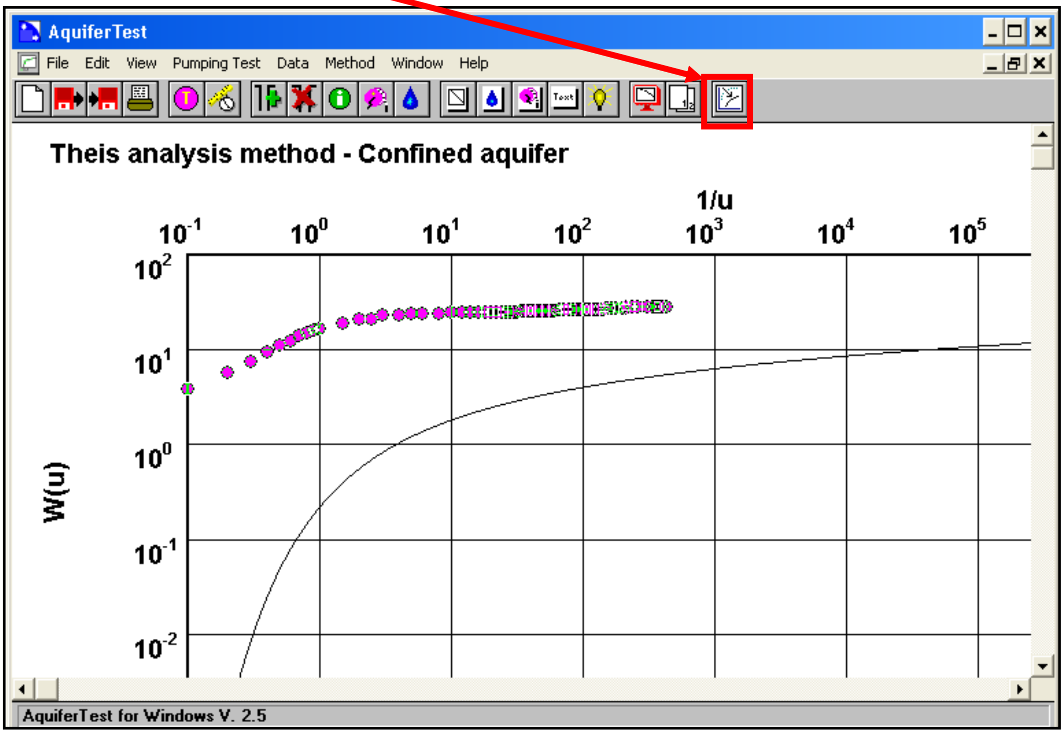
Choose a method by click Method> Select…> choose method> OK



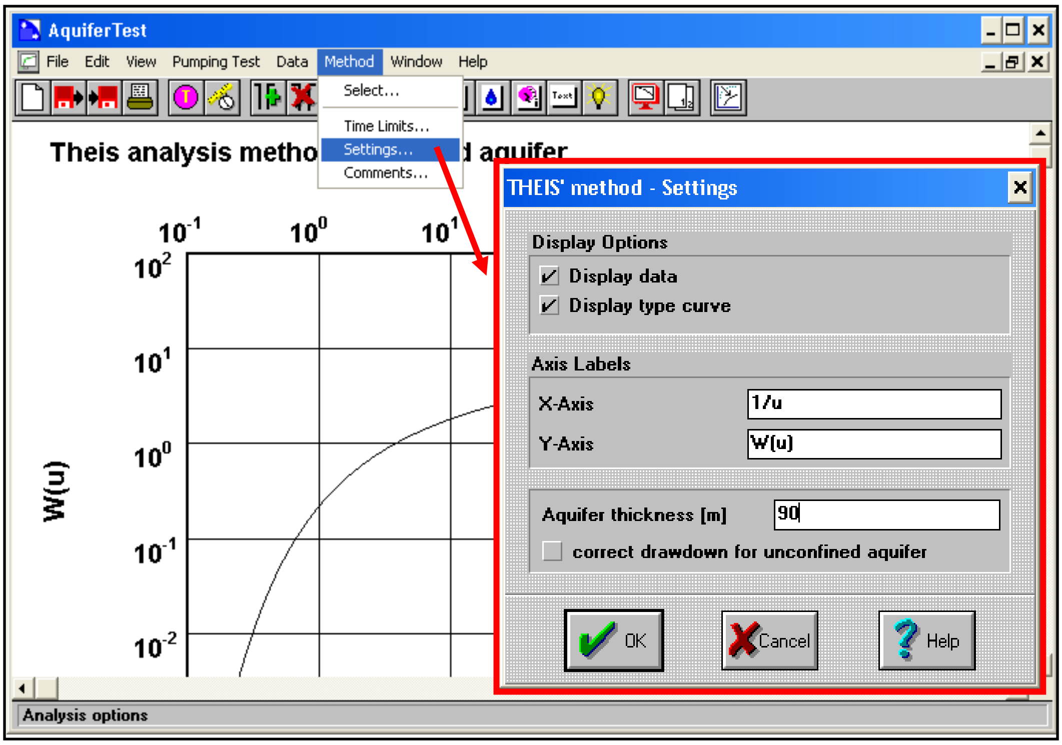
17. For Theis Method case, click Method> Time Limits…> Input time (which stop pumping)> OK



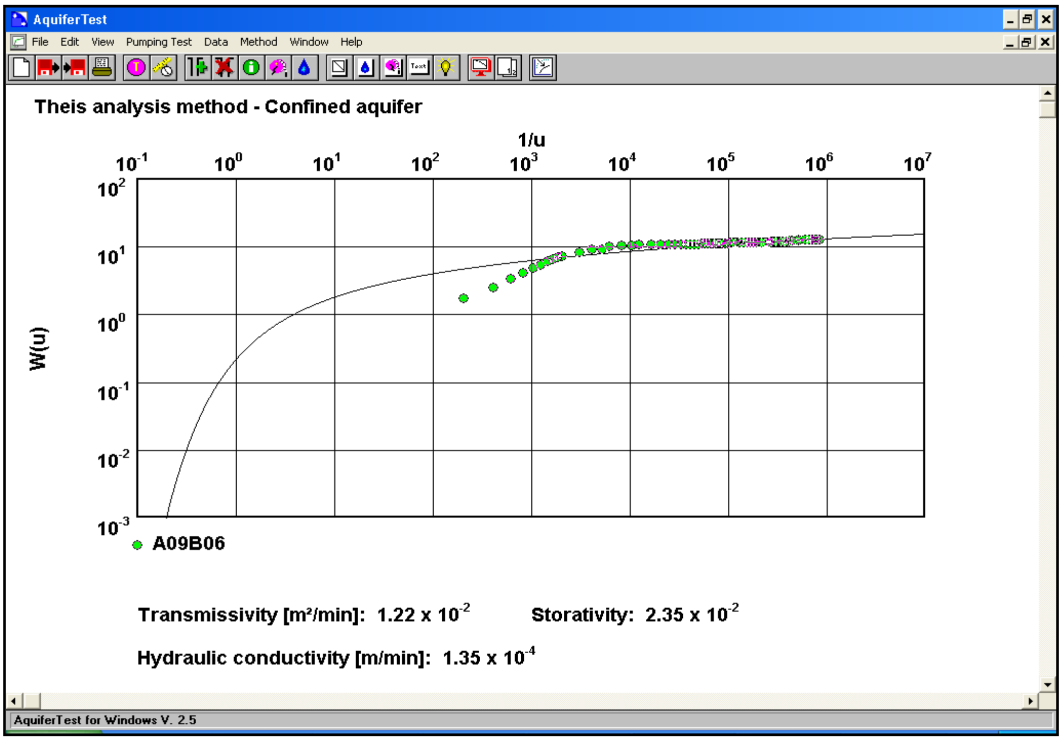
18. Click  icon to fit graph with Type Curve, fit manually is available by using arrow.



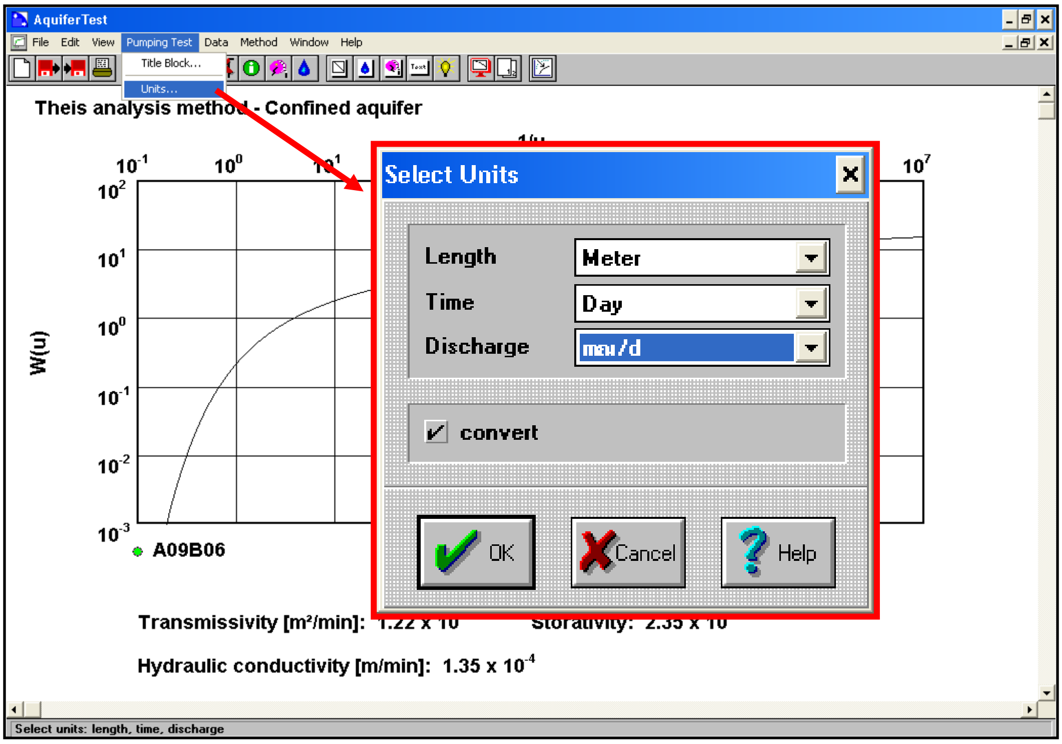
19. Click Method> Settings…> input Aquifer thickness> OK



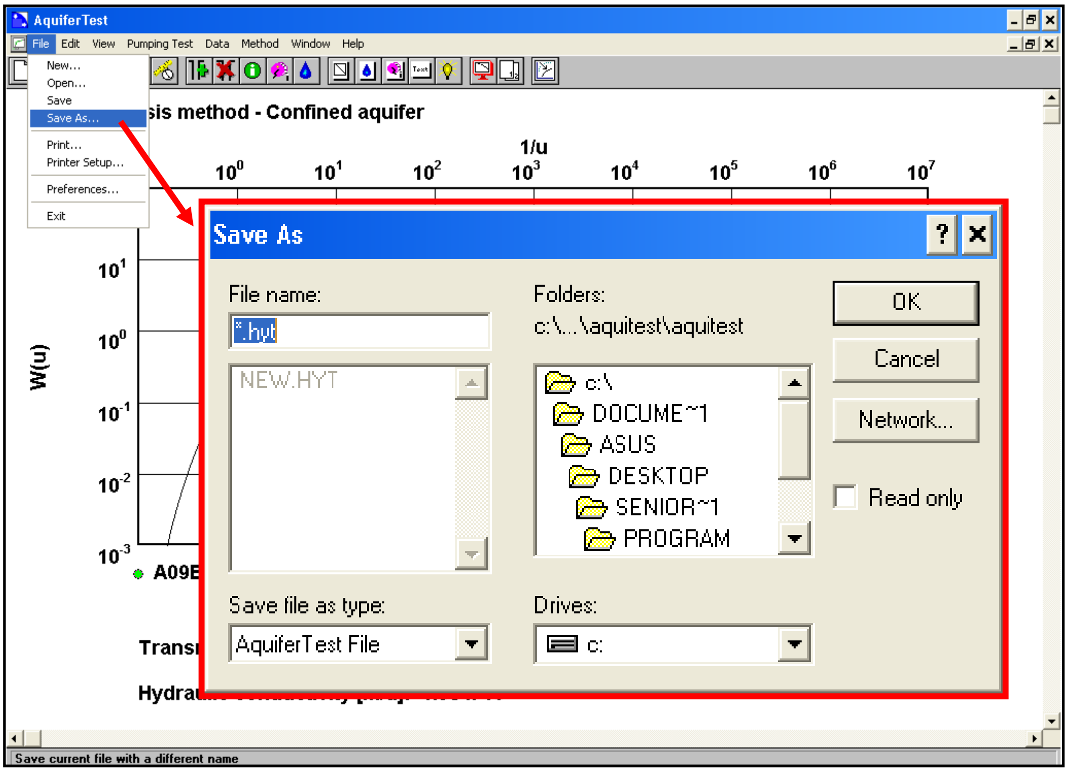
20. Transmissivity (T) and Hydraulic Conductivity are calculated as below.



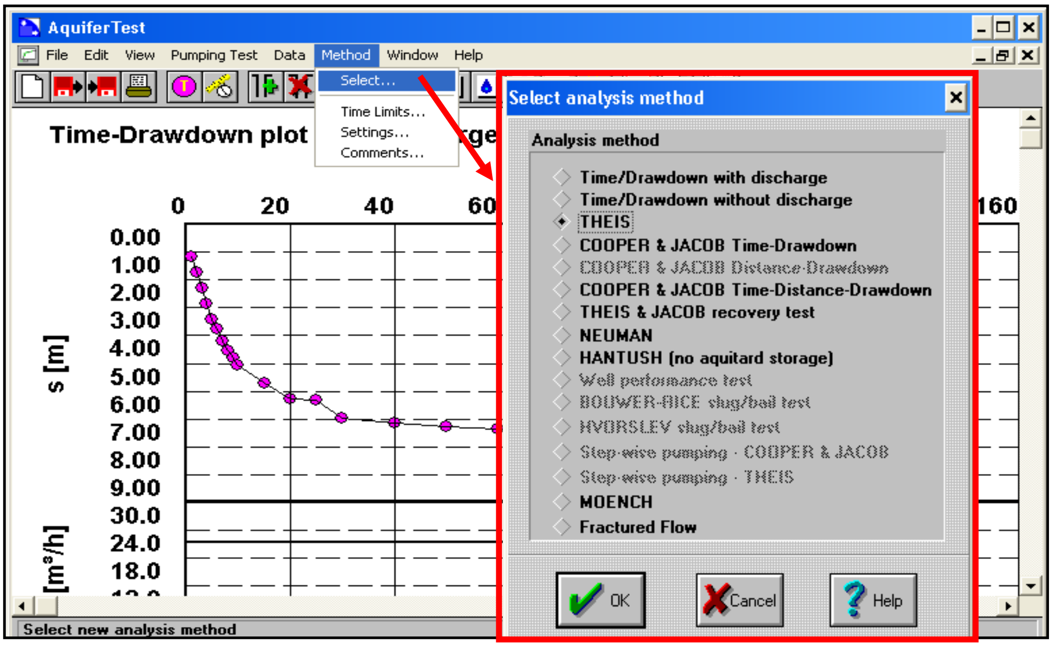
21. Click Pumping Test> Units…> change unit as below> OK



22. Click File> Save as…> browse folder> give File name> OK



23. For the other methods, click Method> Select…> choose method as desire without importing data. Follow the same steps as mentioned above.

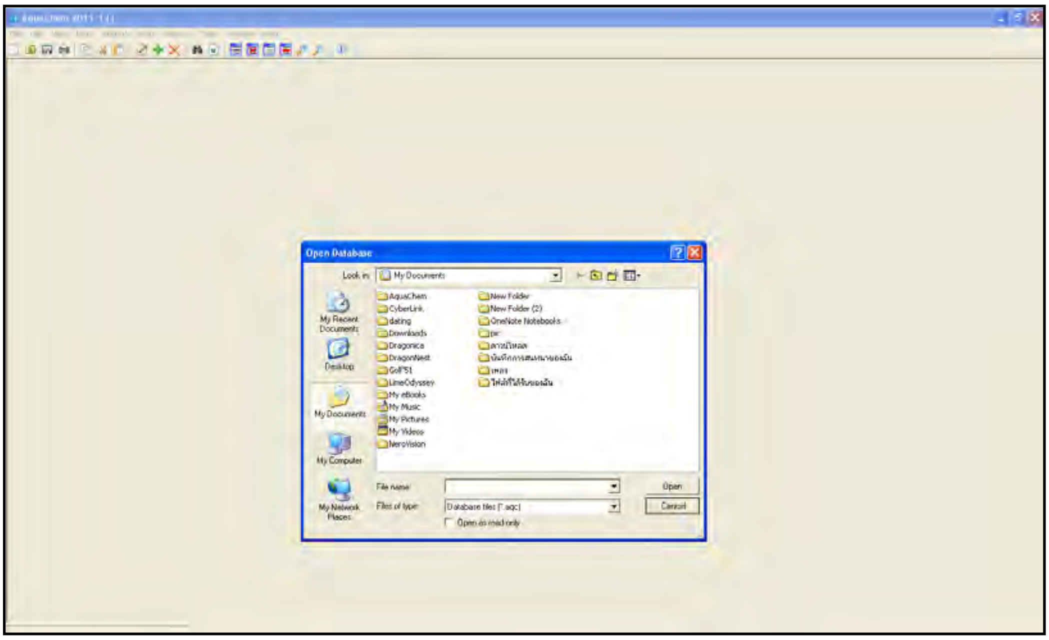


<u>AquaChem 2011.1</u>

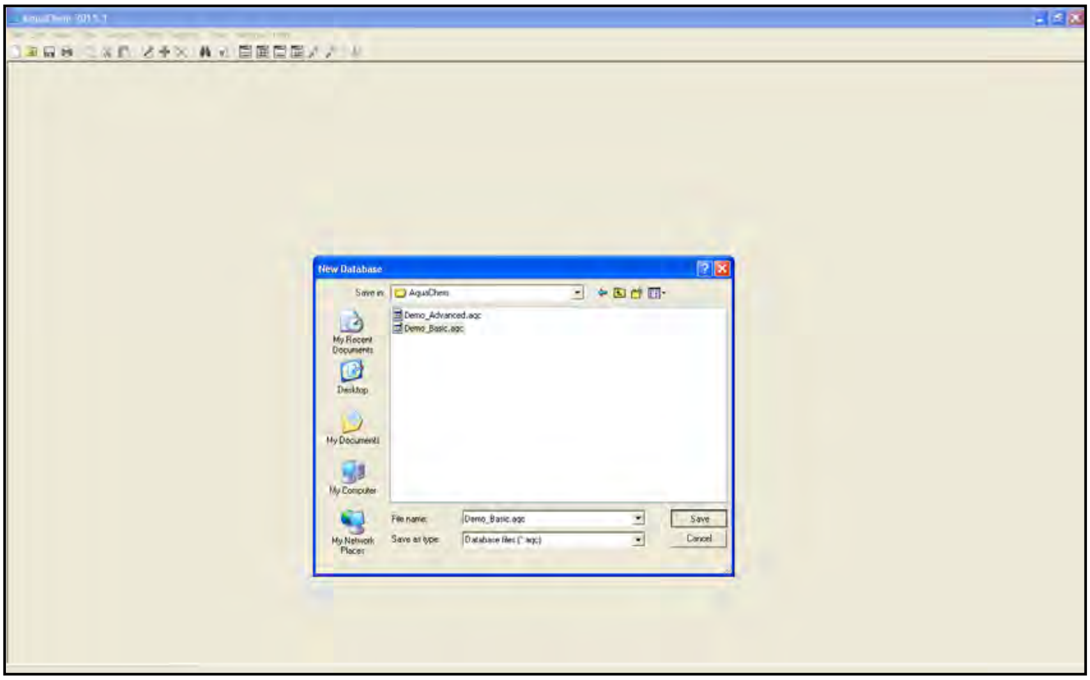
AquaChem 2011.1 is a sotware for water quality data analysis, plotting, and groundwater data reporting. It can also create map, depth profile, radial diagram, Box-Whisker or piper diagram.

For the senior project, this program is used for creating piper diagram, which is used for evaluate water type compared with the study of Galloway and Kaiser (1980). There are the easy steps as follow.

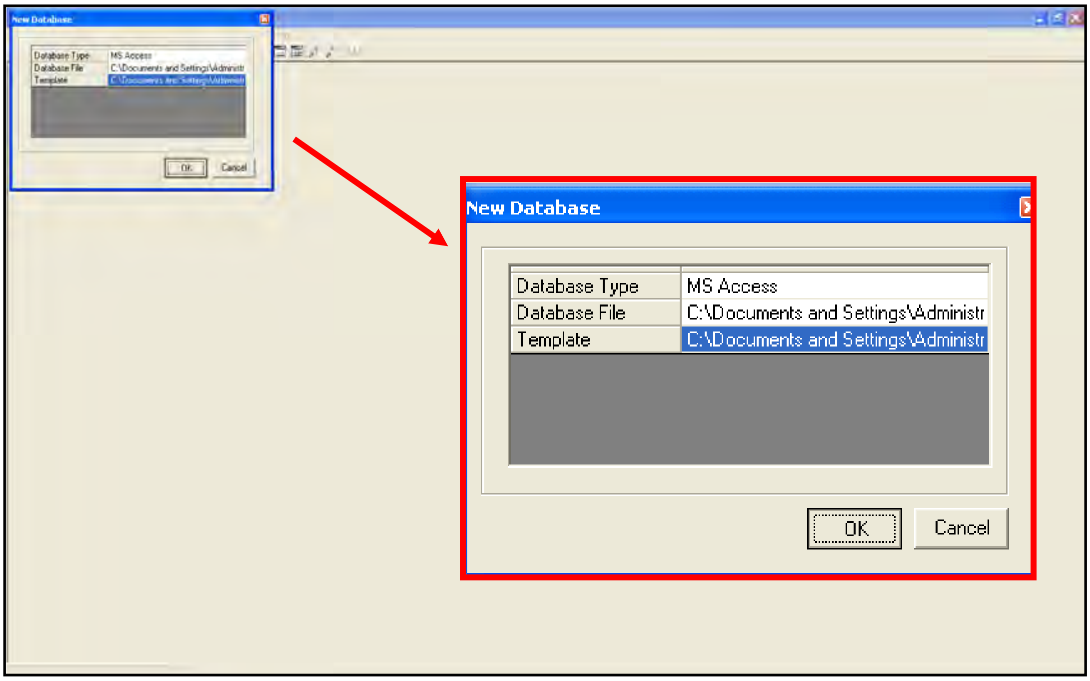
1. Prepare raw data in Microsoft Office Excel. The data should cover the important ions which are used for evaluating. In this case, based on the study of Galloway and Kaiser (1980), the ions are Sodium ion (Na^{+}), Magnesium ion (Mg^{2+}), Potassium ion (K^{+}), Chloride ion (Cl^{-}), Sulfate ion (SO_4^{2-}), Nitrate ion (NO_3^{-}), Bicarbonate (HCO_3^{-}) and Carbonate (CO_3^{2-}), in milligram per liter unit (mg/l).
2. Open AquaChem 2011.1 Program, Open database window will appear, click Cancel.



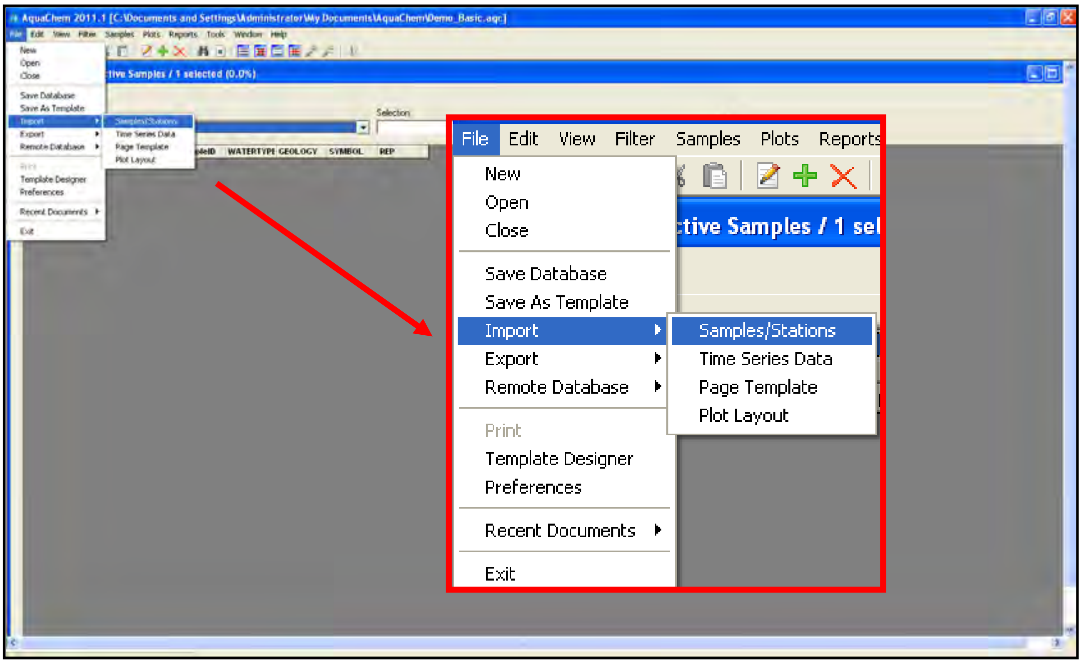
3. Click File> New, New database window will appear> choose AquaChem (come with the demo)> choose Demo_Basic.aqc> click Save.

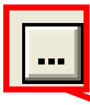


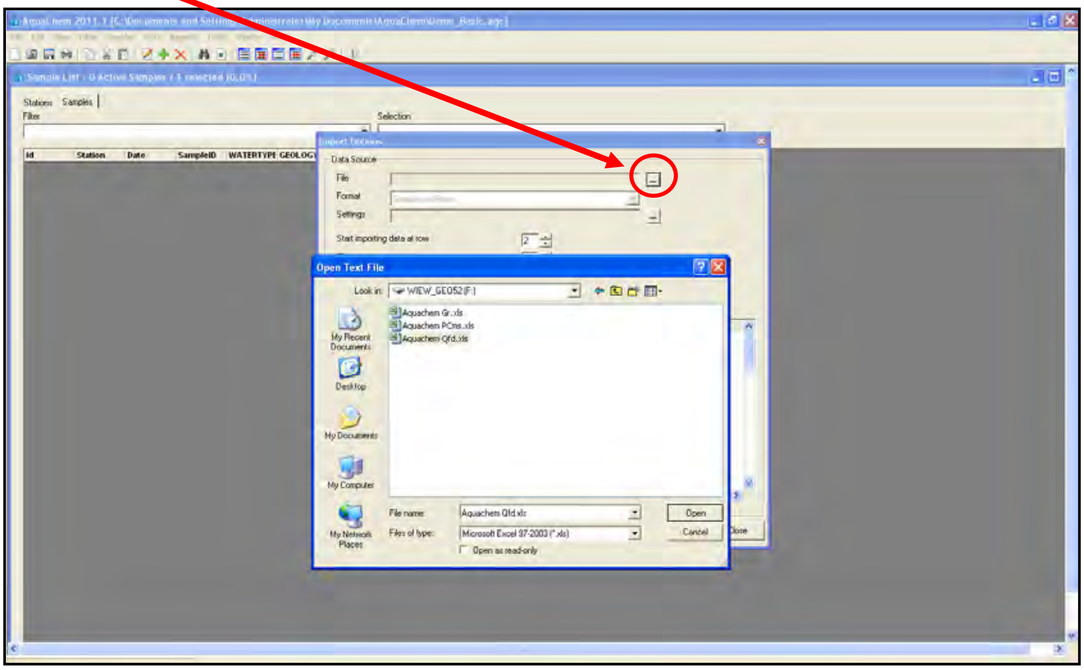
4. Click Database File> browse Demo_Basic> click Template> browse Basic_ Template > OK



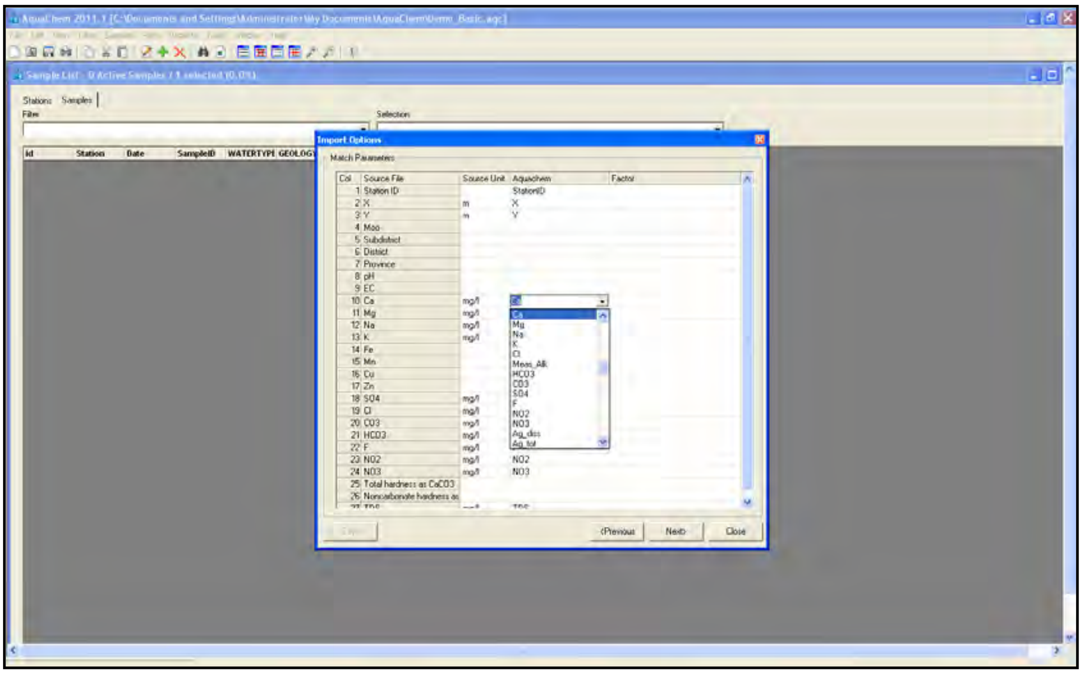
5. Click File> Import> Samples/Stations



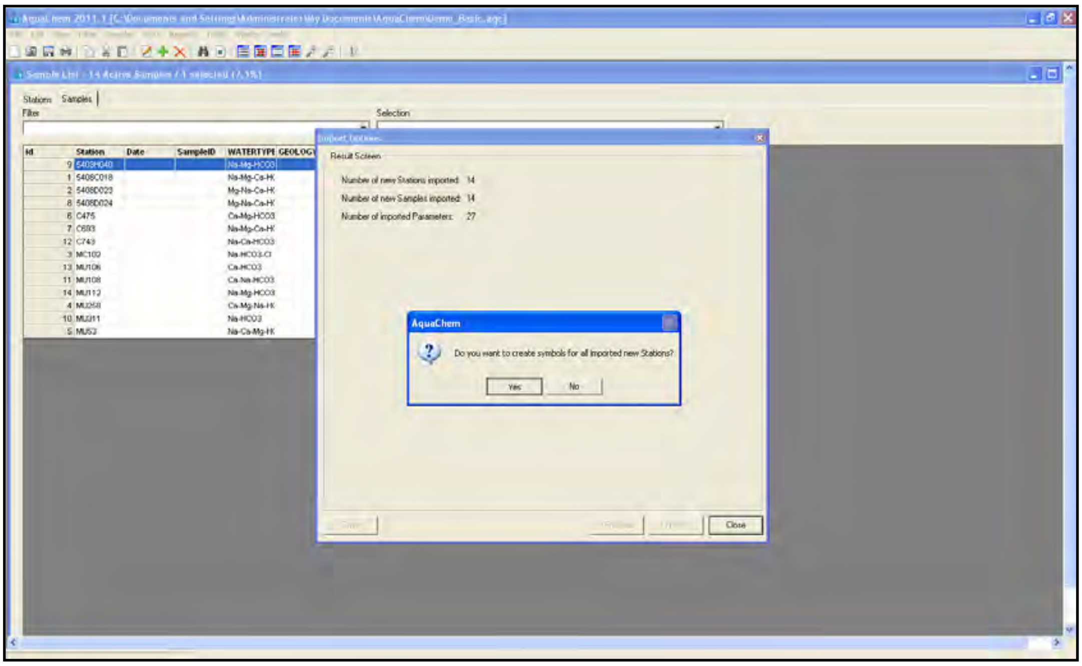
6. Click  icon> browse Excel file from the first step> Open



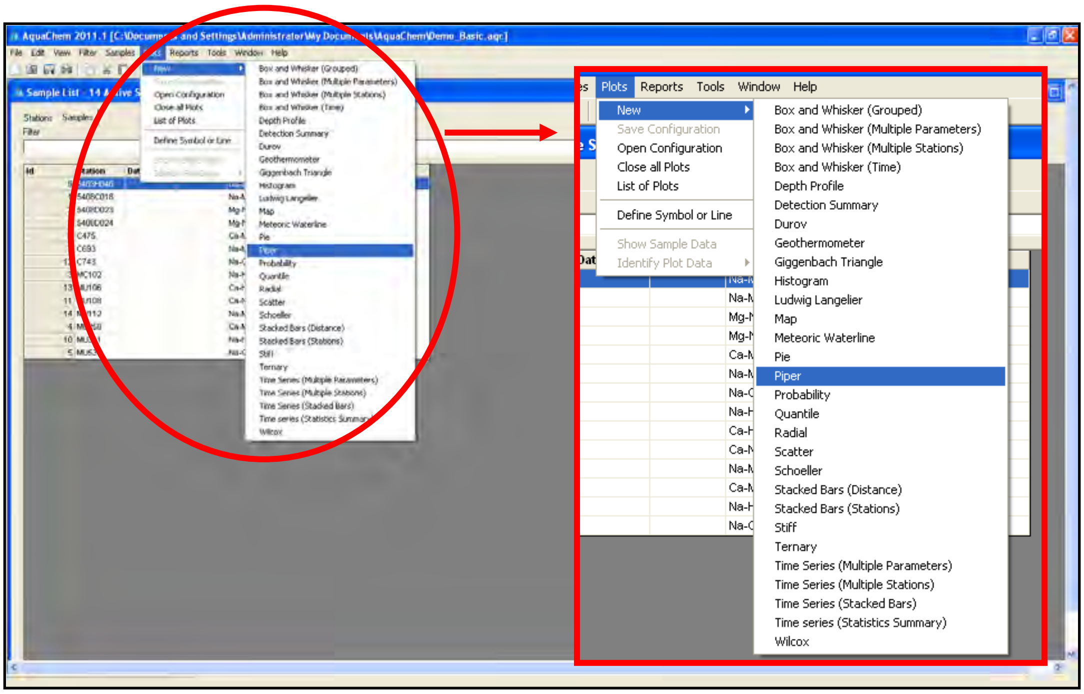
7. Match imported data with the topic in program> Next> Next



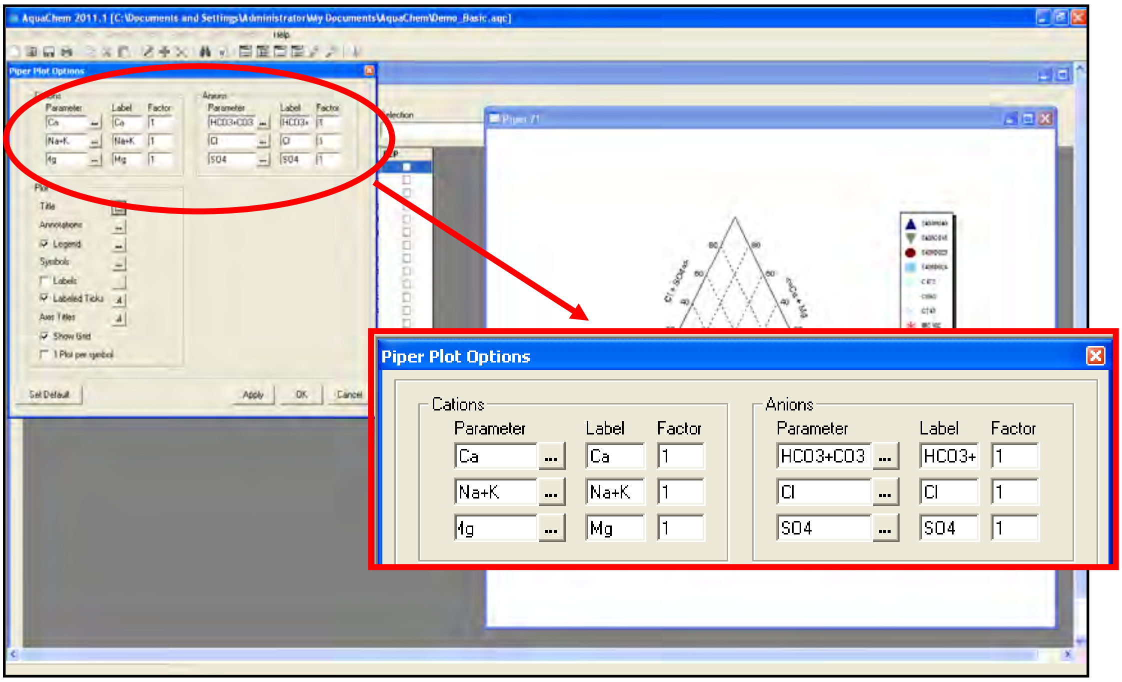
8. Import options window will appear> click Yes> Close



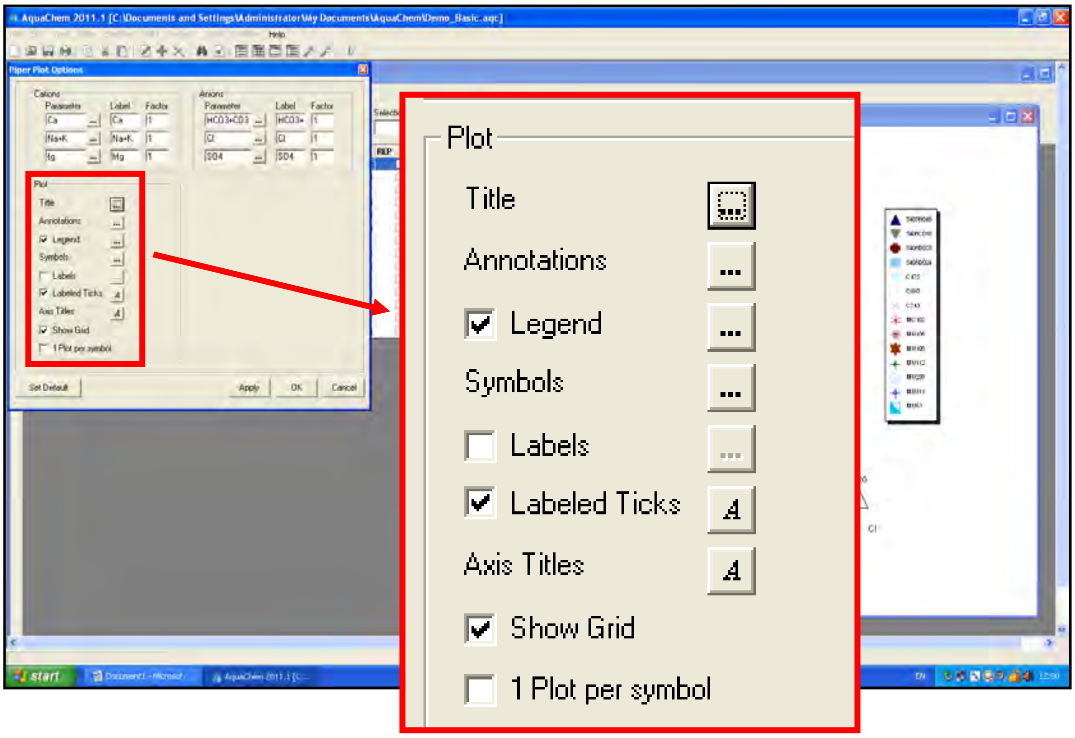
9. Click Plots> New> Piper



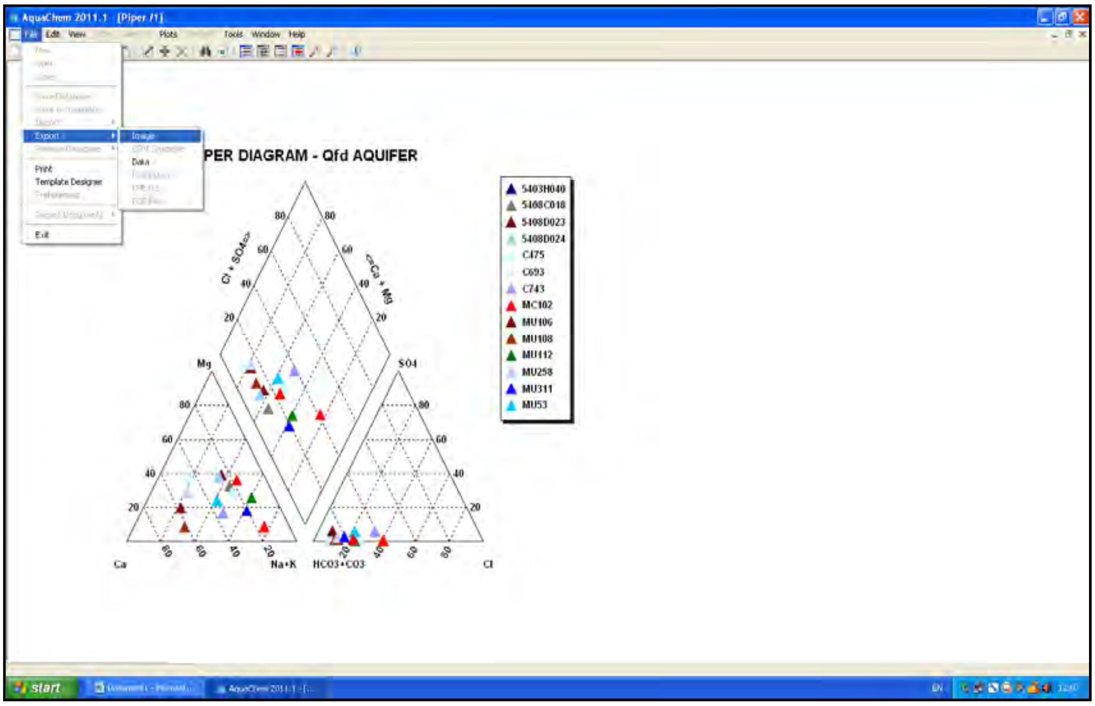
10. Adjust ion position as the picture below (based on the study of Galloway and Kaiser, 1980)> click Apply



11. Give piper diagram, change font and size, change legend or symbol from all ion below> click Apply



12. Maximize finished piper diagram> click File> Export> Image> Save



APPENDIX B

Table 1 Groundwater level data on August 8, 2011

No.	Well Name	Tambon	Easting	Northing	Elevation (m)	Water Level from Ground (m)	No.	Well Name	Tambon	Easting	Northing	Elevation (m)	Water Level from Ground (m)
1	ฯ 1655	Huay Sai Nua	590633	1405475	68±11	5.6	11	5308F011	Sam Phraya	594758	1402417	58±13	23.03
2	ฯ 1652	Huay Sai Nua	589943	1404372	79±11	4.63	12	PCR 100	Sam Phraya	594011	1403350	72±16	7.51
3	ฯ 1657	Huay Sai Nua	586269	1402432	51±9	9.96	13	MU 347	Sam Phraya	594017	1403342	60±10	7.54
4	ฯ 1656	Huay Sai Nua	586118	1403194	58±9	8.54	14	PCR99	Sam Phraya	596922	1400419	70±12	10.97
5	ฯ 1664	Rai Mai Pattana	584624	1401971	73±11	5.05	15	ฯ 1641	Sam Phraya	600552	1405500	30±8	4.67
6	ฯ 1661	Rai Mai Pattana	586846	1398182	75±9	3.96	16	ฯ 1642	Sam Phraya	600168	1404718	23±9	5.23
7	ฯ 1660	Rai Mai Pattana	586556	1398173	81±9	3.31	17	A1	Sam Phraya	598624	1403725	51±12	3.1
8	ฯ 1658	Rai Mai Pattana	590143	1398875	64±14	13.2	18	A2	Sam Phraya	598879	1404247	46±9	11.13
9	ฯ 1662	Rai Mai Pattana	591007	1396286	59±14	10.75	19	A3	Sam Phraya	598566	1403849	43±10	10.01
10	ฯ 1663	Rai Mai Pattana	592439	1396157	59±21	8	20	A4	Sam Phraya	598310	1404129	46±15	16.29

Table 2 Groundwater level data on August 9, 2011

No.	Well Name	Tambon	Easting	Northing	Elevation (m)	Water Level from Ground (m)	No.	Well Name	Tambon	Easting	Northing	Elevation (m)	Water Level from Ground (m)
1	MU82	Huay Sai Nua	585616	1402952	58±9	21	11	PCR105	Sam Phraya	590814	1407185	102±9	11.64
2	MU394	Huay Sai Nua	586027	1402355	72±12	10.41	12	MU97	Sam Phraya	588902	1403011	60±16	13.02
3	DCD14830	Huay Sai Nua	586760	1402230	50±8	-	13	MU284	Sam Phraya	589759	1401668	70±8	9.05
4	MU623	Huay Sai Nua	587363	1402438	77±15	-	14	MU258	Sam Phraya	588133	1402363	66±15	10.57
5	C437	Rai Mai Pattana	587175	1403432	58±11	6.28	15	MU53	Sam Phraya	591873	1402977	70±14	23
6	B1	Rai Mai Pattana	587598	1403891	53±12	7.16	16	MU624	Sam Phraya	591863	1402778	51±12	3.43
7	MU279	Rai Mai Pattana	587819	1404019	44±11	-	17	5308c003	Sam Phraya	584250	1401124	76±10	16.17
8	MU262	Rai Mai Pattana	590301	1404252	68±9	3.51	18	DCD14792	Sam Phraya	584967	1400664	62±9	5.28
9	DCD14835	Rai Mai Pattana	590651	1405621	76±11	-	19	MU338	Sam Phraya	584923	1400838	66±13	4.76
10	MU428	Rai Mai Pattana	589049	1407848	86±17	-							

Table 3 Groundwater level data on August 10, 2011

No.	Well Name	Tambon	Easting	Northing	Elevation (m)	Water Level from Ground (m)	No.	Well Name	Tambon	Easting	Northing	Elevation (m)	Water Level from Ground (m)
1	MU106	Rai Mai Pattana	591282	1396386	67±9	-	12	MU575	Rai Mai Pattana	589653	1399370	60±14	14.53
2	MU116	Rai Mai Pattana	591898	1396241	52±10	-	13	MU328	Rai Mai Pattana	588964	1399432	56±9	12.4
3	C743	Rai Mai Pattana	597160	1396017	59±15	-	14	MU574	Rai Mai Pattana	587737	1399631	61±9	-
4	DCD14799	Rai Mai Pattana	591922	1396162	67±7	12.4	15	MU314	Rai Mai Pattana	587423	1399705	67±11	-
5	C1	Rai Mai Pattana	588357	1396280	72±10	5.25	16	MU312	Rai Mai Pattana	583799	1397576	80±9	-
6	MU326	Rai Mai Pattana	589150	1396244	75±15	-	17	C2	Rai Mai Pattana	583821	1397314	84±12	-
7	MU54	Rai Mai Pattana	590886	1398934	64±8	10.45	18	MU311	Rai Mai Pattana	584571	1396946	88±8	4.18
8	MU434	Rai Mai Pattana	590418	1398771	54±11	-	19	MU259	Rai Mai Pattana	585166	1396312	89±8	5.35
9	C474	Rai Mai Pattana	590068	1399236	75±9	9.03	20	MU117	Rai Mai Pattana	585442	1395985	74±9	3.7
10	DCD14803	Rai Mai Pattana	590099	1399615	57±8	3.4	21	MU378	Rai Mai Pattana	578717	1399462	76±15	-
11	MU315	Rai Mai Pattana	590083	1399867	56±9	11.41	22	MU594	Rai Mai Pattana	578553	1398959	150±10	-

Table 3 Groundwater level data on August 10, 2011 (Cont.)

No.	Well Name	Tambon	Easting	Northing	Elevation (m)	Water Level from Ground (m)	No.	Well Name	Tambon	Easting	Northing	Elevation (m)	Water Level from Ground (m)
23	DCD14790	Rai Mai Pattana	577641	1399112	157±8	4.06	30	MU113	Rai Mai Pattana	585935	1398982	74±8	2.2
24	DOH11446	Rai Mai Pattana	576867	1399317	172±9	-	31	BW10454	Rai Mai Pattana	587263	1399985	67±13	-
25	MU695	Rai Mai Pattana	576708	1399354	183±10	-	32	MU317	Rai Mai Pattana	587669	1401128	61±8	15.12
26	DCD14794	Rai Mai Pattana	577010	1399613	171±12	-	33	C4	Rai Mai Pattana	587412	1400776	48±8	-
27	MU121	Rai Mai Pattana	578555	1398390	139±12	8.58	34	DCD14801	Rai Mai Pattana	587224	1400255	76±9	-
28	MU452	Rai Mai Pattana	578558	1398306	146±15	-	35	MU439	Rai Mai Pattana	586789	1397658	79±20	-
29	C3	Rai Mai Pattana	584661	1398536	138±13	-							

Table 4 Groundwater level data on August 11, 2011

No.	Well Name	Tambon	Easting	Northing	Elevation (m)	Water Level from Ground (m)	No.	Well Name	Tambon	Easting	Northing	Elevation (m)	Water Level from Ground (m)
1	MU442	Sam Phraya	596659	1400598	67±13	-	7	D4	Sam Phraya	597666	1406436	40±10	3.3
2	D1	Sam Phraya	596495	1400870	60±8	-	8	MU267	Sam Phraya	599828	1406055	24±7	4.4
3	D2	Sam Phraya	599591	1398803	43±8	-	9	D5	Sam Phraya	594091	1397067	57±12	9.9
4	จ 1637	Sam Phraya	600469	1401024	27±9	-	10	5208C002	Sam Phraya	594371	1397122	65±10	11.88
5	D3	Sam Phraya	600010	1400946	33±13	27.14	11	จ 78	Sam Phraya	594390	1397084	74±11	16.38
6	C373	Sam Phraya	598854	1406335	52±12	3.9	12	D6	Sam Phraya	597072	1405674	73±11	-

APPENDIX C

Figure 1 Measuring and recording groundwater level data at Tambon Sam Phraya

Figure 2 Measuring and recording groundwater level data at Tambon Huay Sai Nua

Figure 3 Measuring and recording groundwater level data at Tambon Rai Mai Phattana