การวางแผนพัฒนาแหล่งน้ำภายใต้การประเมินปฏิสัมพันธ์ระหว่างน้ำผิวดินและน้ำใต้ดิน บนลุ่มคอนเซิน เกาะคอนเด๊า จังหวัดปาเรียวุงเตา ประเทศเวียดนาม

นายตรัน ทานห์ ลอง

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
สาขาวิชาวิศวกรรมแหล่งน้ำ ภาควิชาวิศวกรรมแหล่งน้ำ
คณะวิศวกรรมศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2556

WATER RESOURCES DEVELOPMENT PLANNING UNDER SURFACE WATER AND GROUNDWATER INTERACTION ASSESSMENT IN CON SON VALLEY, CON DAO ISLAND, BA RIA-VUNG TAU PROVINCE, VIETNAM

Mr. Tran Thanh Long

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Engineering Program in Water Resources Engineering
Department of Water Resources Engineering
Faculty of Engineering
Chulalongkorn University
Academic Year 2013

Thesis Title WATER RESOURCES DEVELOPMENT PLANNING UNDER SURFACE WATER AND GROUNDWATER INTERACTION ASSESSMENT IN CON SON VALLEY, CON DAO ISLAND, BA RIA-VUNG TAU PROVINCE, VIETNAM
By Mr. Tran Thanh Long
Field of Study Water Resources Engineering
Thesis Advisor Associate Professor Sucharit Koontanakulvong, Ph.D.

Accepted by the Faculty of Engineering, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master's Degree

....Dean of the Faculty of Engineering
(Professor Bundhit Eua-arporn, Ph.D.)

THESIS COMMITTEE

....Chairman
(Associate Professor Tuantan Kitpaisalsakul, Ph.D.)

....Thesis Advisor
(Associate Professor Sucharit Koontanakulvong, Ph.D.)

....Examiner
(Piyatida Hoisungwan, Ph.D.)

....Examiner
(Assistant Professor Sunthorn Pumjan, Ph.D.)

....External Examiner
(Associate Professor Chaiyuth Sukhsri)

ตรัน ทานห์ ลอง : การวางแผนพัฒนาแหล่งน้ำภายใต้การประเมินปฏิสัมพันธ์ระหว่างน้ำผิวดินและน้ำใต้ดินบนลุ่มคอนเซิน เกาะคอนเด๊า จังหวัดบาเรียวุงเตา ประเทศเวียดนาม. (WATER RESOURCES DEVELOPMENT PLANNING UNDER SURFACE WATER AND GROUNDWATER INTERACTION ASSESSMENT IN CON SON VALLEY, CON DAO ISLAND, BA RIA-VUNG TAU PROVINCE, VIETNAM) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: รศ. ดร.สุจริต คูณธนกุลวงศ์, 128 หน้า.

เกาะคอนเด๊าเป็นเกาะเพื่อการท่องเที่ยว และอยู่แยกจากแผ่นดินใหญ่ตามสภาพภูมิประเทศ ทำให้สภาพน้ำผิวดินมีข้อจำกัดและยากในการรวบรวมน้ำผิวดินเก็บกักให้พอ นอกจากนี้การขนส่งน้ำจากแผ่นดินใหญ่ก็มีค่าใช้จ่ายสูง ดังนั้นแหล่งน้ำใต้ดินจึงเป็นทรัพยากรสำคัญสำหรับเกาะแห่งนี้ ความต้องการน้ำจากการสูบน้ำใต้ดินมีเพิ่มขึ้นมากตามการเติบโตของประชากรและสภาพเศรษฐกิจและสังคม ซึ่งจะส่งผลให้เกิดสภาพแห้งแล้งบนเกาะได้ ดังนั้น เพื่อการตอบสนองความต้องการน้ำในอนาคต การประเมิน และวางแผนการใช้น้ำใต้ดินบนเกาะดังกล่าวจึงเป็นเรื่องเร่งด่วนในขณะนี้

ด้วยเหตุผลดังกล่าว การศึกษาสมดุลย์น้ำใต้ดินเพื่อตอบสนองต่อความต้องการน้ำในอนาคตจึงมีความจำเป็นอย่างเร่งด่วน การศึกษาจึงแบ่งเป็น ๓ เรื่องคือ การจำลองน้ำผิวดินโดยใช้โปรแกรม HEC-HMS ในการจำลองน้ำท่าจากพื้นที่รับน้ำ การจำลองและประเมินศักยภาพน้ำใต้ดินโดยใช้โปรแกรม GMS พร้อมการประเมินปฏิสัมพันธ์ของน้ำผิวดิน และน้ำใต้ดิน การวางแผนพัฒนาแหล่งน้ำบนเกาะเพื่อตอบสนองความต้องการน้ำสะอาดในปี 2013-2020 ภายใต้การพิจารณาการลดลงของระดับน้ำใต้ดิน การรุกล้ำของน้ำเค็ม ค่าก่อสร้าง และค่าใช้จ่ายถ้าไม่ทำโครงการพัฒนา

การศึกษาพบว่า การวิเคราะห์ปฏิสัมพันธ์ของน้ำผิวดินและน้ำใต้ดินช่วยปรับปรุงการจำลองน้ำใต้ดินและการประเมินความสามารถให้น้ำของชั้นน้ำใต้ดินได้ดียิ่งขึ้น การศึกษายังพบว่าปริมาณการสูบน้ำที่ปลอดภัยภายใต้จำนวนบ่อน้ำบาดาลในปัจจุบันเท่ากับ ๓๕๐๐ ลบมต่อวัน และถ้าต้องการให้ตอบสนองต่อความต้องการน้ำในอนาคตที่ ๖๐๐๐ ลบมต่อวัน จะต้องขยายทะเลสาป (ที่ ๒) และเพิ่มบ่อน้ำบาดาลอีก ๕ บ่อ จะเป็นแนวทางเลือกที่ดีที่สุดสำหรับการพัฒนาแหล่งน้ำบนเกาะคันเด๊า

ภาควิชา วิศวกรรมแหล่งน้ำ ลายมือชื่อนิสิต ....

สาขาวิชา วิศวกรรมแหล่งน้ำ ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก ....

ปีการศึกษา 2556

5570508921 : MAJOR WATER RESOURCES ENGINEERING
KEYWORDS: SW-GW INTERACTION/ GROUNDWATER ASSESMENT/ CON SON VALLEY

TRAN THANH LONG: WATER RESOURCES DEVELOPMENT PLANNING UNDER SURFACE WATER AND GROUNDWATER INTERACTION ASSESSMENT IN CON SON VALLEY, CON DAO ISLAND, BA RIA-VUNG TAU PROVINCE, VIETNAM. ADVISOR: ASSOC. PROF. SUCHARIT KOONTANAKULVONG, Ph.D., 128 pp.

According to the topography, Con Dao Island is considered one of the best tourist area but isolate lands, thus surface water is limited and difficult to be collected properly and it is also very costly to gain support from continent. Therefore, groundwater is the key strategic resources on the island. Along with economic development and population, the demand for groundwater extraction is growing rapidly and gradually affects the land to become drought. In order to satisfy the future demand of water, the evaluation and planning of groundwater is extremely urgent in the present time.

From the imperative reasons above, the study on groundwater balance to satisfy for future demand is conducted. The objectives are to assess the interaction between surface water and groundwater, to assess groundwater capability in Con Son valley, as well as to recommend suitable water resources development plan for the future water demand of the island from 2013-2020. This study is divided into three parts: surface water simulation by HEC-HMS, groundwater simulation by Groundwater Modeling System (GMS) with the analysis of the interaction between groundwater and surface water, and water resources development planning under the considerations of construction cost, drawdown, salt water intrusion, and costs without development plan.

The study showed the interaction analysis of surface water and groundwater helped to improve the groundwater simulation and groundwater capacity assessment. The study found that the safe yield of the existing pumping scheme is 3500 CM/day and to cope with the future demand of 6000 CM/day, the expansion of lake (no. 2) and additional 5 wells is the best choice for water resources development for the Con Dao Island.

Department:	Water Resources Engineering	Student's Signature	....
		Advisor's Signature	....
Field of Study:	Water Resources Engineering		
Academic Year:	2013		

ACKNOWLEDGEMENTS

First of all, I would like to express my sincere gratitude to my advisor Assoc. Prof. Sucharit Koontanakulvong for the continuous support of my master study and research, for his patience, motivation, enthusiasm, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis.

Besides my advisor, I would like to thank all of my thesis committee: Assoc. Prof. Dr.Tuantan Kitpaisalsakul, Assoc. Prof. Dr. Chaiyut Suksrimuang, Asst. Prof. Sunthorn Pumjan and Dr.Piyatida Hoisungwan for their encouragement, and recommendations.

Finally, I would like to thank the support of master program scholarship from Chulalongkorn University of Neighboring Countries Scheme and the Water Resources System Research Unit of Faculty of Engineering, Chulalongkorn University, without that, the study could not be accomplished. I also thank to the staff at Division for Water Resources Planning and Investigation for the South of Vietnam, and Meteorological stations located on Con Dao District supported data for the research.

CONTENTS

Page

FIGURE

TABLE

CHAPTER I

INTRODUCTION

Of all natural resources in the world, water is considered the most essential element of all kind. In particular, most significance of water is the foundation to all vital processes of life. Nowadays, there are over 2 billion of living people in chronic water shortages areas. Quantitative supply and water quality issues are rising and could constrain economic development and human well-being in general. In other words, water no longer can be taken for granted: "Ensuring that present and future generations will have adequate food and water, and concurrent maintenance of the resource base and the environment, are two of the most challenging tasks that have ever faced mankind" (Marcoux (1994)).

Groundwater is one of the key water resources on Earth. Many major cities and small towns in the world depend on groundwater for water supplies, mainly as a result of its abundance, stable quality and also inexpensive exploit (Morris et al., 2003). Groundwater is fundamental resources to meet the urgent expanding urban, industrial and agricultural water requirement, especially in barren areas where surface waters are scarce and seasonal. Uneven distribution of surface water resources leaded to more influential role in development of groundwater resources. The important objective of most groundwater studies is to make a quantitative assessment of the groundwater resources in terms of the total volume of water stored in aquifer or long term average recharge.

A lot of groundwater studies have been applied to computer based mathematical models which essentially comprise a vast array of equations. Also describe groundwater flow and the water balance in the aquifer. Finite difference method is a commonly used method to find a solution of the equations. The equations are solved for each node and the movement of groundwater from one node to its neighbor is calculated. Numerical groundwater models are one of the best predictive tools available for managing water resources in aquifers (Scanlon, Mace, Barrett, & Smith, 2003). These models can be used to test or refine different conceptual models, estimate hydraulic parameters and most significant for water-resource management as well as to predict how the aquifer might respond to changes in pumping and climate. Groundwater abstractions that exceed the average recharge, results in a continuing depletion of aquifer storage and lowering of the groundwater table. Hence, safe groundwater abstraction and proper groundwater management is crucial for sustainability of the resource. Safe yield is the amount of naturally occurring groundwater that can be withdrawn from an aquifer on a sustained basis, economically and legally, without impairing the native ground water quality or creating undesirable effects such as environmental damage (Fetter, 1994). However, both groundwater and surface water should be considered conjunctively in water resources development planning especially in the remote area.

1.1 Background and problems

Con Dao District of Ba Ria - Vung Tau Province is archipelagos consisting of 16 islands which located on the east of Vietnam, 16 miles far from Vung Tau City and 45 miles from Ba Sac River estuary. Water resources of Con Dao consist of groundwater, rain water, small reservoirs and small streams. These water sources are significantly affected by annual rainfall thus makes the water quantity greatly vary throughout the year except for groundwater source. Therefore, groundwater plays a major impact on water supplying for socio-economic development planning stages in the region.

On October 25th 2005, the Prime Minister decided to approve "Project of socio-economic development of Con Dao District, Ba Ria-Vung Tau Province to 2020" (Tang Ng. V. et al., 1998). For achieving the target of the population of 20,000 to the year 2020, in the mentioned project clean water demand is 6,000 m^3/day.

This study area is basically regarded to isolate land on the sea. Due to the fact that surface water is not collected easily. It is also very difficult to gain support from the continent. So that groundwater is the key strategic resources in this area. In order to satisfy future water demand, the evaluation and planning of groundwater are extremely urgent in the present time.

In the past, there were some reports about groundwater potential reserve on Island. However, most of them haven't been cleared up response of aquifer to future demand and recharge from SW to GW, such as:

Long P. H. and Long T. (1997) conducted research on minerals resources assessment of Con Dao archipelagos including hydrogeology and groundwater potential. According to these authors, potential reserve of Con Son valley is 4,500 m^3/day. These results were estimated based on the basis of available data but no monitoring well and validate data.

Nam Bo Geological Corporation (NAGECO: 1997) conducted some research work such as vertical electric sounding (VES), exploration drilling and soil investigation drilling in the Archipelagos. The report indicated that groundwater is stored mainly in soft Pleistocene sediments and regularly recharged by rain water. Reserve of the central Con Son valley is Q = 2,440 m^3/day corresponding to water level drop after 27 years being 6.6m. Potential reserves were also calculated as 5,679 m^3/day in the central Con Son Valley. For surface water, the mentioned authors also assessed water generation ability of basin, calculated flows and suggested plans for construction of reservoirs. The data based on vertical electric sounding (VES), exploration drilling and soil investigation drilling in the Archipelagos but no monitoring well, calibrate and validate data.

Company of Technological and Equipment Consultants and Construction Audit, Southern Branch in Ba Ria-Vung Tau (1997) compiled the feasibility study of water supply system for Con Dao town during 1998-2010. The authors also calculated potential reserve of Con Son valley as Q =6,534 m^3/day and suggested 2 parallel exploitation lines from Quang Trung 2 lake to An Hai lake consisting of 11 wells. Total exploitation yields of 11 wells is Q_{kt} = 5,500 m^3/day with total water level dropdown being 5.27m. The data based on vertical electric sounding (VES), exploration drilling and soil investigation drilling in the Archipelagos but no monitoring well and calibration actually data. The results were estimated for steady state and didn't consider the fluctuation of groundwater during dry season and rainy season.

Chan (2006) completed the supplementary investigation, construction of groundwater monitoring network, exploitation planning, use and protection of water resources in Con Dao archipelagos. Under this research, field investigation was conducted mainly in Con Son valley exploration drilling (the wells will be incorporated into the groundwater monitoring network afterwards). 11 boreholes in Con Son Valley were made with depths from 11 to 27 m. Groundwater monitoring was conducted in 1 year as a result; distribution of the aquifers, hydro chemical features and groundwater behavior was clarified. Problems of salinity intrusion and pollution, planning for groundwater exploitation and use were mentioned in the report. According to lack of monitoring data, the modeling was calibrated only in 1 year. Thus, the research didn't clarify the surface water (SW) – groundwater (GW) interaction. Without the SW/GW interaction, results couldn't show the responding of aquifer to future demand under the rainfall fluctuation.

So far, there has been no research justifying groundwater exploitable reserve for the purpose of completely satisfying water demand of Con Dao Island to the year 2020. Therefore, justification of groundwater source for satisfying this water is essentially in demand.

This study assessed the responding capability of water sources in Con Son valley for clean water demand for socio-economic development of Con Dao island to the year 2020. The research assessed the groundwater exploitable reserves under interaction assessment between surface water and groundwater and possible salt intrusion. Besides, this study also recommended the suitable development plan for water resources with considerations of water supply availability salt intrusion and construction cost.

1.2 Objectives

The main objective of this study is to assess the responding capability of water sources in Con Son valley for clean water demand in the 2nd stage for socio - economical development of Con Dao island to the year 2020;

The specific objectives are:

- To assess the interaction between surface water and groundwater.
- To assess groundwater capability in Con Son valley to satisfy clean water demand of Con Dao district from 2013 - 2020.
- To recommend suitable water resources development plan for the future water demand of the island.

1.3 Research approach and scope

1.3.1 Research approach

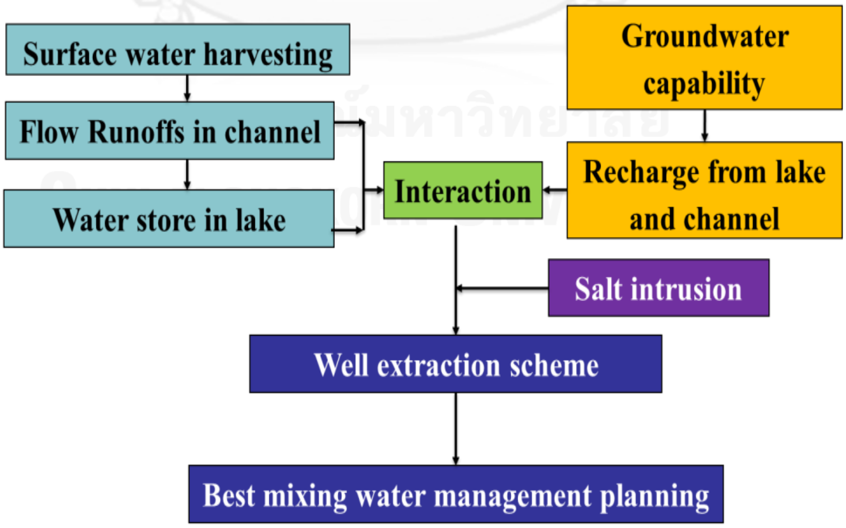


Figure 1.1 Research approach diagram

Due to the previous research, there is no report mentioned about extraction yield and SW-GW interaction capability in the study area. The responding operation of aquifer to future water demand (6000 m^3/day) under SW-GW interaction is simply unclear. Thus, in this study, the SW-GW interaction analysis is used as an approach to find the recharge from surface water resources to give the groundwater capability more accuracy and reliability. The approach of this study involves 4 parts:

- Water harvesting from rainfall-runoff to store in the lake during rainy season and develop wells to be used in dry season under the interaction assessment,
- Rainfall - runoff simulation to estimate runoff volume from mountainous area and channel to lake,
- Groundwater analysis for suitable number of pumping well with the consideration of drawdown, recharge from lakes channel and salt water intrusion prevention,
- Best mix of well development and pond enlargement scheme are considered to find suitable water development plan for the area.

1.3.2 Research scope

The study area is located in the Con Dao District (island). Con Dao District of Ba Ria - Vung Tau Province is archipelagos consists of 12 islands locating in the Southeast of Vietnam, 97 miles far from Vung Tau city and 45 miles far from Ba sac river estuary. The detail of the study and concern are described in Chapter 2.

The proposed study is conducted at district level of Con Dao District, Ba Ria -Vung Tau Province, Vietnam. For this level, all required data are collected from secondary sources. The data is collected from 2 agencies as following:

Division for Water Resources Planning and Investigation for the South of Vietnam. (DWRPIS)

Meteorological station located on Con Dao district. (MSCD)

The summary of collected data is presented in Table 1.1.

Table 1.1 Summary of data collection and models used in the study

No	Name of data	Length	Time Period	Sources	Model used
A	*Meteorological & Hydrological data*				
1	Rainfall	17 years	1995 – 2012	MSCD	HEC-HMS
2	Temperature, evaporation	6 years	2006 – 2012	MSCD	
3	Water level in lake, stream	6 years	2006 – 2012	MSCD	
4	Water demand (domestic, irrigation, industry and tourist)	6 years	2008-2012	MSCD	
5	Runoff	5 years	2006-2010	MSCD	
B	*Groundwater data*				
1	Hydrogeology map			DWRPIS	GMS (Modflow)
2	Hydraulic conductivity		12 wells	DWRPIS	
3	Aquifer profiles		2 layers	DWRPIS	
4	Pumping rate	4 years	2008-2012	MSCD	
5	Observed groundwater level	6 years	2006-2012	DWRPIS	

The scope of study: first, HEC-HMS is used to simulate surface water runoff. Second, groundwater is assessed by GMS - modlfow. Besides, the interaction between groundwater and surface water is also assessed in this part. Third, water resources development is planned and selected based on 12 alternatives come from 2 options: expanding lake and adding new well under the consideration of construction cost, drawdown, and salt water intrusion

The surface water runoff (HEC-HMS): This simulation involves 3 steps: first, the rainfall in 6 years is classified as high and low. Second, Storage – Discharge function, SW parameters (loss, transform, routing, loss/gain) are estimated by calibration and validation. Third, SW level is simulated by 17 years rainfall.

The groundwater modeling system (GMS): there are 4 steps to modeling groundwater system. First, the geological spatial is created by scatter point (coordinates, depth) and 3D grid. Second, the geo-hydrology characteristics (hydraulics conductivity, specific storage, specific yield), sources/sinks boundary (SW level, rainfall recharge), and pumping rate add on layers to interpolate values in each cell. Third, the results are calibrated in 3 years and validated in 3 years base on observed data. Fourth, simulate GW balance due to validated parameters and simulated SW in 17 years.

Water resources development plan: In order to develop water resources in study area, there are 3 options: a) expanding lake, b) adding on more wells and setting up new pumping pattern and c) combination of expanding lake and adding wells. All of alternative are simulated and compared each other by construction cost, groundwater drawdown and salt water intrusion effects. Future climate conditions applied to simulate groundwater balance of alternatives are assumed to repeat as in the study period.

1.4 Thesis content

The content of this thesis composes of 6 chapters the detail of each chapter follows as:

Chapter I : introduction includes background and problems, objectives, research approach and scope, and outcome expected.

Chapter II : study area consists of the characteristic of study area such as the boundary and location, topography, meteorology and hydrology, land use, existing water usage, future water demand planning.

Chapter III: literature review includes surface runoff modeling, groundwater modeling, surface water – groundwater interaction, water resources development.

Chapter IV: methodology and theories used include procedures of study, theory of surface water simulation, theory of groundwater simulation, approach of SW-GW interaction, describe water development options.

Chapter V: results & discussions include surface runoffs simulation, groundwater modeling simulation, recharge, salt intrusion, and comparison of water development schemes.

Chapter VI: conclusions and recommendations include the conclusion in each chapter and the recommendations for the practical water management.

1.5 Study outcomes

1) The ground and surface water interaction mechanism in the area.

2) The characteristic of groundwater flow in Con Son valley

3) The groundwater capability safe yield in Con Son valley with existing pumping scheme.

4) The recommendations based on suitable water resources development to cope with future clean water demand of Con Dao district to the year of 2020 on the island.

CHAPTER II

BACKGROUND OF THE STUDY AREA

2.1 Location

Con Dao District, Ba Ria-Vung Tau Province is archipelagos consisting of 12 islands locating in the Southeast of Vietnam, 97 miles far from Vung Tau city and 45 miles far from Ba sac river estuary. Con Dao Island is the biggest island of Con Dao archipelagos. The study area is the Con Son Valley located in Con Dao Island (Figure 2.1).

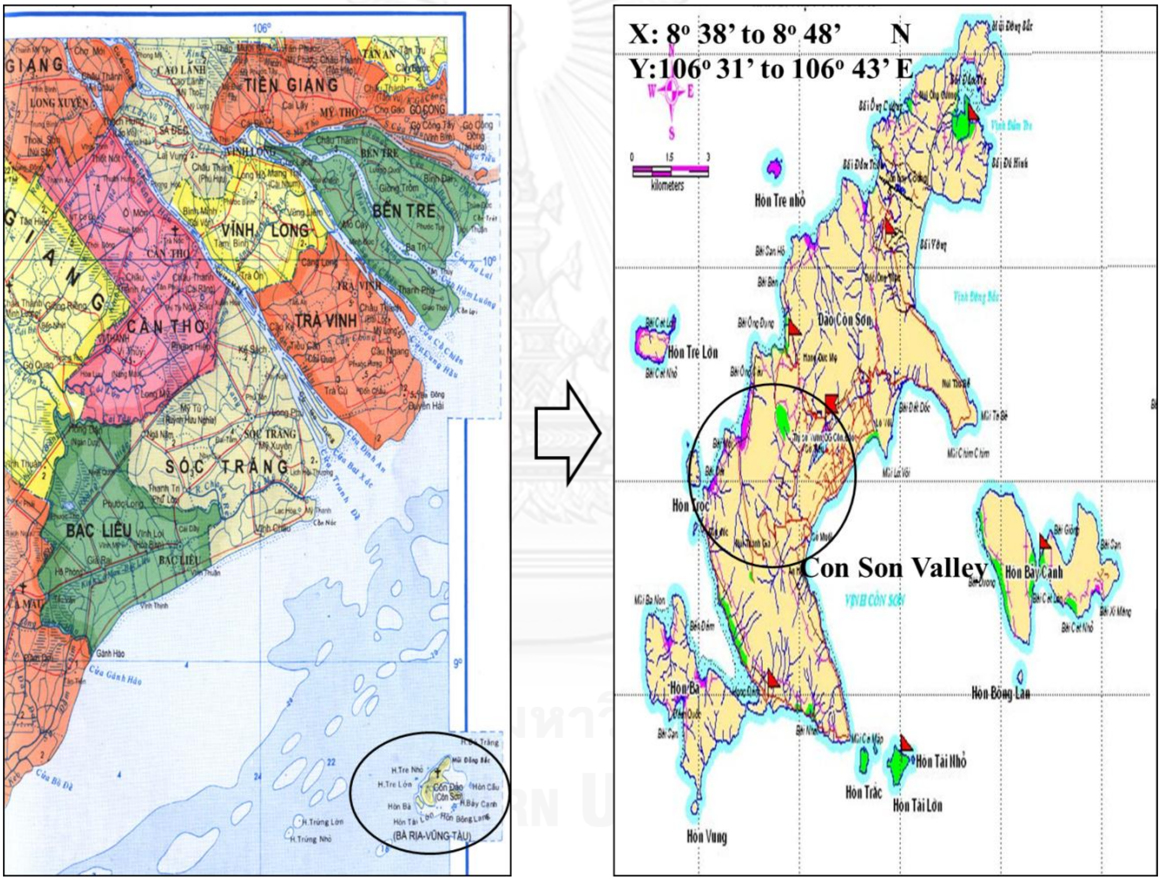


Figure 2.1 Map of Con Son

2.2 Meteorology and Hydrology

All data in this part are come from meteorological station on Le Hong Phong Street in Con Son valley. The location of station is presented in Figure 2.3.

2.2.1 Climate

Climate of Con Dao archipelagos has a marine character on tropical monsoon base: humid, high and stable temperature throughout a year due to regulating effect of the sea. Annually there are 2 distinguished seasons: rainy season lasts from May to October. Dry season lasts from November to April. According to the Con Dao Meteorological Station within 17 recent years from 1995 to 2012, the climate characters are:

A. Air temperature:

In a year, air temperature usually varies from 20^{0}C in February to 35.2^{0}C in May.

The highest air temperature was 35.2^{0}C in May, 1998.

The lowest air temperature was 18.8^{0}C in January, 1997.

Table 2.1 Average temperature data at Con Dao 1995-2012 (unit: ^{o}C)

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average temperature	25.6	26.0	27.2	28.7	28.5	28.5	27.9	27.9	27.5	27.6	27.3	26.5

B. Rainfall:

Rainfall on Con Dao archipelagos is rather high. Observed rainfall from 1996 to 2012 varies from 1390.3 mm to 2360.8 mm, mean 2098.7 mm. Rainfall from May to October to 87.5% of total annual rainfall. Average monthly rainfall is shown in Table 2.2.

Table 2.2 Long term average climate data at Con Dao in year 1996 – 2012

Features	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall (mm/month)	7.2	3.1	10.4	54.2	207.8	286	279	350	313	400	125	62.7
Rainy days	2.0	0.5	2.1	4.7	14	17.1	17.3	19.1	17.2	21	10.7	6.0
Humidity (%)	79.7	80.3	82	80.7	81.2	82.9	82	81.7	83.2	86.5	82.5	50.3

Rainy days in a year are from 109 to 154 days, average as 132 days. Average rainy days of each month are shown in Table 2.2.

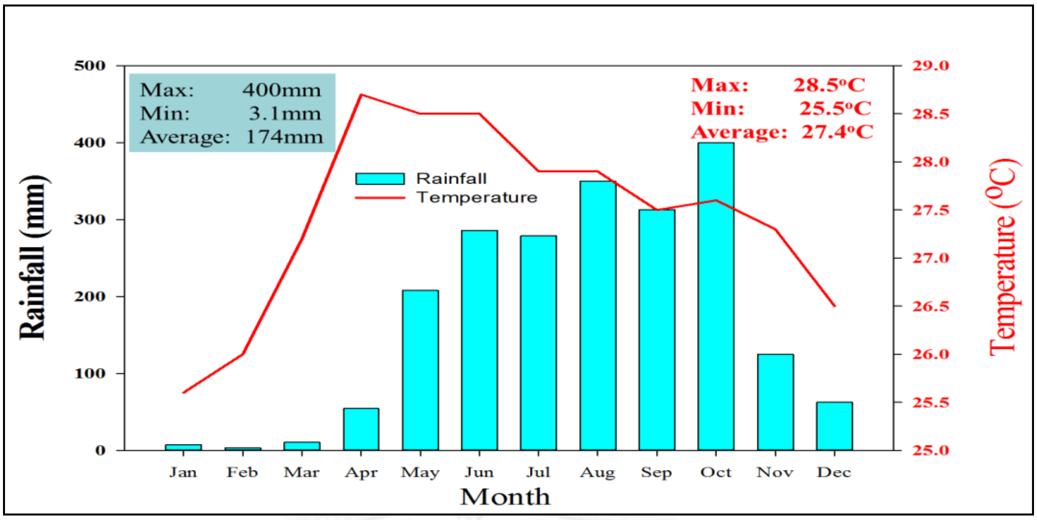


Figure 2.2 The average monthly rainfall and average temperature in Con Dao (1996 - 2012)

C. Air humidity:

Air humidity in the study area changes with seasons. Air humidity is high in rainy season and low in dry season. Meteorological data from 1995 to 2012 gave following results:

Multiple year average humidity: 81.9%.

Highest humidity is in October: 98%.

Lowest humidity is in February: 60.6%.

D. Evaporation:

Evaporation is controlled by many factors such as temperature, relative air humidity, sunlight, wind velocity and varies significantly seasonably. Generally, annual evaporation varies from 1000,4 mm (in 2008) to 1277.5 mm (in 2003), average as 1171.5 mm. Evaporation is usually high during dry season (from December to February). Averaged daily evaporation is 3.1 mm. Daily highest evaporation was 8.3 mm in December of 2001. Average monthly evaporation is indicated in Table 2.3.

Table 2.3 Daily evaporation at Con Dao station (unit: mm/day)

Features	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
E_{avg}	3.7	3.5	3.2	3.2	3.2	2.9	3.1	3.2	2.9	2.2	3.0	3.6
E_{min}	1.8	1.8	1.7	2	1.5	1.5	1.6	1.5	1.3	0.8	1.3	1.4
E_{max}	6.2	6.3	5.2	4.8	5.3	4.6	4.6	4.9	4.5	4.0	5.4	6.5

2.2.2 Hydrological network

A. River and streams

Due to high and steep topography, in the Con Dao archipelagos there is no river, but 45 short, small streams. Stream density is 0.73 km/km^2. Total length of streams is 37.6 km.

Preliminary investigation results show water exists in streams only in rainy season. In dry season there is no or little water.

Surface water bodies are contained in lakes namely An Hai (Lake 1), Quang Trung (Lake 2). Sizes and volumes of 2 lakes are 280,000 m^2 - 414,000 m^3 and 170,000m^2 – 250,000 m^3. The locations of 2 lakes and observed flow runoffs are shown in Figure 2.3.

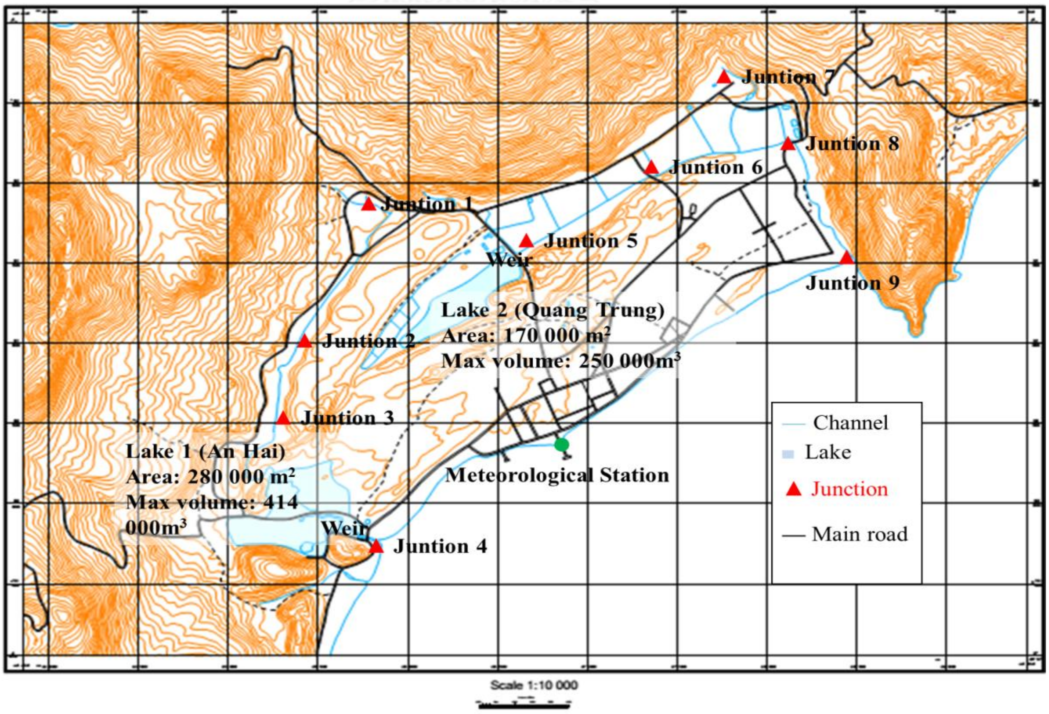


Figure 2.3 Hydrological diagram

B. Marine hydrology

Concerning marine hydrology, in Con Dao archipelagos there has been monitoring for a long time, but monitoring regime has not been continuous. Monitoring frequency was daily, but only 4 times a day at one, seven, 13 and 19 o'clock. Monitored parameters were: water level, water temperature and salinity. Each parameter is shown in Tables below.

Water level fluctuates after semi-diurnal regime (2 times of high tide and low tide). The lowest level was 17 cm on 20-7-2005 and highest was 398 cm on 18-12-2005. Average level is 246cm. Average monthly water levels are displayed in Table 2.4.

Table 2.4 Average hydrological parameters at Con Dao Meteorological station

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Water level	259	259	250	243	227	226	226	228	241	257	265	270
Temperature (°C)	26	26.3	28	28.9	30	29.6	28.8	29	29	30	29	26
Salinity (‰)	3.36	3.41	3.40	3.41	3.40	3.38	3.31	3.27	3.29	2.99	3.27	3.32

Temperature of sea water in Con Son Island is rather warm, average as 26 - 29.6°C. According to temperature data recorded at Quay 914, the lowest water temperature recorded on 9/01/2006 as 23.1°C and the highest was 33.6°C recorded on 25/10/2005. Average monthly temperatures at Con Dao station were presented on Table 2.4.

Salinity of sea water is rather low. The lowest salinity in ‰ was recorded as 1.89‰ (1.89g/l) on October 12th 2005. The highest salinity was 3.44‰ on many days in February 2006. Generally, salinity is usually low in October. Particularly, in October 2005, low salinity was from 1.60 to 1.89 g/l that caused some damage for sea products. Average monthly salinities were presented in Table 2.4.

2.3 Hydrogeology

On the basis of geological structure, existence forms, water bearing features and other hydrogeological factors, in Con Son Island 3 hydrogeological units can be defined as follows:

1. Intergranular Holocene aquifer (qh)
2. Intergranular Pleistocene aquifer (qp)
3. Geological formation aquitard (Mz).

Based on report of Chan (2006), general features of the mentioned above hydrogeological units will be described as shown is Figure 2.4, Figure 2.5, Figure 2.6, Figure 2.7.

2.3.1. Intergranular Holocene aquifer (qh)

Soft unconsolidated Holocene sediments are located mainly in central plain of Con Son island on area of 4.2 km^2. They are the youngest and have various origins: marine, eolian, eolian-marine, swamp-marine, deluvial, elluvial and proluvial. Average thickness in Con Son Island is 3 - 6 m. Lithological compound is: clay, fine sand, medium to coarse sand with pebbles, boulders.

Collected data of investigation, slug tests indicated that discharge of the aquifer is little. Practically, this is a superficial cover. It contains water in rainy season, but is depleted in dry season. Lithological composition is presented by silt, fine sand with organic remainders which creates a low permeable layer. Water quality is good. Water is transparent, colorless, odorless, fresh, polluted by iron in some places. Value of pH = 6.62 - 7.59. Total dissolved solids (TDS) are M = 0. 14 g/l - 0.22 g/l. Water types are bicarbonate – chloride sodium-calcium or chloride-bicarbonate sodium-calcium.

2.3.2. Intergranular Pleistocene aquifer (qp)

Soft unconsolidated Pleistocene sediments are distributed mainly in central Con Son plain. Outcrop area is a stripe about 1.4 km^2. Besides, it is covered by Holocene sediments to depth of from 2-3 m to 7 m (borehole TV2). According to drilling data, the valley has a hollow structure with the biggest thickness in the center. Age of the sediments is from middle to upper. Origin is marine, eolian-marine. Thickness of the aquifer is defined on the basis of data of borehole TV06 (in Figure 2.4). Average thickness of the sediments is 16.5m. Lithological composition of water bearing sediments is fine sand with gravel, shell fragments. Medium sand occupies small percentage. There are lenses of sandy silt somewhere. The boundary layer between Holocene sediments and middle Pleistocene sediments is presented by gray fine sand with shell fragments. Presently, all production wells tap water from this aquifer. In Table 2.5 below thickness and pumping test results of Pleistocene aquifer in Con Son valley are introduced.

From Table 2.5, thickness of the Pleistocene aquifer varies from 7 to 26.8 m, discharge varies from 0.51 to 3.61 l/s, drawdown is from 1.62 to 5.10 m, and specific yield is calculated as from 0.12 to 1.01 l /sm.

Concerning hydraulic relationship, Pleistocene aquifer has tight relationship with overlying Holocene aquifer caused by the absence of a clayed layer separating them. Both aquifers are presented by fine sand. The valley contacts East Sea. So, water of the aquifer has hydraulic relationship with sea water in one way: water in the valley recharges the sea. This can explain why coastal sea water in Con Dao has low salinity.

Table 2.5 Thickness and pumping test results of the aquifer in Con Son valley (Chan (2006))

No.	Well	Aquifer (m)			Cooper & Jacob method		Hantush's method	
		From	To	Thick.	K (m/day)	T (m^2/day)	K (m/day)	T (m^2/day)
1	CS 2	0	11.6	11.6	7.25	84.1	6.92	80.27
2	CS 3	2	24	22	7.50	165	7.60	167.2
3	CS 4	3.2	22	18.8	8.20	154.16	7.77	146.08
4	CS 5	0	13	13	2.43	31.59	2.60	33.8
5	CS 6	1.2	28	26.8	6.52	174.74	6.90	184.92
6	CS 7	3	21	18	7.35	132.3	7.28	131.04
7	CS 9	5	18	13	8.30	107.9	6.50	84.5
8	CS 10	3.5	21	17.5	7.20	126	7.44	130.2
9	CS 11	3	21	18	6.96	125.28	7.25	130.5
10	CS 12	4	19	15	2.30	34.5	2.70	3855
11	TV01	3	10	7	5.30	37.1	5.41	37.87
12	TV04	3	16	13	2.43	31.59	2.83	36.79
13	TV06	6	27	21	7.70	161.7	7.20	151.2
14	26	3	16	13	5.40	70.2	3.50	45.5

Concerning groundwater behavior of Pleistocene aquifer, monitoring results at both valleys show that groundwater behavior is seasonal. From end of April beginning of May (rainy season), due to recharge, water level begins to upraise up to end of November reaches maximal values in December and begins to gradually go down (see monthly groundwater levels of calibration in chapter 5). Water level fluctuation diagram has sine form. Fluctuation amplitude is from 0.53 to 2.04 m (station CS8 which is located between mountain and basin).

Recharge source for the aquifer is rain water and lakes. Common direction of groundwater of the aquifer is towards the sea.

Regarding water quality, results of previous research show that water has good quality for domestic and drinking use. However, VES and drilling data also indicated that there is a salinity boundary (1 g/l) in the valley. This boundary is located near to the water level line but its displacement versus time has not been defined yet. In Table 2.8, main criteria of water of Pleistocene aquifer in Con Son valley at end of dry season are presented.

Table 2.6 Analysis results of water samples at the end of dry season in Con Son valley (Chan (2006))

No.	Well ID	Screen (m)			Results of water quality analysis			
		From	To	Length	pH	Cl (g/l)	M (g/l)	Water type
1	CS1	5.5	11.5	6.0	6.35	14.18	0.057	Chloride-bicarbonate Na
2	CS2	3.5	9.5	6.0	5.43	12.41	0.07	Chloride-bicarbonate Na
3	CS3	7.0	19.0	12.0	6.57	13.12	0.1	Bicarbonate-chloride Na-Ca
4	CS4	5.5	17.5	12.0	5.14	16.66	0.05	Chloride-bicarbonate Na
5	CS5	3.0	11.0	8.0	6.33	53.18	0.27	Bicarbonate-chloride Ca-Na
6	CS7	7.0	19.0	12.0	7.50	48.92	0.40	Bicarbonate Ca-Na
7	CS8		13.0		6.69	77.28	0.33	Bicarbonate-chloride Ca-Na-Mg
8	CS10	3.5	15.5	12.0	7.41	14.18	0.25	Bicarbonate Ca
9	CS11	7.0	15.0	8.0	4.9	28.36	0.12	Chloride Na-NH_4
10	CS12	3.5	7.5	4.0	7.6	47.15	0.35	Bicarbonate Ca

Total dissolved solids are small, from 0.07 to 0.40 g/l. Sample taken from production well gave rather good quality, stable with time. Micro-element contents are below allowable criteria. However, at some places water is polluted by organic compounds.

2.3.3. Geological formation aquitard (Mz)

Geological formation aquitard surrounds Con Son valley on 2 sides, consists of biotite small grain porphyr granite of Deo Ca complex, aged as Cretaceous on the West and Northwest; quartz diorite, gabbrodiorite of Dinh Quan complex aged as Late Jurassic-Early Cretaceous on the North, Northeast; a small block of rhyolite porphyr of crater facies of Nha Trang formation aged as Cretaceous on the East of Lo Voi lake.

At the Forest Guard Station on the right side along the road from Con Son township to Ben Dam port there is a spring. Water flows down and is transparent, colorless, and fresh. According to forest guard officers, water exists only in rainy season. In dry season water nearly exhausts.

Water sample taken from dug well of Radar Station 590 which has depth of 3.95 m, water level of 3.27 m gave chemical formula of water as follows:

$$M_{0,17}\frac{HCO3_{64}CL_{30}SO_{24}^{4}}{Na_{72}Ca_{24}Mg_{14}}pH_{7,0}$$

Water type: Bicarbonate-chloride sodium.

Intrusive rocks of Dinh Quan formation are located on the North of the valley in Chua Mountain (elevation of 515m). They consist of gabbrodiorite, diorite, quartz diorite or monzodiorite. By assessing their high elevation location, litological compound, monolithic structure, we can evaluate their productivity as poor.

To sum up, groundwater in Con Son valley exists mainly in soft unconsolidated middle-upper Pleistocene sediments. The aquifer is unconfined. Distribution depth is shallow. Water of the aquifer has tight relationship with lakes and East Sea. Recharge source for the aquifer is rain water and surface water from the lakes and streams. Groundwater behavior is seasonal. Water quality is good. Water is ultra-fresh. Water quality is production wells are unchanged with time and water of the aquifer can satisfy completely current demand of the island.

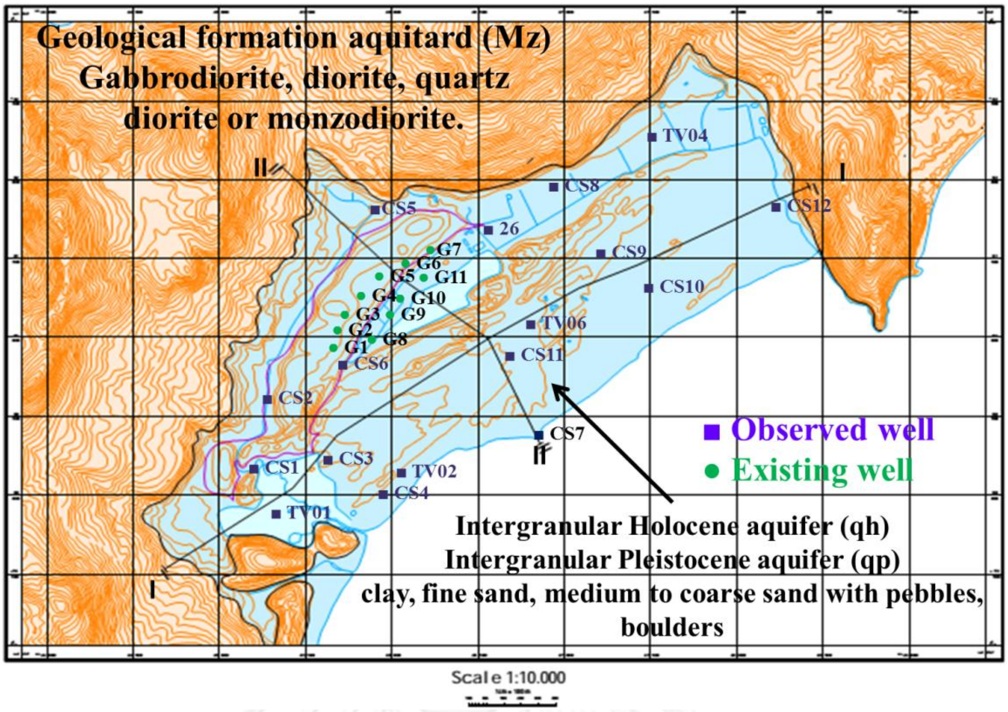
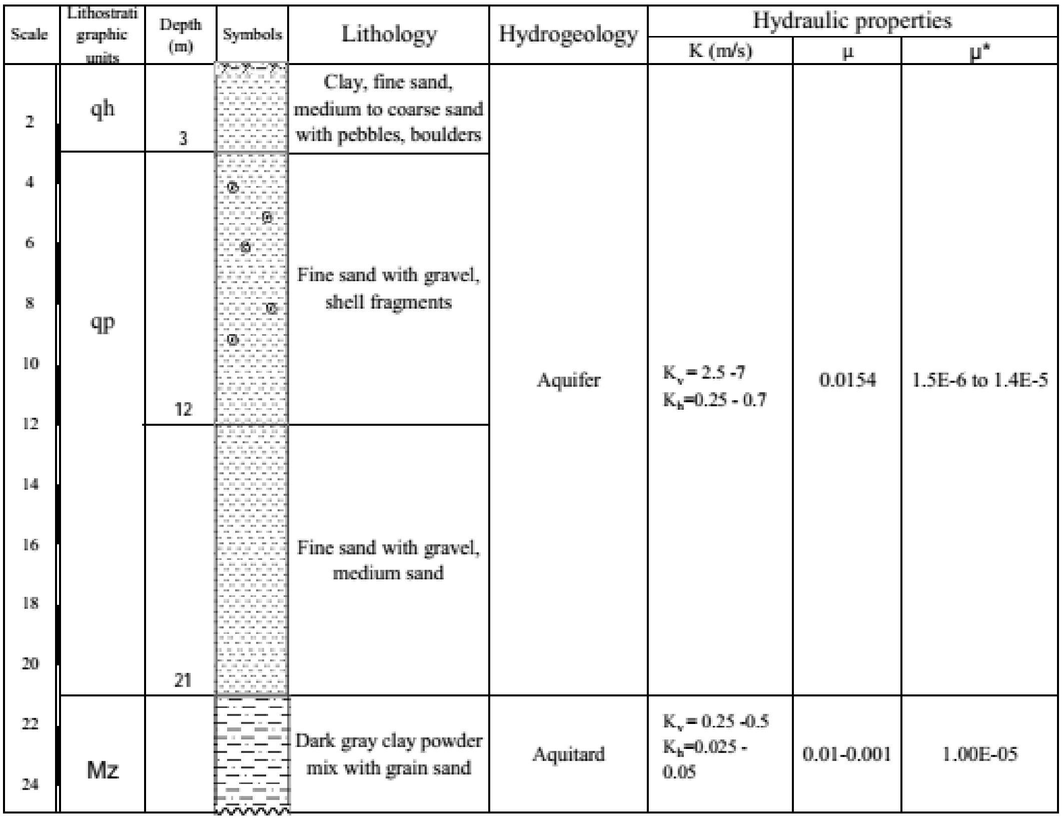


Figure 2.4 Hydrogeology diagram



Scale	Lithostratigraphic units	Depth (m)	Symbols	Lithology	Hydrogeology	Hydraulic properties		
						K (m/s)	μ	μ*
2	qh	3		Clay, fine sand, medium to coarse sand with pebbles, boulders	Aquifer	K_v = 2.5 -7 K_h=0.25 - 0.7	0.0154	1.5E-6 to 1.4E-5
4 6 8 10 12	qp	12		Fine sand with gravel, shell fragments				
14 16 18 20		21		Fine sand with gravel, medium sand				
22 24	Mz			Dark gray clay powder mix with grain sand	Aquitard	K_v = 0.25 -0.5 K_h=0.025 - 0.05	0.01-0.001	1.00E-05

Figure 2.5 Hydrogeological stratigraphic

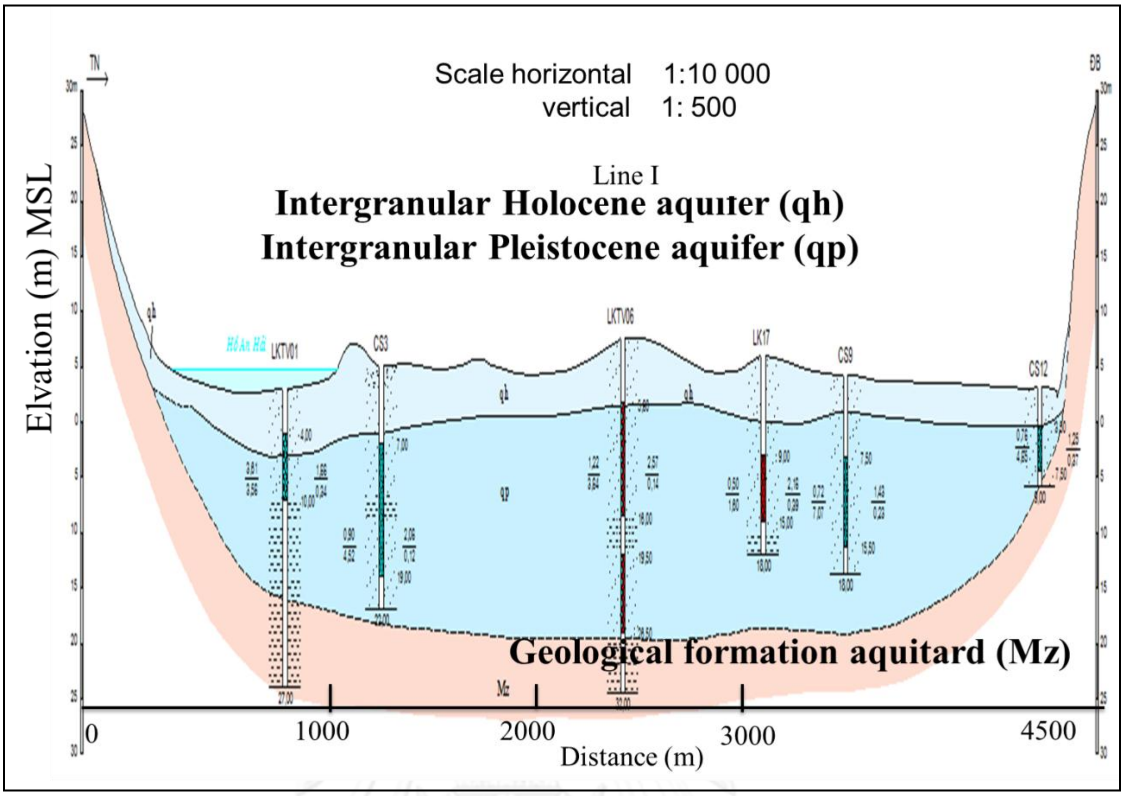


Figure 2.6 Cross section I

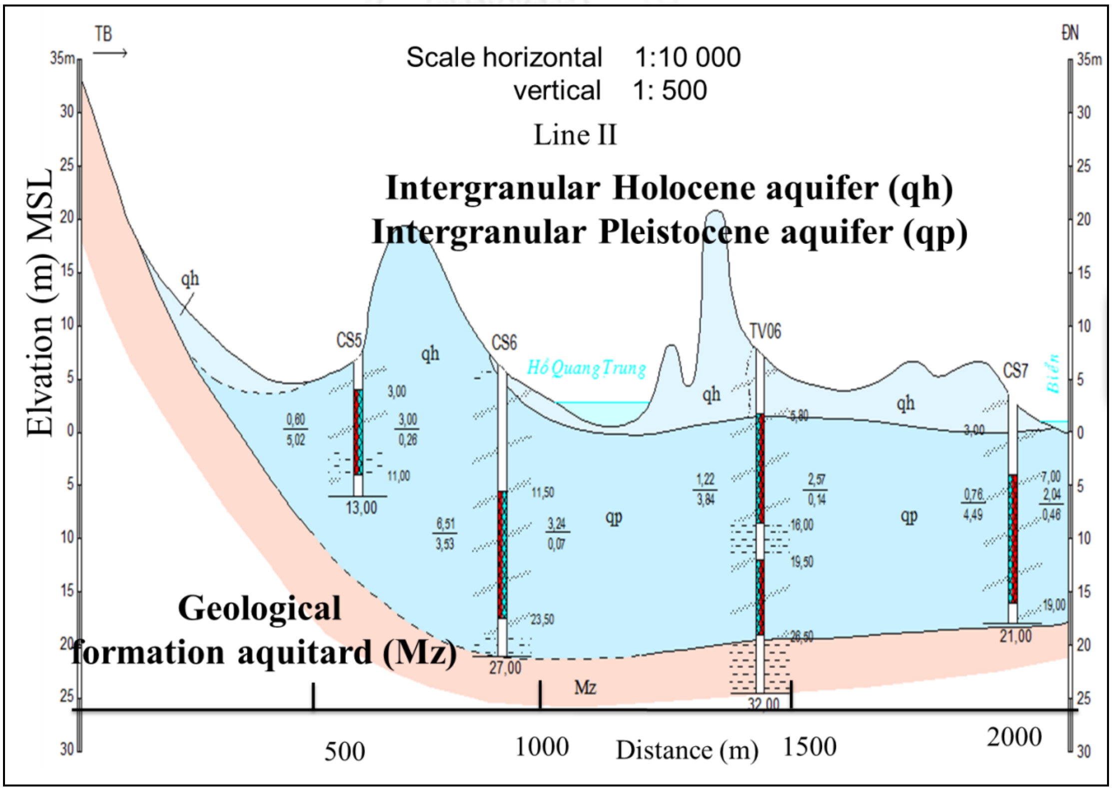


Figure 2.7 Cross section II

2.4 Water use

Currently the total amount of fresh water for domestic and agriculture in Con Dao district are due to water-supply station Con Dao offers.

Water supply system Con Dao includes 15 wells along Quang Trung Lake I. Well diameter is Φ= 200mm, depth 20 - 26 m, distance between wells 90 - 160 m. The amount of extraction is shown in Figure 2.5. From 2006 to 2011, the pumping rate increased gradually from 1500 m^3/day – 2500 m^3/day.

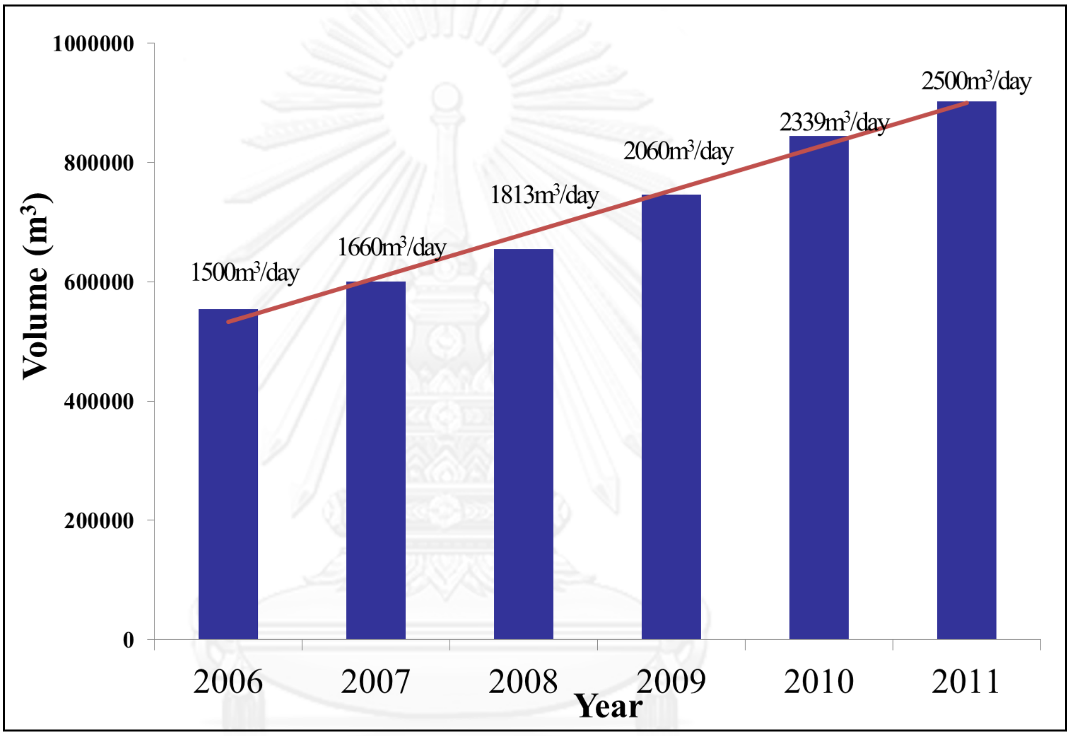


Figure 2.8 Previous groundwater used in year 2006 - 2011

2.5 Future water demand

A. Domestic water

Water used for calculate urban based on Vietnam standards for urban water supply QCXDVN 01:2008/BXD. Urban classified by population size. Water for urban use includes the following:

Table 2.7 Standard water supply for urban in Viet Nam (TCXDVD 33:2006)

	Population (persons)	Water used (l /person/day)
Very large urban	≥500,000	250-300
Large Urban	≥150,000	200-250
Urban medium	≥20,000	150-200
Small Urban	≥4.000	100-150

This is the standard for water use on most water users, on average, the ratio of non-regulation (0.7 to 0.8).

Base on “Project of socio-economical development of Con Dao district, Ba Ria-Vung Tau province to 2020” (Tang Ng. V. et al., 1998), the population in 2020 would be 20.000 persons. Water supply for domestic purposes of the entire district would strive 175 l/person/day Con Dao, with a 2020 population estimated at 20.000 persons. Thus, the average future domestic water demand per day in Con Dao district is 3,500 m^3/day.

B. Water use for public works, services

Water for public works and services get 10% from domestic water estimated at 350 m^3/day.

Water irrigation, street cleaning get 10% from domestic water estimated at 350 m^3/day

Provision for losses of 20% domestic water estimated at 700 m^3/day

Water standards for port logistics fishing regulations do not currently exist, thus; refer to the actual water use in a number of logistical and fishing ports in the South. At the annual Con Dao received about 5,000 ships, boats, expected in 2020 will receive 8,000 boats per year. Thus water port logistics service and fishing around 300m^3/day.

Hence, the total water used for public works, services estimated is 1,700m^3/day

C. Agriculture

According “Project of socio-economical development of Con Dao district, Ba Ria-Vung Tau province to 2020” (Tang Ng. V. et al., 1998), the agriculture area and livestock are showed in the Table 2.8 and Table 2.9, the coefficient of irrigation in Con Dao and water demand for livestock.

Table 2.8 Livestock in Con Son in year 2020

Livestock (unit)	Year 2020
Cattles (animals)	500
Pigs(animals)	2000
Chickens, ducks(animals)	2000
Vegetables(ha)	20
Fruit (ha)	20

Table 2.9 The water demand for livestock

Livestock	Water demand *(l/day/animal)*
Cattles	50
Pigs	30
Chickens, ducks	5

Table 2.10 The coefficient of irrigation in Con Dao (unit: l/s/ha)

	Jan	Feb	Mar	Apr	May	Jun
Vegetables	0.05787	0.144676	0.188	0.351667	0.156	0.133667
Fruit	0.002002	0.073542	0.427075	0.213738	0.400603	0.29866

	Jul	Aug	Sep	Oct	Nov	Dec
Vegetables	0.145	0.156	0.173667	0.176	0.155	0.028935
Fruit	0.335278	0.368167	0.433747	0.31433	0.15702	0.005179

The water demand for agriculture are calculated and estimated in Table 2.11.

Table 2.11 Water demand estimate for agriculture 2020

Purpose	Qualities	Water (m^3/day)
Cattles (animals)	500	25
Pigs(animals)	2000	60
Chickens, ducks(animals)	2000	10
Vegetables(ha)	20	337
Fruit (ha)	20	185
Totals		617

Table 2.12 Summary future water demand (Unit: m^3/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Vegetables	100	250	325	608	270	231	251	270	300	304	268	50
Fruit	3	127	738	369	692	516	579	636	750	543	271	9
Cattles (animals)	25	25	25	25	25	25	25	25	25	25	25	25
Pigs(animals)	60	60	60	60	60	60	60	60	60	60	60	60
Chickens, ducks(animals)	10	10	10	10	10	10	10	10	10	10	10	10
Population	3500	3500	3500	3500	3500	3500	3500	3500	3500	3500	3500	3500
Water used for public works, services	1700	1700	1700	1700	1700	1700	1700	1700	1700	1700	1700	1700
Total (m^3/day)	5398	5672	6358	6272	6257	6042	6125	6201	6345	6142	5834	5354

According the “Project of socio - economical development of Con Dao district, Ba Ria-Vung Tau province to 2020” (Tang Ng. V. et al., 1998) and Vietnam standard for urban water supply, the water demand per day in year 2020 is in range 5398 - 6358 m^3/day. In this study, groundwater capability is assessment under increasing pumping rate approximately to 6500 m^3/day.

CHAPTER III

LITERATURE REVIEW

The literature review for this thesis includes surface modeling, groundwater modeling, interaction between surface water and groundwater, water resources development. The summary is shown as follow:

3.1 Surface modeling

Radmanesh F. (2006) calibrated and evaluated the Hydrologic Engineering Center – Hydrologic Modeling System (HEC-HMS) model in the Yellow River watershed based on rainfall and discharge data. In this study, six rainfalls with their simultaneous floods was selected. The results indicate good fit between the peak discharge of observed and simulated hydrographs. In addition, comparison of simulated and observed discharges by different methods showed that the SCS method had the best result.

A. Majidi (2012) simulated rainfall-runoff process using Green - Ampt method and HEC-HMS Model in Abnama Watershed, Iran. Rainfall-runoff simulation has been conducted using five rainstorm events. The results showed that lag time is sensitive parameter. Model validation using optimized lag time parameter showed reasonable difference in peak flow. Finally it can be concluded that model can be used with reasonable approximation in hydrologic simulation in Abnama watershed.

Mir Mehdi M. (2009) determined the flood of Maroon watershed conduct a study as calibration of HEC - HMS model and assessment of this model response to flood of Maron watershed. Results of calibration and optimization of model showed that SCS method had the least difference in peak discharge and time to peak in simulated and observed hydrographs.

M. Ebrahimian (2012) evaluated the applicability of Natural Resources Conservation Service-Curve Number (NRCS-CN) method together with GIS in estimating runoff depth in a mountainous watershed. The study was carried out in the semi-arid Kardeh watershed which lies about 42 km north of Mashhad, Khorasan Razavi Province, Iran. About 9% of the estimated runoff values were within ±10% of the recorded values and 43% had error percent greater than ±50%. The results indicated that the combined GIS and CN method can be used in semi-arid mountainous watersheds with about 55% accuracy only for management and conservation purposes.

Arekhi (2012) analyzed runoff losses under Green and Ampt, Initial and constant loss rate and Deficit and Constant loss methods by considering various objective functions (percent error in peaks and volumes) in Kan watershed, Iran by using HEC-HMS. Results showed that Initial and constant loss rate method among six events had better results rather than Green - Ampt method, and Deficit and Constant loss method.

Res hma T (2013) has used HEC-HMS model to simulate runoff process in Walnut Gulch watershed located in Arizona, USA. By applying Green - Ampt, Clark's Unit hydrograph and Kinematic wave routing methods, the infiltration, rainfall excess conversion to runoff and flow routing has been calibrated, validated and computed for the seven rainfall events. From the results, it is observed that HEC-HMS model has performed satisfactorily for the simulation runoff for the different rainfall events.

B. M. Golrang (2013) evaluated watershed management Implemented activities in Kushk-Abad Watershed, Iran by HEC-HMS. The evaluation of HECHMS model was applied SCS unit hydrograph, Muskingum routing method in basins. And, results showed that in the bell form (Normal) hydrographs, error was very small.

3.2 Groundwater modeling

Oki (1997) developed two-dimensional, steady-state, areal ground-water flow model for the island of Molokai, Hawaii, to enhance the understanding of the conceptual framework of the ground-water flow system, the distribution of aquifer hydraulic properties, and the regional effects of ground-water withdrawals on water levels and coastal discharge. Model results are in agreement with the general conceptual model of the flow system on Molokai, where ground water flows from the interior and high-recharge areas to the coast. Moreover, the results showed the effects of proposed ground-water withdrawals on water levels and coastal discharge, relative to model-calculated water levels and coastal discharge in 1992-96 withdrawal rates are widespread.

Oki (2002) reassessed ground-water recharge and simulated ground-water availability in Hawi Area of North Kohala, Hawaii. According to study, ground-water availability estimates for the Hawi area are highly dependent on the recharge estimate. Results of this study underscore the importance of collecting information to better constrain the recharge estimate so that better estimates of ground-water availability can be made.

Wa’il Y. (2007) used Modflow and MT3D groundwater flow and transport models as a management tool for the Azraq groundwater system. Simulation results indicate that increasing the current pumping rates by 50% caused the maximum drawdown and should be avoided. According to the study, the effect of the different pumping scheme on the values of Electric Conductivity (EC) is less profound than the effects on the drawdown values.

Zume and Tarhule (2008) used MODFLOW (McDonald and Harbaugh1988), a three-dimensional numerical groundwater flow model, to investigate the impacts of groundwater pumping from an alluvial aquifer on stream–aquifer interactions, specifically, stream flow depletion, in a semiarid but agriculturally important area of north western Oklahoma, USA. According results, the groundwater abstraction forced larger lateral flows from beyond the research area as well as increased infiltration from rivers and lakes.

Chan (2009) assessed of groundwater reserves for the small and isolated area Con Dao by Groundwater Modelling System (GMS). The results of identifying the components of 3,196 m^3/day reserves using an available groundwater flow model at Con Son Island. However, the study just used the monitoring data conducted in 1 year and did not clarify surface – groundwater interaction.

Jaramillo-Nieves L. (2012) examined the groundwater characteristics in the Silver Bell Mountains, Arizona, USA, using a numerical model. The model results show that groundwater flow in the Silver Bell Mountains is strongly influenced by topography and its velocity varies with depth. In addition, the numerical model supports the idea of a continuous sustained interaction between groundwater flow and porphyry copper deposits in the Silver Bell Mountains.

3.3 Interaction between surface water and groundwater

Finch (1998) estimated direct groundwater recharge using a simple water balance model – sensitivity to land surface parameters. This study has shown that the most important land surface parameters required for estimating groundwater recharge are those required by the soil water component of the simple water balance models model. In particular, it is field drainable water, maximum available water, and the rooting depth which have a major impact on estimates of direct groundwater recharge.

Rodgers P. et al. (2004) examined groundwater–surface-water interactions in a braided section of the River Feshie, Cairngorms, and Scotland. This study clearly demonstrates the highly significant and dynamic influence that groundwater–surface-water exchange in the Feshie's braided section has on the hydrochemistry of surface waters flowing through it. This influence is temporally significant in response to seasonal variations in flow conditions over the hydrological year as well as at the shorter, event scale and both provide valuable insight into the processes affecting the buffering of surface water hydrochemistry.

Hantush (2005) assessed management of water resources and riparian zone hydrology. The results presented closed-form solutions to stream–aquifer interactions during storm events and base-flow periods. Assumptions were made to simplify the analysis and solutions were obtained in terms of integral convolutions of linear response functions which relate channel discharge and stream– aquifer discharge, in rates and volumes, to variety of system's excitations pertinent to hillslope hydrology, stream riparian buffer strips, and regulatory water management measures. Discrete-time kernels were derived to simulate the effect of complex hydrographs and system's excitations, and to allow for the segmentation of a heterogeneous stream–aquifer system into a cascade of hydrologic units of homogeneous properties through which flow could be routed in a cascading fashion.

Hunt, Strand, and Walker (2006) measured groundwater–surface water exchange at three wetland stream sites. The three sites included one high groundwater discharge (HGD) site, one weak groundwater discharge (WGD) site and one groundwater recharge (GR) site. The study suggests groundwater–surface water interactions can strongly influence benthic productivity, thus emphasizing the importance of quantitative hydrology for management of wetland-stream ecosystems in the northern temperate regions.

Bailly-Comte V. (2008) assessed Karst/River interactions by the way of flood hydrograph analysis and new tools for time series analysis in this field of research. The results showed that during a flood the modification of the surface flows in the river is treated as a Linear Time-Invariant system (LTI system). For several floods, the frequency response function estimations are interpreted in term of flood wave modifications through the karst area. In this way, according to the initial state of the Karst/River system, the autogenic and/or allogeneic recharge of the aquifer may induce surge flows and a significant karst contribution to surface flows.

Rodriguez Leticia B. (2008) applied methodology designed to improve the representation of water surface profile along open drain channels within the framework of regional groundwater modeling. The proposed methodology employs an iterative procedure that combines two public domain computational codes, MODFLOW and HEC-RAS. The approach not only provides a sounder hydraulic profile along drain canals for a wide range of downstream hydraulic conditions, but also could mean a considerable time saving in the burdensome task of specifying water depths along a large and complex drainage system with limited field data. However, this particular study was limited to the case of groundwater discharge to the surface water ant not the reverse.

Liu and Sheng (2011) have developed a trend-outflow method to gain a better understanding of the interactions based on cumulated inflow and outflow data for any river reaches of interest. Authors found that trend-outflows of the Upper Rio Grande reaches, Española, Albuquerque, Socorro–Engle, Palomas, and Rincon are linear with inflow, while those of reaches, Belen, Mesilla and Hueco are quadratic. Reaches Belen, Mesilla and Hueco are found as water deficit reaches mainly for irrigated agriculture in extreme drought years.

Sanz et al. (2011) characterized the river–aquifer relationship, to determine the influence that groundwater abstraction has on the river discharge. This research has advanced a three-dimensional large-scale numerical groundwater-flow model (MODFLOW 2000) in order to spatially and temporally evaluates, quantify and predict the river–aquifer interactions that are influenced by groundwater abstraction in The Mancha Oriental System (Spanish). The results demonstrated that although groundwater abstraction increased considerably from the early 1980s to 2000, the depletion of aquifer was still lower than might be expected. This is mainly due to aquifer was recharged from the Jucar River, induced by groundwater abstraction. The area of disconnection between the river and the water Table (i.e. where groundwater head is lower than the riverbed) is found to have spread 20km downstream from its position before pumping started.

3.4 Water resources development

John E. Griggs (1993) applied mathematical model to examine development alternatives for a two-phase miscible groundwater system in a cross section through the Laura area of Majuro Atoll, Marshall Islands. Analysis of alternative development methods verifies that multiple pumping centers are more efficient for the extraction of fresh groundwater than individual pumping centers. Simulation results show that sustainable fresh water extraction rates from galleries are about double the extraction rates possible from individual pumping centers.

Khasankhanova (2003) presented the two case studies of the Karshi and South Karakalpakstan regions to illustrate the effects of uniting potential of all interested participants to improve water management and environmental safety. The results show that the privatization of irrigation management is a key of balancing stakeholder interests, and there is a large potential for water users to participate in these interaction. Their participation can improve their contributions to decision making as well as funding. The study also indicates that water management and environmental safety greatly benefit from comprehensive stakeholder participation.

N. C. Mondal (2009) appraised the fresh groundwater in Lakshadweep Island, the western coast of India, in terms of availability, distribution and quality, is needed in order to meet this increasing demand for fresh water and also to formulate future planning and development of water resources. The results indicate that the eastern parts as well as peripherals of western part of the island are more vulnerable for seawater ingress. Therefore, immediate steps to be taken like usage of limited fresh groundwater resources, rainwater harvesting, etc., to stop the seawater ingress and its further encroachment/spread on the island.

Hussein and Al-Weshah (2009) assisted the decision makers in the field of water resources planning and management in Jordan Valley and similar countries in the region to use WEAP model to better manage the water demand / supply cases and forecast for the future. The model was tested and adopted for the current status of the valley. The selected management plan comes from comparison between 3 scenarios: first, the treated wastewater of three treatment plants in the North regions (Irbid, Duqarra, and Wadi Hassan) to be used in the future for irrigation practices; second, raise the efficiency in the irrigation practices in the Jordan Valley by 10%; thirds, using 50 MCM from the Unity Dam to cover Amman city domestic demand. According the study, from the purely technical aspects (quantity and quality), adaptation of supplying the system with 50 MCM of fresh water from the Unity Dam proved to be the best scenario. Raising the efficiency at the irrigation facilities will increase the available water and scale down the unmet fraction by 10% was the second option. Utilization of the treated wastewater in the north will add 15-20 MCM/year to the system but certain but ranked technically as the third. With the application of the unit costs only, the reuse of treated wastewater was selected as the first, rising the efficiency is the second and the Unity Dam is the third.

Kuster (2013) analyzed case study of water resources management in action, tracing the underlying mechanisms of water allocation problems in spate irrigation systems on the basis of qualitative data (2007) from the Tehama region in Yemen.

The study traced out six mechanisms by which the efficiency, equity and sustainability of Yemen’s water management may be enhanced for the future. First, the establishment of rules for quantitative extraction and (tax-relevant) water charges shall be established case-sensitive, based on realities in the different areas/governorates – as a motivation and basis for enforcement. Second, the predictability of volume and quantity of the water-resource should be increased as far as measuring allows – in order to raise awareness for lurking realities underground. Third, and long under way, 'constructive criticism' for local development in water use efficiency should still be continued as far as costs do not outweigh potential improvement. Fourth, to back local-level government-bodies, state-agencies like NWRA have to be decentralized – knowledge, leverage and foremost legitimacy are situated with local actors. Fifth, the government has to design tax-, tariff-, and pricing-instruments that steer the agricultural portfolio back towards a (traditional) focus on water-saving crops. Sixth, donor-aid and equalization transfers (urban to rural) have to be put in place to cushion and bridge the transition phase that most likely follows such an alteration of the agricultural system in particular, and the economic system in general.

CHAPTER IV

STUDY PROCEDURES AND THEORIES USED

The procedure of study has threefold: first, HEC-HMS is used to simulate surface water runoff. Second, groundwater is assessed by Groundwater Modeling System (GMS). Besides, the interaction between groundwater and surface water is also assessed in this part. Third, water resources development is planned and selected based on 12 alternatives under the consideration of construction cost, groundwater drawdown.

The data and water development plan necessary for the study was firstly collected both from the agencies and confirmed the status via site visit during January 2014.

The surface water runoff (HEC-HMS): This simulation involves 3 steps: first, the rainfall in 6 years is classified as high and low. Second, Storage – Discharge function, SW parameters (loss, transform, routing, loss/gain) are estimated by calibration and validation. Third, SW level is simulated by 17 years rainfall.

The groundwater modeling system (GMS): there are 4 steps to modeling groundwater system. First, the geological spatial is created by scatter point (coordinates, depth), 3D grid, and 2 layers. Second, the geo-hydrology characteristics (hydraulics conductivity, specific storage, specific yield), sources/sinks boundary (SW level, rainfall recharge), and pumping rate add on layers to interpolate values in each cell. Third, the results are calibrated in 3 years and validated in 3 years base on observed data. Fourth, simulate GW balance due to validated parameters and simulated SW in 17 years.

Water resources development plan: In order to develop water resources in study area, there are 3 options: a) expanding lake, b) adding on more wells and setting up new pumping pattern and c) combination expanding lake and adding wells. All of alternative are simulated and compared each other by construction cost, water balance (drawdown) and with no salt intrusion effect. The future climate is assumed to be the same as past period from year 1996 to 2012.

The overall study procedures, detailed study elements and methodologies used are shown in Figure 4.1 and Table 4.1

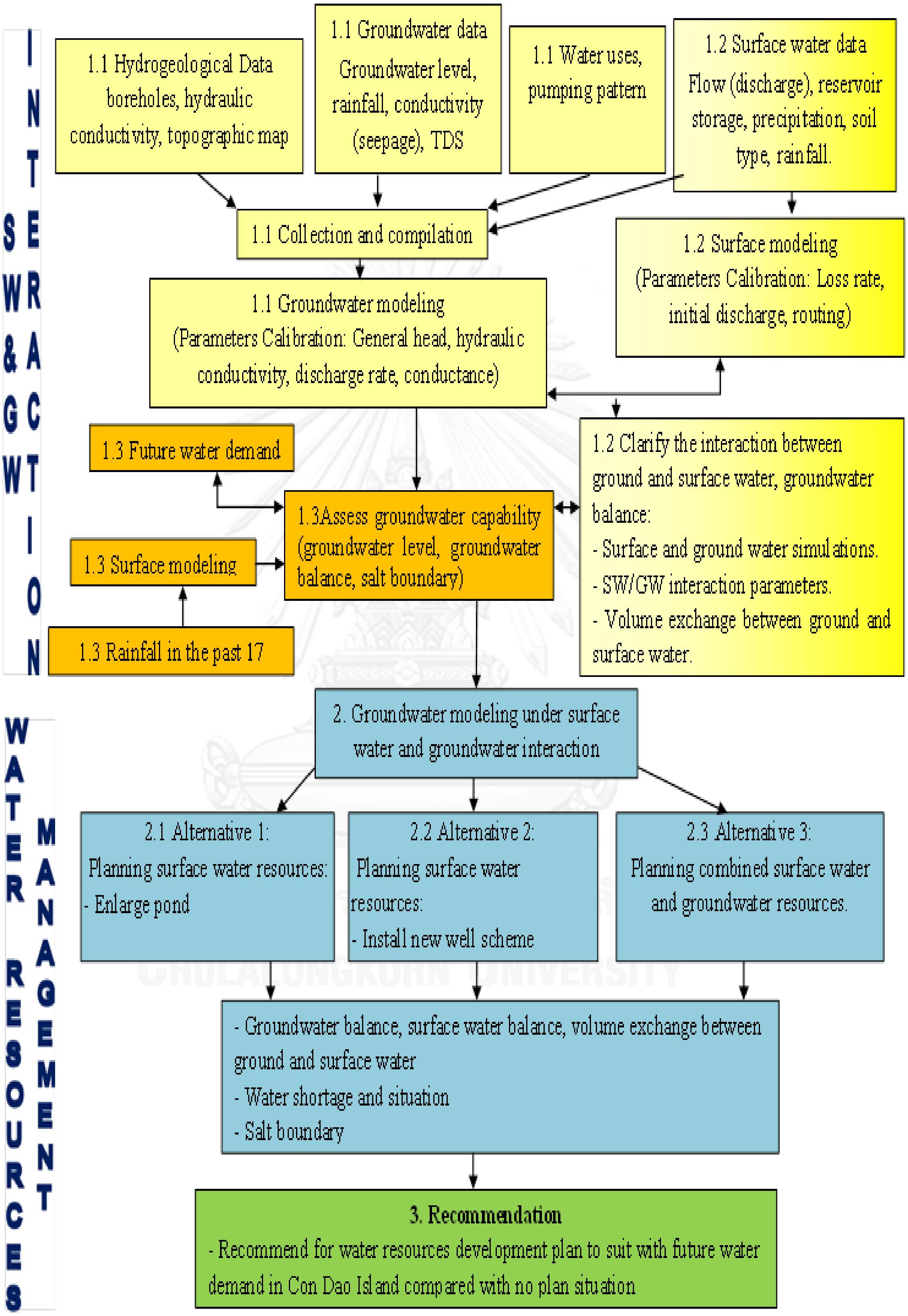


Figure 4.1 Study procedures

Table 4.1 Detailed study elements

No.	Objectives	Sub-objectives	Tasks	Tools/Output
1	Ground – surface water interaction assessment	Calibration ground-surface parameters. Verification ground-surface parameters. Assessment groundwater capability in Con Son.	Visit Meteorological station and go to the field; Collection and compilation data; Data verification; Collect general information; Simulation groundwater resources; Simulation surface water resources.	- Ground – surface water interaction assessment - Assessment groundwater capability
2	Water Development planning	Assessment groundwater capability in Con Son valley for satisfying future water demand in Con Dao Island.	Simulate groundwater resources; Simulate surface water resources; Apply 12 alternatives water management	- Water shortage and situation - Development plan alternatives
3	Recommendation	Selection of the optimal water management for satisfying future water demand in Con Dao Island.	Comparison alternatives under cost construction, water balance, and damage without planning.	- The recommendations on water development plan to satisfy future water demand in Con Dao Island.

4.1 Hydrologic Modeling System (HEC-HMS)

4.1.1 Theories use in HEC-HMS

The Hydrologic Modeling System (HEC-HMS) was designed to simulate the rainfall-runoff processes in a wide variety of watershed types. It was designed to be applicable in a wide range of geographic areas for solving the widest possible range of problems. This includes large river basin water supply and flood hydrology and small urban or natural watershed runoff. Hydrographs produced by the program are used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage deduction, floodplain regulation and systems operation (USACE-HEC, 2000, 2013)

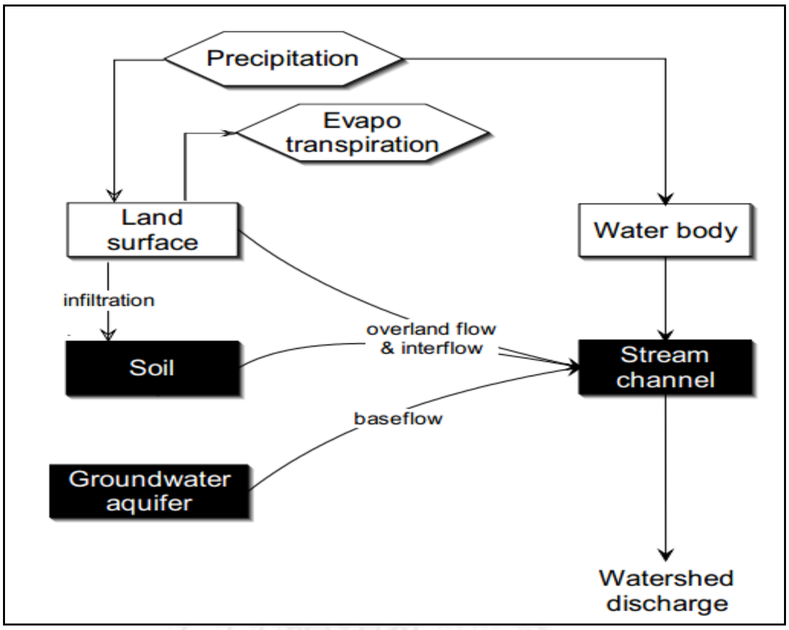


Figure 4.2 System diagram of the runoff process. (USACE-HEC, 2000)

A. Computing Runoff Volume

As illustrated in Figure 4.2, HEC-HMS computes runoff volume by computing the volume of water that is intercepted, infiltrated, stored, evaporated, or transpired and subtracting it from the precipitation. Interception and surface storage are intended to represent the surface storage of water by trees and grass, local depression in the ground surface, cracks and crevices in parking lots or roofs, or a surface area where water is not free to move as overland flow. Infiltration represents the movement of water to areas beneath the land surface. Interception, infiltration, storage, evaporation and transpiration collectively are referred to in the program and documentation as losses. In the study, HEC-HMS will use SCS Curve Number loss model to compute the volume of water.

The underlying concept of the initial and constant-rate loss model is that the maximum potential rate of precipitation loss, f_c, is constant throughout an event. Thus, if p_t is the MAP depth during a time interval t to $t+\Delta t$, the excess, pet, during the interval is given by:

$$P_e = \frac{(P - I_a)^2}{P - I_a + S} \tag{Eq 4.1}$$

Where:

P = accumulated rainfall depth at time t,

S= potential maximum retention

$$S = \frac{25400 - 254CN}{CN} \tag{Eq 4.2}$$

The initial CN is estimated by soil type in study area and the table runoff curve number in (Chow, 1988). The simulated CN is based on calibration and validation of surface modeling.

I_a= initial abstraction

An initial loss, I_a, is added to the model to represent interception and depression storage. Interception storage is a consequence of absorption of precipitation by surface cover, including plants in the watershed. Depression storage is a consequence of depression in the watershed topography; water is stored or evaporates. This loss occurs prior to the onset of runoff.

Until the accumulated precipitation on the previous area exceeds the initial loss volume, no runoff occurs, thus; the excess is given by:

$$pe_t = \left\{ \begin{array}{c} 0 \text{ if } \sum p_i < I_a \\ p_t - f_c \text{ if } \sum p_i > I_a \text{ and } p_t > f_c \\ 0 \quad \sum p_i > I_a \text{ and } p_t < f_c \end{array} \right\} \tag{Eq 4.3}$$

Table 4.2 SCS soil groups and infiltration (loss) rates (Skaggs & Khaleel, 1982)

Soil Group	**Description**	**Range of Loss Rates (in/hr)**
A	Deep sand, deep loess, aggregated silts	0.30-0.45
B	Shallow loess, sandy loam	0.15-0.30
C	Clay loams, shallow sandy loam, soils low in organic content, and soils usually high in clay	0.05-0.15
D	Soils that swell significantly when wet, heavy plastic clays, and certain saline soils	0.00-0.05

B. Modeling Direct Runoff

In case insufficiency of runoffs data, to compute the direct runoff hydrograph the program uses Clack Unit Hydrograph. The linear reservoir model is a common representation of the effects of this storage. That model begins with the continuity equation:

$$\frac{dS}{dt} = I_t - O_t \qquad \text{(Eq 4.4)}$$

Where

dS/dt: time rate of change of water in storage at time t;

I_t= average inflow to storage at time t;

And **O_t**= outflow from storage at time t.

With the linear reservoir model, storage at time t is related to outflow as:

$$S_t=RO_t \qquad \text{(Eq 4.5)}$$

Where R = a constant linear reservoir parameter which is estimated by calibration step. Combining and solving the equations using a simple finite difference approximation yields:

$$O_t=C_AI_t+C_BO_{t-1} \qquad \text{(Eq 4.6)}$$

Where **C_A, C_B** = routing coefficients. The coefficients are calculated from:

$$C_A = \frac{\Delta t}{R+0.5\Delta t} \qquad \text{(Eq 4.7)}$$

$$C_B=1-C_A \qquad \text{(Eq 4.8)}$$

The average outflow during period t is:

$$\bar{O}_t = \frac{O_{t-1}+O_t}{2} \qquad \text{(Eq 4.9)}$$

C. Modeling Channel Flow

Channel Flow is simulated based upon solution of the following form of Muskingum-Cunge model. The continuity equation is follow, (with lateral inflow, q_L, included):

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q_L \qquad \text{(Eq 4.10)}$$

and the diffusion form of the momentum equation:

$$S_f = S_o - \frac{\partial y}{\partial x} \qquad \text{(Eq 4.11)}$$

Combining these and using a linear approximation yields the convective diffusion equation (Miller and Cunge, 1975):

$$\frac{\partial Q}{\partial t} + c\frac{\partial Q}{\partial x} = \mu\frac{\partial^2 Q}{\partial x^2} + cq_L \qquad \text{(Eq 4.12)}$$

where ***C***= wave celerity (speed); and ***μ*** = hydraulic diffusivity. The wave celerity and the hydraulic diffusivity are expressed as follows:

$$c = \frac{\partial Q}{\partial A} \qquad \text{(Eq 4.13)}$$

And

$$\mu = \frac{Q}{2BS_0} \qquad \text{(Eq 4.14)}$$

where **B**= top width of the water surface.

S_o= friction slope or bed slope

4.1.2. Surface water flow simulation

The simulation method is based on the Hydrologic Modeling System (HEC-HMS). The method requires various input parameters to be set. Figure 4.3 shows one of surface schemes in the study area. The input variable data to simulate surface runoffs and calculation steps are as follows:

1) Rainfall, discharge runoffs, evaporation, and reservoir storage, water level: data is based on document from meteorological stations Con Dao district.

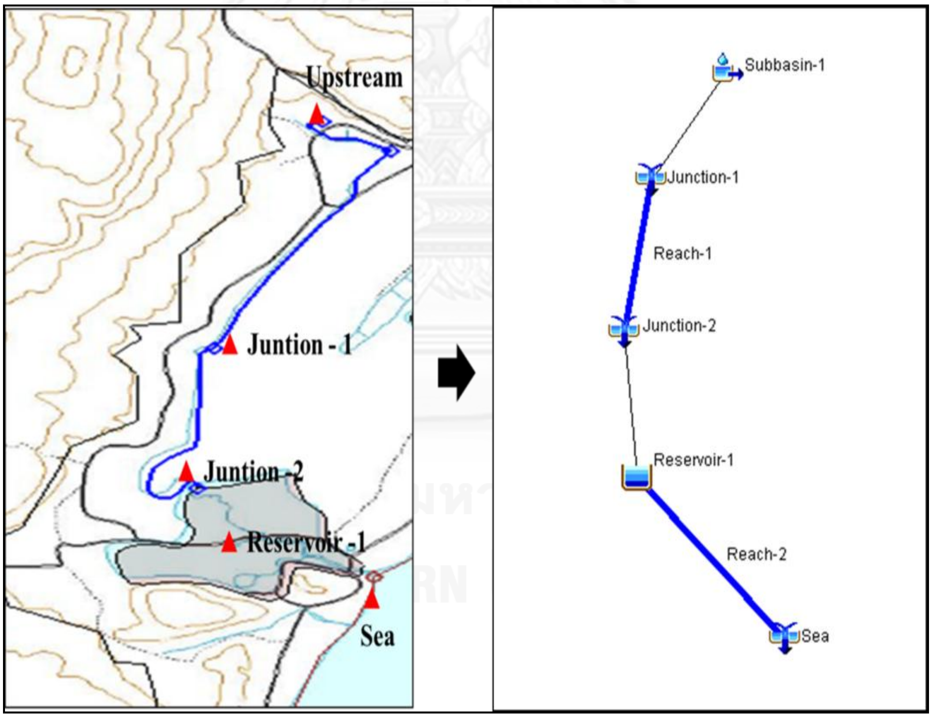
2) Loss: Initial Abstraction, curve number, imperious is referred by characteristic of soil and table runoff curve number in “Applied hydrology” (Chow, 1988). Thus, SCS Curve Number loss model (Eq 4.1 & Ep 4.2) will be applied for simulation. The initial loss specifies the amount of incoming precipitation that will be infiltrated or stored in the watershed before surface runoff begins. There is no recovery of the initial loss during periods without precipitation. The

initial constant loss method is very simple but still appropriate for watersheds that lack detailed soil information. (USACE-HEC, 2000).

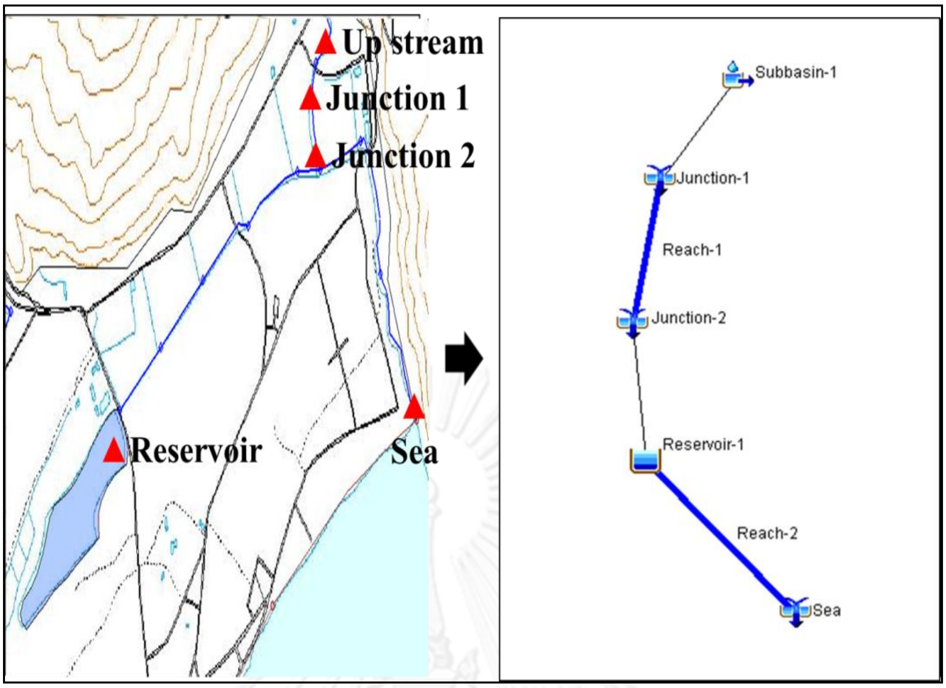
3) Transform: Clack Unit Hydrograph will be applied for simulation. The initial time of concentration, storage coefficient are selected by runoffs calibration. It was originally developed from observed data collected in small agricultural watersheds. The data were generalized as dimensionless hydrographs and a best- approximate hydrograph was developed for general application (USACE-HEC, 2000).
4) Routing: length, slope, shape of river are measured from field side. Manning’s n is referred by characteristic of surface and table Manning’s n Roughness coefficient for various open channel surface (Chow, 1988). Loss/gain of flow channel is selected during the calibration step. Hence, routing is calculation by Muskingum – Cunge which is presented above.
5) Reservoir routing: the discharge is presented as the recharge from lake to groundwater. Thus, discharge was simulated by applying Outflow curve method. Initial Elevation - Discharge Function is estimated by applying SW - GW interaction analysis. The Elevation – Storage is measured from study field (Table 4.3). Initial elevation is set as observed value in that time.
6) Evaluate the result of surface water by using SW – GW interaction.

Table 4.3 The elevation – storage function of Lake 1 and Lake 2

Stage (m)	Storage Lake 1 (m^3)	Storage Lake 2(m^3)
0	0	0
0.5	125	90
0.6	152	108
0.7	179	126
0.8	207	144
1	264	180
1.1	294	198
1.5	414	252

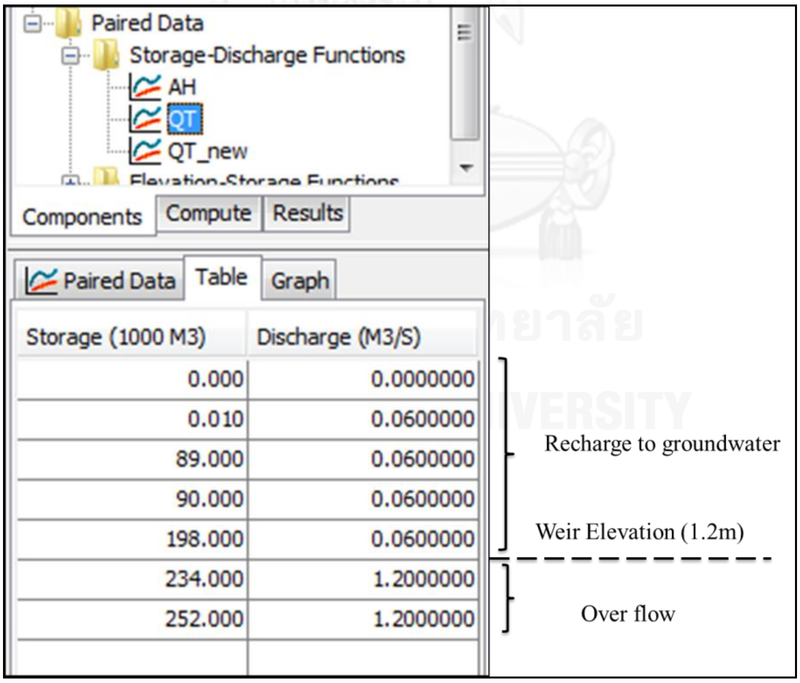


a) Lake 1



b) Lake 2

Figure 4.3 Surface water scheme



Storage (1000 M3)	Discharge (M3/S)
0.000	0.0000000
0.010	0.0600000
89.000	0.0600000
90.000	0.0600000
198.000	0.0600000
234.000	1.2000000
252.000	1.2000000

Figure 4.4 Set up Storage – Discharge function (May 2029)

4.2 Groundwater Modeling System (GMS)

4.2.1 Theories use in GMS

The Groundwater Modeling System (GMS) is a comprehensive graphical user environment for performing groundwater simulations. The entire GMS system consists of a graphical user interface (the GMS program) and a number of analysis codes (MODFLOW, MT3DMS, etc.). The GMS interface is developed by Aquaveo, LLC in Provo, Utah.

GMS was designed as a comprehensive modeling environment. Several types of models are supported and facilities are provided to share information between different models and data types. Tools are provided characterization, model conceptualization, mesh and grid generation, geostatistics and post-processing (GMS User Manual v8.3, 2012).

Governing Equations

Partial Differential equation which represents three dimensional movement of ground water is

$$\frac{\partial}{\partial x}\left[K_{xx}\frac{\partial h}{\partial x}\right]+\frac{\partial}{\partial y}\left[K_{yy}\frac{\partial h}{\partial y}\right]+\frac{\partial}{\partial z}\left[K_{zz}\frac{\partial h}{\partial z}\right]+W=S_s\frac{\partial h}{\partial t} \qquad \text{(Eq 4. 15)}$$

Where $\mathbf{K_{xx}}$, $\mathbf{K_{yy}}$ and $\mathbf{K_{zz}}$ are the values of hydraulic conductivity along the x, y, and z coordinate axes and may be function of space.

h is the potentiometric head (hydraulic head)

W is a volumetric flux per unit volume representing sources and/or sinks of water, where negative values are water extractions, and positive values are injections. It may be a function of space and time (i.e. W = W(x, y, z, t)).

$\mathbf{S_s}$ is the specific storage of the porous material and may be function of space.

t is time (month).

For simple systems, there are possible to analytic solutions of this partial differential equation. But there are a lot of realistic problems, for which various numerical methods must be employed to get an approximate solution. One such approach is finite difference method upon which MODFLOW is based. The process leads to system of simultaneous linear equation and solution yields values at specific points and times.

A spatial discretization of an aquifer system (as in Figure4.1 with a grid of blocks called cells, the locations of which are described in terms of rows, columns, and layers (i=1,2..NROW; j=1,2..NCOL; K=1,2..NLAY). Within each cell a point is taken as representing node at which head is to be calculated. Figure 4.5 shows block centered formulation of these nodes. The grid in MODFLOW is assumed to be rectangular horizontally and vertically. MODFLOW handles discretization of space in the horizontal direction by reading the number of rows, the number of columns and the width of each row and column. Discretization of space in the vertical direction is handled in the model by specifying the number of layers to be used and by specifying the top and bottom elevations of every cell in each layer. Vertical discretization can be viewed as an effort to represent individual aquifers or permeable zones by individual layers of the model.

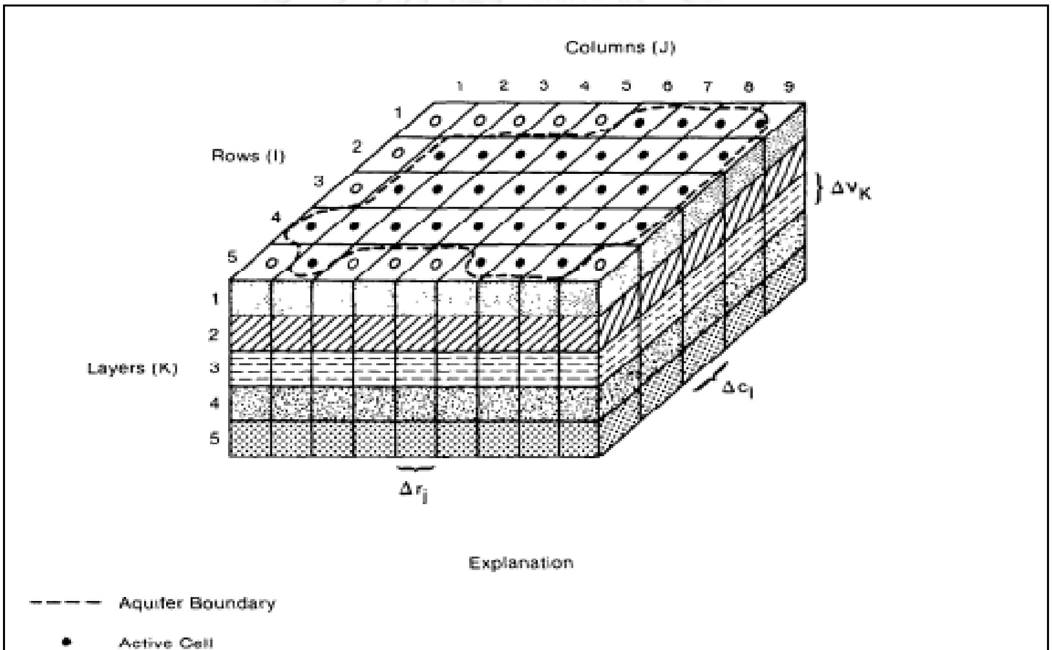


Figure 4.5 A discretized hypothetical aquifer system.(McDonald & Harbaugh, 1988)

4.2.2 Groundwater simulation

The simulation method is based on finite difference based solver (as MODFLOW). The method requires various input parameters to be set. In the study area, the input variable data to groundwater simulation model and calculation steps are as follows:

1) Area: the total study area is 11 km^2.

2) Modeling the geology spatial: topographic maps 1:10,000 ratio would be used as background map. For the surface, the contours are converted into the high point will be entered into GMS - MODFLOW as shown in Figure 4.6. The bottom of layer 1 is built based on stratigraphic borehole and the hydrogeological cross-section. The scatter points include coordinate, top of layer, bottom of layer is applied by functional interpolation with algorithm "Natural Neighbor" to assign data from the grid. The cell of grid is 50 m*50 m (Figure 4.7). The bottom of layer 1 is set based on data borehole. The bottom of layer 2 is set as horizontal plane at -40 m depth.

Table 4.4 Grid cell in groundwater model

Unit	Length	Width	Depth
m	5500	3900	40
Cell	110	58	2

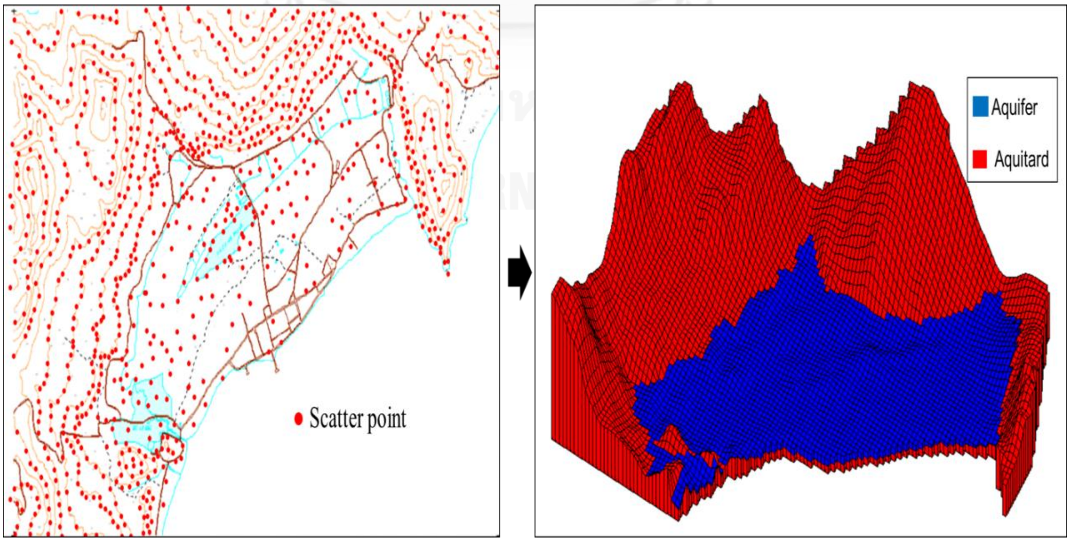
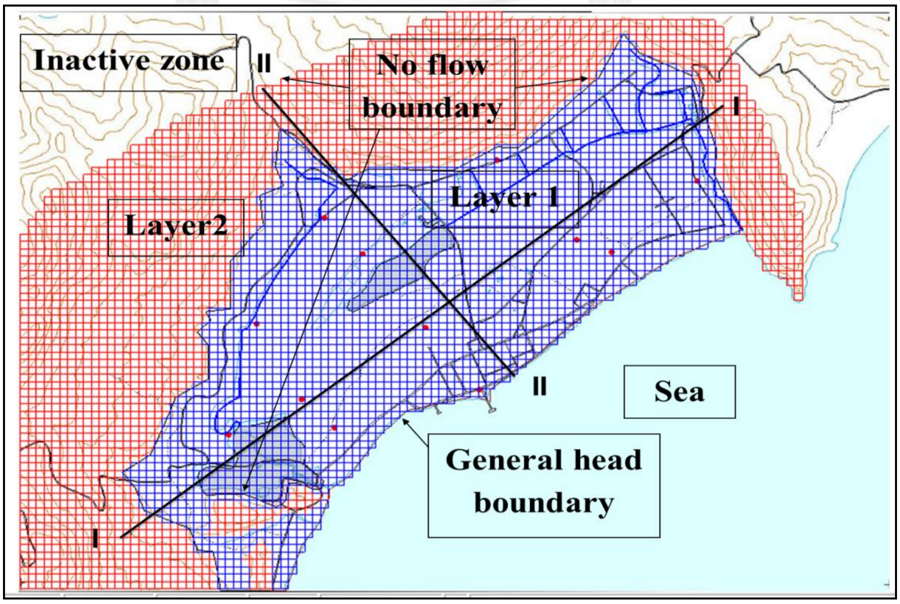


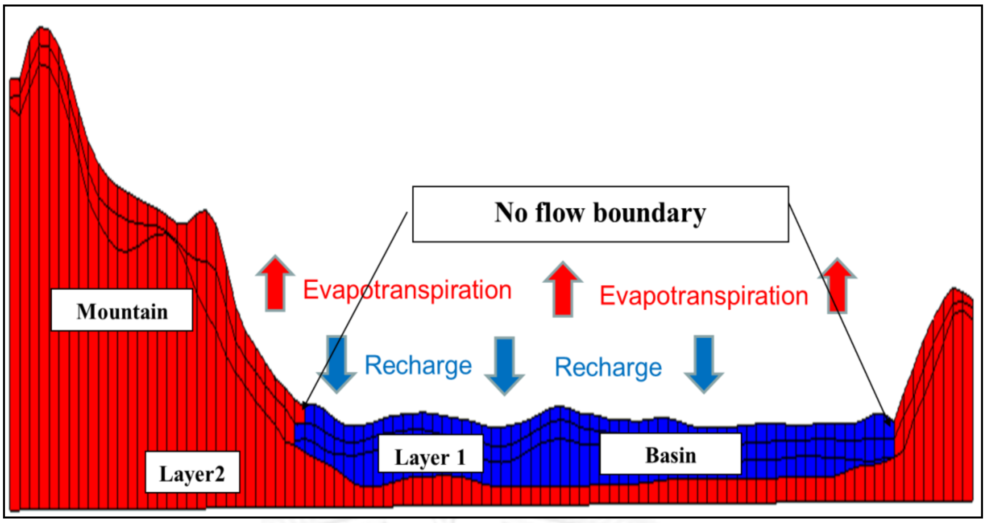
Figure 4.6 Modeling the geology spatial

3) Boundary Condition: Based on the characteristics of the aquifer, the model will be built in two layers to simulate the aquifer as follows:

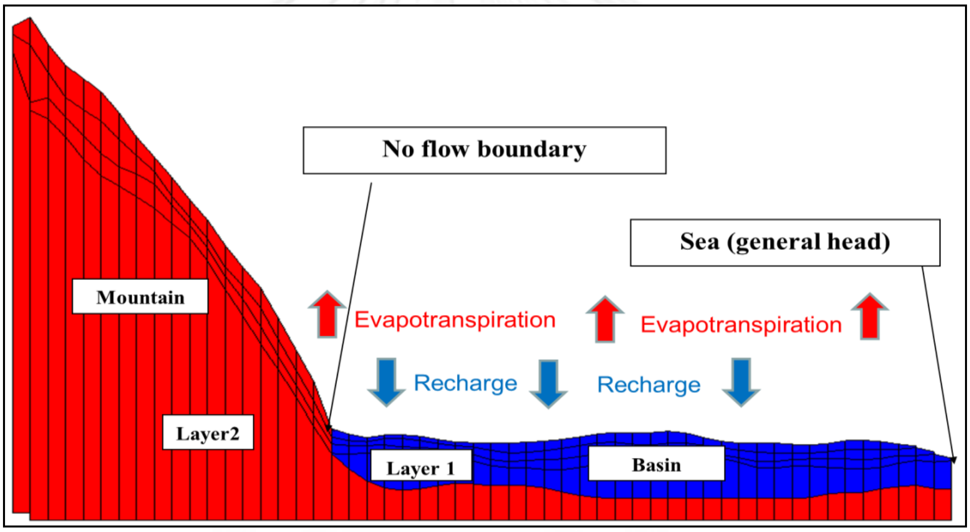
- The top layer (intergranular Cenozoic sediments): as both Holocene and Pleistocene aquifers do not appear aquitard and lithological composition did not differ in terms of permeability should be considered as an aquifer. An area occupies about 6 km^2 in the central calculation area. This is seen as unconfined aquifer. The exposed part with the Mezozoi formations are considered non-flow (Q=0). The southern part connected shoreline will be considered as a general head boundary (Q=h(t)). The main hydrogeological parameters: permeability coefficient K = 2.5 – 7 m/day and gravitational storability μ = 0.154.
- Bottom layer (geological formation aquitard): Includes the top of the fractured Mezozoi rock to -50m depth (from sea level). It occupies entire area of computation. This is seen as secmi - confined aquifer. The model along the edge of the watershed is seen as a non-flow boundary (Q = 0). The southern part connected to shoreline is considered as a general head boundary (Q=h(t)). The main hydrogeological parameters: permeability coefficient K = 0.05 - 0.5 m/day and gravitational storability μ = 0.01 - 0.001.



a) Design grid and boundary condition of groundwater model



b) Cross section I of Grid 3D



c) Cross section II of grid 3D

Figure 4.7 Design grid and boundary condition of groundwater model

4) Conductance is calculated as follow:

- In the case of rivers, conductance should be calculated as:

$$C_{river} = \frac{\frac{k}{t} l w}{L} = \frac{k}{t} w \qquad \text{(Eq 4.16)}$$

C$_{river}$ = conductance per unit length [(m^2/day)/m) or [m/day]

t = the thickness of the material [m] (the measured thickness is 0.5)

l_w = the cross-sectional area perpendicular to the flow direction [m^2]

w = the width of the material along the length of the arc [m]

$$w = b + 2y\sqrt{1 + z^2} \qquad \text{(Eq 4.17)}$$

Where

b is the bottom width of the stream (m), y is the water depth in stream (m), z is the side slope of stream H:V (m).

k = Vertical hydraulic conductivity [m/day] (According the Table 2.7, the hydraulic conductivity is selected as 0.05m/day)

L = the length of flow [m]

- In the case of lakes, conductance should be calculated as:

$$C_{lake} = \frac{\frac{k}{t}lw}{A} = \frac{k}{t} \qquad \text{(Eq 4.18)}$$

C_{lake} = conductance per unit area [(m^2/day)/m^2] or [1/day]

t = the thickness of the material [m] (the measured thickness is 0.5m)

A = gross cross-sectional area of lake [m^2]

5) Recharge: In this study area, the recharge could be separated in 3 resources: rainfall, streams and lakes.

The rainfall recharge is set as Figure 4.8 due to previous report (Chan, 2006).

The lakes recharge and stream recharge are estimate by SW-GW analysis and water level in surface area. The water level in lake is simulated by surface modeling. The water in stream is converted from simulation runoffs in channel by solving equation follow:

$$V = \frac{Q}{A} = \frac{1}{n} R^{\frac{2}{3}} \sqrt{s}$$

$$\frac{Q}{y(b+zy)} = \frac{1}{n} \left(\frac{y(b+zy)}{b+2y\sqrt{1+z^2}}\right)^{\sqrt{S}} \qquad \text{(Eq 4. 19)}$$

Where

y = the depth of flow (m).

b = bottom witch of stream (m) (the measure bottom witch of stream is 3m.

z is side slope H to V (z is measured as 3).

S is longitudinal slope

n = manning coefficient (According table ”Value of the roughness coefficient”(Chow, 1988), n is selected as 0.035)

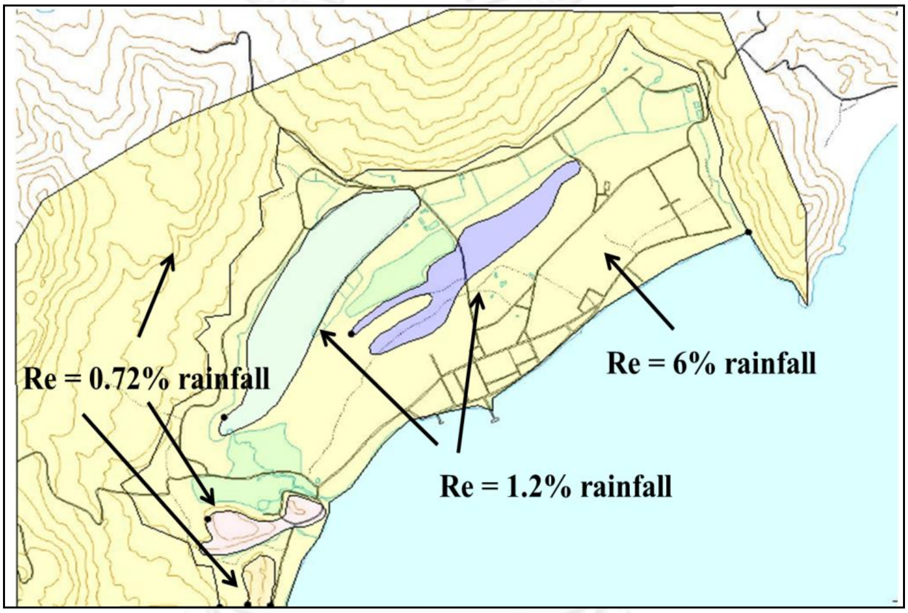


Figure 4.8 Rain fall recharge estimate (Chan, 2006)

6) Evaporation: data is selected from document daily evaporation of meteorological stations Con Dao district.

7) Starting Head values: data is based on the calibration model in steady-state and the observed data.

8) Pumping pattern: data is collected from meteorological stations located Con Dao district.

9) Evaluate the result of groundwater level by the observed data.

10) SW/GW interaction analysis.

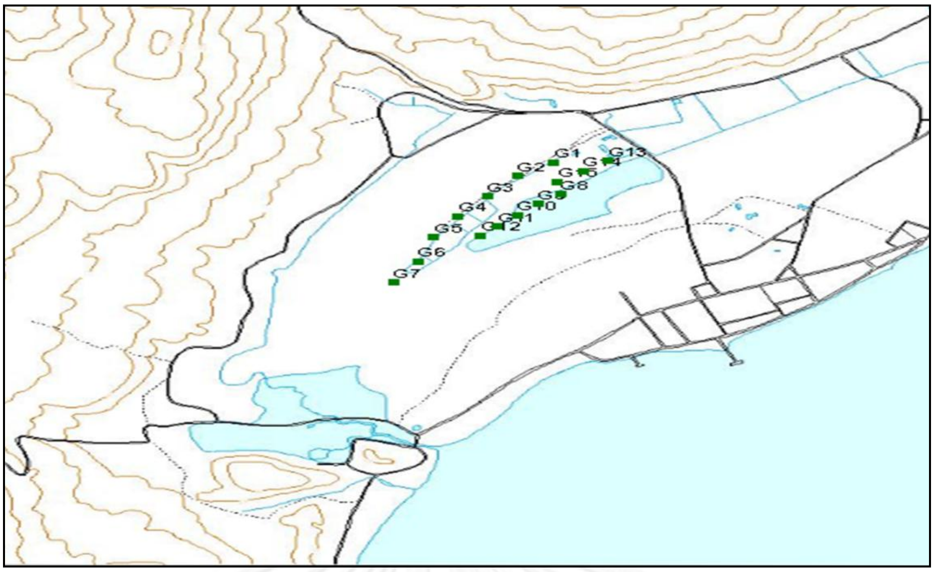


Figure 4.9 Existing scheme wells in model.

4.3 SW- GW Interaction analysis

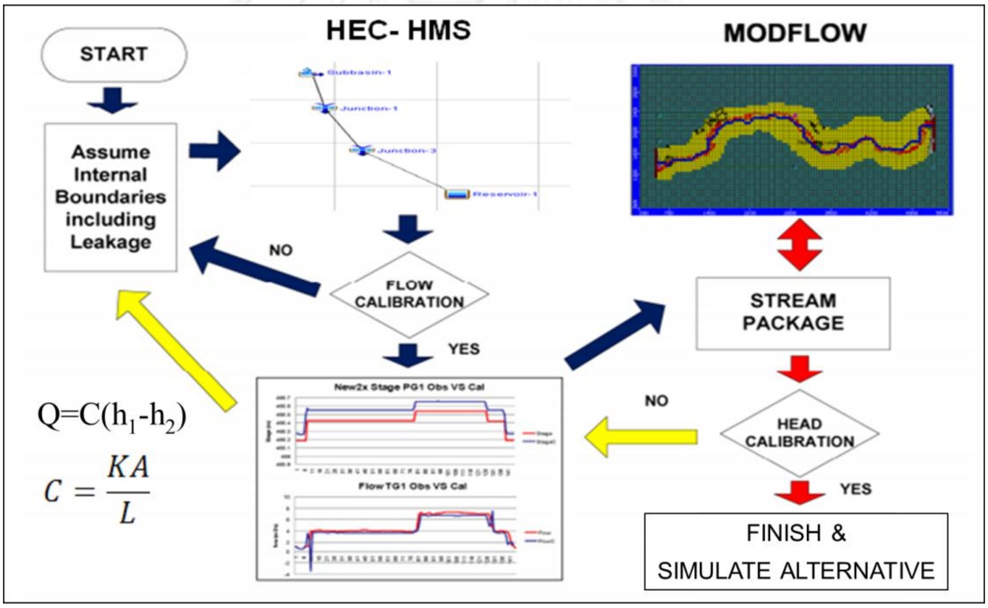


Figure 4.10 Interaction analysis under linking HEC-HMS and GMS-Modflow

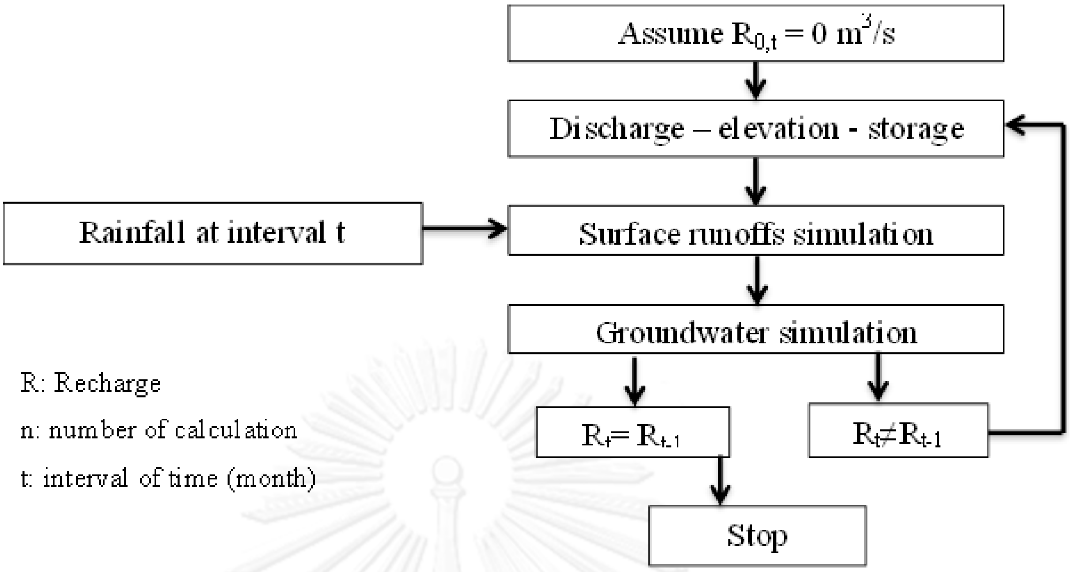


Figure 4.11 Interaction analysis diagram

The procedure of SW-GW interaction analysis is shown as Figure 4.10 and Figure 4.11:

1) The initial discharge from lake to groundwater is assumed $0m^3/s$.

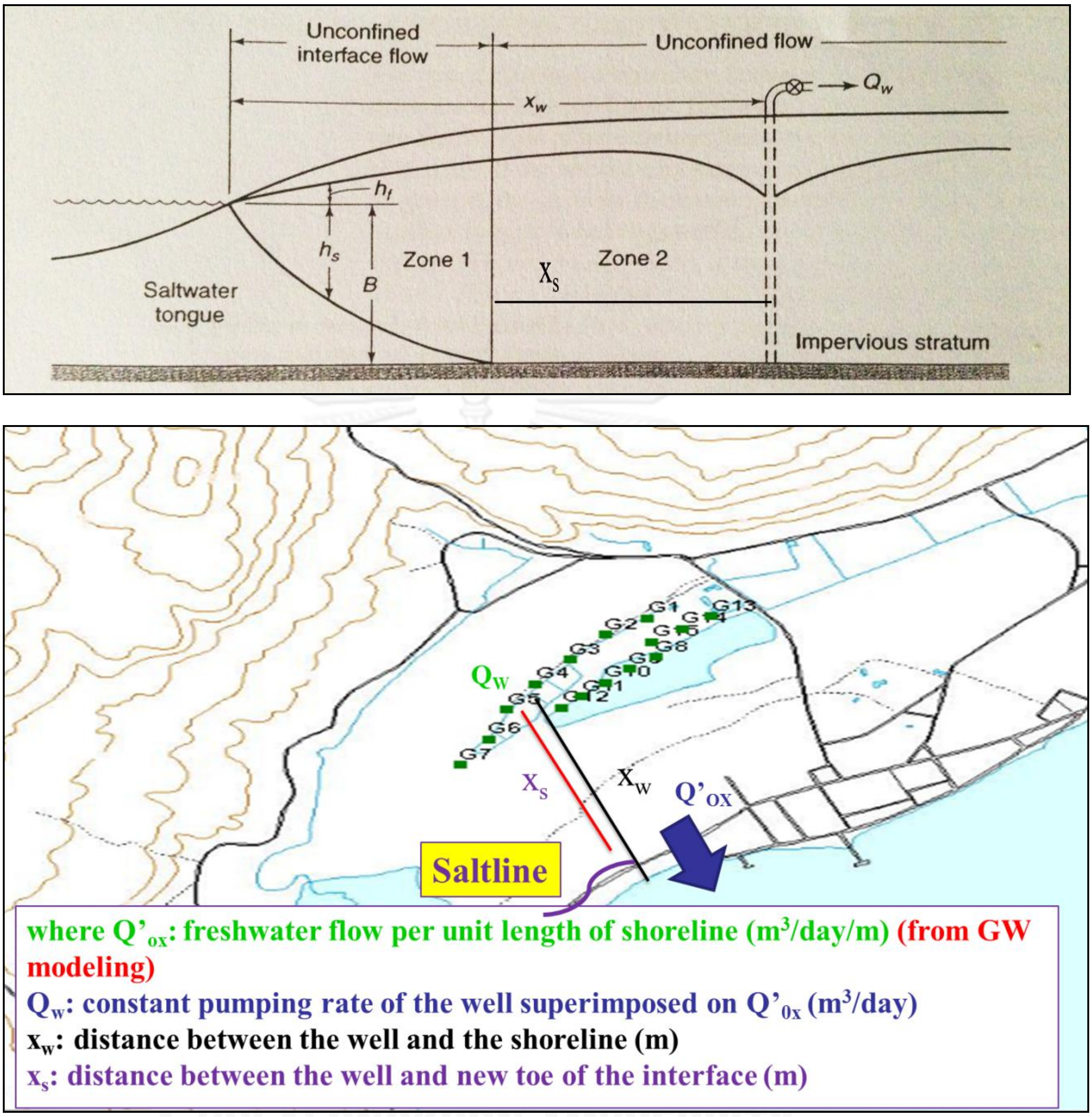
2) Select Loss/gain of channel by defining rainfall, the discharge – elevation – storage function is built by initial recharge.

3) Simulate surface runoffs.

4) Simulate groundwater level.

5) After simulate groundwater, the recharge is compared with the recharge of previous loop. The results are corrected when the recharges are equal. If the recharges are different, the recharge of last loop are used to build the discharge the discharge – elevation – storage function again which will apply for next loop simulation.

4.4 Salt intrusion estimation



where Q'_{ox}: freshwater flow per unit length of shoreline (m^3/day/m) (from GW modeling)

Q_w: constant pumping rate of the well superimposed on Q'_{0x} (m^3/day)

x_w: distance between the well and the shoreline (m)

x_s: distance between the well and new toe of the interface (m)

Figure 4.12 Salt intrusion estimation

The length of between the well and new toe interface is calculated by equation of Ghyben – Herzberg and Strack ((Freeze & Cherry, 1979)):

$$x_s = x_w \left[1 - \frac{Q_w}{\pi Q'_{0,x} x_w} \right] \qquad \text{(Eq 4.20)}$$

Where Q'_{ox}: freshwater flow per unit length of shoreline (m^3/day/m)

Q_w: constant pumping rate of the well superimposed on Q'_{0x} (m^3/day)

x_w: distance between the well and the shoreline (m)

x_s: distance between the well and new toe of the interface (m)

4.5 Water resources development planning

Due to the insufficient water situation, about surface water, the water development is implemented by expanding Lake 2 with 3 options: 400 000m^3, 267 000m^3, 180 000m^3. For groundwater, there are 3 pumping rate to select: 400m^3/day (no addition wells), 300m^3/day (5 addition wells), and 250m^3/day (10 addition wells) Figure 4.12 shows the combination of surface water improvement options and groundwater improvement options. The selection is chosen by comparing water balance, the construction cost, and the damage without planning of combination all surface water and groundwater development options. The procedure to modeling water development plan as follows:

1) Applying SW-GW analysis step with varies expanding size of lake. (Location expanding Lake 2 and addition wells is shown in Figure 4.14 and Figure 4.15)
2) Simulate surface runoffs.
3) Distribute scheme pumping well and install data to groundwater modeling.
4) Simulate groundwater balance.
5) Evaluate results by comparing recharge - ΔH function with present period.
6) Calculate length between salt interface and well.
7) Calculate construction cost.
8) Calculate damage of dry situation.
9) Select the suitable alternative which satisfies drawdown, salt intrusion and cheapest construction cost.

.

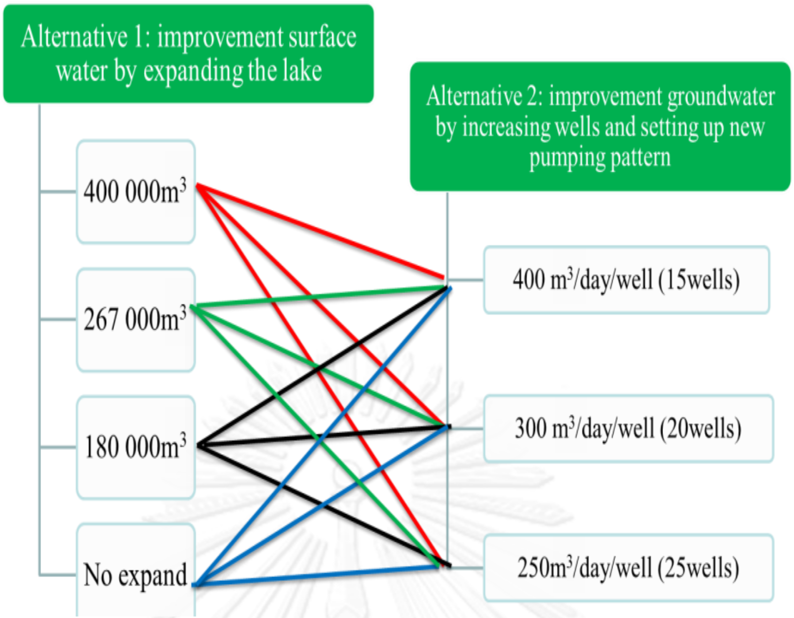


Figure 4.13 Water resources improvement options

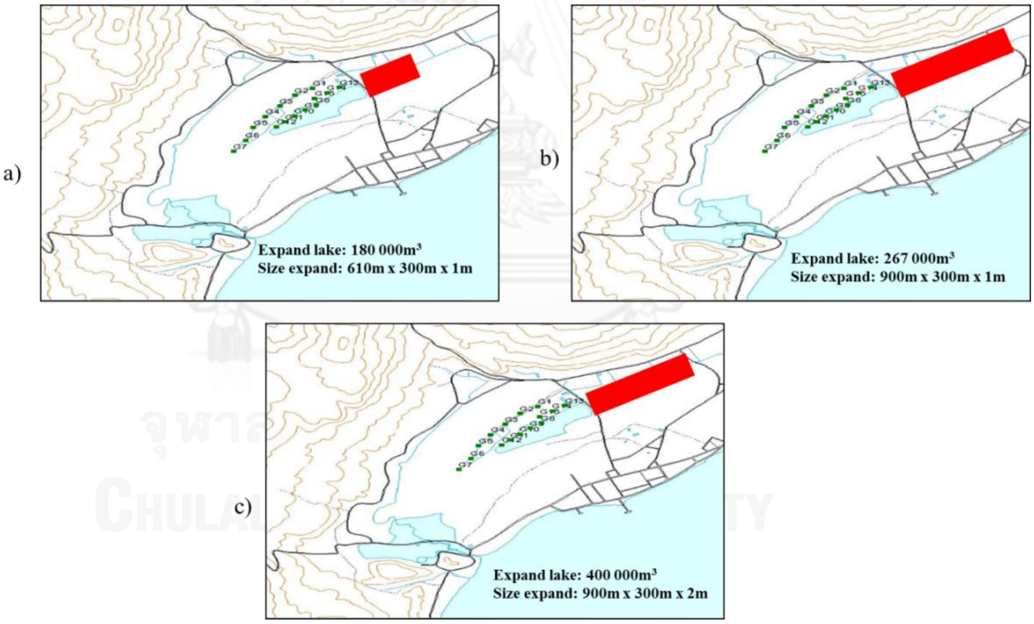


Figure 4.14 Location of expading lake
(a: Location expanding lake 180 000m^3, b: Location expanding lake 267 000m^3, c: Location expanding lake 400 000m^3)

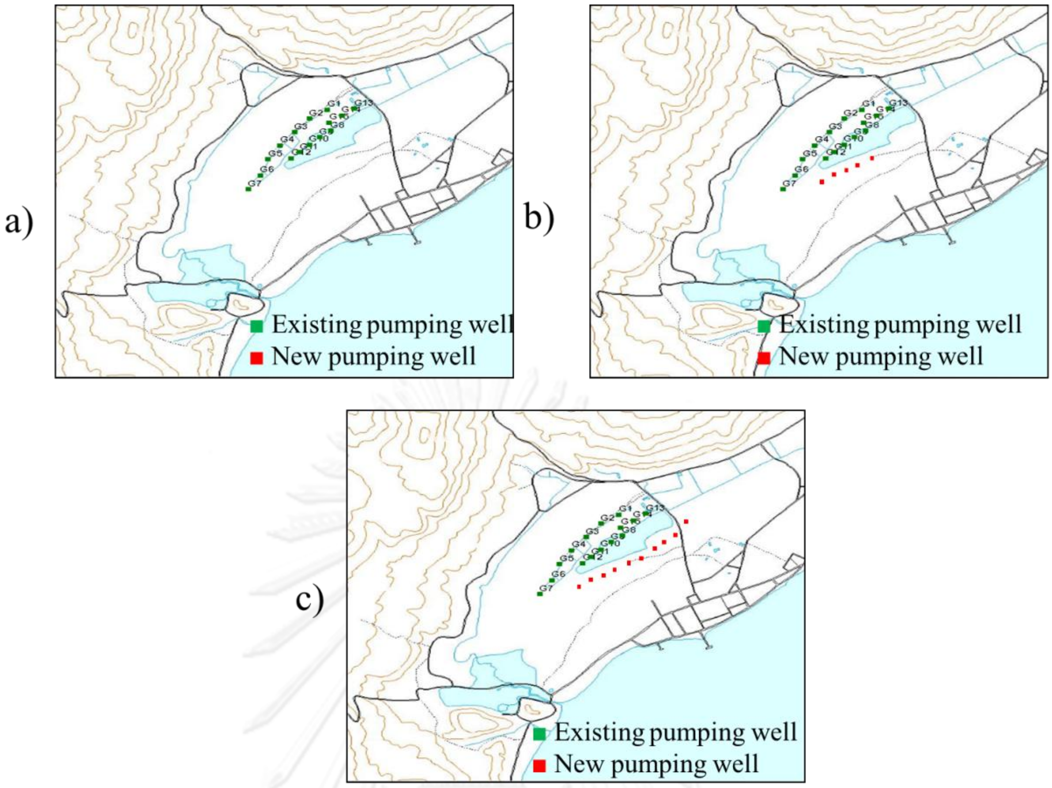


Figure 4.15 Well locations of alternatives
(a: pumping rate 400m^3/day, b: pumping rate 300m^3/day pumping rate 250m^3/day)

CHAPTER V

RESULTS AND DISCUSSIONS

5.1 SW model calibration – validation

This part describes calibration – validation of surface water in Lake 1 and Lake 2 under high rainfall and low rainfall in comparison. All of the observed data of water level in lake and flow runoff from channel to lake are correspondence. Under increasing pumping rate, the stability of water level in Lake 1 illustrated in Figure 5.1 and Figure 5.2 as water level decreases during dry season and recover maximum storage in rainy season. Meanwhile, during the dry season, water level in Lake 2 tends to cause drought situation and restore in rainy season (see in Figure 5.5 and Figure 5.6).

There are no significant different flow runoffs between 2 channels of Lake 1 and Lake 2. Also, the stability of both flow runoffs appears only in rainy season. Therefore, both channels are not impacted by increasing pumping rate (see Figure 5.3, Figure 5.4, Figure 5.7, and Figure 5.8).

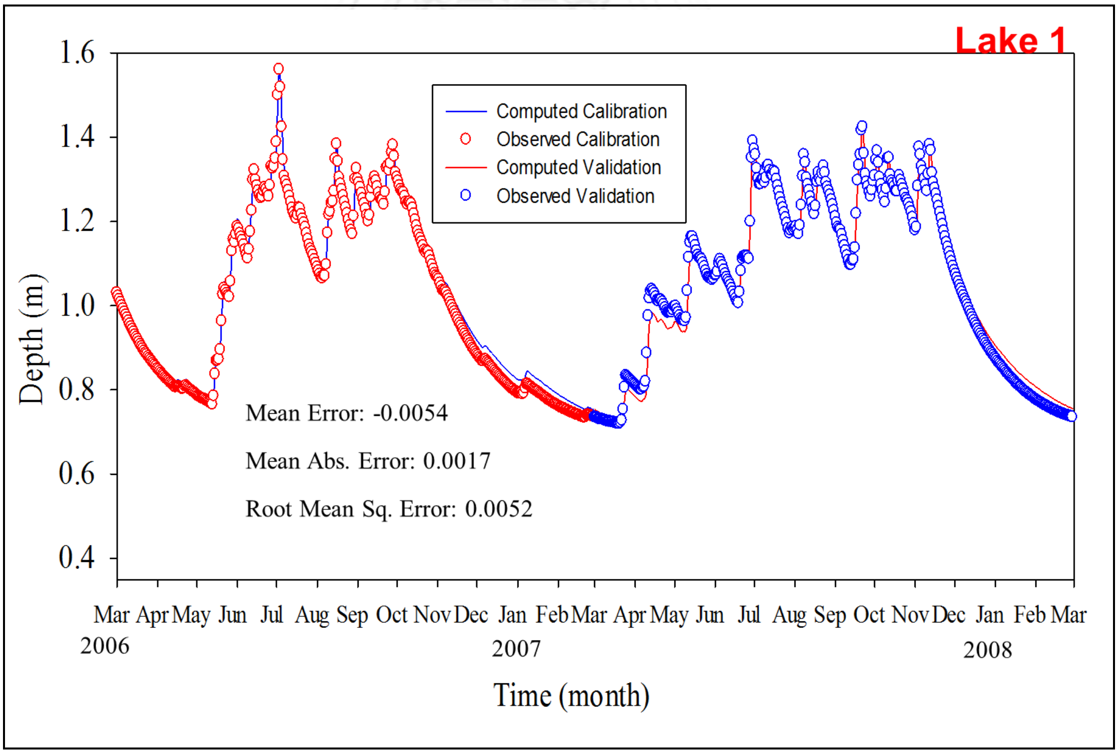


Figure 5.1 Water level calibration – validation of Lake 1 (high rainfall)

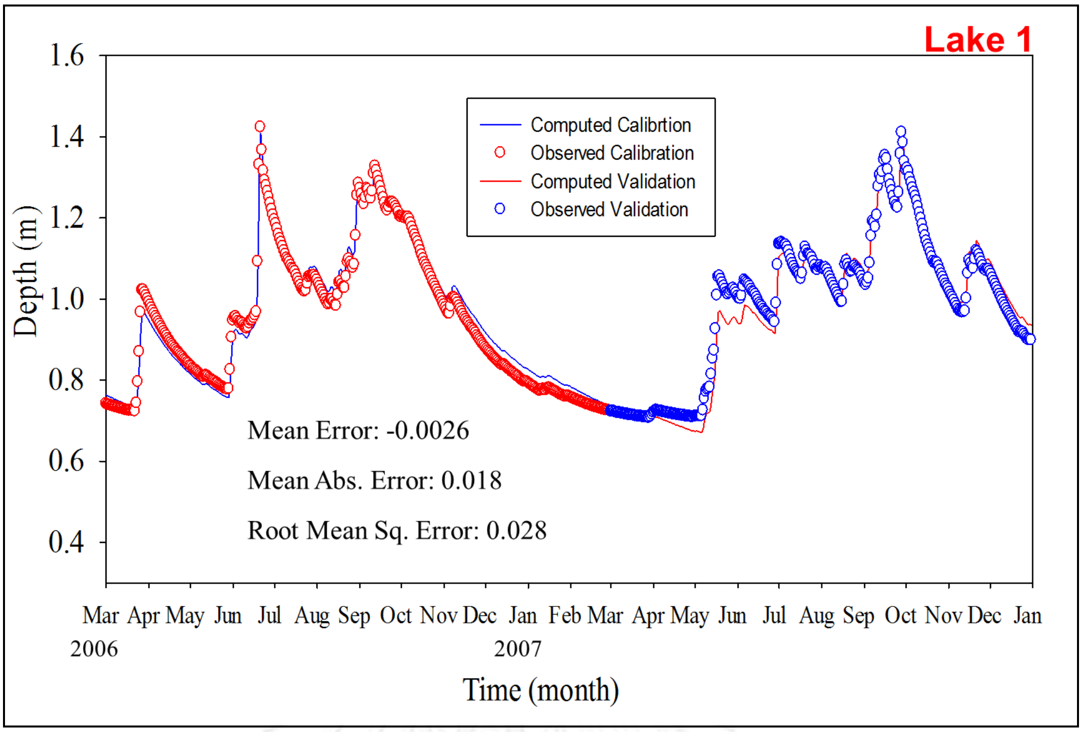


Figure 5.2 Water level calibration – validation of Lake 1 (low rainfall)

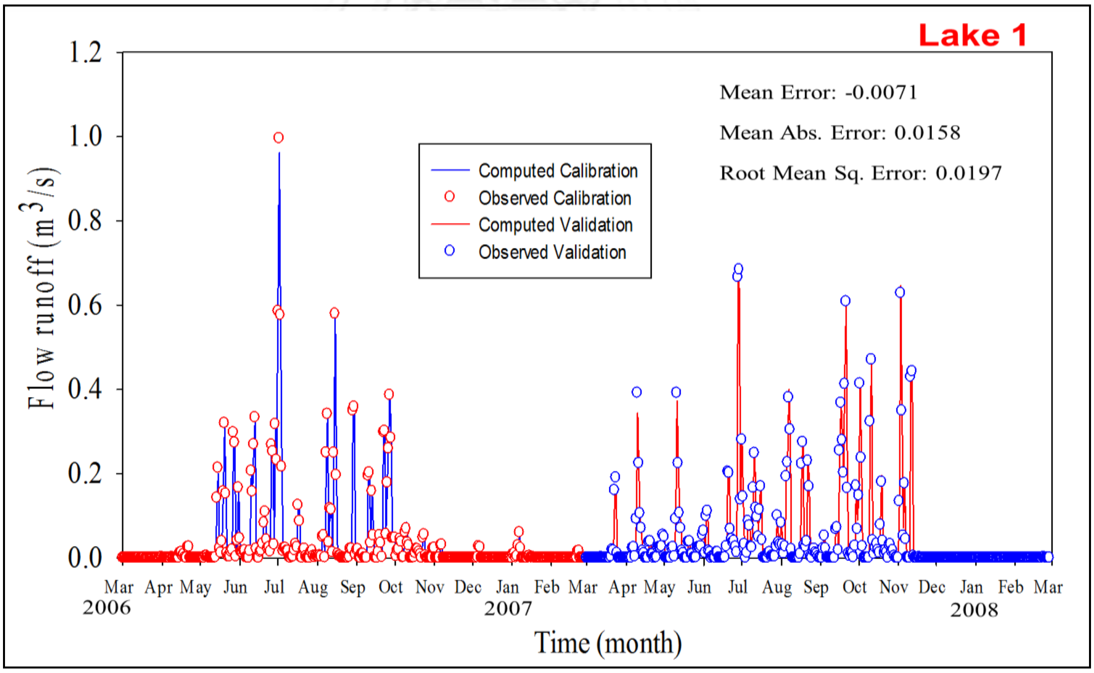


Figure 5.3 Calibration – validation of flow runoff from channel to lake 1 (high rainfall)

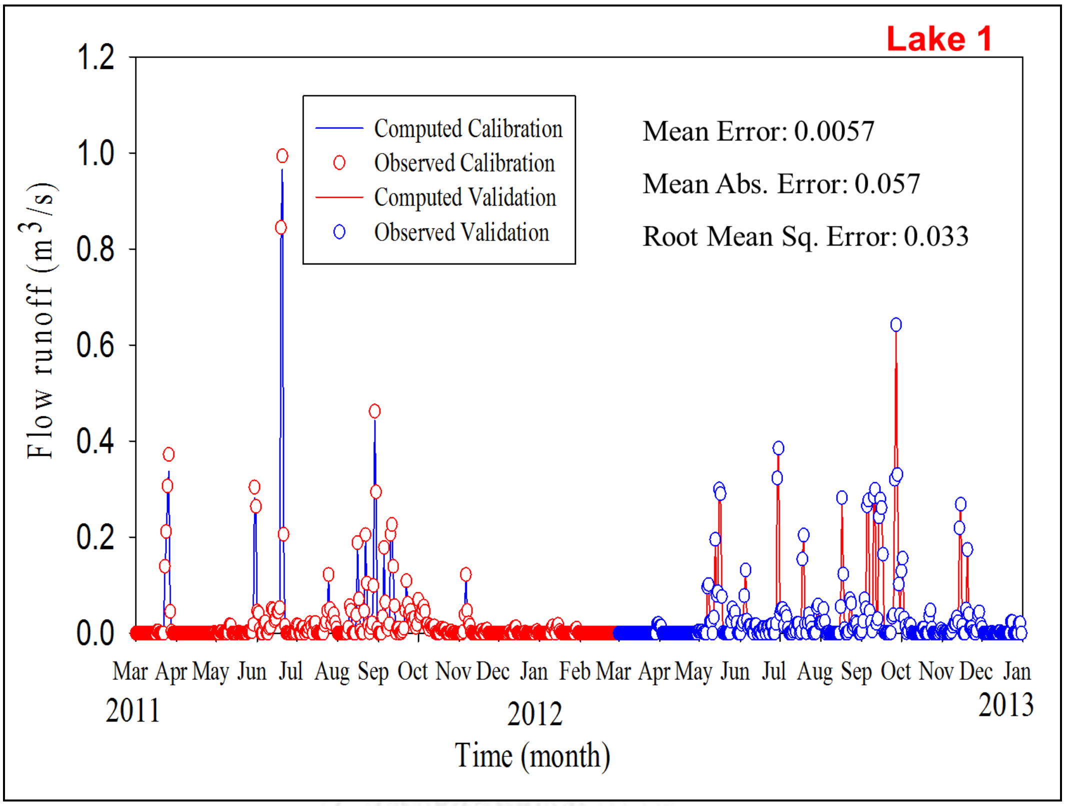


Figure 5.4 Calibration – validation of flow runoff from channel to lake 1 (low rainfall)

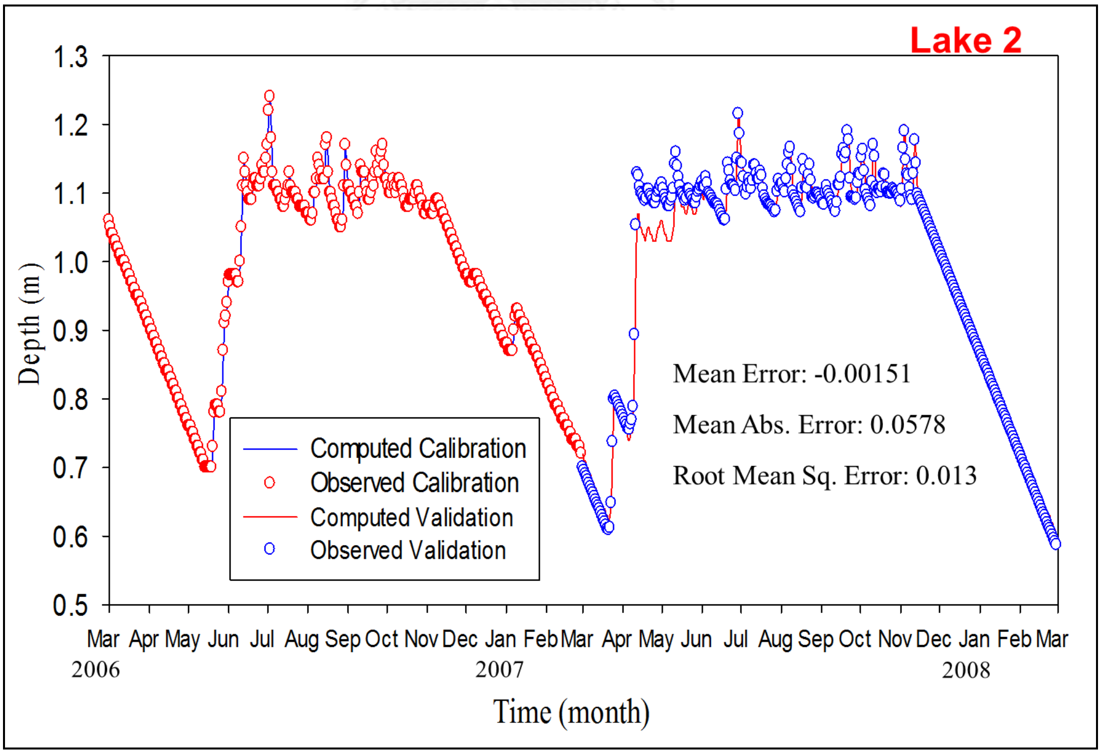


Figure 5.5 Water level calibration – validation of Lake 2 (high rainfall)

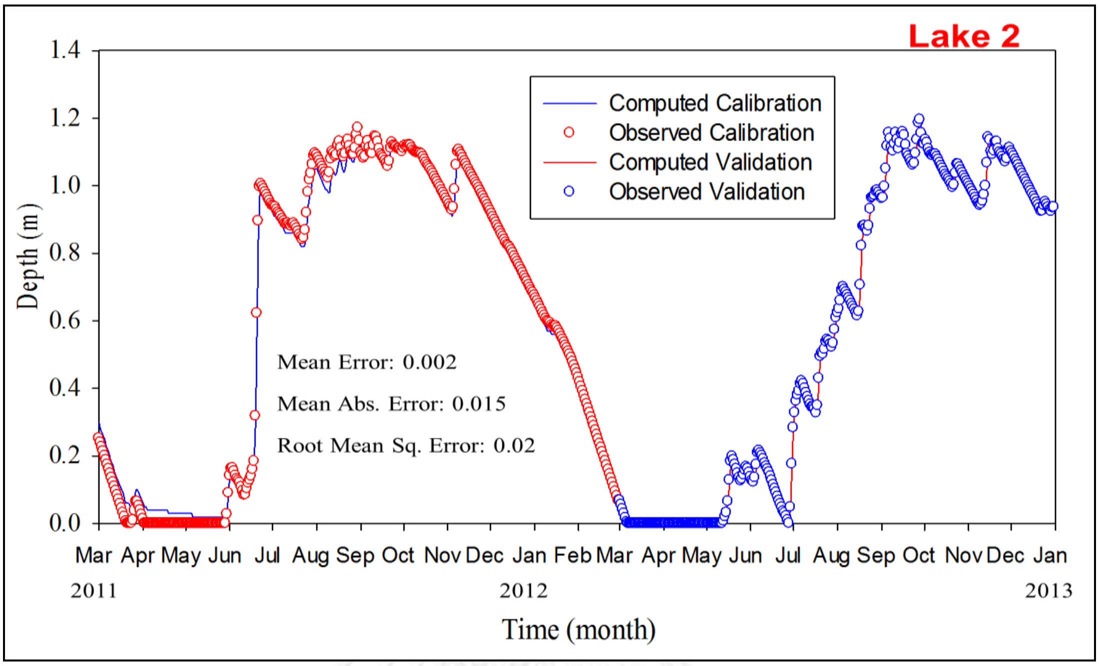


Figure 5.6 Water level calibration – validation of Lake 2 (low rainfall)

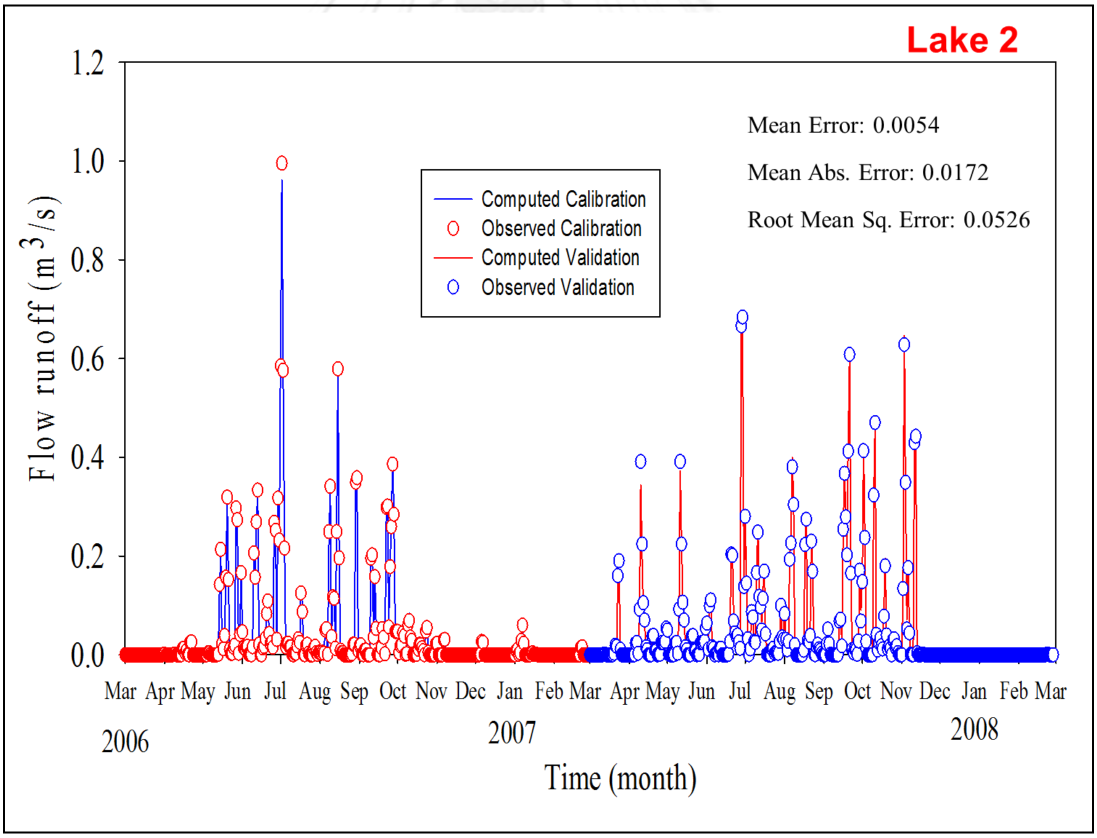


Figure 5.7 Calibration – validation of flow runoff from channel to lake 2 (high rainfall)

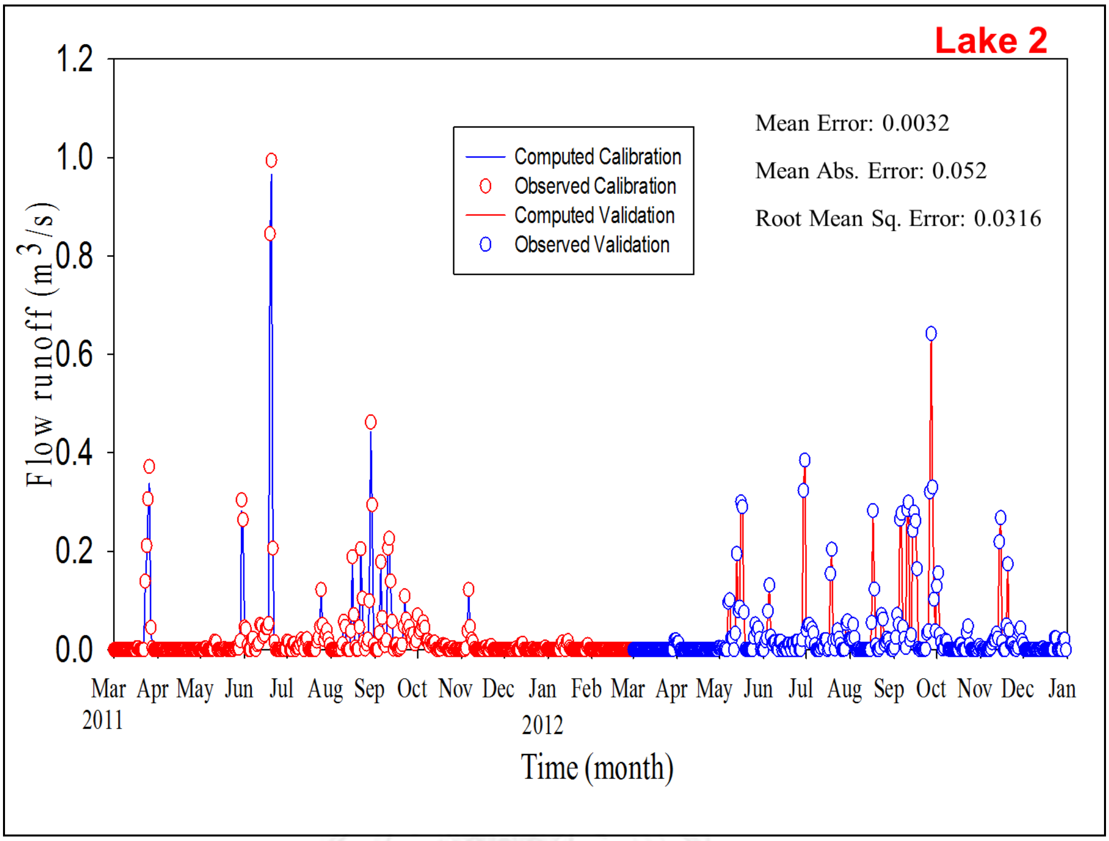


Figure 5.8 Calibration – validation of flow runoff from channel to lake 2 (low rainfall)

The surface model parameter estimated due to SW calibration – validation presented in Table 5.1.

Table 5.1 Surface water model parameters

			Lake 1		Lake 2	
			High rainfall	Low rainfall	High rainfall	Low rainfall
Sub-basin	Area (km^2)		1.4	1.4	1.3	1.3
	Loss	Initial Abstraction (mm)	10	10	10	10
		Curve Number	70	70	80	80
		Impervious (%)	5	5	3	3

Table 5.1 Surface water model parameters (continue)

			Lake 1		Lake 2	
			High rainfall	Low rainfall	High rainfall	Low rainfall
Sub-basin	Transform	Time of Concentration (hr)	12	12	12	12
		Storage Coefficient	4	4	4	4
Reach	Routing	Length (m)	2500	2500	2500	2500
		Slope (m/m)	0.0086	0.0086	0.01	0.01
		Manning's n	0.035	0.035	0.035	0.035
		Bottom width (m)	2	2	2	2
		Side Slope (xH:1V)	3	3	3	3
	Loss/Gain	Rate (m^3/s/1000 m^2)	0.04	0.02	0.04	0.02

5.2 GW model calibration – validation

The results of GW calibration – validation of groundwater level near both Lake 1 and Lake 2 are relevant. The groundwater level of Lake 1 appears stable under increasing pumping rate (from 1500m^3/day to 3000m^3/day) (see in Figure 5.11). Meanwhile, groundwater level of Lake 2 tends to decrease from 2.5 m to 1.5 m in dry season (see in Figure 5.13). The groundwater level near in both lakes created curve sine from dry season to rainy season.

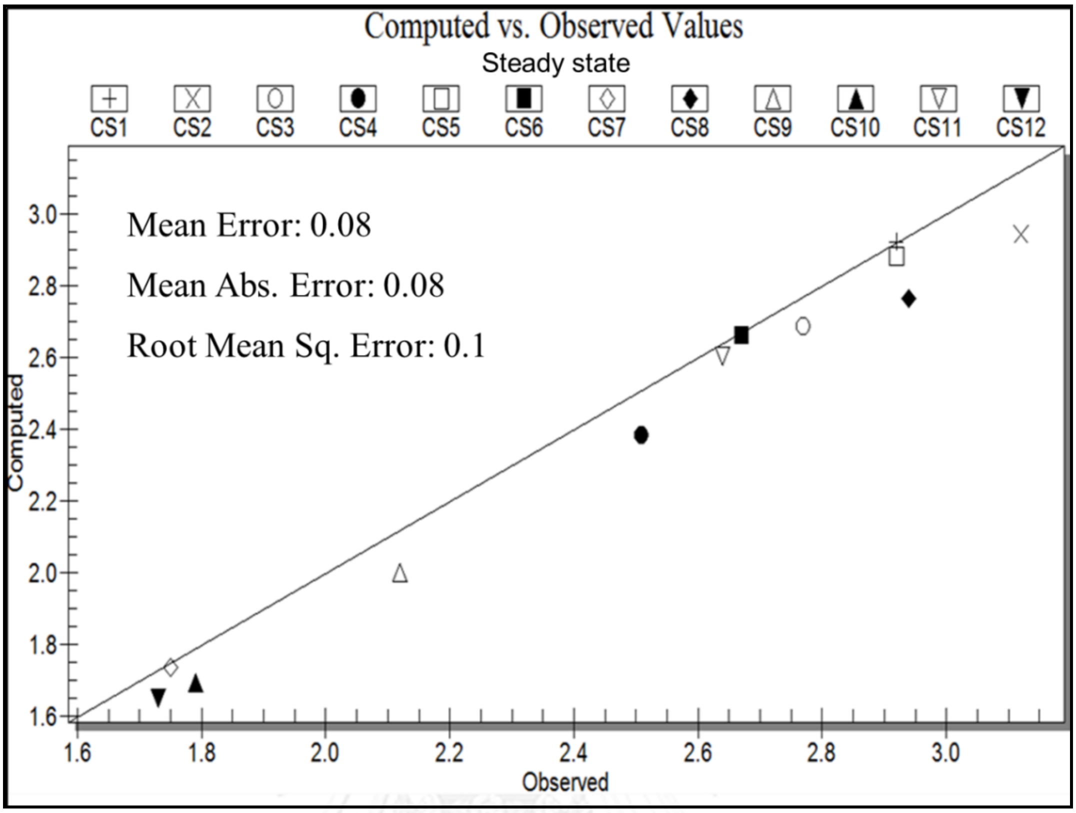


Figure 5.9 Groundwater level calibration in steady state

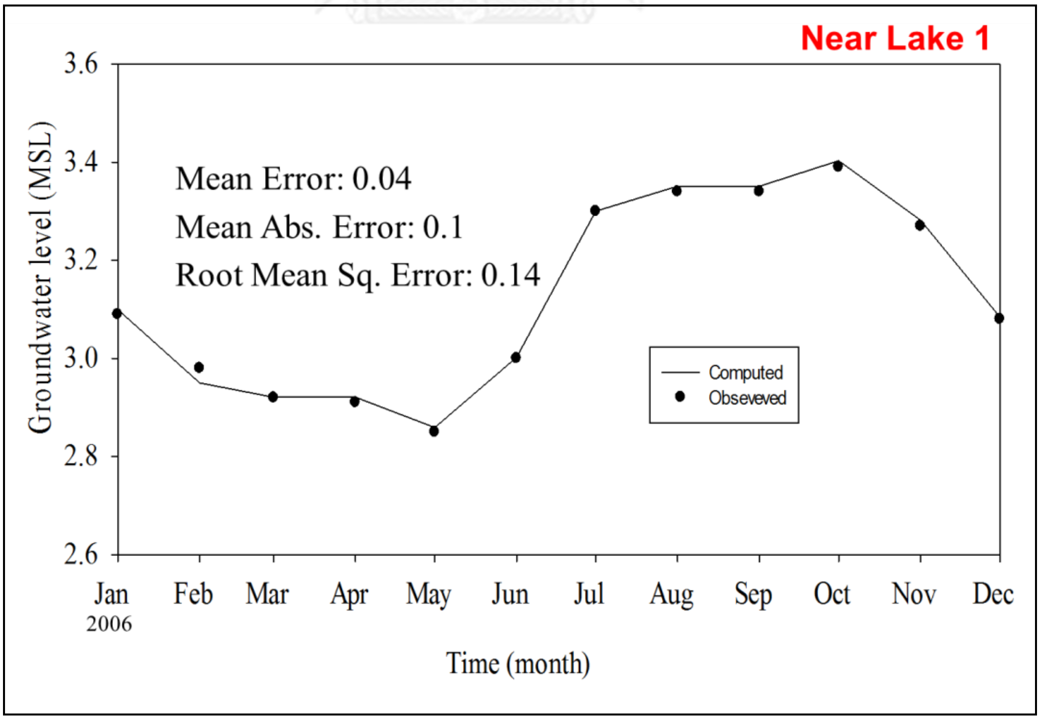


Figure 5.10 Groundwater near Lake 1 calibration (2006)

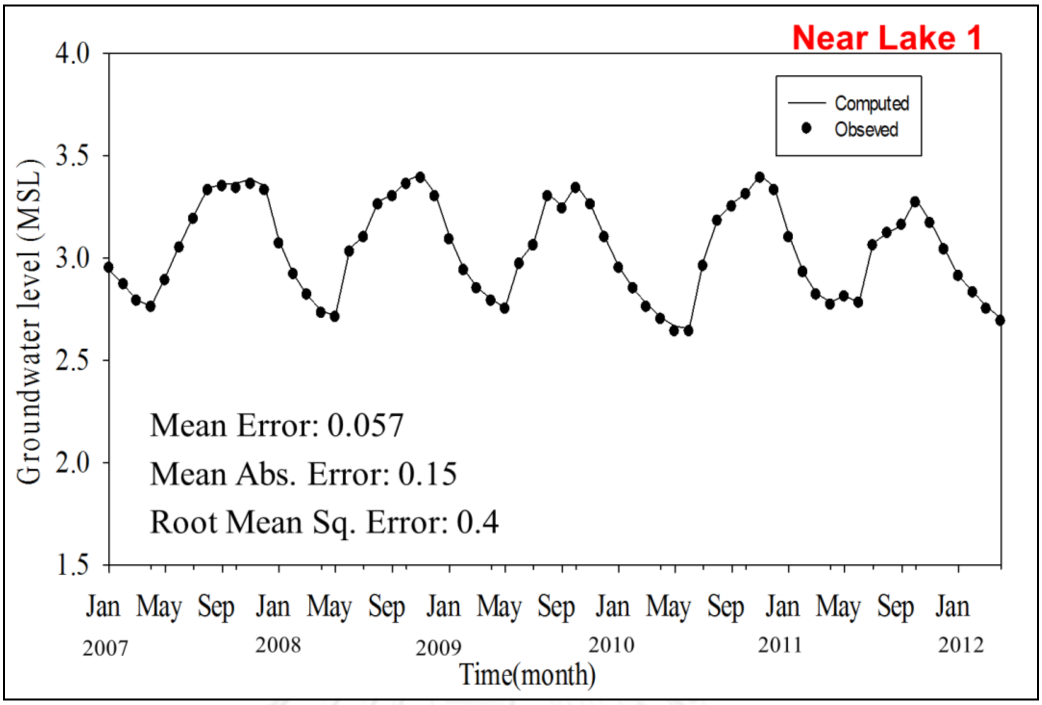


Figure 5.11 Groundwater level near Lake 1 validation (2007 -2012)

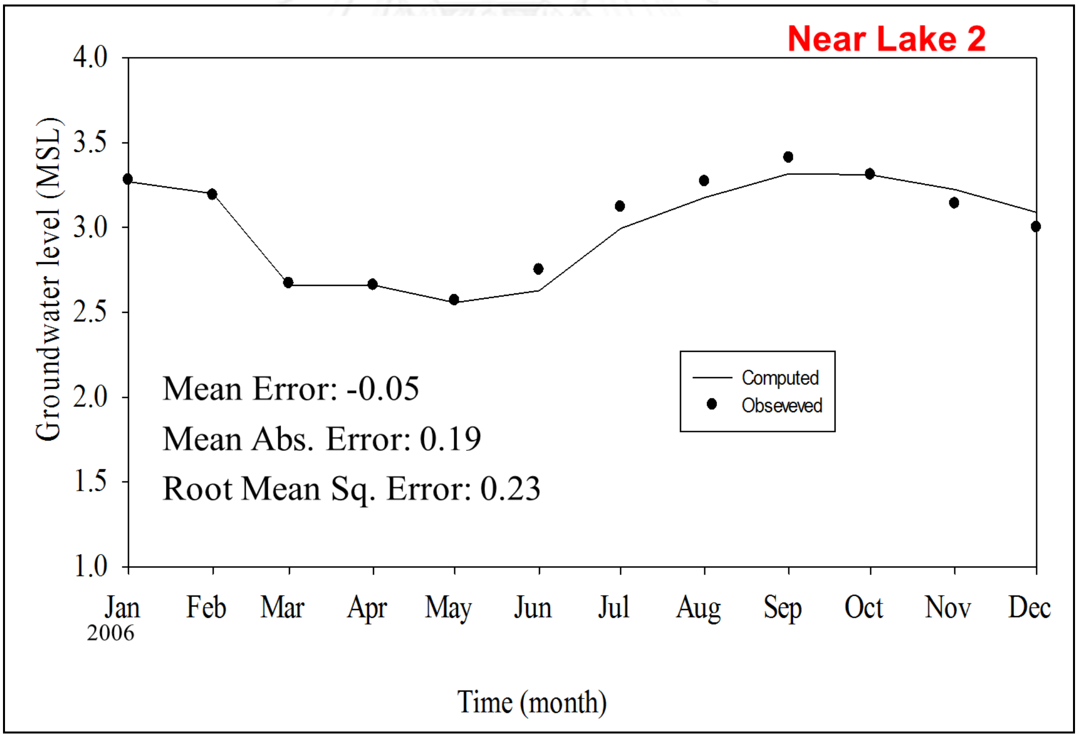


Figure 5.12 Groundwater level near Lake 2 calibration (2006)

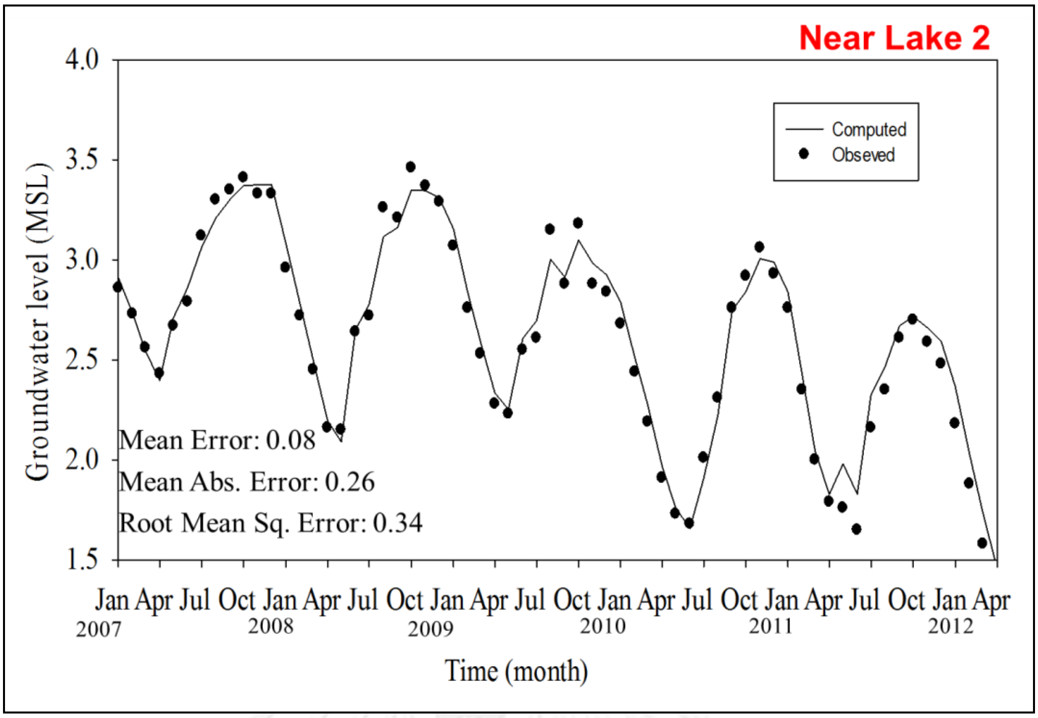


Figure 5.13 Groundwater level near Lake 2 validation (2007 -2012)

The groundwater properties of aquifer and aquitard estimated from GW calibration – validation step show in Figure 5.14, Figure 5.15.

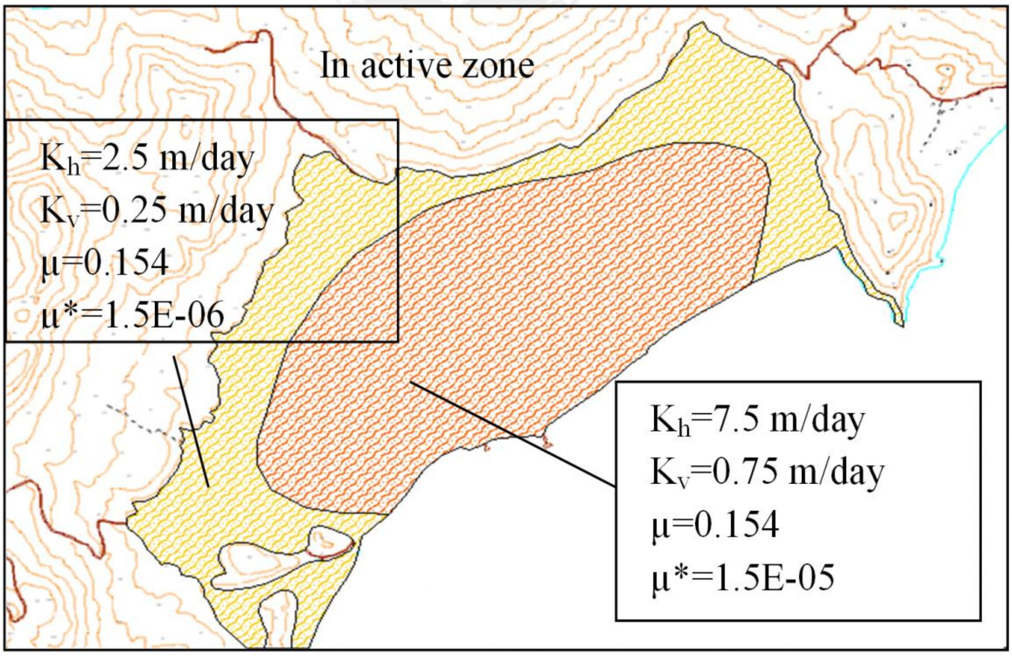


Figure 5.14 Hydrogeology properties of aquifer

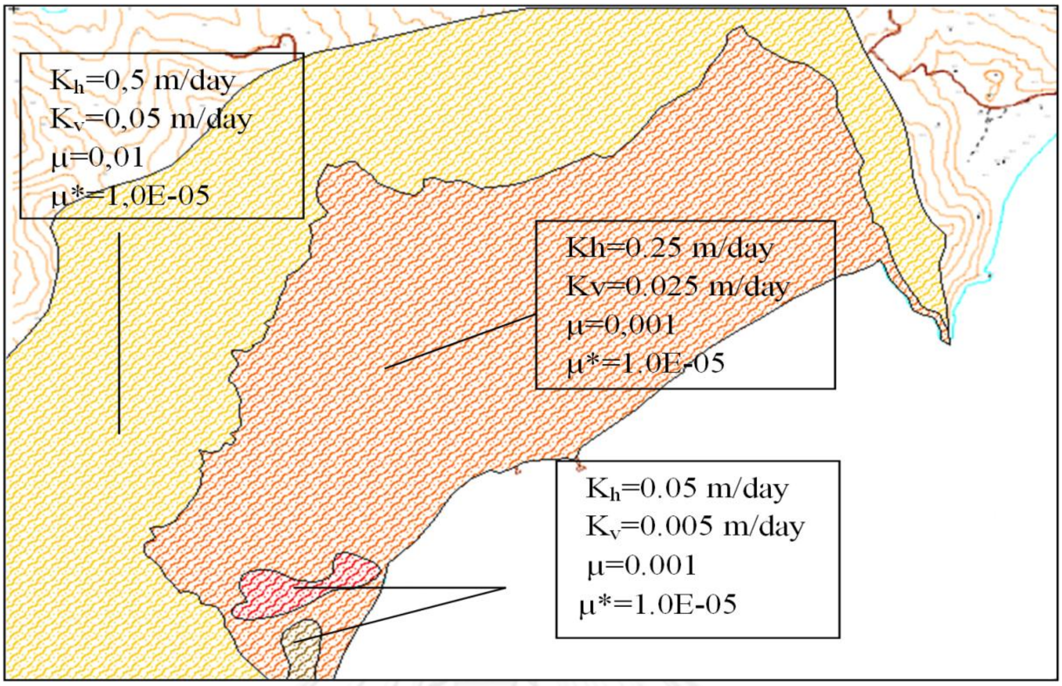


Figure 5.15 Hydrogeology properties of aquitard

5.3 SW-GW interaction analysis

5.3.1 Recharge estimation

In this study area, there are 3 recharge resources: rainfall, streams and lakes. The recharges from rainfall and streams are only existed in rainy season. Meanwhile, the recharges from lakes occurred in both dry season and rainy season. By applying SW-GW analysis, the recharge from lakes is estimated clearer than previous study.

The surface runoffs recharge estimation is accomplished by linking HEC-HMS and GMS. The key of recharge estimation is the storage – discharge reservoir function. The interval time to simulation is monthly. The discharge from lake to groundwater in HEC-HMS model during the interval calculation is set as the recharge from groundwater simulation. For the initial iteration, the recharge is assumed as zero. The results are evaluated when the recharge of previous iteration is equal to the next iteration. During simulation, surface runoff parameters and groundwater parameters shared the same input in the calibration – validation simulation. The rainfall pattern and evaporation regarding the period of past 17 years are used in simulating surface runoffs modeling.

According Figure 5.16, Figure 5.17, Figure 518, recharge and ΔH (the different head between lake water level and groundwater level) which clearly exhibited under changing pumping rate could be set as a factor to simulate groundwater. The recharge value and ΔH are matched after 3 iterations simulation. Figure 5.16 and Figure 5.17 display that under impact of pumping rate, water level in Lake 2 would tend to be dry during the end of dry season and cannot recharge to aquifer. Figure 5.18 proves that under the over exploitation, the ΔH increases and bring more recharge from Lakes 2 to aquifer. However, the storage of Lake 2 is not enough to supply to aquifer during dry season and the dry situation appeared. Thus, with insufficient recharge from Lake 2, aquifer will deplete under impact of extraction. Hence, the SW-GW interaction analysis was used as a method to estimate the recharge from lake to aquifer to assess groundwater capability in the study area.

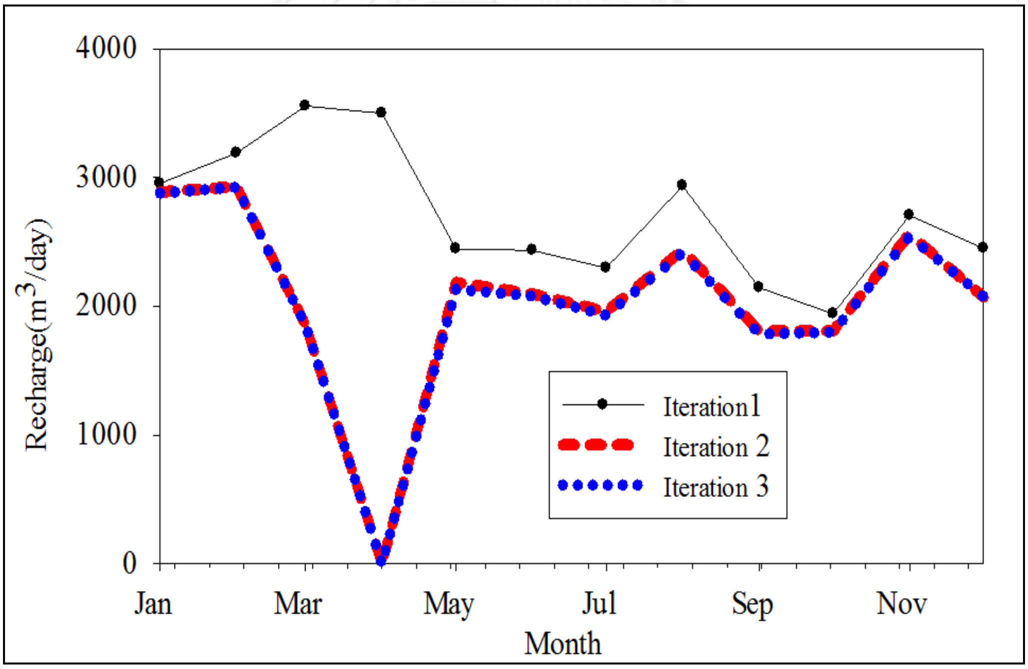


Figure 5.16 Estimated recharge from Lake 2 to aquifer in year 2013

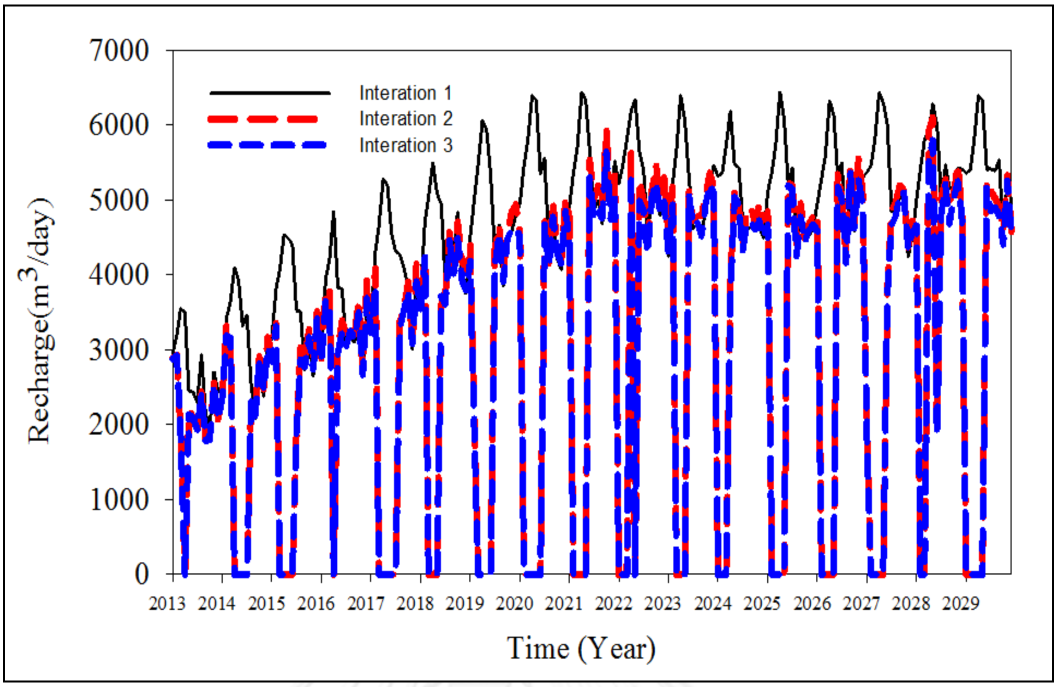


Figure 5.17 Estimated recharge from Lake 2 to aquifer (2013 – 2029)

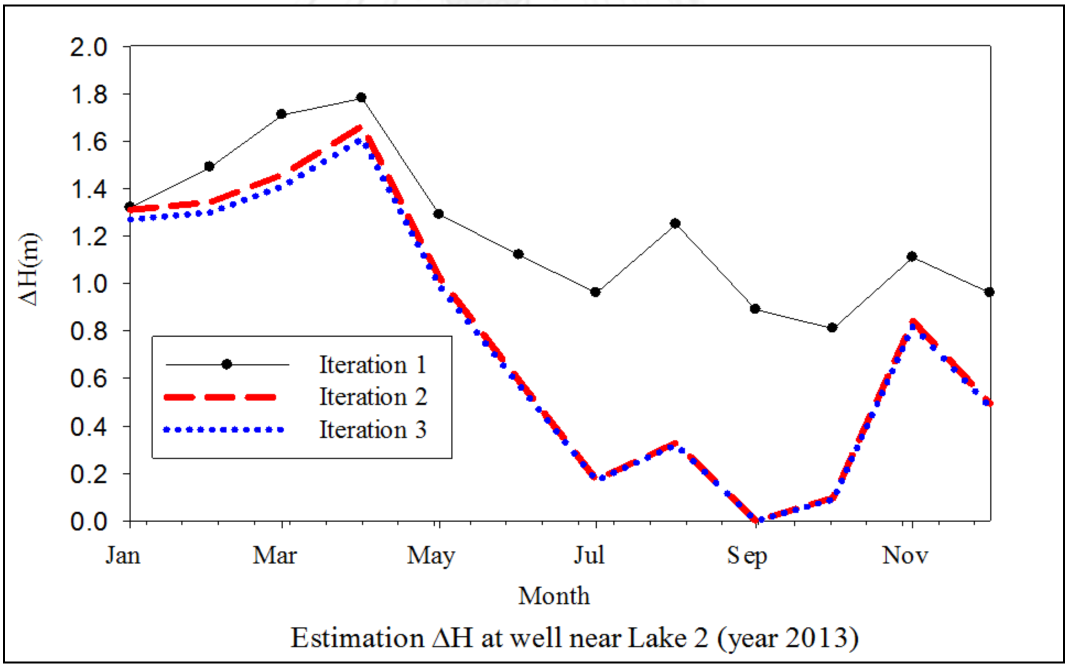


Figure 5.18 Estimated ΔH at Lake 2 in year 2013

Due to Figure 5.19, the recharges from both rainfall and streams are stable under increasing pumping rate. The fluctuation of both 2 recharges sources depend on season. Meanwhile, the recharges from 2 lakes are impacted by extraction as Figure 5.19. From 2006 to 2014, the recharge from 2 lakes is decrease in rainy season and increase in dry season. However, since

2015 to 2029, the recharges from 2 lakes increase with high amount in rainy season and decrease in dry season and cause the dry situation at Lake 2.

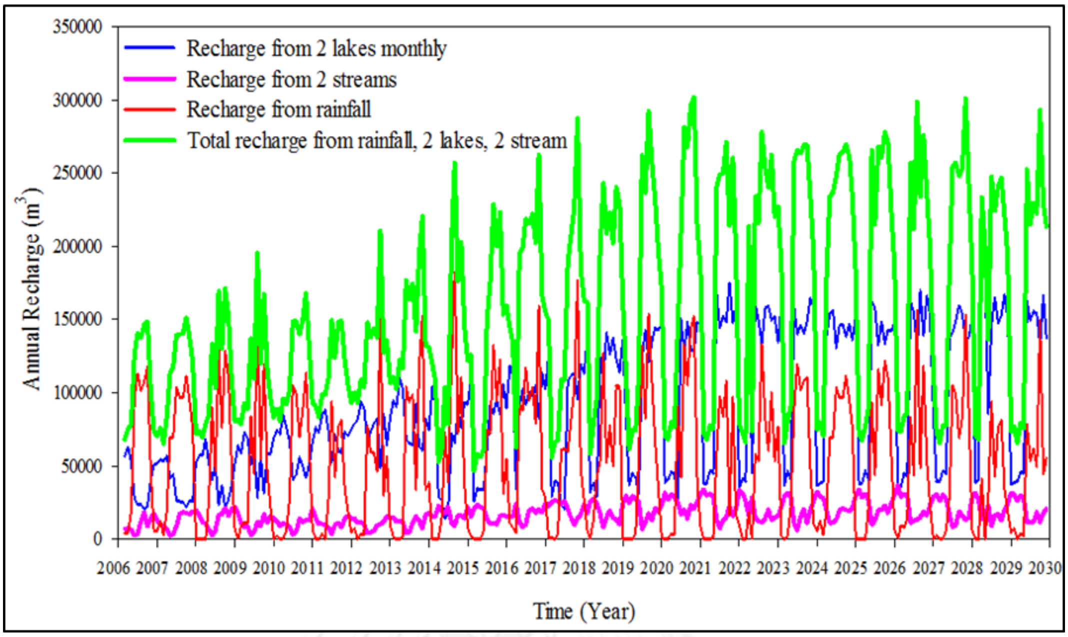


Figure 5.19 Annual recharge of 3 resources in 2006 - 2029

5.3.2 SW-GW analysis

Due to groundwater simulation, the relationship of recharge - ΔH is built as Figure 5.20. From Figure 5.20, recharge and ΔH relationship is in well proportional when water depth in lake is full enough to supply to aquifer. The relationship is indicated as function: y= 1231.3 x +1307, R^2=0.8954 (with x= ΔH and y=recharge). The maximum recharge is 5797m^3/day corresponding with ΔH =4.7m. Hence, this function is effectively used as evidence to evaluate result of groundwater simulation or a way to estimate the minimum recharge to recover aquifer when drawdown goes down.

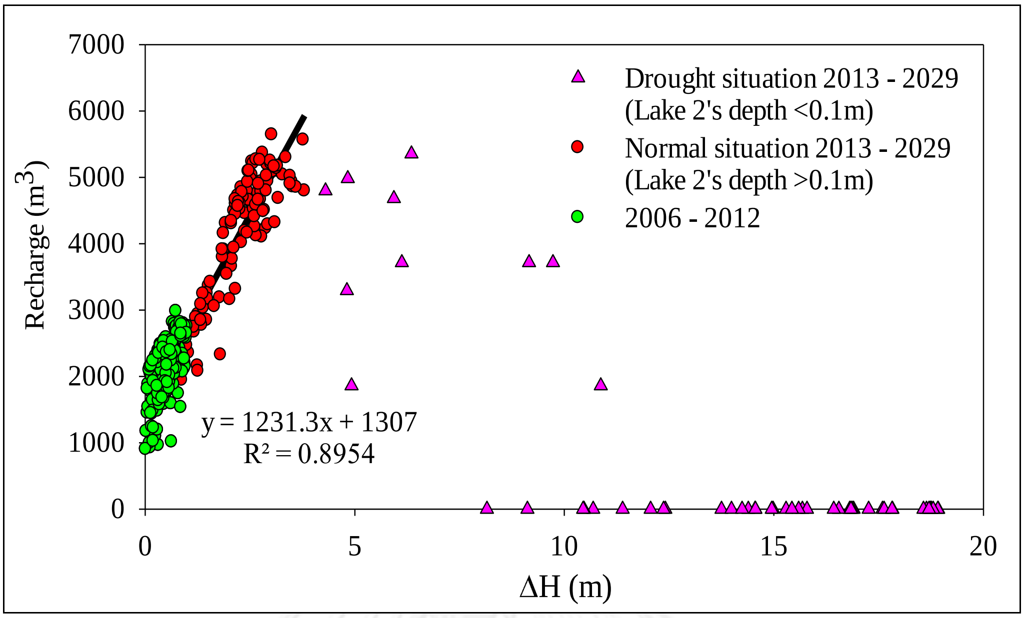


Figure 5.20 Recharge - ΔH function in Lake 2

Due to groundwater simulation, relationship between recharge in lake and pumping rate could build up a function as in Figure 5.21. The correlation function is y=0.9517x-30.94, R^2=0.61. Thus, the initial recharge could be estimated approximately by this function to simulate groundwater capability or planning water resources in study area.

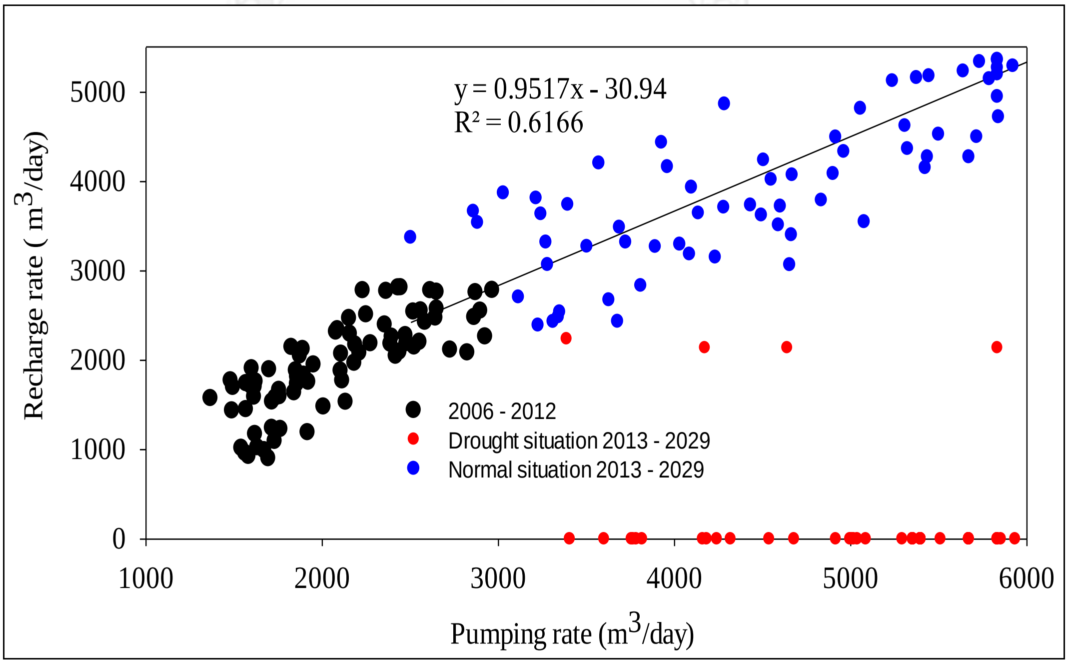


Figure 5.21 Recharge – Pumping rate Function in Lake 2

5.4 Surface simulation

In order to assess groundwater capability in this study area, the future surface runoffs are simulated base on increasing of recharges under future water pumping (6000 m^3/day) and pumping rate (3500 m^3/day). In the long term simulation, past rainfall pattern are used as input variables of modeling. The parameters variable input are estimated by calibration and validation step which is exhibited in section 5.1. In this part, the results of SW simulation under SW-GW interaction are presented follow:

A. Surface runoffs in Lake 1

Figure 5.22, Figure 5.23, Figure 5.24 present the water depth of Lake 1 and flow runoff in channel to Lake 1 are simulated in 2013-2014. Results of pumping rate 6000 m^3/day and pumping rate 3500 m^3/day matches each other. Figure 5.23 shows water depth of both case are fluctuated by season. During dry season, the depth would decrease to half of maximum depth of the lake in rainy season. As the Figure 5.24, the water depth at Lake 1 which are simulated in 2013 – 2029, can be considered as the future water level with the increasing pumping in the range of 0.7 m-1.5 m and the mean around 1.1 m. The trends of water level in both 2 cases are stable comparing with increasing pumping rate. In addition, the flow in channel near Lake 1 as Figure 5.22 is high flow during rainy season and no flow in dry season. The flows patterns are not different compared with same rainfall pattern. Thus, surface runoffs near region of Lake 1 are not impacted from the increasing pumping rate.

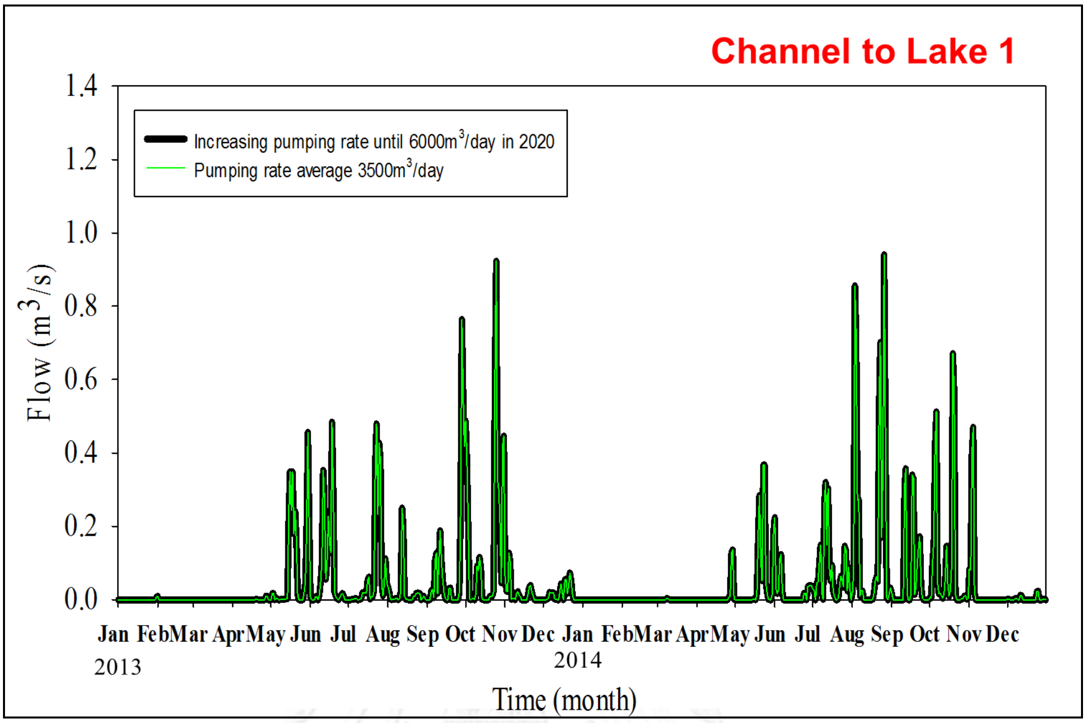


Figure 5.22 Flow runoff in channel to Lake 1 in 2013 -2014

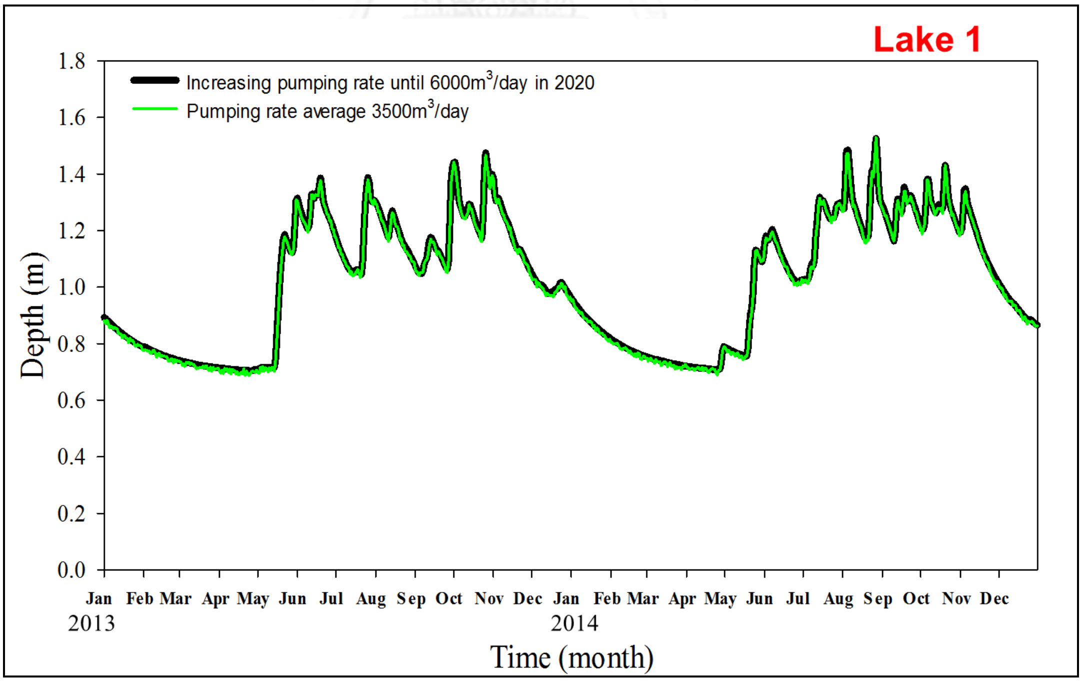


Figure 5.23 Water depth of Lake 1 in 2013 -2014

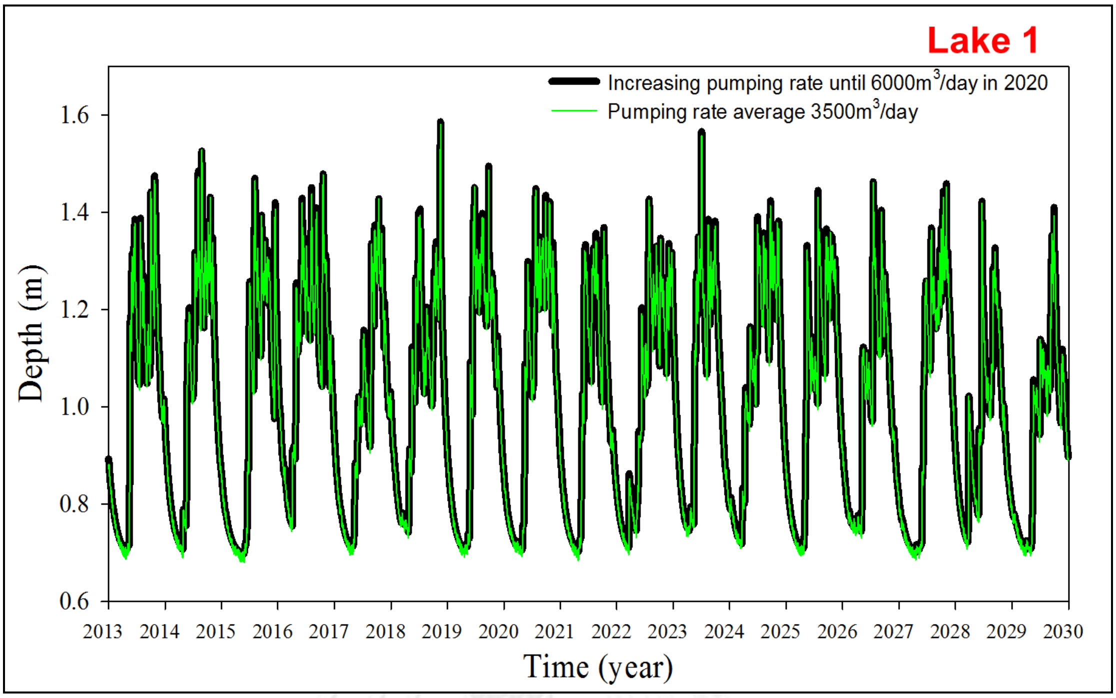


Figure 5.24 Water depth of Lake 1 in 2013 -2029

B. Surface runoff in Lake 2

According to the Figure 5.25, the flow runoff of future pumping rate and safe yield pumping rate are relevant. The runoff flow simulated in 2013-2014 doesn't indicate sign of changing flow pattern under both 2 pumping rate. Thus, the impact of pumping rate is not affected to channel connected to Lake 2.

In contrast, Figure 5.26 and Figure 5.27 illustrate the impact of 2 pumping rates to Lake 2 during the dry season. With increasing pumping rate of 6000 m^3/day, the dry situation occurs during the end of dry season; meanwhile the water depth in pumping rate 3500 m^3/day is still higher than bottom of Lake 0.2 m. Thus, with the drought situation under pumping rate 6000 m^3/day there is the potentially to appear insufficiency of water resources during dry season in this island. Whereas, with 0.2 m water depth, the water in Lake 2 still recharges to aquifer and keep water resources balance during dry season under pumping rate 3500 m^3/day as a safe yield. In both cases, water in Lake 2 restores maximum depth in rainy season.

Due to surface simulation, the total direct runoffs in basin near Lake 2 are estimated approximately 2.2 MCM in high rainfall year and 1.3 MCM in low rainfall year. In order to prevent the dry situation, when current storage of Lake 2 is 180,00m^3, expanding lake solution is possible to store water during rainy season and recharge to groundwater in the end of dry season.

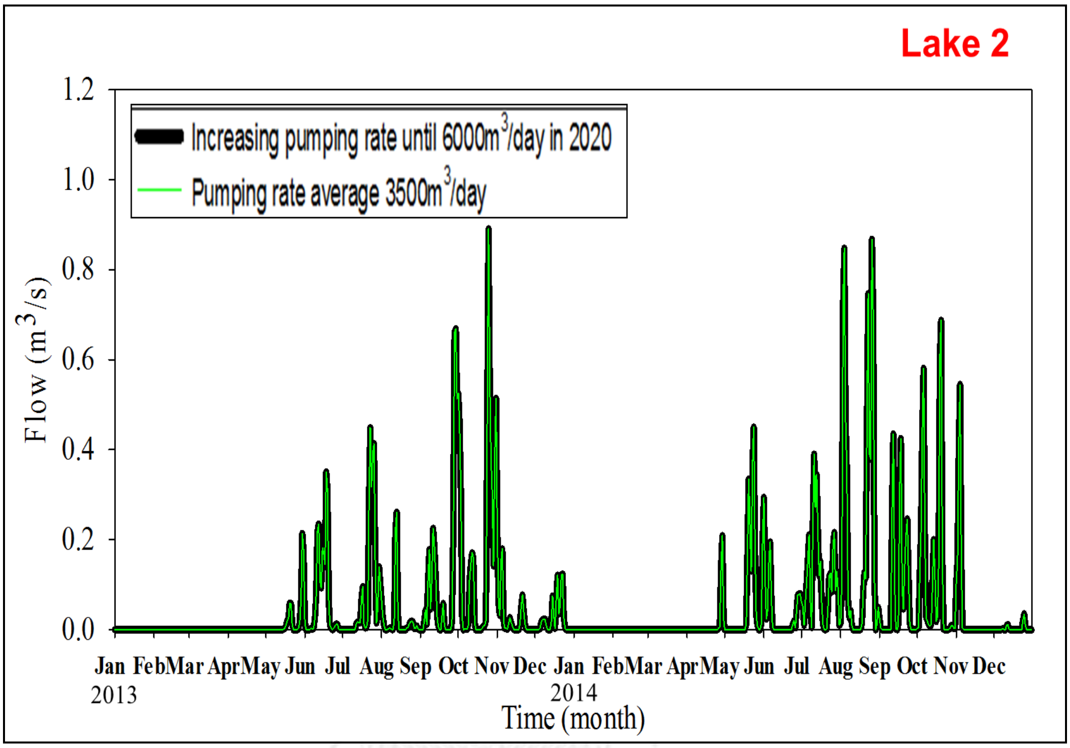


Figure 5.25 Surface runoff simulations in stream near Lake 2 in 2013 -2014

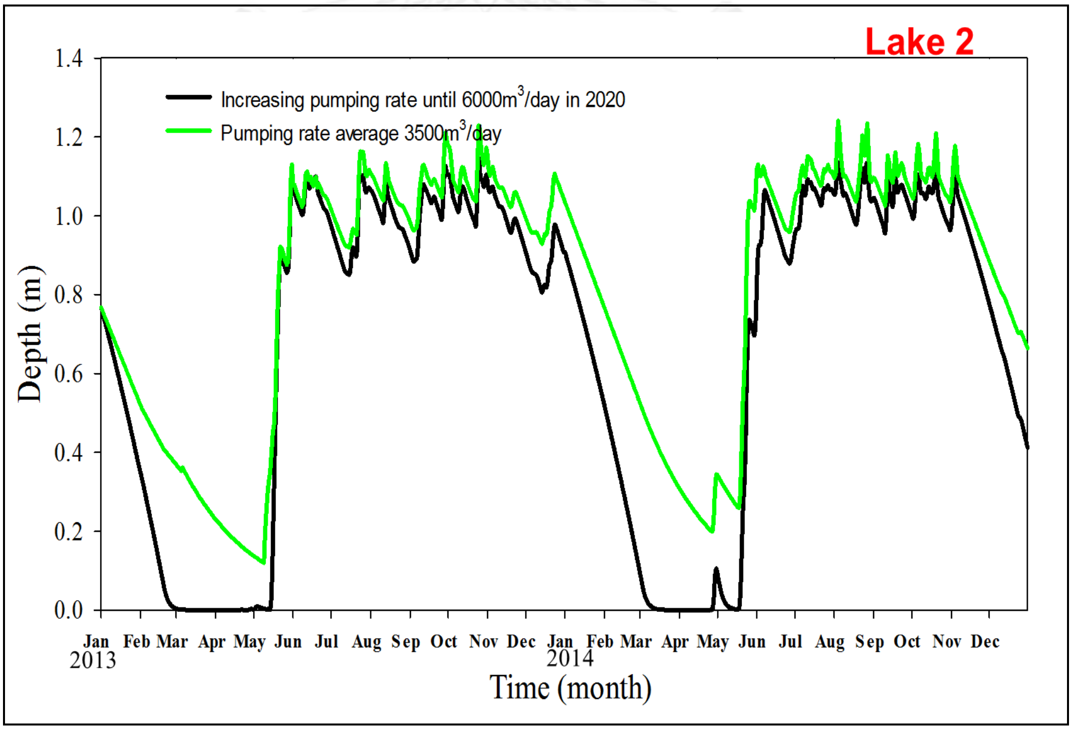


Figure 5.26 Water depth in Lake 2 in 2013 - 2014

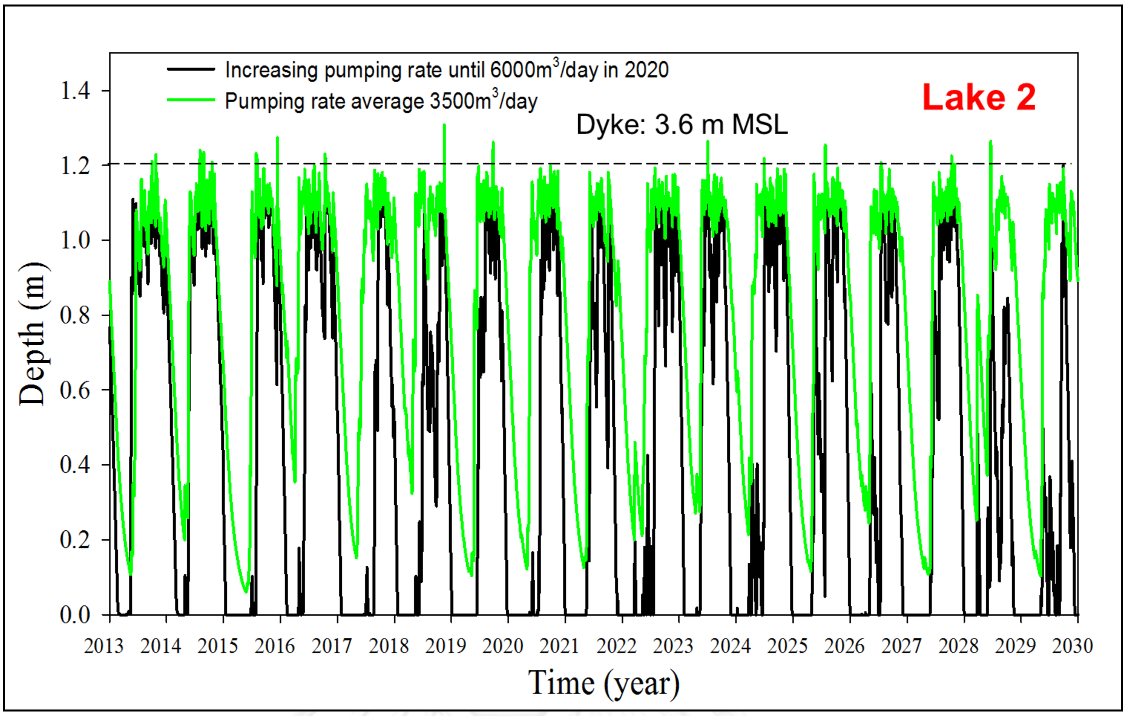


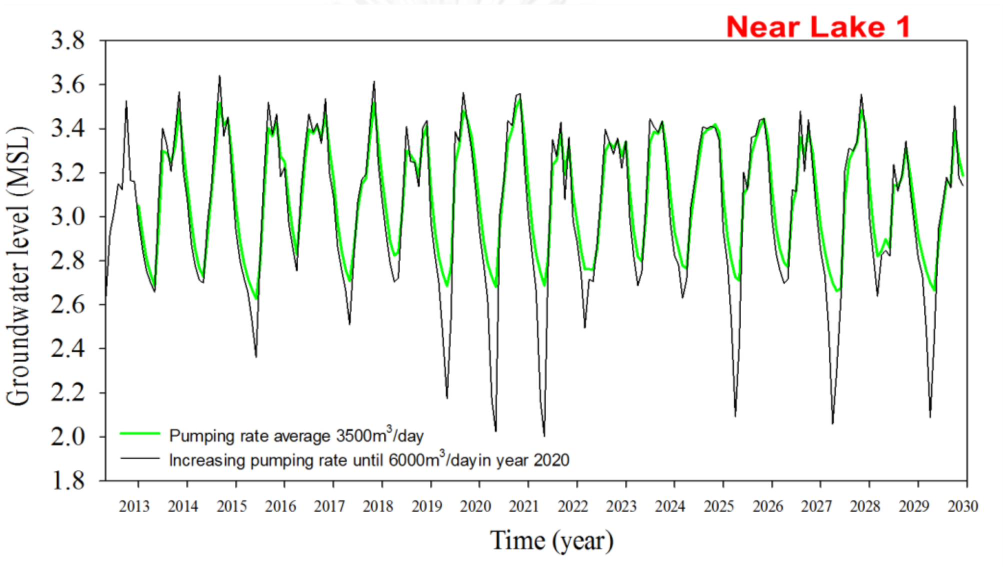
Figure 5.27 Water depth in Lake 2 in 2013 – 2029

5.5 Groundwater simulation

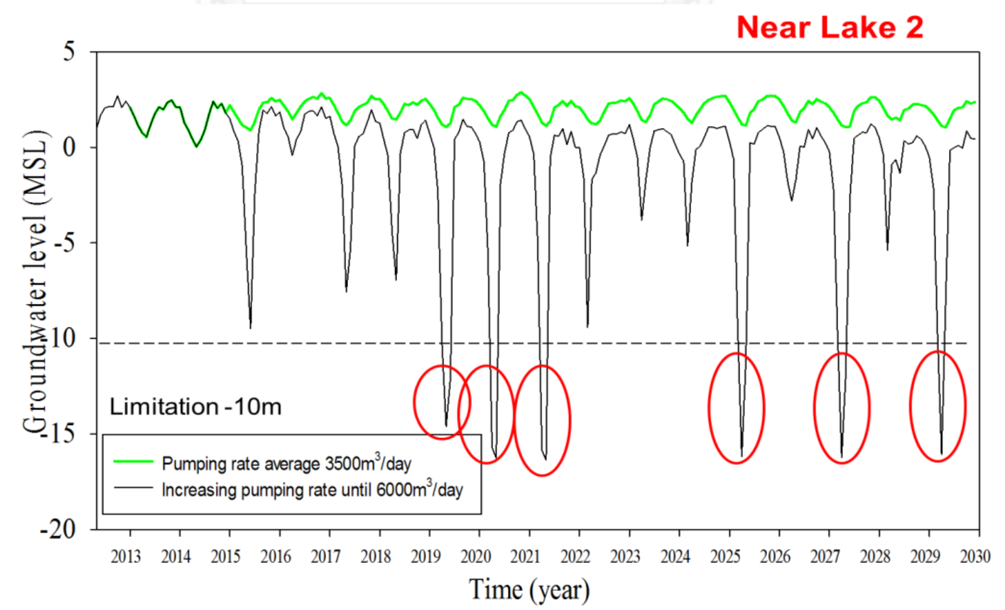
The variable input data of groundwater involves 2 components: 1) hydrogeology parameters; 2) recharges from the channel and lake. The parameters are validated in calibration and validation step is described in section 5.2. The recharges were estimated including SW-GW analysis and also demonstrated in section 5.3. This section shows the results of groundwater simulation under safe yield extraction and increase future pumping rate in the study area. Figure 5.28 provides the fluctuation of groundwater level at wells near Lake 1, Lake 2.

The groundwater of well near Lake 1 is performed as Figure 5.28 a). In the dry season, the groundwater level of safe yield extraction is just lower 0.1 - 0.2 m than case increasing future pumping rate. Overall, the groundwater of pumping rate 3500 m^3/day has no much different compared with the case of pumping rate 6000 m^3/day. Groundwater levels in both cases go down in dry season and rise up in rainy season. Trend of piezometric seems stable in long term under increasing pumping rate. Furthermore, the estimated water depth in Lake 1 has no significant change during future pumping rate. Hence, the radius of pumping rate influence could not reach to area near Lake 1.

For wells located near Lake 2, groundwater level of increasing pumping rate until 6000m^3/day seems insufficient during the dry season in year 2019, 2020, 2021, 2025, 2026, 2029. In Figure 5.26 b), future groundwater can be seen with the increasing pumping will be in the range of -16.0 MSL and 3.4 MSL and the mean of -9.0m MSL and the decreasing trend of groundwater capability after 2012 are well simulated. The drought situation occurs when Lake 2 is dry (Mar–May). Groundwater level near Lake 2 is evidence of future pumping rate impact. Since the signification water resource on Island is groundwater from Pleistocene aquifer. Meanwhile, groundwater under safe yield pumping rate 3500 m^3/day is stable in the range of 1.5 MSL and 3.4 MSL during 17 years.



a) Groundwater table of well CS1 (near Lake 1) simulation in 2012-2029



b) Groundwater level of well CS6 (near Lake 2) simulation in 2013-2029

Figure 5.28 Groundwater level simulation with future pumping rate in year 2013-2029

Figure 5.29 presents the groundwater contour of pumping rate 3500m^3/day and 6000m^3/day in May 2029 with annual rainfall 1600mm (see Table 5.2). Groundwater level of near Lake 2 under pumping rate 6000 m^3/day is lower than limitation as -10 MSL. Meanwhile, the groundwater level in case pumping rate 3500 m^3/day is up to 2 MSL. In both case, the groundwater level near Lake 1 seem stable as 2.4 MSL during the dry season.

Table 5.2 Precipitation input to groundwater modeling in 2029

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total of monthly rainfall	8.8	-	2.1	18.7	91.9	343.0	323.8	228.2	287.8	548.2	219.3	21.5
Number of rainy day	3	-	1	4	12	19	22	20	22	28	16	12

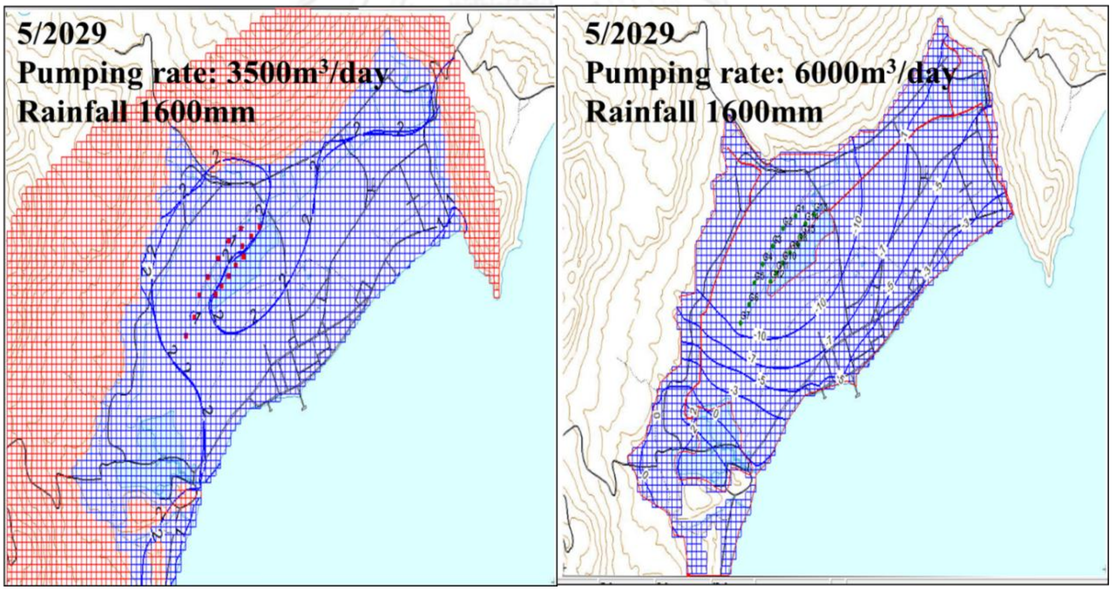


Figure 5.29 Groundwater level contour of pumping rate 3500m^3/day and 6000m^3/day in May 2029 with annual rainfall 1600mm

Figure 5.30 illustrates the Groundwater flow direction of pumping rate 3500m^3/day and 6000m^3/day. Under pumping 3500 m^3/day, the groundwater flows from Lake 2 to the sea. Meanwhile, with the pumping 6000 m^3/day, the groundwater flow direction is from sea to Lake 2 which will cause the salt intrusion.

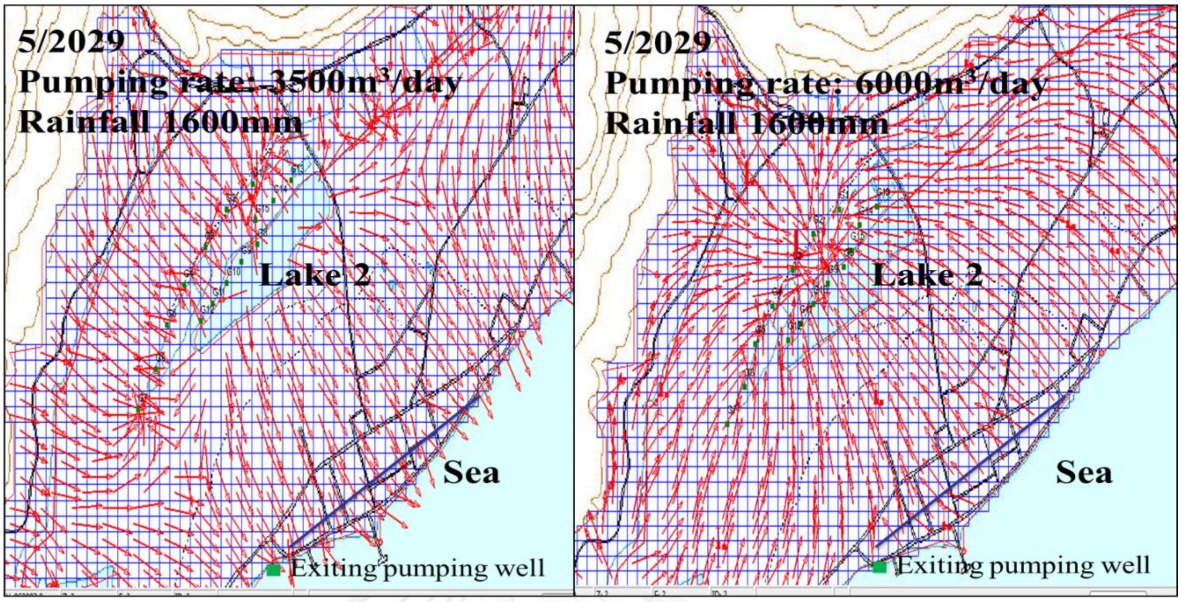


Figure 5.30 Groundwater flow direction of pumping rate 3500m^3/day and 6000m^3/day

According to the Water Resources Law of Vietnam, the drawdown is not allowed to be lower than ½ of aquifer thickness (≤ 10m). With drawdown -19m, the results show that the aquifer unable to satisfy future domestic demand. In order to meet the future domestic demand, the development plan by expanding the lake is very significant to satisfy future water domestic demand. In case of no water development plan, the pumping rate as safe yield should conduct within after consider salt water intrusion 3500 m^3/day to prevent the insufficient of water resources and salt intrusion.

According to the study, the recharge sources of aquifer in Con Son Valley are estimated as Table 5.3. In the future simulation, the maximum groundwater level as 2.44 m would exist in 11/2013 and the minimum as -16.54 m could occur in 04/2027. The amounts of recharges come from rainfall and water storage in lake. The recharge from two lakes was simulated as 4,511,738 m^3 with current pumping rate in present period and 20,786,902m^3 with future pumping rate in future period. The percentage of lakes recharges increase from 47.44% to 58.62%. Hence, the alternative such as Lake Enlargement is possible and requires further investigation to solve water shortage in the future (Long & Koontanakulvong, 2014).

Table 5.3 Impacts from increasing pumping towards piezometric heads

	Water Table (m, MSL)			Recharge from two lakes to groundwater (m^3/day)			Recharge from the stream (m^3/day)			Recharge from the rainfall (m^3/day)		
	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
Present pumping rate (present period)	3.4	1.37	2.63	3015	1124	1960	1497	0	331	5055	0	1624
Future pumping rate (future period)	2.44	-16.54	-3.4	6006	101	2812	1653	0	440	5870	0	1708

	Total volume recharge from two lakes to groundwater in 6 years (m^3)	Total volume recharge charge from the stream in 6 years (m^3)	Total volume recharge from the rainfall in 6 years (m^3)
Present pumping rate	4 511 738	933 232	4 066 068
	47.44%	9.81%	42.75%

	Total volume recharge from two lakes to groundwater in 17 years (m3)	Total volume recharge charge from the stream in 17 years (m3)	Total volume recharge from the rainfall in 17 years (m3)
Future pumping rate	20 786 902	4 002 870	10 671 807
	58.62%	11.29%	30.09%

5.6 Salt intrusion estimate

When the drawdown is too low in pumping region located near Lake 1, the length between well and new toe of salt water interface is calculated by equation of Ghyben – Herzberg and Strack to estimate the impact of salt intrusion. The variable data is simulated by groundwater modeling with increasing pumping rate. The resulf of salt intrusion calculation is shown in Figure 5.31.

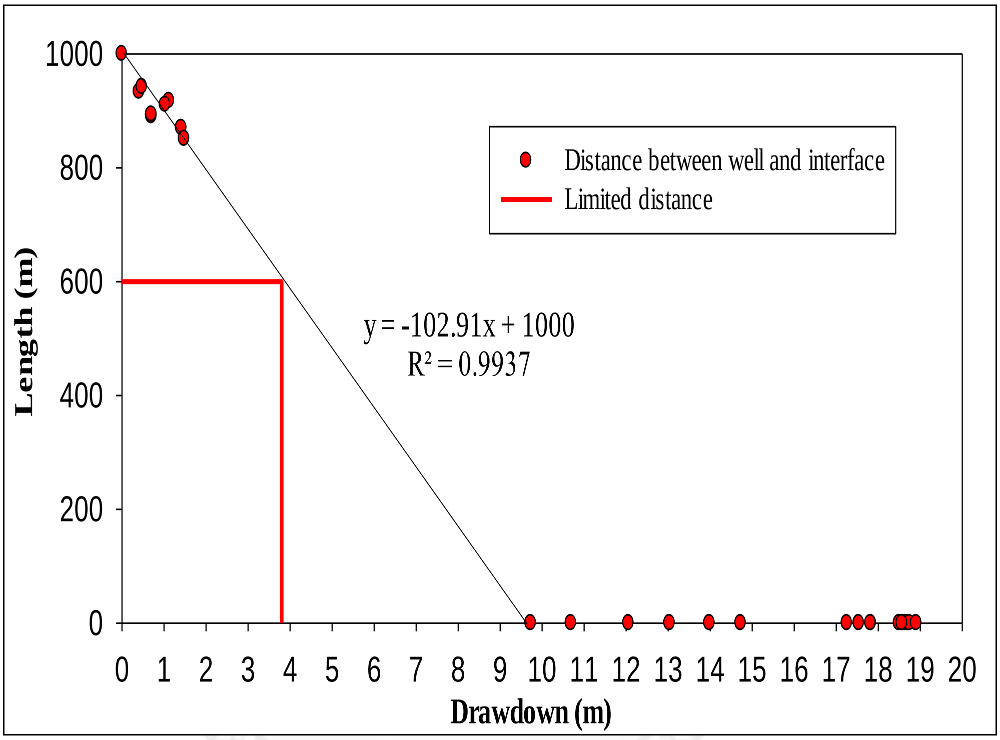


Figure 5.31 Distance between well and interface

According the figure above, the function of length and drawdown is y=-102.91x+1000, R^2=0.9937. The longest distance is 1000m with 0m drawdown. The smallest distance is 0m with 9.7m drawdown. To prevent salt intrusion, the selected distance between well and new toe interface should not be lower than 1/3 of distance between well and sea (≥600m). Thus, based on Drawdown – Salt Intrusion Function, the drawdown should be limited to 3.9m in the pumping region.

5.7 Selection of water resources development plan

In this part, 12 alternatives is from mixing options expanding Lake 2: 180,000 m^3; 267,000 m^3; 400,000 m^3; no expanding Lake 2 and options using existing wells, adding 5 wells, adding 10 wells alternatives. All alternatives are simulated to examine groundwater level under increasing pumping rate of 6000 m^3/day.

Figure 5.32 presents the groundwater level of some alternatives. Most of alternatives could bring better groundwater level under increasing pumping rate 6000 m^3/day. The maximum drawdown of alternatives is summarized in Table 5.4. The alternative from the option of no expanding Lake 2 and using existing wells indeed drawdown over than limitation to prevent salt intrusion. Meanwhile, alternatives of option expanding Lake 2 and adding more wells are corresponding to protect aquifer and prevent salt intrusion condition (drawdown ≤ 10m). Thus, the selection of water development base on comparison of construction cost of each alternative.

Table 5.5 illustrates the summary construction cost of alternatives base on the main construction and construction cost from DWPIRS. For option of no expanding Lake 2, in order to surmount the dry situation, the delivery cost water from mainland to island is limitation 11,194,738 USD which is over budget to conduct possible. Whereas, alternatives come from expanding Lake and adding wells have the cost from 581,296 USD - 1,043,997 USD. Since, the selection has lowest cost, drawdown under limitation, length interface in safety zone of alternative with expand lake 180,000m^3 and add on 5 wells is more suitable. The alternative will cost approximately 695,605 USD and low drawdown of 3.83 m to prevent 600m length of new toe between well and interface saltline impact on the aquifer.

Table 5.4 Maximum drawdown of all alternatives (unit: m)

Expand lake (m^3) / Pumping rate (m^3/day)	400 000	267 000	180 000	No expanding
400	4.15	4.62	5.14	18.9
300	3.04	3.14	3.83	17.54
250	2.14	2.37	2.74	16.53

Table 5. 5 Cost of all alternatives (unit: USD)

Expand lake (m^3) Pumping rate (m^3/day)	400 000	267 000	180 000	No Expanding
400 (+0 wells)	815,380	722,688	581,296	11,404,490
300 (+5 wells)	929,689	836,997	695,605	10,757,643
250 (+ 10 wells)	1,043,997	951,306	809,914	10,312,183

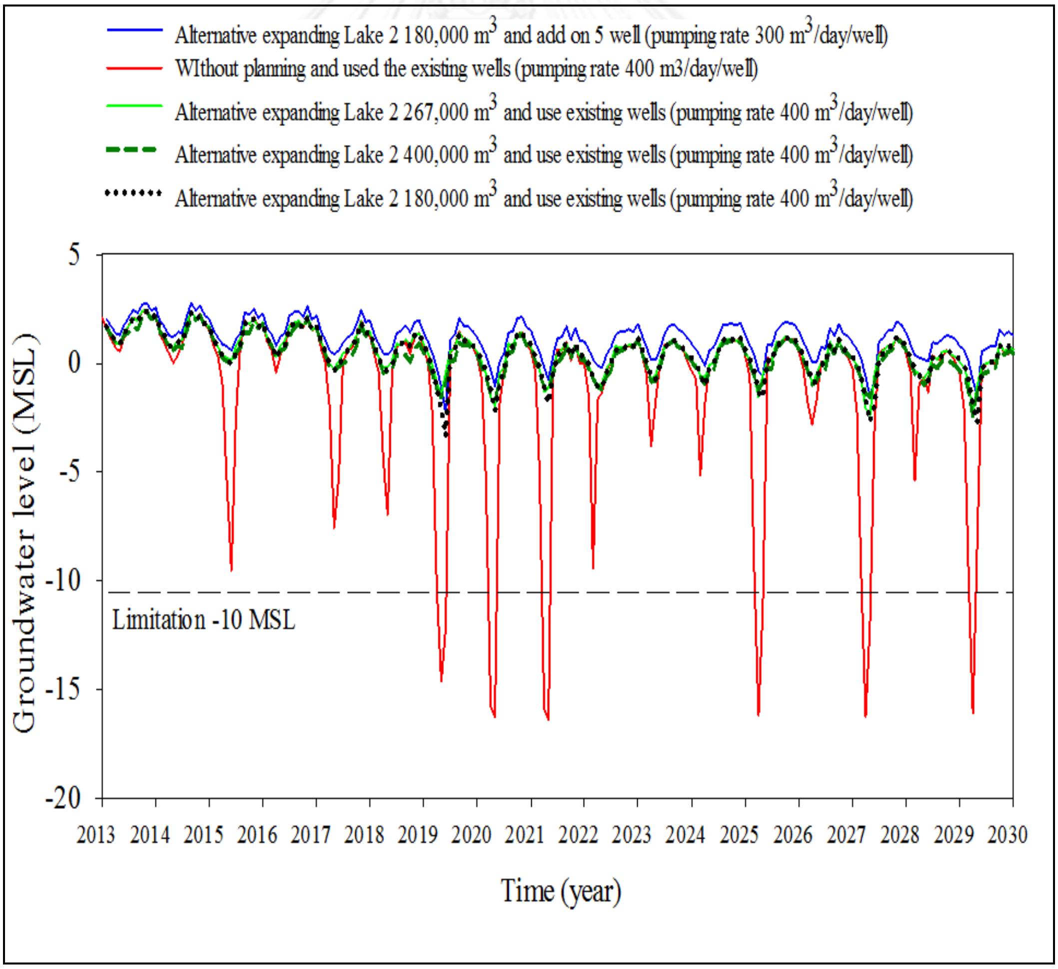


Figure 5.32 Groundwater level of some alternatives

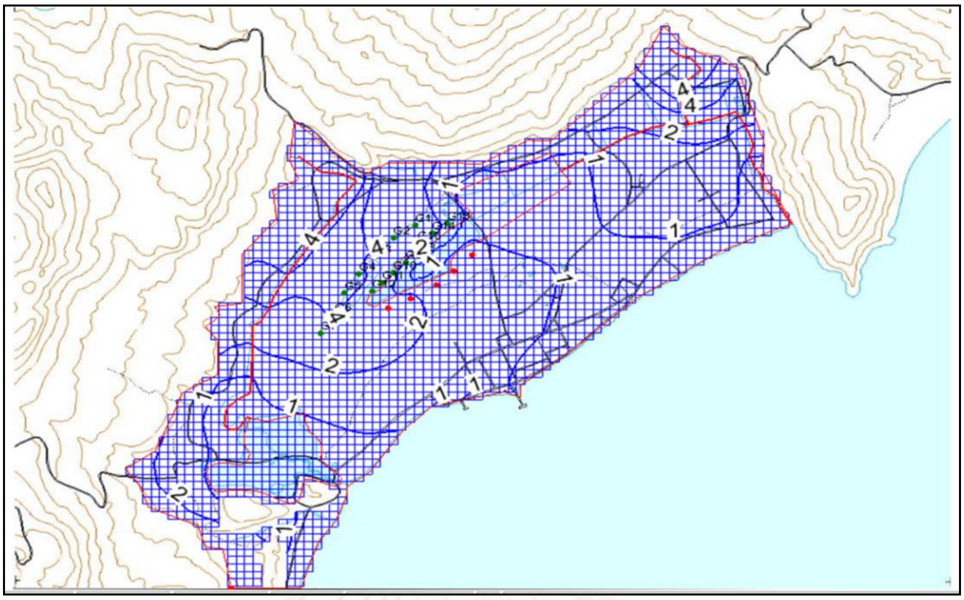


Figure 5.33 Groundwater drawdown of alternative expanding lake 2 180,000m^3 and add on 5 wells

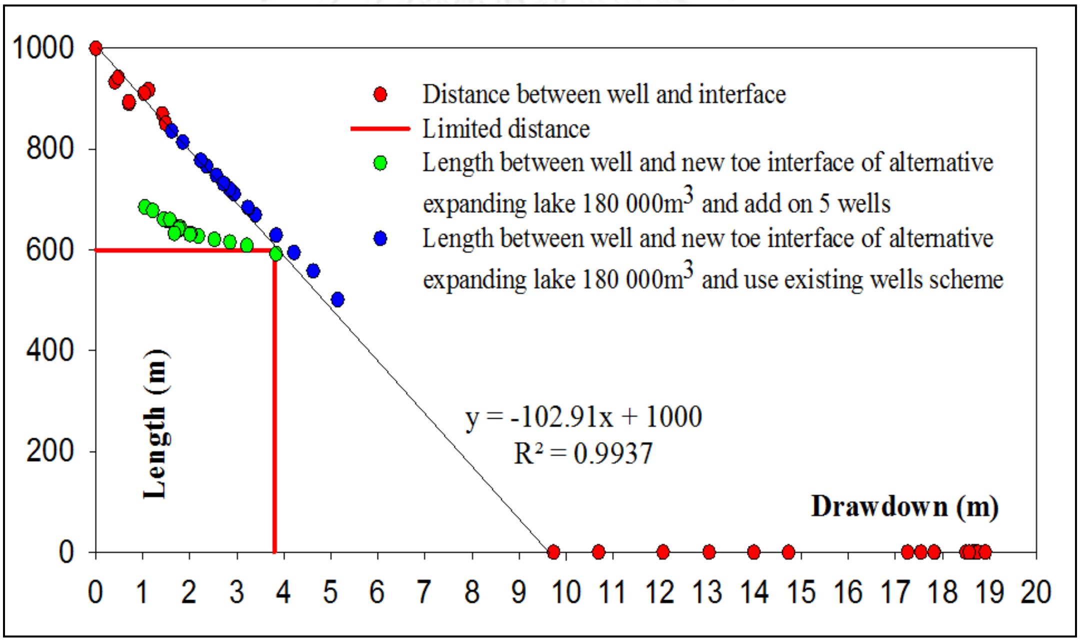


Figure 5.34 Estimated salt water intrusion interface of some alternatives.

5.8 Summary

The objectives of this study is to gain better perception regarding behavior of the Con Son Valley groundwater system under SW-GW interaction in order to improve water resources planning to satisfy future domestic demand. The research presented a method to assess responding of Pleistocene aquifer to future pumping rate which is double time with current period in Con Son Valley, Con Dao District, Ba Ria – Vung Tau. From the simulation can be summarized the research as:

A. SW-GW interaction

By SW-GW interaction approach, the recharge of lake to groundwater could be estimated approximately to support groundwater simulation provides more accurate results.

The SW-GW interaction also clears the role of lake with aquifer by recharge. With the future pumping rate, the ΔH will increase and requires more recharge to balance groundwater resources. The relationship of recharge and ΔH is indicated by function $y= 1231.3\ x +1307$, $R^2=0.8954$ (with $x= \Delta H$ and $y=$recharge). The function could be used as the measurement to evaluate groundwater simulation in this study area.

Due to the groundwater simulation, the relationship between recharge and pumping rate are linear as the function: $y=0.9517x-30.94$, $R^2=0.61$. With this function, the requirement recharge could be approximately estimated which could be initial condition to planning water resources management.

B. Surface water resources:

The water depth in Lake 1 will not affect under the increasing pumping rate due to the present pumping rate. The water level is fluctuated by the rainfall and would be in range 0.7m - 1.5m and mean of 1.1m.

The water level in Lake 2 is impacted by future pumping rate. The dry of the lake situation would occur during the end of dry season (March – May). The water reserves could recover back to the maximum storage of lake as 180 000m^3 after the rainfall season. Meanwhile, under safe yield pumping rate 3500 m^3/day, water level in Lake 2 seems to be stable and not lower than 0.2 m during dry season.

The total direct runoffs in basin near Lake 2 are calculated approximately 2.2 MCM in high rainfall year and 1.3 MCM in low rainfall year. Due to amount of direct runoffs, enlarging lake is the only possible solution to store water during rainy season and recharge to groundwater in the end of dry season.

C. Groundwater resources

The aquifer got recharges from: lake, stream, and rainfall. The amounts of recharges come from rainfall and water storage in lake. The percentage of lakes recharges is from 47.4% to 58.62%. Thus, recharge from lake play an important role in keep water resources on Island balance.

Under increasing pumping rate, groundwater level of extraction region would decrease to -16.9 m which will make Pleistocene aquifer drought during the end of dry season in pumping region then the piezometric head could recover as maximum state after rainy season. Moreover, with the high drawdown, the salt intrusion would reach to all aquifer and make the insufficient groundwater more critical. With 3 months of no water, the activity of Island will be paralyzed and hardly to recover. Therefore, aquifer is no longer satisfactory to future water domestic use (6000m^3/day).

In order to meet the future water demand, enlargement lake alternative is possible and requires further detail investigation to solve water shortage in the future.

In case of no water resources development plan, the safe yield pumping rate in this island should be around 3500 m^3/day which can protect aquifer out of insufficient situation and prevent salt intrusion from spreading.

D. Salt intrusion estimation

To prevent salt intrusion, the distance between well and new toe interface should be up to 1/3 of distance between well and sea (≥600m). Thus, from Drawdown – Salt Intrusion Function, the drawdown should be limited to 3.9m.

E. Selection water resources development plan

The selected alternative which consist of combinations of lake expansion of 180 000m^3 and additional 5 wells has the lowest cost under the condition of drawdown, and salt interface. This alternative will cost approximately 695,605 USD and also reduce drawdown to 3.83m to keep the aquifer safe with salt intrusion.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

1) The study showed the improvement of groundwater simulation with the consideration of SW-GW interaction by transferring the simulated surface profile to estimate the recharge value in the groundwater model simulation.

- The amounts of recharges are collected from rainfall and water storage in lake. The recharge from two lakes was simulated as 4,511,738m^3 with current pumping rate in present period and 20,786,902m^3 with future pumping rate in future period. The percentage of lakes recharges increase from 47.44% to 58.62%. Hence, an alternative of expanding lake is possible and requires further investigations to solve water shortage in the future.

- The relationship between recharge & ΔH in the study area from the SW – GW analysis was found $y= 1231.3\ x +1307$ (y= recharge, x= ΔH). With this function as results of groundwater simulation could be evaluated with higher accuracy. Besides, the relationship between recharge and pumping is indicated as the function $y=0.9517x-30.94$ (y= recharge, x= pumping rate). The function could be used to estimate recharge volume when design water development plan. With both functions, the results give more reliable piezometrics than the previous studies. Moreover, the SW-GW interaction analysis was also applied to investigate the impact of future pumping on the piezometric heads in the aquifers. The method and information can be used to assess water resources plan to counter with drought management on the island.

2) The total direct runoffs in basin near Lake 2 are calculated approximately 2.2 MCM in high rainfall year and 1.3 MCM in low rainfall year. Due to amount of direct runoffs, enlarging lake is the only possible solution to store water during rainy season and recharge to groundwater in the end of dry season.

3) According to groundwater simulation in this island with the existing pumping scheme, groundwater level near wells pumping scheme tend to decrease by 18m in the future during dry season (April, May, June) which will potentially cause salt intrusion into the aquifer in the future. With 3 months lack of water, the activity of the island would be paralyzed and hardly to recover. In order to surmount the drought situation, the delivery cost of water from mainland to island would be 11,194,738 USD (Appendix E), thus the expense regarding this solution is likely to be

over budget for actual implementation. Therefore, without the improvement of water resources alternative, Pleistocene aquifer in Con Son Valley is unable to reach satisfactory future water demand as 6000m^3/day. In case of the contribution of satisfactory future, to enlarge the size of lake would be very significant. Due to the insufficient amount of water resources, the minimum size of lake is estimated to be 180 000 m^3. Meanwhile, in case of no water resources development plan, the safe yield pumping rate should be around 3500 m^3/day.

4) The selection water resources development plan is selected by comparing among 12 alternatives from mixing options of expanding Lake 2 (180,000 m^3, 267,000 m^3, 400,000 m^3, and no expanding) and options adding new pumping well (addling 5 wells, addling 10 wells, using the existing wells) under 3 comparative aspects: 1) groundwater drawdown, 2) salt water intrusion, 3) construction cost or damage cost. Due to the comparison, alternative of expanding size of Lake 2 180,000m^3 and more additional 5 wells is the cheapest alternative. This alternative also long dry situation and prevent salt water intrusion from spreading into the pumping wells.

6.2 Recommendations

1) For future water planning on the island, the permanent monitoring wells and surface runoffs should be installed to monitor piezometric heads and water level in lake in the potential increasing pumping in the future to investigate the fluctuation of groundwater table and to prevent possible salt water intrusion phenomena in the low area.

2) For future extraction, the well structure should be designed according to standards to be able to ensure the efficiency of wells and avoid high water head difference in side of well.

3) For future water planning on the island, the salt intrusion sample need to be investigated under further research to give more information about the interface of salt intrusion. With salt intrusion consideration, the water resources management could be selected more suitably for Con Dao Island.

REFERENCES

A. Majidi, K. S. (2012). Simulation of Rainfall-Runoff Process Using Green-Ampt Method and HEC-HMS Model (Case Study: Abnama Watershed, Iran). International Journal of Hydraulic Engineering, 1(1), 4.

Arekhi, S. (2012). Runoff modeling by HEC-HMS Model (Case Study: Kan watershed, Iran). International Journal of Agriculture and Crop Sciences., 4(23), 1807-1811.

B. M. Golrang, F. S. L., S.H. R. Sadeghi, Khamurudin M. N., Kamziah Abd Kudus, M. Mashayekhi , R. Bagherian. (2013). Assessment of Watershed Management Implemented on Springal Peak Flood Discharge and Flood Volume, Using HEC-HMS Model (Case study: Kushk Abad sub-basin in Iran). Science and Nature, 2 (2), 59-64.

Bailly-Comte V. , J. H., Roesch A. , Pistre S. , Batiot-Guilhe C. . (2008). Time series analyses for Karst/River interactions assessment: Case of the Coulazou river (southern France). Journal of Hydrology, 349(1–2), 98-114. doi: http://dx.doi.org/10.1016/j.jhydrol.2007.10.028

Chan, N. D. (2006). The supplementary investigation, construction of groundwater monitoring network, exploitation planning, use and protection of water resources in Con Dao archipelagos. Division for Water Resources Planning And Investigation For The South Of Viet Nam (DWRPIS).

Chan, N. D. (2009). ASSESSMENT OF GROUNDWATER RESERVES IN CON DAO AREA BY MODELLING. Journal of Science and Technology, 12(5), 9.

Chow, V. T., Maidment, D. R., Mays, L. W. (1988). Applied Hydrology. McGraw-Hill, New York.

Company of Technological and Equipment Consultants and Construction Audit, Report on feasibility study of water supply system for Con Dao town during 1998-2010. Ba Ria – Vung Tau, Vietnam.

Fetter, C. W. (1994). Applied Hydrogeology.

Finch, J. W. (1998). Estimating direct groundwater recharge using a simple water balance model – sensitivity to land surface parameters. Journal of Hydrology, 211(1–4), 112-125. doi: http://dx.doi.org/10.1016/S0022-1694(98)00225-X

Freeze, R. A., & Cherry, J. A. (1979). Groundwater. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Hantush, M. M. (2005). Modeling stream–aquifer interactions with linear response functions. Journal of Hydrology, 311(1–4), 59-79. doi: http://dx.doi.org/10.1016/j.jhydrol.2005.01.007

Hunt, R. J., Strand, M., & Walker, J. F. (2006). Measuring groundwater–surface water interaction and its effect on wetland stream benthic productivity, Trout Lake watershed, northern Wisconsin, USA. Journal of Hydrology, 320(3–4), 370-384. doi: http://dx.doi.org/10.1016/j.jhydrol.2005.07.029

Hussein, I., & Al-Weshah, R. (2009). Optimizing the water allocation system at jordan valley through adopting water evaluation and planning system model (WEAP). Thirteenth International Water Technology Conference, IWTC 13 2009, 753-777.

Jaramillo-Nieves L. , G. S. (2012). Groundwater modeling of the Silver Bell Mountains, Arizona, USA. Environmental Earth Sciences, 66(7).

John E. Griggs, F. L. P. (1993). Groundwater flow dynamics and development strategies at Atol Scale. Ground Water, 31(2), 11.

Khasankhanova, G. (2003). PUBLIC PARTICIPATION TO IMPROVE WATER RESOURCE MANAGEMENT IN UZBEKISTAN. Paper presented at the Diffuse Pollution Conference Dublin, Uzbekistan.

Kuster, S. M. (2013). Managing water for social equity, economic efficiency and environmental stability: governing spate-flood Irrigation for social equity, environmental sustainability and economic output. Paper presented at the National Conference for the Management and Development of Water Resources in Yemen.

Liu, Y., & Sheng, Z. (2011). Trend-outflow method for understanding interactions of surface water with groundwater and atmospheric water for eight reaches of the Upper Rio Grande. Journal of Hydrology, 409(3–4), 710-723. doi: http://dx.doi.org/10.1016/j.jhydrol.2011.09.004

Long, T. T., & Koontanakulvong, S. (2014). SW-GW Interaction Analysis for Drought Management in Con Son Valley, Con Dao Island, Ba Ria-Vung Tau Province, Vietnam. Paper presented at the The 1st AUN/SEED-Net Regional Conference on Natural Disaster, Universitas Gadjah Mada, Yogyakarta, Indonesia.

M. Ebrahimian, A. A. N., M. A. B. Mohd Soom, A. M. Sood. (2012). Application of NRCS-curve number method for runoff estimation in a mountainous watershed. Caspian Journal of Environmental Sciences, 10(1), 11.

Marcoux, A. (1994). Population and Water Resources. FAO.

McDonald, M. G., & Harbaugh, A. W. (1988). A modular three-dimensional finite-difference ground-water flow model: U.S. Geological Survey Techniques of Water-Resources Investigations (Vol. Chap. A1). U.S.A: U.S. Geological Survey Techniques of Water-Resources Investigations.

Mir Mehdi M., J. A. (2009). Calibration of HEC-HMS model and assessment of this model response to flood of Maron watershed. Paper presented at the 4th National conference of civil engineering, Tehran university.

Morris, B. L., Lawrence, A. R. L., Chilton, P. J. C., Adams, B., Calow, R. C., & Klinck, B. A. (2003). Groundwater and its susceptibility to degradation : a global assessment of the problem and options for management. Early warning and assessment report series /UNEP-DEWA, RS.03-3.

N. C. Mondal, V. S. S., D. V. Sarwade , M. V. Nandakumar. (2009). Appraisal of groundwater resources in an island condition. Journal Earth System Science, 118(3), 12.

Nam Bo Geological Corporation (NAGECO) (1997) . Report vertical electric sounding (VES), exploration drilling and soil investigation drilling in the Archipelagos. Ho Chi Minh city, Vietnam.

Nguyen, V. T. et al.(1998). Report of feasibility study of project ”Irrigation work in Con Dao, Ba Ria-Vung Tau province”.

Oki, D. S. (1997). Geohydrology and Numerical Simulation of the Ground-Water Flow System of Molokai, Hawaii. In W.-R. I. Report (Ed.). U.S. Geological Survey.

Oki, D. S. (2002). Reassessment of Ground-Water Recharge and Simulated Ground-Water Availability for the Hawi Area of North Kohala, Hawaii. In W.-R. I. Report (Ed.), (Vol. 02). U.S. Geological Survey.

Radmanesh F., P. H. J., Behnia A., Khond A., Ali Mohamad B. (2006). Calibration and assessment of HEC-HMS model in Roodzard watershed. Paper presented at the 17th international conference of river engineering, University of Shahid Chamran, Ahvaz. .

Res hma T, V. n. R. d. K., Deva Pratap. (2013). Simulation of Event Based Runoff Using HEC-HMS Model For an Experimental Watershed. International Journal of Hydraulic Engineering, 2(3), 42-46.

Rodgers P., Soulsby C., Petry J. , Malcolm I. , Gibbins C., & Dunn S. . (2004). Groundwater–surface-water interactions in a braided river: a tracer-based assessment. Hydrol. Process, 18, 1315–1332.

Rodriguez Leticia B. , C. P. A., Vionnet Carlos A., Goodrich David. (2008). Fully conservative coupling of HEC-RAS with MODFLOW to simulate stream–aquifer interactions in a drainage basin. Journal of Hydrology, 353(1–2), 129-142. doi: http://dx.doi.org/10.1016/j.jhydrol.2008.02.002

Sanz, D., Castaño, S., Cassiraga, E., Sahuquillo, A., Gómez-Alday, J., Peña, S., & Calera, A. (2011). Modeling aquifer–river interactions under the influence of groundwater abstraction in the Mancha Oriental System (SE Spain). Hydrogeology Journal, 19(2), 475-487. doi: 10.1007/s10040-010-0694-x

Scanlon, B. R., Mace, R. E., Barrett, M. E., & Smith, B. (2003). Can we simulate regional groundwater flow in a karst system using equivalent porous media models? Case study, Barton Springs Edwards aquifer, USA. Journal of Hydrology, 276(1–4), 137-158. doi: http://dx.doi.org/10.1016/S0022-1694(03)00064-7

Skaggs, R. W., & Khaleel, R. (1982). Infiltration, Hydrologic modeling of small watersheds. American Society of Agricultural Engineers, St. Joseph, MI.

USACE-HEC. (2000). Hydrologic Modeling System HEC-HMS Technical Reference Manual: US Army Corps of Engineers, Hydrologic Engineering Center.

USACE-HEC. (2013). Hydrologic Modeling System, HEC-HMS v4.0 User’s Manual: US Army Corps of Engineers, Hydrologic Engineering Center.

Wa’il Y., A. E. S. r., Randa, I. Hatamleh. (2007). Using Modflow and MT3D Groundwater Flow and Transport Models As a Management Tool for the Azraq Groundwater System. Jordan Journal of Civil Engineering ,, 1(No. 2), 153-172.

Zume, J., & Tarhule, A. (2008). Simulating the impacts of groundwater pumping on stream–aquifer dynamics in semiarid northwestern Oklahoma, USA. Hydrogeology Journal, 16(4), 797-810. doi: 10.1007/s10040-007-0268-8

APPENDIX

APPENDIX A

Surface water budget in Lake 2

APPENDIX A

Surface water budget in Lake 2

Time	In flow (m^3)	Storage (m^3)	Recharge (m^3)	Out flow (m^3)
01/2013 - 05/2013	0	0	163,000	0
06/2013 - 12/2013	1,754,266	218,000	448,811	1,087,454
01/2014 - 05/2014	0	0	218,000	0
06/2014 - 12/2014	1838160	218,000	478,196	1,141,964
01/2015 - 05/2015	0	0	218,000	0
06/2015 - 12/2015	1,626,566	218,000	542,553	866,014
01/2016 - 05/2016	0	0	218,000	0
06/2016 - 12/2016	2,199,053	218,000	605,852	1,375,201
01/2017 - 05/2017	0	0	218,000	0
06/2017 - 12/2017	1,627,344	218,000	661,103	748,241
01/2018 - 05/2018	0	0	218,000	0
06/2018 - 12/2018	1,612,224	218,000	718,252	675,972
01/2019 - 05/2019	0	0	218,000	0
06/2019 - 12/2019	1,774,310	218,000	777,530	778,780
01/2020 - 05/2020	0	0	218,000	0
06/2020 - 12/2020	1,971,475	218,000	887,557	865,919
01/2021 - 05/2021	0	0	218,000	0
06/2021 - 12/2021	1,266,192	218,000	898,542	149,650
01/2022 - 05/2022	0	0	218,000	0

06/2022 - 12/2022	1,585,613	218,000	892,056	475,556
01/2023 - 05/2023	0	0	218,000	0
06/2023 - 12/2023	1,646,093	218,000	867,171	560,921
01/2024 - 05/2024	0	0	218,000	0
06/2024 - 12/2024	1,957,306	218,000	926,554	812,752
01/2025 - 05/2025	0	0	218,000	0
06/2025 - 12/2025	1,732,406	218,000	945,798	568,609
01/2026 - 05/2026	0	0	218,000	0
06/2026 - 12/2026	1,353,370	218,000	899,865	235,505
01/2027 - 05/2027	0	0	21,800	0
06/2027 - 12/2027	1,679,875	218,000	935,002	526,873
01/2028 - 05/2028	0	0	21,800	0
06/2028 - 12/2028	1,014,768	103,900	856,265	54,603
01/2029 - 05/2029	0	0	158,900	0
06/2029 - 12/2029	1,176,854	109,218	989,214	78,422

APPENDIX B

Groundwater budget in Con Son Island

APPENDIX B

Groundwater budget in Con Son Island

Time	Storage (m^3)	Recharge from 2 lakes & channels (m^3/month)	Well (m^3/month)	Rainfall (m^3/month)	Flow to sea (m^3/month)
1/1/2013	713	98,043	77,655	9,508	30,608
2/1/2013	419	110,567	89,280	1,426	23,132
3/1/2013	301	103,051	84,840	0	18,512
4/1/2013	252	123,378	105,090	0	18,540
5/1/2013	101	115,584	100,350	1,932	17,267
6/1/2013	1,346	72,560	103,695	104,299	74,511
7/1/2013	240	69,968	96,750	93,850	67,308
8/1/2013	263	76,000	101,370	98,785	73,679
9/1/2013	514	108,527	102,765	33,847	40,124
10/1/2013	906	75,889	101,700	119,797	94,893
11/1/2013	290	67,933	101,835	152,694	119,082
12/1/2013	1,074	99,886	93,600	33,676	41,036
1/1/2014	95	92,826	88,815	38,506	42,612
2/1/2014	1,022	120,573	100,440	0	21,155
3/1/2014	487	109,446	95,340	0	14,593
4/1/2014	8,445	50,788	118,575	570	-58,771
5/1/2014	228	44,972	112,950	13,802	-53,948
6/1/2014	3,600	31,070	116,715	72,449	-9,597
7/1/2014	805	39,410	108,900	38,644	-30,041
8/1/2014	7,128	83,763	113,925	119,131	96,098
9/1/2014	1,143	74,858	115,320	182,072	142,753
10/1/2014	873	103,874	114,300	72,688	63,135
11/1/2014	364	92,918	114,390	110,384	89,276
12/1/2014	899	108,105	105,300	37,724	41,429
1/1/2015	720	114,663	99,510	7,796	23,670
2/1/2015	835	125,020	111,600	1,902	16,156

Time	Storage (m^3)	Recharge from 2 lakes & channels (m^3/month)	Well (m^3/month)	Rainfall (m^3/month)	Flow to sea (m^3/month)
3/1/2015	8,206	45,567	105,840	0	-52,067
4/1/2015	1,966	56,116	131,595	285	-73,228
5/1/2015	118	54,136	125,550	0	-71,296
6/1/2015	369	53,129	129,270	6,465	-69,307
7/1/2015	8,707	75,881	121,050	74,436	37,975
8/1/2015	2,136	102,342	126,480	72,544	50,542
9/1/2015	1,511	96,839	128,340	132,157	102,166
10/1/2015	330	106,041	126,900	94,310	73,781
11/1/2015	401	100,984	126,945	122,935	97,374
12/1/2015	1,013	123,238	116,550	31,007	38,708
1/1/2016	226	105,676	110,670	54,764	49,996
2/1/2016	1,069	134,303	122,760	11,029	23,641
3/1/2016	787	127,000	120,495	7,827	15,119
4/1/2016	10,024	56,941	144,615	4,088	-73,561
5/1/2016	10,586	102,856	138,150	92,654	67,946
6/1/2016	673	111,046	142,290	88,136	57,565
7/1/2016	1,105	102,109	133,200	117,129	87,143
8/1/2016	268	121,251	139,500	94,887	76,905
9/1/2016	98	119,071	140,895	103,729	82,003
10/1/2016	328	123,999	139,500	79,037	63,863
11/1/2016	802	103,193	139,500	159,254	123,749
12/1/2016	1,303	132,656	128,250	34,044	39,753
1/1/2017	235	128,172	121,830	28,143	34,719
2/1/2017	1,158	149,130	133,920	951	17,318
3/1/2017	9,795	53,191	127,260	1,202	-63,071
4/1/2017	2,707	63,976	157,635	95	-90,857
5/1/2017	175	61,507	150,750	3,220	-85,848
6/1/2017	4,235	46,982	155,310	60,849	-43,243

Time	Storage (m^3)	Recharge from 2 lakes & channels (m^3/month)	Well (m^3/month)	Rainfall (m^3/month)	Flow to sea (m^3/month)
7/1/2017	1,179	45,826	144,900	61,923	-35,972
8/1/2017	6,671	129,229	152,055	60,089	43,934
9/1/2017	1,152	126,330	153,915	81,671	55,238
10/1/2017	785	123,890	152,550	102,775	74,900
11/1/2017	997	110,460	152,520	177,128	136,065
12/1/2017	1,311	137,000	139,950	48,213	46,575
1/1/2018	432	137,738	132,990	26,431	31,611
2/1/2018	1,053	156,165	145,080	6,180	18,318
3/1/2018	10,692	56,196	137,760	515	-70,356
4/1/2018	1,734	63,804	170,655	13,596	-91,522
5/1/2018	2,201	52,006	162,900	42,233	-66,461
6/1/2018	9,027	142,048	168,330	53,719	36,464
7/1/2018	2,669	116,409	157,050	126,882	88,910
8/1/2018	546	157,308	164,610	52,102	45,347
9/1/2018	282	145,629	166,470	77,963	57,404
10/1/2018	552	152,848	165,150	49,777	38,028
11/1/2018	928	136,453	165,075	104,680	76,986
12/1/2018	179	125,094	151,650	104,339	77,962
1/1/2019	1,600	161,934	143,685	570	20,419
2/1/2019	6,568	111,061	156,240	0	-38,611
3/1/2019	6,319	59,019	148,260	0	-82,921
4/1/2019	2,279	71,379	184,140	0	-110,482
5/1/2019	265	67,316	175,500	3,956	-103,962
6/1/2019	4,015	54,443	180,885	55,905	-66,522
7/1/2019	11,925	130,458	169,200	132,034	105,217
8/1/2019	344	154,863	177,165	82,337	60,379
9/1/2019	1,051	139,299	179,490	153,549	114,409
10/1/2019	479	148,197	177,750	109,860	80,786

Time	Storage (m^3)	Recharge from 2 lakes & channels (m^3/month)	Well (m^3/month)	Rainfall (m^3/month)	Flow to sea (m^3/month)
11/1/2019	365	166,425	177,630	67,315	56,474
12/1/2019	571	162,511	163,350	35,976	35,708
1/1/2020	983	170,863	154,845	1,236	18,237
2/1/2020	11,853	68,308	167,400	0	-87,240
3/1/2020	2,114	65,092	164,430	356	-96,869
4/1/2020	1,806	73,387	197,160	3,708	-118,259
5/1/2020	69	70,199	188,100	3,496	-114,336
6/1/2020	6,591	50,074	193,905	91,274	-45,966
7/1/2020	8,360	167,125	181,350	42,233	36,367
8/1/2020	2,533	148,068	189,720	133,488	94,369
9/1/2020	367	163,276	192,045	105,250	76,848
10/1/2020	684	153,083	190,350	143,628	107,045
11/1/2020	50	150,287	190,185	152,313	112,465
12/1/2020	1,154	174,911	175,050	39,380	40,395
1/1/2021	861	177,683	166,005	8,937	21,476
2/1/2021	11,952	70,160	167,400	0	-85,288
3/1/2021	1,992	65,575	158,760	0	-91,193
4/1/2021	2,472	74,766	197,160	0	-119,922
5/1/2021	88	70,769	188,100	1,840	-115,402
6/1/2021	15,988	183,466	193,905	57,997	63,546
7/1/2021	1,373	152,438	181,350	97,531	69,992
8/1/2021	135	166,563	189,720	83,858	60,836
9/1/2021	545	164,174	192,045	108,007	80,681
10/1/2021	1,281	199,123	190,350	16,102	26,156
11/1/2021	1,059	164,414	190,185	97,169	72,457
12/1/2021	1,429	180,240	175,050	16,194	22,813
1/1/2022	10,896	67,039	166,005	9,983	-78,087
2/1/2022	2,151	70,095	167,400	0	-95,154

Time	Storage (m^3)	Recharge from 2 lakes & channels (m^3/month)	Well (m^3/month)	Rainfall (m^3/month)	Flow to sea (m^3/month)
3/1/2022	1,274	62,958	158,760	0	-94,528
4/1/2022	11,981	195,491	197,160	18,540	28,852
5/1/2022	12,563	70,200	188,100	0	-105,337
6/1/2022	14,103	176,301	193,905	58,187	54,686
7/1/2022	962	163,152	181,350	53,642	36,406
8/1/2022	1,058	144,756	189,720	133,583	89,677
9/1/2022	422	172,848	192,045	82,242	63,467
10/1/2022	152	180,610	190,350	60,543	50,955
11/1/2022	274	163,368	190,185	100,116	73,573
12/1/2022	440	167,837	175,050	53,274	46,501
1/1/2023	411	151,485	166,005	76,822	62,714
2/1/2023	1,411	183,724	167,400	2,377	20,112
3/1/2023	12,567	63,594	158,760	0	-82,599
4/1/2023	3,188	74,905	197,160	2,377	-116,690
5/1/2023	1,498	66,143	188,100	21,898	-98,560
6/1/2023	14,712	169,916	193,905	89,277	80,001
7/1/2023	1,109	146,842	181,350	119,705	86,307
8/1/2023	193	162,633	189,720	101,732	74,838
9/1/2023	131	161,698	192,045	108,198	77,982
10/1/2023	228	159,903	190,350	110,320	80,101
11/1/2023	607	186,062	190,185	48,870	45,354
12/1/2023	947	184,971	175,050	10,397	21,266
1/1/2024	11,477	67,448	166,005	5,419	-81,661
2/1/2024	919	64,899	167,400	12,645	-88,937
3/1/2024	1,557	65,105	164,430	2,757	-95,011
4/1/2024	8,065	157,568	197,160	19,301	-12,226
5/1/2024	6,078	165,702	188,100	69,192	52,871
6/1/2024	125	168,145	193,905	69,406	43,771

Time	Storage (m^3)	Recharge from 2 lakes & channels (m^3/month)	Well (m^3/month)	Rainfall (m^3/month)	Flow to sea (m^3/month)
7/1/2024	554	144,277	181,350	103,787	67,269
8/1/2024	709	166,902	189,720	96,883	74,774
9/1/2024	20	168,545	192,045	96,503	73,024
10/1/2024	124	158,997	190,350	111,516	80,287
11/1/2024	149	167,429	190,185	94,887	72,281
12/1/2024	155	158,532	175,050	76,552	60,189
1/1/2025	1,583	182,186	166,005	0	17,764
2/1/2025	11,675	69,899	167,400	190	-85,637
3/1/2025	2,081	64,298	158,760	515	-91,866
4/1/2025	2,391	74,391	197,160	0	-120,378
5/1/2025	1,616	64,486	188,100	22,450	-99,547
6/1/2025	15,405	173,714	193,905	92,985	88,199
7/1/2025	338	171,665	181,350	44,165	34,817
8/1/2025	941	152,322	189,720	116,184	79,728
9/1/2025	285	169,718	192,045	91,559	69,517
10/1/2025	376	156,813	190,350	121,729	88,568
11/1/2025	177	161,671	190,185	110,099	81,762
12/1/2025	407	167,432	175,050	58,702	51,492
1/1/2026	1,146	179,419	166,005	6,560	21,120
2/1/2026	11,604	71,591	167,400	570	-83,634
3/1/2026	1,577	62,573	158,760	8,845	-85,764
4/1/2026	2,386	72,712	197,160	8,272	-113,790
5/1/2026	581	69,103	188,100	14,078	-104,339
6/1/2026	15,271	174,394	193,905	83,573	79,333
7/1/2026	311	168,576	181,350	43,705	31,242
8/1/2026	1,566	142,355	189,720	156,592	110,793
9/1/2026	978	186,379	192,045	48,489	43,801
10/1/2026	971	158,101	190,350	118,509	87,231

Time	Storage (m^3)	Recharge from 2 lakes & channels (m^3/month)	Well (m^3/month)	Rainfall (m^3/month)	Flow to sea (m^3/month)
11/1/2026	831	183,741	190,185	52,958	47,344
12/1/2026	653	177,053	175,050	23,463	26,118
1/1/2027	7,665	113,172	166,005	0	-45,167
2/1/2027	5,259	68,106	167,400	2,662	-91,373
3/1/2027	1,682	62,831	158,760	0	-94,248
4/1/2027	2,001	73,955	197,160	666	-120,538
5/1/2027	358	69,293	188,100	5,705	-112,745
6/1/2027	10,579	153,650	193,905	28,143	-1,533
7/1/2027	6,339	149,673	181,350	105,167	79,830
8/1/2027	205	159,465	189,720	98,500	68,450
9/1/2027	287	179,892	192,045	69,121	57,255
10/1/2027	138	170,826	190,350	83,453	64,067
11/1/2027	724	148,275	190,185	153,549	112,363
12/1/2027	586	153,605	175,050	88,238	67,378
1/1/2028	1,325	179,792	166,005	6,560	21,673
2/1/2028	12,164	68,460	167,400	285	-86,491
3/1/2028	2,196	65,390	164,430	0	-96,844
4/1/2028	13,599	192,998	197,160	41,454	50,891
5/1/2028	482	199,895	188,100	276	12,554
6/1/2028	7,284	107,459	193,905	27,572	-51,589
7/1/2028	9,141	154,635	181,350	93,942	76,368
8/1/2028	355	182,518	189,720	42,499	35,652
9/1/2028	326	164,934	192,045	76,727	49,942
10/1/2028	375	166,441	190,350	81,337	57,803
11/1/2028	529	188,210	190,185	34,418	32,972
12/1/2028	826	175,322	175,050	19,046	20,144
1/1/2029	11,320	67,144	166,005	4,469	-83,072
2/1/2029	971	67,414	167,400	7,511	-91,504

Time	Storage (m^3)	Recharge from 2 lakes & channels (m^3/month)	Well (m^3/month)	Rainfall (m^3/month)	Flow to sea (m^3/month)
3/1/2029	1,684	62,842	158,760	0	-94,234
4/1/2029	1,808	72,997	197,160	3,708	-118,648
5/1/2029	55	70,534	188,100	2,392	-115,118
6/1/2029	16,360	175,055	193,905	78,534	76,044
7/1/2029	135	162,186	181,350	53,550	34,520
8/1/2029	223	168,182	189,720	61,990	40,676
9/1/2029	478	173,377	192,045	49,345	31,156
10/1/2029	1,814	144,003	190,350	149,700	105,168
11/1/2029	942	185,741	190,185	44,211	40,708
12/1/2029	270	158,626	175,050	55,574	39,420

Remark: For flow to sea, positive mean direction of groundwater flow is from aquifer to sea. Negative means salt water go to aquifer.

APPENDIX C

Results of recharge estimation

APPENDIX C
Results of recharge estimation

Recharge from stream estimated by the SW-GW analysis under increasing pumping rate without development plan is show as Table C.1. First, the initial loss/gain from stream in surface is assumed as zero. Second, after simulated groundwater, the loss/gain is re-inputted again by recharge from groundwater modeling. Third, the surface runoffs modeling and groundwater modeling is re-run as loop until the loss/gain in surface simulation equal recharge from groundwater simulation. Due to the results, future pumping rate are not influenced much to recharge in 2 streams.

Table C.1 Recharge and Conductance from 2 streams in Con Son Valley

Time (month)	Stream 1 (m^3/day)	Stream 2 (m^3/day)	Conductance stream 1 (m^2/day/m)	Conductance stream 2 (m^2/day/m)
3/1/2006	0	0	3.03	3.76
4/1/2006	0	0	3.03	3.76
5/1/2006	2	0	3.24	4.02
6/1/2006	120	537	3.6	4.46
7/1/2006	237	794	3.52	4.36
8/1/2006	237	715	3.62	4.49
9/1/2006	280	789	3.72	4.61
10/1/2006	289	871	3.33	4.13
11/1/2006	61	330	3.09	3.83
12/1/2006	0	0	3.06	3.79
1/1/2007	0	0	3.11	3.86
2/1/2007	0	0	3.05	3.78
3/1/2007	0	0	3.03	3.76
4/1/2007	2	44	3.12	3.87
5/1/2007	70	397	3.29	4.08
6/1/2007	73	441	3.52	4.36

7/1/2007	223	742	3.6	4.46
8/1/2007	241	703	3.59	4.45
9/1/2007	245	703	3.66	4.54
10/1/2007	302	841	3.58	4.44
11/1/2007	237	685	3.47	4.3
12/1/2007	191	573	3.03	3.76
1/1/2008	0	0	3.03	3.76
2/1/2008	0	0	3.03	3.76
3/1/2008	0	0	3.03	3.76
4/1/2008	0	0	3.03	3.76
5/1/2008	7	21	3.24	4.02
6/1/2008	121	537	3.23	4.01
7/1/2008	38	290	3.6	4.46
8/1/2008	326	928	3.51	4.35
9/1/2008	159	555	3.75	4.65
10/1/2008	365	984	3.67	4.55
11/1/2008	279	796	3.4	4.22
12/1/2008	110	401	3.07	3.81
1/1/2009	0	0	3.03	3.76
2/1/2009	0	0	3.08	3.82
3/1/2009	0	0	3.03	3.76
4/1/2009	0	0	3.03	3.76
5/1/2009	0	0	3.19	3.96
6/1/2009	88	486	3.23	4.01
7/1/2009	35	272	3.76	4.66
8/1/2009	389	1108	3.3	4.09
9/1/2009	51	363	3.68	4.56
10/1/2009	305	887	3.38	4.19

11/1/2009	41	323	3.17	3.93
12/1/2009	11	175	3.03	3.76
1/1/2010	0	0	3.05	3.78
2/1/2010	0	0	3.03	3.76
3/1/2010	0	0	3.03	3.76
4/1/2010	0	0	3.03	3.76
5/1/2010	0	0	3.03	3.76
6/1/2010	10	20	3.34	4.14
7/1/2010	126	518	3.49	4.33
8/1/2010	119	530	3.42	4.24
9/1/2010	99	474	3.47	4.3
10/1/2010	155	613	3.9	4.84
11/1/2010	289	851	3.56	4.41
12/1/2010	105	491	3.06	3.79
1/1/2011	0	0	3.03	3.76
2/1/2011	0	0	3.03	3.76
3/1/2011	0	0	3.04	3.77
4/1/2011	0	0	3.03	3.76
5/1/2011	0	0	3.05	3.78
6/1/2011	8	26	3.37	4.18
7/1/2011	108	561	3.22	3.99
8/1/2011	28	233	3.42	4.24
9/1/2011	88	501	3.51	4.35
10/1/2011	109	559	3.25	4.03
11/1/2011	22	222	3.14	3.89
12/1/2011	4	125	3.05	3.78
1/1/2012	0	0	3.07	3.81
2/1/2012	0	0	3.03	3.76

3/1/2012	0	0	3.03	3.76
4/1/2012	0	0	3.03	3.76
5/1/2012	0	0	3.13	3.88
6/1/2012	70	301	3.18	3.94
7/1/2012	55	330	3.36	4.17
8/1/2012	48	361	3.29	4.08
9/1/2012	29	275	3.83	4.75
10/1/2012	349	1098	3.23	4.01
11/1/2012	17	190	3.35	4.15
12/1/2012	55	364	3.09	3.83
1/1/2013	0	0	3.03	3.76
2/1/2013	0	0	3.03	3.76
3/1/2013	0	0	3.03	3.76
4/1/2013	0	0	3.03	3.76
5/1/2013	0	0	3.21	3.98
6/1/2013	91	429	3.48	4.32
7/1/2013	89	464	3.52	4.36
8/1/2013	110	534	3.23	4.01
9/1/2013	21	175	3.61	4.48
10/1/2013	208	806	3.87	4.8
11/1/2013	308	1040	3.29	4.08
12/1/2013	25	213	3.27	4.05
1/1/2014	24	202	3.03	3.76
2/1/2014	0	0	3.03	3.76
3/1/2014	0	0	3.03	3.76
4/1/2014	0	0	3.12	3.87
5/1/2014	0	0	3.41	4.23
6/1/2014	6	19	3.33	4.13

7/1/2014	0	0	3.79	4.7
8/1/2014	124	595	3.96	4.91
9/1/2014	401	1252	3.5	4.34
10/1/2014	85	496	3.66	4.54
11/1/2014	189	751	3.26	4.04
12/1/2014	25	213	3.08	3.82
1/1/2015	0	14	3.04	3.77
2/1/2015	0	3	3.03	3.76
3/1/2015	0	0	3.03	3.76
4/1/2015	0	0	3.03	3.76
5/1/2015	0	0	3.06	3.79
6/1/2015	0	0	3.47	4.3
7/1/2015	30	42	3.45	4.28
8/1/2015	48	179	3.74	4.64
9/1/2015	206	870	3.6	4.46
10/1/2015	102	616	3.8	4.71
11/1/2015	210	847	3.26	4.04
12/1/2015	19	188	3.28	4.07
1/1/2016	41	283	3.08	3.82
2/1/2016	0	12	3.1	3.84
3/1/2016	0	6	3.05	3.78
4/1/2016	0	0	3.6	4.46
5/1/2016	53	226	3.57	4.43
6/1/2016	63	289	3.68	4.56
7/1/2016	147	738	3.67	4.55
8/1/2016	125	636	3.64	4.51
9/1/2016	153	692	3.53	4.38
10/1/2016	82	507	3.89	4.82

11/1/2016	334	1083	3.3	4.09
12/1/2016	22	200	3.21	3.98
1/1/2017	12	117	3.04	3.77
2/1/2017	0	4	3.04	3.77
3/1/2017	0	0	3.03	3.76
4/1/2017	0	0	3.05	3.78
5/1/2017	0	0	3.4	4.22
6/1/2017	0	0	3.45	4.28
7/1/2017	0	9	3.44	4.27
8/1/2017	19	92	3.5	4.34
9/1/2017	55	261	3.67	4.55
10/1/2017	100	605	4.03	5
11/1/2017	362	1231	3.39	4.2
12/1/2017	36	286	3.2	3.97
1/1/2018	9	75	3.07	3.81
2/1/2018	0	7	3.03	3.76
3/1/2018	0	0	3.11	3.86
4/1/2018	0	0	3.29	4.08
5/1/2018	0	0	3.38	4.19
6/1/2018	4	31	3.78	4.69
7/1/2018	118	639	3.37	4.18
8/1/2018	33	233	3.51	4.35
9/1/2018	61	370	3.38	4.19
10/1/2018	24	139	3.66	4.54
11/1/2018	98	604	3.62	4.49
12/1/2018	109	666	3.03	3.76
1/1/2019	0	8	3.03	3.76
2/1/2019	0	0	3.03	3.76

3/1/2019	0	0	3.03	3.76
4/1/2019	0	0	3.06	3.79
5/1/2019	0	0	3.36	4.17
6/1/2019	0	0	3.78	4.69
7/1/2019	121	620	3.52	4.36
8/1/2019	65	417	3.91	4.85
9/1/2019	248	1035	3.71	4.6
10/1/2019	114	727	3.46	4.29
11/1/2019	55	396	3.26	4.04
12/1/2019	15	137	3.04	3.77
1/1/2020	0	6	3.03	3.76
2/1/2020	0	0	3.03	3.76
3/1/2020	0	0	3.05	3.78
4/1/2020	0	0	3.05	3.78
5/1/2020	0	0	3.59	4.45
6/1/2020	0	9	3.31	4.1
7/1/2020	2	28	3.81	4.72
8/1/2020	135	708	3.65	4.53
9/1/2020	98	636	3.91	4.85
10/1/2020	244	1013	3.94	4.89
11/1/2020	255	1038	3.29	4.08
12/1/2020	28	217	3.09	3.83
1/1/2021	0	12	3.03	3.76
2/1/2021	0	0	3.03	3.76
3/1/2021	0	0	3.03	3.76
4/1/2021	0	0	3.04	3.77
5/1/2021	0	0	3.39	4.2
6/1/2021	18	46	3.63	4.5

7/1/2021	82	529	3.55	4.4
8/1/2021	63	426	3.7	4.59
9/1/2021	104	682	3.15	3.91
10/1/2021	0	46	3.62	4.49
11/1/2021	85	552	3.14	3.89
12/1/2021	0	18	3.1	3.84
1/1/2022	0	0	3.03	3.76
2/1/2022	0	0	3.03	3.76
3/1/2022	0	0	3.14	3.89
4/1/2022	0	4	3.03	3.76
5/1/2022	0	0	3.4	4.22
6/1/2022	11	40	3.36	4.17
7/1/2022	20	88	3.79	4.7
8/1/2022	120	666	3.55	4.4
9/1/2022	67	471	3.45	4.28
10/1/2022	46	348	3.64	4.51
11/1/2022	89	588	3.38	4.19
12/1/2022	34	279	3.49	4.33
1/1/2023	65	457	3.05	3.78
2/1/2023	0	7	3.03	3.76
3/1/2023	0	0	3.04	3.77
4/1/2023	0	0	3.18	3.94
5/1/2023	0	0	3.54	4.39
6/1/2023	52	237	3.76	4.66
7/1/2023	115	755	3.63	4.5
8/1/2023	94	618	3.65	4.53
9/1/2023	109	651	3.75	4.65
10/1/2023	108	715	3.36	4.17

11/1/2023	30	252	3.1	3.84
12/1/2023	0	14	3.06	3.79
1/1/2024	0	0	3.11	3.86
2/1/2024	0	0	3.05	3.78
3/1/2024	0	0	3.15	3.91
4/1/2024	0	0	3.45	4.28
5/1/2024	34	142	3.47	4.3
6/1/2024	35	166	3.64	4.51
7/1/2024	85	446	3.68	4.56
8/1/2024	94	612	3.64	4.51
9/1/2024	95	609	3.7	4.59
10/1/2024	122	710	3.61	4.48
11/1/2024	92	592	3.48	4.32
12/1/2024	71	468	3.03	3.76
1/1/2025	0	6	3.03	3.76
2/1/2025	0	0	3.03	3.76
3/1/2025	0	0	3.03	3.76
4/1/2025	0	0	3.13	3.88
5/1/2025	0	0	3.62	4.49
6/1/2025	62	348	3.32	4.12
7/1/2025	16	103	3.67	4.55
8/1/2025	106	598	3.6	4.46
9/1/2025	84	552	3.76	4.66
10/1/2025	159	802	3.72	4.61
11/1/2025	116	709	3.44	4.27
12/1/2025	51	363	3.07	3.81
1/1/2026	0	11	3.04	3.77
2/1/2026	0	0	3.08	3.82

3/1/2026	0	0	3.1	3.84
4/1/2026	0	0	3.12	3.87
5/1/2026	0	0	3.54	4.39
6/1/2026	47	223	3.33	4.13
7/1/2026	12	57	3.9	4.84
8/1/2026	182	922	3.35	4.15
9/1/2026	26	227	3.74	4.64
10/1/2026	133	779	3.42	4.24
11/1/2026	32	274	3.19	3.96
12/1/2026	1	30	3.03	3.76
1/1/2027	0	0	3.05	3.78
2/1/2027	0	0	3.03	3.76
3/1/2027	0	0	3.03	3.76
4/1/2027	0	0	3.07	3.81
5/1/2027	0	0	3.2	3.97
6/1/2027	0	0	3.72	4.61
7/1/2027	90	495	3.62	4.49
8/1/2027	80	513	3.49	4.33
9/1/2027	53	403	3.52	4.36
10/1/2027	72	508	3.95	4.9
11/1/2027	218	1028	3.59	4.45
12/1/2027	84	552	3.07	3.81
1/1/2028	0	12	3.03	3.76
2/1/2028	0	0	3.03	3.76
3/1/2028	0	0	3.28	4.07
4/1/2028	2	24	3.03	3.76
5/1/2028	0	1	3.17	3.93
6/1/2028	0	0	3.58	4.44

7/1/2028	66	373	3.31	4.1
8/1/2028	15	104	3.51	4.35
9/1/2028	49	241	3.56	4.41
10/1/2028	63	397	3.28	4.07
11/1/2028	11	88	3.16	3.92
12/1/2028	0	18	3.06	3.79
1/1/2029	0	0	3.08	3.82
2/1/2029	0	0	3.03	3.76
3/1/2029	0	0	3.04	3.77
4/1/2029	0	0	3.06	3.79
5/1/2029	0	0	3.53	4.38
6/1/2029	42	153	3.31	4.1
7/1/2029	21	84	3.49	4.33
8/1/2029	28	134	3.36	4.17
9/1/2029	13	69	3.92	4.86
10/1/2029	167	902	3.25	4.03
11/1/2029	24	183	3.38	4.19
12/1/2029	32	151	3.1	3.84

APPENDIX D

Determination of salt water interface length

APPENDIX D

Determination of salt water interface length

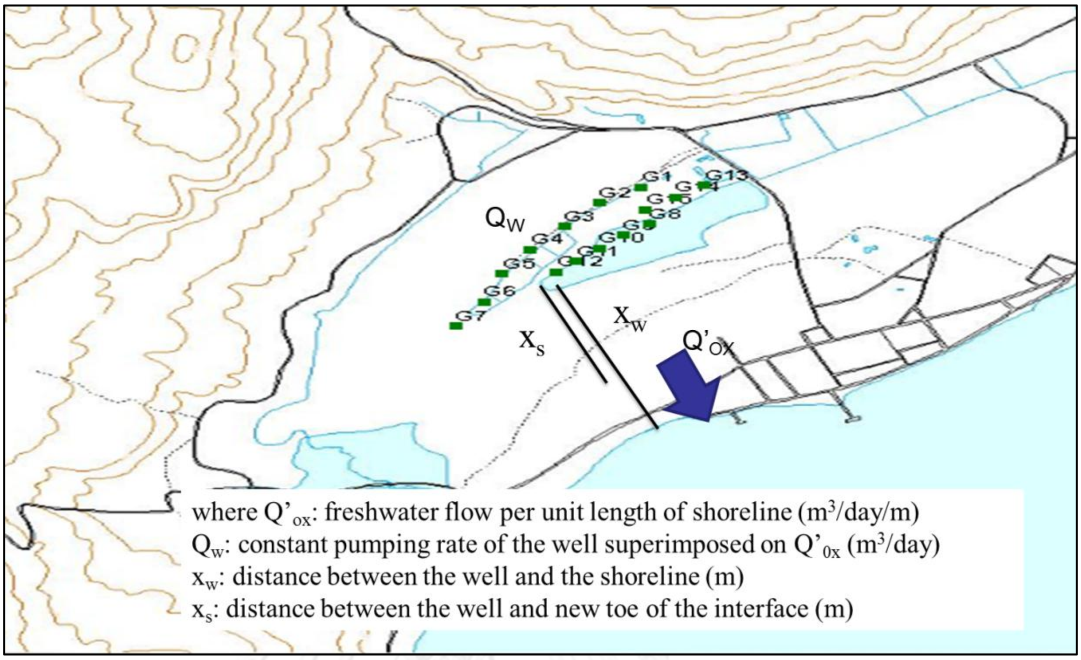


Figure D.1 Map of salt intrusion length and sea level 0.7 m MSL

According to the equation Eq 4.20, the length of salt interfaces are determined as the follow table:

Table D.1 Length of salt interface

	X_w(m)	Q_w(m^3/day/m)	Q_{ox}(m^3/day/m)	X_s (m)
5/1/2006	1000	106	0.38	934
8/1/2006	1000	106	0.59	953
5/1/2007	1000	115	0.5	942
8/1/2007	1000	114	0.59	950
5/1/2008	1000	126	0.34	918
8/1/2008	1000	125	0.65	950
5/1/2009	1000	144	0.34	911
8/1/2009	1000	142	0.7	948
5/1/2010	1000	163	0.28	891
8/1/2010	1000	161	0.52	928

	X_w(m)	Q_w(m^3/day/m)	Q_{ox}(m^3/day/m)	X_s (m)
5/1/2011	1000	174	0.31	894
8/1/2011	1000	172	0.45	917
5/1/2012	1000	195	0.25	870
8/1/2012	1000	193	0.5	916
5/1/2013	1000	223	0.27	934
4/1/2014	1000	255	0	0
6/1/2015	1000	278	0	0
4/1/2016	1000	311	0	0
5/1/2017	1000	335	0	0
5/1/2018	1000	362	0	0
5/1/2019	1000	390	0	0
5/1/2020	1000	418	0	0
5/1/2021	1000	418	0	0
5/1/2022	1000	418	0	0
5/1/2023	1000	418	0	0
4/1/2024	1000	424	0	0
4/1/2025	1000	424	0	0
5/1/2026	1000	418	0	0
5/1/2027	1000	418	0	0
5/1/2028	1000	418	0	0
5/1/2029	1000	418	0	0

APPENDIX E

Some groundwater level results of water development alternatives

APPENDIX E

Some groundwater level results of water development alternatives

In this section, results piezometric of some water development alternatives are performed as follow figures.

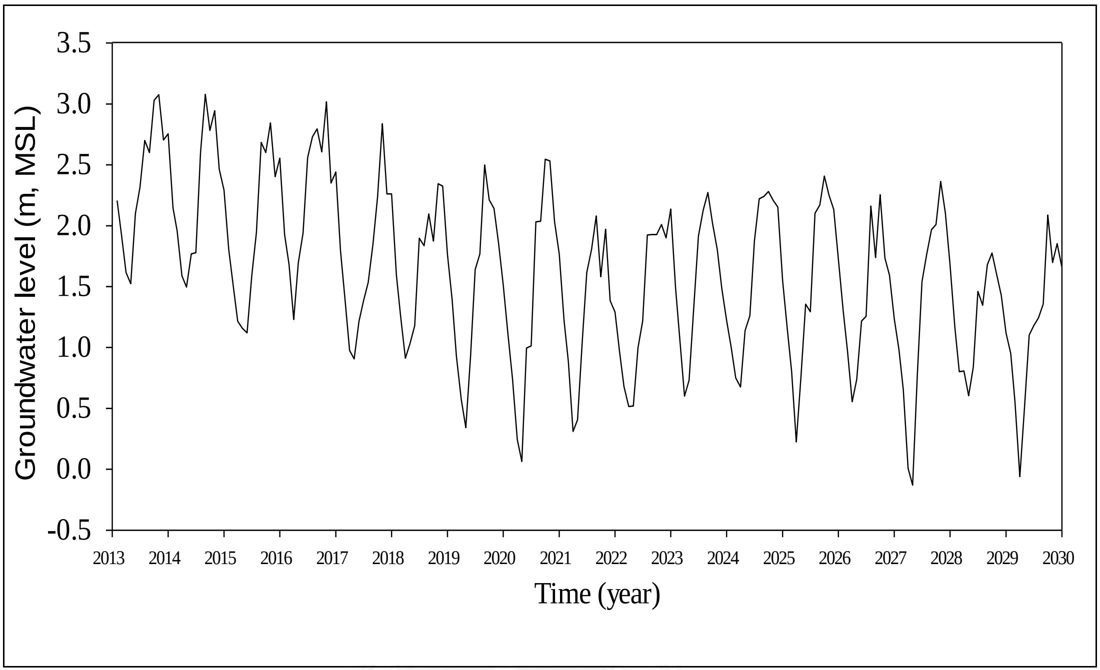


Figure E.1 Groundwater level of alternative: combined expanding Lake 2 as 400 00 m^3 and 5 addition wells

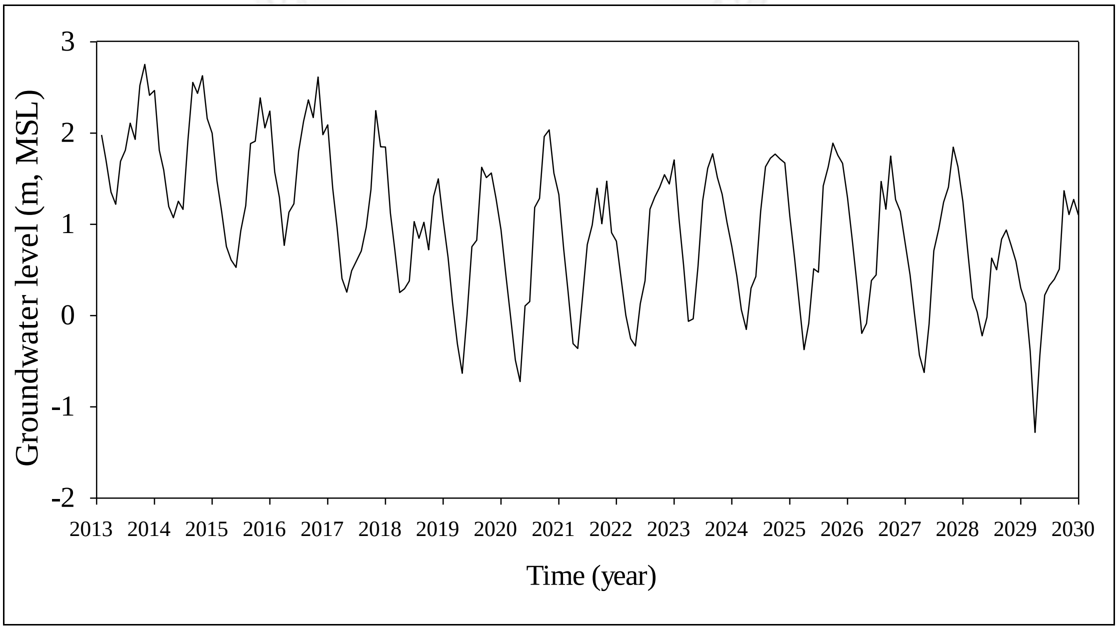


Figure E.2 Groundwater level of alternative: combined expanding Lake 2 as 267 000 m^3 and 5 addition wells

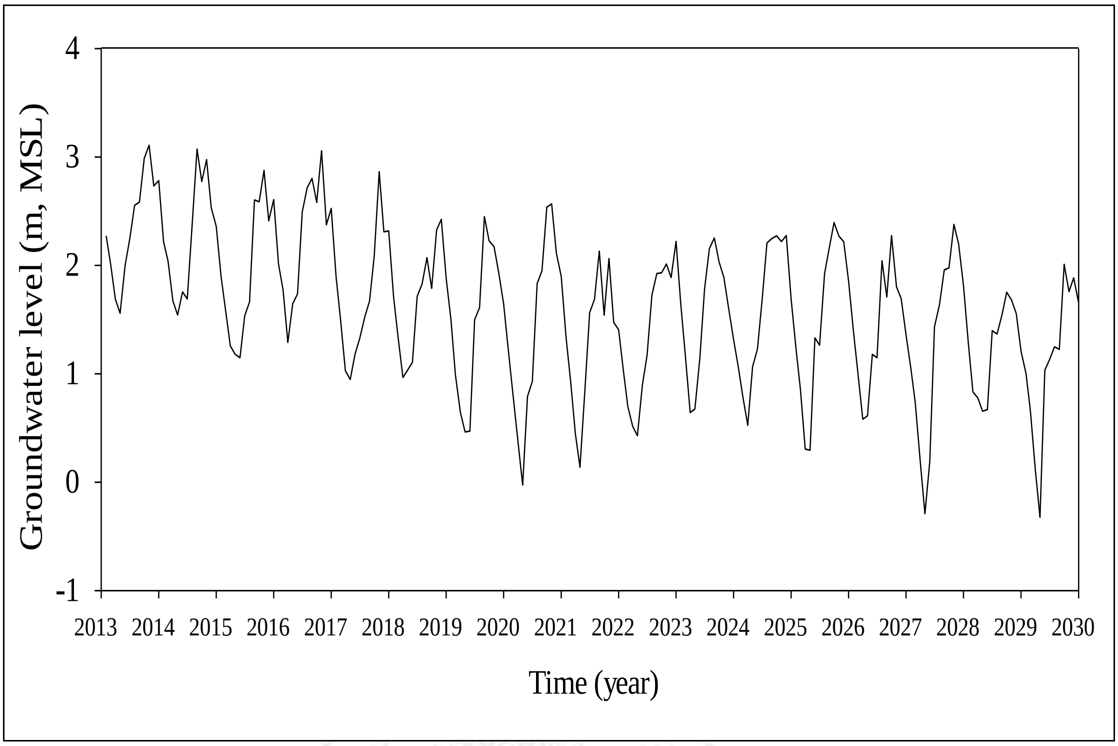


Figure E.3 Groundwater level of alternative: combined expanding Lake 2 as 400 000 m^3 and 10 addition wells

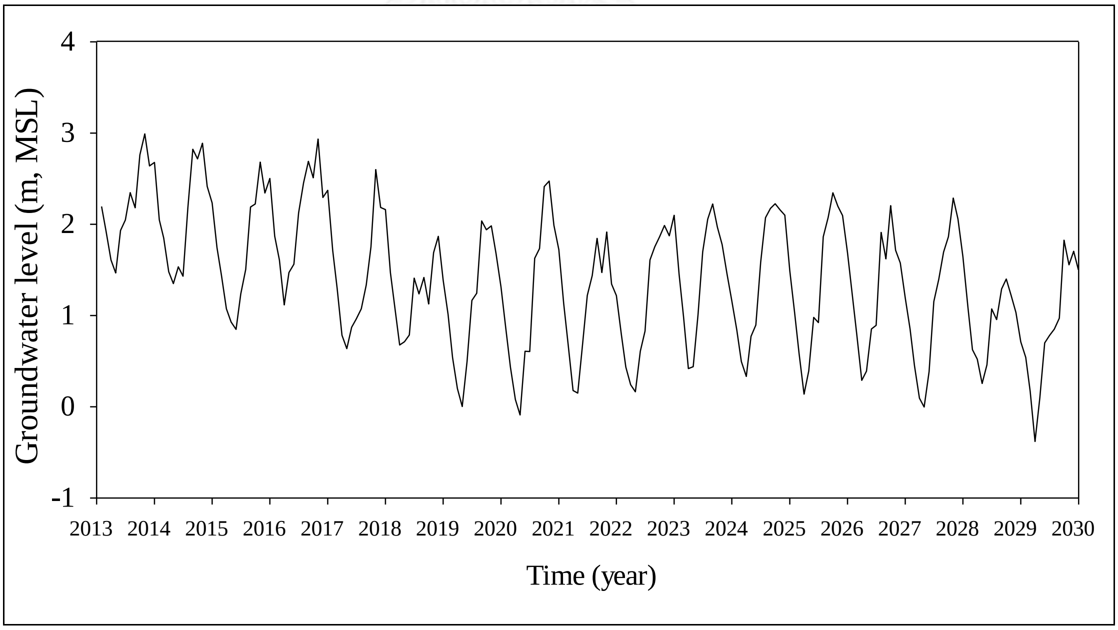


Figure E.4 Groundwater level of alternative: combined expanding Lake 2 as 267 000 m^3 and 10 addition wells

APPENDIX F

Construction cost of water development alternative

APPENDIX F

Construction cost of water development alternatives

Table F.1 The construction cost of enlarge lake

	Unit	Price/Unit		
		Material (VNĐ)	Labor (VNĐ)	Vehicles (VNĐ)
Build road to construct lake	100m^3	1,500,000	650,000	4,500,000
Excavate soil to build lake				
- Clear surface area	100m^2		85,500	45,500
- Excavate soil to build lake	100m^3		650,000	815,000
- Backfill soil in the bottom lake (Depth 0.5m)	100m^3	2,200,000	250,000	172,000
- Release water to keep lake dry	Hours			110,000
- Embankment	100m^3		700,000	890,000

Table F.2 The BOQ of enlarge lake 180 000m^3

	Unit	Quantity
Build road to construct lake	100m^3	94
Excavate soil to build lake		
- Clear surface area	100m^2	1830
- Excavate soil to build lake	100m^3	2745
- Backfill soil in the bottom lake (Depth 0.5m)	100m^3	915
- Release water to keep lake dry	Hours	8000
- Embankment	100m^3	5.4

Table F.3 Well construction cost

Calculation for 01 well Cash unit: đồng

No.	Content	Unit	Quantity	Cost (đồng/unit)	Total
I	Construction				187,322,364
1	Drilling	đồng			77,998,462
1.1	Drilling open hole Φ 130mm from 0 to 23,5m.	m	23.5	1,582,998	37,200,450
1.2	Drilling under ream Φ 450mm from 0 to 23,5m.	m	23.5	1,736,086	40,798,012
2	Supply water for drilling	m	23.5	371,145	8,721,914
4	Well constructure	đồng			1,328,268
	Casting and filter PVC Φ220mm	m	23.0	57,751	1,328,268
5	Well completion				3,057,142
-	Heat jeacket	m^3	4	764,285	3,057,142
6	Pumping	đồng			69,981,013
6.1	Recovery pumping	time	1	19,085,731	19,085,731
6.2	Pumping test	hour	8	6,361,910	50,895,282
7	Sampling	đồng			9,392,646
7.1	Sampling	sample			
-	Overall sampling	sample	1	2,703,187	2,703,187
-	Fe sampling	sample	1	2,162,069	2,162,069
	Microbiological sampling	Sample	1	2,027,390	2,027,390
	Micronutrient sampling	sample	1	2,500,000	2,500,000
8	Material and equipment	đồng			16,842,920
-	Casting PVC Φ220 thickness 8,7mm	m	7.8	367,800	2,868,840
-	Filter PVC inox Φ220	m	2	662,040	1,324,080
-	Cover PVC D220mm	item	1	350,000	350,000
-	Bottom valve PVC D220mm	item	1	550,000	550,000
-	Cement platform (0,8mm x 0,8mm x 0,5mm)	item	1	1,300,000	1,300,000

-	Cementation	ton	1.2	2,000,000	2,400,000
-	Gravel	m^3	4	1,650,000	6,600,000
-	Pumping machine	item	1	1,450,000	1,450,000
II	Delivery material and equipment	đồng			8,000,000
III	Pumping operation cost	đồng			2,217,600
-	Electricity cost	hour	24	92,400	2,217,600
	Total	đồng			197,539,964

Table F.4 Delivery water cost from main land per month.

	unit	Quality	Price (USD/m^3)	Total (USD)
Transfer water cost from main land in 1 year	1m^3	180000	6.8	1,240,000

Due to the results of groundwater simulation, the insufficient water resources situation has potential to exit in dry season of 17 years. Therefore, the total water cost from mainland is converted to net profit value (NPV) to estimate the total damage of increasing pumping rate without planning. The rate interest in Vietnam is 8%. Hence, the NPV of water cost from mainland is 11,194,738 USD.

APPENDIX G

Pictures during field study

APPENDIX G
Pictures during field study

Figure G.1 Field trip on Januaray 2014 at Lake 1, ConSon Island

Figure G.2 The weir at Lake 2

Figure G.3 Stream from Lake 1 to sea

Figure G.4 the 1stAUN/SEED-Net Regional Conference on Natural Disaster 22-23 January 2014,Universitas Gadjah Mada Yogyakarta, Indonesia

VITA

Name Mr. Tran Thanh Long

Birth date 03 July 1988

Education

2006 Graduate Bachelor Degree of Geology and Petroleum Engineering, Faculty of Geology and Petroleum Engineering, Ho chi minh University of Technology, Viet Nam.

Publications

Long, T. T., & Koontanakulvong, S. (2014). SW-GW Interaction Analysis for Drought Management in Con Son Valley, Con Dao Island, Ba Ria-Vung Tau Province, Vietnam. Proceeding The 1st AUN/SEED-Net Regional Conference on Natural Disaster, Universitas Gadjah Mada, Yogyakarta, Indonesia.