ผลกระทบของการเปลี่ยนแปลงสภาพภูมิอากาศต่อระบบน้ำบาดาลภายใต้การใช้น้ำร่วมกันในที่ราบภาคกลางตอนบน

นายโชคชัย สุทธิธรรมจิต

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรดุษฎีบัณฑิต
สาขาวิชาวิศวกรรมแหล่งน้ำ ภาควิชาวิศวกรรมแหล่งน้ำ
คณะวิศวกรรมศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
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THE IMPACT OF CLIMATE CHANGE ON GROUNDWATER RESOURCES SYSTEM UNDER CONJUNCTIVE USE IN THE UPPER CENTRAL PLAIN

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A Dissertation Submitted in Partial Fulfillment of the Requirements
for the Degree of Doctor of Engineering Program in Water Resources Engineering
Department of Water Resources Engineering
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Thesis Title	THE IMPACT OF CLIMATE CHANGE ON GROUNDWATER RESOURCES SYSTEM UNDER CONJUNCTIVE USE IN THE UPPER CENTRAL PLAIN
By	Mr. Chokchai Suthidhummajit
Field of Study	
Thesis Advisor	Associate Professor Sucharit Koontanakulvong, D.Eng.

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พื้นที่ราบภาคกลางตอนบนของประเทศไทยมีศักยภาพสูงต่อการพัฒนาทางเศรษฐกิจและสังคม ทั้งยังเป็นแหล่งผลผลิตทางการเกษตรโดยเฉพาะข้าวในปริมาณสูง อย่างไรก็ตามในปีที่มีภาวะน้ำแล้ง น้ำที่กักเก็บในเขื่อนมีไม่เพียงพอเพื่อส่งไปยังระบบชล ประทาน เกษตรกรมีความจำเป็นต้องหาแหล่งน้ำเสริมโดยการสูบน้ำบาดาลมาใช้ นอกจากนี้พื้นที่ดังกล่าวยังได้รับผลกระทบจากการเปลี่ยนแปลงภูมิอากาศซึ่งส่งผลต่อปริมาณน้ำต้นทุนในเขื่อนและอาจจะทำให้เกิดการขาดแคลนมากขึ้นในอนาคต การศึกษานี้มีจุดมุ่งหมายเพื่อลักษณะของระบบน้ำบาดาลซึ่งมีบทบาทสำคัญในการใช้น้ำร่วมกับน้ำผิวดิน และศึกษาผลกระทบจากการเปลี่ยนแปลงภูมิอากาศต่อระบบน้ำบาดาล พร้อมทั้งนำเสนอมาตรการการปรับตัวเพื่อบรรเทาภาวะน้ำแล้งในอนาคต

ผลจากการวิเคราะห์ระบบน้ำบาดาลที่เป็นอยู่ในปีปัจจุบันนั้นพบว่า ปัจจัยสำคัญที่มีผลต่อปริมาณกักเก็บน้ำบาดาลได้แก่ปริมาณการเติมน้ำจากผิวดิน(land recharge)เข้าสู่ระบบน้ำบาดาลและการสูบน้ำบาดาลออกจากระบบน้ำบาดาล การศึกษานี้ได้พัฒนาสูตรความสัมพันธ์ระหว่างการเติมน้ำจากผิวดิน กับตัวแปรปริมาณฝนและสภาพภูมิอากาศที่จะเปลี่ยนแปลงไป และสร้างแผนที่แสดงพื้นที่ศักยภาพการสูบน้ำบาดาลซึ่งแบ่งเป็นพื้นที่ศักยภาพต่ำ กลางและสูง

การเปลี่ยนแปลงสภาพภูมิอากาศจะทำให้ค่าเฉลี่ยความต้องการน้ำมีค่าสูงขึ้นและทำให้ปริมาณการใช้น้ำผิวดินและการสูบน้ำบาดาลจะสูงขึ้นตาม อัตราส่วนการใช้น้ำร่วมในฤดูฝนในอนาคตอันใกล้มีค่าเท่ากับปีปัจจุบัน แต่ในอนาคตอันไกลมีค่าลดลงเท่ากับ 14.29% สำหรับฤดูแล้งจะมีค่าเพิ่มขึ้น 23.08% และ 56.41% ในอนาคตอันใกล้และอนาคตอันไกล ค่าอัตราส่วนการใช้น้ำร่วมเฉลี่ยรายปีจะมีค่าเพิ่มขึ้น 6.59%และ 6.18% ในอนาคตอันใกล้และอนาคตอันไกลตามลำดับ มาตรการปรับตัวที่เสนอสามารถลดความเสี่ยงของการขาดแคลนน้ำจากผลกระทบของการเปลี่ยนแปลงสภาพภูมิอากาศได้ ทั้งในอนาคตอันใกล้และอันไกล

ภาควิชา	วิศวกรรมแหล่งน้ำ	ลายมือชื่อนิสิต	....
สาขาวิชา	วิศวกรรมแหล่งน้ำ	ลายมือชื่อ อ.ที่ปรึกษาหลัก	....
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CHOKCHAI SUTHIDHUMMAJIT: THE IMPACT OF CLIMATE CHANGE ON GROUNDWATER RESOURCES SYSTEM UNDER CONJUNCTIVE USE IN THE UPPER CENTRAL PLAIN. ADVISOR: ASSOC. PROF. SUCHARIT KOONTANAKULVONG, D.Eng., 146 pp.

The Upper Central Plain Basin of Thailand has high potential for social and economic development. It is also high-volume source of agricultural products, especially rice. However, in the drought year, water storage in the dams is inadequate to allocate for agriculture, and caused water deficit in many irrigation projects. Farmers need to find extra source of water by pumping the groundwater. This area is also affected from climate change phenomena, which cause significant decrease of the water storage in the dam and may cause further shortage in the future. The objective of this study is to characterize of groundwater system under conjunctive use, to analyze the impact of climate change, and to propose adaptation measures under climate change to alleviate drought in the future. Based on the analysis of groundwater systems in the present period, it was found that significant factors affecting groundwater storage are land recharge and groundwater pumping. The study developed the climate-soil based recharge formula that described the relationship between land recharge and rainfall, climate condition parameters and produced groundwater pumping potential map which classify the study area into 3 zones: low potential, intermediate potential and high potential for future pumping planning.

The study of climate change impact concludes that the average demand, surface water supply and groundwater pumping will increase. The conjunctive use ratio in wet season, in near future will be the same as present, while it will decrease 14.29% in the far future. In dry season, the ratio will increase 23.08% and 45.83%, respectively. The conjunctive use ratio in annual, will increase 6.59% and 6.18%, respectively. The two proposed adaptation measures will reduce drought risk under climate change in the near future and far future.

Department: Water Resources Engineering Student's Signature ....
Field of Study: Water Resources Engineering Advisor's Signature ....
Academic Year: 2016

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LIST OF ABBREVIATIONS

CJ = Conjunctive

DIW = Department of Industrial Works

DGR = Department of Groundwater Resources

DPA = Department of Provincial Administration

DWR = Department of Water Resources

EGAT = Electric Generation Authority of Thailand

GCM = Global Circulation Model

GW = Groundwater

LDD = Land Development Department

MSL = mean sea level

MRI = Meteorological Research Institute, Japan

MWA = Metropolitan Waterworks Authority

OAE = Office of Agricultural Economic

PWA = Provincial Waterworks Authority

RID = Royal Irrigation Department

SW = Surface water

TMD = Thai Meteorological Department

CHAPTER I
INTRODUCTION

1.1. Background and problems

The Upper Central Plain Basin of Thailand has high potential for social and economic development with rapid growth in population. In this basin, irrigated areas have been developed for long time and have high agricultural productivity especially rice. This area is known as the rice bowl of Thailand. The water scarcity has become prevalent in this region, where most of the country's water intensive crops are grown (Poapongsakorn, N., et. al., 1998). The groundwater plays roles in the dry year when the surface water storage amount is not adequate for dry season rice and causes water deficit in irrigation projects. Though in the central plain, there are two big reservoirs stored water for dry season but water allocated is limited, water shortage during dry season, especially in agricultural use. Most of farmers then turn to use groundwater to supplement irrigation water (JIID, 2010).

Climate change phenomena, such as higher temperature, more fluctuated weather shifts of climatic zones, also affected the area. From the GCMs' data, the variation of change in the region for average temperature, precipitation and runoff in the year 2100 are in the range of +1.0 to +4.5 degree Celsius, -20 % to + 20 % and -10 to +30 % respectively (IPCC, 2001). This phenomena will directly affect the water management in basin wide, e.g., irrigation water allocation, and it will induce direct affect to irrigation area, e.g., Yom, Nan Basin or Chao Phraya Basin in the dry year when the storage amount is not adequate for summer rice and will cause more water deficit in many irrigation projects. This will cause more groundwater use too.

AR5 IPCC (2014) mentioned key risks at the global scale. There are comments on groundwater with few studies on groundwater observations. The continental area will be affected by decreases of groundwater resources, increases linearly with global mean temperature rise between 0°C and 3°C. For each degree of temperature rise, an additional 4% of the global land area is projected to suffer a groundwater recharge decrease of more than 30%. In the 3rd UNECWAS Annual Seminar, 2014, the groundwater was mentioned in Theme 2, i.e., groundwater in a changing environment, enhancing sustainable groundwater resources management, addressing strategies for management of aquifers recharge, adapting to the impacts of climate change on aquifer systems, etc.

For the reasons mentioned above, the understandings of the climate change impact on groundwater system under conjunctive use and the adaptation measures to reduce drought risk are necessary for sustainable water management in the study area.

1.2. Objectives of the study

The specific objectives of the study are:

1) To characterize of groundwater system under conjunctive use
2) To analyze the impact of climate change on the groundwater system
3) To propose adaptation measures under climate change to reduce drought risk.

1.3. Methodology and scope of the study

The objectives of the study are accomplished by adopting the methodology as shown in Figure 1.1. The framework includes the study of the characteristics of groundwater system under conjunctive use in the present period, the study of the impact of climate change on groundwater system in the future and the adaptation measures under climate change to reduce drought risk.

The content of this study consists of three parts (Figure 1.2), which correspond to the study objectives. The first is to understand the relationships of the groundwater system (flow in, flow out, storage change). The flows of water into the groundwater system caused by rainfall and rivers. The recharge from the rain in this study is called land recharge. Recharging from the river in this study is called recharge from the river. The water from the river is dependent on the river stage. If the river stage in the river is higher than the water level in the groundwater, it will be added to the groundwater system. If it is opposite, the groundwater will recharge to river instead. Another part of the inflow is the continuous flow within the aquifer layer, which is also due to the inflow from the boundaries and leakage between aquifer layer.

In the flows out of the groundwater system is the use of groundwater such as the household sector, industry sector and agriculture sector. And another part of the water flowing out of the system is a continuous flow within the aquifer layer, which is also flowing from the boundaries and leaking between aquifer layers.

Both inflow and outflow water conditions will show its effects in terms of changes in groundwater storage and groundwater levels that will increase or decrease in the groundwater system.

In the case of land recharge, there are relevant elements besides rain, i.e., temperature and evapotranspiration. In this study, additional elements considered are the ET value and the temperature. These will contribute to the change of the water recharge to the groundwater system affected by the climate change. In this study, this factor will be taken into consideration by establishing the land recharge formula.

In this area, there are conjunctive use of water between surface water and groundwater. The main water sources used are surface water from the main dams in the area. Water management is based on water years under conditions of the water storage of the dams. During drought, if the surface water supply is not enough, the farmers will pump groundwater for supplemental use which will depend on the state of water deficit condition, i.e., the condition of the water year. Because the characteristics of groundwater in each area are not the same, therefore, the ability to pump more water for use is different in the area. This is one of the main issues of this study. This study aims to understand this groundwater system. This corresponds to section 1 in Figure 1.1 and will be discussed in Chapter 5.

Climate change will affect rainfall, temperature, evapotranspiration, water demand, and water supply in the future, which are components of inflow and outflow from groundwater systems. The volume of the groundwater pumping will change, resulting in a change in the water supply. This study will analyze the climate change impact to groundwater system. This corresponds to the section 2 in Figure 1.1 and will be discussed in Chapter 6.

From future water deficit conditions which will take into account the climate change condition. This study proposes adaptation measures based on the increase of dam release and increasing groundwater pumping in the groundwater pumping potential areas. This will match section 3 in Figure 1.1, and will be addressed in Chapter 7.

The methodology of this study is summarized as follows:

1). The characteristic study of groundwater system under conjunctive use in the present period comprises of 1) groundwater model development, 2) groundwater land recharge study, 3) groundwater pumping potential assessment and 4) groundwater system characteristics under conjunctive use. The groundwater model is developed cover the periods of good, normal, dry and extreme dry years from the past periods to understand the groundwater flow conditions and the conjunctive use pattern up to now. The land recharge formula is developed using the precipitation, evaporation, temperature and soil type in the study area and groundwater model developed with best fit with observation data. The groundwater pumping potential is defined from groundwater parameters and physical conditions using Kriging and mapping techniques.

2) The study of the impact of climate change on groundwater system in the future comprises of 1) impact on groundwater recharge 2) impact on groundwater supply and 3) impact on groundwater system (by using climate and surface water data from the Dissertation of Chaowiwat W. (2013). Projected future climate data are used to estimate future recharges, groundwater pumping and its impact to groundwater system using the developed groundwater model and land recharge formula.

3) The adaptation measures under climate change to reduce drought risk comprise of 1) review existing water management scheme, 2) analyze the deficit under mitigation measures and 3) evaluation of adaptation measures under drought risk reduction. To counter with climate change impact towards groundwater, three alternatives of adaptation measures, i.e., increase surface water supply by adjusting

dam operation rules (using previous study), increase groundwater pumping in the potential area from the pumping potential study and mixed measures compared with BAU case. The drought reduction maps are created to see the risk reduction from measures proposed.

The scope of the area, time period, groundwater modeling's data, of this study and definition of groundwater system are as follows:

1) The study area is the upper Chao Phraya Plain covering the areas of Uttaradit, Sukhothai, Pitsanilok, Kampangphet, Pichit, and Nakornsawan provinces (Figure 1.3)

2) The study periods are following:
   - present period : 1993-2000 (11 years)
   - near future period : 2015-2029 (15 years)
   - far future period : 2075-2089 (15 years)

3) The water year is defined by the reservoir storage of Bhumibol dam and Sirikit Dam. There are 4 types of water year and the water year in present period between 1993-2003 is shown in Table 1.1.

Table 1.1. Type of water year and water year in 1993-2003

Water year	Storage of Bhumibol dam and Sirikit dam(MCM)	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
wet	> 12,500			▨	▨					▨	▨	▨
normal	8,500 – 12,500					▨	▨		▨			
dry	4,200 – 8,500	▨										
drought	< 4,200		▨					▨				

4) This study focuses on sedimentary aquifer comprised of 2 layers, upper aquifer layer and lower aquifer layer (Koontanakulvong S., et. al., 2006).

5) The definition of groundwater system means groundwater recharge, groundwater pumping, groundwater storage change and groundwater level. There are 4 reference control points of groundwater level used as representative in each zone, i.e., Pitsanilok (PSL), Sukhothai (SKT), Pichit (PIC) and Nakornsawan (NKS) and one critical point(Hotspot) in Nakornsawan (shown in Figure 1.2).
6) In this study, the conjunctive use ratio (GW/SW) means the percentage of groundwater supply (GW) over surface water supply (SW)
7) The bias corrected MRI-GCM climate data used in the study comprised of precipitation, mean temperature and relative humidity. These data were referred from the Dissertation of Chaowiwat W. (2013).
8) The impact of climate change on dam operation data comprised of inflow data, release data and storage data, and the adjusted reservoir operation data were referred from the dissertation of Chaowiwat W. (2013) by which the Sirikit Dam was selected as the case study for the adaptive dam operation.
9) The water demand data and surface water supply data were referred from the study of conjunctive use of groundwater and surface water in Northern Chao Phraya basin (Koontanakulvong S., et al. 2006).
10) The groundwater model software is MODFLOW. MODFLOW is the USGS's three-dimensional (3D) finite-difference groundwater model. MODFLOW was first published in 1984. It has a modular structure that allows it to be easily modified to adapt the code for a particular application.

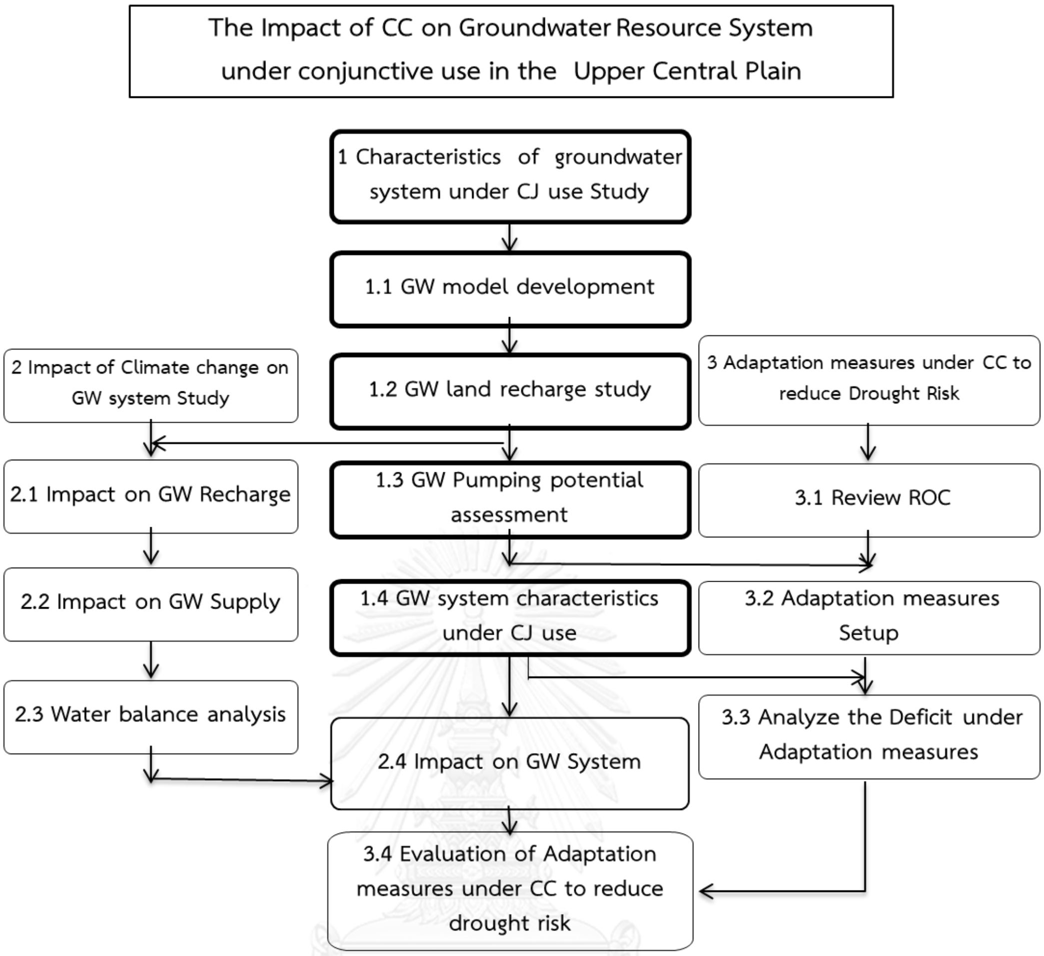


Figure 1.1. Schematic representation of the study methodology

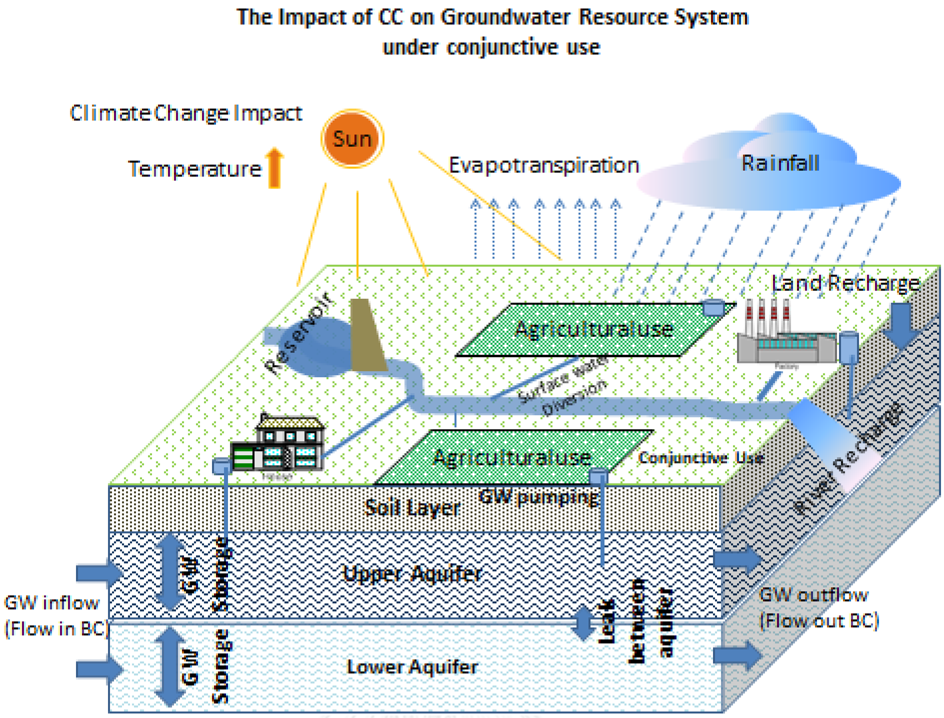


Figure 1.2. Concept of the impact of climate change on groundwater resources system under conjunctive use

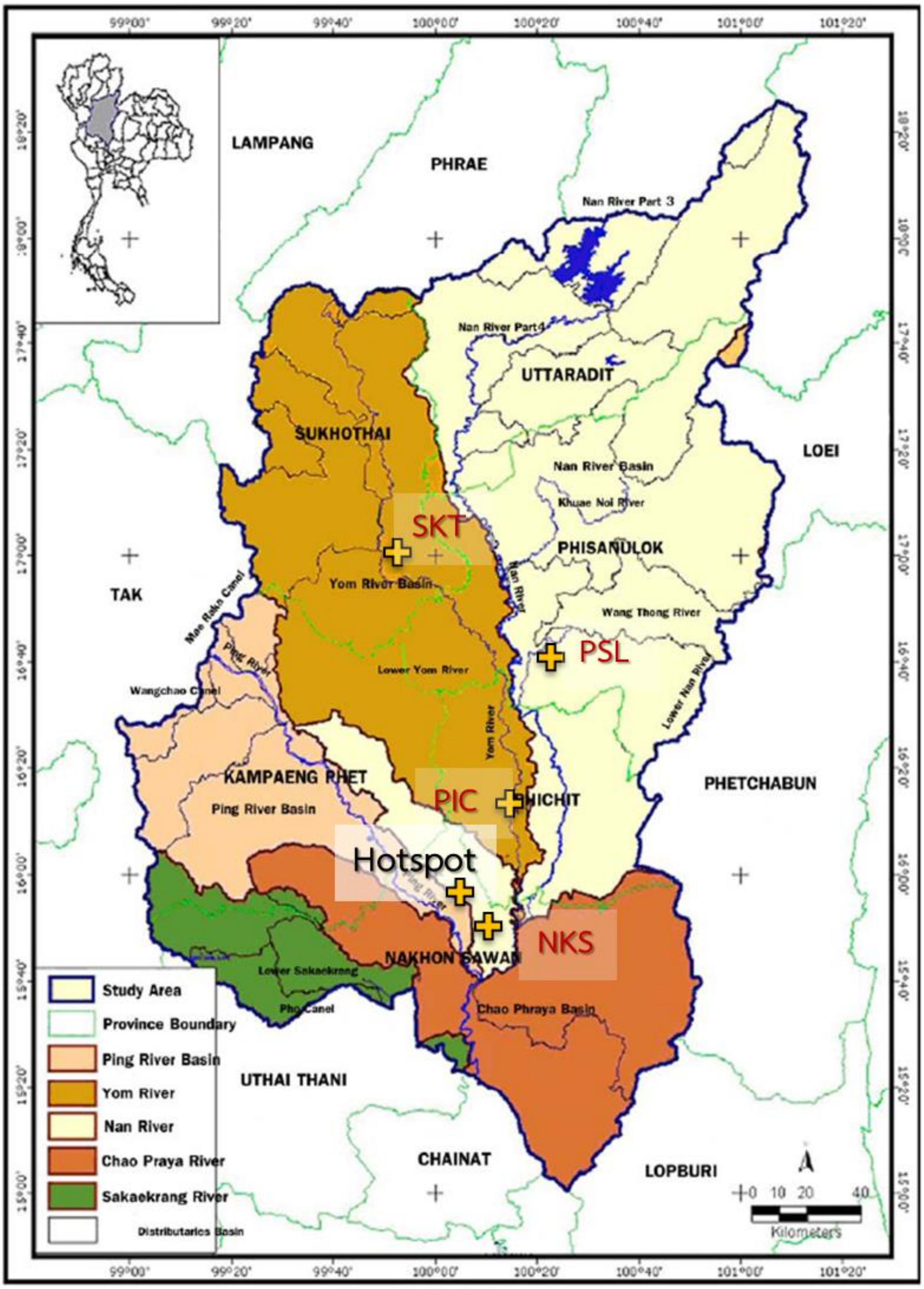


Figure 1.3. Study area

1.4. Study procedures

This study is composed of 3 main components: the characteristic study of groundwater system under conjunctive use, the study of the impact of climate change on groundwater system, and the adaptation measures under climate change to reduce drought risk. The brief study procedures of these components are as follow:

1.4.1.The characteristic study of groundwater system under conjunctive use

1) Collect the climate data, hydrological data and hydro-geological data of the meteorological station from the related government agencies such as Royal Irrigation Department(RID), Thai Meteorological Department(TMD) and Department of Groundwater Resource(DGR) include rainfall, average temperature, water stage in gate stations, river cross section, relative humidity, pumping test data, well data, etc.

2) Develop the groundwater model

This section describes the construction, calibration, and application of a computer model to simulate the groundwater flow system beneath the upper central plain. The steps for groundwater flow model development are shown in Figure 1.4. The description of each steps are as follows.

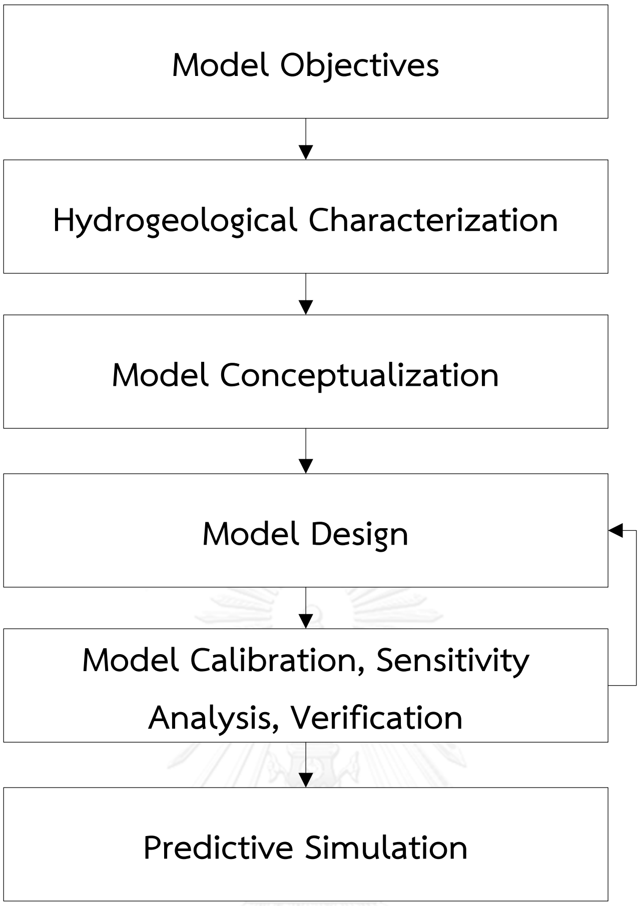


Figure 1.4. Groundwater flow model development

Model objectives

Model objectives were defined to simulate the groundwater situations iin the study area.

Hydrogeological characterization

Proper characterization of the hydrogeological conditions at a site is necessary in order to understand the importance of relevant flow. The study used the Hydrogeological map from DGR and the study of groundwater potential with boring well data.

Model conceptualization

Model conceptualization is the process in which data describing field conditions are assembled in a systematic way to describe groundwater at a site. The model conceptualization aids in determining the modeling approach.

Model design

Model design includes all parameters that are used to develop a calibrated model. The input parameters include model grid size and spacing, layer elevations, hydraulic conductivity/transmissivity, boundary conditions, pumping, recharge, any additional model input, transient or steady state modeling.

Model calibration and verification

Model calibration starts with changing values of model input parameters to match field conditions within some acceptable criteria. Model calibration requires that field conditions at a site be properly characterized. A calibrated model uses selected values of hydrogeologic parameters, pumping and recharge and boundary conditions to match historical field conditions. After the model has successfully reproduced measured changes in field conditions, it is ready for predictive simulations. The detail calibration and verification will be described in Chapter 5.1

Predictive Simulations

The model will be used to predict some future groundwater flow such as impact study and results from adaptation measures in Chapter 6.1.

3) Groundwater land recharge study.

The steps to find the land recharge equation are following

- Collect meteo-hydrological from Royal Irrigation Department and the bias corrected MRI-GCM climate data comprise of precipitation, mean temperature and relative humidity (Chaowiwat, 2013),
- Find relationship of evapotranspiration and mean temperature,
- Classify soil data type group in 7 groups by using their permeability property,

- Using the groundwater model to find the coefficient of the precipitation and evapotranspiration which describe in Chapter 4.4,
- Recalibrate the former model by input the estimation recharge values to the model with new formula concept till the guess recharge values generate the best fit of groundwater peizometric head with observed values.
- Formulate the land recharge formula from the precipitation, evaporation, temperature and soil type with calibrated recharge value from the groundwater model.

4) Groundwater pumping potential assessment

To evaluate the possibilities pumping potential the steps are following

- Investigate the water table of the Aquifer
- Develop a regional geomorphological map based on field surveys, remote sensing and previous environmental studies
- Interpolate the well data were analyzed in relation to rainfall, streamflow, yield and pumpage by using geostatistical techniques
- The results were analyzed via integrated zoning based on color theory as applied to multivariate visualization. The analysis results indicate areas that would be more suitable for groundwater extraction in a conjunctive management framework with regard to the natural hydrogeological processes and the effects of human interaction.

5) Groundwater system characteristics under conjunctive Use

Summarize the groundwater system patterns which are land recharge, river recharge, flows from boundary, pumping, leakage between aquifer layer and groundwater storage change in the past period also in water year.

1.4.2. the Impact of climate change on groundwater system

- Impact on groundwater recharge In this step, using climate data in near future and far future (precipitation, temperature) to calculate the land recharge and input to groundwater model to simulate the groundwater flow and summarize the impact to land recharge
- Impact on groundwater supply

Use the groundwater pumping potential assessment study to increase the groundwater pumping to meet the needs in the deficit area and to estimate the groundwater potential supply in the future.

- Water balance analysis

Using the water balance equation (4), which water demand and surface water supply referred from Koontanakulvong S., et al. (2006) and the groundwater supply from the groundwater model.

1.4.3. Summarize the groundwater system, which are land recharge, river recharge, flows from boundaries, pumping, leakage between aquifer layer and groundwater storage change in the near future and far future periods.

1.4.4.The adaptation measures under climate change to reduce drought risk

In this study we proposed 4 adaptation measures: 1) measure 0: BAU, no measure with climate change, 2) measure1: with adjusting the Reservoir Operation of Sirikit Dam, which collected the data from Chaowiwat (2013), 3) measure2: increasing Groundwater Pumping to meet the limit of Groundwater potential and 4) measure 3: measure 1 combined with measure 2 and summarize the effect of adaptation measures to reduce risk.

1.5. Expected outcomes

1) Understand the groundwater system characteristics
2) Achieve the recharge function and GW pumping potential pattern
3) Understand the impact of climate change on the groundwater System

4) Achieve the effectiveness of adaptation measures to reduce drought risk

CHAPTER II

STUDY AREA

2.1. Topography

The boundary of the upper central plain covers the areas of Uttaradit, Sukhothai, Pitsanilok, Kampangphet, Pichit, and Nakornsawan provinces. Total area is 47,986 km^2 or 29,991,699 rais. Average height is approximately 40-60 meters above mean sea level. The areas consist of sediments which were changed from erosion and decay of rock, then accumulate and generate as plain, terrace, and swamp. Figure 2.1 shows topography and boundary.

2.2 Climate condition

The climate of upper central plain is under the influences of monsoon winds i.e. southwest and northeast monsoon. From the meteorological point of view the climate of upper central plain can be divided into three seasons that are summer (mid-February to mid-May), rainy season (mid-May to October), and winter (November begin to mid-February).

From the collecting data of climate condition during the year 1971¬2000, climate condition of each province shows in Table 2.1.

Table 2.1. Meteorological conditions in the study area during 30 years (1971-2000)

Province	Temperature (oC)			Relative Humidity (%)			Pan evaporation (mm.)			Wind speed (knot)		
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
Nakornsawan	25	32	28.2	60	82	70	127	244	2018.0	1.5	5.4	3.0
Kampangphet	24	31	27.4	63	84	75	92	166	1429.4	1.1	1.9	1.4
Pitsanulok	24	31	27.7	61	80	71	110	187	1647.6	0.9	2.1	1.4
Uttaradit	23	31	27.3	62	83	73	112	182	1607.0	0.7	1.0	0.9
Sukhothai	25	29	27.2	70	86	79	104	171	1638.9	0.9	3.8	2.4

Source: The Meteorological Department, 2000

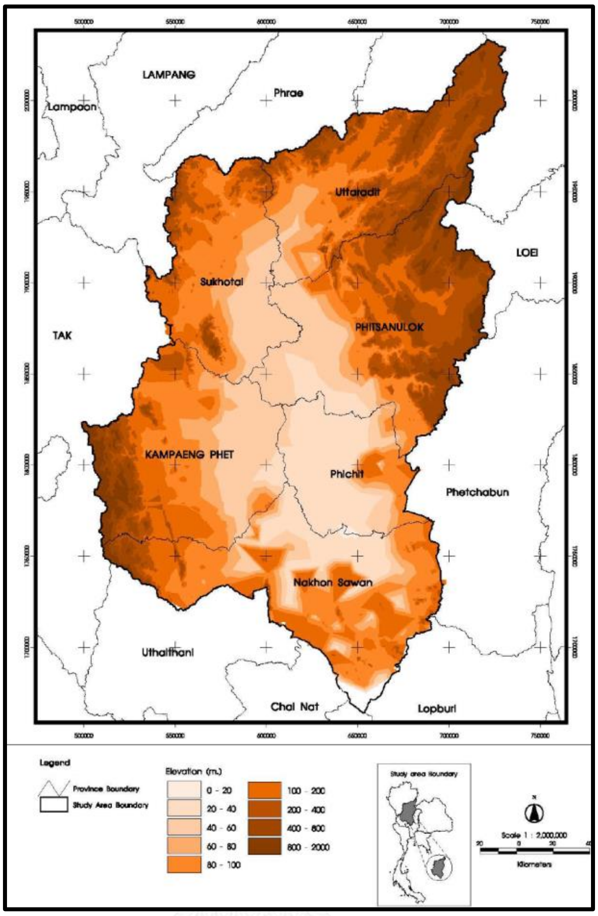


Figure 2.1. Topography and boundary of the study area

(Source: NAZA: STRM DEM. 2007)

2.3 Hydrology

The study area is composed of 5 basins that are Lower Ping basin, Lower Yom basin, Lower Nan basin, Upper Sa-Gae-Grang basin, and Upper Chao Praya basin, as shown in Figure 2.2.

The main rivers in the study areas are the Yom and the Nan River which flow parallel from north to south and join at Ban Gei Chai, Amphor Chumsang, Nakornsawan province. In addition, there is the Ping River which flows from west side and joins with the Yom and the Nan River at Amphor Paknampho, Nakornsawan province. They become the Chao Phraya River, which continuously flow to the Central Plain.

2.3.1 Rainfall Amount

From daily and monthly rainfall data of rainfall stations that collected during 1974 to 2003, totals are 68 stations, can conclude that the amount of rainfall in the Upper

Central Plain is between 900 to 1,450 mm/year. In case of aspect considering, Nan Basin has the highest rainfall while Chao Phraya Basin is the lowest. Average rainfall in each basin shows in Table 2.2. The high intensity of annual rainfall, mostly distributed in Pitsanulok, has an amount of rainfall over 1,400 mm/year (as shown in Figure 2.3).

Table 2.2. Amount of rainfall in each basin in the Upper Central Plain

Basin	Average monthly rainfall (mm.)												Total
	Apr.	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	(mm)
1. Ping	40.7	174.6	137.9	118.5	151.7	232.0	185.9	45.2	3.8	2.6	12.3	26.3	1,131.5
2. Yom	39.5	173.2	141.0	147.1	195.0	242.8	125.4	26.4	5.0	4.3	8.9	26.3	1,134.9
3. Nan	67.2	196.8	175.8	182.2	239.2	243.3	104.6	21.1	5.0	4.8	12.8	27.0	1,279.8
4. ChaoPhraya	45.3	120.7	90.5	112.1	147.4	210.2	127.6	21.9	3.8	3.3	9.4	25.9	917.9
5. Sa- Gae Grang	62.8	169.5	129.6	131.3	172.6	242.1	157.3	36.4	4.7	4.2	16.9	37.4	1,164.6

(Source: Koontanakulvong S., et. al. 2006)

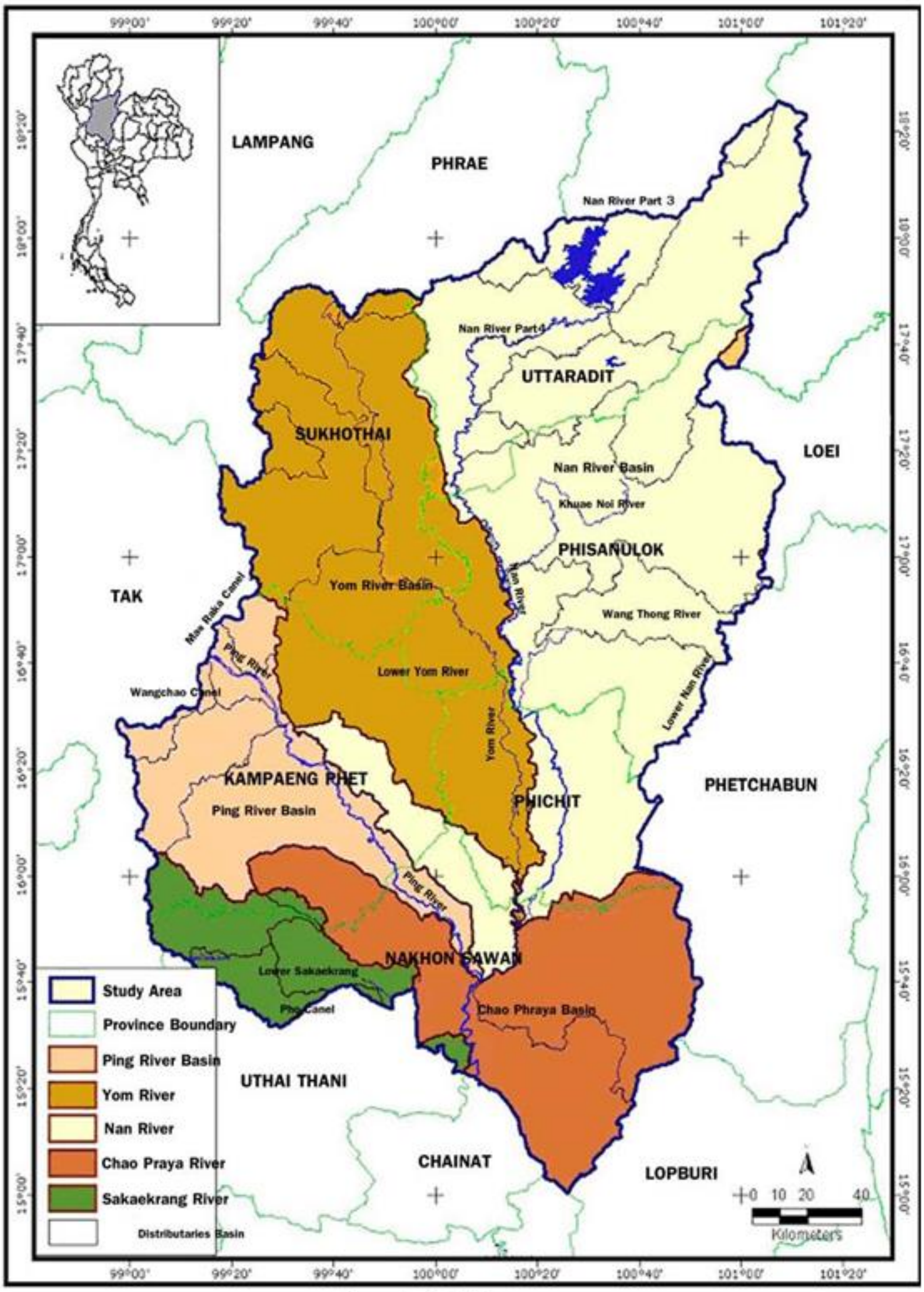


Figure 2.2. Upper Central Plain Basins

(Source: Koontanakulvong S., et. al. 2006)

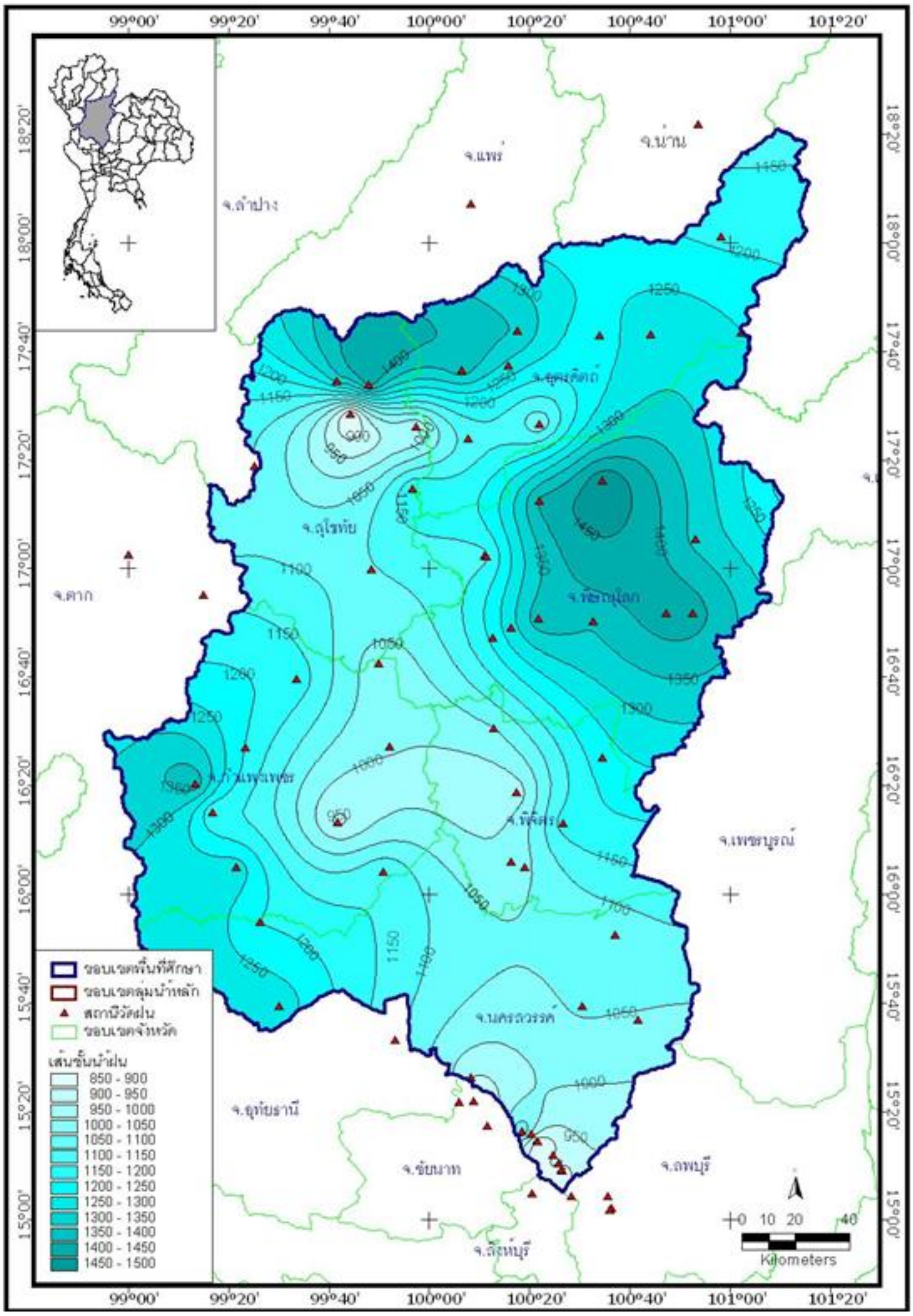


Figure 2.3. The annual rainfall isohyets in the study area

(Source: Koontanakulvong S., et. al. 2006)

2.3.2 Runoff amount

From runoff data of Royal Irrigation Department that collected during 1994 to 2003, totals are 52 stations, can conclude as follow. Total watershed area of Upper Central Plain is 46,008 square kilometers. While total runoff 15,481.9 million cubic meters per year, divided into rainy season 13,625 million cubic meters, 88% of total runoff, and dry season 1,856.9 million cubic meters, 12% of total runoff.

2.4. Geomorphology and geology

Geomorphology of the Upper Central Plain is undulating terrain and the averaged heights are between 40 to 60 meters above mean sea level. The area consists of sediments which formulate by erosion and weathering of rock. Then the sediments were transported and deposit become flood plain, terrace, and swamp.
Sediments in this area normally are alluvial and alluvial on bed rock. Because of shale in the Upper Central Plain is shallower than shale in the Lower Central Plain, so Quaternary sediments in this area are less thick than the Lower Central Plain.
Details of these sediments are differing in each area. Most of sediments are composed of gravel, coarse sand, and clay. Three types of sediments are accumulated by geological process and generate as layers, lens, and slope. Figure 2.4 shows geological condition in the study area.

2.5. Hydrogeology

Groundwater sources in the study area can be found in both unconsolidated and consolidated aquifers. (Figure 2.5) Unconsolidated aquifer can be found in Upper Chao Phraya Basin; covers 6 provinces i.e. Uttaradit, Sukhothai, Pitsanilok, Kampangphet, Pichit, and Nakornsawan province.

Most of sediments are unconsolidated sediments that store up in the plain, average thickness is 300 to 500 meters. The center of basin is the thickest approximately 700 meters. Type of aquifers in the study area are present alluvial sediment, an influence of Ping Yom and Nan River, and old alluvial sediment or old terrace sediment which divide into low terrace and high terrace. Moreover also there are sediments generated from alluvial fan.

Bed rock aquifer will generate at the edge of the study area which mostly find at Uttaradit and Nakornsawan province. Bed rock aquifer consists of limestone aquifer, Khorat aquifer, metamorphored aquifer, and igneous.

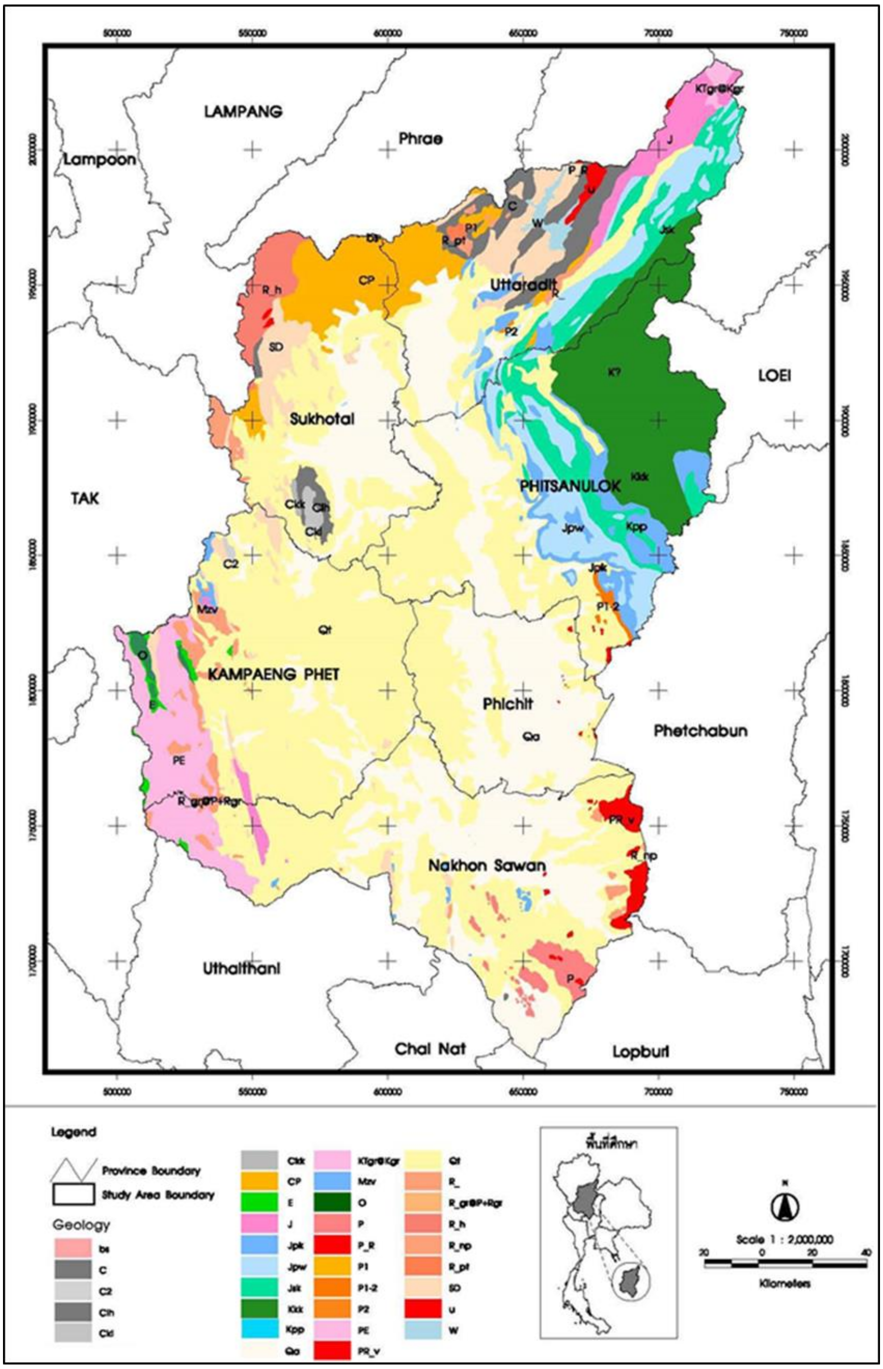


Figure 2.4. Geology characteristic in the study area

(Source: DGR, 2005)

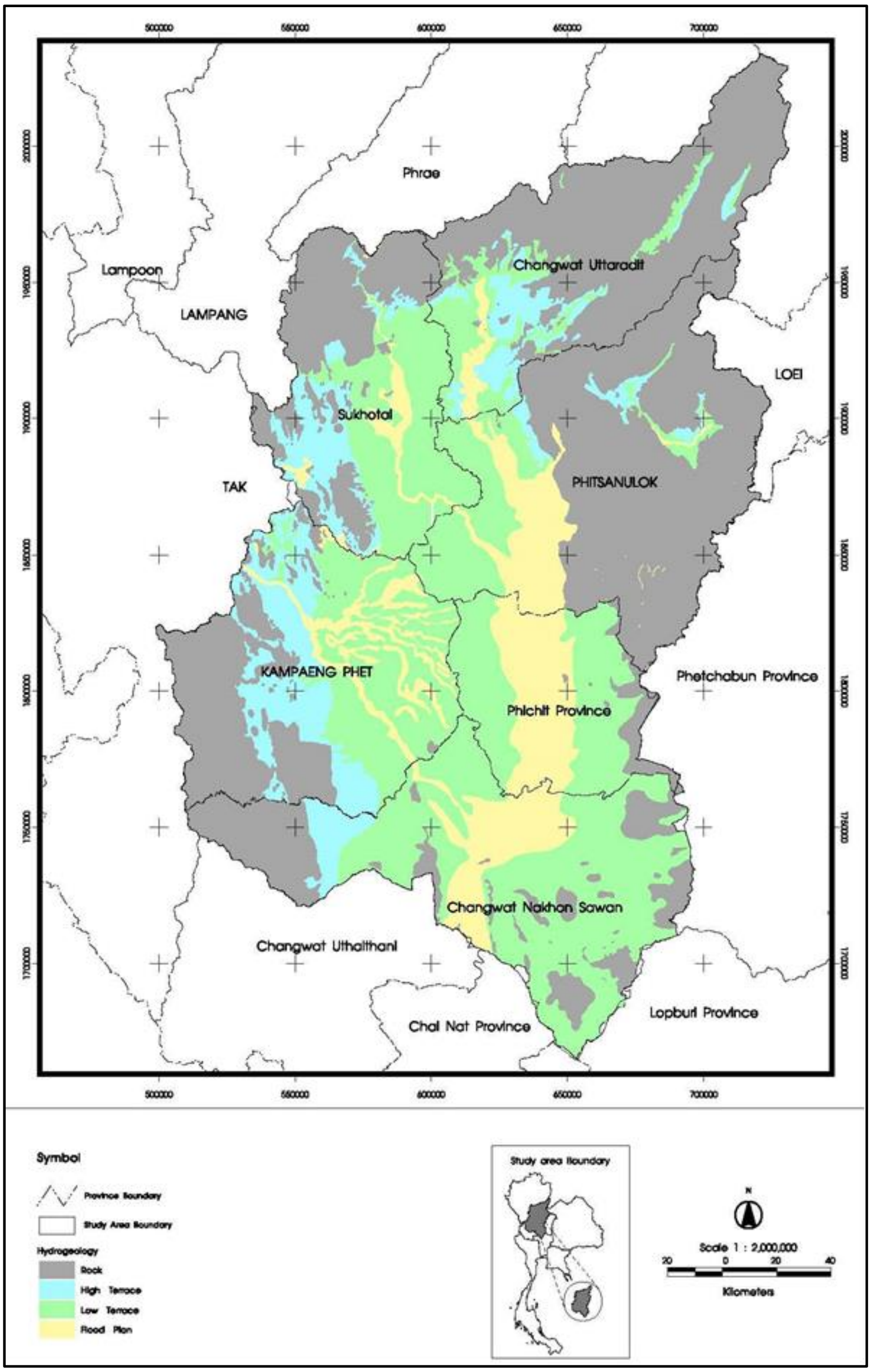


Figure 2.5. Hydro-geology characteristic in the study area

(Source: DGR, 2005)

2.6. Groundwater situation

2.6.1 Well Yields

From the study each layer of aquifer has various yields due to influence of sediment proportion, surface water route, and groundwater flow. Average yield of unconsolidated aquifer is comparatively high which is between 10 to15 m^3/hr. The areas have the highest yields, some reach to 40 m3/hr. i.e. Amphor Muang, Amphor Si-ngam, and Amphor Lankabue Kampangphet province; Amphor Photalay Amphor Bangmoonnak Pichit province (Figure 2.6). Anyhow because of unconsolidated aquifer is located in groundwater flow route and influence of surface water adding up, the Ping and the Nan River.

Yields of Young Terrace and Old Terrace aquifer are lower. Average yield is 5 to 15 and 1 to 10 m^3/hr respectively. Because these aquifers receive less affect from surface water and bad size grain distribution.

However yield at center of basin has more yield than at the edge of basin which is bed rock. Due to groundwater flow route flow through the direction as mentioned. For some areas, yields may reach to 40-50 m^3/hr such as high terrace and low terrace that support alluvial fan at Amphor Muang, Amphor Singam, and Amphor Lankabue Kampangphet province and varied Amphor in Pichit province.

2.6.2 Water Level and Flow Direction of Groundwater

Changing of groundwater level depends on seasons and fluctuates in the range of 1 to 5 meters, groundwater level in April is the lowest and start to higher from June to August because it close to rainy season. The areas that groundwater level has big fluctuation are in Amphor Muang or main Amphor of each province since they are the center of province that has high water use such as Pichit and Pitsanulok province.

Groundwater flow direction under gravity, flow from higher area to lower area, and water pressure. Besides it also has water flow from west side and east side, which is following the surface water flow. That means groundwater in Kampangphet and Sukhothai will flow from east side to center of basin while groundwater from Pitsanulok and Pichit province alike flow from west side to center of basin. Then they will combine and flow follows the river flow direction to groundwater aquifer in Nakornsawan province.

2.6.3 Groundwater quality

Most of groundwater in the study area, Upper Central Plain, is good water quality except Amphor Kaolaew and Amphor Nongbua, Nakornsawan province, that groundwater is saline. Groundwater quality in the study area is differing from good, moderate, and low quality which is not suitable for drink.

From the result of study, amount of iron nearly all area and every aquifer layers are exceed the standard of groundwater for consumption (> 1.0 mg/l). Except some area with iron within standard (0.5-1.0 mg/L) are in Amphor Ladyao, Amphor Banpotpisai Nakornsawan; Amphor Kongkailas, Amphor Srisachanalai, Amphor Muang Sukhothai; and Amphor Bangmoonnak, Amphor Samngam Pichit.

For parameters of total dissolved solid and total hardness, most of the area are in good quality except some areas in Nakornsawan which the values are over standard i.e. Amphor Chumsang, Amphor Payuhachiri, Amphor Pisaree, Amphor Kokpra, and Amphor Kaolaeo.

Moreover, suitability of groundwater for agriculture was studied by considering SAR, 50 locations, The result shows that the quality of groundwater is very good for agriculture.

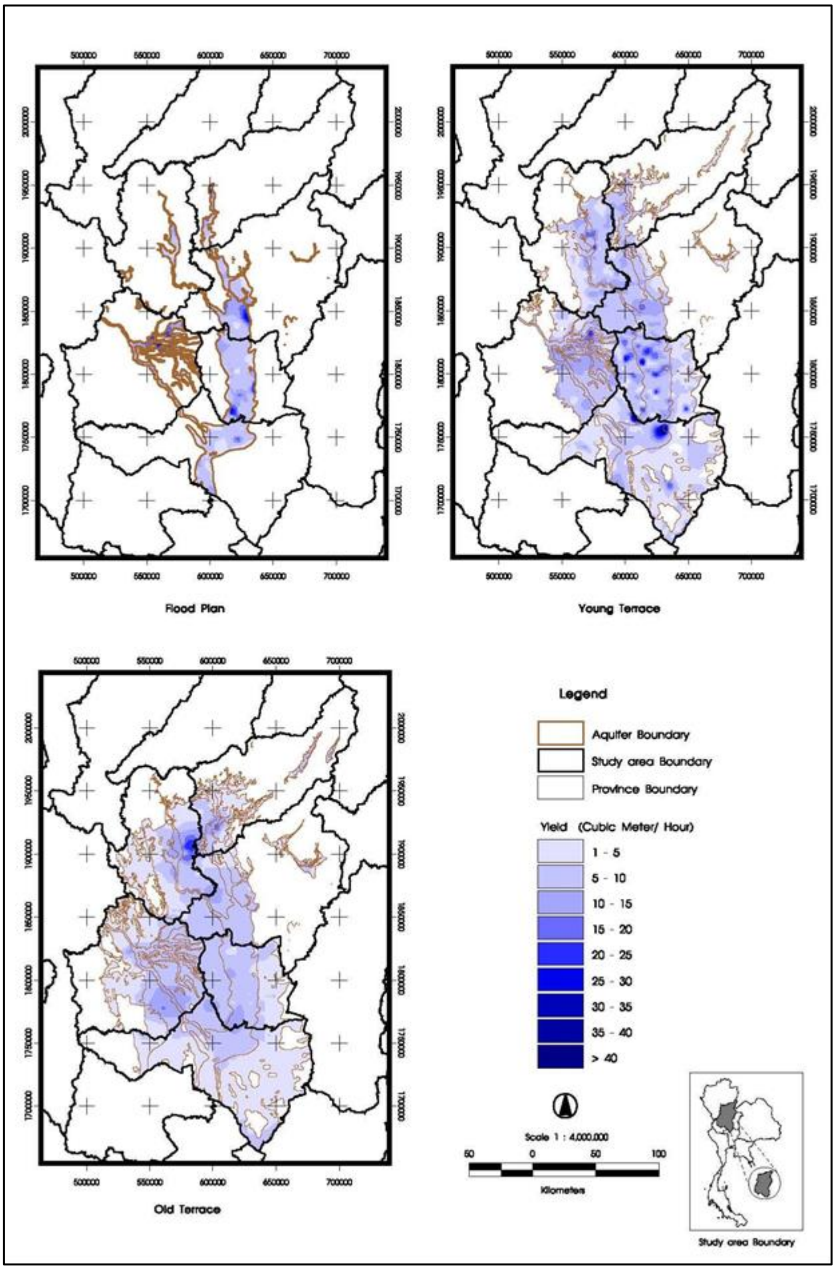


Figure 2.6. The amount of Groundwater Yields (Source: DGR, 2005)

2.7. Social and economic conditions

There are the total of 4,286,000 peoples residing in the Upper Central Plain. The most populated provinces are Nakornsawan, Pitsanilok, Kampangphet, Sukhothai, Pichit, and Uttaradit, respectively. The majority of peoples are relying on agriculture, ranging from farms, ranches, and fruit orchards.

Data from the Office of Economic and Social Development Board (2004) revealed that the total GPP of 224,713 million bahts and average annual income per capita of

52,826 bahts. Table 2.3 below summarizes the GPP and average annual income per capita.

Table 2.3. GPP and average annual income per capita of the studying area

Provinces	GPP (million baht)	Income (per capita) (baht)
1. Kampangphet	56,414	71,389
2. Sukhothai	23,227	39,048
3. Uttaradit	21,742	47,103
4. Pitsanilok	42,408	53,507
5. Pichit	24,122	49,571
6. Nakornsawan	56,800	56,336
Total	224,713	316,954
Average	37,452	52,826

(Source: Koontanakulvong S., et. al. 2006)

2.8. Agricultural conditions

The overall lifestyle study in the area of interest reveal that more than 90% of the population rely mainly on rice farming, 7.6% are ranchers, and 1.8% are fruit orchard farmers. By evaluating the agricultural data in the Upper Central Plain, this area consists of 17,156,471 rais (27,450 km^2) of agricultural area, divided into 13,295,266 rais (21,272 km^2) in rainy season and 3,861,206 rais (6,178 km^2) in summer. The detailed information are as follows:

Kampangphet province: The total agricultural area of 3,381,629 rais (5,411 km^2) are divided into 28% Paddy field, 20% plantation, and 1% unidentified. The major economic plants include rice, cassava, corn, and sugarcane.

Sukhothai province: The total agricultural area of 1,264,935 rais (2,024 km^2) are divided into 31% Paddy field, 30% plantation, and 1% unidentified. The major economic plants are rice, soybean, mung bean, corn, sugarcane, and Burley's tobacco leaf.

Uttaradit province: The total agricultural area of 851,932 rais (1,363 km^2) are divided into 12% paddy field, 5% plantation, and 1% unidentified. The major economic plants are rice, corn, soybean, and sugarcane.

Pitsanulok province: The total agricultural area of 2,186,005 rais (3,498 km^2) are divided into 22% Paddy field, 7% plantation, and 1% unidentified. The major economic plants are rice, corn, soybean, and sugarcane.

Pichit province: The total agricultural area of 2,186,005 rais (3,498 km^2) are divided into 71% paddy field, 5% plantation, and 1% unidentified. The major economic plants are rice, corn, soybean, and sugarcane.

Nakornsawan province: The total agricultural area of 4,311,788 rais (6,899 km^2) are divided into 45% paddy field, 24% plantations, and 3% unidentified. The major economic plants are rice, sorghum, mung bean, soybean, peanut, sugarcane, cotton, and sesame seeds. Nakornsawan is considered the biggest paddy filed source and the second biggest corn and sugar field source in the northern part of Thailand.

2.8.1 Cultivated area

The cultivated area of the upper central plain during 1993-2003 present in Figure 2.6 The total agriculture area in irrigation area was 3,579,279 rais (5,727 km^2). It comprised of the large and medium-Scale project of 1,740,835 rais (2,785km^2) and The small-scale project of 1,838,444 rais (2,942 km^2). There was 9,715,985 rais (15,546 km^2) in non-irrigation area. The overall of the cultivated area was 13,295,266 rais (21,272 km^2).

Table 2.4. Summary of the cultivated area of the study area

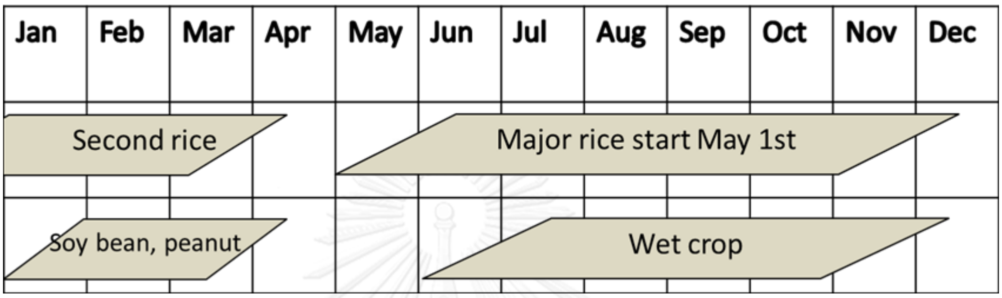
No.	Provinces	Cultivated area (rais)			
		The large-scale and medium-scale project	The small-scale project	Non-irrigation area	Total
1	Kampangphet	373,464	436,294	1,847,034	2,656,792
2	Nakornsawan	328,992	435,180	3,547,616	4,311,788
3	Phicit	450,968	315,790	1,419,247	2,186,005
4	Phitsanulok	333,498	236,157	1,454,159	2,023,814
5	Sukhothai	161,920	205,010	898,005	1,264,935
6	Uttaradit	91,995	210,013	549,924	851,932
Total		1,740,835	1,838,444	9,715,985	13,295,266

Remark: 1 rai=0.0016 km^2

Cropping pattern

The cropping patterns were reviewed by DWR (2005). In the study area, the farmers mostly start to cultivate major rice in the early May and harvest in the middle of November, while they start to cultivate second rice in early-December and harvest in mid- April.

Table 2.5. The cropping pattern in irrigated area in study area



2.9. Climate change in study area

In this section, it demonstrates the impact of climate change on rainfall, river runoff and water demand.

2.9.1 Rainfall

The bias corrected rainfall data collected from Koontanakulvong, S., et. al. (2006) are used for the study. From Figure 2.7 and Table 2.6, the average annual rainfall in near future will be 1,255 mm. which will increase 10% from the present period. The average wet season will be 889.3 mm. which decrease 17% from the present period, in dry season, it will be 366.9 mm. which will increase 13% from the present period. This means there will more rainfall in dry season.

The average annual rainfall in far future will be 1,354 mm. which will decrease 3% from the present period. The average wet season will be 969 mm. which will decrease 9% from the present period, in dry season, it will be 389.9 mm. which will increase 20% from the past. This means there will be more rainfall in dry season.

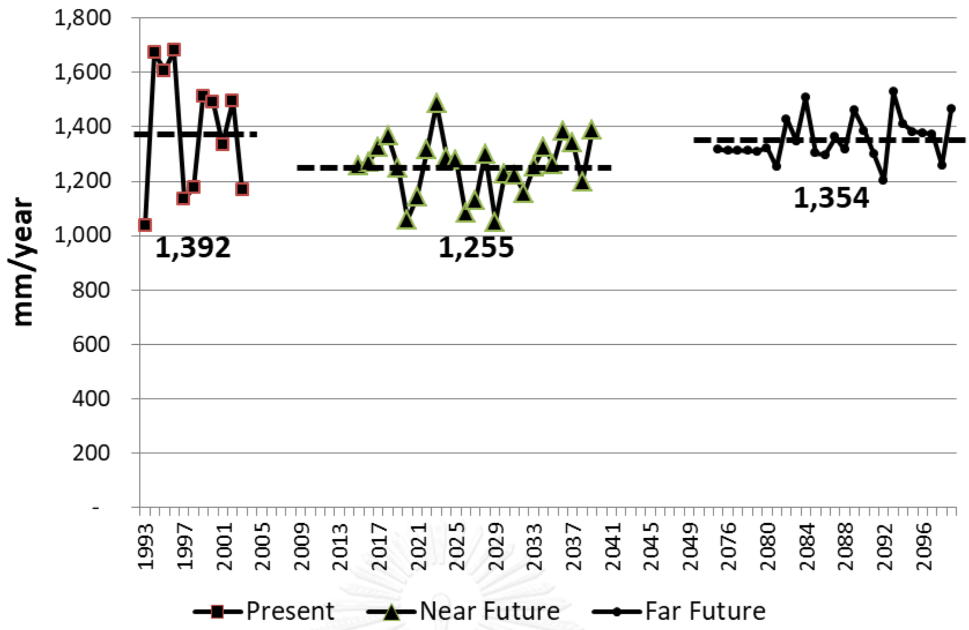


Figure 2.7. The comparison of rainfall in near future, far future: unit in mm/year

Table 2.6. The seasonal comparison of rainfall in near future, far future: unit in mm.

Basin		Present			Near Future						Far Future					
		wet	dry	annual	wey	%	dry	%	annual	%	wey	%	dry	%	annual	%
Nan	Max	1,230.7	469.3	1,568.4	1,303.0	5.9	667.7	42.3	1,970.6	25.6	1,451.6	17.9	605.9	29.1	2,057.5	31.2
	Min	669.0	146.3	977.3	548.0	-18.0	183.7	25.6	732.0	-25.1	580.6	-13.2	148.1	1.2	728.6	-25.4
	Avg.	955.0	300.7	1,255.7	887.3	-7.1	333.5	10.9	1,220.9	-2.8	953.8	-0.1	339.3	12.8	1,293.1	3.0
	S.D.	144.6	85.9	169.4	180.8	25.0	111.1	29.3	289.7	71.0	194.5	34.5	116.1	35.1	309.3	82.5
Ping	Max	1,284.9	427.6	1,469.8	1,278.7	-0.5	583.5	36.5	1,862.2	26.7	1315.5	2.4	492.2	15.1	1,807.7	23.0
	Min	470.1	134.3	693.7	504.0	7.2	135.3	0.7	639.3	-7.8	513.3	9.2	147.7	10.0	661.1	-4.7
	Avg.	859.0	243.4	1,102.4	808.5	-5.9	268.4	10.3	1077.0	-2.3	891.9	3.8	266.0	9.3	1,158.0	5.0
	S.D.	221.4	86.2	243.4	187.7	-15.2	101.9	18.3	288.3	18.4	215.4	-2.7	88.5	2.7	302.8	24.4
Yom	Max	1,188.7	445.3	1,498.1	1,271.3	6.9	609.4	36.8	1880.7	25.5	1486.7	25.1	651.0	46.2	2,137.8	42.7
	Min	589.7	115.9	805.3	525.5	-10.9	148.8	28.4	674.2	-16.3	560.5	-4.9	141.3	21.9	701.8	-12.9
	Avg.	857.6	246.9	1,104.6	856.6	-0.1	315.9	27.9	1172.5	6.2	931.6	8.6	327.7	32.7	1,259.3	14.0
	S.D.	164.3	89.4	201.9	177.1	7.8	109.2	22.1	285.5	41.4	224.4	36.6	117.8	31.7	341.3	69.0
Upper Chao Phraya	Max	1,016.8	388.5	1,322.1	1,110.8	9.2	587.9	51.3	1698.7	28.5	1272.5	25.1	751.7	93.5	2,024.1	53.1
	Min	455.2	110.5	582.8	416.0	-8.6	118.0	6.7	533.9	-8.4	386.6	-15.1	114.3	3.4	500.9	- 14.1
	Avg.	692.9	202.9	895.8	720.1	3.9	271.2	33.6	991.2	10.7	767.5	10.8	302.1	48.9	1,069.6	19.4
	S.D.	145.1	72.8	168.5	191.7	32.1	113.0	55.2	302.6	79.6	217.0	49.6	156.0	114.2	372.9	121.3
Sa- Gae Grang	Max	1,461.3	527.9	1,644.6	1,405.9	-3.8	648.0	22.8	2053.9	24.9	1314.5	-10.0	675.2	27.9	1,989.7	21.0
	Min	528.3	146.7	764.3	459.5	-13.8	121.2	-17.4	580.7	-24.0	441.7	-16.4	115.2	-21.4	557.0	-27.1
	Avg.	879.4	291.7	1,171.1	801.5	8.9	304.2	4.3	1105.8	-5.6	851.8	-3.1	330.9	13.4	1,182.7	1.0
	S.D.	215.3	95.6	234.9	220.5	2.4	138.5	44.9	358.0	52.4	215.9	0.3	153.1	60.1	367.7	56.6
all area	Max	1,461.3	527.9	1,644.6	1,405.9	9.2	667.7	51.3	2,053.9	28.5	1,486.7	25.1	751.7	93.5	2,137.8	53.1
	Min	455.2	110.5	582.8	416.0	-18.0	118.0	-17.4	533.9	-25.1	386.6	-16.4	114.3	-21.4	500.9	-27.1
	Avg.	1,068.4	323.6	1,392.0	889.3	-16.8	366.9	13.4	1,255.0	-9.8	969.0	-9.3	389.9	20.5	1,354.0	-2.7
	S.D.	178.1	86.0	203.6	191.6	10.4	114.8	34.0	304.8	52.5	213.4	23.7	126.3	48.8	338.8	70.8

2.9.2 Runoff

The projected river runoff in the future consider in out let stations of each river basin in the study area (Figure 2.8). Table 2.7 demonstrates the change of river runoff in the near future and far future, the summary of each basin are follows:

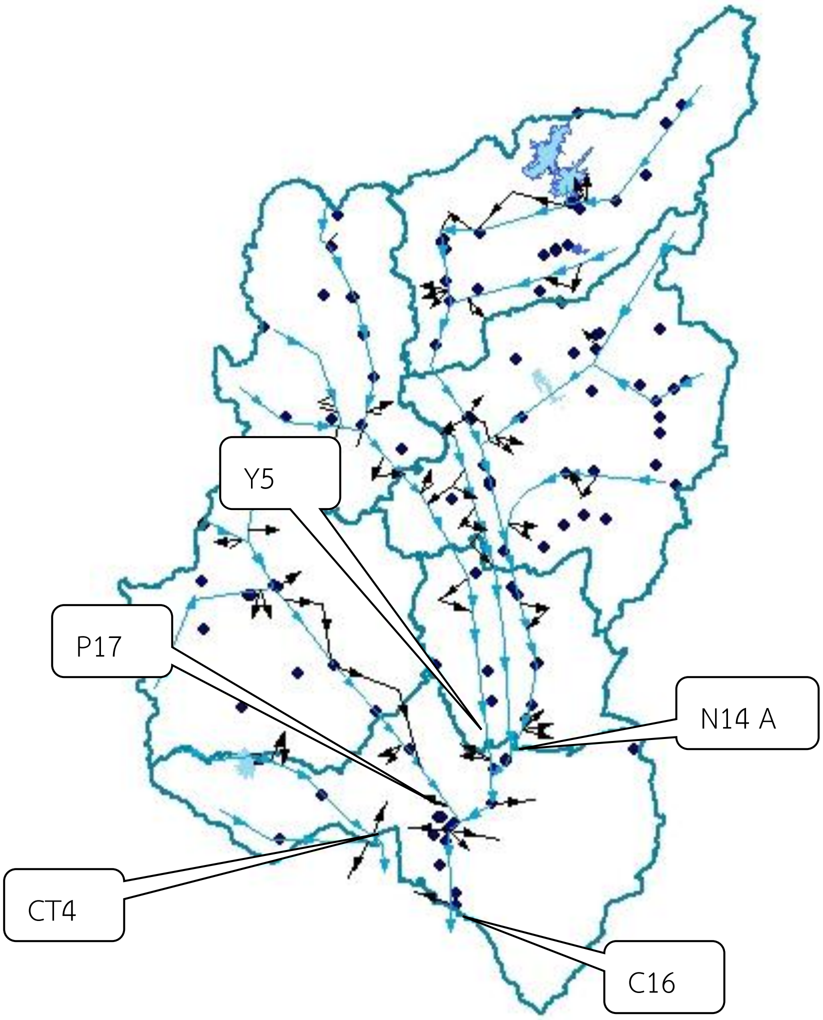


Figure 2.8. The in-outlet stations of each river basins

(Source: Koontanakulvong S., et al. 2006)

Nan river basin (N14A): The average near future runoff will be 13,576.5 MCM, which will increase 5.6 % and the average far future runoff will be 14,580.6 MCM, which will increase 13.4% from the present period runoff. When consider in seasonal aspect, the average near future runoff in wet season will be 9,015.6 MCM that will increase 0.4% from the present period. The average near future runoff in dry season will be 4,561.0 MCM which will increase 17.7% from the present period. The average far future runoff in wet season will be 7,883.9 MCM which will decrease 12.2 % from the present period. The average far future runoff in dry season will be 5,016.7 MCM which increase 29.5% from the present period.

Ping river basin (P17): The average near future runoff will be 6,119.6 MCM, which will increase 28.9 % and the average far future runoff will be 6,738.3 MCM, which will increase 21.7% from the present period runoff. When consider in seasonal aspect, the average near future runoff in wet season will be 2,579.9 MCM that will decrease 45.5% from the present period. The average near future runoff in dry season will be 3,542.6 MCM which will decrease 8.7% from the present period. The average far future runoff in wet season will be 2,906.7 MCM which will increase 38.5 % from the present period. The average far future runoff in dry season will be 3,831.6 MCM which decrease 1.2 % from the present period.

Yom river basin (Y5): The average near future runoff will be 2,732.4 MCM, which will increase 27.4 % and the average far future runoff will be 3,528.2 MCM, which will decrease 6.2 % from the present period runoff. When consider in seasonal aspect, the average near future runoff in wet season will be 2,356.1 MCM that will decrease 29.7% from the present period. The average near future runoff in dry season will be 376.4 MCM which will decrease 8.4 % from the present period. The average far future runoff in wet season will be 3,549.8 MCM which will increase 5.9 % from the present period. The average far future runoff in dry season will be 593.3 MCM which increase 44.3 % from the present period.

Upper Chao Phraya river basin (C16): The average near future runoff will be 14,482.3 MCM, which will decrease 19.2% and the average far future runoff will be 17,511.6 MCM, which will decrease 2.3 % from the present period runoff. When consider in seasonal aspect, the average near future runoff in wet season will be 8,765.7 MCM that will decrease 29.2% from the present period. The average near future runoff in dry season will be 5,716.5 MCM which will increase 3.2 % from the present period. The average far future runoff in wet season will be 11,005.1 MCM which will decrease 11.2 % from the present period. The average far future runoff in dry season will be 6,506.5 MCM which increase 17.4 % from the present period.

Sa- Gae Grang river basin (CT4): The average near future runoff will be 643.3 MCM, which will decrease 15.9 % and the average far future runoff will be 708.1 MCM, which will decrease 7.4 % from the present period runoff. When consider in seasonal aspect, the average near future runoff in wet season will be 522.1 MCM that will decrease 21 % from the present period. The average near future runoff in dry season will be 121.2 MCM which will increase 16.8 % from the present period. The average far future runoff in wet season will be 587.9 MCM which will decrease 11.1 % from the present period. The average far future runoff in dry season will be 87.2 MCM which decrease 16.0 % from the present period.

2.9.3 Water demand

The water demand data of this study area was collected from Koontanakulvong S., et al. (2006). The water demand was calculated with WUSMO (Water Use Simulation Model). The study considered 60% irrigation efficiency in irrigation canal system and 90 percent irrigation efficiency in electric pumping systems. The summary of the water demand during 1993-2003 of each basin demonstrated as following:

Nan River basin: The average water demand in wet season was 517.7 MCM and the average water demand in dry season was 689.4 MCM. The average annual water demand was 1,207.1 MCM

Ping River basin: The average water demand in wet season was 178.8 MCM and the average water demand in dry season was 96.3 MCM. The average annual water demand was 275.1 MCM

Yom River basin: The average water demand in wet season was 143.6 MCM and the average water demand in dry season was 17.1 MCM. The average annual water demand was 160.7 MCM

Table 2.7. The seasonal comparison of river runoff in near future, far future: unit in MCM

Basin		Present			Near Future						Far Future					
		wet	dry	annual	wey	%	dry	%	annual	%	wey	%	dry	%	annual	%
Nan	Max	13,622.9	5,472.4	17,789.0	10,666.7	-21.7	5,530.4	1.1	15,904.7	-10.6	6,505.9	-52.2	6,113.6	11.7	16,051.1	-9.8
	Min	4,564.2	2,112.5	6,676.7	6,505.9	42.5	3,461.8	63.9	10,453.7	56.6	10,416.2	128.2	4,096.2	93.9	12,679.8	89.9
	Avg.	8,983.8	3,874.4	12,585.2	9,015.6	0.4	4,561.0	17.7	13,576.5	5.6	7,883.9	-12.2	5,016.7	29.5	14,580.6	13.4
	S.D.	3,107.1	994.5	3,814.6	926.7	-70.2	576.0	-42.1	1,299.7	-65.9	9,563.9	207.8	526.0	-47.1	824.7	-78.4
Ping	Max	7,816.7	5,413.7	12,734.8	3,708.4	-52.6	4,290.5	-20.7	7,483.7	-41.2	3,477.7	-55.5	4,577.1	-15.5	7,709.3	-39.5
	Min	1,762.8	2,045.7	4,639.2	1,895.6	7.5	2,668.1	30.4	4,702.6	1.4	2,081.3	18.1	2,945.7	44.0	5,429.9	17.0
	Avg.	4,725.4	3,879.1	8,604.5	2,576.9	-45.5	3,542.6	-8.7	6,119.6	-28.9	2,906.7	-38.5	3,831.6	-1.2	6,738.3	-21.7
	S.D.	1,821.0	1,082.3	2,675.8	471.3	-74.1	446.7	-58.7	771.7	-71.2	364.3	-80.0	364.9	-66.3	638.9	-76.1
Yom	Max	6,336.4	954.8	6,802.9	2,870.5	-54.7	721.0	-24.5	3,240.0	-52.40	3,649.3	-42.4	680.3	-28.7	4,230.1	-37.8
	Min	651.5	69.9	792.6	1,843.7	183.0	230.4	229.5	2,100.5	165.0	3,572.5	448.3	595.3	751.4	3,030.1	282.3
	Avg.	3,352.2	411.1	3,763.3	2,356.1	-29.7	376.4	-8.4	2,732.4	-27.40	3,549.8	5.9	593.3	44.3	3,528.2	-6.2
	S.D.	1,949.4	298.4	2,164.4	287.5	-85.3	114.2	-61.7	319.8	-85.20	3,543.9	81.8	569.3	90.8	372.1	-82.8
Upper Chao Phraya	Max	21,891.7	8,447.8	28,541.6	11,113.0	-49.2	7,488.8	-11.4	17,728.0	-37.90	12,567.2	-42.6	8,258.0	-2.2	20,825.2	-27.0
	Min	1,767.1	1,497.4	3,751.4	5,815.9	229.1	4,166.2	178.2	11,359.7	202.8	8,014.2	353.5	4,954.4	230.9	14,969.1	299.0
	Avg.	12,388.8	5,539.9	17,928.6	8,765.7	-29.2	5,716.5	3.2	14,482.3	-19.2	11,005.1	-11.2	6,506.5	17.4	17,511.6	-2.3
	S.D.	6,949.0	2,236.9	8,700.3	1,509.5	-78.3	896.6	-59.9	2,087.7	-76.0	982.1	-85.9	874.2	-60.9	1,371.9	-84.2
Sa- Gae Grang	Max	1,127.6	364.0	1,447.4	1,206.1	7.0	623.5	71.3	1,951.1	34.8	1,214.7	7.7	192.4	-47.1	1,381.4	-4.6
	Min	57.3	7.3	64.6	380.1	563.4	-	-100.0	420.0	550.2	391.2	582.7	35.3	383.6	430.4	566.3
	Avg.	661.2	103.7	764.9	522.1	-21.0	121.2	16.8	643.3	- 15.9	587.9	-11.1	87.2	-15.9	708.1	-7.4
	S.D.	392.8	101.1	448.5	868.3	121.1	197.4	95.3	1,001.7	123.3	283.6	-27.8	54.7	-45.9	314.1	-30.0
all area	Max	48,270.2	19,396.1	64,124.6	30,147.1	-37.5	17,621.7	-9.1	46,254.3	-27.9	30,511.3	-36.8	19,198.0	-1.0	49,709.3	-22.5
	Min	9,493.7	5,817.9	16,280.1	17,459.3	83.9	11,151.1	91.7	31,340.7	92.5	21,707.8	128.7	12,837.2	120.6	38,356.8	135.6
	Avg.	30,111.4	13,808.2	43,919.6	24,150.0	-19.8	14,399.1	4.3	38,549.1	-12.2	27,373.3	-9.1	15,845.4	14.8	43,218.6	-1.6
	S.D.	13,363.9	4,347.0	16,785.8	3,473.7	-74.0	1,759.7	-59.5	4,599.4	-72.6	1,893.4	-85.8	1,677.0	-61.4	2,600.1	-84.5

(Source: Koontanakulvong S., et. al. 2006)

Upper Chao Phraya River basin: The average water demand in wet season was 60.8 MCM and the average water demand in dry season was 28.8 MCM. The average annual water demand was 89.6 MCM

Sa- Gae Grang River basin: The average water demand in wet season was 23.8 MCM and the average water demand in dry season was 29.7 MCM. The average annual water demand was 53.5 MCM

All over study area: The average water demand in wet season was 924.7 MCM and the average water demand in dry season was 861.3 MCM. The average annual water demand was 1,786.0 MCM

The water demand in the near future and far future will be as follows (Table 2.8).

Nan river basin: The average near future water demand will be 1,26.9 MCM, which will increase 7.4% and the average far future water demand will be 1,334.2 MCM, which will increase 10.5% from the present period water demand. When consider in seasonal aspect, the average water demand in wet season will be 564.8 MCM that will increase 8.0% from the present period. The average far future water demand in dry season will be 774.9 MCM which increase 12.4% from the present period.

Ping river basin: The average near future water demand will be 319 MCM, which will increase 15.9% and the average far future water demand will be 315.7 MCM, which will increase 14.7% from the present period water demand. When consider in seasonal aspect, the average near future water demand in wet season will be 204.2 MCM that will increase 14.2% from the present period. The average near future water demand in dry season will be 114.8 MCM which will increase 19.2% from the present period. The average far future water demand in wet season will be 201.8 MCM which will increase 12.9% from the present period. The average far future water demand in dry season will be 113.8MCM which increase 18.2% from the present period.

Yom river basin: The average near future water demand will be 189.4 MCM, which will increase 17.8% and the average far future water demand will be 184.1 MCM, which will increase 14.5% from the present period water demand. When consider in seasonal aspect, the average near future water demand in wet season will be 169.3 MCM that will increase 17.9% from the present period. The average near future water demand in dry season will be 20.1 MCM which will increase 17.5% from the present period. The average far future water demand in wet season will be 68.0 MCM which will increase 52.7% from the present period. The average far future water demand in dry season will be 116.1MCM which increase 579.5% from the present period.

Upper Chao Phraya river basin: The average near future water demand will be 102.2 MCM, which will increase 14.0% and the average far future water demand will be 98.9 MCM, which will increase 10.3% from the present period water demand. When consider in seasonal aspect, the average near future water demand in wet season will be 69.3 MCM that will increase 14.1% from the present period. The average near future water demand in dry season will be 32.9 MCM which will increase 14.0% from the present period. The average far future water demand in wet season will be 67.0 MCM which will increase 10.2% from the present period. The average far future water demand in dry season will be 31.9 MCM which increase 10.5% from the present period.

Sa- Gae Grang river basin: The average near future water demand will be 63.4 MCM, which will increase 18.5% and the average far future water demand will be 61.7 MCM, which will increase 15.3% from the present period water demand. When consider in seasonal aspect, the average near future water demand in wet season will be 30.6 MCM that will increase 28.7% from the present period. The average near future water demand in dry season will be 32.8 MCM which will increase 10.3% from the present period. The average far future water demand in wet season will be 29.9 MCM which will increase 25.8% from the present period. The average far future water demand in dry season will be 31.7 MCM which increase 6.8% from the present period.

All over study area: The average near future water demand will be 1,970.9 MCM, which will increase 10.4% and the average far future water demand will be 1,994.5 MCM, which will increase 11.7% from the present period water demand. When consider in seasonal aspect, the average near future water demand in wet season will be 1,038.2 MCM that will increase 12.3 % from the present period. The average near future water demand in dry season will be 932.7 MCM which will increase 8.3% from the present period. The average far future water demand in wet season will be 926.1 MCM which will increase 0.2% from the present period. The average far future water demand in dry season will be 1,068.4 MCM which increase 24.0% from the present period.

Table 2.8. The seasonal comparison of water demand in near future, far future

Basin		Present			Near Future						Far Future					
		wet	dry	annual	wey	%	dry	%	annual	%	wey	%	dry	%	annual	%
Nan	Max	1,425.1	1,318.1	2,743.2	1,672.2	17.3	1,710.6	29.8	3,382.9	23.3	953.9	-33.10	1,831.7	39.0	3,343.8	21.9
	Min	805.8	49.4	952.6	953.9	18.4	44.6	-9.7	1,077.0	13.1	1,512.1	87.6	163.9	231.9	1,131.5	18.8
	Avg.	1,052.6	969.7	2,022.3	1,198.0	13.8	1,105.0	14	2,303.0	13.9	878.5	-16.50	1,210.7	24.9	2,376.9	17.5
	S.D.	178.2	428.1	570.1	202.3	13.5	521.0	21.7	665.2	16.7	1,166.1	554.4	528.1	23.4	658.5	15.5
Ping	Max	1,365.6	533.0	1,823.0	1,601.0	17.2	657.3	23.3	2,167.2	18.9	1,439.2	5.4	528.8	9.3	1,941.7	6.5
	Min	705.6	185.9	891.4	798.7	13.2	233.3	25.5	1,038.8	16.5	742.8	5.3	213.5	14.9	956.3	7.3
	Avg.	877.3	364.1	1,241.4	983.9	12.2	419.1	15.1	1,403.0	13.0	974.2	11.0	433.4	19.0	1,407.6	13.4
	S.D.	191.2	119.1	265.6	210.7	10.2	148.5	24.7	314.2	18.3	191.6	0.2	127.7	7.3	272.5	2.6
Yom	Max	825.3	108.0	873.4	1,090.6	32.1	50.3	-53.4	1,133.9	29.8	992.0	20.2	54.2	-49.8	1,023.2	17.1
	Min	454.3	25.3	543.5	581.4	28.0	14.1	-44.3	606.8	11.6	980.7	115.8	52.2	106.5	594.9	9.5
	Avg.	638.9	48.9	687.9	772.6	20.9	27.5	-43.8	800.1	16.3	972.3	52.2	44.2	-9.7	792.5	15.2
	S.D.	99.7	26.0	92.6	133.1	33.5	10.7	-59	132.4	43.0	967.0	869.8	43.7	67.9	130.2	40.6
Upper Chao Phraya	Max	427.5	38.0	465.5	503.8	17.8	44.0	15.6	547.5	17.6	455.2	6.5	44.3	16.5	495.2	6.4
	Min	292.2	30.9	330.2	321.0	9.9	34.7	12.1	362.2	9.7	334.2	14.4	33.8	9.2	376.8	14.1
	Avg.	343.6	37.1	380.7	392.4	14.2	41.8	12.7	434.3	14.1	382.1	11.2	40.8	10.0	423.0	11.1
	S.D.	38.2	2.1	38.6	46.2	20.8	2.4	13.1	46.9	21.4	34.8	-8.90	2.6	27.1	35.2	-8.9
Sa- Gae Grang	Max	148.6	125.4	263.4	158.8	6.8	177.2	41.3	336.1	27.6	148.6	-0.0	159.8	27.4	302.2	14.7
	Min	96.2	99.6	195.8	106.9	11.1	114.1	14.5	221.0	12.9	101.4	5.4	112.9	13.4	228.6	16.8
	Avg.	122.3	113.4	235.7	127.9	4.6	146.5	29.2	274.4	16.4	126.5	3.4	141.2	24.6	267.7	13.6
	S.D.	16.7	9.2	22.5	16.5	-0.9	15.1	64.1	29.3	30.4	15.8	-5.2	12.9	40.5	23.3	3.5
all area	Max	4,192.2	1,970.8	6,162.9	5,026.4	19.9	2,541.1	28.9	7,567.5	22.8	4,520.0	7.8	2,559.8	29.9	6,886.4	11.7
	Min	2,522.8	699.3	3,222.2	2,910.8	15.4	784.7	12.2	3,695.6	14.7	2,704.8	7.2	750.3	7.3	3,455.0	7.2
	Avg.	3,052.3	1,563.9	4,616.2	3,486.1	14.2	1,754.7	12.2	5,240.9	13.5	3,420.0	12.0	1,903.6	21.7	5,323.6	15.3
	S.D.	464.2	466.2	800.2	562.7	21.2	620.5	33.1	1,035.6	29.4	513.1	10.5	583.5	25.2	962.1	20.2

(Source: Koontanakulvong S., et. al. 2006)

2.10. Adjusted reservoir operation rule curve

This study collected the future release data form the adjusted Reservoir Operation of Sirikit Dam which proposed by Chaowiwat W. (2013). For the analysis of water release rules from Sirikit Dam, it can be considered from the patterns of reservoir release. The release rules can be determined from the proportion between the monthly release and effective storage corresponding to water year.

The release ratio can be classified based on the effective storage of the water year and probability which is classified into five levels i.e. higher (Probability >= 0.9), high (0.9 > Probability >= 0.7), medium (0.7 > Probability > 0.3), low (0.3 >= Probability > 0.1) and lower (Probability <= 0.1), respectively. However, the improvement of release ratio cannot reduce water deficit.

The reduction of water deficit should be considered with water allocation rules. Water management will be more effective and sufficient to the water demand.

The simulated storage obtained from the reservoir water balance model can be used to formulate new reservoir operation by setting the lower rule curve at the probability of 0.2 and upper rule curve at the probability of 0.8 in each month. The proposed reservoir rule curves of Sirikit Dam as demonstrated in Figure 2.8

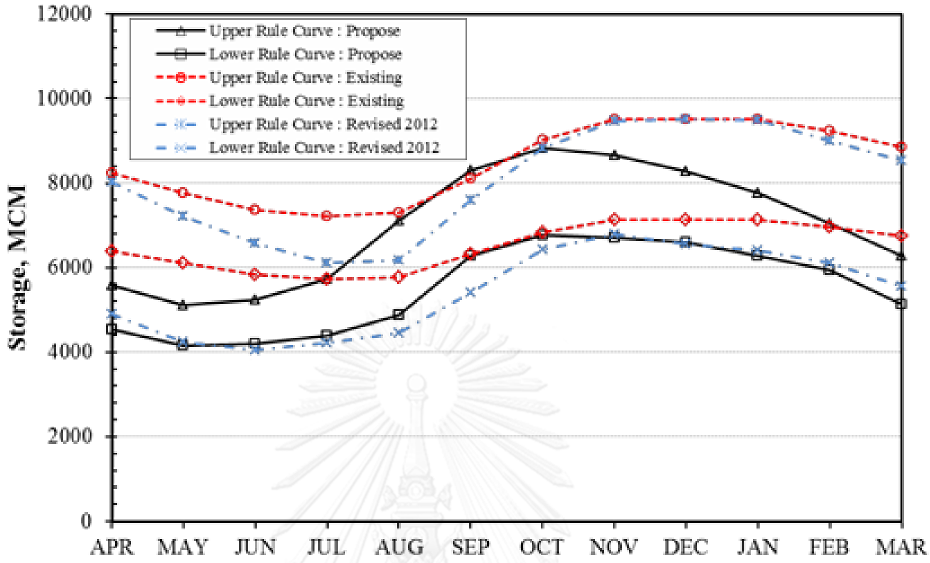


Figure 2.9. The proposed reservoir rule curves of Sirikit Dam

Source: Chaowiwat W. (2013).

CHAPTER III
LITERATURE REVIEWS

The references from the literature review for this thesis includes groundwater system, techniques use in classifies groundwater pumping potential, conjunctive, climate change impact on groundwater and adaptation for drought risk reduction. The summary is shown as follows:

3.1. Groundwater system

Recharge may be represented as either gross recharge (the volume of water that infiltrates through the unsaturated zone and crosses the water table) or net recharge, net recharge may simply be approximated by the difference between rainfall and remotely sensed total ET estimates minus runoff (Crosbie et al. 2015). For field estimates of recharge, the water table fluctuation (WTF) method is commonly used to estimate gross recharge (Healy and Cook 2002; Meinzer and Stearns 1929)

At a catchment scale, this relationship may also be deduced from water balance studies. It was observed that during the Australian Millenium Drought of 1997–2008, in the Mediterranean climate regions of south Western Australia (Hughes et al. 2012; Petrone et al. 2010) and south eastern Australia (Petheram et al. 2011), that catchments with low relief and moderate rainfall showed significantly more reduction in runoff than higher-relief high-rainfall catchments. The studies suggested that the relatively shallow groundwater levels in these catchments resulted in increased runoff during pre-drought conditions due to a reduced storage capacity in the unsaturated zone. Although this level of detail in the recharge function may not be required for models with larger spatial and temporal scales, it should not be ignored where quantification of recharge to shallow groundwater is required.

The factors that affect groundwater recharge include climate, particularly precipitation and potential evapotranspiration (PET), vegetation cover, soil texture, macropores and preferential pathways, soil moisture, surface topography and depth to groundwater or bedrock.

Changes in the magnitude of groundwater recharge will not always occur in the same direction as precipitation changes. Recharge is not only influenced by the magnitude of precipitation but also by its intensity, seasonality, frequency, and type. Other factors, such as changes in soil properties or vegetation type, and water use can also affect recharge rates. Van Roosmalen L et al. (2007) concluded that changes in groundwater recharge rates were highly dependent on the geological setting of the area

Pratoomchai, W., Kazama, S., Hanasaki, N., Ekkawatpanit, C. and Komori, D.(2014) describes a catchment-scale study on projected groundwater recharge and storage in the Upper Chao Phraya River basin under changing climate scenarios. The period from 2026 to 2040 was assessed using climate projection results from global climate models (GCMs). The projected changes in groundwater recharge and storage were quantified as percent differences from the simulated recharge and storage for the reference period (1986–2000). This change in rainfall pattern was projected to reduce the mean annual groundwater recharge (storage) by −12.9%, −9.7%, −13.9%, and −10.7% for the RCP 2.6, 4.5, 6.0, and 8.5 scenarios, respectively.

3.2. Techniques use in classifies groundwater pumping potential

Jain et al. (2009) proposed a zoning of spatial-temporal changes of water table depth, to understand the risk of groundwater stress in Andhra Pradesh (India). Chen et al. (2010) also used water table spatial-temporal change to develop a groundwater suitability zone for expansion of irrigated agriculture. The fluctuation of the water table is also one of the most widespread bases for estimating aquifer recharge (Healy and Cook 2002). In this aspect, the elevation of the water table in the rainy (or flood) period may be used to estimate the recharge surplus in the water budget of the aquifer. In the context of cyclic conjunctive use of groundwater and surface water, the areas with more recharge would replenish the aquifer more efficiently in the rainy (or flood) period, after the abstraction stress of the dry period.

Kriging and Co-kriging are used as standard tools to interpolate groundwater table levels based on observation wells (Ahmadi and Sedghamiz 2008; Nikroo et al. 2010; Moslemzadh et al. 2011). However, the confidence in the interpolation of the water table depends on whether the statistical assumptions of stationarity and normality are reached by the samples (Peterson et al. 2011) and should be evaluated both by results of cross-validation and by the coherency of the trends in the interpolation map, especially in the areas that are more distant from the observation points (Desbarats et al. 2002, p. 35).

3.3. Conjunctive use

Zhang X(2015) has review the status of conjunctive use under climate change, the irrigation is the largest water use in the world, accounting for about 70% of global water withdrawals and about 90% global consumptive water use (Döll et al., 2012). The conjunctively coordinated management of surface water and groundwater could achieve the maximum benefits of efficient use of total water resources (de Wrachien and Fasso , 2002). Barlow et al. (2003) developed a conjunctive management model through coupling numerical simulation with linear programming optimization model into a general framework to determine sustainable yield of the alluvial-valley stream-aquifer systems. Tradeoffs between groundwater withdrawals and stream flow depletion were analyzed. An integrated surface water and groundwater management model could meet urban water demand in the Jakarta region, Indonesia (Syaukat and Fox, 2004). Net benefits from cropping activities were maximized considering water demand and availability. An increase of groundwater development was suggested to handle the surface water shortage problems.

Many researches attempted to incorporate climate change impacts into the planning and management issues in conjunctive water use (Hoekema and Sridhar, 2013; Pingale et al., 2014). The application which using Texas water availability modeling (WAM) system by incorporating a climate model and a watershed hydrology model in the Brazos River Basin in Texas showed a general decrease in the mean stream flow due to decreased precipitation and increased temperature-induced greater evapotranspiration (Wurbs et al, 2005). The significantly-varying effects of climate change on water availability were found in various regions and among various water users. Water supply shortage would increase from 4.0 m^3/s under the historical climate scenario to 8.9 m^3/s under the 2050 climate scenario. Hanson et al. (2010) used an extended MODFLOW with Farm Process (MF-FMP) to analyze conjunctive surface water and groundwater use management

In Thailand, a physically more precise formulation of the complicated relationships between stream flow and groundwater storage has been set up and implemented into a surface-groundwater interaction model by Orhan and Aral (2005). Bejranonda et al. (2007b) used a groundwater model for conjunctive use patterns investigation in the upper central plain of Thailand, whereas Bejranonda et al. (2007a) developed a physically more pertinent semi-coupled model by combining the SWAT surface water- and the MODFLOW groundwater model and applied it to the upper Chao Phraya surface- groundwater system.

3.4. Climate change impact on groundwater

Natural groundwater recharge occurs directly from rainfall recharge and focused recharge via leakage from surface waters bodies (streams, lakes and wetlands), and it is highly dependent on the prevailing climate, land cover and underlying geology. Climate and land cover largely influence precipitation and evapotranspiration process, whereas the geomorphology and formations dictate whether a water surplus (precipitation minus evapotranspiration) can be transmitted and stored in the subsurface. Döll P and Fiedler K (2007), Döll P (2009) and Wada Y et al. (2010) estimated that the diffuse recharge globally ranges from 13 000 to 15 000 km^3/yr, which is equivalent to 30% of the world’s renewable freshwater resources or a mean per capita groundwater recharge of 2 100 to 2 500 m^3/yr

(Taylor R G et al. 2012). These estimates represent potential recharge fluxes because they are based on a water surplus rather than measured contributions to aquifers. Spatial variability in modeled recharge is related primarily to the distribution of global precipitation. In Himalayan watersheds, climate change will produce reductions in glacial mass and increased evaporation of groundwater recharge, which is projected to be offset by increases in precipitation (Immerzeel W. W., et al. 2012).

The only global-scale estimates of climate change impacts to groundwater recharge are those developed by Döll P and Fiedler K (2005). Based on calculations from the global hydrological model WGHM (Water GAP Global Hydrology Model), these authors estimated diffuse recharge (1961-1990 baseline) at the global scale with a resolution of 0.5° by 0.5° and then simulated the impacts of climate change for the 2050s under a high (A2) and low (B2) greenhouse gas emission scenario. These global estimates identify regions where groundwater is potentially vulnerable to climate change; however, they are not appropriate for scaling down to a country or watershed scale. Precipitation and groundwater systems can vary significantly between watersheds, and this variability has not been incorporated into Döll P and Fiedler K's (2005) modeling; moreover, their method only represents diffuse recharge-recharge from rivers, and other surface waters were not accounted for.

Climate change is expected to modify the hydrological cycle and affect freshwater resources. Groundwater is a critical source of fresh drinking water for almost half of the world's population and it also supplies irrigated agriculture. Groundwater is also important in sustaining streams, lakes, wetlands, and associated ecosystems (Treidel H et al. 2011). However, the impacts of climate change on groundwater quantity and quality in Thailand are poorly understood.

The direct impacts of climate change on natural processes (groundwater recharge, discharge, storage, saltwater intrusion, biogeochemical reactions, chemical fate and transport) may be exacerbated by human activities (indirect impacts, Treidel H et al. 2011).

For groundwater systems, the natural variability in groundwater quantity and quality will depend on the size of the capture zone and the scale of the groundwater system (Kløve B et al. 2014). Groundwater plays an integrated role in sustaining certain types of aquatic, terrestrial and coastal ecosystems and the associated landscapes (humid and arid). A lack of control over groundwater resource development and protection has negative impacts on certain aquatic fauna (Foster S. and Kemper K. 2004).

Shresthaa, Bachb and Pandeya (2016) was study climate change impacts on groundwater resources in Mekong Delta under representative concentration pathway (RCPs) scenarios. Average annual temperature and precipitation were considered as indicators of future climate. It found that groundwater recharge is projected to decline in short-, medium-, and long-terms. As a result, groundwater levels and storage are also projected to decline in future. The future recharge in wet season at the end of 21st century is projected to remain almost same value of 28 mm as in the baseline period, but in dry season it is expected to decrease by 2 mm and 4 mm under RCP4.5 and RCP8.5 scenarios, respectively.

Srisuk and Nettasana (2017) was reviewed the climate change and groundwater resources in Thailand. There are lack of knowledge of groundwater recharge mechanism. A change in rainfall patterns in the Upper Chao Phraya Basin will reduce the mean annual groundwater recharge(storage) by 12.9% (1.46 km3), 9.7% (1.35 km3), 13.9% (1.49 km3), and 10.7% (1.38 km3) (Pratoomchai W et al. 2014). Suthidhummajit C and Koontanakulvong S (2011) evaluated the climate change impacts on groundwater at the Wang Bua Irrigation Project in Kampheng Phet province and found that additional fluctuations in the rainfall patterns, reduced rainfall in the wet season and more rainfall in the dry season will occur. Groundwater level fluctuations are sensitive to the pumping scheme and seasonal factors.

3.5. Adaptation for drought risk reduction

Due to the flood event in year 2012, RID was assigned by the Thai government to be a major agency to arrange the plan for managing the main dams and arrange the water management of nation in year 2012. The objective is to improve water management system of nation and main dams to be efficient and to increase the capacity to protect and mitigate flood problems that occurred in each year (RID. 2012). The main dams in the Chao Phraya River Basin were also affected from the flood event in year 2012. Since then RID had modified the main reservoir operation rule curves to response to the flood event that may happen again in the future.

Chaowiwat W.(2013) study proposed to improve the reservoir release rules of Sirikit Dam via fuzzy neuro inference techniques (ANFIS) with responding of water demand of irrigation, water supply, industrial and environmental release in order to minimize the water shortage and flood at the downstream. The main study area included Sirikit Dam and Nan River Basin, for the concerned area is Yom, Wang, Ping River Basin and Chao Phraya Irrigation Project. It is found that the developed adaptive reservoir operation system can mitigate the water shortage and flood more effectively, i.e. the proposed reservoir operation system can improve water release to satisfy with water demand and reduce the peak of flood at the downstream compared with the existing general and flood rule curves.

The adaptation measures of irrigation systems for the future climate change (JIID, 2012), are proposed as follows:

Non-structural measures:

- Monitor climate warning
- Adjust cropping pattern
- Adjust agricultural area
- Adjust reservoir operation rule curves
- Participation of stakeholders/ water users
- Knowledge dissemination
- Improve telemetering system

Structural measures :

- Improve irrigation efficiency
    - Improve irrigation efficiency
    - Improve watershed management
- prepare temporary storage such as farm ponds
- reforestation
- Increase reservoir storage
    - Enhance dam embankment

- Dredging sediment
- Sediment control

It is recommended to review all irrigation operational manuals by adding future climate conditions and possible adaptation measures/scheme(s), and to assess the impact to other irrigation projects/regions or other reservoir operation for preparedness in the country using the drafted impact assessment manual developed from the study

CHAPTER IV

THEORIES AND TECHNIQUES USED

The theories and techniques used for this thesis includes equations used in groundwater model, land recharge formula, water balance and techniques used in classifying groundwater pumping potential. The summary is described as follows:

4.1. Groundwater model

Investigation tool that groundwater hydrologists may use for a number of applications. Groundwater model used in this study is MODFLOW (the USGS's three-dimensional (3D) finite-difference groundwater model). MODFLOW is considered an international standard for simulating and predicting groundwater conditions and groundwater/surface-water interactions. The three-dimensional movement of groundwater of constant density through porous earth material may be described by the partial-differential equation

$$\frac{\partial}{\partial x}\left[K_{xx}\frac{\partial h}{\partial x}\right]+\frac{\partial}{\partial y}\left[K_{yy}\frac{\partial h}{\partial y}\right]+\frac{\partial}{\partial z}\left[K_{zz}\frac{\partial h}{\partial z}\right]+W=S_s\frac{\partial h}{\partial t} \qquad (1)$$

where

K_{xx}, K_{yy} and K_{zz} are the values of hydraulic conductivity along the x, y, and z coordinate axes (space function).

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)).

S_s is the specific storage of the porous material (space function).

t is time.

4.2. Land recharge formula

From the water budget analysis in the soil layer, the simple water budget is

$$P = ET+\Delta S+R_{off}+D \qquad (2)$$

where

P is precipitation:

ET is evapotranspiration:

ΔS is change in water storage in soil column:

R_{off} is direct surface runoff:

D is drainage out of the bottom soil which is equivalent to recharge(R)

From the above relation, The recharge can be approximated simpler by using following equation (Krüger, A., Ulbrich, U., & Speth, P.,2001) with the assumption of no change in water storage in soil column:

$$R = P-ET-Q_0 \qquad (3)$$

Where Q_0 is runoff outflow (or Roff in equation (2)),

Water recharge can be modified as a linear function of a unit of precipitation and temperature by manipulating the equation(3) (with the assumption that runoff is zero in the regional scale) as follow:

$$R/P=a_i*(P-ET)/P +b_i \qquad (4)$$

where

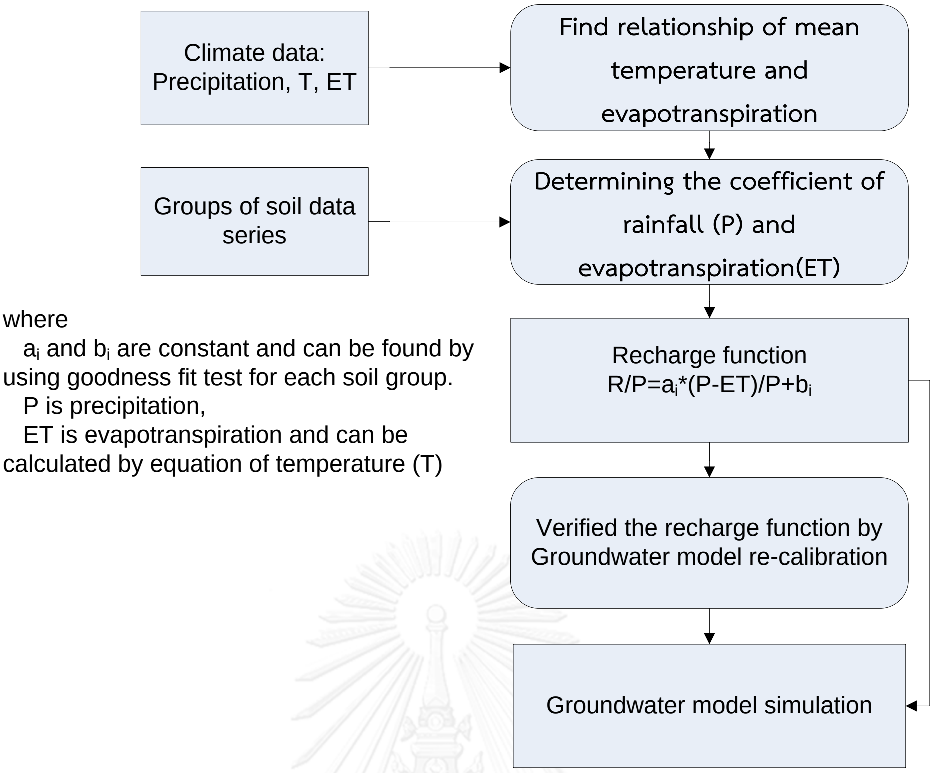
a_i and b_i are constant and can be found by using goodness fit test for each soil group.

b_i is a constant which incorporates the effects of runoff outflow

P is precipitation, and ET is evapotranspiration and can be calculated by equation of temperature (T) (Singh, V. P.,1992):

$$ET = c*T+d \qquad (5)$$

where c and d are constants and can be found by using regression fit for each month.



where
a_i and b_i are constant and can be found by using goodness fit test for each soil group.
P is precipitation,
ET is evapotranspiration and can be calculated by equation of temperature (T)

Figure 4.1. Formulation steps of groundwater land recharge formula

4.3. Water balance analysis

Analyzed water deficit in existing and future periods from water balance equation

$$Def(i) = Re(i) - D_{ir}(i) \tag{6}$$

where Def(i) = Water Deficit, MCM,
S(i) = Water Supply (Surface water and Groundwater), MCM

4.4. Techniques used in classifying groundwater pumping potential

In this study, the Techniques use in classifies Groundwater Pumping Potential is analysis of Spatial-temporal Patterns of Water Table Change as a tool for Conjunctive Water Management the concept in each step as follows:

1) Collect data sources

This study used the groundwater and surface water data from the upper central plain of Thailand compiled by Koontanakulvong (2006). The data were acquired from the Groundwater Department of Thailand, the Department of Industry Works, the

Royal Irrigation Department and the water authorities at the provincial, municipal and village levels.

2) Collect the Geomorphological map

The geomorphological map of the area followed the geomorphological framework proposed by Takaya (1971), Murata and Matsumoto (1974), Haruyama (1993). The floodplain (back swamps and levees) system is surrounded by systems of fans and terraces and is bottlenecked by a geomorphic threshold on its southern boundary. The map was developed based on field surveys performed in January 2014

3) Collect rainfall and stream flow

Monthly rainfall time series were collected from 23 rainfall stations. Using the time series, Thiessen polygons with centers at each rainfall station were delineated on the Aquifer. The annual and monthly rainfall at each station was weighted proportionally to the area of the respective polygon overlying the aquifer surface.

4) Interpolation

- Kriging techniques

To interpolate the water table and yield data points, Kriging and Co-Kriging techniques were employed, making use of the Geostatistical Analyst tool in the ArcGIS 10.1 software. The parameters used in the interpolations were optimized by cross validation. Simple Kriging was used to interpolate the yield data using the dataset containing all of the wells.

- Data subsets and respective thresholds

To investigate the spatial–temporal changes in the water table, the observation wells with measurement dates were used as the primary dataset. To compare hypotheses regarding these changes, the dataset was divided into subsets via various approaches. In the approaches that used rainfall and stream flow as the controlling thresholds and in the approach that differentiated between sets before and after 1992/1993, the analyses were designed to determine both the cause of the changes in the water table and the effects on the proposed conjunctive use of the water resources.

- Data normalization

As the observation data from the wells are not randomly or regularly spaced, there are areas with higher sampling densities. For this reason, it was important to use a normal score transformation of the samples and a declustering technique, which are available as part of the simple Kriging approach in the Geostatistical Analyst tool, to ensure that the histogram sample better reflects the population histogram(ESRI 2005, p. 211).

- Co-Kriging procedure

The results of the Kriging of water table data from the wells that have measurement dates were compared to the Co-Kriging interpolation using the water table observations that lacked measurement dates as a secondary auxiliary dataset. As the interpolation proceeded farther from the primary observation points, the Co-Kriging gradually used the cross covariation between the primary and the secondary datasets to improve the predictions (Desbarats et al. 2002). Because the subsets contained observations from various locations, the key role of the auxiliary data in the method used in this study was to provide a fixed reference in the areas with fewer observations and thus guarantee a minimum coherence between the compared interpolation maps of the complementary subsets.

- Radial basis interpolation of pumping rate

The rates of pumping from the wells were grouped in squared grids of 10,000 ha each. These values were divided by the areas of the grids, and each specific pumping value (m3/day/ha) was attributed to the centroid of each grid. Subsequently, the values at the centroids were interpolated using the radial basis function in the Geostatistical Analyst tool.

5) Integrated zoning

- Multivariate maps

The objective of the zoning is to illustrate areas that have a greater or lesser potential to expand the conjunctive use of groundwater and surface water. The proposed multivariate visualization technique consists of a set of six maps: three univariate maps and three multivariate maps. This paper presents three map sets: (1)

natural potential, (2) human interaction potential and (3) integrated zoning (composed of the integrated results of two first sets and the well yields).

- Histogram ranking and visualization techniques

The histogram of the univariate layers was stretched into rank percentiles in relation to the raster pixels (equivalent to the Histogram Equalize remote sensing technique of Muray (1996, p. 190–191)). This procedure was performed to focus on the areal differentiation and make the variables comparable among one another. Based on the percentile rank, the legend of each univariate layer shows the quantile distribution of the box plot. The multivariate map sets (each with 3 multivariate maps) were developed for the intermediate zoning (natural potential and human interaction potential) and for the final integrated zoning.

6) Qualitative zoning

A final zoning was determined based on the qualitative interpretation of the patterns identified in the maps presented in this study. To discuss the physical meaning of their spatial heterogeneity, the quantitative values were also analyzed with regard to their distribution among the primary geosystems identified in the geomorphological map.

This study used the qualitative zoning combined with the groundwater pumping level limit concept to find the pumping potential for groundwater use in the future. The groundwater level limit set as not lower than 15 meters below the ground surface, this limit is from the study of Koontanakulvong, S.(2002) which set by the capacity of farmer pumping not more than 15 meters below the ground surface.

CHAPTER V

GROUNDWATER SYSTEM CHARACTERISTICS ASSESSMENT

The groundwater system characteristics assessment for this thesis includes groundwater model development, land recharge formula, groundwater pumping potential assessment and groundwater system characteristics under conjunctive use in the present period. The study developed the groundwater model to simulate the groundwater system in the study area with soil based recharge formula. The study developed the climate-soil based recharge formula and improve the groundwater modeling. The pumping potential area is explored by using groundwater parameter and physical properties of the study area by mapping and Kriging techniques.

5.1. Groundwater model development

The objective of this groundwater model development is to simulate the flow of this aquifer and to use this model for understanding the groundwater system under conjunctive use and its changes due to climate change impact in the next section.

5.1.1 Model Design

The aquifer system in this study was defined as a two-layer aquifer, whereby the thickness of the upper, semi-confined layer varies between 40 and 100 m and that of the lower, confined layer between 100 and 300 m (Figure 5.1).

The grid design for this conceptual model using the 3-D block-centered grid model representing the groundwater basin, which has a grid-size 10kmX10 km, resulting in 320 elements in the layer 1 and 346 elements in the layer 2 (Figure 5.2).

The boundary condition of this model is defined as the western, eastern and northern borders of the model where assumed as an impermeable body of consolidated rock and were defined as specific inflow boundaries (total 587 million m^3/year) derived from the available head distribution along these boundaries. The southern boundary, which is partially blocked by impermeable rocks and forms a narrow trough between the mountains in the east and west, was set as an outflow boundary. A previous study on the lower Central Plain groundwater basin (Siriputtichaikul, 2003) provided an outgoing flow rate between the upper and lower plain of 56 million m^3/year and this number was also used here.

An average land recharge estimate based on the amount of rainfall and soil type of each area. The rate of land recharge is in the range 0.08% -1.2% of amount rainfall by each soil types. The average amount of land recharge was 555 million m^3/year, derived from rainfall and from a map of the soil-type and its infiltration rate (Koontanakulvong, S., 2002), was applied on the top layer and on the outcropping sections of the lower layer.

The river-aquifer interaction of the five main rivers giving an average annual recharge of 337 million m^3 were derived from the hydraulic properties of the river bed materials, the river cross-sections, the river stages and the seasonally varying computed groundwater table. The river cross-sections were shown in Figure 5.4. As for the possibility of return flow of irrigated water into the canals, we assumed it negligible since, (1) the drainage canals in the irrigation area are usually nearly dried out, except during the flood season and, (2) the irrigation area covers only 13% of the entire model where the overall recharge takes place.

The hydraulic conductivity and specific storage were estimated from pumping tests data. The hydraulic conductivity in this study area is in the range 0.5-200 m/day. The specific storage is in the range $1.0 \times 10^{-3} - 5 \times 10^{-2}\ m^{-1}$. In addition, the aquifer properties as well as vertical leakage were obtained from three previous sub-regional groundwater models of the area (Jindasagnon, 1997; Chulalongkorn, 1998). The vertical leakage is 2.0×10^{-5} m/day. The land recharge, river stages, surface and groundwater use were adapted in response to the climatic conditions, namely, in terms of the amount of rainfall and the water year.

2-layer aquifer conceptual model.

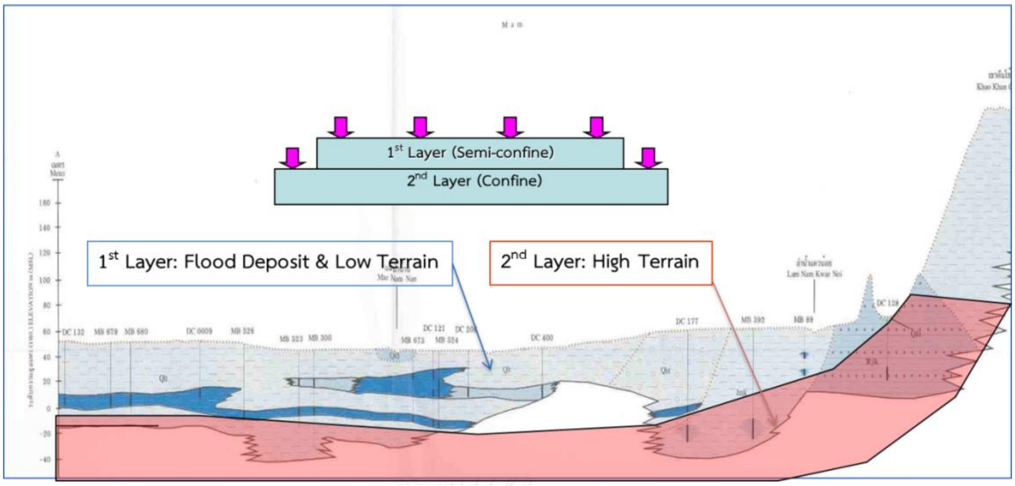


Figure 5.1. 2-layer aquifer conceptual model.

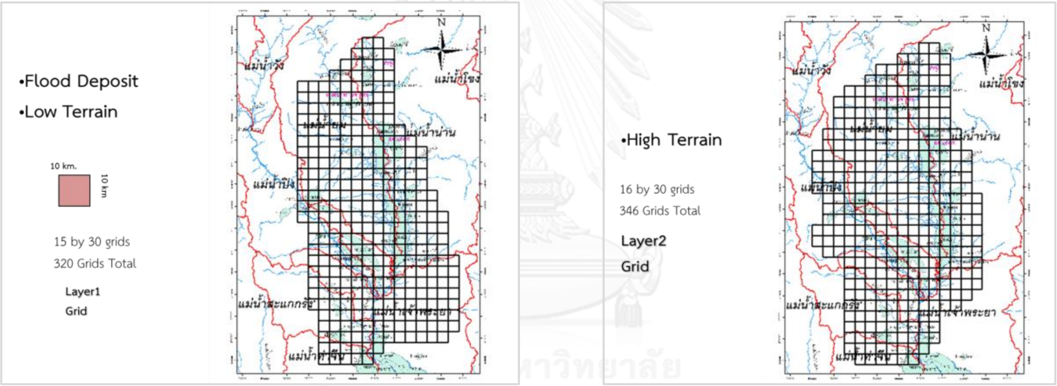


Figure 5.2. Model grid design.

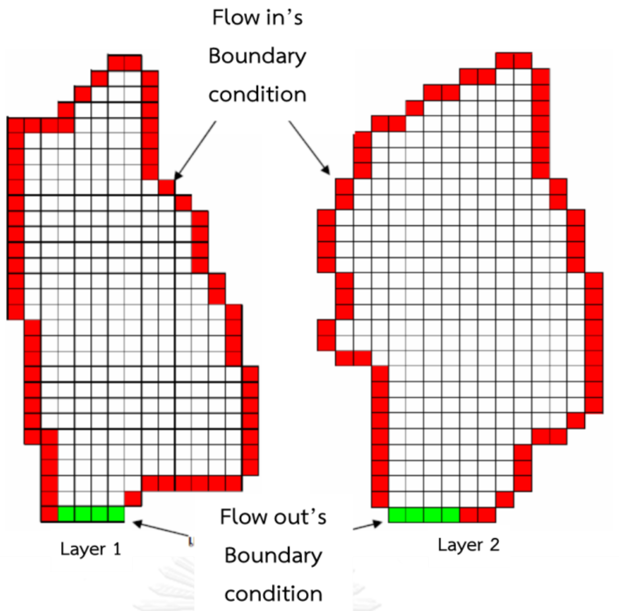


Figure 5.3. The boundary condition

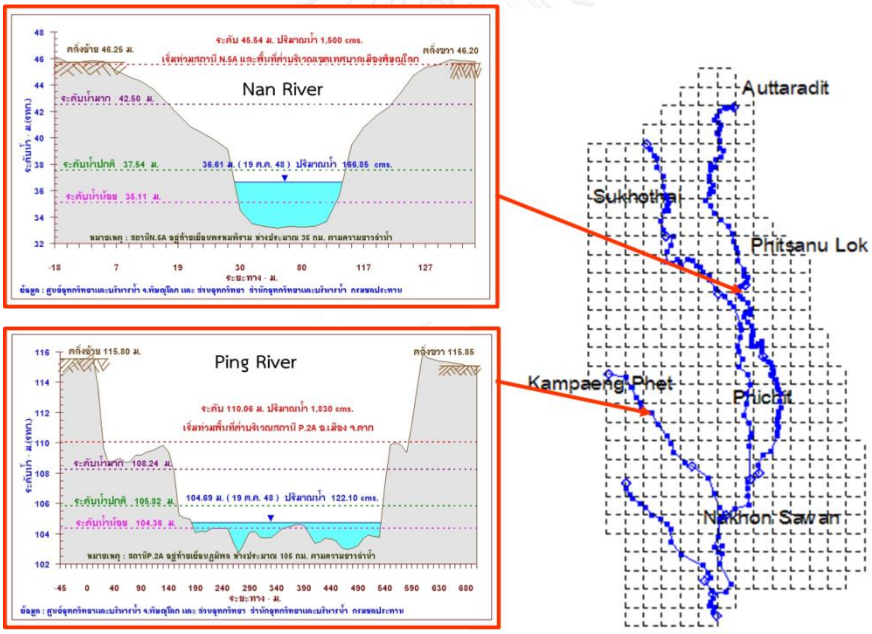


Figure 5.4. The main river paths and river cross-sections

5.1.2 Groundwater Pumping

The major groundwater use in this area is by agriculture, namely, for rice and some sugar cane in the western section of study area. Since the crop pattern is seasonally planed, the agricultural stress-period used in the model is also based on the climatic conditions, i.e. the wet and dry seasonal cycle. Agricultural wells are usually installed by the farmer to supplement a shortage of surface irrigation water, therefore, records often do not exist and the pumping behavior is unknown. Because of this reason, the past study (Koontanakulvong, S., et al. 2006) selected a pilot study area inside the Plychumpol irrigation project area in Phitsanulok province to investigate the actual water use pattern, farmers' behavior and constraints, i.e. harvest terms, groundwater pumping hours, pumping rates, maximum water drawdown, etc. Moreover, 500 questionnaires were distributed to 30 sample sub-districts located in five surface-basins throughout the entire study area.

The major pumping statistics retrieved from the survey is summarized in Table 5.1. From the data listed there one can deduce that the average pumping capacity per well is 41m^3/hour, whereas the average pumping rate per well is 79m^3/day inside the irrigation project, and 76m^3/day outside. As for the groundwater-well database, it is based on records of the year 2003. The historical yearly record of the wells in each province during 1993–2003 has been converted to a growth rate of the well concentration for the future. As mentioned, besides the seasonally triggered agricultural water use, the latter depends also on the surface water supply available during the time which, in turn, is linked to the actual storage of two main upstream reservoirs, the Bhumibol and Sirikit reservoirs which provide surface-water and irrigation water to this area (Koontanakulvong S., 2002). The usable storage of these two reservoirs on May 1st was used to define the situation of surface water availability, namely, wet, normal, dry and drought. The yearly pumping rates were weighted relative to this surface water situation, using 1999 as the base year as it has been a drought year, i.e. when the pumping rate has been at a maximum. In addition, agricultural groundwater use was rechecked by considering the amount of compensable water to the agricultural surface-water shortage, which was calculated from the water demand using the model WUSMO and, a water balance using the model MIKE BASIN. (Koontanakulvong S., et al. 2006). The disribution of pumping wells using in gorundwater model as Figure 5.5 (a)

Table 5.1. Average pumping frequency from five surface-basins with 500 questionnaires (Koontanakulvong, S., et al. 2006)

Area	Harvest frequency (crops/year)	Season	Number of pumping for each crop (times)	Duration of each pumping (days)	Pumping period each day (hours)
Irrigation	2.5	dry	6.0	2.6	19.3
		wet	3.8	2.3	19.3
Rainfed	2.0	dry	6.5	3.1	22.0
		wet	3.1	2.1	16.0
Pilot area (irrigation)	2.28	dry	5.4	4.9	20.4
		wet	3.5	4.5	23.8

5.1.3 Calibration and verification

Model calibration and verification/prediction was performed in steady state as well as in transient state. Following the seasonal crop pattern, the seasonal stress period was used in the calibration of two years of recorded historical groundwater levels. The early water level data were obtained from registered wells that recorded water levels during well construction. Since during 2001–2003, the groundwater use was almost stable, due to a constant situation for the surface water, the average water level during the dry season of 2003 was selected to be the representative steady-state water level for the calibration. 13 groups of the hydraulic conductivity were adjusted during the steady-state calibration process. There are 77 data sets of observation wells for using to compare the simulated heads from groundwater model (Figure 5.5). Figure 5.6 illustrates the observed and simulated steady-state groundwater levels for the semi-confined layer 1. The simulate and observed heads are in good agreement with the root mean square calibration error is 3.70 m and a mean error of 0.97 m. The scatter-plot of the observed versus modeled heads shown in the left panel of Figure 5.6

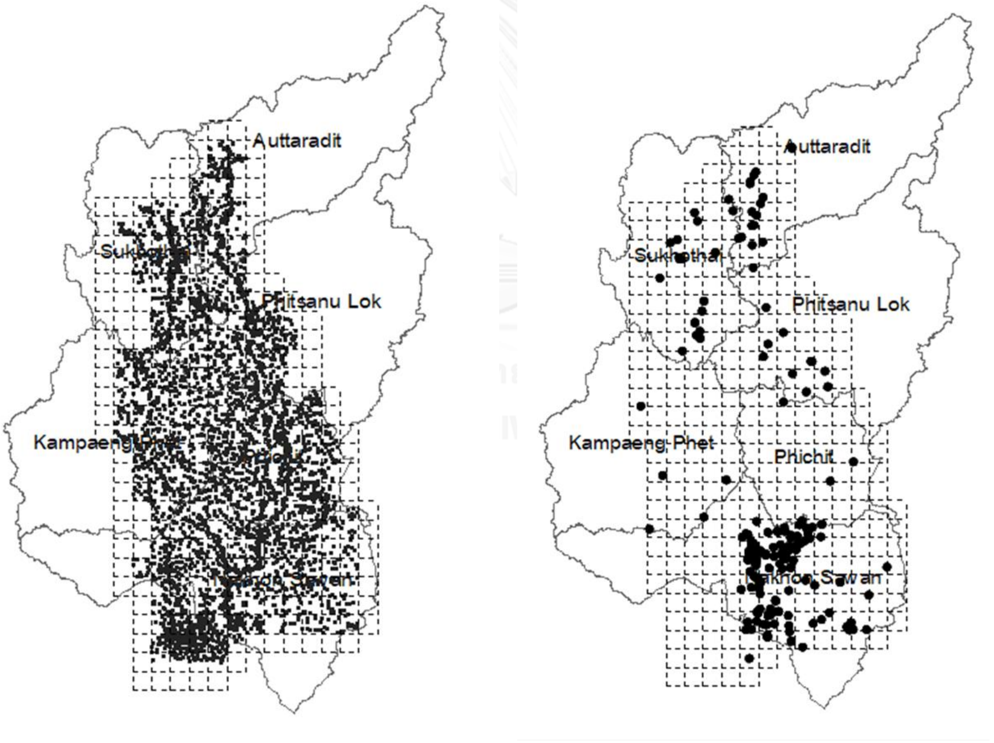
Calibration in transient state has been carried out, using the 1993–2003 historical water levels, whereby groups of specific storage have been calibrated. The transient simulation is initialized from an average wet-season water level. There are 124 data sets of observation wells for using to compare the simulated heads from groundwater model. During the transient-state calibration, the pumping rate weights were fine-tuned, as these are often prone to errors. In transient state, a root mean square calibration error is 5.11 m and a mean error of 2.85 m.in transient mode (see Figure 5.6, right panel). There are some simulated head that have error more than 10 m because these observation wells are near the boundary which out of concerned area. The verification model, using two years of groundwater level monitoring data (2004–2005), has been performed, resulting in a root mean square error of 5.95m and a mean error of 3.84 m.

5.1.4 Model results

The groundwater flow simulations show that, depending on the surface water availability, the water levels are, on average, about 4m below ground surface in the wet season, but drop to 6–9 m below ground surface in the dry season. Significant head drops of 2.5–7m are observed between the wet and the dry season in one year, especially in the dry season of a drought year, when the head changes amount to 3–8 m. The water inflow-outflow (shown in Figure 5.7 for dry season) illustrates that the total groundwater use was 1.29 MCM/day (236.7MCM/season) in 2003. For the year 2003, the total inflow amounts to 1.45 MCM/day (276.7MCM/season) and the natural outflow to 0.15 MCM/day (27.9MCM/season). Furthermore the aquifer contributes only an average 12% of the annual aquifer-recharge into the rivers in the wet season, but is recharged from the rivers in the dry season with 42% of the total recharge in dry season. Moreover, over recent times, while the groundwater use has been increasing and the surface water supply decreasing, the river-aquifer interaction has been declining.

The groundwater flow model has been used to compute historical seasonal groundwater uses, based on the assumption that the ratio of groundwater use in the dry season is 2–4.3 times that in the wet season of the same year which referred from investigation of groundwater pumping behavior (Koontanakulvong, S. et al.,

2006) . Moreover, the results of the study show clearly that the farmers are the major groundwater users in this region with 715 MCM/year, with a ratio of groundwater use of 91%:5%:4% for the agricultural, domestic and industrial sectors, respectively. Figure 5.8 show the variation of conjunctive use ratio in the range 8%-25% which correspond the water year. The variation of conjunctive use ratio (CJ ratio) was shown in Table 5.2. The values of the average, minimum, maximum and Standard deviation were 15.5%, and 8.6%, 24.8% and 35.9%., respectively. The groundwater use patterns vary significantly with the water availability situation, as farmers are attempting to compensate the lack of surface water by groundwater during drought years. The groundwater use runs inversely with the surface water use, and that during the drought years 1994 and 1999, an increasing amount of groundwater had to make up for the scarcity of surface water.



(a) pumping wells (b) Observation wells

Figure 5.5. Location of pumping wells (a) and Observation wells (b)

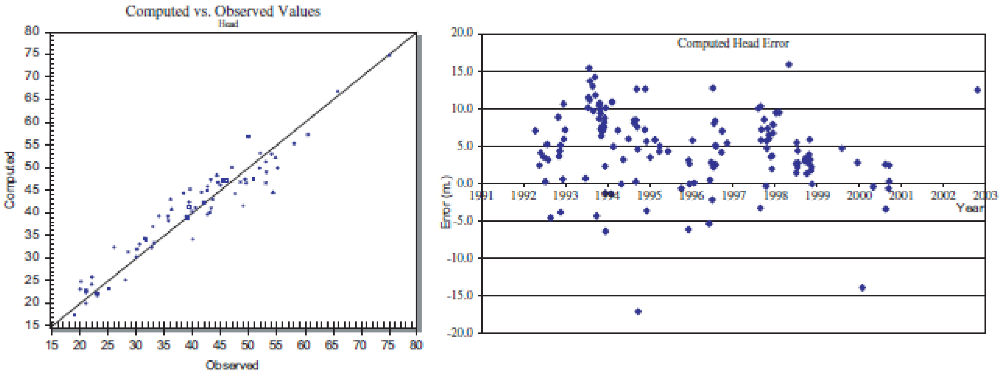


Figure 5.6. Computed versus observed heads for layer 1 in steady state (left panel) and error as a function of time in layer 1 for the transient simulation (right panel).

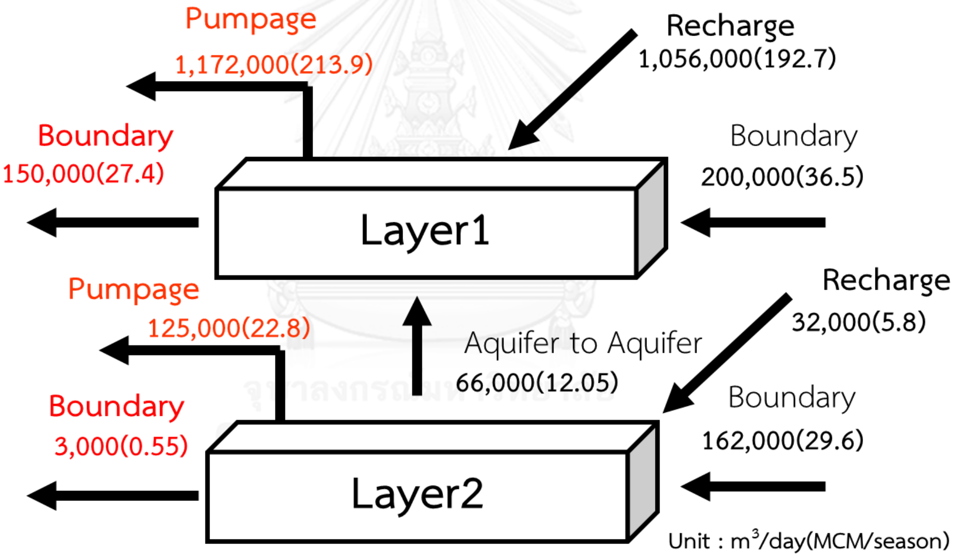


Figure 5.7. Groundwater balance (Dry season, 2003)

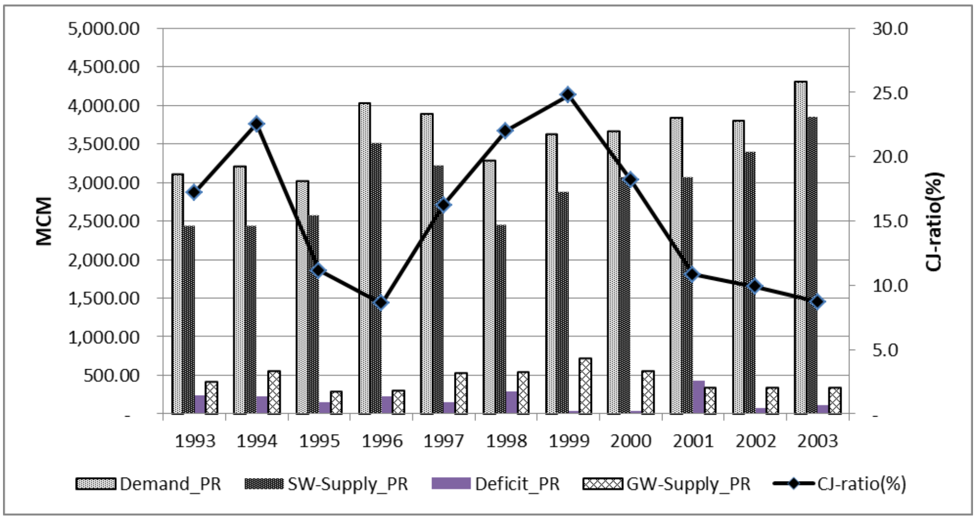


Figure 5.8. Comparison of water demand, groundwater supply, surface water supply, water deficit and CJ-ratio

Table 5.2. The Variation of water demand, surface water supply, groundwater supply, water deficit and Conjunctive use ratio (CJ ratio)

Values	Demand (MCM)	SW-Supply (MCM)	GW-Supply (MCM)	Deficit (MCM)	CJ Ratio(%)
Average	3,621.81	2,995.47	445.94	180.40	15.5
Min	3,019.84	2,443.30	286.86	31.43	8.6
Max	4,311.02	3,858.09	714.58	435.31	24.8
SD	414.32	482.99	139.42	120.19	35.9

5.2. Land recharge formula

The land recharge is the dominant factor of flow in to the groundwater system which many research commented that need to study the impact of climate change (AR5 IPCC, 2014; Srisuk and Nettasana, 2017). In Koontanakulvong, S., et al.(2006)'s study, recharge rates were defined by percentage of rainfall in each soil group zone and the land recharge played an important role as an input to groundwater system. In this study, in order to response to climate change impact, the land recharge formula was developed. Soil zone was grouped in 7 zones by the similarity of soil series property as shown in Figure 5.9.

1) Find relationship of mean temperature and evapotranspiration

The data of mean temperature (T) and calculated evapotranspiration (ET) between 1993-2003 referred Chulalongkorn (2010). This study use linear regression to find the relationship between T and ET as equation (5) in monthly basis. A comparison of ET and mean T have relationship as linear function as shown in Table 5.3. From Table 5.3, the computed ET are in good agreement, the R^2 of each month are 0.4 and 0.9. The coefficient c and d are in range 2.9-8.4 and -105-70, respectively.

Table 5.3. Coefficients of linear function expressed relationship between evapotranspiration and mean temperature in each month.

Month	c	d	R^2
Jan	8.4	-107.5	0.4
Feb	8.4	-107.5	0.4
Mar	8.4	-107.5	0.4
Apr	2.9	70.5	0.9
May	4.0	27.3	0.9
June	2.9	22.8	0.9
July	3.0	23.8	0.9
Aug	2.9	23.9	0.9
Sep	3.1	23.4	0.9
Oct	3.4	23.9	0.86
Nov	5.0792	-20.275	0.99
Dec	3.9656	-0.8793	0.87

2) Determining the coefficient of rainfall (P) and evapotranspiration(ET)

In this step, recharge values in each soil group were arbitrary input into the groundwater model (from 5.1) and the best guest of recharge values in each soil group zone are decided by minimizing error between calculated and observed peizometric values. The observed wells for this step in all soil groups are 142 wells. The summary error for each soil group zone as shown in Table 5.4

Table 5.4. Error summary in each soil group

Soil group zone	Mean error	Abs. Mean Error	RMS Error
1	1.8	2.2	6.3
2	1.0	2.0	5.1

Soil group zone	Mean error	Abs. Mean Error	RMS Error
3	2.4	2.3	5.7
4	2.3	2.2	6.0
5	2.4	2.6	6.5
6	3.2	3.1	7.2
7	1.6	1.6	3.9

The rates of groundwater recharge in each soil group zone from the above groundwater model were used to develop relationship between recharge and amount of monthly precipitation minus monthly evapotranspiration per precipitation (Equation 4). Results demonstrated good relationship between groundwater recharge fluxes with amount of monthly precipitation minus monthly evapotranspiration as shown in Table 5.5

To verify the formula derived, the recharge rates from the equation were compared with permeability class (Bejranonda W., et.al., 2007) and classification properties of each soil series (Sridhavat Na Ayudhya, S.,1995), Table 5.6 shows the classification of each soil group zone of this study and Figure 5.9 shows the relationship of the hydraulic conductivity/permeability and the coefficient of recharge per precipitation from the study which shows good correlations. Hence, Figure 5.10 could be used to estimate the coefficient of recharge for other soil group zone from hydraulic conductivity value.

Table 5.5. Coefficients of linear formula expressed relation between (P-ET)/P and R/P.

Soil group zone	**a**	**b**	**R^2**
1	0.0034	0.0009	0.93
2	0.0045	0.0012	0.93
3	0.0057	0.0015	0.94
4	0.0068	0.0018	0.94
5	0.008	0.0022	0.94
6	0.0091	0.0025	0.93
7	0.0113	0.0031	0.93

Table 5.6. Classification of hydraulic conductivity of each soil series group zone of this study

Permeability Class(O'Neal 1952)	hydraulic conductivity(cm/hour)	Soil Group zone (This Study)
Very Slow	<0.125	1
Slow	0.125-0.5	2
Moderately Slow	0.5-2.0	3
Moderate	2.0-6.25	4
Moderately Rapid	6.25-12.5	5
Rapid	12.5-25.0	6
Very Rapid	>25.0	7

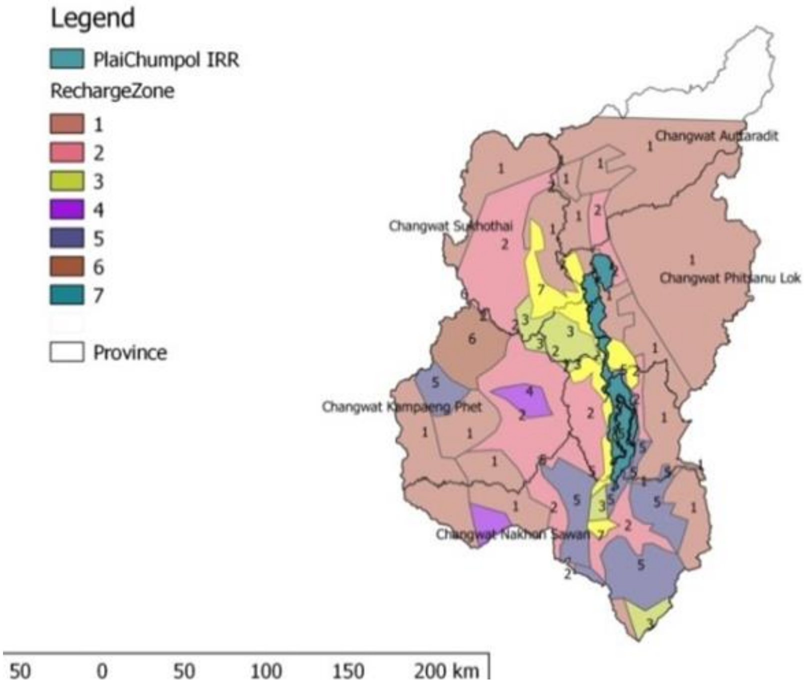


Figure 5.9. The soil group zone representing the recharge zone

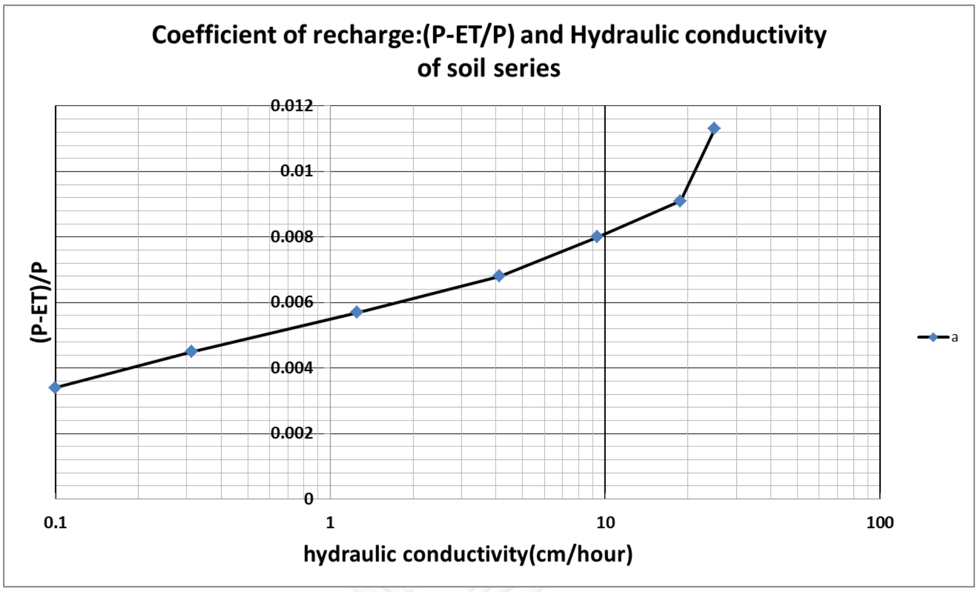


Figure 5.10. The relationship of coefficient of recharge and hydraulic conductivity in each soil series in the study area

The model was recalibrated compared with observation data using recharge equation derived. Results of recalibration model show that simulation values were closer with observation data compared with the former model calibration results as shown in Table 5.7. Figure 5.11 shows the transient error of the re-calibration by using the new land recharge equation. It presents the better simulation by decreasing the error of 26%

Table 5.7. Comparison error and recharge rate of the former model and this study model.

Error(m)	Model From 5.1	New land recharge equation	%Difference
Mean Error	2.85	2.11	26.16
Abs mean error	3.13	2.3	26.44
RMS error	5.11	3.9	15
Recharge rate(m^3/day)	1,157,597	995,113	-14.04

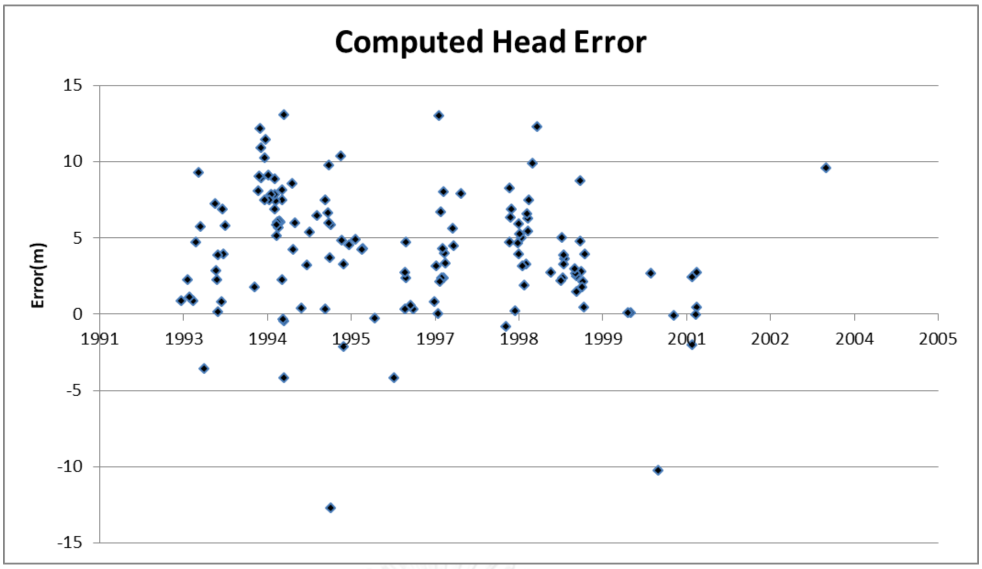


Figure 5.11. Transient errors as a function of time in layer 1 in the re-calibration

5.3. Groundwater pumping potential assessment

As a counter measure to reduce drought risk in the future, more use on groundwater pumping is expected in the study area. The assessment of groundwater pumping (how much and where to pump more) should be considered. In this section, it is joint work with Vasconcelos V.V., Koontanakulvong S., C.,Junior, P.P.M., and Hadadtive R.M.. The contribution of this section provides the hydrological data, meteorological data, hydro-geological data, pumping data and summarizing the groundwater pumping potential map.

The whole study area were classified as a piedmont plain, broadly covered with soils of dominant clay texture. However, a more detailed inspection can unveil geomorphological systems and subsystems, as shown in the proposed geomorphological map (Figure 5.12).

The mean and standard deviation of geomorphic indexes (Table 5.8) show a clear coherence with the flooding patterns of each geomorphological system, that is, [A] continuous flood for the flood plain that is lower in relation to rivers and more homogenously flat; [B] scattered flood from local rain on the tributaries sub-basins in the fans-terrace complex, which is slightly more wavier and rugged than the floodplain but is still near the rivers level; [C] no flood at the geomorphic threshold, that is higher in relation to the rivers, and which also has landscape even slightly more wavier than the fans-terrace complex.

Table 5.8. Hydro-geomorphic Indexes for each geomorphological system

Geomorphological System	**Vertical distance to Rivers Base Level (meters)**		**Slope (degrees)**		**Terrain Ruggedness Index**	
	Mean	STD	Mean	STD	Mean	STD
Floodplain	0,950	1,576	0,422	0,411	0,811	0,593
Fans-terrace	1,336	3,110	0,483	0,745	0,899	0,976
Geomorphic Threshold	3,547	5,847	0,688	1,304	1,139	1,860

On the western, northern and eastern borders of the aquifer, it is possible to identify the patterns of the fans, which reflect the original process that gave origin to the sediments of this aquifer. They present a pattern of gentle conic dissected fans on which the hydrography shows a pattern of radial divergence and the surface is gently wavier following the same radial pattern, thus generating intercalated strips of bad and well drained soils, in the respective lower and higher areas. The alluvial fans complexes are characterized by temporary, switching and diverging stream channels due to active erosion and aggradation of the less cohesive surface of outwash sediments (Takaya 1971, p. 392; Muramata and Matsumoto 1974, p. 283). These sediments are relatively porous and many channels are seasonal or suddenly vanish along their courses. Thus, the flooding patterns in these areas use to be an ever-changing mosaic of relatively small local drainage and flooding due to local rainfall.

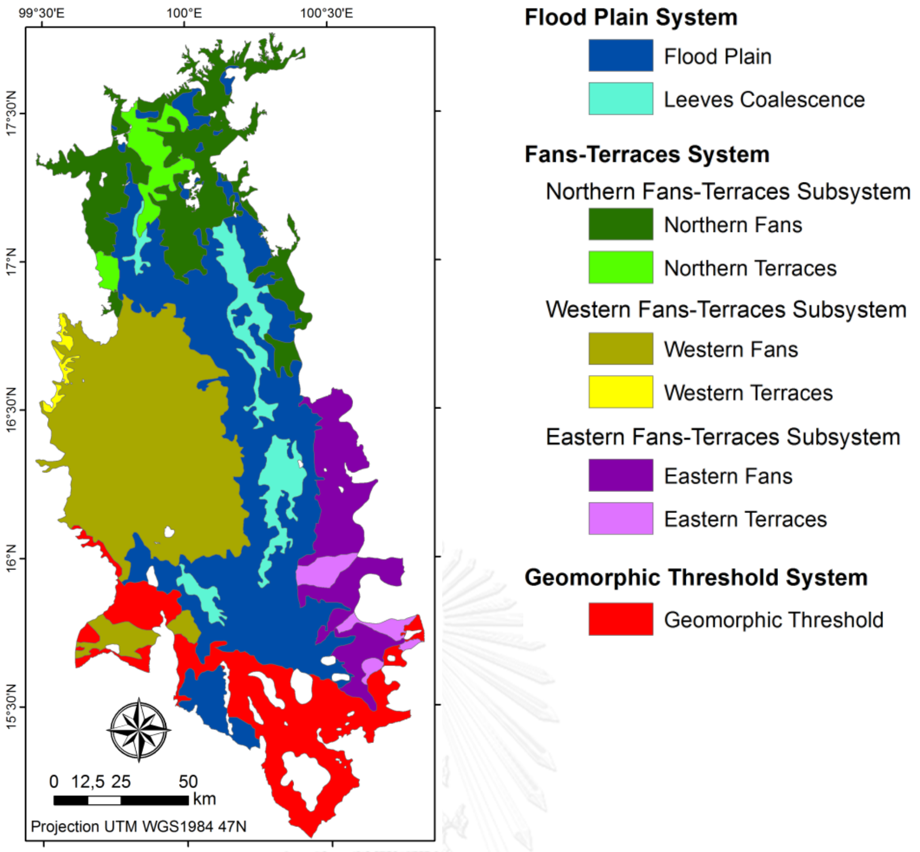


Figure 5.12. Geomorphological Map of the Younger Terrace Aquifer

The geomorphological mapping brings some useful understanding regarding the relationship between water and agricultural plants, as the conjunctive water management for agriculture should consider not only the surface and groundwater use, but also the water stored in the soil and used by the plants. On the back swamps of the floodplain, the traditional paddy fields are the most adapted crop to the hydromorphic soils, but the farmers should care about the seasonal floods in their cropping calendar. However, the flood also brings new organic matter which contributes for the soil fertility and inter-granular water retention. On the levees, the better drainage favors the orchards that supply food for the local villages and cities, which are also located along the levees in order to remain safe from the floods. On the alluvial fans, the gently wavier area generates a striping pattern where on the upper strips the farmers should take more care about the water stress in the soil, while on the lower areas there must be some eventual flood in the crops, in the case of heavy local rains. On the terraces and on the geomorphic threshold, the field crops area relatively more widespread than the paddy fields (Land Development

Department 2009a), because the formers adapt better to the soil that do not get saturated in the surficial layers. However, on all the geomorphic features, the irrigation (from surface water or groundwater) brings a better stability for agriculture production as a way to maintain the desired soil humidity along the dry season.

Rainfall and Runoff Analysis

The time-series of rainfall, runoff in wet season and runoff in dry season are presented in Figure 5.13. The three data series show coherence among them, as for the peaks in rainfall in runoff in the years of 1970, 1981 and 1995, as well of for the drier period between 1990 and 1993. However, these peaks and depressions have a different magnitude among the three series, generating different subsets in relation to the proposed thresholds. It is worth noting that a slight increase occurs in the average rainfall of the period 1993-2004 (50mm) when compared to 1968-1992, mainly because of the heavy rainfall in 1995.

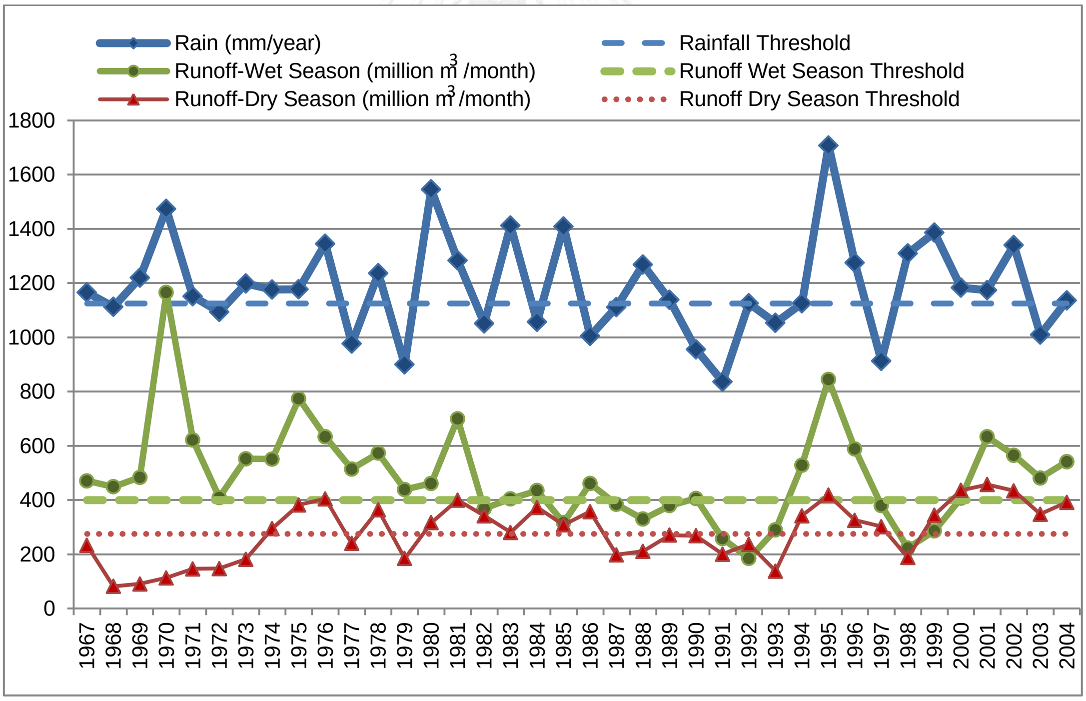


Figure 5.13. Rainfall and Runoff time series for the studied period

Tebakari (2004) analyzed that the runoff in the Chao Phraya basin in the dry season is mostly controlled by the release of the Bhumibol and Sirikit dams, rather than on natural flow. In this aspect, the separation of runoff between dry and wet season will be mainly a matter of dams' management, which depends heavily on whether the rainfall matches the weather forecast, especially at the end of the wet season. This is particularly important for conjunctive water use management, as Koontanakulvong (2006) and Bejnaronda et al. (2011) estimated that the runoff in the surficial rivers in the dry season would be the main factor controlling the inter-annual change in the amount of pumped groundwater in the region.

Table 5.9. Coincidence of wells measurement data among the different classifications (Rain, Runoff in Dry Season, Runoff in Wet Season)

Compared subsets	**Coincidence in wet/dry classification (%)**
Rain - Runoff Dry Season	60.39
Rain - Runoff Wet Season	43.83
Runoff Dry and Wet Season	66.56

The graph of Figure 5.14 compares the rainfall and runoff monthly averages. The average rainfall is 1,186 mm/year, of which 88.5% fall in the wet season and 11.5% in the dry season. The average runoff follows the general pattern of the rainfall, while also shows accentuated higher peak from August to September, when the main orographic storms use to happen in the heads of the basin, upstream from the aquifer.

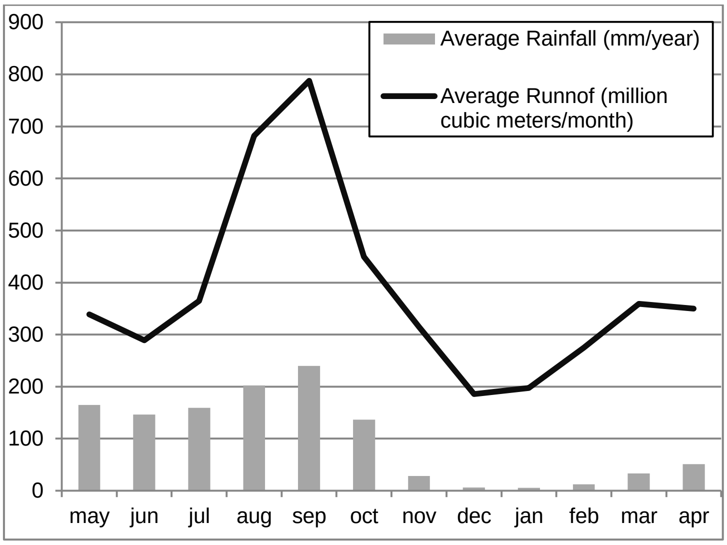


Figure 5.14. Monthly Rainfall and Average Runoff

Kriging Analysis

Table 5.10 shows that the Co-Kriging technique improved the results of the interpolation, as the procedure decreased the standard error and the root mean squared error of the interpolations, and made the standard root mean squared error nearer to 1. As a consequence, it was visually perceptible that the addition of the auxiliary data improved the coherence of the spatial interpolation in the areas that are more distant from the observation wells of the primary dataset.

The comparison of the subsets based on rainfall and runoff (both wet and dry season) showed that there is a general lowering of the water table in the dry years. It shows that the aquifer is affected more expressively on the time scale of years than of months (wet and dry seasons).

Table 5.10. Comparison of cross-validation results of Kriging and Co-Kriging interpolation

	Standard Error	**Root Mean Squared Error**	**|1 - SRMSE|**
Kriging of the whole dataset with measurement date	3.135	2.987	0.038
Co-Kriging of the whole dataset with measurement date	2.973	2.936	0.011
Kriging of the Subsets *	3.266	3.055	0.063
Co-Kriging of the Subsets *	2.962	3.008	0.055

*average results

SRMSE = Standard Root Mean Squared Error

Figure 5.15 presents the Box-Plot graph with the average results of the interpolation on the aquifer for each subset approach. The absence of a general lowering of the water table at dry seasons and comparing the periods before and after 1992/1993 support the hypothesis that the aquifer still would have a good potential for cyclic seasonal conjunctive use. The stability of the overall level of the water table between wet and dry season may indicate that the aquifer has a significant interaction with the rivers or other aquifers in order to regularize the surplus or deficit in the water balance in the wet and dry season, respectively.

It is interesting to interpret that the comparison of the subsets before and after 1992/1993 presents an elevations in the water table along the periods. One hypothesis for this difference could be due to the irrigation channels and ponds carved along the years for rice irrigation, helping the water to pass through the clay layers and thus allowing more recharge into the aquifer (the irrigation itself would also be a contributor, too). This effect was already pointed out by Bejnaronda et al. (2008), in a field study in the area, and seems advantageous for the expansion of future irrigation projects based on conjunctive water use.

Nevertheless, besides the average difference of the Box-Plot, the results over the maps (Figures 5.16-5.18) show a very distinctive spatial heterogeneity of the water table change in the aquifer. This heterogeneity may provide indicators for the areas with better potential for expansion of seasonal groundwater use.

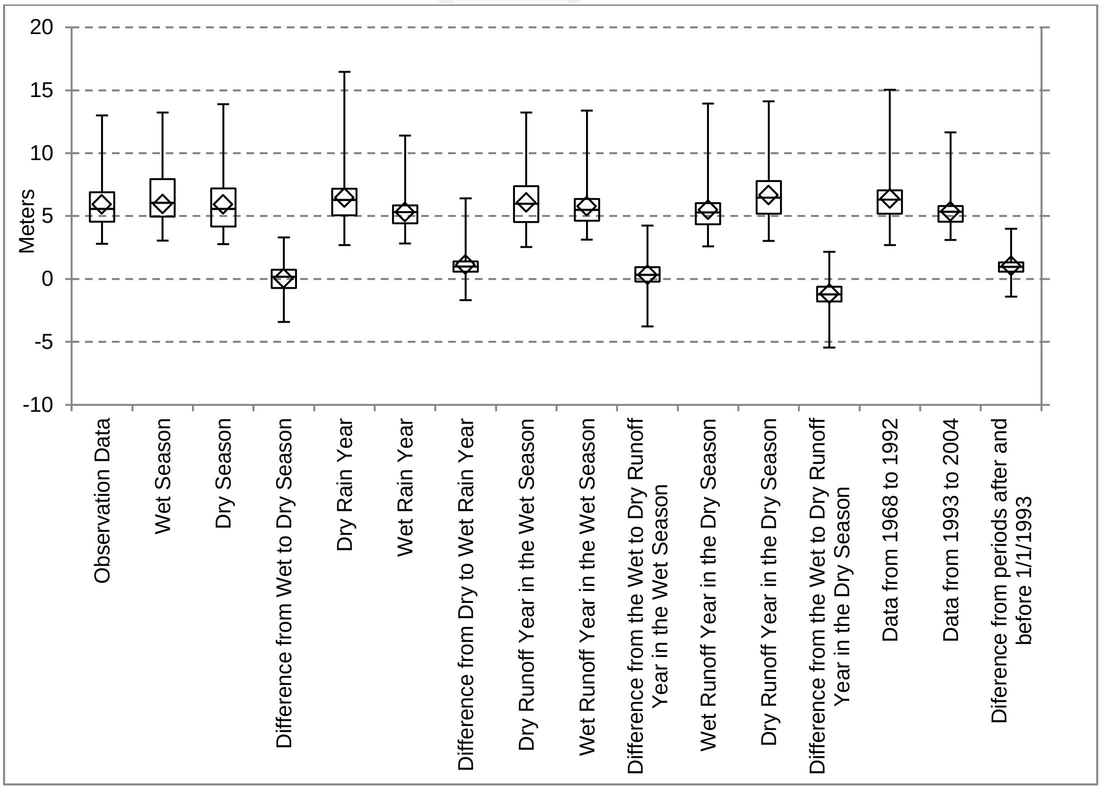


Figure 5.15. Box-Plot of the interpolation results

The variables for developing the natural potential map by multivariate analysis for expansion of conjunctive use are seasonal balance, effect of flood recharge and effects of rainfall recharge. Figure 5.16 shows that the areas with better natural favorability for the expansion of conjunctive use would be in the western fans, while the worst area would be the northern fans-terraces systems. The northern fans and the floodplain show a good potential just regarding the flood recharge. The eastern fans and the geomorphic threshold systems show good attributes regarding rainfall recharge and seasonal balance, but not for flood recharge.

The variables for developing multivariate zoning regarding human interaction map for expansion of conjunctive use of water resources. Figure 5.17 shows that the best areas would be the eastern fans-terraces system and the geomorphic threshold area. Following a north to south gradual change, the northern part of the aquifer presents mostly the favorable potential regarding the occupation progress. Reaching the latitude of the city of Phitsanulok, there is a belt with the worst values, which may be partly due to the higher pumping around the cities of Phitsanulok, Phichit, Sukhothai and Kamphaeng Phet. To the south of this belt, there is an area with good potential both regarding the occupation trends and also with fewer pumping density (the purple color indicates this convergence). Following to the southern area of the aquifer, there is the part with less water shortage stress in the dry season, with fewer pumping density, but with less potential regarding the effect of occupation trends.

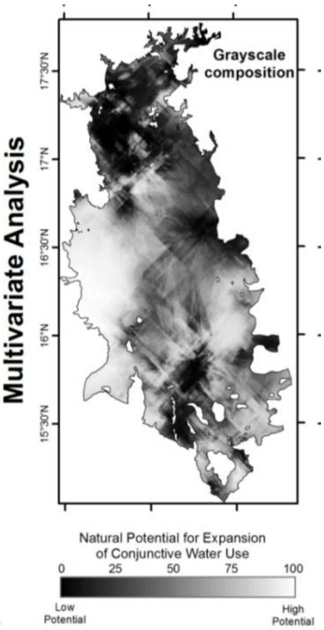


Figure 5.16. Multivariate zoning of natural potential for conjunctive use of water resources

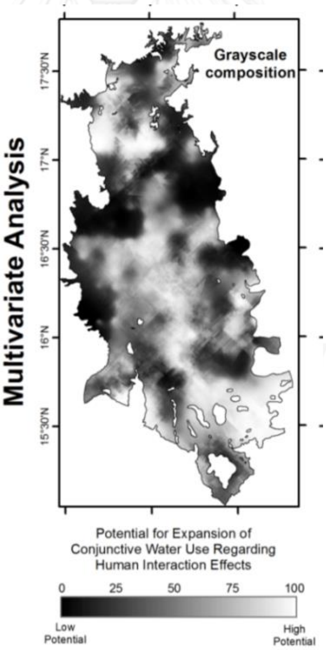


Figure 5.17. Multivariate zoning of the potential for conjunctive use of water resources

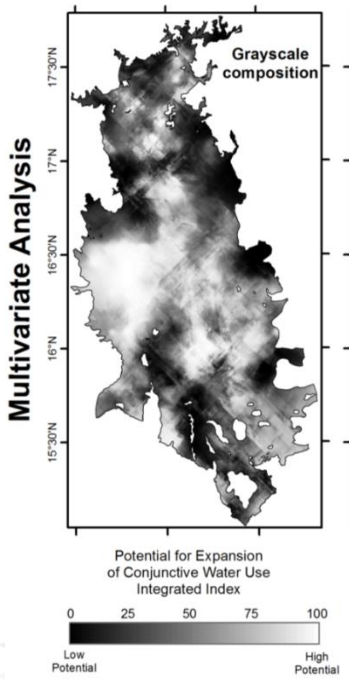


Figure 5.18. Integrative multivariate zoning regarding the expansion of conjunctive use of water resources

The variables for developing the integrated zoning were human interaction potential, wells' yield and natural potential. Figure 5.18 indicates that the better area for expansion of conjunctive use would be the western fans (except for its northern area). Moreover, the integrated maps show other spots with good overall attributes along the aquifer, many of them on the flood plain. The borders of the northern half of the aquifer show the worst overall potential, what may be partially because the aquifer has high hydraulic gradient (Figure 5.19), which make this areas diverge rather than converge the water flow, and the thinner thickness makes the aquifer exhausts easier. The geomorphic threshold and the eastern fans have good potential regarding natural and human interaction effects, but have the poorest yields. However, some areas of the geomorphic threshold with more rocky outcrops and less thickness also present poor overall results.

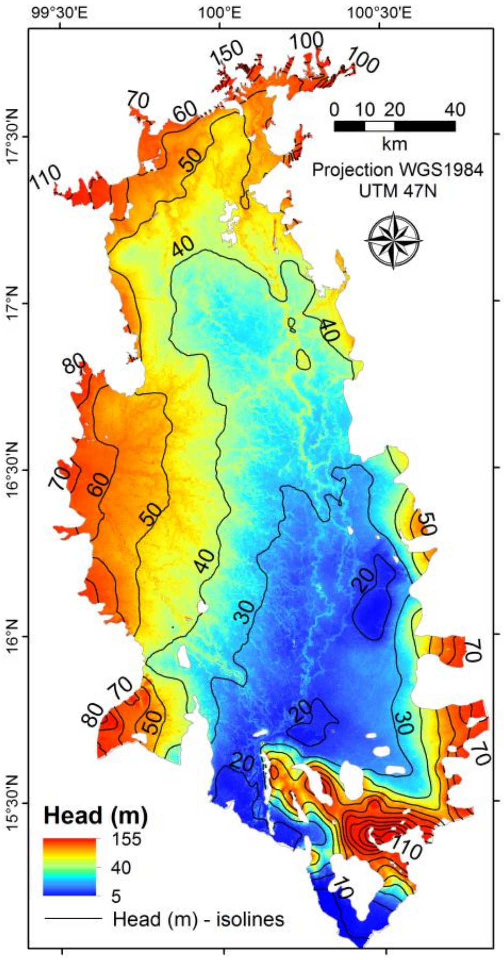


Figure 5.19. Head levels of the water table in the Younger Terrace Aquifer

The map of Figure 5.20 shows a qualitative zoning of the patterns discussed in the previous paragraphs.

Table 5.11 presents the average results of the interpolation for each geomorphological system. When compared to the average results of the fans-terraces and geomorphic threshold systems, the flood plain system shows less recharge from rainfall, more recharge from flood, more stress in the dry season, and also more stress when there is less surface water in the dry season. In contrast, the geomorphic threshold systems showed the inverse results and also less pumping, worst yield and less increase of the water table comparing the years before and after 1992/93.

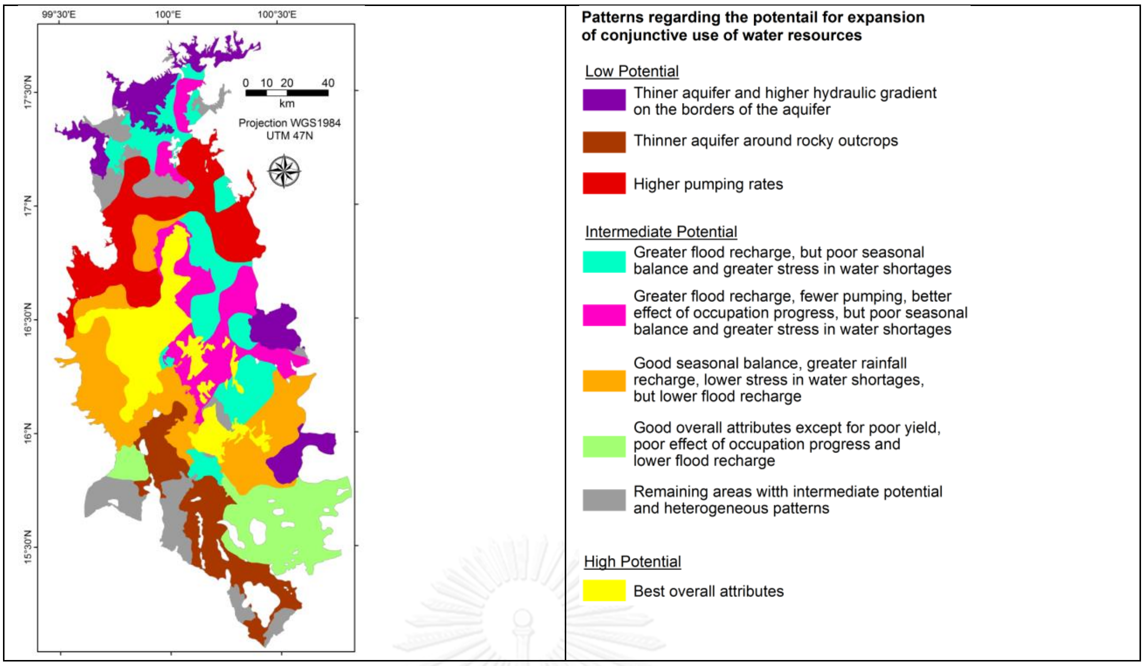


Figure 5.20. Patterns of the potential for conjunctive use of water resources.

Table 5.11. Average interpolation results of each geomorphological system.

Geomorphological System	Rain Difference	Seasonal Difference	Runoff in wet season Difference	Runoff in Dry season difference	Before and after 1992/ 1993	Pump	Yield
Floodplain	*0,487*	*-0,326*	**0,554**	-1,280	1,048	*0,101*	**6,912**
Fans-terrace (average)	0,761	0,112	0,374	-1,213	1,133	0,119	6,582
Northern	*0,137*	*-0,922*	**1,029**	*-1,292*	**1,552**	0,115	6,502
Western	**0,993**	**0,773**	0,320	*-1,287*	*0,820*	**0,122**	**7,249**
Eastern	**1,125**	-0,053	*-0,528*	**-0,884**	**1,325**	**0,117**	*4,869*
Geomorphic Threshold	0,804	**0,709**	*-0,547*	**-0,780**	*0,581*	*0,046*	*4,176*
Whole Aquifer	0,672	0,036	0,320	-1,181	1,034	0,103	6,389

Remarks: The red and italic fonts depict the two lower values and the blue bold fonts depict the two higher values (not taking into account the average for the fans-terrace system as a whole, but considering each of the three subsystems)

A plausible hypothesis for the smaller amount of rainfall recharge in the floodplain could be the increased deposition of clay along the quaternary story of the flood plain, hampering the percolation of the pluvial water. This thick clay layer also could hamper the leakage from rivers in the dry season, contributing to the more intense drawdown in that period of the year. Evaluating the patterns for the flood plain, for a strategy of conjunctive use expansion, the abstraction in the flood plain should pay higher attention to water table lowering in this area. However, there would be also a positive counterbalancing effect because, while the thicker clay layer hampers the leakage from rivers to the aquifer in the dry season, thus groundwater abstraction in that season would affect less the conflicts for surficial water use downstream in the Chao Phraya river basin.

The fans-terraces system showed average results between the floodplain and the geomorphic threshold. However, when this system is subdivided into northern, western and eastern subsystems, the results are clearly different. The northern fans-terraces subsystem has results much closer to the flood plain and, many times, even slightly more accentuated. As the flood plain and the northern fans area intertwined in the northern part of the aquifer, this likeness between them could be due to a similar water use pattern, or similar aquifer attributes and processes, as well as maybe due to a thicker clay layer covering the northern area of the aquifer as a whole.

The western fans-terrace subsystem, in its turn, has the better water budget (fluctuation) of the water table in the dry season. Lastly, the eastern fans-terraces subsystem is the less affected by the flood recharge and also has the worse yield, very similar to the one of the geomorphic threshold system. Two possible factors leading to these patterns in the western fans and the geomorphic threshold system could be the thinner thickness of the aquifer and the influence of the clay and silt from igneous rocks, mixed in the sediments of this aquifer (as pointed by Takaya (1971, p. 394)).

The integrated zoning and the comparison among the subsystem also shows a general spatial trend in the overall results, starting from the north (northern-terraces) and flood plain, then changing gradually to the western, eastern and, especially to southern edges of the aquifer (geomorphic threshold). This pattern is coherent with the flow of the aquifer, which can be inferred by the overall head elevation of the dataset (Figure 5.19), as each side which contributes for the aquifer (north, west and southeast) shows a different pattern for the zoned attributes.

The terraces and of the coalescence of levees, as for being intertwined within the broader systems (fans and flood plain, respectively), usually reflected the same pattern surrounding them. Because of their smaller areas, the regional scale results of the Kriging interpolation maybe could not reflect precisely their effect in the local water table.

As a conclusion, the comprehension of these patterns can group in 3 zones as Figure 5.21. It is already a useful contribution for water conjunctive use management. Therefore, the high potential zoning is able to indicate areas that could have higher or fewer potential for the expansion of the cyclic use of groundwater along the dry seasons. The intermediate potential areas with higher yield, higher recharge from rainfall and flood and less drawdown considering pumping, water shortages and inter-seasonal balance should be considered the better ones for conjunctive use. In the low potential areas, it would be better to have increased caution regarding the amount and the timing of groundwater use for future planning in the next section (adaptation measure).

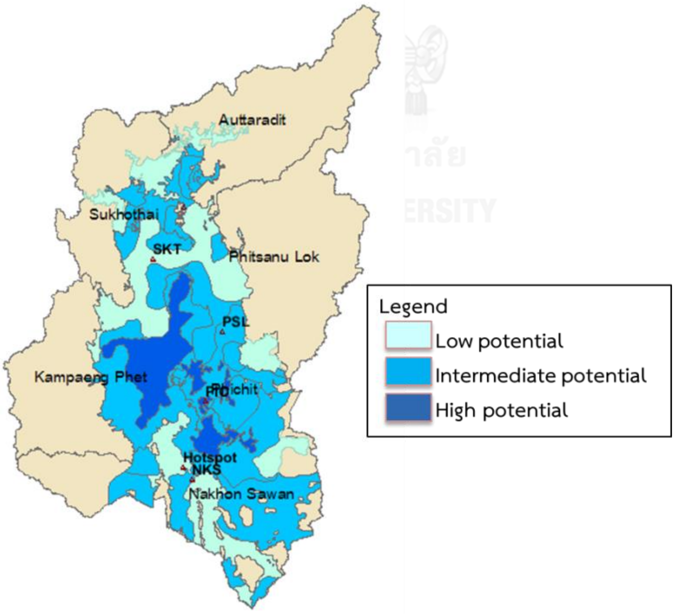


Figure 5.21. Groundwater pumping potential map

5.4. Groundwater system characteristics under conjunctive use

The characteristics of groundwater system under present period (without climate change impact) were investigated to have better understandings on how are the flow-in, storage, flow-out of groundwater system. The situation of conjunctive use pattern and ratio was also investigated especially in the dry years to see the role of groundwater to supplement water to the study area.

The recharge equation in section 5.2 was put in groundwater model to simulate groundwater situations in 1993-2003. The average groundwater system in annual, wet and dry season are shown in Figure 5.22-5.24. The land recharge, boundary's flow in and the leakage from layer 2 were the flow in groundwater system in annual, the flow volume were 433 MCM, 73 MCM and 105 MCM, respectively. The river recharge, groundwater pumping, groundwater storage change and Boundary's flow out were the flow out groundwater system In annual, the flow volume were 103 MCM, 446 MCM, 8MCM and 55 MCM, respectively . The seasonal flow budget in groundwater system is shown in Table 5.12. The percentage of each component of groundwater system compared with the total flow in/ total flow out are shown in Table 5.13. When considered in annually flow in, there are land recharge, flow in from boundary and Leak from lower aquifer. It can be seen that land recharge was the dominant annual flow in, the percentage was 55%. When considered in annually flow out, there were the river recharge, groundwater pumping and flow out to boundary. The dominant annual flow out was groundwater pumping (80.9%).

Figure 5.25 shows the groundwater system in time series, the represent groundwater levels are fluctuated with groundwater pumping and recharge, the change of head between wet season and dry season was 5-10 m.

Figure 5.26 shows the average groundwater system in each water year, the volumes of land recharge in each water year are 455.79 MCM, 387.66 MCM, 434.00 MCM and 504.47 MCM, respectively. The volumes of river recharge in each water year are -49.98 MCM,-46.62 MCM, -126.43 MCM and -8.32 MCM, respectively. The volumes of groundwater pumping in each water year are 319.01 MCM,-511.16 MCM,-551.09 MCM and 714.58 MCM, respectively. The volumes of the leak from lower aquifer in each water year are 37.11 MCM, 40.58 MCM, 45.33 MCM and 38.96, respectively. The volumes of storage change in each water year are 141.86 MCM,-110.79 MCM,-131.92 MCM and-179.93 MCM, respectively.

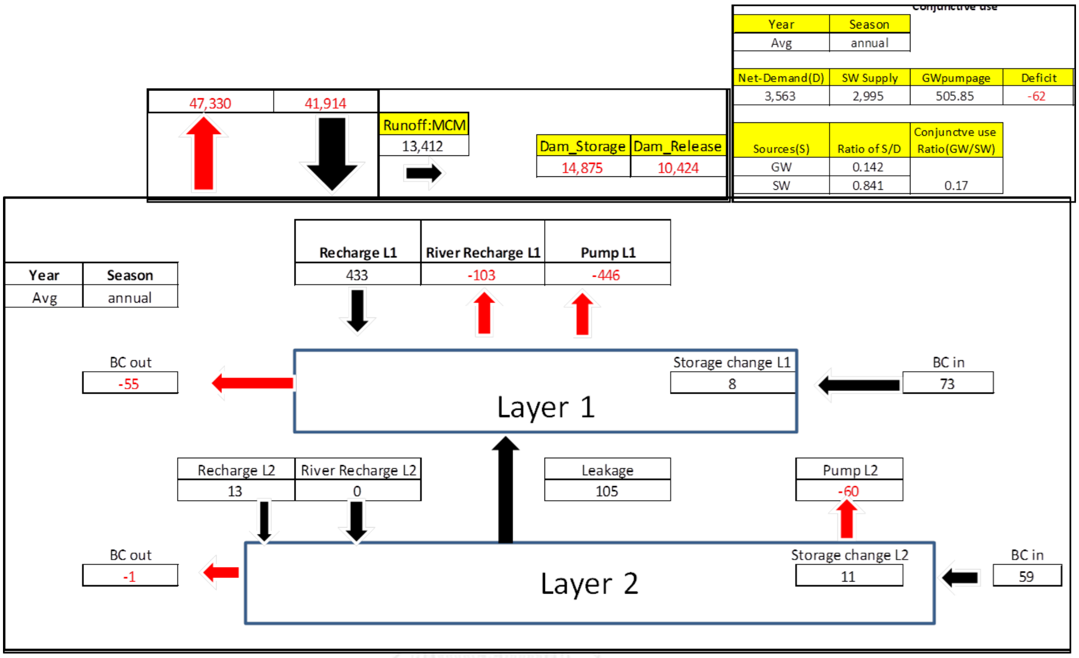


Figure 5.22. The average groundwater system in annual (1993-2003)

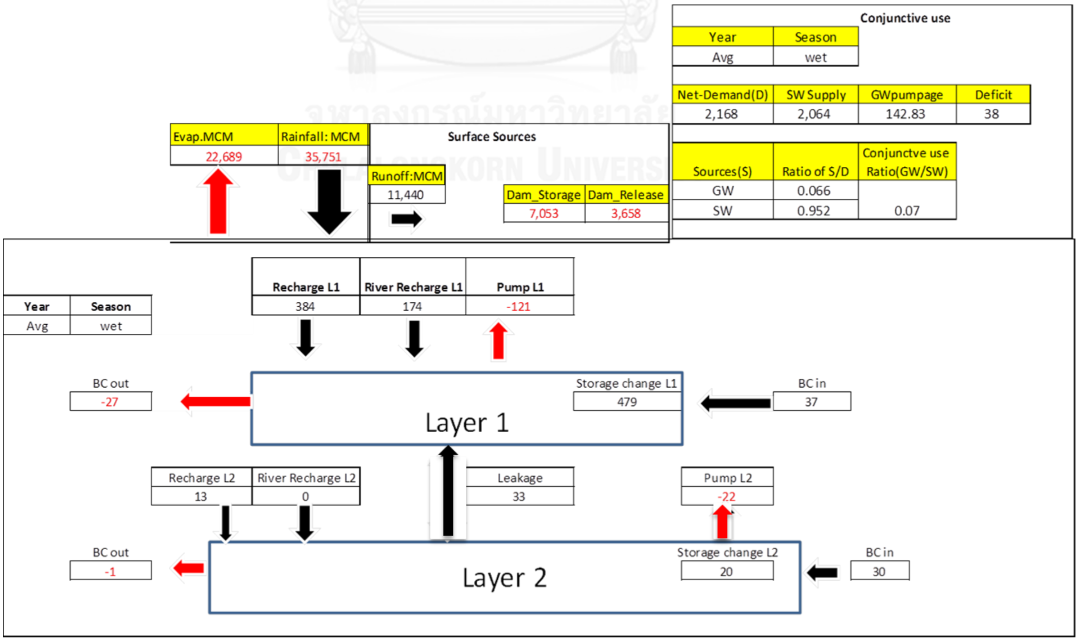


Figure 5.23. The average groundwater system in wet season (1993-2003)

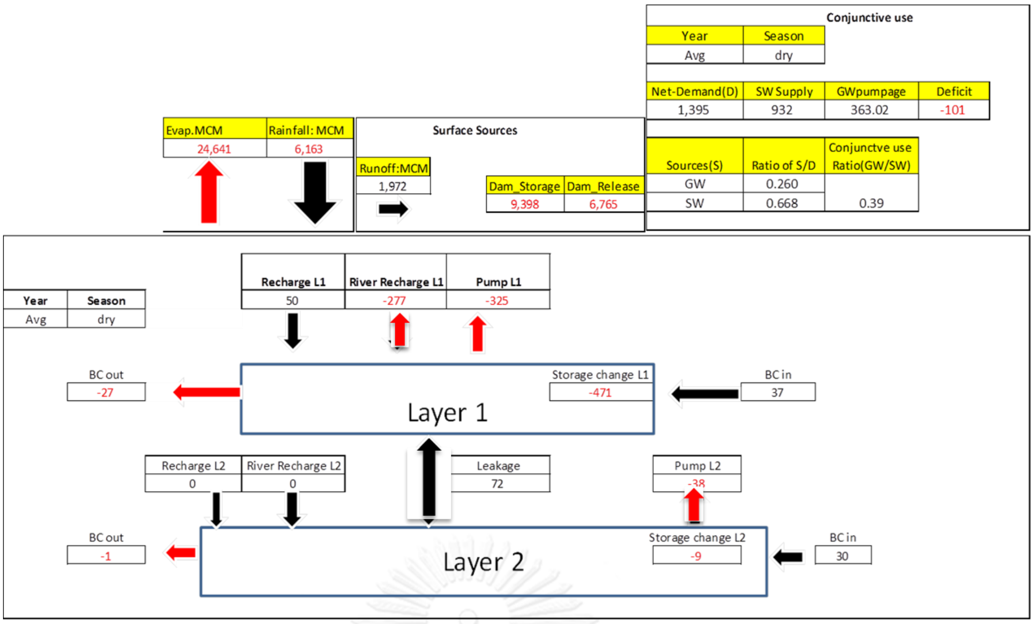


Figure 5.24. The average groundwater system in dry season (1993-2003)

Table 5.12. The average seasonal flow budget in groundwater system (MCM/day)

Time Period	**Present(MCM/day)**		
Season	**wet**	**dry**	**annual**
River recharge	0.350	-0.560	-0.210
GW_Storage change	1.586	-1.500	0.086
Land recharge	1.100	0.137	1.237
GW_Pumpage	-0.391	-1.780	-2.171
Flow in (Boundary)	0.200	0.200	0.400
Flow out (Boundary)	0.150	0.150	0.300
FromAquifer 2	0.177	0.350	0.527

Table 5.13. The average percentage of each component of groundwater system compared with the total flow in/ total flow out

Time Period	**Present(%)**		
Season	**wet**	**dry**	**annual**
River recharge	10.253	-14.035	-7.832
GW_Storage change	46.463	-37.594	3.822
Land recharge	32.225	19.926	54.963
GW_Pumpage	-72.289	-44.612	-80.979
Flow in (Boundary)	5.859	29.118	17.775
Flow out (Boundary)	-27.711	-3.759	-11.189
FromAquifer 2	32.790	50.956	23.440

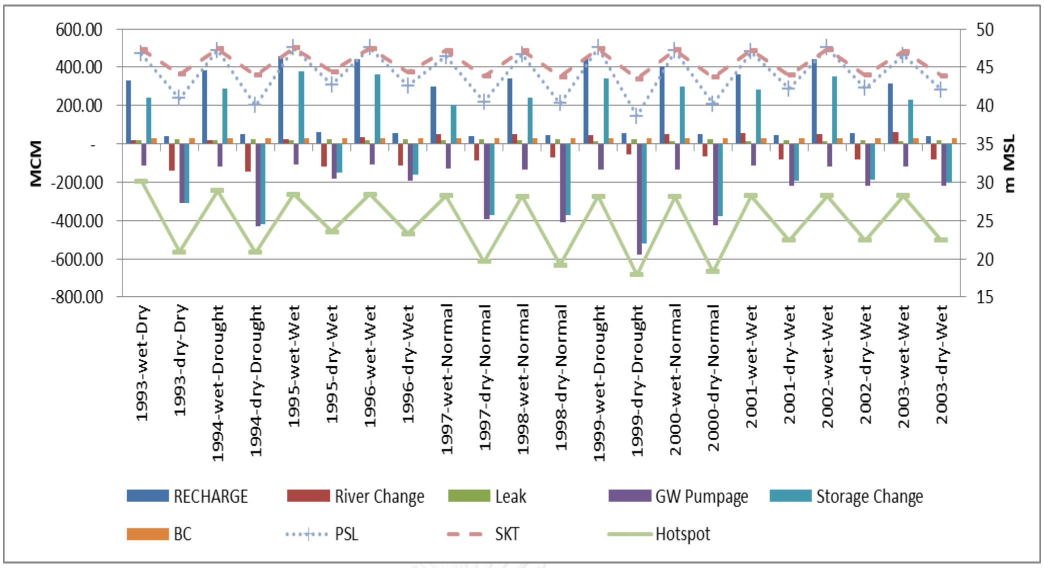


Figure 5.25. The fluctuation of each components of Groundwater System and represented groundwater level in 1993-2003

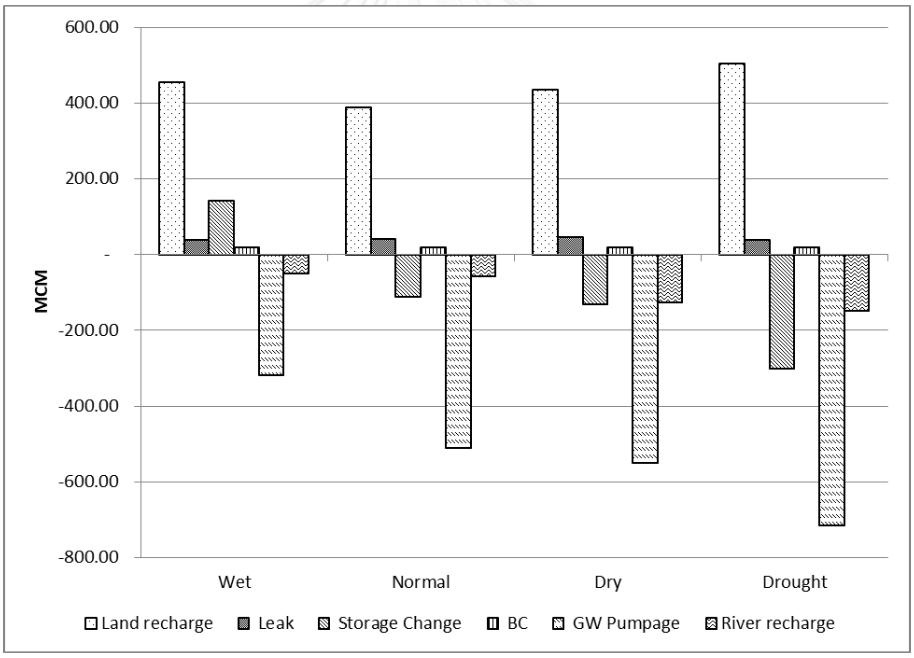


Figure 5.26. Average groundwater system in eachs water year

In summary, the formula of land recharge rate with climate data and soil type was developed in terms of precipitation, evapotranspiration, temperature and soil type under monthly time series data and the study found that there were in good relationship and can be used to study the impact of climate change on groundwater recharge and water table based on future climate data.

The groundwater pumping potential map was developed. It is a useful contribution information for water conjunctive use management and adaptation measure in the future

When considered in the average percentage of each components of groundwater system over total in/out, the average percentage of land recharge in was 56%. The average percentage of river recharge was 8%. The average percentage of groundwater pumping was 81%, respectively. The average percentage of the leak from lower aquifer to upper aquifer was 23%. This can conclude that the land recharge was dominant component of the flow in the aquifer and the groundwater pumping was dominant component of the flow out from the aquifer.

CHAPTER VI

IMPACT OF CLIMATE CHANGE ON GROUNDWATER SYSTEM

The impact of climate change on groundwater system for this thesis includes impact of climate change on groundwater system and impact of climate change on conjunctive use.

6.1. Impact of climate change on groundwater system

The impact of climate change is considered from the change of recharge and groundwater table and groundwater pumping compared with present period. The groundwater recharge rate from the above formula for each soil series group, were calculated and input to groundwater model to simulate the impact of climate change with future climate data. Figure 6.1 and Table 6.1 show that recharge tend to decrease in the periods of both near future and far future and will be lower than in the past due to the increase of the temperature and evapotranspiration. The average land recharge in near future and far future compared with present will decrease 42%, and 37% respectively. The heads of groundwater in the selected stations in the study area are shown in Figure 6.2. It can be seen that climate change will induce lower water table in the north due to higher temperature (including the area of Plaichumpol Operation and Maintenance Project), i.e. , water table will decrease approximately 0.23, 0.16 m/year in near future and far future periods respectively.

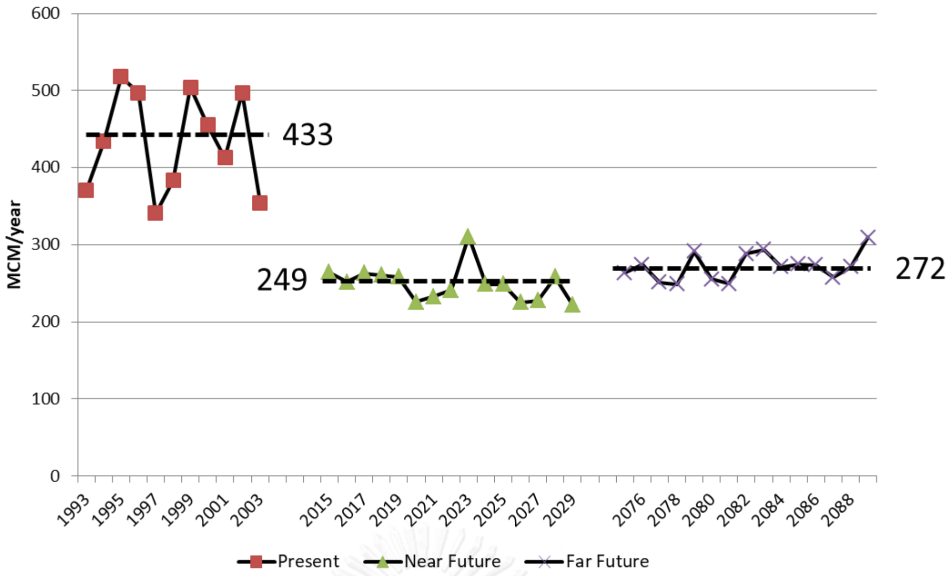


Figure 6.1. Average groundwater land recharge rate from projected future climate data

Table 6.1. The difference of Rain, ET, P-ET and Recharge Rate in near future, far future compared with present period

Variable	Present (unit)	%Difference compared with Present Period	
		Near Future	Far Future
Rain(P)	1,392(mm)	-9.87	-2.73
ET	1,424(mm)	+2.74	+8.78
P-ET	571(mm)	-48.71	-39.9
Recharge Rate	433(MCM)	-42	-37

Remark: - means decreasing, + means increasing

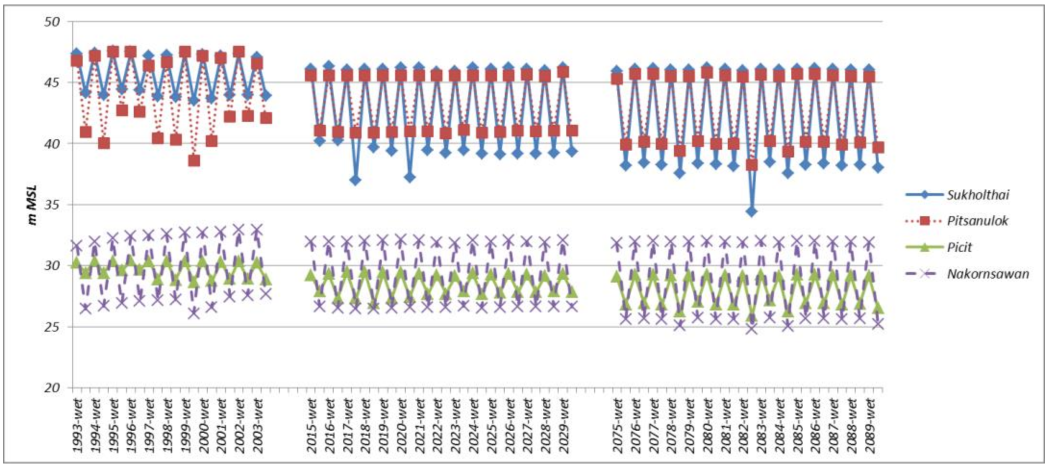


Figure 6.2. The groundwater level change at selected locations in each represent stations

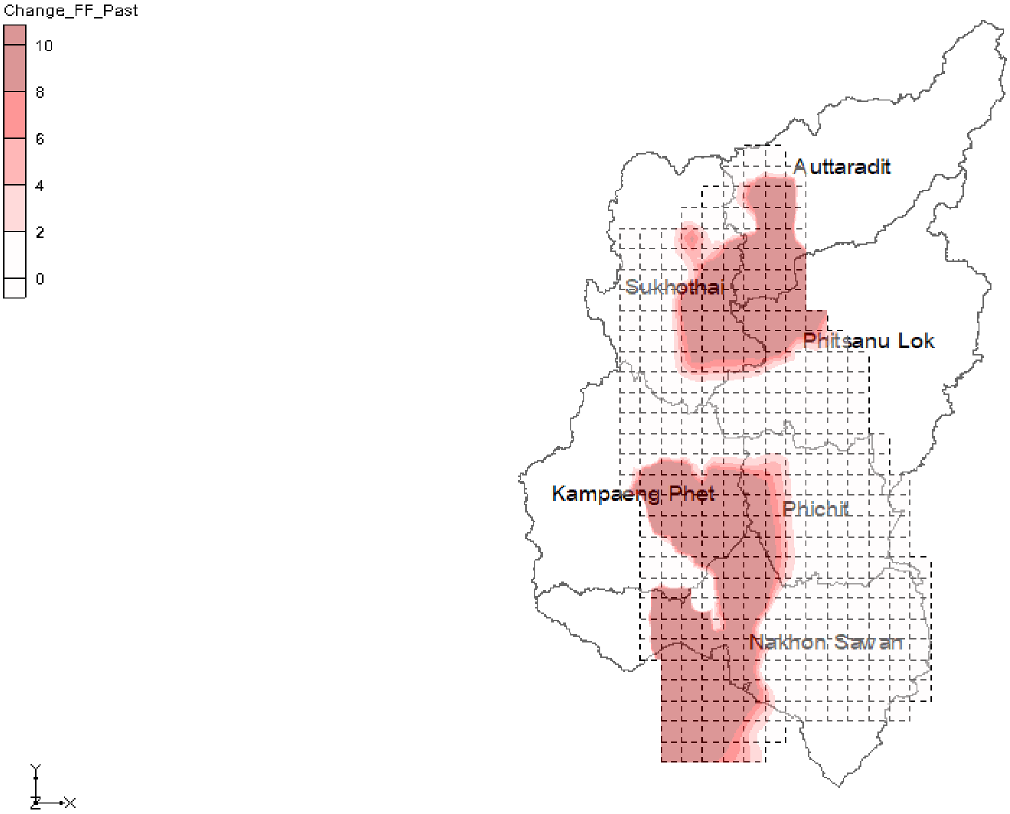


Figure 6.3. The change of water level (in meter) in the aquifer by the end of far future period

From Figure 6.3, the hot spot in lower water level will occur in some part of Uttraradit, Sukholthai, Phitsanulok, Kampaengphet, Pichit and Nakhonsawan provinces, especially in upper part of Plaichumpol Operation and Maintenance Project and the decrease of water level is up to 10 m.

The average annual groundwater system and their change are show in Figure 6.4-6.5. The groundwater system, in near future period are as follows:

The land recharge, boundary's flow in and the leakage from layer 2 were the flow in groundwater system in annual, the flow volume will be 249.3 MCM, 73 MCM and 39.4 MCM, respectively. The river recharge, groundwater pumping, groundwater storage change and boundary's flow out will be the flow out groundwater system In annual, the flow volume will be 11.3 MCM, 502.9 MCM, 97.8MCM and 54.7 MCM, respectively . The seasonal flow budget in groundwater system is shown in Table 6.2. When consider in annually flow in, there will be land recharge, inflow from boundary and leak from lower aquifer. It can be seen that land recharge was the dominant annual flow in. When consider in annually flow out, there will be the river recharge, groundwater pumping and flow out to boundary. The dominant annual flow out will be groundwater pumping.

In far future period, the land recharge, boundary's flow in and the leakage from layer 2 were the flow in groundwater system in annual, the flow volume will be 252.3 MCM, 73 MCM and 17.4 MCM, respectively. The river recharge, groundwater pumping, groundwater storage change and boundary's flow out will be the flow out groundwater system In annual, the flow volume will be 93.8 MCM, 489 MCM, 184.3MCM and 54.7 MCM, respectively . The seasonal flow budget in groundwater system is shown in Table 6.2. When consider in annually flow in, there will be land recharge, inflow from boundary and leak from lower aquifer. It can be seen that land recharge was the dominant annual flow in. When consider in annually flow out, there will be the river recharge, groundwater pumping and flow out to boundary. The dominant annual flow out will be groundwater pumping.

Figure 6.6 show the average groundwater system in near future, as a function of the surface water year: wet, normal, dry and drought, the volume of land recharge in each water year will be 258 MCM, 259 MCM, 246 MCM and 241 MCM respectively. The volume of river recharge in each water year will be 512 MCM, 220 MCM, 207 MCM and 259 MCM, respectively. The volume of groundwater pumping in each water year will be -489MCM,-516 MCM, 559 MCM and-825 MCM, respectively. The volume of the leak from lower aquifer in each water year will be 186 MCM, 2 MCM, 7 MCM and 31MCM respectively. The volume of storage change in each water year will be 95 MCM, -150 MCM, -138 MCM and -226 MCM respectively. All the representatives of groundwater level in dry season will be corresponded with water year. In drought year the groundwater level is lowest and highest in wet year. The different water level in dry season between wet year and drought year is in range 0.1-3.0 m

Figure 6.7 shows the average groundwater system in far future, as a function of the surface water year: wet, normal, dry and drought, the volume of land recharge in each water year will be 260.8 MCM, 272.7MCM, 274.3 MCM and 288.4 MCM respectively. The volume of river recharge in each water year will be 132.8 MCM, 136.8 MCM, 136.7 MCM and 165.6 MCM respectively. The volume of groundwater pumping in each water year will be -492.3 MCM, -519.4 MCM, -609.2 MCM and -940.6 MCM, respectively. The volume of the leak from lower aquifer in each water year will be 29.3 MCM, 11.2 MCM, 19.2 MCM and 26.3 MCM respectively. The volume of storage change in each water year will be -367.8 MCM, -366.4 MCM,-321.9 MCM and -440.4 MCM respectively. All the representatives of groundwater level in dry season will be corresponded with water year. It is the same results as in near future period. In drought year the groundwater level is lowest and highest in wet year. The different water level in dry season between wet year and drought year is in range 0.1-4.0 m

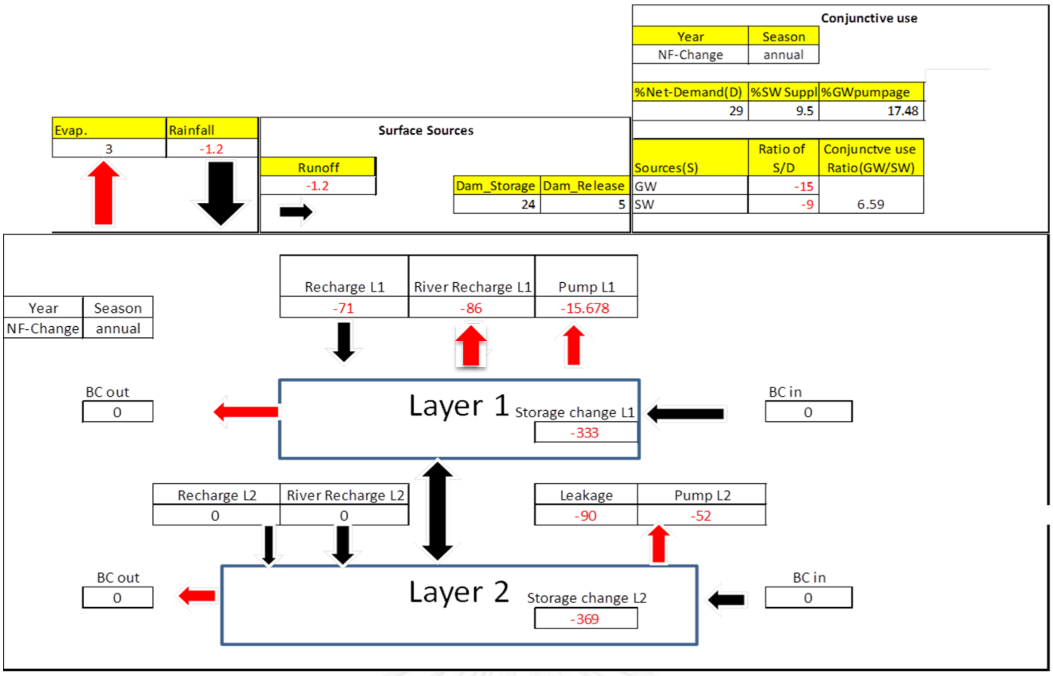


Figure 6.4. The average annual change of groundwater system (%) in near future period compared with present period (2015-2029)

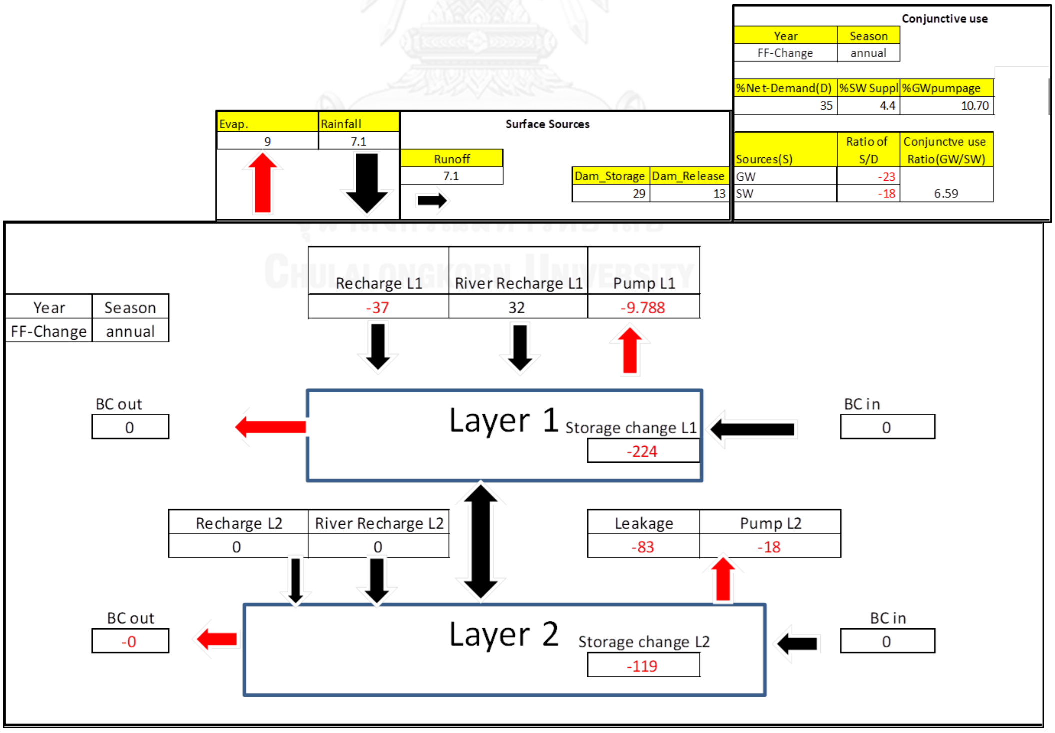


Figure 6.5. The average annual change of groundwater system (%) in far future period compared with present period (2075-2089)

Table 6.2. The average groundwater system in near future and far future period (MCM)

Time Period	Near Future			Far Future		
Season	wet	dry	annual	wet	dry	annual
River recharge	36.50	-47.83	-11.33	40.15	-134.05	-93.90
GW_Storage change	112.06	-209.88	-97.82	114.98	-299.30	-184.33
Land recharge	197.82	51.52	249.34	197.82	54.47	252.29
GW_Pumpage	-147.53	-355.45	-502.99	-135.32	-354.27	-489.59
Flow in (Boundary)	36.50	36.50	73.00	36.50	36.50	73.00
Flow out (Boundary)	-27.38	-27.38	-54.75	-27.38	-27.38	-54.75
FromAquifer 2	-38.58	78.03	39.45	-51.54	68.95	17.41

Table 6.3. Percentage of each component in groundwater system compared with total in/out and change in future

Time Period	Present(MCM)			%Change in Near Future			% Change in Far Future		
Season	wet	dry	annual	wet	dry	annual	wet	dry	annual
River recharge	63.88	-102.20	-38.33	-43	-53	-70	-37	31	145
GW_Storage change	289.45	-273.75	15.70	-61	-23	-723	-60	9	-1274
Land recharge	200.75	24.98	225.73	-1.5	106	10	-1	118	12
GW_Pumpage	-71.41	-324.85	-396.26	107	9	27	89	9	24
Flow in (Boundary)	36.50	36.50	73.00	0	0	0	0	0	0
Flow out (Boundary)	27.38	27.38	54.75	0	0	0	0	0	0
From aquifer 2	32.39	63.88	96.27	-219	22	-59	-259	8	-82

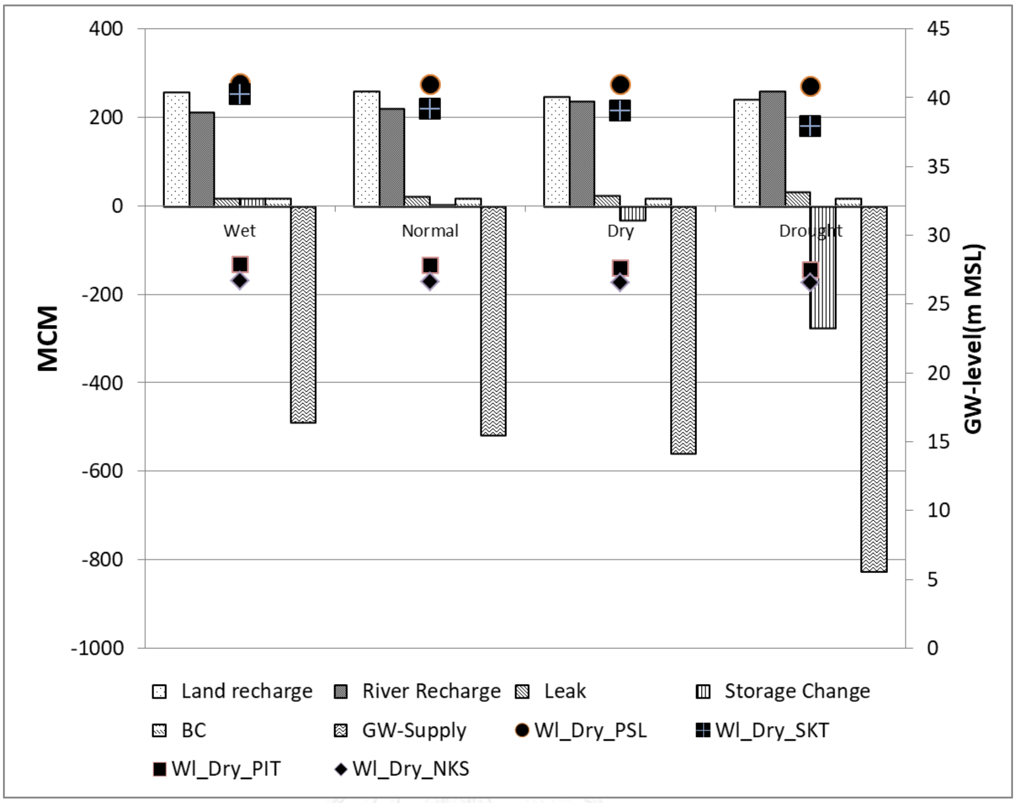


Figure 6.6. The average groundwater system in near future period by each water year

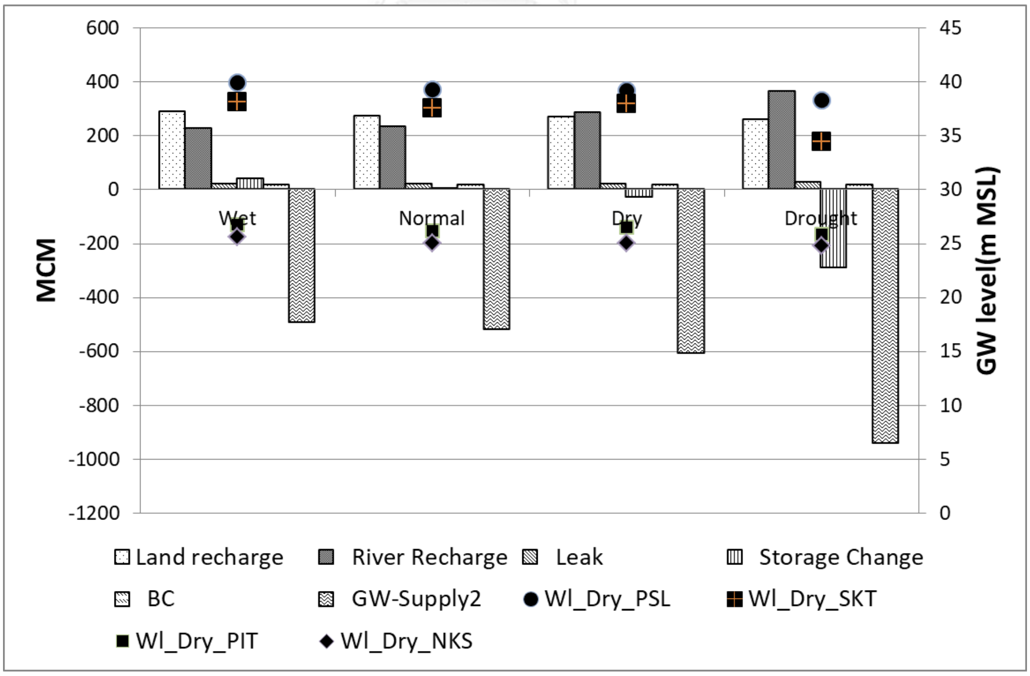


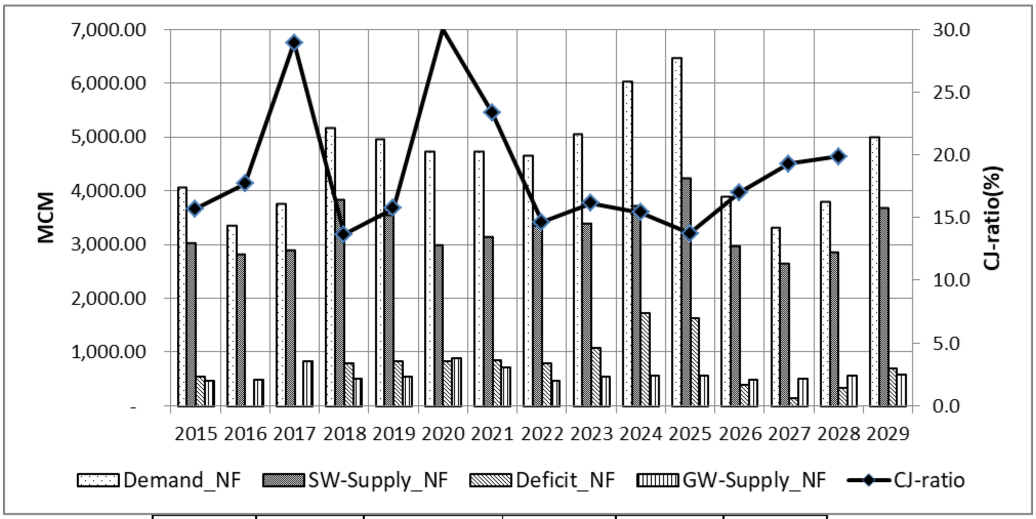
Figure 6.7. The average groundwater system in far future period by each water year

6.2. Impact of climate change on conjunctive use

According to the result from section 6.1, the impact of climate change on conjunctive use perform as the ratio of water supply sources over water demand(SW or GW/D) and the ratio of groundwater supply over surface water(GW/SW)

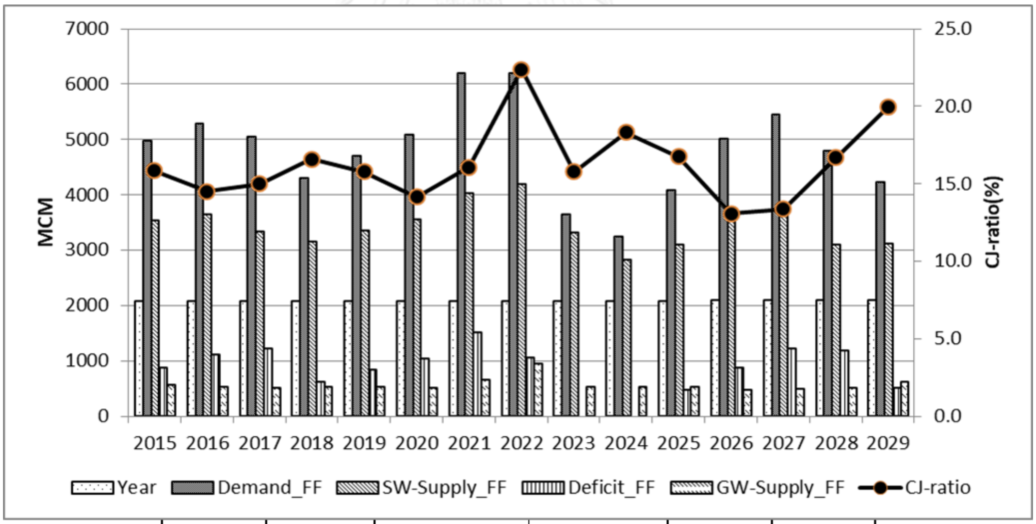
Figure 6.8 demonstrates the comparison of water demand, total groundwater supply, surface water supply, water deficit and conjunctive use ratio in near future period. The conjunctive use ratio(GW/SW) will be 18.7%(range 13.6%-30%). Figure 6.9 demonstrates the comparison of water demand, total groundwater supply, surface water supply, water deficit and conjunctive use ratio in near future period. The average conjunctive use ratio will be 16.3% (range 13.1%-22.4%).

From Figure 6.10, it demonstrates the comparison of the conjunctive use ratio in present period, near future period and far future period. The trend of the ratio is increasing. Table 6.4 show the conjunctive use ratio and their change as function of season. The conjunctive use ratio in near future will be 7%, 48% and 18.5% in wet season, dry season and annual, respectively. The ratio in far future will be 6%, 61% and 16.3% in wet season, dry season and annual, respectively. The ratio in near future period will be increasing 0%, 23% and 19.3% from present period, in wet season, dry season and annual, respectively. The ratio in far future period will be decreasing -14.29% in wet season, and will be increasing 56.4% and 5.1% in dry season and annual, respectively. These can conclude that the ratio will increase 5.1%-19.3%, in annual and the ratio will increase 23%-56%, in dry season but reversely, the ratio will decrease 0%-14.29%, in wet season.



Values	Demand	SW-Supply	GW-Suppl	Deficit	CJ-ratio
Average	4,600	3,281	594	725	18.7
Min	3,323	2,651	477	18	13.6
Max	6,472	4,241	900	1,736	30.0
SD	914	450	128	511	5.3

Figure 6.8. Comparison of water demand, groundwater supply, surface water supply, water deficit and CJ-ratio in near future period.



Values	Demand	SW-Supply	GW-Supply	Deficit	CJ-ratio
Average	4,817	3,441	560	965	16.3
Min	3,241	2,827	478	479	13.1
Max	6,199	4,201	941	1,518	22.4
SD	830	374	115	306	2.5

Figure 6.9. Comparison of water demand, groundwater supply, surface water supply, water deficit and CJ ratio in far future period.

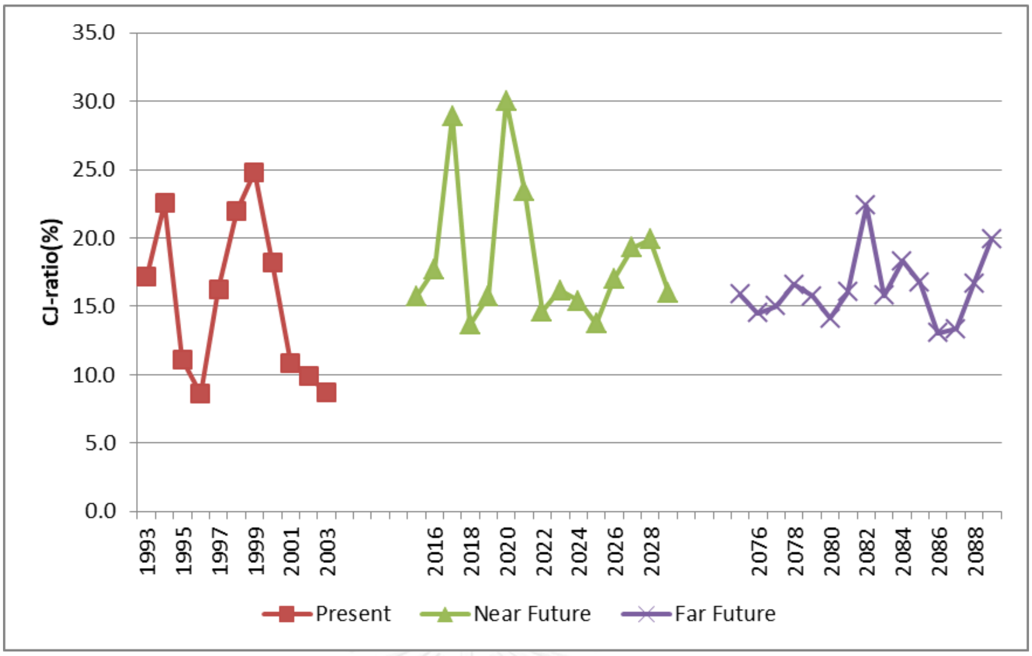


Figure 6.10. Comparison of the conjunctive use ratio in present period, near future period and far future period

Table 6.4. Conjunctive use ratio and the change in future period

	CJ ratio (%)			Change of CJ ratio (%)	
season	Present	Near Future	Far Future	Near Future	Far Future
wet	7.00	7.00	6.00	0.00	-14.29
dry	39.00	48.00	61.00	23.08	56.41
annual	15.50	18.50	16.30	19.35	5.16

The impact of climate change on the groundwater system when compared with the present period can be summarized as follows:

i. The average water demand will increase as 27%, 33%. Surface supply will increase as 9.5%, 4.2% and average groundwater supply will increase as 33.2%, 25.5% in near future and far future, respectively.

ii. The average deficit compared with present deficit will increase as 18.8% and 31.7% in near future and far future, respectively.

iii. The conjunctive use ratio (GW/SW): The percentage of change in near future and far future will be as following

a. In wet season: in near future will be the same but in far future will decrease 14.29%

b. In dry season: in near future and far future, both will increase 23% and 56%, respectively.

c. In annual: in near future and far future, both will increase 19% and 5%, respectively.

CHAPTER VII
ADAPTATION MEASURES

In order to lessen the drought risk from climate change, this study proposed adaptation measures are 1) measure 0; do nothing in future climate, 2) measure 1; to increase surface water by adjusting Reservoir Operation, 3) measure 2: increasing groundwater pumping (with potential map) and 4) measure 3: combined measure 1 and measure 2. The changes in water deficit and role of conjunctive use are investigated. The results of each measure from the study are as follows.

7.1. Measure 0: No measure with future climate

In this measure, it represented the existing operation conditions by which the water release from Sirikit's Dam and the groundwater pumping will be the same as in Chapter VI. The water deficit in near future and far future are shown in Table 7.3.

7.2. Measure 1: Increase surface water by adjusting reservoir operation

In this measure, The new release data of Sirikit Dam from Chaowiwat (2013) are used in the study and from Table 7.1, the surface water supply volume will increase 3.8% and 3.97% in near future and far future from existing condition, respectively. The average deficit will decrease 13.4% and 11.0% from existing condition in near future and far future from existing condition, respectively (Table 7.4). The average change of conjunctive use ratio will be the same, they will decrease from existing condition 0.28% and 0.71% in near future and far future from existing condition, respectively.

Table 7.1. Change from existing condition (Measure 0) of surface water supply and conjunctive use ratio in case measure 1

Values	Surface water supply in existing condition (MCM)		Change from existing condition (%)		Existing condition CJ-Ratio (%)		Change from existing condition (%)	
	NF	FF	NF	FF	NF	FF	NF	FF
Average	3281.0	3127.9	3.80	3.97	18.11	17.90	-0.5	-0.7
Min	2651.4	2570.0	1.25	1.88	17.98	18.59	-4.5	-4.6
Max	4240.6	3819.0	2.10	10.86	21.22	24.63	4.5	-2.4
SD	449.9	340.4	-2.93	12.27	28.54	33.65	-24.6	-31.5

7.3. Measure 2: Increasing groundwater pumping

In this measure, groundwater pumping up will be increased to the limit that groundwater level not lower than 15 m. from ground surface and increasing the pumping wells in the high pumping potential from Chapter 5 (Figure 5.16). From Table 7.2, the average groundwater supply volume will increase 14.9% and 15.9% in near future and far Future from existing condition, respectively. The average deficit will decrease 10.7% and 7.7% from existing condition in near future and far future from existing condition, respectively (Table 7.4). The average change of conjunctive use ratio will decrease from existing condition 5.81% and 2.89% in near future and far future from existing condition, respectively.

Table 7.2. Change from existing condition (Measure 0) of groundwater supply and conjunctive use ratio in case increase measures 2

Values	GW supply in existing Condition (MCM)	Change from existing condition (%)		Existing Condition CJ-Ratio (%)	Change from existing condition (%)	
		NF	FF		NF	FF
Average	594.29	14.98	15.9	17.9	5.81	2.89
Min	476.64	6.47	11	18.59	5.43	-1.03
Max	899.8	16.58	7.62	24.63	10.23	1.88
SD	128.38	12.56	-5.58	33.65	438.38	-31.05

7.4. Measure 3: Combined measure 1 and 2

In these measures, the surface water supply volume will increase 3.8% and 3.97% in near future and far future from existing condition, respectively. The average groundwater supply volume will increase 14.9% and 15.9% in near future and far Future from existing condition, respectively. The average deficit will decrease 24.2% and 18.7% from existing condition in near future and far future from existing condition, respectively (Table 7.4). The average change of conjunctive use ratio will decrease from existing condition 5.81% and 2.89% in near future and far future from existing condition, respectively.

Table 7.3. Change from existing condition (Measure 0) of conjunctive use ratio in case increase measures 3

Values	**Existing Condition CJ-Ratio (%)**		**Change from existing condition (%)**	
	NF	FF	NF	FF
Average	18.11	17.90	2.2	2.1
Min	17.98	18.59	-4.2	-1.5
Max	21.22	24.63	8.1	-0.7
SD	28.54	33.65	-24.0	-31.6

7.5. Drought risk reduction

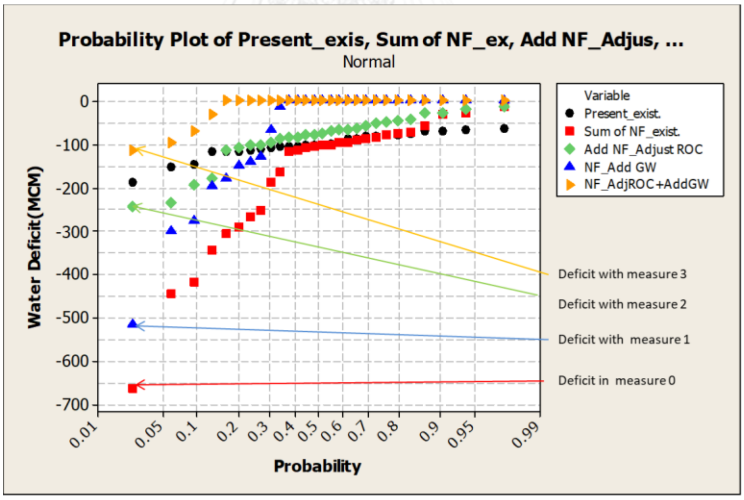
In the study area, each measure will decrease the average deficit from existing condition (measure 0) in near future and far future. The measure 1 will decrease more deficit than measure 2, the different volume will be 19 MCM (2.6%) and 36.52 MCM (3.2%), respectively. The measure 3 will help alleviate the water deficit in near future and far future to 175.5(24.2%) and 212.1(18.7%), respectively.

For in the upper Nan basin, these proposed measures are found to help alleviate the problem of water deficit for the entire Nan basin in both near future and far future. From Figure 7.1-7.2, they show that the risk of deficit will decrease and the deficit will occur only less than probability =0.16, when applied measure 3.

Table 7.4. The reduction of water deficit from each adaptation measures

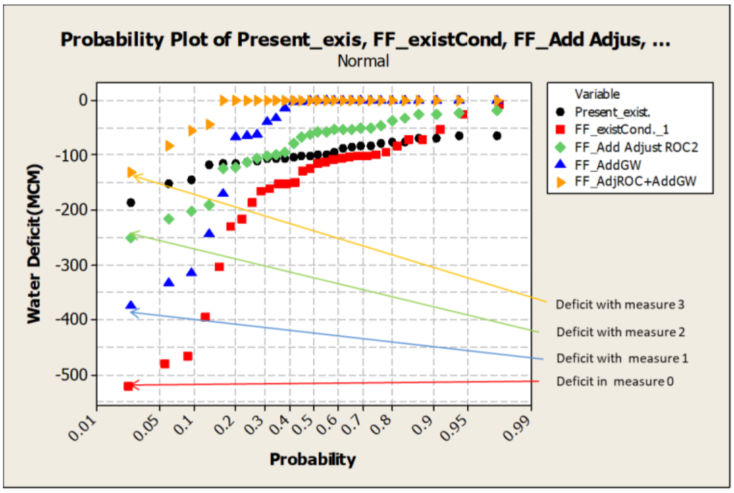
	Deficit(MCM): Near Future				Deficit(MCM): Far Future			
Values	Measure 0	Measure1	Measure2	Measure3	Measure 0	Measure1	Measure2	Measure3
Average	725.0	627.8	646.8	549.5	1129.6	1005.3	1041.8	917.5
Min	17.6	0.0	0.0	0.0	106.5	17.7	0.0	0.0
Max	1735.8	1732.4	1647.2	1643.8	1884.4	1858.8	1856.2	1830.6
SD	511.1	516.2	508.2	513.3	506.3	517.6	508.6	519.9

	% Deficit change in Near Future			% Deficit change in Far Future		
Values	Measure1	Measure2	Measure3	Measure1	Measure2	Measure3
Average	-13.4	-10.8	-24.2	-11.0	-7.8	-18.8
Min	-100.0	-100.0	-100.0	-83.4	-100.0	-100.0
Max	-0.2	-5.1	-5.3	-1.4	-1.5	-2.9
SD	1.0	-0.6	0.4	2.2	0.5	2.7



Remarks:
Measure 0 is no measure with future climate
Measure 1 is Adjusted Reservoir operation
Measure 2 is increasing pumping
Measure 3 is Measure1+2

Figure 7.1. Probability plot of deficit in present period, near future period with measures



Remarks:
Measure 0 is no measure with future climate
Measure 1 is Adjusted Reservoir operation
Measure 2 is increasing pumping
Measure 3 is Measure1+2

Figure 7.2. Probability plot of deficit in present period, far future period with measures

CHAPTER VIII

CONCLUSIONS AND RECOMMENDATIONS

8.1. Conclusions

1) The relationship of land recharge rate with climate-soil data was developed in terms of precipitation, evapotranspiration, temperature and soil type under monthly time series data and the study found that the formula has a good relationship and can be used to study the impact of climate change on groundwater recharge and water table based on future climate data.
2) The groundwater pumping potential map for expansion of conjunctive use of water resources has been generated. It can classify the study area into 3 zones: low potential, intermediate potential and high potential.
3) The groundwater system under existing conjunctive use

   When considered in the average percentage of each components of groundwater system over total in/out, the land recharge was the dominant component of the flow in the aquifer in (56% of total flow in). The volume of storage change was decreasing highest in drought year (-179.9MCM) according to the groundwater pumping which has the highest in this water year (-714.58 MCM). Although the land recharge (504.4MCM) in this water year was the highest but it was lower than groundwater pumping. But in wet year, the volume of storage change was increasing to the aquifer (141.8MCM) because of the land recharge (455.79 MCM) was higher than groundwater pumping (319.01 MCM). The fluctuation of the groundwater level between wet season and dry season was 2.5-7 m. but in drought year, it was 3-8 m.
4) The impact of climate change on the groundwater system when compared with the present period as follows:
   4.1) The average water demand will increase as 27%, 33%. Surface supply will increase as 9.5%, 4.2% but It cannot accommodate the

amount of water demand. For this reason, the groundwater supply will increase as 33.2%, 25.5% in near future and far future, respectively, but it is not enough, so the water deficit compared with present deficit will increase as 18.8% and 31.7% in near future and far future, respectively.

4.2) The conjunctive use ratio: the percentage of change in near future and far future will be as following

i. In wet season: in near future will be the same but in far future will decrease 14.29%

ii. In dry season: in near future and far future, both will increase 23% and 56%, respectively.

iii. In annual: in near future and far future, both will increase 19% and 5%, respectively.

5) The propose adaptation measures under climate change to reduce drought risk:

5.1) The study proposed adaptation measures are 1) measure 0; do nothing in future climate change, 2) measure 1; to increase surface water by adjusting reservoir operation, 3) measure 2: increasing groundwater pumping in the potential area and 4) measure 3: combining measure 1 and 2.

5.2) Measure 1: increase surface water by adjusting reservoir operation: the surface water supply volume from the release of Sirikit Dam will increase 3.8% and 3.97% in near future and far future from existing condition, respectively. The average deficit will decrease 13.4% and 11.0% from existing condition in near future and far future from existing condition, respectively. The average change of conjunctive use ratio will be the same with the existing condition both in near future and far future.

5.3) Measure 2: Increase groundwater pumping in the potential area: the average groundwater supply volume will increase both in near future and far Future from existing condition. The average deficit will decrease 10.7% and 7.7% from existing condition in near future and far future from existing condition, respectively. The average change of conjunctive use ratio will decrease from existing condition 5.81% and 2.89% in near future and far future from existing condition, respectively.

5.4) Measure 3: combining measures 1 and 2: In this measure, the surface water supply volume will increase 3.8% and 3.97% in near future and far future from existing condition, respectively. The average groundwater supply volume will increase 14.9% and 15.9% in near future and far Future from existing condition, respectively. The average deficit will decrease 24.2% and 18.7% from existing condition in near future and far future from existing condition, respectively. The average change of conjunctive use ratio will decrease from existing condition 5.81% and 2.89% in near future and far future from existing condition, respectively.

8.2. Recommendations

1) The formula of and recharge rate with climate data was developed in terms of precipitation, evapotranspiration, temperature and soil type under monthly time series data. This can perform to simulate the impact of climate change but the land use change impact in the future is not

considered in the study. Therefore, the impact of land use change should be a focus of further research.

2) With the restrictions on this area that it is difficult to construct a new large dam, hence the demand side management should be considered and applied to this area such as increasing water productivity (better water control, cultivation area control, improved production processes) to reduce water deficit to zero.

3) Water supply in the urban and rural area, should be prepared to provide potable water supply (tap water) to reserve for all cities and villages due to possible impact from climate change which will induce more water shortage.

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APPENDIXES

Appendix A

Input parameters for the groundwater model

A.1 River Characteristic and monthly river stage records

Table A.1 River station and their characteristic for input to River package of Groundwater model

Station	Location	Basin	Stage (msl)	Bottom (msl)	Width (m.)	K m/day	Depth	C
Y7	Ban Wat Noi, Si Satchanalai,Sukhothai,	Yom	45.7	43	38	0.05	2	0.95
Y.16	Ban Bang Rakam , Bang Rakam ,Phitsanulok	Yom	33.8	30.5	60	0.05	2	1.5
N.5A	Muang, Muang, Phitsanulok	Nan	37.5	33	78	0.05	2	1.95
N.7A	Mueang, Mueang, Phichit	Nan	29.3	24	84	0.05	2	2.1
N14A	Wat Luang PhoKaeo,A.Chum Saeng,NakhonSawan,	Nan	21	13.5	92	0.05	2	2.3
N26	Tron,Tron,Uttaradit,	Nan	8	2	174	0.05	2	4.4
P.2A	Ban Chiang Ngoen, Mueang, Tak	Ping	105.8	103.5	380	0.05	2	9.5
P.7A	Ban Huai Yang, Mueang, Kamphaeng Phet	Ping	73.6	71.5	300	0.05	2	7.5
P.17	Ban Tha Ngiu,Banphot Phisai,NakhonSawan,	Ping	35	32.5	224	0.05	2	5.6
P15	Ban Khlong Khlung,Khlong Khlung, Kampheang Phet,	Ping	16	11	42	0.05	2	1.05
C.2	Ban Phai Lom,A.Mueang,NakhonSawan,	Upper Chao Phraya	20	14.5	237	0.05	2	5.925

Table A.2 Station Y7 Ban Wat Noi, SiSatchanalai, Sukhothai,

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual	Wet	Dry
1975	58.1	58.26	59.44	60.03	62.51	62.15	60.69	59.45	58.67	58.23	58.02	57.86	59.45	60.08	58.82
1976	57.84	58.59	58.77	58.23	60.89	-	-	59.74	58.8	58.78	58.26	58.17	58.81	58.86	58.75
1977	58.32	58.74	58.34	58.24	59.77	62.17	60.58	59.61	58.68	58.39	58.16	58.06	59.09	59.26	58.91
1978	58.03	58.64	58.51	61.08	62.25	62.67	61.02	59.22	58.65	58.33	58.16	58.07	59.55	60.20	58.91
1979	58.04	58.82	59.76	58.85	59.96	60.19	59.19	58.32	58.16	58.04	57.98	57.88	58.77	59.27	58.26
1980	58.02	58.28	59.84	59.6	60.35	-	60.32	59.19	58.68	58.32	58.17	58.08	58.99	59.22	58.79
1981	6.78	8.07	2.65	4.85	5.07	3.74	3.81	2.89	1.95	1.46	1.21	1.07	3.63	5.19	2.07
1982	1.6	1.39	1.51	-	1.99	3.69	3.4	1.93	1.38	1.14	1.03	0.93	1.82	2.04	1.64
1983	1.02	1.38	1.63	1.82	3.43	4.99	3.95	2.73	1.78	1.38	1.17	1.02	2.19	2.38	2.01
1984	58.04	1.81	2.25	2.3	-	4.33	-	2.31	1.63	1.22	1.05	0.93	7.59	13.75	1.43
1985	0.96	1.62	1.88	-	3.03	4.1	3.52	3.36	2.12	58.41	1.17	1.01	7.38	2.32	11.60

Table A.2 Station Y7 Ban Wat Noi, SiSatchanalai, Sukhothai,

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual	Wet	Dry
1986	58.01	59.24	2.01	1.72	3.32	4.25	2.69	2.04	1.54	1.14	1.02	1.02	11.5	21.43	1.58
1987	-	-	-	-	-	-	-	-	-	-	-	-	-		
1988	-	-	-	-	-	-	-	-	-	-	-	-	-		
1989	57.77	58.71	59.65	59.96	60.34	-	-	-	-	-	-	-	59.29	59.29	
Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual	Wet	Dry
1990	57.92	58.64	59.35	59.03	59.84	61.26	60.04	59.34	58.47	58.14	58	-	59.09	59.34	58.80
1991	57.96	58.45	58.91	58.2	59.81	61.31	60.46	59.2	58.4	58.2	58	58.09	58.91	59.11	58.73
1992	57.76	57.73	58.08	57.99	60.04	60.36	61.14	59.12	58.81	58.61	58.15	58.09	58.82	58.66	58.99
1993	58.07	58.31	58.64	58.97	58.63	60.82	59.67	58.66	58.16	57.84	57.54	57.42	58.56	58.91	58.22
1994	58.22	59.03	60.22	60.12	63.63	63.13	60.66	59.5	59.06	58.65	58.46	58.32	59.92	60.73	59.11
1995	58.62	59	58.75	-	-	-	-	-	-	-	-	-	58.79		
Aver	46.37	43.93	41.06	45.06	43.81	38.61	41.41	39.21	38.53	41.55	37.97	36.63	41.18	43.14	39.22

Table A.3 Station Y.16 Ban Bang Rakam , Bang Rakam ,Phitsanulok

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual	Wet	Dry
1967	0.65	1.61	1.69	1.03	1.84	4.95	8.48	2.87	1.39	0.87	0.65	0.58	2.22	1.96	2.47
1968	0.73	2.46	3.35	2.14	2.98	3.76	3.44	1.39	1.01	0.77	0.55	0.42	1.92	2.57	1.26
1969	0.36	0.68	1.53	1.87	3.38	5.97	8.3	3.75	1.55	-	0.56	0.35	2.57	2.30	2.90
1989	32.9	33.17	36.98	34.79	35.77	36.86	38.05	37.49	33.56	32.27	32	31.94	34.65	35.08	34.22
1990	32.45	33.46	36.1	33.92	35.2	36.26	37.13	35.84	33.35	32.43	32.08	31.98	34.18	34.57	33.80
1991	32.13	32.97	33.63	32.59	34.15	37.47	38.14	36.09	33.02	32.38	32.15	32.01	33.89	33.82	33.97
1992	31.97	32.05	32.41	32.47	36.11	36.51	38.21	37.71	33.9	33.22	32.14	31.86	34.04	33.59	34.51
1993	31.98	32.53	32.92	32.99	33.09	35.77	36.27	33.92	32.76	32.07	31.92	31.79	33.17	33.21	33.12
1994	32.68	33.13	38.15	37.84	38.35	42.16	39.93	35.42	33.56	32.47	32.05	31.97	35.64	37.05	34.23
1995	32.31	33.33	33.06	32.92	37.87	42.25	41.44	38	35.15	33.02	32.6	32.63	35.38	35.29	35.47
1996	32.81	33.88	34.02	33.7	35.18	38.67	41.57	38.94	34.93	32.74	32.24	32.53	35.1	34.71	35.49
Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual	Wet	Dry
1997	32.66	32.42	32.4	32.52	34.96	37.7	38.64	35.87	32.84	31.91	31.87	31.89	33.81	33.78	33.84
1998	32.03	32.31	32.34	34.65	34.78	37	36.81	33.75	32.58	31.89	31.8	31.73	33.47	33.85	33.09
1999	31.85	33.48	35.08	34.52	35.41	38.1	40.18	40.38	37.66	33.13	32.18	32.28	35.35	34.74	35.97
2000	32.12	34.74	36.49	36.18	36.55	38.91	39.87	38.61	34.11	32.56	32.43	33.79	35.53	35.83	35.23
2001	32.61	35.08	36.89	36.06	39.02	41.1	40.9	39.88	35.31	32.45	32.09	32.55	36.16	36.79	35.53
2002	32.12	32.94	34.86	34.5	36.5	41.64	41.34	39.91	37.02	33.62	32.3	32.84	35.8	35.43	36.17
2003	32.4	32.04	33.15	34.73	35.87	38.32	39.46	34.29	32.04	31.91	32.24	32.07	34.04	34.42	33.67
2004	31.84	33.17	35.66	36.16	37.57	37.77	39.33	33.52	32.14	31.9	31.79	31.88	34.39	35.36	33.43
Aver	27.29	28.18	29.51	29.24	30.77	33.22	34.08	31.45	28.84	28.98	27.14	27.22	29.66	29.70	29.62

Table A.4 Station N.7A Mueang, Mueang, Phichit

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual	Wet	Dry
1944	26.47	27.22	29.37	32.91	34.6	34.5	33.35	31.84	28.25	26.75	-	-	30.52	30.85	30.05
1945	-	28.88	30.46	32.97	34.96	36.19	33.91	28.81	27.28	26.35	-	-	31.09	32.69	29.09
1946	-	27.25	29.83	30.76	33.84	35.75	34.02	29	27.45	26.5	26.64	26.24	29.75	31.49	28.31
1947	-	27.4	29.56	32.23	34.2	36.07	34.21	29.07	27.43	26.79	26.41	-	30.34	31.89	28.78
1948	-	26.8	27.75	29.4	33.32	36.21	35.38	30.12	27.83	26.71	-	-	30.39	30.70	30.01
1949	-	-	27.75	30.31	35.2	35.71	35.95	32.02	28.85	-	-	-	32.26	32.24	32.27
1951	26.62	27.49	30.56	32.14	35.97	36.3	35.87	32.56	28.9	27.72	27.19	27.13	30.7	31.51	29.90
1952	26.88	27.28	27.75	30.82	35.23	36.63	35.36	30.55	28.17	27.46	27.59	27.03	30.06	30.77	29.36
1953	26.67	28.13	30.01	30.49	34	36.04	34.43	31.1	28.54	27.28	26.58	26.48	29.98	30.89	29.07
1954	26.42	27.01	28.75	28.3	30.75	34.96	34.25	29.2	27.62	26.93	26.43	26.4	28.92	29.37	28.47
1955	26.69	27.42	28.95	30.02	33.58	36.28	32.5	28.45	27.51	26.95	26.73	26.46	29.3	30.49	28.10
1956	26.41	27.86	29.1	31.94	35.67	36.47	33.13	28.49	27.03	26.8	26.67	26.51	29.67	31.24	28.11
1957	26.54	27.03	28.12	29.47	30.29	33.56	33.45	29.06	27.78	27.11	26.89	26.74	28.84	29.17	28.51
1958	26.77	27.09	28.05	29.65	30.81	33.89	30.27	28.29	27.53	26.99	26.93	26.84	28.59	29.38	27.81
1959	26.9	27.47	28.21	29.03	33.64	36.25	33.02	28.83	27.78	27.15	25.81	26.61	29.23	30.25	28.20
1960	26.46	27.11	27.56	29.03	32.85	35.62	32.7	29.41	28.19	27.33	26.81	26.62	29.14	29.77	28.51
1961	26.62	27.51	29.77	30.37	33.87	36.72	36.24	31.51	28.05	26.82	26.55	26.44	30.04	30.81	29.27
1962	26.55	26.96	27.95	29.4	32.31	33.74	34.69	29.74	27.85	27.09	26.7	26.77	29.15	29.49	28.81
1963	26.49	26.31	27.7	30.07	35.5	35.41	33.72	32.86	29.04	27.77	27.03	26.4	29.86	30.25	29.47
1964	26.3	27.53	29.1	30.58	30.9	34.99	35.26	30.36	28.37	27.63	27.12	26.36	29.54	29.90	29.18
1965	26.27	26.67	28.78	28.63	31.5	33.55	30.45	29.43	27.94	26.96	26.8	26.39	28.61	29.23	28.00
1966	26.22	27.3	28.81	29.65	34.15	35.7	30.02	29.35	28.2	27.15	26.78	26.58	29.16	30.31	28.01
1967	26.6	27.39	27.83	28.34	30.19	33.49	32.61	28.55	28.09	26.95	26.67	26.59	28.61	28.97	28.24
1968	26.71	28.61	29.35	29.99	31.73	31.94	29.88	27.9	27.42	26.91	26.53	26.03	28.58	29.72	27.45
1969	26	26.28	28.56	30.94	32.94	33.34	30.84	29.49	28.03	27.3	26.67	26.17	28.88	29.68	28.08
1970	26.54	27.51	29.64	33.55	35.95	36.8	33.67	30.97	-	-	-	26.78	31.27	31.67	30.47
1971	26.63	27.48	28.3	29.34	32.39	34.17	31.45	28.98	28.01	27.21	27.08	27.33	29.03	29.72	28.34
1972	-23.57	-13.46	28.99	29.54	30.72	29.71	30	28.66	27.29	26.45	26.99	27.59	20.74	13.66	27.83
1973	27.19	27.11	27.75	28.64	30.06	31.5	30.15	28.23	27.48	26.91	26.41	27.03	28.21	28.71	27.70
1974	28.65	28.78	28.56	29.21	31.44	31.17	29.83	29.96	28.61	28.09	28.05	28.7	29.25	29.64	28.87
1975	28.92	29.01	29.87	30.68	32.39	36.3	34.62	30.87	29.89	28.64	29.28	29.77	30.85	31.20	30.51
Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual	Wet	Dry
1976	30.08	30.71	30.59	29.99	31.87	34.37	34.49	31.62	29.98	29.33	29.3	29.65	31	31.27	30.73
1977	29.57	30.14	29.81	30.01	30.84	33.79	30.6	28.1	28.56	27.76	27.7	28.27	29.6	30.69	28.50
1978	28.62	28.07	28.17	31.66	33.42	33.59	34.88	30.13	29.37	28.73	29.07	30.09	30.48	30.59	30.38
1979	30.2	30.08	30.5	29.75	30.9	30.97	29.88	29.54	28.64	27.67	27.23	27.61	29.41	30.40	28.43
1980	1.96	2.49	3.52	4.4	6.58	10.04	7.55	3.34	3.11	2.43	3.02	3.43	4.32	4.83	3.81
1981	29.64	30.37	30.74	31.53	34.78	31.69	30.13	30.04	29.38	28.72	29.28	29.81	30.51	31.46	29.56
1982	30.2	29.42	28.46	28.79	29.83	31.95	31.32	29.81	28.83	28.7	29.21	29.02	29.63	29.78	29.48
1983	30.5	29.72	28.47	28.95	29.73	31.25	30.92	29.9	28.34	27.59	28.53	29.57	29.46	29.77	29.14
1984	29.61	28.87	30.01	29.09	29.91	32.28	31.65	30.24	28.71	28.63	29.37	30.19	29.88	29.96	29.80
1985	30.49	29.52	28.83	29.79	30.2	31.06	31.26	32.11	29.81	27.86	28.73	29.67	29.94	29.98	29.91
1986	29.43	30.34	31.05	30.21	29.87	30.38	28.35	29.44	28.75	27.74	29.45	29.09	29.51	30.21	28.80
1987	28.99	28.99	28.46	27.93	29.24	30.21	30.38	28.31	28.08	27.31	28.44	27.95	28.69	28.97	28.41
1988	26.99	29.28	27.97	28.43	28.84	28.3	29.09	27.86	27.87	27.2	27.21	26.94	28	28.30	27.70
1989	27.85	29.29	30.15	28.19	27.86	29.45	28.09	27.84	27.74	27.22	27.66	28.84	28.35	28.80	27.90
1990	28.72	29.31	31.79	29.82	28.96	31.25	29.25	28.24	28.13	27.1	28.23	28.85	29.14	29.98	28.30

Table A.4 Station N.7A Mueang, Mueang, Phichit

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual	Wet	Dry
1991	28.81	28.18	27.81	27.65	30.72	31.79	29.28	27.88	27.84	27.07	27.31	27.45	28.48	29.16	27.81
1992	27.54	26.33	27.49	26.85	29.51	28.92	28.97	27.69	28.01	26.82	27.45	28	27.8	27.77	27.82
1993	28.1	28.37	28.62	28.12	29.2	30.94	27.56	28.09	27.82	26.87	27.28	27.53	28.21	28.89	27.53
1994	26.93	28.28	32.06	30.28	32.27	36.02	31.24	29.03	29.49	28.87	29.48	29.64	30.3	30.97	29.63
1995	29.84	29.82	30.02	29.57	34.77	37.21	35.86	31.78	30.21	29.89	29.8	30.38	31.6	31.87	31.32
1996	30.43	31.37	32.28	30.39	32.84	34.95	35.41	31.5	29.21	27.56	28.56	29.23	31.14	32.04	30.25
1997	29.37	29.13	28.12	28.62	29.74	31.49	31.18	29.03	28.59	27.22	28.58	28.47	29.13	29.41	28.85
1998	28.57	28	27.38	29.56	29.08	29.62	27.79	27.97	27.67	27.59	27.84	28.06	28.26	28.70	27.82
1999	28.4	29.13	28.93	27.8	30.03	33.82	31.57	30.73	27.42	28.23	29.77	29.97	29.65	29.69	29.62
2000	29.65	30.85	30.77	30.74	30.19	34.4	33	30.39	28.86	29.18	29.72	29.75	30.63	31.10	30.15
Average	26.38	27.06	28.66	29.4	31.54	33.19	31.7	29.18	27.83	27.04	27.21	27.36	28.88	29.44	28.48

Table A.5 Station N.5A Muang, Muang, Phitsanulok

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual	Wet	Dry
1966	34.9	35.37	36.03	37.25	41.44	42.2	37.16	36.63	35.94	35.16	34.91	34.74	36.81	37.87	35.76
1967	34.87	35.46	35.8	36.39	37.84	41.26	39.02	36.25	35.91	35.12	34.93	34.82	36.47	36.94	36.01
1968	35.04	36.49	36.87	37.17	38.81	39.14	37.13	35.68	35.24	34.92	34.62	34.53	36.3	37.25	35.35
1969	34.37	34.48	36.62	38.49	40.33	39.32	37.09	36.53	35.75	35.12	34.74	34.55	36.45	37.27	35.63
1970	34.76	35.62	37.44	40.79	44.03	45.11	40.64	37.67	36.17	35.42	35.11	34.92	38.14	39.63	36.66
1971	34.89	35.43	35.97	36.96	39.8	40.94	38.2	36.48	35.81	35.27	35.17	35.25	36.68	37.33	36.03
1972	35.25	35.65	36.7	37.33	38.28	37.18	37.18	36.14	34.98	34.63	35.11	35.72	36.18	36.73	35.63
1973	35.26	35.28	35.57	36.47	37.6	38.39	36.92	35.81	35.26	34.9	34.5	35.21	35.93	36.43	35.43
1974	36.58	36.64	36.39	37.06	38.94	38.41	37.17	36.93	36.23	35.97	35.98	36.59	36.91	37.34	36.48
1975	36.83	36.85	37.47	38.29	39.95	42.84	40.79	37.94	37.32	36.4	37.07	37.48	38.27	38.71	37.83
1976	37.96	38.28	38.17	37.46	38.79	40.49	39.71	37.92	37.39	37.01	37.12	37.44	38.14	38.53	37.77
1977	37.39	37.84	37.6	37.79	38.34	39.65	37.19	37.14	36.37	35.65	35.74	36.33	37.25	38.10	36.40
1978	36.66	35.98	36.1	38.63	40.04	40.07	39.84	36.88	37.02	36.52	36.97	37.91	37.72	37.91	37.52
1979	37.92	37.78	37.64	37.32	38.34	38.11	37.36	37.2	36.36	35.7	35.42	35.79	37.08	37.85	36.31
1980	36.01	36.4	36.89	37.16	39.04	42.32	38.67	36.36	36.61	36.29	36.94	37.24	37.49	37.97	37.02
1981	37.5	38.18	38.4	38.97	41.14	38.55	37.59	37.66	36.87	36.61	37.27	37.69	38.04	38.79	37.28
1982	38.05	37.32	36.24	36.66	37.49	38.56	37.36	36.74	36.52	36.63	37.12	37.05	37.15	37.39	36.90
1983	38.44	37.59	36.33	36.76	36.88	37.8	37.27	36.18	35.75	35.5	36.53	37.53	36.88	37.30	36.46
1984	37.6	36.73	37.29	36.53	37.5	39.32	38.16	37.29	36.27	36.59	37.35	38.14	37.4	37.50	37.30
1985	38.41	37.25	36.39	37.13	37.15	37.86	37.61	37.14	36.6	35.75	36.65	37.65	37.13	37.37	36.90
1986	37.38	38.04	38.71	37.8	37.33	37.71	36.01	37.27	36.46	35.9	37.52	37.07	37.27	37.83	36.71
1987	37.03	37	36.38	36.08	37.11	37.02	36.16	35.76	35.73	35.45	36.65	36.06	36.37	36.77	35.97
1988	35.29	37.01	35.91	36.25	36.13	35.63	35.97	35.05	35.76	35.45	35.45	35.13	35.75	36.04	35.47
1989	36.18	37.21	36.97	35.92	35.88	37.01	35.48	35.67	35.7	35.56	36.05	37.02	36.22	36.53	35.91
1990	36.86	37.36	39.01	37.21	36.52	38.67	36.5	36.05	36.03	35.36	36.49	36.99	36.92	37.61	36.24
1991	36.92	36.31	35.83	35.89	37.83	37.35	36.2	35.58	35.8	35.4	35.65	35.75	36.21	36.69	35.73
1992	35.89	35.55	35.36	35.26	36.92	36.56	35.8	35.09	36	35.16	35.87	36.25	35.81	35.92	35.70
1993	36.39	36.55	36.55	36.27	37.19	37.9	35.21	36.16	35.86	35.24	35.58	35.87	36.23	36.81	35.65
1994	35.27	36.24	38.47	36.86	39.06	41.3	36.73	36.62	36.82	36	37.13	37.63	37.34	37.87	36.82
1995	37.8	37.64	37.82	36.92	41.78	44.76	41.56	38.54	37.08	36.43	37.47	38.34	38.85	39.45	38.24
1996	38.38	38.74	39.45	37.91	40.18	41.83	39.91	37.75	36.61	35.67	36.68	37.31	38.37	39.42	37.32
1997	37.34	37.27	36.56	36.66	37.5	38.53	37.74	36.71	36.62	35.56	36.85	36.66	37	37.31	36.69
1998	36.78	36.18	35.72	36.77	36.47	36.3	35.16	35.87	35.66	35.69	36.22	36.4	36.1	36.37	35.83
1999	36.23	36.9	36.34	35.65	37.28	40.32	37.41	36.49	35.07	36.5	37.84	38.03	37	37.12	36.89
2000	37.71	38.18	38.04	37.52	37.67	39.59	38.16	36.63	36.74	37.2	37.71	37.68	37.74	38.12	37.35
2001	37.78	37.13	36.58	37.42	40.73	41.89	38.09	36.32	36.83	37.04	37.44	37.83	37.92	38.59	37.26
2002	37.75	37.53	36.98	37.3	39.03	41.51	38.18	37.28	35.76	36.57	37.39	37.52	37.73	38.35	37.12
2003	36.65	37.61	37.46	37.71	38.26	38.99	36.27	36.82	36.24	36.26	36.91	36.93	37.18	37.78	36.57
2004	37.1	36.64	37.76	37.58	37.08	39.81	36.91	37.17	37.65	37.29	37.51	37.56	37.51	37.66	37.35
Average	36.65	36.81	36.97	37.17	38.5	39.49	37.58	36.65	36.23	35.87	36.35	36.63	37.08	37.60	36.55

Table A.6 Station N26Tron,Tron,Uttaradit,

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual	Wet	Dry
1965	-	-	1.34	1.66	2.82	3.45	1.89	1.56	0.88	0.79	0.48	0.41	1.53		
1966	0.29	1.36	1.3	2.47	4.56	4.38	1.79	1.4	0.91	0.68	0.54	0.42	1.67	2.39	0.96
1967	0.58	0.86	1.22	1.7	2.75	4.6	2.68	1.25	0.88	0.66	0.48	0.5	1.52	1.95	1.08
1968	0.7	1.54	1.82	1.98	3.17	3.24	1.9	1.09	0.76	0.57	0.44	0.33	1.46	2.08	0.85
1969	0.29	0.45	1.71	3.12	4.16	2.74	1.77	1.49	0.87	0.63	0.47	0.39	1.51	2.08	0.94
1970	0.56	1.17	2.37	4.3	6.88	6.91	4.92	1.57	1.26	0.95	0.82	0.71	2.7	3.70	1.71
1971	0.63	1.1	0.99	1.55	3.72	4	1.81	1.13	1.04	0.92	0.87	0.9	1.55	2.00	1.11
1972	0.93	1.3	1.73	2.54	2.92	2	1.72	1.36	0.55	0.42	0.88	1.23	1.46	1.90	1.03
1973	0.84	0.94	0.66	1.71	1.78	1.66	0.92	1.03	0.41	0.58	0.36	1	0.99	1.27	0.72
1974	2.06	1.92	1.8	2.27	3.17	2.7	2.05	1.65	1.42	1.4	1.52	2.03	2	2.32	1.68
1975	2.31	2	2.03	2.71	3.67	4.5	3.64	2.44	2.22	1.78	2.41	2.8	2.71	2.87	2.55
1976	3.11	3.17	3.2	2.61	2.93	3.29	2.68	2.29	2.36	2.28	2.55	2.74	2.77	3.05	2.48
1977	52.15	52.34	52.37	52.28	52.36	51.54	51.1	51.83	50.98	50.48	50.72	51.28	51.62	52.17	51.07
1978	51.56	50.91	50.94	52.04	52.13	52.24	51.9	51.14	51.45	51.46	51.91	52.67	51.7	51.64	51.76
1979	52.56	52.49	51.87	51.96	52.48	51.86	51.72	51.95	49.67	50.77	50.62	50.87	51.57	52.20	50.93
1980	51.11	51.11	51.05	51.06	51.25	52.88	51.47	50.9	51.02	51.33	51.75	51.98	51.41	51.41	51.41
1981	52.44	52.47	52.71	52.44	53.83	52.49	51.96	52.31	51.46	51.64	52.36	52.62	52.39	52.73	52.06
1982	52.93	52.19	51.25	51.75	52.35	51.66	51.32	51.46	51.08	51.65	52.12	52.28	51.84	52.02	51.65
1983	53.12	52.42	51.31	51.94		51.14	50.77	50.4	50.17	50.61	51.83	52.64	38.86	51.99	51.07
1984	52.62	51.91		51.41	52.19	53.04	51.57	52.09	50.81	51.72	52.53	53.12	39.42	52.23	51.97
1985	53.24	52.26	51.38	51.28	50.97	51.56	50.64	50.74	50.61	50.74	52.07	52.81	51.53	51.78	51.27
1986	52.53	52.47	52.55	52.24	51.92	51.76	51.65	52.51	51.08	51.25	52.68	52.41	52.09	52.25	51.93
1987	52.39	52.22	51.38	51.89	51.91	51.25	50.61	50.92	50.24	50.73	52.1	51.66	51.44	51.84	51.04
1988	-	-	-	-	-	-	-	-	-	-	-	-	-		
1989	52.05	52.34	50.83	50.95	51.63	52.31	51.04	51.47	50.5	50.92	51.76	52.59	51.53	51.69	51.38
1990	52.56	52.22	52.17	51.7	51.82	52.63	51.59	51.53	50.83	50.85	52.19	52.57	51.89	52.18	51.59
1991	52.43	51.57	50.82	51.18	51.73	50.79	50.89	51.2	50.71	50.87	51.49	51.86	51.3	51.42	51.17
1992	51.93	51.41	50.64	50.55	50.64	50.97	50.47	50.87	51.02	50.68	51.46	51.78	51.03	51.02	51.05
1993	51.8	51.66	51.48	51.73	52.45	51.85	50.79	52	50.68	50.82	51.21	51.26	51.48	51.83	51.13
1994	50.69	50.75	51.05	50.5	51.84	52.51	51.86	52.06	51.65	51.6	52.61	53.13	51.69	51.22	52.15
1995	53.04	52.52	52.26	51.59	54.17	56.38	53.58	52.62	52.13	52.16	53.1	53.72	53.11	53.33	52.89
1996	53.45	52.97	53.1	52.4	53.27	53.27	51.81	51.86	51.22	51.5	-	52.81	52.51	53.08	51.84
1997	52.72	52.37	51.69	51.86	51.69	51.6	51.3	51.84	-	-	-	-	51.88	51.99	51.57
Average	34.18	34.08	28.16	33.17	29.16	33.97	32.99	32.81	31.64	31.72	31.54	32.5	32.16	32.12	32.2

Table A.7 Station N14A Wat Luang Pho Kaeo, A.Chum Saeng, NakhonSawan,

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual	Wet	Dry
1973	20.24	20.22	20.88	21.37	22.93	24.82	25.66	22.79	20.67	19.8	19.74	20.14	21.61	21.74	21.47
1974	21.01	21.27	21.22	21.44	23.56	24.37	24.15	24.58	22.04	20.66	20.49	21.22	22.17	22.15	22.19
1975	21.24	21.35	22.21	22.94	24.89	27.64	27.42	25.17	22.65	21.03	21.44	21.9	23.32	23.38	23.27
1976	22.19	22.91	22.83	22.2	24.03	26.74	27.14	25.72	22.81	21.67	21.55	21.85	23.47	23.48	23.46
1977	21.85	22.4	22.08	22.12	22.93	26.5	24.25	22.71	21.38	20.29	20.18	20.65	22.28	22.98	21.58
1978	20.98	20.69	20.72	24.6	26.03	26.18	27.42	24.07	21.96	21.06	21.22	22.08	23.08	23.20	22.97
1979	22.23	22.22	23.2	22.32	23.13	23.36	22.66	21.98	21.27	20.12	19.66	19.92	21.84	22.74	20.94
1980	20.22	20.92	22.39	23.61	25.26	27.4	27.32	23.9	21.85	20.77	21.25	21.56	23.04	23.30	22.78
1981	21.79	22.53	23.49	24.04	26.99	25.32	23.51	23.82	22.51	21.2	21.57	22.07	23.24	24.03	22.45
1989	20.73	21.69	23.54	21.22	21.28	22.79	22.69	22.47	21.4	19.71	19.71	20.25	21.46	21.88	21.04
1990	20.26	20.74	23.27	21.24	22	24.02	23.32	22.25	21.53	19.61	20.41	21.1	21.65	21.92	21.37
1991	21.18	20.55	20.37	19.9	22.97	25.95	23.61	21.92	20.85	19.53	19.69	19.85	21.36	21.82	20.91
1992	19.88	19.72	19.37	19.04	22.5	21.78	23.87	22.02	21.16	19.42	19.67	20.25	20.72	20.38	21.07
1993	20.4	20.59	21.09	20.32	21.29	24.09	21.65	20.54	20.43	18.9	19.27	19.48	20.67	21.30	20.05
1994	18.79	20.6	25.07	23.9	24.84	27.83	25.87	22.2	21.91	20.15	21.05	21.55	22.81	23.51	22.12
1995	21.87	21.96	22.13	22.33	26.66	28.26	28.03	25.86	22.46	20.53	21.41	22.57	23.67	23.87	23.48
1996	22.71	23.84	24.59	22.75	25	26.94	28.05	26.45	22.94	20.07	21.02	21.65	23.83	24.31	23.36
1997	-	-	-	-	22.38	-	-	-	-	19.42	22.22	-	21.34	22.38	20.82
1998	20.84	20.26	19.55	22.17	21.64	22.82	22.91	21.35	20.3	19.35	19.95	20.1	20.94	21.21	20.66
1999	20.22	22.03	22.74	20.93	23.21	26.69	26.44	26.22	22.37	20.55	21.85	22.08	22.94	22.64	23.25
2000	21.76	23.6	24.28	24.32	23.46	27.34	26.97	25.13	21.63	21.26	21.81	22.26	23.65	24.13	23.18
2001	21.8	22.49	22.83	22.79	26.46	27.83	27.16	24.98	22.09	21.05	21.47	21.95	23.58	24.03	23.12
2002	21.91	21.75	22.13	22.03	24.2	28.25	27.79	26.18	22.58	20.91	21.86	22.01	23.47	23.38	23.56
2003	21.07	21.74	22.38	22.87	23.81	25.44	24.66	22.15	20.53	20.18	21.09	20.99	22.24	22.89	21.60
2004	21.02	21.24	24.25	24	25.14	25.66	25.21	22.01	21.66	21.26	21.46	21.51	22.87	23.55	22.19
Average	21.09	21.55	22.36	22.27	23.86	25.75	25.32	23.6	21.71	20.34	20.84	21.21	22.49	22.81	22.17

Table A.8 Station P15 Ban KhlongKhlung, Khlong Khlung, Kampheang Phet,

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual	Wet	Dry
1966	53.63	53.76	53.96	53.6	53.84	54.46	54.2	53.71	53.54	53.52	53.61	53.78	53.8	53.88	53.73
1967	53.73	53.61	53.74	53.97	53.87	54.22	54.47	54.08	53.82	53.66	53.63	53.68	53.87	53.86	53.89
1968	53.65	53.78	53.81	53.89	54.01	54.02	54.09	53.87	53.79	53.69	53.67	53.59	53.82	53.86	53.78
1969	53.67	53.62	53.69	53.69	53.88	55.27	54.25	53.65	53.49	53.63	53.81	53.78	53.87	53.97	53.77
1970	53.93	54.26	54.26	54.17	54.76	54.71	54.75	54.32	54.2	53.83	53.87	53.91	54.25	54.35	54.15
1971	54	54.12	54.09	54.25	54.66	55.05	54.9	54.45	54.04	53.93	53.9	53.92	54.28	54.36	54.19
1972	53.86	53.93	53.95	53.97	54.01	54.25	54.46	54.05	53.9	53.79	53.87	53.94	54	54.00	54.00
1973	53.64	54.15	54.29	54.28	54.68	55.24	54.94	54.16	54.01	53.95	54.28	54.37	54.33	54.38	54.29
1974	53.96	54.09	54.13	54.05	54.23	54.71	54.75	54.79	53.69	53.7	53.85	54.12	54.17	54.20	54.15
1975	54.16	54.09	54.1	54.17	54.38	55.22	55.27	54.93	54.06	53.77	53.91	54.16	54.35	54.35	54.35
1976	54.29	54.28	54.5	54.49	54.57	-	54.67	54.6	53.84	53.8	53.93	54.24	54.29	54.43	54.18
1977	8.01	8.03	7.84	7.84	7.76	8.22	7.88	8.22	7.61	-	2.46	7.71	7.42	7.95	6.78
1978	7.71	7.62	7.66	8.13	7.94	8.22	8.32	7.19	7.3	10.34	7.37	7.84	7.97	7.88	8.06
1979	7.96	7.94	8.22	8.07	7.9	8.03	8.03	8.25	7.73	6.11	6.05	6.2	7.54	8.02	7.06
1980	5.55	6.49	6.17	5.78	5.85	6.47	6.4	5.68	6.22	6.05	5.95	5.95	6.05	6.05	6.04
1981	7.54	7.87	7.82	7.4	7.82	7.79	7.59	7.62	7.42	7.49	7.87	7.97	7.68	7.71	7.66
1982	54.07	54	53.98	54.29	54.41	54.12	54.07	53.69	53.64	53.74	54.22	54.49	54.06	54.15	53.98
1983	54.13	54.07	53.9	53.85	53.85	54.45	55.17	54.78	53.29	53.21	53.92	54.19	54.07	54.04	54.09
1984	54.09	53.9	53.67	53.64	53.82	53.87	54.13	53.57	53.3	53.49	53.86	54.03	53.78	53.83	53.73
1985	54	53.91	53.81	53.78	53.88	54.21	54.5	54.04	53.54	53.38	54.1	54.27	53.95	53.93	53.97
1986	54.27	54.53	54.15	54.05	54.05	54.27	54.33	54.2	53.46	53.46	53.99	54.42	54.1	54.22	53.98
1987	54.36	53.93	53.88	53.98	54.3	54.48	53.96	53.98	53.36	53.42	53.71	54.54	53.99	54.16	53.83
1988	-	-	-	-	-	-	-	-	-	-	-	-	-		
1989	54.63	54.07	53.7	53.55	54.21	54.05	54.59	53.99	53.45	53.66	53.92	54.27	54.01	54.04	53.98
1990	54.3	54.18	54.09	-	53.77	54.22	54.44	54.11	53.65	-	-	-	54.1	54.11	54.07
1991	53.91	53.52	53.28	53.36	53.78	53.82	54.13	53.75	53.74	53.74	53.94	54.06	53.75	53.61	53.89
1992	54.06	53.89	53.51	53.22	53.82	53.57	54.56	53.67	53.71	53.58	53.84	53.95	53.78	53.68	53.89
1993	54.02	53.9	53.92	53.65	53.82	53.76	53.92	53.93	53.41		53.42	53.52	49.42	53.85	53.64
1994	53.46	53.89	54.17	53.81	54.12	54.94	54.14	53.78	53.81	53.57	53.81	54.14	53.97	54.07	53.88
1995	54.18	54.05	54.09	53.96	54.06	54.99	54.27	53.9	53.81	53.87	54.18	54.56	54.16	54.22	54.10
1996	54.47	54.36	54.46	54.07	54.36	55.54	54.99	54.49	53.84	53.92	54.39	54.61	54.46	54.54	54.37
1997	54.44	54.43	54.08	54.05	53.63	53.68	54.05	53.72	53.65	53.73	54.05	54.36	53.99	54.05	53.93
1998	54.45	53.99	53.49	53.41	53.66	53.65	53.49	53.53	53.3	53.46	53.6	53.46	53.62	53.78	53.47
1999	53.43	53.78	53.59	53.22	53.48	53.89	54.71	54.65	53.15	53.31	53.71	53.82	53.73	53.57	53.89
2000	53.68	53.72	53.76	53.36	53.79	54.04	54.28	53.59	53.46	53.62	53.78	53.76	53.74	53.73	53.75
2001	53.83	54.16	53.73	53.38	53.86	53.62	54.01	53.74	53.33	53.39	53.63	53.81	53.71	53.76	53.65
2002	53.7	53.64	53.23	53.29	53.2	54.97	53.9	54.75	54.05	53.66	53.91	54.02	53.86	53.67	54.05
2003	53.79	54.08	54.04	53.49	53.39	53.81	53.4	53.5	53.48	53.37	53.47	53.45	53.61	53.77	53.45
2004	53.31	53.21	53.01	53.13	53.12	53.27	52.84	53	52.82	52.95	52.98	52.94	53.05	53.18	52.92
Average	47.84	47.86	47.78	47.52	47.86	48.03	48.18	47.89	47.52	47.04	47.36	47.67	47.71	47.82	47.61

Table A.9 Station P.17 Ban Tha Ngiu ,Banphot Phisai, Nakhon Sawan,

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual	Wet	Dry
1954	0	24.83	35.03	34.38	34.75	36.07	36.8	34.85	34.52	34.01	33.73	33.58	31.05	27.51	34.58
1955	33.48	34.05	35.36	34.7	35.67	36.98	36	35.11	34.34	33.83	33.68	33.4	34.72	35.04	34.39
1956	33.4	34.72	34.74	34.77	36.35	37.31	36.55	35.02	34.4	34	33.76	33.59	34.88	35.22	34.55
1957	33.42	33.39	34.25	34.29	34.86	36.34	36.17	34.47	33.96	33.56	33.48	33.29	34.29	34.43	34.16
1958	33.23	33.4	33.95	34.36	35.02	35.8	35.66	34.58	34.01	33.67	33.28	33.1	34.17	34.29	34.05
1962	99.99	-99.99	33.88	34.21	34.86	36.56	37.49	35	33.87	33.38	33.15	33.2	12.13	10.08	34.35
1963	33.2	33.12	33.3	33.2	34.28	34.79	35.68	35.07	33.9	33.45	34.21	34.17	34.03	33.65	34.41
1964	34.28	34.21	34.27	34.46	34.74	35.41	36.96	35.03	34.58	34.45	34.59	34.8	34.82	34.56	35.07
1965	34.95	35.1	34.9	35.34	35.07	35.56	35.28	35.5	34.77	34.46	34.67	34.92	35.04	35.15	34.93
1966	34.83	34.82	35.2	34.83	35.03	35.82	35.52	35	34.77	34.66	-	-	35.05	35.09	34.99
1967	34.69	34.66	35.06	35.21	35.13	35.59	35.62	35.67	35.06	34.8	34.73	34.82	35.09	35.06	35.12
1968	34.87	34.95	34.98	35.19	35.16	35.23	35.32	35.09	34.99	34.89	34.81	34.68	35.01	35.06	34.96
1969	34.77	34.74	34.77	34.79	35.08	36.4	35.65	35.04	34.64	34.68	-	-	35.06	35.09	35.00
1970	35.16	-	35.53	35.45	36.05	35.95	36.03	35.58	35.45	35.06	35.1	35.15	35.5	35.63	35.40
1971	35.16	35.28	35.3	35.35	35.77	36.22	36.02	35.7	35.35	35.21	35.22	35.23	35.48	35.51	35.46
1972	35.3	35.23	35.17	35.16	35.13	35.45	35.73	35.34	35.16	34.99	35.1	35.21	35.25	35.24	35.26
1973	35.38	35.33	35.51	35.43	35.86	36.54	36.18	35.34	35.27	35.15	35.45	35.52	35.58	35.68	35.49
1974	35.3	35.41	35.37	35.2	35.36	35.86	36.1	36.05	34.86	34.82	35.03	35.41	35.4	35.42	35.38
1975	35.53	35.39	35.38	35.34	36.54	36.4	36.43	35.98	35.32	35.19	35.2	35.39	35.67	35.76	35.59
1976	35.46	35.48	35.59	35.59	35.42	35.87	35.9	36	35.04	36.86	35.13	35.37	35.64	35.57	35.72
1977	35.63	35.64	35.36	35.28	35.19	35.64	35.31	35.45	35.02	34.67	35.16	35.22	35.3	35.46	35.14
1978	35.22	35.16	35.17	35.71	35.48	35.76	36.05	34.8	34.91	34.84	35.03	35.35	35.29	35.42	35.16
1979	35.6	35.43	35.57	35.55	35.68	35.42	35.39	35.41	35.3	34.61	34.53	34.62	35.26	35.54	34.98
1980	34.53	35.12	35.5	35.01	35.13	35.79	36.02	34.9	34.6	34.52	35.28	35.26	35.14	35.18	35.10
1981	-	35.42	35.39	34.96	35.38	35.16	35.17	36	34.93	34.8	35.19	35.43	35.26	35.26	35.25
1982	35.29	35.22	35.16	35.37	35.42	35.22	35.21	-	34.74	34.79	35.31	35.59	35.21	35.28	35.13
1983	35.29	35.17	34.94	34.81	34.84	35.55	36.42	36.25	34.55	34.4	35.11	35.4	35.23	35.10	35.36
1984	35.37	35.15	34.85	34.79	34.95	35.05	35.29	34.77	34.47	34.57	35.02	35.28	34.96	35.03	34.90
1985	35.08	34.95	34.77	34.79	34.79	35.18	35.71	35.27	34.65	34.48	35.16	35.34	35.01	34.93	35.10
1986	35.3	35.7	35.37	35.17	35.18	35.38	35.41	35.31	-	34.53	35.1	35.44	35.26	35.35	35.16
1987	35.43	35	34.96	35.04	35.29	35.56	35.16	35.09	34.57	34.53	34.67	35.55	35.07	35.21	34.93
1988	-	35.03	-	-	34.79	35.56	36.2	34.83	34.45	34.82	35.23	35.67	35.18	35.13	35.20
1989	35.73	35.21	34.87	34.64	35.26	35.15	35.64	35.12	34.57	-	35	-	35.12	35.14	35.08
1990	35.44	35.22	35.23	34.78	34.81	35.26	35.53	35.22	34.73	-	-	-	35.14	35.12	35.16
1991	35	34.61	34.4	34.39	34.7	34.93	35.2	34.83	34.82	34.76	34.97	35.15	34.81	34.67	34.96
1992	35.06	34.9	34.4	34.22	34.9	34.57	35.74	34.95	34.83	34.61	34.9	35.09	34.85	34.68	35.02
1993	35.11	34.96	34.99	34.62	34.77	34.72	34.91	34.96	34.42	34.27	34.39	34.49	34.72	34.86	34.57
1994	34.35	34.9	35.36	34.93	35.15	36.2	35.34	34.84	34.9	34.58	34.83	35.2	35.05	35.15	34.95
1995	35.21	35.14	35.16	35.03	35.14	36.26	35.66	35.07	34.92	34.88	35.34	35.61	35.29	35.32	35.25
1996	35.57	35.47	35.52	35.16	35.32	36.58	36.32	35.7	35.06	34.96	35.42	35.45	35.54	35.60	35.49
1997	32.39	35.32	35.13	35.06	34.64	34.67	35.13	34.76	0	0	0	-	25.19	34.54	13.98
1998	35.19	34.97	34.44	34.39	34.64	34.69	34.63	34.57	34.37	34.37	34.57	34.44	34.61	34.72	34.49
1999	34.37	34.95	34.79	34.25	34.47	35.02	36.23	36.19	34.27	34.36	34.93	35.05	34.91	34.64	35.17
2000	34.82	34.93	34.9	34.4	34.99	35.32	35.72	34.91	34.55	34.77	35.1	35.09	34.96	34.89	35.02
2001	35.04	35.6	35.13	34.58	35.22	34.9	35.45	35.78	34.64	34.69	34.99	35.25	35.11	35.08	35.13
2002	35.11	35.05	34.61	34.61	34.54	36.82	35.66	36.53	35.54	35.06	35.3	35.42	35.35	35.12	35.59

Table A.9 Station P.17 Ban Tha Ngiu ,Banphot Phisai, Nakhon Sawan,

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual	Wet	Dry
2003	35.13	35.44	35.38	34.95	34.84	35.37	35.01	34.95	34.95	34.85	34.93	34.89	35.06	35.19	34.93
2004	34.74	34.7	34.52	34.67	34.78	34.94	34.43	34.54	34.3	34.5	34.5	34.47	34.59	34.73	34.46
Average	31.29	31.39	34.22	34.84	35.16	35.72	34.51	30.56	28.66	28.4	28.42	29.01	31.85	33.77	29.93

Table A.10 Station C.2 Ban Phai Lom, A.Mueang, Nakhon Sawan,

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual	Wet	Dry
1949	-	-	-	-	-	-	-	-	-	17.75	17.79	17.8	17.78		
1950	17.78	18.1	19.33	20.02	21.37	22.58	24.68	24.44	-	18.73	18.34	17.8	20.29	19.86	20.80
1951	17.61	18.03	19.99	20.46	22.73	23.68	32.11	24.16	20.71	19.37	18.3	18.03	21.26	20.42	22.11
1952	17.93	17.96	18.41	19.06	21.32	23.16	24.47	22.95	19.23	18.45	18.5	18.12	19.96	19.64	20.29
1953	17.71	18.48	19.45	19.98	21.73	23.48	24.29	22.73	20.02	18.65	18.11	17.8	20.2	20.14	20.27
1954	17.73	18.52	19.23	18.58	19.5	22.13	24.3	20.66	18.74	18.03	17.64	17.47	19.38	19.28	19.47
1955	17.64	18.18	19.66	19.52	21.18	23.61	23.49	19.73	18.44	17.93	17.77	17.55	19.56	19.97	19.15
1956	17.52	18.75	19.04	20.09	22.36	23.91	24.26	20.54	18.74	18.18	17.84	17.57	19.9	20.28	19.52
1957	17.52	17.54	18.44	18.88	19.5	22.41	23.03	20.16	18.35	17.84	17.69	17.41	19.07	19.05	19.08
1958	17.31	17.49	18.15	19.08	20.03	21.96	21.5	18.95	18.04	17.57	17.36	17.31	18.73	19.00	18.46
1959	17.18	17.53	18.47	18.83	21.36	23.24	24.58	20.38	18.6	17.98	17.79	17.5	19.45	19.44	19.47
1960	17.36	17.59	18.33	18.83	20.53	22.9	23.54	20.84	19.24	18.14	17.77	17.57	19.39	19.26	19.52
1961	17.51	18.06	19.69	19.91	21.45	23.99	25.51	23.13	19.52	18.76	18.24	17.91	20.31	20.10	20.51
1962	17.7	18	18.44	18.99	20.6	22.68	24.92	21.75	18.75	18.01	17.75	17.67	19.6	19.40	19.81
1963	17.52	17.43	18.13	18.83	21.87	22.64	23.63	22.74	20.01	18.22	18.15	18.08	19.77	19.40	20.14
1964	18.12	18.35	18.95	19.61	19.89	22.16	24.92	22.42	19.1	18.4	18.31	18.44	19.89	19.51	20.27
1965	18.45	18.55	18.94	19.26	20.06	21.62	21.24	20.21	18.63	18.05	18.09	18.23	19.28	19.48	19.08
1966	18.14	18.39	19.98	19.36	21.26	23.8	22.31	20.45	19.03	18.3	18.18	18.25	19.79	20.16	19.42
1967	18.24	18.27	18.69	18.92	19.57	21.21	23.38	20.31	18.97	18.35	18.11	18.13	19.35	19.15	19.54
1968	18.23	19.05	19.39	19.73	20.6	20.62	20.05	18.88	18.52	18.17	18.04	17.85	19.09	19.60	18.59
1969	17.93	17.92	18.71	19.68	20.76	22.55	22.96	20.72	18.95	18.43	18.51	18.46	19.63	19.59	19.67
1970	18.56	19.13	20.17	21.85	22.93	24.94	24.95	21.83	19.97	19.01	18.85	18.8	20.92	21.26	20.57
1971	18.76	19.03	19.54	19.88	21.4	23.07	23.24	21.29	19.41	18.84	18.78	18.8	20.17	20.28	20.06
1972	18.8	18.76	19.09	19.26	19.88	20.11	20.71	20.04	19.11	18.32	18.44	18.66	19.26	19.32	19.21
1973	18.73	18.69	19.2	19.37	20.52	22.03	23.51	20.79	19.16	18.64	18.82	19	19.87	19.76	19.99
1974	19.08	19.28	19.19	19.15	20.31	21.42	22.1	22.35	19.79	18.76	18.71	19.1	19.94	19.74	20.14
1975	19.3	19.24	19.67	20.08	21.11	24.29	25.35	22.95	20.36	19.2	19.41	19.76	20.89	20.62	21.17
1976	19.93	20.35	20.41	20.1	20.62	22.74	23.84	22.82	20.11	19.3	19.24	19.6	20.76	20.69	20.82
1977	19.77	20.07	19.71	19.63	19.99	22.2	21.42	20.31	19.16	18.35	18.62	18.88	19.84	20.23	19.46
1978	18.94	18.82	18.86	21.22	22.28	22.77	24.84	21.45	19.48	18.88	19	19.65	20.52	20.48	20.55
Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual	Wet	Dry
1979	19.83	19.83	20.43	19.92	20.21	20.5	20.42	19.92	19.35	18.26	17.99	18.14	19.57	20.12	19.01
1980	18.24	18.93	20.11	20.46	21.52	23.2	25.17	21.63	19.43	18.67	19.15	19.44	20.5	20.41	20.58
1981	19.71	20.01	20.65	20.55	22.7	22.4	21.05	21.65	20.07	18.9	19.31	19.82	20.57	21.00	20.13
1982	19.72	19.34	19.09	19.33	19.79	21.19	22.19	20.82	19.22	18.73	19.36	19.59	19.86	19.74	19.99
1983	19.77	19.51	18.97	18.88	19.83	21.37	23.09	23.39	20.09	18.42	19.1	19.71	20.18	19.72	20.63
1984	19.71	19.35	19.81	19.19	19.6	21	21.48	20.91	19.38	18.67	19.31	19.84	19.85	19.78	19.93
1985	19.86	19.46	19.25	19.64	20.23	21.33	22.68	23.07	20.98	18.6	19.36	19.85	20.36	19.96	20.76
1986	19.71	20.72	20.81	20.09	20.18	20.89	20.45	20.33	19.47	18.24	19.45	19.77	20.01	20.40	19.62

Table A.10 Station C.2 Ban Phai Lom, A.Mueang, Nakhon Sawan,

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual	Wet	Dry
1987	19.68	19.27	19.06	18.74	19.62	21.22	22.18	20.58	19.41	18.03	18.51	19.5	19.65	19.60	19.70
1988	19.22	19.69	19.87	19.78	19.88	20.87	21.92	21.35	19.45	18.55	18.94	19.41	19.91	19.89	19.94
1989	19.64	19.52	20.36	18.95	19.47	20.14	20.72	20.43	19.21	18.23	18.55	19.49	19.56	19.68	19.44
1990	19.5	19.6	21.05	19.51	19.45	20.69	20.86	20.1	19.42	18.23	18.47	18.98	19.66	19.97	19.34
1991	19.05	18.38	18.21	17.89	19.63	21.66	21.02	19.95	19.05	18.08	18.34	18.54	19.15	19.14	19.16
1992	18.48	18.3	17.59	17.24	19.9	19.11	21.35	20.1	19.19	18.01	18.27	18.69	18.85	18.44	19.27
1993	18.77	18.74	19.12	18.36	18.94	20.42	19.62	18.84	18.35	17.28	17.56	17.77	18.65	19.06	18.24
1994	17.28	18.79	21.51	20.86	21.15	23.86	23.28	20.02	19.63	18.26	18.92	19.44	20.25	20.58	19.93
1995	19.62	19.7	19.79	19.74	22.08	24.89	25.6	22.98	20.3	19.1	19.76	20.42	21.16	20.97	21.36
1996	20.42	20.87	21.15	20.11	21.11	23.07	24.87	23.9	20.74	18.81	19.55	19.84	21.2	21.12	21.29
1997	19.8	19.61	19.1	19.09	19.53	20.65	21.29	19.7	19.15	18.19	18.82	19.22	19.51	19.63	19.40
1998	19.31	18.69	17.86	19.22	19.07	19.93	20.56	19.19	18.23	17.52	18.02	17.94	18.8	19.01	18.58
1999	17.96	19.52	20.08	18.62	19.67	21.79	23.29	23.49	19.94	18.27	19.26	19.47	20.11	19.61	20.62
2000	19.14	20.22	20.66	20.45	20.33	22.52	23.28	21.98	19.21	18.91	19.41	19.7	20.48	20.55	20.42
2001	19.36	20.35	20.36	19.79	22	22.8	23.5	22.23	19.7	18.81	19.21	19.67	20.65	20.78	20.52
2002	19.52	19.45	19.43	19.34	20.36	24.35	25.32	23.82	20.9	19.4	19.87	20.03	20.98	20.41	21.56
2003	19.42	19.86	20.18	20.14	20.5	21.6	21.64	19.84	18.95	18.63	19.08	18.98	19.9	20.28	19.52
2004	18.85	19.02	20.39	20.57	21.42	21.54	21.71	19.29	18.78	18.72	18.82	18.81	19.83	20.30	19.36
Average	18.7	18.95	19.46	19.54	20.63	22.2	23.05	21.26	19.37	18.43	18.58	18.74	19.91	19.91	19.91

A.2 Historical Wells' data

Table A.11 Sample wells' data in upper aquifer layer

Well No.	UTM-E	UTM-N	Date	Depth of Well	Head(m bgl.)	Flow rate	surface level (m MSL)
K0034	679000	1960650	10/8/1965	15.00	5.08	-38.27	155.00
Q0069	637250	1966840	2/4/1966	30.00	7.49	-6.82	217.00
Q0070	649340	1958750	28/4/1966	45.00	8.74	-2.86	104.00
Q0073	689250	1972550	5/9/1966	69.00	12.60	-4.09	200.00
Q0083	699150	1989940	4/8/1967	15.00	3.68	-7.20	23.00
Q0088	674340	1959400	24/11/1967	31.50	4.31	-6.55	186.00
Q0089	658250	1944190	9/1/1968	27.00	4.12	-7.20	144.00
Q0090	601500	1938800	27/1/1968	63.00	12.48	-4.50	60.00
Q0091	638750	1964250	28/2/1968	42.00	6.47	-3.56	96.00
MA0003	647600	1724150	6/11/1971	28.50	1.50	-1.14	30.00
MB0012	567700	1929550	5/4/1972	36.00	2.48	-7.12	93.00
MB0013	573500	1927340	12/4/1972	42.00	5.40	-1.14	92.00
MB0014	569000	1932050	25/4/1972	27.00	5.02	-4.23	87.00
N0126	641950	1848190	19/11/1972	30.00	5.44	-16.57	41.00
MB0027	586200	1927300	1/2/1973	36.00	9.86	-4.80	64.00
MB0029	572790	1929090	25/2/1973	36.00	4.95	-7.20	139.00
MB0030	605200	1922500	7/3/1973	60.00	7.03	-43.26	58.00
MB0033	613590	1944900	7/4/1973	60.00	8.02	-43.26	60.00
MC0061	643200	1754450	12/5/1973	69.00	3.40	-155.91	24.00
MC0063	647900	1752400	18/7/1973	60.00	2.51	-109.09	23.00
MB0047	589900	1911590	25/8/1973	60.00	9.00	-34.09	55.00
MB0050	601650	1938940	17/12/1973	79.50	7.50	-3.41	60.00
MB0083	617150	1945590	26/11/1975	30.00	9.09	-48.59	60.00
MB0085	583290	1855190	15/12/1975	13.50	3.90	-4.55	47.00

Well No.	UTM-E	UTM-N	Date	Depth of Well	Head(m bgl.)	Flow rate	surface level (m MSL)
MB0099	674590	1832090	20/5/1976	13.50	1.92	-7.05	55.00
MB0102	645950	1848940	10/6/1976	60.00	3.89	-2.52	43.00
MB0103	645950	1845400	17/6/1976	30.00	5.89	-37.20	38.00
MB0105	664650	1846550	30/6/1976	18.00	3.99	-2.88	85.00
MB0108	664650	1860190	6/8/1976	21.00	3.60	-2.27	290.00
MB0111	692700	1877090	17/10/1976	18.00	7.50	-1.14	278.00
MB0112	692500	1887550	26/10/1976	30.00	10.70	-6.02	239.00
MB0113	692200	1887300	8/11/1976	30.00	4.74	-4.12	239.00
MB0114	694700	1892300	21/11/1976	30.00	4.03	-3.20	213.00
MB0115	701790	1893840	29/11/1976	30.00	1.80	-3.41	224.00
MB0117	703500	1894500	17/12/1976	30.00	3.66	-4.11	224.00
MB0118	700340	1901840	24/12/1976	30.00	3.00	-6.57	267.00
MB0123	630040	1929250	15/3/1977	24.00	6.93	-23.86	4.00
MB0124	630450	1929900	23/3/1977	30.00	6.96	-3.60	65.00
MB0126	620900	1928800	10/4/1977	30.00	3.61	-28.53	54.00
MB0127	621540	1920800	23/4/1977	54.00	6.61	-18.01	65.00
MB0128	601900	1942050	30/4/1977	18.00	3.79	-5.04	65.00
MB0131	605650	1933650	2/6/1977	30.00	5.10	-22.73	63.00
MB0134	610590	1952590	16/7/1977	30.00	1.74	-7.12	86.00
MB0135	606250	1945000	26/7/1977	54.00	5.70	-5.04	70.00
MB0136	613650	1943250	2/8/1977	30.00	8.45	-7.20	65.00
MB0137	612400	1953800	14/8/1977	43.50	9.54	-7.20	95.00
MB0138	612790	1954590	23/8/1977	36.00	4.51	-10.57	101.00
MB0139	610540	1951840	5/9/1977	21.00	10.12	-4.78	111.00
MW0003	610250	1952050	30/11/1977	24.00	1.29	-5.17	130.00
MW0004	641590	1942750	8/12/1977	48.00	5.74	-2.77	122.00
MW0005	608000	1956500	13/12/1977	42.00	6.87	-11.48	100.00

Well No.	UTM-E	UTM-N	Date	Depth of Well	Head(m bgl.)	Flow rate	surface level (m MSL)
MW0014	560340	1915150	22/3/1978	87.00	2.75	-2.52	77.00
MB0148	626700	1794150	9/5/1978	48.00	5.10	-22.73	224.00
MQ0020	661150	1697050	23/7/1978	60.00	8.70	-3.41	81.00
ME0182	668590	1848800	15/8/1978	30.00	1.50	-1.14	85.00
MQ0023	641650	1690650	16/8/1978	24.00	3.76	-2.06	24.00
ME0183	687200	1863000	23/8/1978	21.00	9.00	-1.14	185.00
MB0158	653700	1829650	31/8/1978	30.00	2.36	-10.69	39.00
MW0025	657400	1943340	10/11/1978	36.00	9.00	-3.13	175.00
MW0026	654500	1942500	24/11/1978	60.00	5.90	-4.12	102.00
MW0028	690290	1978190	15/1/1979	66.00	3.71	-2.74	22.00
ME0191	675200	1871090	4/2/1979	24.00	3.60	-1.14	165.00
MW0029	640250	1963400	5/2/1979	60.00	17.59	-2.51	110.00
ME0192	660790	1863190	15/2/1979	30.00	11.03	-6.67	285.00
MB0171	641250	1840150	19/2/1979	66.00	6.66	-14.78	42.00
MB0172	644590	1837190	26/2/1979	36.00	8.74	-4.24	41.00
ME0193	672000	1844400	4/3/1979	36.00	3.00	-2.27	65.00
ME0194	670840	1845340	17/3/1979	30.00	4.00	-5.04	65.00
MQ0052	647100	1760700	9/4/1979	30.00	5.10	-13.64	30.00
MB0178	602290	1863800	22/5/1979	48.00	12.52	-7.20	45.00
MB0182	676700	1847190	28/7/1979	24.00	3.61	-2.92	65.00
MB0186	705290	1895000	27/8/1979	36.00	5.40	-4.09	224.00
MB0188	646500	1832050	30/11/1979	30.00	5.80	-7.21	38.00
MB0189	684450	1893090	5/12/1979	30.00	5.35	-3.73	194.00
MB0191	605250	1858500	16/12/1979	48.00	12.12	-7.20	45.00
MB0197	701090	1893550	6/2/1980	39.00	7.46	-5.04	224.00
MB0198	701200	1893440	12/2/1980	36.00	8.74	-3.89	224.00
MB0200	689500	1894050	27/2/1980	36.00	3.60	-6.82	182.00

Well No.	UTM-E	UTM-N	Date	Depth of Well	Head(m bgl.)	Flow rate	surface level (m MSL)
MB0206	683590	1895500	15/5/1980	36.00	3.30	-5.04	190.00
MB0207	680290	1899340	23/5/1980	36.00	7.50	-2.27	195.00
MB0210	649250	1940940	14/6/1980	9.00	3.81	-4.78	102.00
MB0211	627590	1912800	24/7/1980	33.00	1.29	-2.52	65.00
MC0318	608840	1958340	6/8/1980	33.00	12.00	-2.27	300.00
MB0212	638450	1963900	15/8/1980	18.00	3.64	-2.52	5.00
MB0213	639700	1967550	4/9/1980	19.50	0.90	-4.09	165.00
MQ0091	634500	1953750	4/9/1980	45.00	1.20	-2.27	75.00
MC0320	642450	1931440	14/9/1980	30.00	6.00	-2.27	85.00
MQ0092	662950	1946940	18/9/1980	61.50	4.44	-2.74	186.00
MC0321	702400	1995840	23/9/1980	33.00	4.50	-2.27	220.00
MQ0093	658500	1944190	29/9/1980	25.50	0.60	-4.55	145.00
MB0215	685700	1967500	30/9/1980	24.00	4.80	-4.09	185.00
MB0217	601500	1938690	12/12/1980	48.00	4.90	-2.40	60.00
MB0218	613590	1943440	19/12/1980	30.00	44.48	-4.80	65.00
MB0219	610340	1952500	31/12/1980	51.00	7.50	-3.41	130.00
MB0220	610250	1952690	7/1/1981	18.00	13.50	-3.60	95.00
MB0221	613400	1948000	12/1/1981	36.00	9.15	-2.40	75.00
MB0222	613500	1945650	18/1/1981	27.00	5.91	-10.39	65.00
MB0223	612340	1945800	24/1/1981	24.00	9.36	-1.99	70.00
MB0224	611290	1924550	30/1/1981	54.00	7.13	-12.16	60.00
MB0226	640700	1931650	13/2/1981	33.00	5.10	-4.80	75.00
MB0227	610200	1950190	26/2/1981	48.00	7.83	-7.20	78.00
MQ0114	610840	1782930	15/3/1981	60.00	9.11	-4.81	303.00
MB0230	701340	1901150	23/3/1981	24.00	5.70	-3.41	267.00

Table A.12 Wells' data in lower aquifer layer

Well No.	UTM-E	UTM-N	Date	Depth of Well	Head(m bgl.)	Flow rate	surface level (m MSL)
MB0051	619040	1937690	12/1/1973	108.00	7.50	-3.41	56.00
MQ0168	576250	1895550	31/8/1982	126.00	12.41	-2.57	50.00
MQ0185	573250	1890250	31/1/1983	108.00	14.09	-8.13	53.00
MQ0186	574250	1894250	12/2/1983	111.00	22.50	-1.14	53.00
MQ0224	584540	1766300	18/11/1983	186.00	0.00	-0.45	44.00
MQ0239	578750	1776930	29/2/1984	186.00	0.00	-0.23	56.00
MM0233	585790	1861400	13/8/1990	111.00	12.00	-4.55	49.00
DI0017	582790	1872400	7/12/1991	102.00	3.60	-3.41	48.00
DI0029	586090	1860500	21/1/1992	111.00	8.61	-3.60	49.00
DI0072	593290	1903000	20/9/1992	114.00	12.00	-18.18	55.00
MR0203	624000	1917000	31/1/1993	108.00	2.10	-7.20	65.00
DI0103	585900	1861090	6/3/1993	103.50	12.90	-3.41	49.00
MR0285	616590	1949000	30/4/1994	108.00	11.40	-15.91	61.00
TK0036	624400	1714300	30/6/1994	109.50	6.00	-2.73	38.00
TK0105	676450	1724700	26/3/1995	114.00	20.98	-1.00	37.00
TK0127	640450	1686600	9/7/1995	115.50	8.00	-10.00	18.00
TK0128	638900	1686900	13/7/1995	121.50	30.52	-7.20	19.00
TK0130	666850	1687550	21/7/1995	120.00	536.97	-6.34	39.00
TK0131	623050	1702150	25/7/1995	121.50	76.03	-4.05	22.00
MD1030	650350	1804150	31/5/1998	104.00	6.00	-4.50	33.00
TK0516	621200	1732675	20/11/1999	102.00	2.00	-7.00	39.00
TK0517	621200	1732675	30/11/1999	108.00	2.00	-3.00	39.00
TA0406	666750	1687900	17/5/2001	103.50	18.00	-3.00	39.00
MB0298	585700	1923250	31/12/1982	90.00	6.95	-1.29	63.00
DI0027	592900	1878400	13/1/1992	90.00	7.50	-6.82	42.00

Well No.	UTM-E	UTM-N	Date	Depth of Well	Head(m bgl.)	Flow rate	surface level (m MSL)
MR0207	627790	1953150	21/2/1993	90.00	3.60	-2.27	60.00
MR0214	683400	1966300	17/3/1993	90.00	11.40	-4.55	185.00
MR0215	686290	1963590	22/3/1993	96.00	20.40	-4.55	320.00
TK0049	626550	1709200	13/8/1994	91.50	6.00	-2.27	25.00
TK0119	676450	1724700	9/6/1995	93.00	17.71	-3.00	37.00
TK0122	642800	1685900	20/6/1995	91.50	8.68	-9.29	25.00
TK0391	641500	1690600	28/7/1998	90.00	5.00	-3.00	24.00
TY0246	635850	1700250	22/3/2001	91.00	7.00	-3.00	34.00
TA0410	648830	1729700	11/6/2001	91.50	6.00	-3.00	33.00
TA0411	643300	1732650	17/6/2001	90.00	11.00	-3.00	25.00

Table A.13 Monitoring wells and Record's data

Well No.	Water level(m bgl.)	Record Date	UTM-E	UTM-N
MB0046	5.88	1 January 2537	555687	1825116
MB0046	6.25	2 February 2537	555687	1825116
MB0046	6.16	3 March 2537	555687	1825116
MB0046	6.65	1 April 2537	555687	1825116
MB0046	2.87	1 May 2537	555687	1825116
MB0046	2.56	3 June 2537	555687	1825116
MB0046	2.9	31 July 2537	555687	1825116
MB0046	1.46	30 August 2537	555687	1825116
MB0046	2.5	29 September 2537	555687	1825116
MB0046	4.3	30 November 2537	555687	1825116
MB0046	4.88	31 December 2537	555687	1825116
MB0046	5.34	21 January 2538	555687	1825116
MB0046	5.64	28 February 2538	555687	1825116
DC0312	10.95	26 February 2541	636265	1842332
DC0312	10.94	26 March 2541	636265	1842332
DC0312	11.4	29 March 2541	636265	1842332
DC0312	11.4	29 March 2541	636265	1842332
DC0312	11.67	27 April 2541	636265	1842332
DC0312	11.68	27 April 2541	636265	1842332
MB0969	12.03	27 May 2541	604601	1928802
DC0312	12.04	25 June 2541	636265	1842332
DC0312	16.31	27 June 2541	636265	1842332
DC0312	11.59	29 July 2541	636265	1842332
MB0969	12.19	29 July 2541	604601	1928802
DC0312	16.7	29 August 2541	636265	1842332
MB0969	12.07	29 August 2541	604601	1928802
DC0312	16.08	28 September 2541	636265	1842332
MB0969	11.92	28 September 2541	604601	1928802
DC0312	16.4	28 November 2541	636265	1842332
MB0969	12.31	28 June 2542	604601	1928802
DC0312	15.93	28 July 2542	636265	1842332
MB0969	12.31	28 July 2542	604601	1928802
DC0312	13.82	29 August 2542	636265	1842332
MB0969	12.09	29 August 2542	604601	1928802
DC0312	41.4	28 September 2542	636265	1842332
MB0969	11.65	29 September 2542	604601	1928802

Well No.	Water level(m bgl.)	Record Date	UTM-E	UTM-N
DC0312	15.28	29 November 2542	636265	1842332
MB0969	10.89	29 November 2542	604601	1928802
DC0312	16.34	29 December 2542	636265	1842332
MB0969	11.72	29 December 2542	604601	1928802
DC0312	17.1	29 January 2543	636265	1842332
MB0969	11.94	30 January 2543	604601	1928802
DC0312	16.79	27 March 2543	636265	1842332
MB0969	11.88	27 March 2543	604601	1928802
DC0312	15.88	27 April 2543	636265	1842332
MB0969	11.77	27 April 2543	604601	1928802
DC0312	14.66	29 May 2543	636265	1842332
MB0969	10.86	29 May 2543	604601	1928802
DC0312	15.15	24 June 2543	636265	1842332
MB0969	11.38	24 June 2543	604601	1928802
DC0312	15.06	25 July 2543	636265	1842332
MB0969	11.4	25 July 2543	604601	1928802
MB0969	11.23	29 August 2543	604601	1928802
DC0312	15.29	30 August 2543	636265	1842332
MB0969	10.79	29 September 2543	604601	1928802
DC0312	11.69	30 September 2543	636265	1842332
DC0312	11.34	28 October 2543	636265	1842332
MB0969	10.58	28 October 2543	604601	1928802
DC0312	13.7	27 November 2543	636265	1842332
MB0969	10.52	28 November 2543	604601	1928802
DC0312	15.64	27 December 2543	636265	1842332
MB0969	10.65	27 December 2543	604601	1928802
DC0312	19.9	27 January 2544	636265	1842332
MB0969	10.89	27 January 2544	604601	1928802
MB0969	10.98	25 February 2544	604601	1928802
DC0312	16	26 February 2544	636265	1842332
MB0969	11.05	24 March 2544	604601	1928802
DC0312	15.18	26 March 2544	636265	1842332
DC0312	15.45	28 April 2544	636265	1842332
MB0969	10.94	28 April 2544	604601	1928802
DC0312	15.26	27 May 2544	636265	1842332
MB0969	10.91	27 May 2544	604601	1928802
DC0312	15.35	26 June 2544	636265	1842332
MB0969	10.92	26 June 2544	604601	1928802
B0969	10.67	26 July 2544	604601	1928802

Well No.	Water level(m bgl.)	Record Date	UTM-E	UTM-N
DC0312	15.21	27 August 2544	636265	1842332
MB0969	10.42	27 August 2544	604601	1928802
DC0312	13.69	26 September 2544	636265	1842332
MB0969	10.09	26 September 2544	604601	1928802
DC0312	15.18	12 November 2544	636265	1842332
MB0969	8.94	12 November 2544	604601	1928802
MB0969	8.79	27 November 2544	604601	1928802
DC0312	16.76	29 November 2544	636265	1842332
DC0312	17.85	24 December 2544	636265	1842332
MB0969	9.06	24 December 2544	604601	1928802
DC0312	18.19	27 January 2545	636265	1842332
MB0969	9.38	27 January 2545	604601	1928802
DC0312	18.21	26 February 2545	636265	1842332
MB0969	9.67	26 February 2545	604601	1928802
DC0312	18.45	23 March 2545	636265	1842332
MB0969	10.06	24 March 2545	604601	1928802
DC0312	20.09	25 April 2545	636265	1842332
MB0969	9.91	25 April 2545	604601	1928802
DC0312	19.9	25 May 2545	636265	1842332
MB0969	9.75	25 May 2545	604601	1928802
DC0312	19.08	22 June 2545	636265	1842332
MB0969	9.95	22 June 2545	604601	1928802
DC0312	18.41	23 July 2545	636265	1842332
MB0969	9.96	23 July 2545	604601	1928802
DC0312	16.55	23 August 2545	636265	1842332
MB0969	9.3	23 August 2545	604601	1928802
MB0969	31.6	22 June 2546	604601	1928802
DC0312	9.23	23 June 2546	636265	1842332
MB0969	9.61	20 July 2546	604601	1928802
DC0312	9.32	21 July 2546	636265	1842332
GWA0024	6.6	31 July 2546	617129	1710848
GWA0025	6.13	31 July 2546	617129	1710848
MB0969	9.32	24 August 2546	604601	1928802
DC0312	8.14	25 August 2546	636265	1842332
MB0969	8.75	24 September 2546	604601	1928802
DC0312	6.34	25 September 2546	636265	1842332
DC0492	9.32	28 February 2547	619300	1932700
GWA0024	6	28 February 2547	617129	1710848
GWA0025	6	28 February 2547	617129	1710848

Well No.	Water level(m bgl.)	Record Date	UTM-E	UTM-N
MB0683	11.94	28 February 2547	613900	1944400
GWA0024	6.17	31 March 2547	617129	1710848
GWA0025	6.16	31 March 2547	617129	1710848
DC0492	8.16	30 April 2547	619300	1932700
GWA0024	6.71	30 April 2547	617129	1710848
GWA0025	6.73	30 April 2547	617129	1710848
MB0683	11.36	30 April 2547	613900	1944400
GWA0024	6.61	31 May 2547	617129	1710848
GWA0025	6.51	31 May 2547	617129	1710848
GWA0024	6.91	30 June 2547	617129	1710848
GWA0025	6.88	30 June 2547	617129	1710848
MB0136	11.6	30 June 2547	613650	1943250
GWA0024	6.8	31 July 2547	617129	1710848
GWA0025	6.72	31 July 2547	617129	1710848
GWA0024	6.35	31 August 2547	617129	1710848
GWA0025	6.26	31 August 2547	617129	1710848
MB0136	12.09	31 August 2547	613650	1943250
GWA0024	6.45	30 September 2547	617129	1710848
GWA0025	6.74	30 September 2547	617129	1710848
MB0136	12.32	28 February 2548	613650	1943250
GWA0024	7.1	30 April 2548	617129	1710848
GWA0025	7.05	30 April 2548	617129	1710848
GWA0024	7.5	30 June 2548	617129	1710848
GWA0025	7.43	30 June 2548	617129	1710848
MB0136	11.95	30 June 2548	613650	1943250

Table A.14 Estimated Pumping rate for each water users

Year	Season	Layer1					Layer2					Grand Total
		Person	Village	Agriculture	Private	Total	Personal	Village	Agriculture	Private	Total	
1993	wet	12,578	75,553	38,301	70,096	196,528	6,501	10,964	19,797	381	37,643	234,170
	dry	12,578	75,553	345,050	70,096	503,277	6,501	10,964	178,351	381	196,197	699,474
1994	wet	14,925	75,553	45,446	70,096	206,020	7,411	10,964	22,567	381	41,322	247,342
	dry	14,925	75,553	511,780	70,096	672,354	7,411	10,964	254,132	381	272,888	945,242
1995	wet	16,381	75,553	24,971	70,096	187,002	8,037	10,964	12,251	381	31,632	218,634
	dry	16,381	75,553	137,363	70,096	299,394	8,037	10,964	67,391	381	86,772	386,166
1996	wet	18,274	75,553	27,856	70,096	191,779	8,811	10,964	13,431	381	33,587	225,366
	dry	18,274	75,553	153,234	70,096	317,157	8,811	10,964	73,885	381	94,040	411,197
1997	wet	19,677	75,553	59,916	70,096	225,242	9,384	10,964	28,576	381	49,304	274,546
	dry	19,677	75,553	449,822	70,096	615,148	9,384	10,964	214,533	381	235,261	850,409
1998	wet	20,582	75,553	62,673	70,096	228,904	9,816	10,964	29,889	381	51,049	279,954
	dry	20,582	75,553	470,519	70,096	636,750	9,816	10,964	224,395	381	245,554	882,305
1999	wet	21,276	75,553	64,788	70,096	231,713	10,176	10,964	30,986	381	52,506	284,219
	dry	21,276	75,553	729,590	70,096	896,515	10,176	10,964	348,941	381	370,461	1,266,976
2000	wet	21,643	75,553	65,903	70,096	233,195	10,372	10,964	31,585	381	53,301	286,496
	dry	21,643	75,553	494,768	70,096	662,060	10,372	10,964	237,122	381	258,839	920,898
2001	wet	22,239	75,553	33,900	70,096	201,788	10,640	10,964	16,219	381	38,203	239,990
	dry	22,239	75,553	186,478	70,096	354,366	10,640	10,964	89,218	381	111,202	465,568
2002	wet	22,586	75,553	34,429	70,096	202,665	10,797	10,964	16,458	381	38,600	241,264
	dry	22,586	75,553	189,392	70,096	357,628	10,797	10,964	90,536	381	112,677	470,305
2003	wet	22,587	75,553	34,431	70,096	202,667	10,798	10,964	16,460	381	38,602	241,269
	dry	22,587	75,553	189,401	70,096	357,638	10,798	10,964	90,543	381	112,685	470,322

Appendix B

Input and results of the groundwater system calculations

B..1 Groundwater system in Present period

Table B.1 Groundwater's part: unit in MCM/day

Year	Land RECHARGE	Pumping	River Change	Storage Change	BC-in	BC-out
1993	2,033,547	2,307,195	-535,998	-345,375	400,000	300,000
1994	2,378,071	3,019,684	-2,139,639	-1,752,425	400,000	300,000
1995	2,839,209	1,571,854	-1,515,496	88,983	400,000	300,000
1996	2,723,692	1,654,921	-1,162,570	476,240	400,000	300,000
1997	1,868,031	2,868,689	-359,592	-1,125,229	400,000	300,000
1998	2,100,957	2,961,450	-97,131	94,534	400,000	300,000
1999	2,764,236	3,915,482	149,115	-122,647	400,000	300,000
2000	2,494,075	3,066,140	93,480	170,066	400,000	300,000
2001	2,261,564	1,827,261	-248,382	529,489	400,000	300,000
2002	2,723,789	1,843,004	-306,459	728,109	400,000	300,000
2003	1,939,226	1,843,085	-73,496	338,349	400,000	300,000
AVG	2,375,127	2,443,524	-563,288	-83,628	400,000	300,000
Max	2,839,209	3,915,482	149,115	728,109	400,000	300,000
Min	1,868,031	1,571,854	-2,139,639	-1,752,425	400,000	300,000

Table B.2 Surface water's part

Year	Rainfall (MCM)	Evap (mm)	Runoff (MCM)	Temp (^{o}C)	Demand (MCM)	Surface supply (MCM)	Average of Dam Storage (MCM)	Dam Release (MCM)
1993	33,176	1,410	10,616	54	3,108	2,445	1,865	7,412
1994	46,105	1,412	14,754	54	2,573	2,443	7,923	6,635
1995	42,774	1,399	13,688	54	3,020	2,575	11,253	13,595
1996	46,188	1,440	14,780	54	4,043	3,517	9,646	14,598
1997	31,297	1,434	10,015	55	3,898	3,222	6,561	12,165
1998	37,447	1,399	11,983	54	3,290	2,457	3,187	6,928
1999	56,201	1,421	17,984	54	3,628	2,882	6,907	5,651
2000	49,960	1,422	15,987	53	3,670	3,072	10,789	9,554
2001	39,749	1,400	12,720	54	3,843	3,074	11,352	11,453
2002	45,828	1,429	14,665	55	3,811	3,404	11,989	12,872
2003	32,328	1,433	10,345	54	4,311	3,858	9,008	13,797
AVG	41,914	1,418	13,412	54	3,563	2,995	8,225	10,424
Max	56,201	1,440	17,984	55	4,311	3,858	11,989	14,598
Min	31,297	1,399	10,015	53	2,573	2,443	1,865	5,651

B.3 Groundwater system in Near Future period

Table B.3 Groundwater’s part: unit in MCM/day

Year	Land Recharge	Pumping	River Recharge	Leak from lower aquifer	Storage Change	BC in	BC out
2015	1,447,949	2,501,103	-124,660	344,962	-475,616	400,000	300,000
2016	1,379,828	2,558,803	104,915	416,595	-399,666	400,000	300,000
2017	1,442,068	3,359,052	506,892	16,809	-506,863	400,000	300,000
2018	1,428,544	2,592,106	-116,516	290,014	-255,752	400,000	300,000
2019	1,416,082	2,669,544	108,905	218,464	-198,404	400,000	300,000
2020	1,237,599	3,433,822	105,946	77,026	-397,953	400,000	300,000
2021	1,275,466	3,084,406	109,266	-231,440	-289,896	400,000	300,000
2022	1,321,333	2,524,019	-128,562	-209,586	-1,766	400,000	300,000
2023	1,702,209	2,649,036	-340,144	179,455	-30,465	400,000	300,000
2024	1,363,954	2,693,503	-362,343	151,338	-81,665	400,000	300,000
2025	1,365,311	2,720,988	-410,943	-102,689	-110,193	400,000	300,000
2026	1,233,677	2,564,516	-409,721	58,734	-60,829	400,000	300,000
2027	1,247,536	2,569,030	-441,839	206,702	-45,820	400,000	300,000
2028	1,414,602	2,691,771	-523,336	261,051	-85,960	400,000	300,000
2029	1,217,302	2,729,722	-497,908	-18,371	-122,651	400,000	300,000
AVG	1,366,231	2,756,095	-161,336	110,604	-204,233	400,000	300,000
Max	1,702,209	3,433,822	506,892	416,595	-1,766	400,000	300,000
Min	1,217,302	2,501,103	-523,336	-231,440	-506,863	400,000	300,000
Year	Land Recharge	Pumping	River Recharge	Leak from lower aquifer	Storage Change	BC in	BC out

Table B.4 Surface water's part

Year	Rainfall (MCM)	Runoff (MCM)	Temp (^{o}C)	Evap (mm)	Demand (MCM)	Surface supply (MCM)	Average of Dam Storage (MCM)	Dam Release (MCM)
2015	42,028	13,449	27	1,441	4,059	3,034	19,170	12,529
2016	42,337	13,548	27	1,418	3,358	2,832	18,603	11,055
2017	44,302	14,177	27	1,425	3,764	2,906	18,954	10,945
2018	45,653	14,609	27	1,443	5,167	3,831	18,646	11,801
2019	41,687	13,340	27	1,429	4,963	3,559	18,764	10,847
2020	35,323	11,303	27	1,439	4,740	2,995	18,163	11,850
2021	38,139	12,205	27	1,437	4,738	3,147	17,729	9,349
2022	43,907	14,050	27	1,422	4,656	3,354	18,101	9,948
2023	49,565	15,861	28	1,501	5,051	3,402	19,122	10,585
2024	42,989	13,756	27	1,439	6,027	3,718	18,987	12,531
2025	42,631	13,642	27	1,438	6,472	4,241	18,387	10,638
2026	36,202	11,585	28	1,483	3,894	2,986	18,388	10,868
2027	37,727	12,073	28	1,467	3,323	2,651	18,428	11,094
2028	43,464	13,909	28	1,503	3,798	2,870	18,102	10,055
2029	35,065	11,221	28	1,491	4,996	3,689	17,704	10,764
AVG	41,401	13,248	28	1,452	4,600	3,281	18,483	10,991
Max	49,565	15,861	28	1,503	6,472	4,241	19,170	12,531
Min	35,065	11,221	27	1,418	3,323	2,651	17,704	9,349

B.3 Groundwater system in Far Future period

Table B.5 Groundwater's part: unit in MCM/day

Year	Land Recharge	Pumping	River Recharge	Leak from lower aquifer	Storage Change	BC in	BC out
2075	1,445,029	2,681,798	-589,488	15,466	-107,727	400,000	300,000
2076	1,501,731	2,605,777	-644,141	122,143	-12,775	400,000	300,000
2077	1,375,574	2,543,762	-658,962	121,669	2,572	400,000	300,000
2078	1,362,500	2,600,012	-679,044	197,369	-28,915	400,000	300,000
2079	1,596,201	2,600,303	-755,035	175,443	-37,398	400,000	300,000
2080	1,399,309	2,547,245	-745,246	155,512	-30,800	400,000	300,000
2081	1,368,410	2,843,486	-739,789	60,093	-115,405	400,000	300,000
2082	1,580,514	3,632,155	-592,706	144,047	-413,067	400,000	300,000
2083	1,610,858	2,593,675	-724,666	-468,730	11,089	400,000	300,000
2084	1,486,210	2,580,922	-786,824	-58,236	83,968	400,000	300,000
2085	1,506,972	2,582,250	-811,847	108,312	-16,058	400,000	300,000
2086	1,500,083	2,506,474	-826,861	143,795	-25,441	400,000	300,000
2087	1,411,993	2,551,382	-830,443	215,437	-22,475	400,000	300,000
2088	1,488,053	2,577,334	-858,140	258,341	-29,497	400,000	300,000
2089	1,695,893	2,793,935	-923,822	240,440	-68,634	400,000	300,000
AVG	1,488,622	2,682,701	-744,468	95,407	-54,038	400,000	300,000
Max	1,695,893	3,632,155	-589,488	258,341	83,968	400,000	300,000
Min	1,362,500	2,506,474	-923,822	-468,730	-413,067	400,000	300,000

Table B.6 Surface water's part

Year	Rainfall (MCM)	Runoff (MCM)	Temp (°C)	Evap (mm)	Demand (MCM)	Surface supply (MCM)	Average of Dam Storage (MCM)	Dam Release (MCM)
2075	43,973	14,071	30	1,583	4,978	3,218	18,868	12,596
2076	43,801	14,016	29	1,555	5,283	3,310	19,668	12,132
2077	43,871	14,039	29	1,527	5,058	3,034	19,476	12,357
2078	43,817	14,021	29	1,533	4,295	2,864	19,488	11,959
2079	43,686	13,979	30	1,558	4,710	3,045	19,438	12,692
2080	44,157	14,130	29	1,537	5,092	3,225	19,375	11,655
2081	41,771	13,367	29	1,515	6,191	3,661	19,056	11,721
2082	47,673	15,255	30	1,547	6,199	3,819	19,041	11,150
2083	44,985	14,395	30	1,557	3,638	3,009	18,959	12,220
2084	50,322	16,103	30	1,547	3,241	2,570	19,339	12,126
2085	43,533	13,931	30	1,546	4,089	2,811	18,922	10,936
2086	43,276	13,848	30	1,547	5,008	3,323	18,807	10,918
2087	45,513	14,564	30	1,550	5,451	3,392	19,067	12,641
2088	43,914	14,053	30	1,549	4,793	2,810	19,186	11,791
2089	48,827	15,625	30	1,551	4,234	2,827	18,735	10,290
AVG	44,875	14,360	30	1,547	4,817	3,128	19,162	11,812
Max	50,322	16,103	30	1,583	6,199	3,819	19,668	12,692
Min	41,771	13,367	29	1,515	3,241	2,570	18,735	10,290

VITA

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