ผลกระทบจากการเปลี่ยนแปลงสภาพภูมิอากาศโลกต่อการเติมน้ำใต้ดินของพื้นที่เมืองโฮจิมินท์

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วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
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IMPACT OF CLIMATE CHANGE ON GROUNDWATER RECHARGE IN HO CHI MINH CITY AREA

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A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Engineering Program in Water Resources Engineering
Department of Water Resources Engineering
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ฮา กวาง คาย : ผลกระทบจากการเปลี่ยนแปลงสภาพภูมิอากาศโลกต่อการเติมน้ำใต้ดินของพื้นที่เมืองโฮจิมินท์ (IMPACT OF CLIMATE CHANGE ON GROUNDWATER RECHARGE IN HO CHI MINH CITY AREA) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: สุจริต คูณธนกุลวงศ์, 149 หน้า.

โฮจิมินห์เป็นเมืองใหญ่ที่สุดในประเทศเวียตนามและคาดว่าจะได้รับผลกระทบจากการเปลี่ยนแปลงสภาพภูมิอากาศ นอกจากนี้ น้ำบาดาลมีความสำคัญต่อการพัฒนาเมืองนี้ เนื่องจากเป็นแหล่งน้ำกับเมืองกว่า 32 % ของน้ำประปาในเมือง ซึ่งส่งผลให้ระดับน้ำในเมืองลดลงอย่างมาก ในช่วงหลายปีที่ผ่านมา เนื่องจากความต้องการด้านสังคมและเศรษฐกิจน้ำบาดาลในเมืองโฮจิมินห์ ได้รับผลกระทบโดยตรงจากสภาพภูมิอากาศ อาทิเช่น ปริมาณฝน การระเหยและคายน้ำ ระดับน้ำแม่น้ำ แต่การศึกษาผลกระทบจากสภาพการเปลี่ยนแปลงสภาพภูมิอากาศต่อน้ำบาดาลในพื้นที่ยังอยู่ในระยะเริ่มต้น

การศึกษาครั้งนี้ได้นำเสนอการประยุกต์ใช้แบบจำลองน้ำบาดาล (MODFLOW) ซึ่งใช้ข้อมูลจากแบบจำลลองภูมิอากาศโลกในการศึกษาผลกระทบของการเปลี่ยนแปลงสภาพภูมิอากาศต่อการเติมน้ำในพืนที่ศึกษา แบบจำลองสภาพภูมิอากาศโลกที่ใช้เป็น แบบจำลอง MRI-ABCM3.2 และใช้ข้อมูลอนาคตของ ฝน อุณหภูมิ ในพื้นที่ศึกษาในสองช่วงเวลา คือ อนาคตอันใกล้ (2015-2035) และอนาคตอันไกล (2075-2099) วิธีการแก้ความลำเอียงสามารถลดความลำเอียงทั้งในเชิงปริมาณและการกระจาย เมื่อเปรียบเทียบระหว่างข้อมูลวัดจริงและข้อมูลคำนวณ ในแต่ละกริดในพื้นที่ศึกษา โดยใช้รูปแบบการกระจายของฝนจากค่าวัดจริงในแกนพื้นที่ จากนั้นได้ประยุกต์ใช้แบบจำลองน้ำบาดาลในการประมาณอัตราการเติมน้ำในช่วงปี 1995-2012 และทำการจำลองการไหลเพื่อหาผลกระทบจากการเปลี่ยนแปลงสภาพภูมิอากาศต่อการเติมน้ำของน้ำบาดาล

การศึกษาครั้งนี้ได้จำลองสภาพน้ำบาดาลเป็นสองกรณี คือ การประเมินผลกระทบกรณีที่มีและไม่มีการเพิ่มของระดับน้ำทะเล ผลการประเมินผลกระทบพบว่าสภาพน้ำบาดาลในอนาคตในพื้นที่ศึกษาจะได้รับผลกระทบจากการเปลี่ยนแปลงของสภาพภูมิอากาศและการขึ้นของระดับน้ำทะเล อัตราการเติมน้ำจากพื้นดินจะลดลง 17 % เนื่องจากการเพิ่มของอัตราการระเหยและฟื้นกลับมาเท่าค่าปัจจุบันเนื่องจากมีปริมาณฝนมากขึ้น นอกจากนี้ การเปลี่ยนแปลงของสภาพภูมิอากาศและการขึ้นของระดับน้ำทะเลส่งผลการเพิ่มของระดับน้ำบาดาลในอนาคต แต่ก็ส่งผลให้มีโอกาสของการแทรกตัวของน้ำเค็มเข้าสู่ชั้นน้ำบาดาลด้วยเช่นกัน

ในการปรับปรุงการจัดการน้ำบาดาล การศึกษาได้จำลองสภาพน้ำบาดาลในอนาคตโดยการควบคุมการสูบน้ำบาดาล ผลการศึกษาพบว่า ถ้าสามารถลดอัตราการสูบน้ำบาดาลลง 41 % ในอนาคตอันใกล้และ 56 % ในอนาคตอันไกล จะทำให้ระดับน้ำบาดาลคืนตัว 2.86 เมตรในอนาคตอันใกล้ และ 4.56 เมตร ในอนาคตอันไกล และยังลดการไหลของน้ำเค็มเข้าชั้นน้ำบาดาลได้ 41% และ 56 % ในอนาคตอันใกล้ และอนาคตอันไกล ตามลำดับ

ภาควิชา	วิศวกรรมแหล่งน้ำ	ลายมือชื่อนิสิต	....
สาขาวิชา	วิศวกรรมแหล่งน้ำ	ลายมือชื่อ อ.ที่ปรึกษาหลัก	....
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HA QUANG KHAI: IMPACT OF CLIMATE CHANGE ON GROUNDWATER RECHARGE IN HO CHI MINH CITY AREA. ADVISOR: ASSOC. PROF. SUCHARIT KOONTANAKULVONG, Ph.D., 149 pp.

Groundwater is very important for the development of Ho Chi Minh City since it provides 32% of water supply, however, the groundwater level is decreasing dramatically in recent years due to the socio-economical demand. Moreover, groundwater in Ho Chi Minh City is directly impacted by climate factors such as precipitation, evapotranspiration, and river water stage. However, the study of climate change impact on groundwater for the area is just in the starting stage.

The study presented the application of groundwater model (MODFLOW) using Global Climate model (GCM) data to study the impact of climate change on groundwater recharge in the area. Global Climate Model (GCM) named MRI-AGCM3.2s is used to project precipitation and temperature for the area in two future timeframes, i.e., near future (2015-2039) and far future (2075-2099). Bias-correction method exhibited ability of reducing biases from the frequency and amount when compared with observed and computed values at grid nodes; based on spatially interpolated observed rainfall data. Groundwater model is applied to estimate historical recharge rate (1995-2007) and develop recharge function as well as groundwater simulation, to determine the impacts of climate towards groundwater recharge. Calibration groundwater model is implemented during 1995-2007 and verification groundwater model during 2008-2012. Calibrating and verifying groundwater model show that the simulation result is more reasonable when using recharge rate function with effective rainfall and with the recharge function, the impact of climate factor such as precipitation and temperature on groundwater recharge can be examined in the future.

Two cases of future groundwater simulation were conducted such as with/without sea level rise to assess the impacts. As a result, future groundwater simulations show that groundwater resources in the area will be impacted by climate change and sea level rise. Groundwater recharge from land surface will decrease 17% in the near future due to more evapotranspiration and recover in the far future period due to more precipitation. Besides, climate change and sea level rise will increase groundwater level in the future, however, it also leads to the increase possibility of salt water intrusion in the same time.

For groundwater management improvement, this study simulated future groundwater conditions by controlling groundwater pumping. The results show that groundwater pumping reduction of 41% in the near future and 56% in the far future can make groundwater level increase 2.86 m in the near future period and 4.56 m in the far future period, and decrease 41% and 56% of salt water flow from salt water zone to fresh water zone in near future and far future, respectively.

Department:	Water Resources Engineering	Student's Signature	
Field of Study:	Water Resources Engineering	Advisor's Signature	
Academic Year:	2014		

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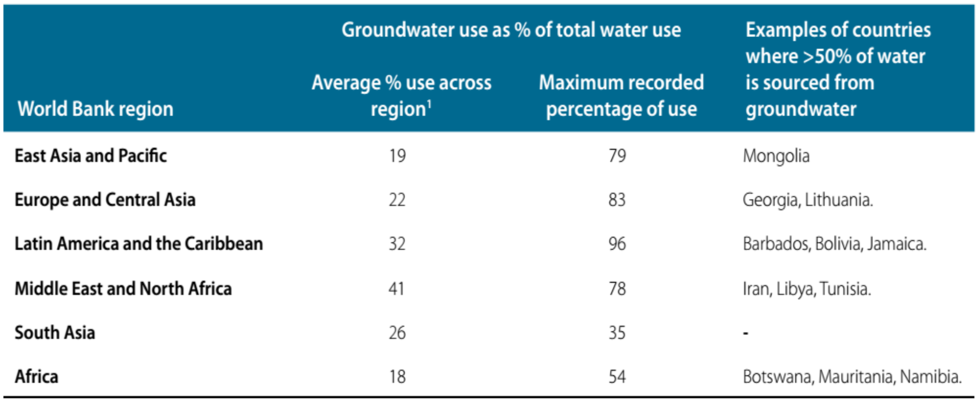
CHAPTER I

INTRODUCTION

I.1 Background of the Problem

Groundwater is a very important part of life and socio-economic development of the country. It provides water for the lives of more than two billion people in the world. In the Europe and Central Asia, groundwater provide up to 83% for total water use, and 35% in south Asia (Clifton et al., 2010).

Table 1: Groundwater use in the World Bank region



World Bank region	Groundwater use as % of total water use Average % use across region[1]	Maximum recorded percentage of use	Examples of countries where >50% of water is sourced from groundwater
East Asia and Pacific	19	79	Mongolia
Europe and Central Asia	22	83	Georgia, Lithuania.
Latin America and the Caribbean	32	96	Barbados, Bolivia, Jamaica.
Middle East and North Africa	41	78	Iran, Libya, Tunisia.
South Asia	26	35	-
Africa	18	54	Botswana, Mauritania, Namibia.

Source data: IGRAC

Groundwater resources is related to climate through the direct interaction with surface water resources, such as lakes and rivers, and indirectly through the recharge process. The direct effect of climate change on groundwater resources depends upon the change in the volume and distribution of groundwater recharge (Taylor et al.,2013).

I.2 Statement of Problem

Vietnam was reported as a country where is strongly affected by climate change. In late 21st century, annual mean temperature over all area will go up by 2-3^{0}C. The total annual and seasonal rainfall increase, while the rainfall in dry seasons will decrease in comparison to those in 1980-1999 period (Quang, 2012).

Specifically, in Ho Chi Minh City area, annual mean temperature was forecasted to increase by 2.5-2.8^{o}C, and annual rainfall will also increase by 3-5% in late 21st century compared with those in period of 1980 -1999. Historically, during in the last 50 years, the annual average temperature has increased by around 0.5^{o}C. Rainfall increased by 5 to 20% in the southern region including Ho Chi Minh City area (Quang, 2012).

Climatic factors are strongly affected on groundwater resources in Ho Chi Minh area in terms of both direct and indirect impacts. According to the results of groundwater observation network in Ho Chi Minh from 1993 to 2012, it is shown that groundwater levels in Ho Chi Minh City are clearly under the influence of climate factors, tide and exploitation. Groundwater levels also have gradually decreased in recent years. And according to the studies on groundwater system in Sai Gon river basin including Ho Chi Minh City area, it is also shown that generating sources of groundwater reserves involved five components as recharge, seepage, leakage, flow from surrounding areas and changing storage. Among them, recharge accounted around 14.5% in rainy season, and river leakage accounted around 20.17% (Chan,2011).

In Ho Chi Minh City, 34% amount of water supply comes from groundwater resources. Particularly, groundwater resources are mainly used for human activities and high profitable industries. This shows that the lives of 7 million people and the development of the local economy depend~~s~~ heavily on groundwater resources.

Therefore, the purpose of this study is to extend the analysis of climate change impact on groundwater recharge by groundwater flow model within the Ho Chi Minh City area under transient conditions for climate change scenarios. This will permit a more comprehensive evaluation of groundwater budgets and provide for a better understanding of the direct impact of climate change on recharge of aquifers in the area.

I.3 Objectives of the study

The main objective of this study is to assessment the impact of climate change on groundwater resources.

The specific objectives are:

- To project the future climate on the Ho Chi Minh City area via bias correcting of GCM named MRI AGCM3.2s;

- To develop recharge function with climate factors;

- To assess the impact on groundwater recharge via groundwater modeling;

- To recommend on groundwater management for the area from the impact on groundwater recharge to cope with climate change in the future.

I.4 Scope of the study

I.4.1.Study area

Study area stretches from latitude 10.320 E to 11.201 E and from longitude 106.215 N to 107.024 N with an area of 8,659 km2.

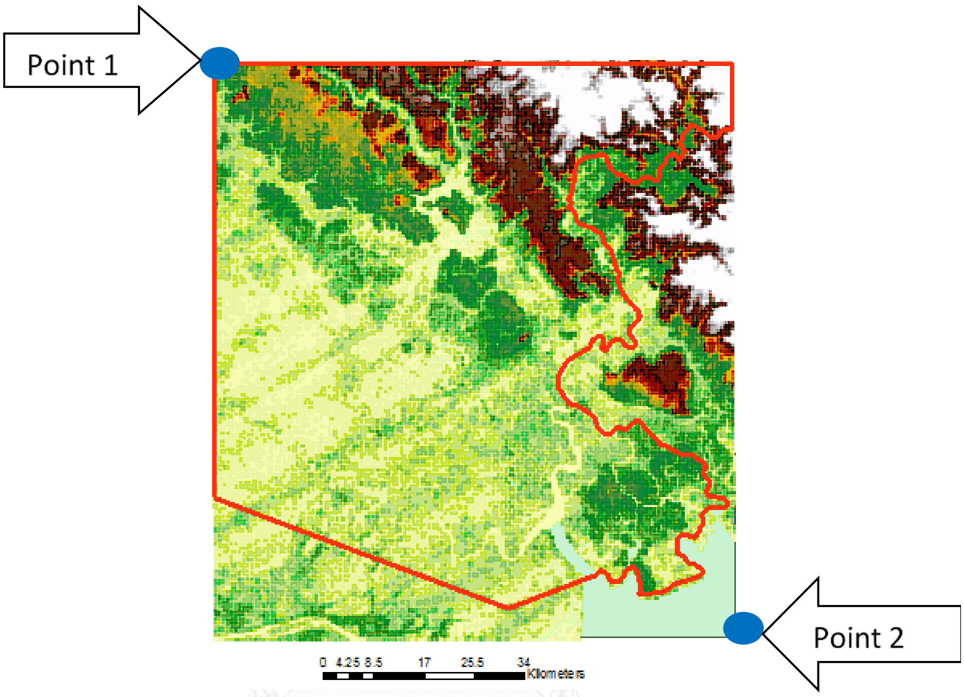


Figure 1: Study area

I.4.2.General Circulation model

Used MRI AGCM3.2s data and applied Gama – Gama transformation method for bias correction GCMs.

I.4.3.Groundwater model

- Apply GMS software version 9.1 to build Groundwater flow model and to estimate historical recharge. Recharge function will be derived from the temperature, precipitation and evapotranspiration in the area.

- Apply multiple linear regression method to estimate river water level at river stations.

- Recommendations to groundwater management on demand control and/or new water supply.

I.4.4.Data usage in the study

No	Data	Period of data	Sources
1	Hydrogeology map	1993-2012	Division for Water resources Planning and Investigation of the South of Vietnam
2	Borehole strata		
3	Geophysical		
4	Groundwater level		
5	Groundwater Exploitation	1993-2012	Department of Resources and Environmental
6	Water Use		
7	Rainfall	1980-2010	Southern Regional Hydrometeorology Center
8	Temperature, Evaporation		

I.4.5.Limitations of the study

-This study only concerns on assessment of the impacts of climate change on groundwater quantity.

-The study is based on secondary data collection;

-Land use change in the future is not taken into account in this research and the future water demand projection will base on the study of water supply expansion project on “Ho Chi Minh City Water Supply Master Plan to 2025” (Ho Chi Minh City, 2011).

I.4.6.Expected outcomes

The expected outcomes from this study would be as follows:

- Climate change projection scenarios in Ho Chi Minh City area.
- Amount of groundwater recharge under climate change scenarios
- Future the groundwater table and river water table at selected stations under climate change scenarios
- Groundwater reserves under climate change scenarios
- Groundwater management recommendations in context of climate change

CHAPTER II
LITERATURE REVIEW

II.1 Climate change in Vietnam

In 1994, based on the climate change scenario of Australia’s Commonwealth Scientific and Industrial Research Organization (CSIRO), the experts who participated in the project “Climate Change in Asia” developed the first climate change scenario for Viet Nam, called as climate change in 1994. Similarly in 1998, climate change scenarios in Viet Nam were developed for 3 main climatic elements: temperature, rainfall and sea level, and the time slice milestones were 2010s, 2050s and 2070s (Nguyen, 2009).

In 2009, in order to implement the National Target Program in Response to Climate Change, experts of the Institute of Meteorology, Hydrology and Environment have developed the Climate Change scenario as the guideline for ministries, sectors and provinces to develop action plans on response to Climate Change. The scenario has been officially published by Ministry of Natural Resources and Environment (MONRE) in June 2009. Through the application of statistical downscaling methods and MAGICC/SCENGEN tools with output of MRI/AGCM and PRECIS, the authors identified the average annual increase in temperature, changes of rainfall and sea level rise for each decade in the 21stcentury. The scenarios were divided in 3 groups according to IPCC emissions scenarios, including: High emissions group (A1FI, A2), medium emissions group (A1B, B2), and low emissions group (A1T, B1).

In 2011, Ministry of Natural Resources and Environment provided Climate Change scenario version 2011 to update scenario in 2009 (Quang, 2012). This version has more details than one in 2009, as well as it was also developed based on more data than the version in 2009.

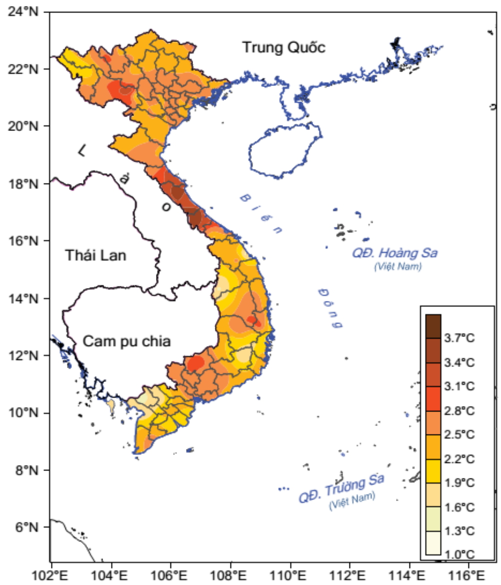


Figure 3:A1B1: Change of average temperature in 2100 compared with 1990s

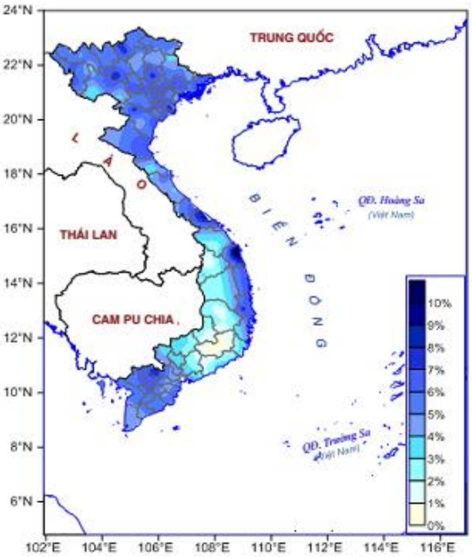


Figure 2:A1B1: Change of annual rainfall in 2100 compared with 1990s

II.2 Groundwater resources in Ho Chi Minh City.

There are several important researches on groundwater resources system in Ho Chi Minh City area as hydrogeology map (1983) and the newest version in 2010 (Vuong, 2010) or applied groundwater modeling to study on groundwater (Chan, 2011), or applied isotope techniques on groundwater (Chinh, 2012). Besides, since 1990s groundwater monitoring national network started to observe groundwater resources for all of the southern delta area including Ho Chi Minh City area.

Earlier 1990s, Ministry of Industry Vietnam had invested to build groundwater observation wells in all area of the southern delta of Vietnam including 40 wells on Ho Chi Minh City. These wells use to monitor groundwater level and groundwater quality. Based on the result of monitoring network in 20 years from 1992 to 2012, groundwater resources system in Ho Chi Minh City had been divided into three region as areas affected by tidal, areas affected by climate – surface water and areas damaged by groundwater exploitation. Moreover, results of these groundwater observation wells also shown that groundwater level was decreasing in all wells. Particularly, on the well ID Q 019340, groundwater level had decreased by 30 m compared with 1995.

In 2010, reconstruction of hydrogeological map for Ho Chi Minh City at scale of 1: 50 000 was manipulated by Vuong (2010). The map based on historical data included geophysical, well, pumping tests, previous researches etc.., to determine distribution of aquifers, aquitards and distribution of salt water. Result of this research shows that there are six aquifers in Ho Chi Minh City area with age ranging from Pleistocene to Upper Miocene

Boehmer (2000) had built groundwater flow model for the whole of the south delta area of Vietnam by using software GMS 3.0. This model simulated 4 aquifer include Pleistocene, Middle Pliocene, Lower Pliocene and upper Miocene. This model also used monitoring data during 1992 to 1997. However, because of the study area was quite huge, so model grid size was thus large 6000x6000m that affected to results of model. Consequently, this model could only simulated water level of overall area and seawater intrusion in some provinces.

Lanh Do T (2010) had developed groundwater flow model in Ho Chi Minh City and neighborhood area at the lower part Dong Nai river system basin. Based on presently water withdrawal to predict water demand in 2007, 2015, 2020 and his determined generating sources groundwater reserves with three scenarios of groundwater withdrawal by 398,047, 1,205,306, and 1,396,953 cubic meter per day. Result of model determined generating sources groundwater reserves from 5 parts as recharge, surface, leaky, flow from neighborhood area and changing storage.

Chan N D (2011) applied groundwater flow modelling to estimate generating sources groundwater exploitation reserves on Sai Gon river basin, including Ho Chi Minh city area. To limit the influence of boundary to the model results, he had extended area of model around 18,210km^2 to compute for Sai Gon river basin area by 3,870km^2, and model grid size by 1000x1000m with fifteen layers. Aquifer hydraulic conductivities come from pumping test of previous researches, and the model boundary conditions included: General Head assigned to big rivers or Lakes and western boundary, no flow simulate aquitards and location aquifer thickness small, river boundary conditions and recharge is assumed at 10% amount of rainfall. Initial groundwater withdrawal was used as collected data, after that it was change during model calibration. Calibration divided into two steps as steady stage and transient stage. Result of this model shows that generating sources groundwater reserves involved five components as recharge, surface, leaky, flow from the surrounding areas and changing storage. Among them, recharge accounts from 0 to 10.3%, river leakage accounted from 18.54% to 21.41%.

Chinh (2012) used the isotope techniques to study groundwater recharged availability in Ho Chi Minh City Area. Results of the study show that shallow groundwater is formed by meteoric water, recharge rate of 139.73 mm/year, and accounted 4.62% of precipitation. The spatial recharge distributed mainly in the northern – western part in Ho Chi Minh City area.

In summary: from previous researches on groundwater resources in Ho Chi Minh Area: hydrogeological strata had been determined such as depth, distribution, thickness, material. Results of pumping tests were used to determine hydrogeological parameters of aquifers. In addition, these studies show that there is closed relationship among groundwater, surface water and climate as well. In some researches, the results also estimated generating sources groundwater reserves which involved five components such as recharge, surface, leaky, flow from neighborhood area and changing storage. Among these, recharge accounted around 0-10.83%, and river leakage accounted around 18.56-21.78%. Particularly, the study of applying isotope method on groundwater resources had determined that the amount of recharge equaled 4.62% of annual rainfall.

II.3 Impact of climate change on groundwater resources

In recent years, researches on impact of climate on groundwater had been dramatically developed and improved from studies using empirical models up to the mathematical model.

Chen, Grasby, and Osadetz (2002) developed an empirical model to link climate factor with groundwater level and proposed to use it for predicting groundwater level under climate change conditions for a carbonate rock aquifer in Manitoba (Canada). Within this model, recharge was linked with precipitation and temperature using simple water balance equation. In the same way, (Okkonen & Kløve, 2010) developed a conceptual and statistical approach for the analysis of climate impact on ground water table fluctuation patterns in cold conditions an unconfined esker aquifer in boreal environment in central Finland.

Brouyère, Carabin, and Dassargues (2004) modeled groundwater flows under climate change conditions in a chalk aquifer in Belgium. The saturated groundwater flow model was implemented with the finite element code 'SUFT3D''. Recharge rates are calculated with the soil model 'EPIC-GRID', which performs water budget at the ground surface level and in the unsaturated zone. Exchange fluxes were unidirectional, from the soil model to the groundwater model.

Scibek and Allen (2006) modeled impacts of predicted climate change on recharge and groundwater levels. A methodology was developed for linking climate models and groundwater models to investigate future impacts of climate change on groundwater resources. An unconfined aquifer, situated near Grand Forks in south central British Columbia, Canada, was used to test the methodology. Climate change scenarios from the Canadian Global Coupled Model 1 (CGCM1) model runs were downscaled to local conditions using Statistical Downscaling Model (SDSM). The recharge model simulated the direct recharge to the aquifer. And three-dimensional transient groundwater flow model, implemented in MODFLOW, was then used to simulate four climate scenarios in 1-year runs during (1961–1999 present, 2010–2039, 2040–2069, and 2070–2099) and compared groundwater levels to present. Result of the study show that more recharge to the unconfined aquifer from spring to the summer season.

Woldeamlak, Batelaan, and De Smedt (2007) modeled effects of climate change on the groundwater system in the Grote-Nete catchment, Belgium, using wet (greenhouse), cold or NATCC

(North Atlantic Thermohaline Circulation Change) and dry climate scenarios. Low, central and high estimates of temperature changes were adopted for wet scenarios. Recharge rates are calculated with WetSpass model and applied steady-state MODFLOW groundwater model to modeled effects of climate change on the groundwater.

Serrat-Capdevila et al. (2007) assessed the climate change impacts in the water resources of a semi-arid basin in southeastern Arizona and northern Sonora using results from an ensemble of 17 global circulation models (GCMs) and four different climate change scenarios from the Intergovernmental Panel on Climate Change (IPCC). Annual GCM precipitation data for the region was spatially downscaled and used to derive spatially distributed recharge estimates in the San Pedro Basin. A three dimensional transient groundwater surface water flow model is used to simulate the hydrology of the current century, from 2000 to 2100, under different climate scenarios and model estimates. Groundwater extraction in the basin was maintained constant and equal to current. The use of multiple climate model results provided a highest-likelihood mean estimate as well as a measure of its uncertainty and a range of less probable outcomes. Results suggested that recharge in the San Pedro basin will decrease, affecting the dynamics of the riparian area in the long term.

Goderniaux et al. (2009) provided an improved methodology for the estimation of the impacts of climate change on groundwater reserves, where a physically-based surface–subsurface flow model is combined with advanced climate change scenarios for the Geer basin(465 km^2), Belgium. Coupled surface–subsurface flow was simulated with the finite element model HydroGeoSphere. Climate change simulations were obtained from six regional climate model (RCM) scenarios assuming the SRES A2 emission (medium–high) scenario.

II.4 General Circulation Models

According to IPCC, numerical models (General Circulation Models; GCMs), representing physical processes in the atmosphere, ocean, cryosphere and land surface, are the most advanced tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations (criterion 1). While simpler models have also been used to provide globally- or regionally-averaged estimates of the climate response, only GCMs, possibly in conjunction with nested regional models, have the potential to provide geographically and physically consistent estimates of regional climate change which are required in impact analysis, thus fulfilling criterion 2

K. E. Taylor, Stouffer, and Meehl (2012) provided an overview of CMIP5, as in earlier CMIP phases, calls for integrated sets of experiments that offered a multi-model perspective of simulated climate change and climate variability. Most modeling groups worldwide were participating in CMIP5, and their simulations were expected not only to be useful to research scientists in a variety of climate-related disciplines but also of relevance to national and international assessments of climate science (e.g., the IPCC AR5). The CMIP5 model output is freely available to all researchers through gateways linked to modeling and data centers worldwide, where the data will be archived. Compared to previous phases of CMIP, not only will be more comprehensive set of output be produced but better documentation will be made available.

Mizuta et al. (2012) introduced about MRI AGCM 3.2s is a new version of the atmospheric general circulation model from the Meteorological Research Institute (MRI), with a horizontal grid size of about 20 km. The model shows improvements in simulating heavy monthly-mean precipitation around the tropical Western Pacific, the global distribution of tropical cyclones, the seasonal march of East Asian summer monsoon, and blockings in the Pacific.

II.5 Bias correction of GCM data

Bias is defined as the time independent component of the error. It is well known that some form of pre-processing is necessary to remove biases presented in the simulated climate output fields before they can be used for hydrological modeling. The bias correction methods are used to remove the bias from GCM data such as gamma-gamma transformation. The bias correction method is reviewed in the following.

Ines and Hansen (2006) proposed the use of gamma distribution to represent observed rainfall intensity, and applied both gamma and empirical distributions to correct the bias of GCM rainfall intensity. At the study site, the proposed bias correction methodology was applied to correct the bias of both the mean and variance of monthly and seasonal GCM rainfall, including frequency and mean. All of the bias correction procedures improved maize yield simulations, but resulted in substantial negative mean bias. This bias appeared to be associated with a tendency for the GCM rainfall to be more strongly auto correlated than observed rainfall, resulting in unrealistically long dry spells during the growing season.

Sharma, Das Gupta, and Babel (2007) employed bias-correction and spatial disaggregation methods to improve the quality of ECHAM4/OPYC SRES A2 and B2 precipitation for the Ping River Basin in Thailand. The bias-correction method, based on gamma-gamma transformation, was applied to improve the frequency and amount of raw GCM precipitation at the grid nodes. The bias-correction method showed the ability of reducing biases from the frequency and amount compared observed rainfall data.

Hanittinan and Koontanakulvong (2014) used two bias corrected, super high-resolution Global Climate Models (GCMs), namely MRI-AGCM 3.1S and ECHAM5, and also downscaled CSIRO-MK3.5 to simulate precipitation scenarios in two future timeframes, which are near future period (A.D. 2015-2039) and far future period (A.D. 2075-2099). Gamma-Gamma transformation model was used to reduce the biases in terms of frequency and intensity from raw GCM precipitation. Spatial disaggregation model is used to tackle the scale issues. The results showed the change of rainfall volume and patterns in the Yom River Basin and the projection from GCMs after bias correction, with reasonable accuracy

II.6 Recharge function development

Wu, Zhang, and Yang (1996) used in-situ lysimeter experiments and numerical simulations were used to study the relationships between rainfall and recharge by infiltration at different groundwater depths. Relationships between rainfall and infiltration recharge at different groundwater depths were investigated. The results showed that: for shallow groundwater depths, groundwater regime data may be used to obtain the correlation between rainfall and recharge. For a groundwater system of intermediate depth recharge was function of effective rainfalls. For very deep groundwater table, annual recharge rate may be treated as a constant.

Krüger, Ulbrich, and Speth (2001) used water budget equation combined with Turc (1954) equation to estimate groundwater recharge in Northrhine-Westfalia. A statistical model is applied to project future region climate along with the ECHAM4/OPYC3 model output is used to estimate future recharge.

Thomas, Jaiswal, Galkate, and Singh (2009) development a Rainfall-Recharge relationship for a Fractured Basaltic Aquifer in Central India by approached water balance method to estimate rainfall recharge and then the result of method is compared with four existing models. In this study also developed two models to estimate recharge by analysis relationship between annual rainfall and recharge.

Misstear, Brown, and Daly (2009) provided a methodology for making initial estimates of groundwater recharge. The author shown that recharge to an aquifer can be estimated by first calculating the effective rainfall using a soil moisture budgeting technique, and then by applying a recharge coefficient to indicate the proportion of this effective rainfall that contributes to groundwater recharge from groundwater vulnerability mapping.

Healy (2010) wrote a book on estimating groundwater recharge. In the book show methods used for estimating groundwater recharge such as: groundwater budget method, empirical method, applied Isotope method and groundwater model method as well.

Khai and Koontanakulvong (2015)applied concept of effective rainfall and through calibration groundwater model (MODFLOW) process during 2010-2012 to drive recharge function. After that, using recharge function and future climate projected by MRI AGCM 3.2s to project future recharge in Ho Chi Minh City area.

II.7 MODFLOW model

MODFLOW is an extremely versatile finite-difference groundwater model that simulates three dimensional groundwater flow through a porous medium (McDonald & Harbaugh, 1988). It was designed to have a modular structure that facilitates ease of understanding and ease of enhancing. MODFLOW includes procedures to simulate effects of wells, recharge, rivers, drains, evapotranspiration, and "general-head boundaries", with solution algorithms that include Strongly Implicit Procedure (SIP), Slice-Successive Over Relaxation (SSOR), and Preconditioned Conjugate Gradient (PCG) iteration techniques. Layers can be either confined, unconfined or a combination of both. It is set up as a series of separate modules, which are independent; the user selects only the modules needed for the particular system that is under study.

The MODFLOW model was developed to simulate the movement of the water flow underground. Using 3D finite difference method, groundwater flow model can simulate a number of different types of aquifers. There are two steps of a groundwater modeling process:

II.7.1. Conceptual model

A conceptual model is a simplified but accurate representation of the field groundwater flow system shown as cross section or block diagram. In the conceptual model definition, preliminary water balance, flow systems, model boundaries, and flow rate need to be specified.

II.7.2. Numerical model

This is considered as mathematical model, a highly idealized approximation of the real-world system involving many simplifying assumption based on knowledge of the system, experience and professional judgment. The governing equation for groundwater flow in 3D is based on the law of mass balance and Darcy’s law.

Numerical groundwater modeling can be performed in steady state or transient state conditions.

Anderson and Woessner (1992) provided quite details on methodology and theology of groundwater model as well as steps to build groundwater model and choosing boundaries condition.

II.8 Groundwater management

Arlai, Koch, and Koontanakulvong (2006) used 3D finite difference MODFLOW96 model coupled with the solute transport model MT3DMS to set up for the Bangkok aquifer and applied to estimate the sustainable yield using a forward iterative trial-and-error approach. The sustainable yield is then defined as “the maximal groundwater yield that may be withdrawn so that the water levels in the third, fourth and fifth layer do not decrease by more than 25% of their current water levels (Dec, 2002) and/or that their chloride concentration stay beneath 250 mg/l”. Result of the study found that the sustainable yield in 2032 is 5*10 5 m3/d.

W Bejranonda, Koontanakulvong, and Suthidhummajit (2008) studied of the interaction between stream flow and groundwater for conjunctive use management. This study focused on water use and allocation in an irrigation area from both canals and local shallow wells. Water use patterns and interaction between surface water and groundwater were considered to determine the potential of conjunctive use. The groundwater flow model, MODFLOW, was used to determine groundwater use in 3 irrigation zones as well as its potential. The model results showed that stream flow was an important source of recharge and helped maintain groundwater level beneath agricultural area, therefore the farmers were able to access groundwater resources from their own wells. The capacity of conjunctive surface water and groundwater use in the study area was indicated by considering the groundwater potential over the water shortage in each service zone. The sustainable water allocation required the combination of surface-water and subsurface-water supply towards the comprehensive management.

Candela, von Igel, Elorza, and Aronica (2009) presents an integrated methodological approach for assessing the quantitative impact of management and climate change scenarios on the water cycle and in the S’Albufera wetland. Temperature and precipitation based on the downscaled output from a general circulation model (GCM) was coupled to a groundwater model to estimate the impacts of climate change and management practices on groundwater. Management practices were based on changes in the volume of water extracted for agricultural and domestic purposes. Climate change impacts on the hydrogeological system were based on downscaled GCMs. Assessment of the impacts on the water level of the wetland were carried out by estimating the flow rate of springs discharging from the aquifer obtained by changes of agricultural land use and water supply allocation and variation of recharge according climate scenarios. The study also recommended that in order to preserve the spring discharge at its current level (17 Mm^3/yr), which successfully prevents the wetland from drying up, a decrease in groundwater extraction is needed. In addition, the allocation of agricultural wells was recommended under both scenarios.

Werapol Bejranonda, Koch, and Koontanakulvong (2013) studied surface water and groundwater dynamic interaction models as guiding tool for optimal conjunctive water use policies in the central plain of Thailand. This studied found that conjunctive water management is basically a tool to optimize productivity, equity, and environmental sustainability through simultaneous management of surface water and groundwater resources. A numerical groundwater model with a special module for simulating surface-groundwater interaction was applied in the PIP area. A set-up of different agricultural water allocation schemes that depend on the local weather conditions and the regional management rules are examined by the numerical models. The results of the simulations provide adaptation guidelines for the proper management of the conjunctive water resources, namely, optimal water utilization. The analysis of the groundwater balance also showed that the present available groundwater potential is not fully exploited by the farmers. In contrast, the adoption of an optimal conjunctive management scheme would ensure extra water availability for additional annual rice crops in the region.

CHAPTER III

STUDY AREA CONDITION

III.1 Location

The study area covers an area of 6000 square kilometers. It locates from 10°10'-10°38' North and 106°2'-106°54' East, including Ho Chi Minh City area and some district of Binh Duong and Long An and Tay Ninh Province.

Ho Chi Minh City is 1,730km far from Hanoi by land and is at the crossroads of international maritime routes. It is also at the center of Southeast Asia region. The city center is 50km from the East Sea in a straight line. It is a transport hub of the southern region and a gateway to the world, having the largest port system and airport in Vietnam. Saigon Port can handle 10 million tons of cargo a year. Tan Son Nhat International Airport, 7km far from the city center, has tens of international routes.

Table 2: List of Ho Chi Minh City Administrative Units

Name of district	Area (km²)	Population 2010	Name of district	Area (km²)	Population 2010
District 1	8	187,435	Thu Duc	48	455,899
District 2	50	140,621	Tan Phu	16	407,924
District 3	5	188,945	Tan Binh	22	430,436
District 4	4	183,261	Phu Nhuan	5	175,175
District 5	4	174,154	Go Vap	20	548,145
District 6	7	253,474	Binh Thanh	21	470,054
District 7	36	274,828	Binh Tan	52	595,335
District 8	19	418,961	Binh Chanh	253	447,291
District 9	114	263,486	Can Gio	704	70,697
District 10	6	232,450	Cu Chi	435	355,822
District 11	5	232,536	Hoc Mon	109	358,640
District 12	53	427,083	Nha Be	100	103,793
			Sum	2096	7,396,445

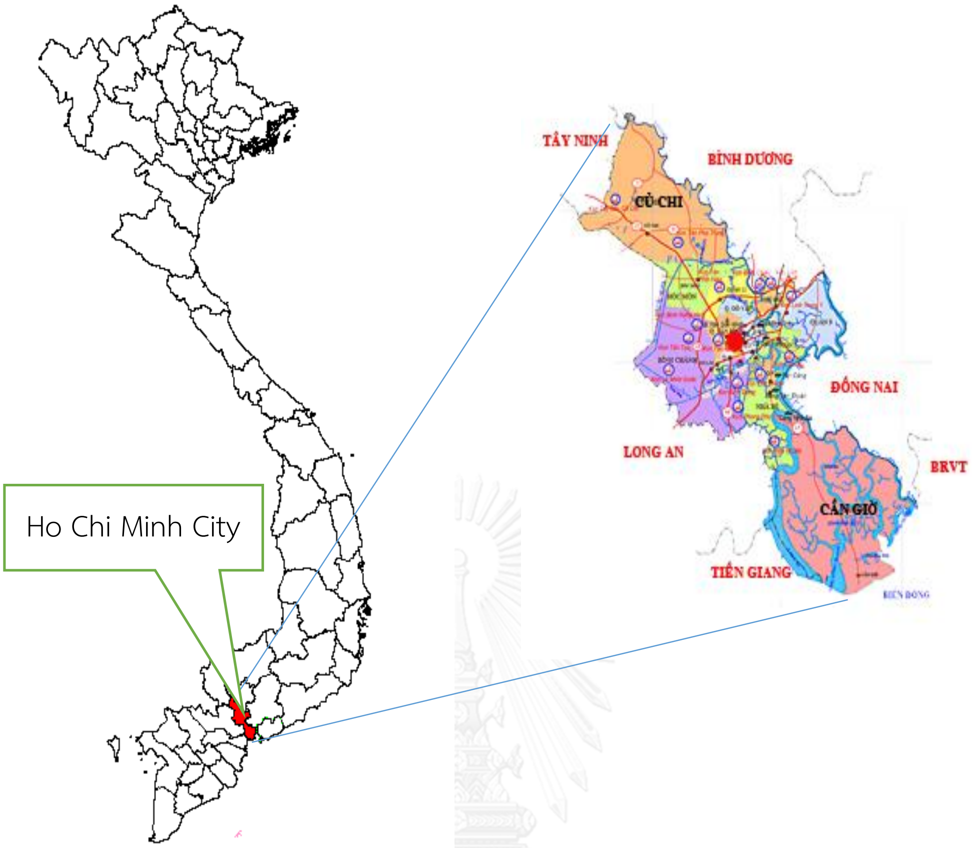


Figure 4: Location of Ho Chi Minh City

III.2 Topography

The area belongs to a transitional region between the southeastern and Mekong Delta regions. The general topography is that terrain gets lower from north to south and from east to west. There are five types of terrain as shown in Figure 5.

The highest terrain lies in the northeastern area. This is the bending terrain with average height of more than 50 meters.

The depression terrain lies in the southern-south western and south eastern part. The area height is in the range of 0.5 to 4 meters.

The medium-height terrain lies in the middle of the area. The area height is 4-20 meters.

In general, the topography of Ho Chi Minh City area is not complicated but fairly diverse and therefore has good conditions for multi-faceted development.

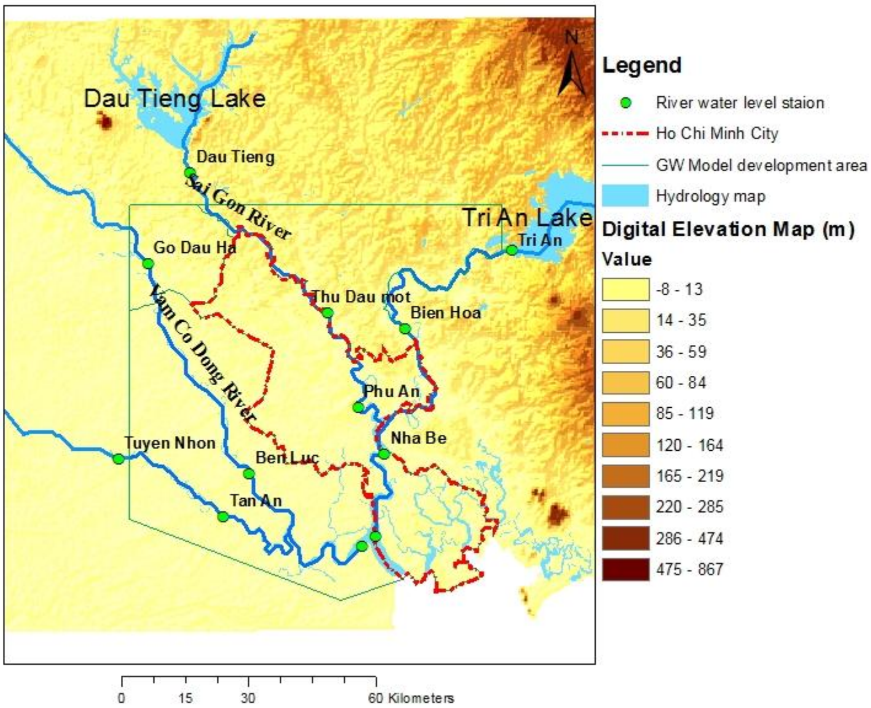


Figure 5: Topography map and river stations

III.3 Climate

The city has a tropical climate, specifically a tropical wet and dry climate, with an average humidity of 75%. The year is divided into two distinct seasons. The rainy season, with an average rainfall of about 1,544 millimeters (71 in) annually (about 150 rainy days per year), usually begins in May and ends in late November. The dry season lasts from December to April. The average temperature is 27 °C, the highest temperature sometimes reaches 39 °C around noon in late April, while the lowest may fall below 16 °C in the early mornings of late December into early January.

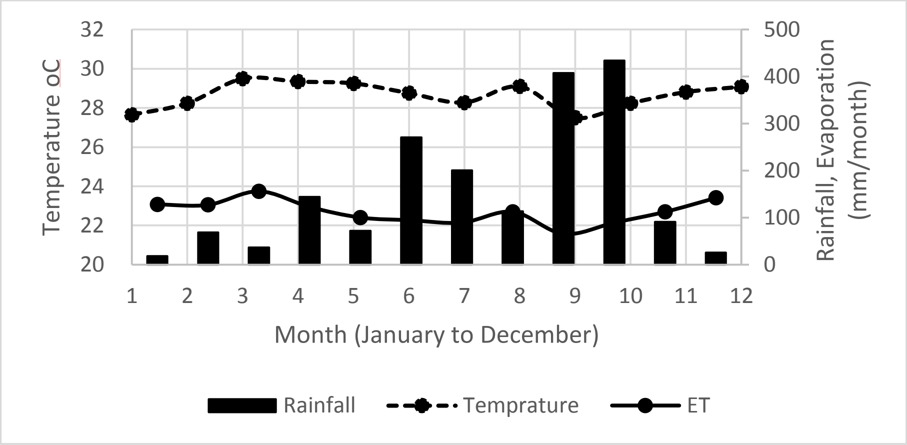


Figure 6: Average monthly rainfall, temperature and evaporation in Tan Son Hoa station during 1980-2012

III.4 Surface water

III.4.1. River systems

The total length of this river system is 7,885 km. Ho Chi Minh City is at the convergence of Sai Gon and Dong Nai Rivers and Vam Co Dong River. Therefore, water system in the area is aslo affected by the river flows.

At the same time, the river system of Ho Chi Minh city is major under influences of tide. On the Sai Gon river, Sea water level affect upward to the downstream of the Dau Tieng Reservoir. On the Dong Nai River, tide also affect up to Bien Hoa station on Dong Nai River. At the same time, tide also affects up to Go Dau station on Vam Co Dong River.

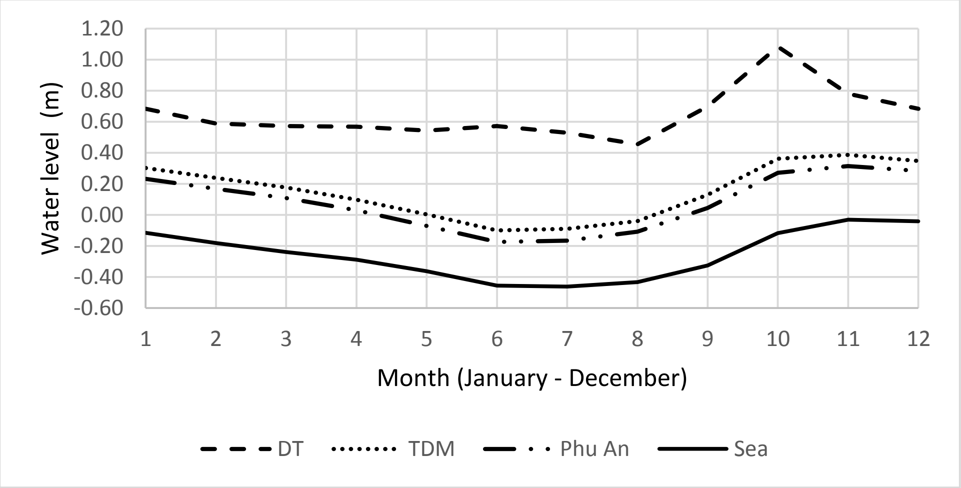


Figure 7: Average monthly water level in Sai Gon River during 1980-2007

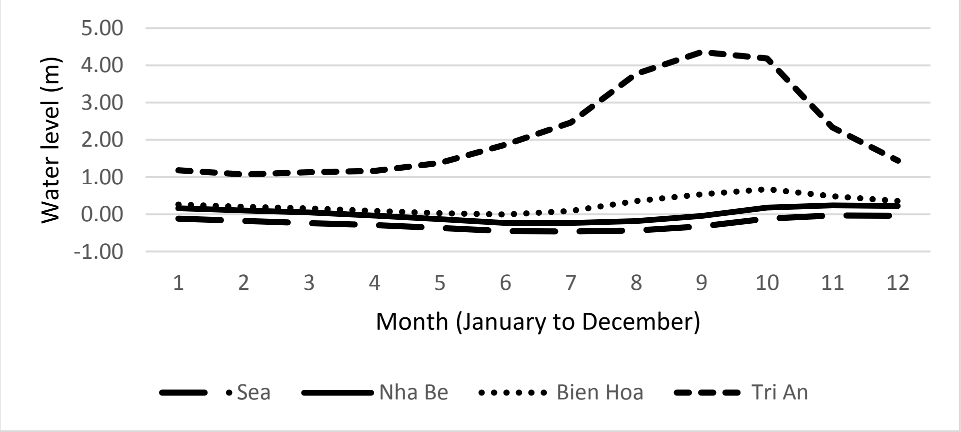


Figure 8: Average monthly water level on Dong Nai River during 1980-2007

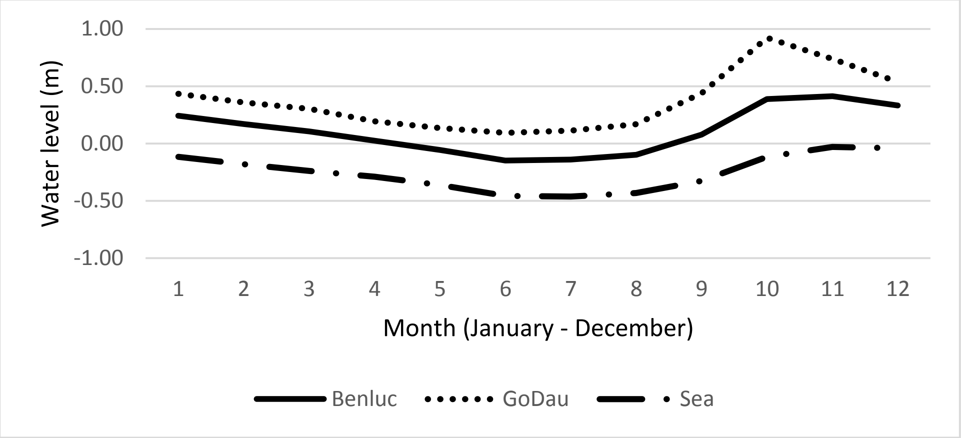


Figure 9: Average monthly water level on Vam Co Dong River during 1980-2007

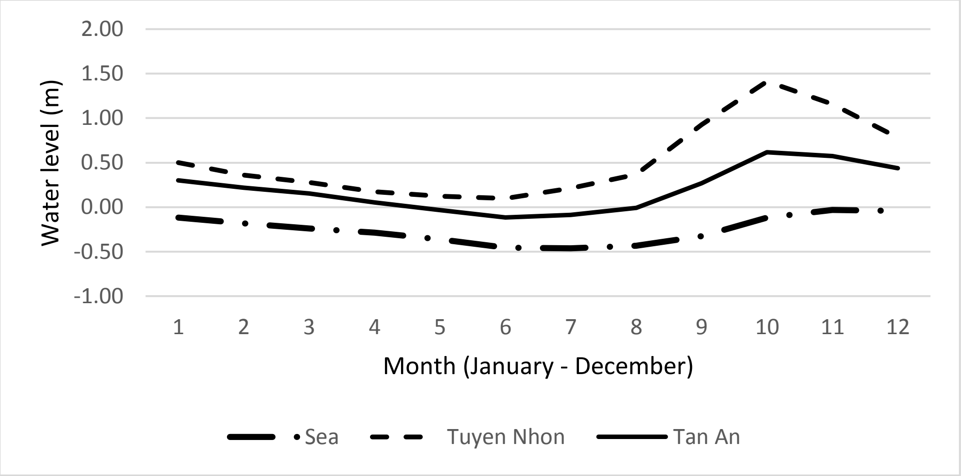


Figure 10: Average monthly water level on Vam Co Tay River during 1980-2007

Water level trend in rivers in the area tend to increase in recent 27 years. For example, monthly water level at Phu An station in Saigon River during 1980-2007 as show in the Figure 11 and monthly water level at Bien Hoa station on Dong Nai River is showed in the Figure 12.

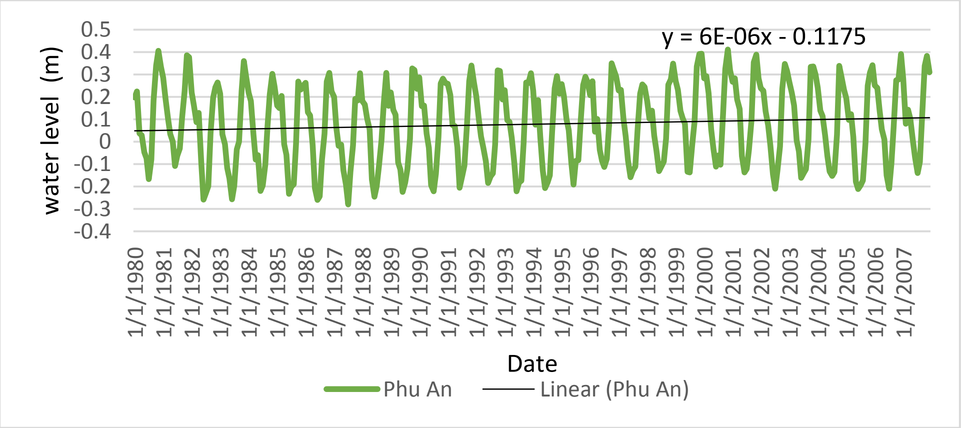


Figure 11: Monthly water level on Sai Gon River at Phu An station during 1980-2007

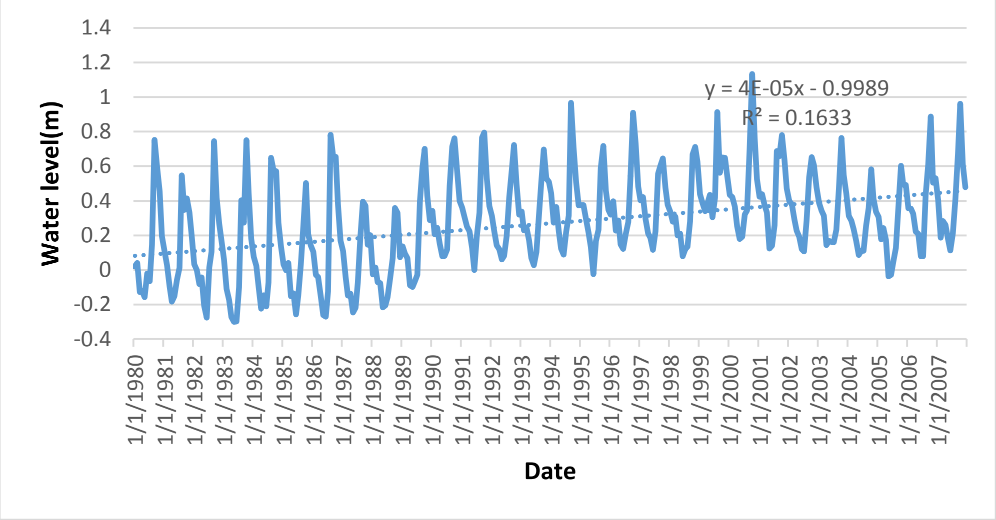


Figure 12: Monthly water level on Dong Nai River at Bien Hoa Station during 1980-2007

III.4.2. Reservoir

In the upstream of Sai Gon and Dong Nai River have two reservoirs rnamed Dau Tieng and Tri An reservoirs, which were constructed for irrigation and hydropower in 1985 and 1989, respectively. These reservoirs help to control the water flow of Sai Gon and Dong Nai Rivers. In dry season, from February to April, Sai Gon and Dong Nai Rivers receive a flowrate of 20–22 m^3/s and 200 m^3/s for pushing salt intrusion, respectively.

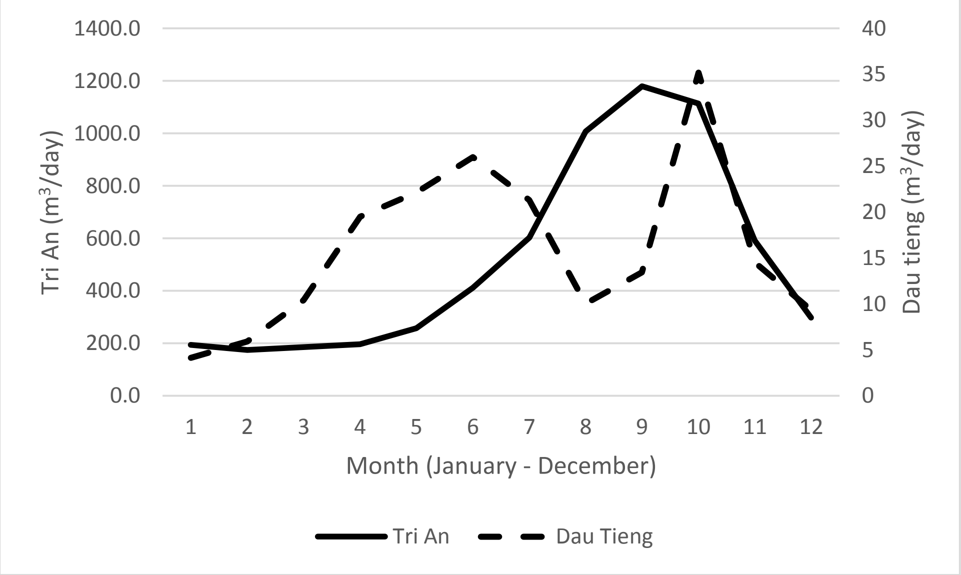


Figure 13: Average monthly dams release

III.4.3. Sea water level

Sea water levels at Vung Tau station during 1980 to 2007 show that water level has increased at 0.1m.

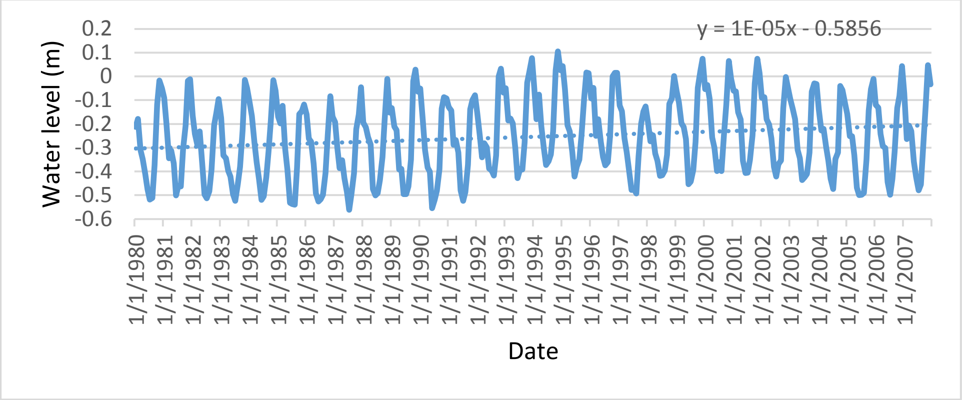


Figure 14: Sea water level at Vung Tau station

III.5 Hydrogeology condition

The hydrogeology of the Ho Chi Minh City area is complex. The aquifers classification in the Ho Chi Minh City Area were divided into six major aquifers ranging in geologic age from the Pleistocene through to the Upper Miocene.

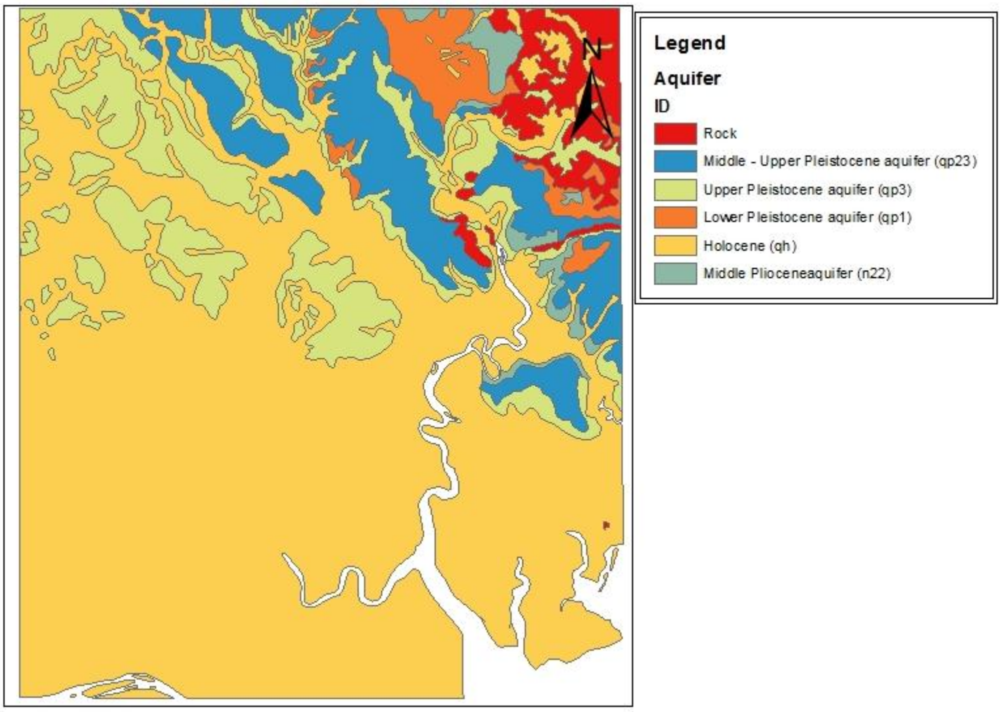


Figure 15: Hydrogeological map

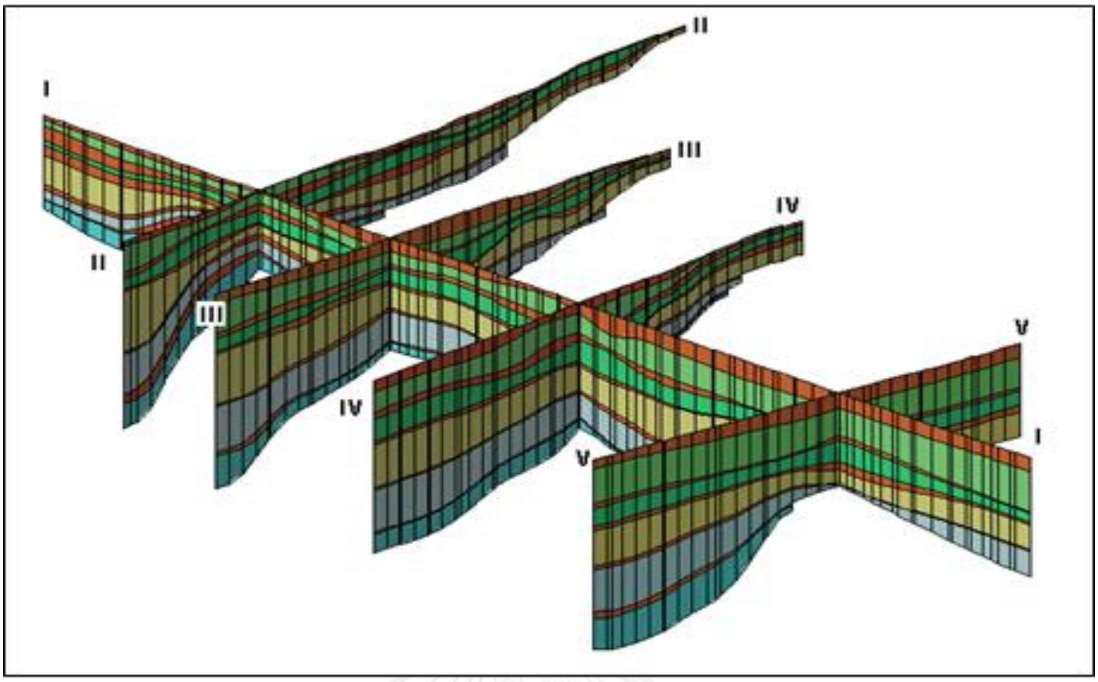


Figure 16: Hydrogeological Strata

III.5.1. Intergranular upper Pleistocene aquifer (aquifer 1)

Intergranular upper Pleistocene aquifer (qp_3) distributes on over 1983 km^2 and this aquifer does not appear in some areas of Cu Chi district, and district 9. Top of aquifer depth vary from 0.0 m to 65.0 m and the bottom of aquifer depth vary from 6.0 m to 90.0 m and aquifer thickness vary from 2.0 m to 63.0 m.

The main lithological composition of the aquifer is fine – medium sand, somewhere is coarse sand, siltly sand, sandly silt, etc..

Pumping tests at 86 wells display its poor to high productivity with groundwater discharge range from 0.05 to 11.48l/s, groundwater level drawdown range from 0.2 to 19.24m and specific discharge range from 0.01 to 3.617l/sm.

Poor productivity area distribute from Cu Chi district to Le Minh Xuan Ward and small area in district 9. Medium productivity area distribute at apart of Cu Chi, Go Vap and Can Gio district. Hight productivity area distribute at small part in the study area.

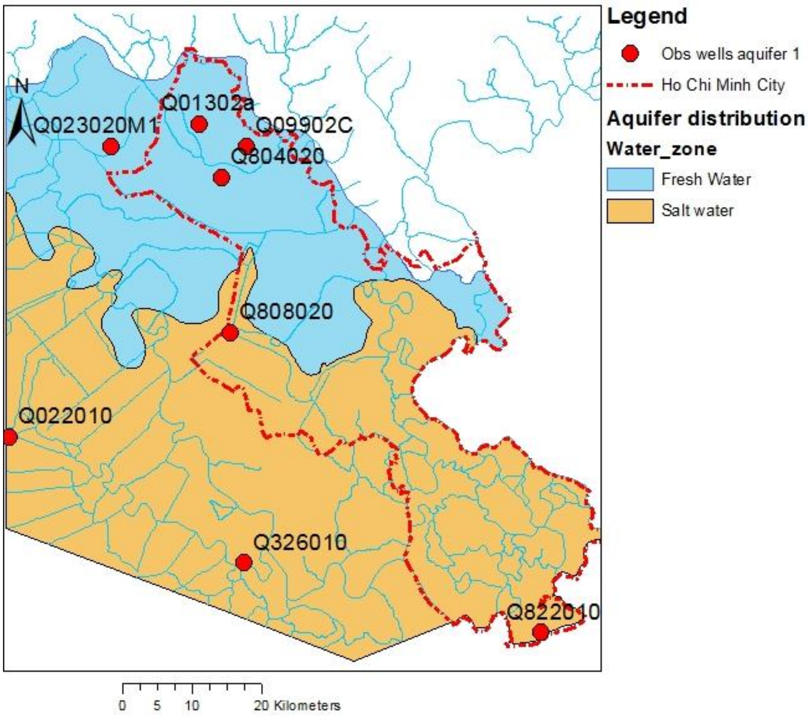


Figure 17: Upper Pleistocene aquifer distribution map

Water quality:

Fresh water area is 784 km^2 distributed in the north of Ho Chi Minh City from the center to Cu Chi district. Results of chemical analysis show that total dissolved solids (TDS) range from 0.04 to 0.51g/l (average as 0.1g/l), pH ranging from3.81 to 7.32 (average as 5.99), average hardness is 1.12meq/l (soft water) and typical water types are chlorine and bicacbonate.

Salt water area is about 1,199 km^2, ditributed on the south of the study area include Can Gio and Nha Be district and district 9 and the south of Binh chanh district. Results of chemical analysis show that total dissolved solids (TDS) range from 1.75 to 21.23g/l (average as 10.60g/l), pH ranging from 3.1 to 7.6 (average as 5.17), average hardness is 81.5meq/l (hard water) and typical water types are chlorine and bicacbonate.

In summary, Intergranular upper Pleistocene aquifer (qp$_3$) distribute on shallow area and water in the fresh water area has good water quality. However, thickness is small, therefore potential of groundwater exploitation of this aquifer seem to be not much, and it can be appropriate only for domestic water supply of household with small capacity.

III.5.2. Intergranular Upper - middle Pleistocene aquifer (aquifer 2)

Inter-granular Upper - middle Pleistocene aquifer (qp$_{2-3}$) distribute on the area of 2,020 km^2 and it does not appear on the Thu Duc district, eastern part of Cu Chi (near Sai Gon River). The top of aquifer depth vary from 0 m to 120.0 m and The aquifer bottom depth vary from 4.0 to 155.0 m, thickness vary from 4.0 to 84.0 m (average is 27.2 m).

The main lithological composition of the aquifer is fine to coarse sand.

Pumping tests results at 112 wells show the aquifer change from poor to high productivity with groundwater discharge range from 0.34 to 36.1 l/s, groundwater level drawdown range from 0.19 to 20.94 m and specific discharge range from 0.002 to 4.168 l/sm.

Poor productivity area distribute on Cu Chi district, the City Centre area and district 9. Medium productivity area distribute on western apart of Cu Chi and Binh Chanh district and eastern part of Thu Duc district and Can Gio district. High productivity area distribute on district 12, 7, Hoc Mon, Binh Chanh and a small part in Cu Chi district.

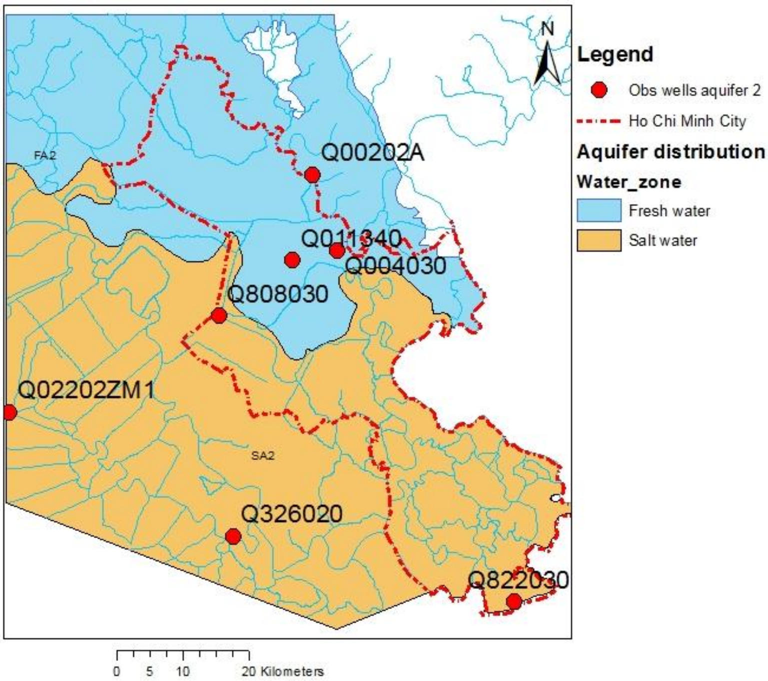


Figure 18: Upper - middle Pleistocene aquifer map

Water quality:

Fresh water area distribute on 830 km^2 at Cu Chi, Tan Phu, Binh Tan, Hoc Mon, District 12, Go Vap and Thu Duc. Total dissolved solids (TDS) range from 0.03 to 0.83g/l (average 0.10g/l), pH ranging from 3.52 to 7.80 (average 6.58) and average hardness 0.42meq/l. Typical water types are: chlorur, chlorur - bicacbonat, chlorur – sulfat and bicacbonat - chlorur.

Salt water area is distributed on 1190 km^2 at District 9, Nha Be, Binh Chanh, and Can Gio district. Total dissolved solids (TDS) range from 1.75 to 8.65 g/l (average 3.71g/l), pH ranging from 2.80 to 4.80 (average : 3.73), and average hardness is 33.80 meq/l. Typical water types are chlorine

In summary, potential groundwater exploitation of this aquifer seemed to be good, due to the fresh water distribute on the large area of 830 km^2. However, the aquifer thickness average about 27.2 m, it is not enough thick. Besides, there are many exploitaion wells in this aquifer as well as the phenomenon of overexploitaion is increasing. As a result, groundwater level is decreasing at all monitoring wells.

III.5.3. Intergranular Lower Pleistocene aquifer (aquifer 3)

Inter-granular Lower Pleistocene aquifer (qp_1) distribute on the area of 2,042 km^2. According to, the results of 302 wells then the aquifer top depth vary from 11.0 to 160.0m and bottom depth vary from 25.0m to 195.0m, and average thickness about 27.1m.

The main lithological composition of the aquifer is fine to coarse sand, gravel sand.

Pumping tests results at 54 wells display its poor to high productivity with groundwater discharge range from 0.52 to 39.77 l/s, groundwater table drawdown range from 1.0 to 25.0 m and specific discharge range from 0.014 to 5.560 l/sm.

Poor productivity area distribute on Cu Chi district, Tan Phu District, district 2 and district 9. Medium productivity area distribute on western apart of Cu Chi, Binh Chanh district, the City Centre, and Can Gio district. High productivity area distribute on district 12, 7, Thu Duc, Hoc Mon, Binh Chanh and a small part in Cu Chi district.

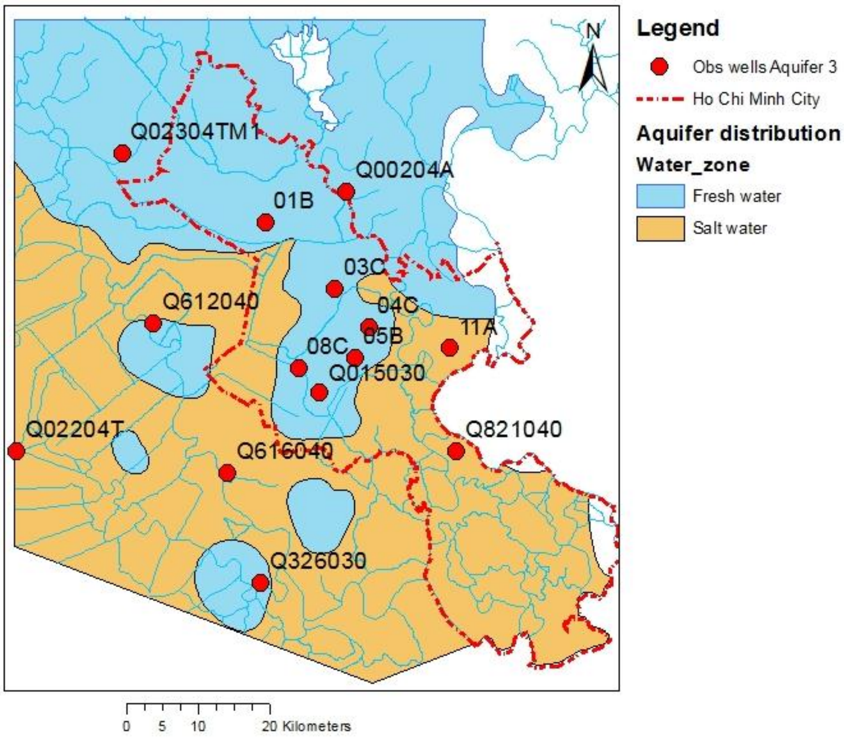


Figure 19: Lower Pleistocene aquifer map

Water quality:

Fresh water area 885 km^2 distribute on the north of Ho Chi Minh city. Total dissolved solids (TDS) range 0.04 to 0.73g/l (average 0.17g/l), pH ranging from 3.25 to 8.32 (average 6.48), and average hardness 1.56meq/l. Typical water types are: chlorur, chlorur – bicacbonat and bicacbonat.

Salt water area 1157 km^2, distribution on weastern part of Cu Chi district, Binh Chanh district, Nha Be district, district 7, and Can gio district. Total dissolved solids (TDS) rang from 1.82 to 14.21g/l (average 7.27 g/l), pH ranging from 3.50 to 7.50 (average 4.75) and average hardness 42.15 6meq/l. Typical water types are chlorur.

In summary, fresh water area of this aquifer distribute on large area of 885 km^2, but aquifer thickness is not large. In addtion, there are many abstraction wells in this aquifer as well as phenomenal of overexploitation, thus groundwater water level declined in all monitoring wells.

III.5.4. Intergranular middle Pliocene aquifer (aquifer 4)

Inter-granular middle Pliocene aquifer (n_2^2) distribute on the area of 2,012 km^2. The top depth vary from 34.0 m to 209.0 m, bottom depth vary from 55.0 to 236.0 m, thickness vary from 10 m to 85.0 m.

The main lithological composition of the aquifer is fine sand somewhere is coarse sand and gravel sand.

Pumping tests results at 100 wells display its poor to high productivity with: groundwater discharge range from 0.12 to 28.57 l/s, groundwater table drawdown range from 0.15 to 35.00 m and specific discharge range from 0.012 to 3.47 l/sm.

Poor productivity area distribute on small area. Medium productivity area distribute on nothern apart of Cu Chi and Hoc Mon district, district 9, district 7 and Can Gio district. High productivity area distribute on district Cu Chi district and centre of city.

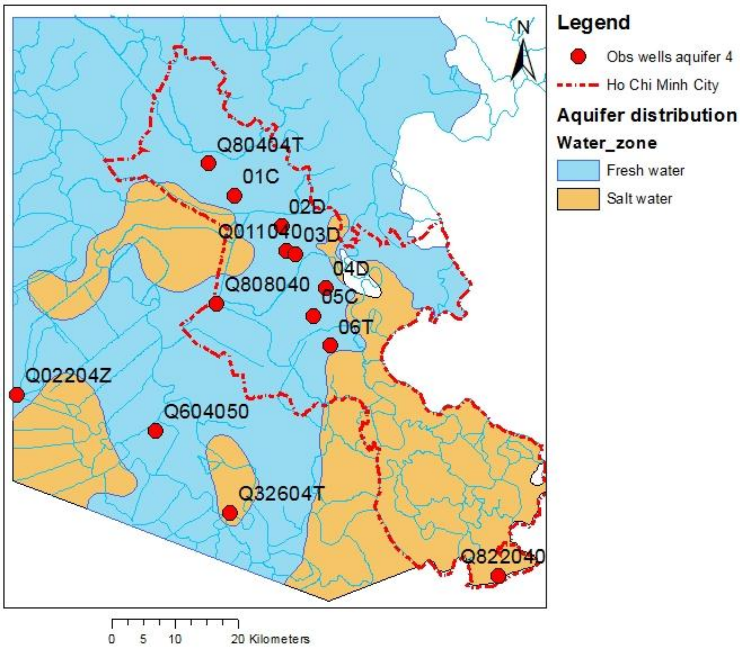


Figure 20: Middle Pliocene aquifer map

Water quality:

Fresh water area is 1,100 km^2 distributed in the area, where cover from Cu Chi district to the City Centre and Ben luc district. Results of 24 chemical analysis show that total dissolved solids TDS range from 0.02 to 0.96 g/l (average 0.22 g/l), pH ranging from 4.75 to 8.34, and average hardness is 1.652 meq/l. Typical water types are: chlorur, chlorur - bicacbonat, bicacbonat, and bicacbonat - chlorine.

Salt water area of 912 km^2, distributed on the southern part of the city. Results of 14 chemical analysis show that total dissolved solids range from 1.39 to 51.00 g/l (average 14.79 g/l), pH ranging from 1.39 to 8.30 (average 5.40), and average hardness is 74.69 meq/l. Typical water types are chlorine, and chlorine – bicacbonate.

In summary, this aquifer is medium depth and fresh water area is large. Water quality is good. Nowaday, there are many abstraction wells in this aquifer.

III.5.5. Intergranular lower Pliocene aquifer (aquifer 5)

Intergranular lower pliocene aquifer (n_2^1) distribute in the area of 1,634 km^2. The top depth vary from 101 m to 260 m and the bottom depth vary from 134 m to 343 m and thickness vary from 3.0 m to 80.1 m.

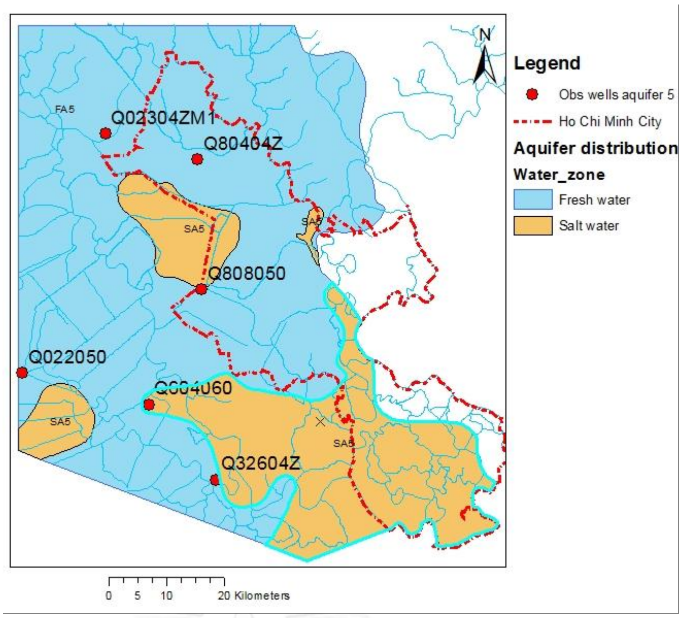


Figure 21: Lower Pliocene aquifer map

The main lithological composition of the aquifer is coarse sand and somewhere is Gravel sand.

Pumping tests results at 13 wells display its poor to high productivity with: groundwater discharge range from 0.11 to 13.02 l/s, groundwater table drawdown range from 3 to 29.71 m and specific discharge range from 0.028 to 0.876 l/sm.

Water quality:

Fresh water area is 653 km^2 distributed from Cu Chi district to the City centre and Ben Luc district. Salt water area is 981 km^2, distribution on the southern part of city

In summary, fresh water area is large but there are not many research in this quifer.

III.6 Water table fluctuation

III.6.1. Aquifer 1

Groundwater level in aquifer 1 is influenced by rainfall and it also changes along seasons. Dry season groundwater level is lower than rainy season (Figure 22). However, while groundwater level trend decreases in dry season then in rainy season slightly increases.

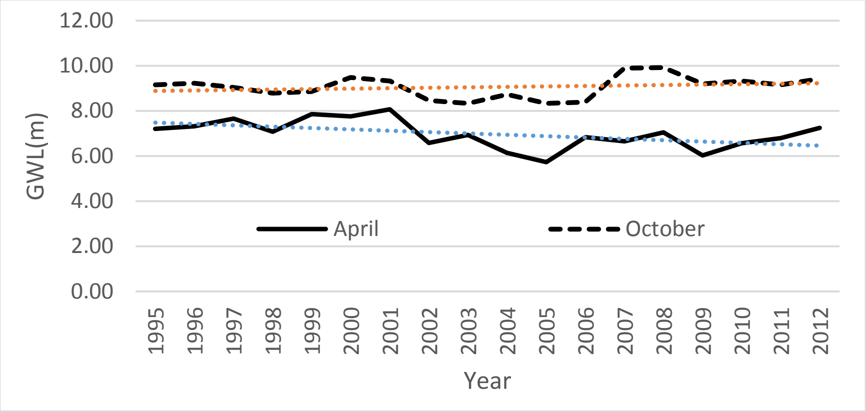


Figure 22: Groundwater level in aquifer 1 in April and October

Groundwater level fluctuation in this aquifer is not only affected by rainfall but also by irrigation system and tide. In the city center, the overexploitation of groundwater leaded groundwater level gradually decreased in recent years (Q808020). (Figure 23)

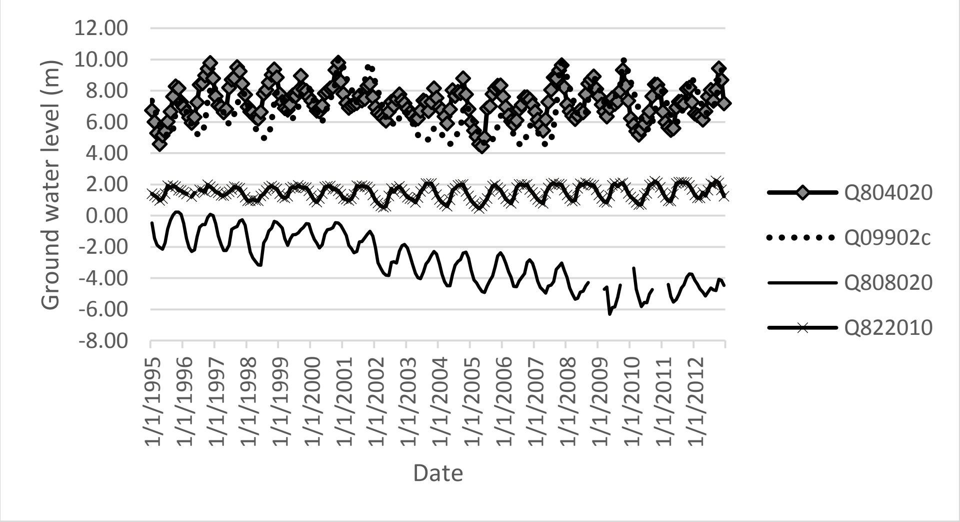


Figure 23: Groundwater level during 1995-2012 in aquifer 1 at monitoring wells

III.6.2. Aquifer 2

Groundwater level in aquifer 2 is also influenced by rainfall and difference groundwater level is around 2m between rainy season and dry season. Average groundwater level decreased in recent years, as details in Figure 24.

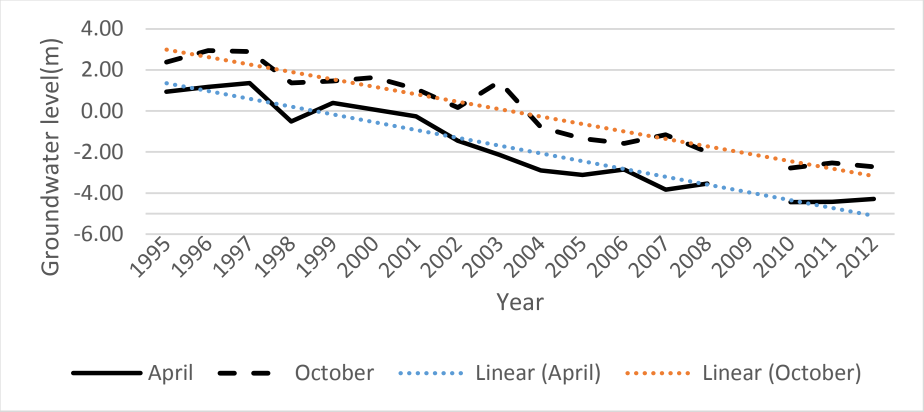


Figure 24: Groundwater level in aquifer 2 in April and October

In generally, monthly groundwater level is stable, however, in the city center groundwater was dramatically declining. Specially, at observation well name Q011340, groundwater level declined to -20m under sea level. It is likely due to overexploitation groundwater in Ho Chi Minh City center.

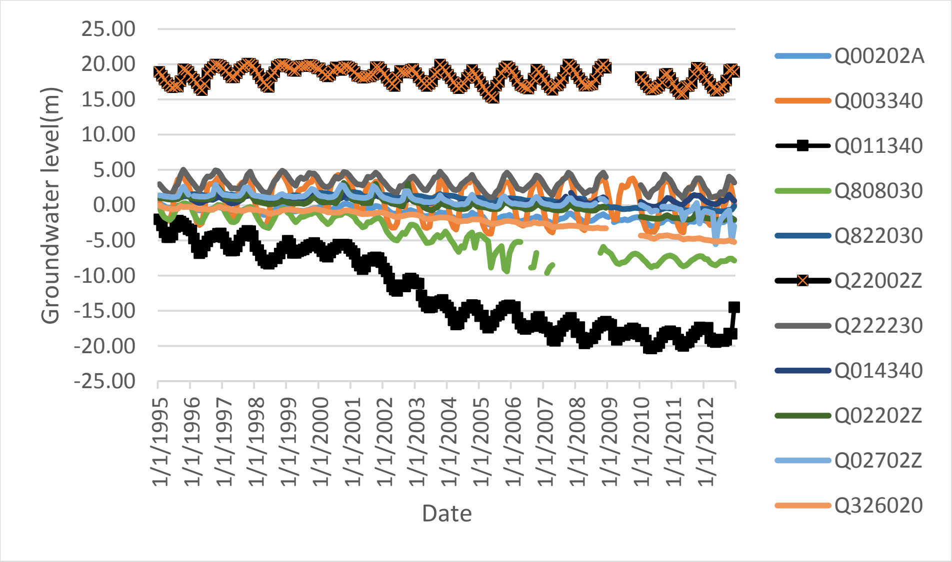


Figure 25: Monthly groundwater level in aquifer 2 at observation wells

III.6.3. Aquifer 3

Also the same with two aquifers above, groundwater fluctuation in this aquifer change along season and water level in dry season is lower than in rainy season. Average groundwater level in this area strongly decreased from 2001 to 2012. Mainly causing come from groundwater abstraction as details in Figure 26.

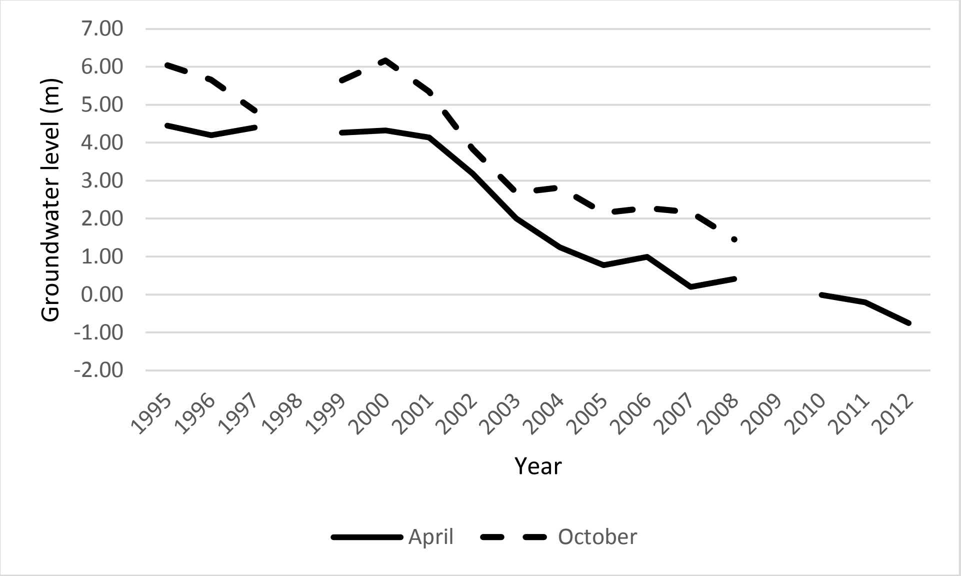


Figure 26: Groundwater level in aquifer 3 in April and October

According to monitoring wells data, groundwater level trend decrease only at some observation wells located in Ho Chi Minh City center and some wells near here. Specifically, in wells name Q015030 groundwater level decreased to -26m under sea water level in 2012.

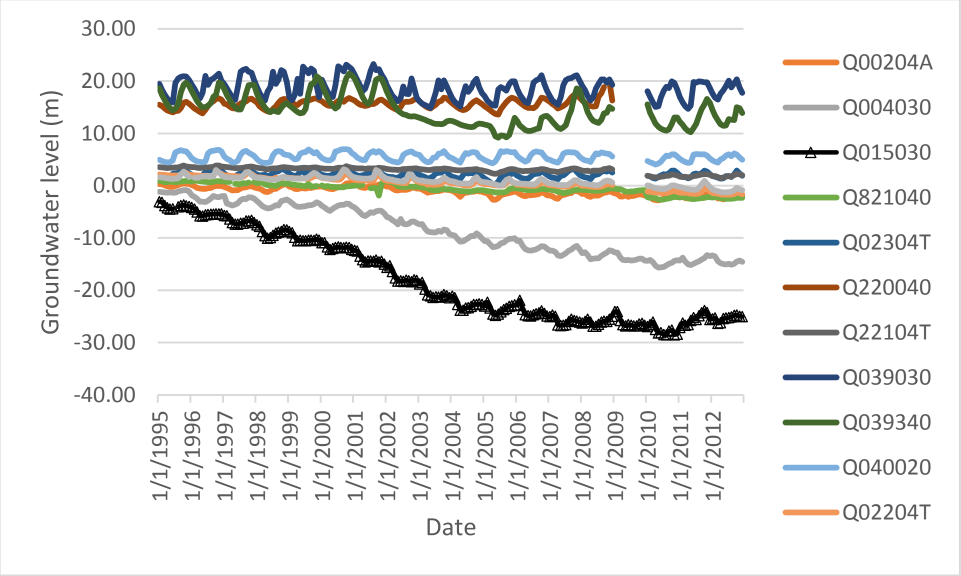


Figure 27: Groundwater level in monitoring wells in aquifer 3 during 1995-2012

III.6.4. Aquifer 4

Groundwater level in aquifer 4 is influenced by rainfall and it also change along seasons. Dry season groundwater level is lower than in rainy season. And groundwater level gradually decrease in recent years from 1995 to 2012. Detail is described in Figure 28.

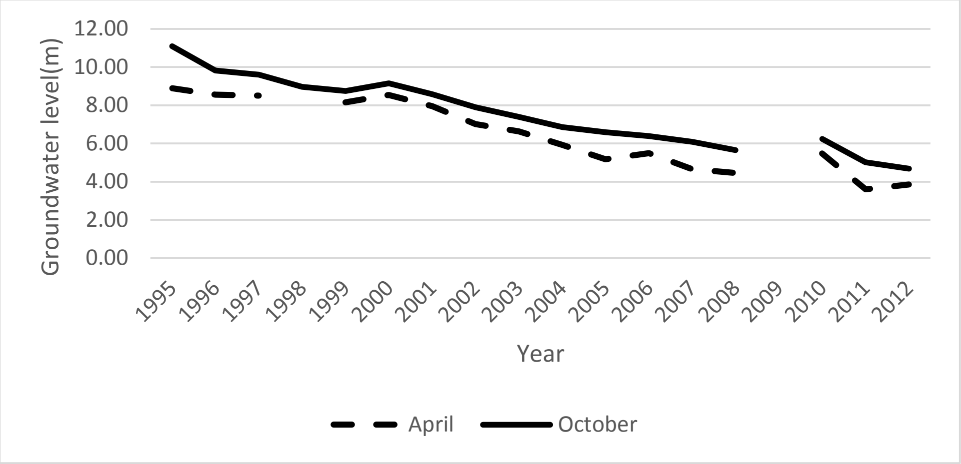


Figure 28: Groundwater level in April and October in aquifer 4

In aquifer 4, groundwater level fluctuated stably in the high terrain area but it slightly decreased in low terrain. In Ho Chi Minh City center groundwater level is dramatically decreased from 2001 to 2012. Specially, Groundwater level at observation well Q011040 decreased to -20m below the sea level. Details is in Figure 29.

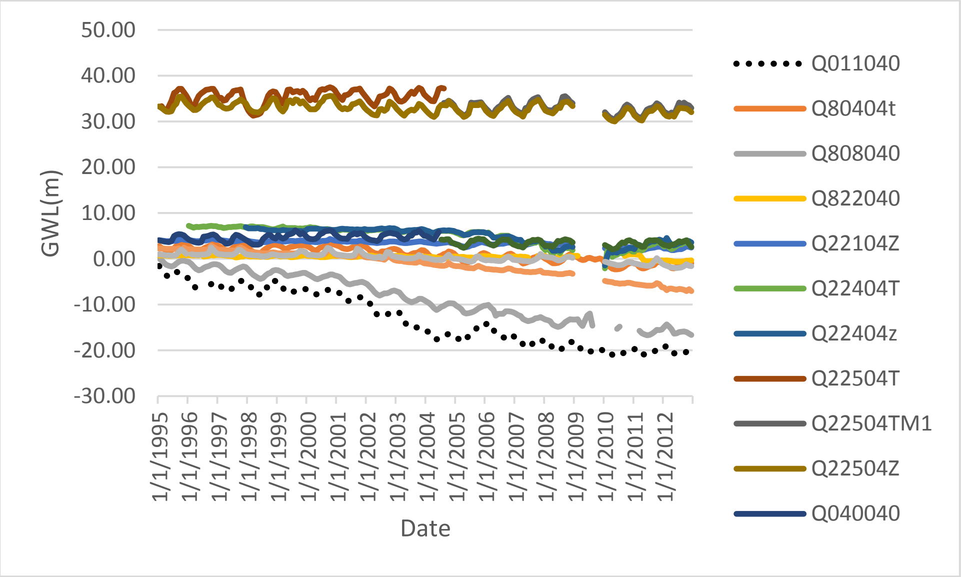


Figure 29: Monthly groundwater level in aquifer 4 during 1995 to 2012

III.6.5. Aquifer 5

Groundwater level aquifer 5 fluctuated along season and difference of groundwater level between seasons is not too high around 0.5m. Groundwater level decreased from 2000 to 2012. Detail is in Figure 30.

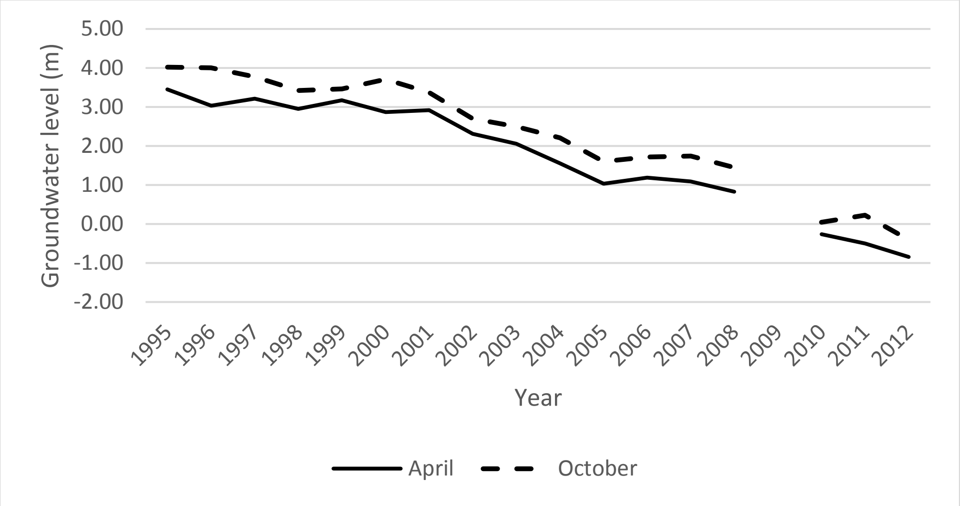


Figure 30: Groundwater level in April and October in aquifer 5

Groundwater level in some observation wells was gradually decreased in recent years. Detail is in Figure 31.

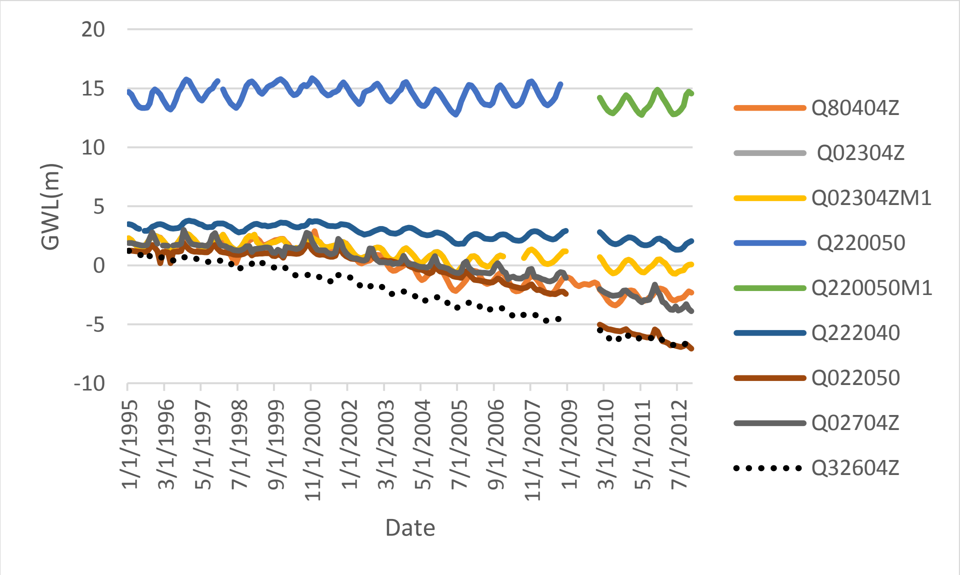


Figure 31: Groundwater level in aquifer 5 at observation wells

III.7 Groundwater Use

Groundwater has been used in Ho Chi Minh City since 1920. Rapid increase of groundwater use started in 1990 when the economic policies of Viet Nam were opened. High industrialization and urbanization resulted in the quick increase of water demands. The expansion of surface water works in HCMC has not met this rapid demand increase. Besides, until now free of charge groundwater and uncontrolled exploitation has increasingly augmented the exploitation rate.

Details of Groundwater exploitation and some indicators social economic development were shown in the Table 3 (Statistical office of Ho Chi Minh city, 2012).

Table 3: Groundwater exploitation and Population and GDP in Ho Chi Minh City

Year	Industrial Value (Billion VND)	GDP (Billion VND)	Population	GW (m^3/day)
1996	20,678	37,380	4,747,900	357,628
1998	24,352	45,760	4,957,300	475,492
1999	30,570	59,940	5,073,100	524,456
2000	34,446	75,863	5,274,900	505,815
2001	39,190	84,852	5,454,000	510,232
2002	45,060	96,403	5,619,400	515,907
2003	55,668	113,326	5,809,100	524,221
2004	67,011	137,087	6,007,600	528,621
2005	79,538	165,297	6,230,900	532,751
2006	90,324	190,561	6,483,100	546,789
2007	106,661	229,197	6,725,300	570,406
2008	126,900	287,513	6,946,100	613,557
2009	150,020	337,040	7,196,100	651,304
2010	191,246	422,270	7,378,000	678,200
2011	228,332	512,721	7,517,900	731,451
2012	239,977	571,900	7,663,800	739,360

CHAPTER IV

METHODOLOGY AND THEORIES USES

This chapter describes step-by-step methodologies to achieve the objectives of the study as shown in the below framework:

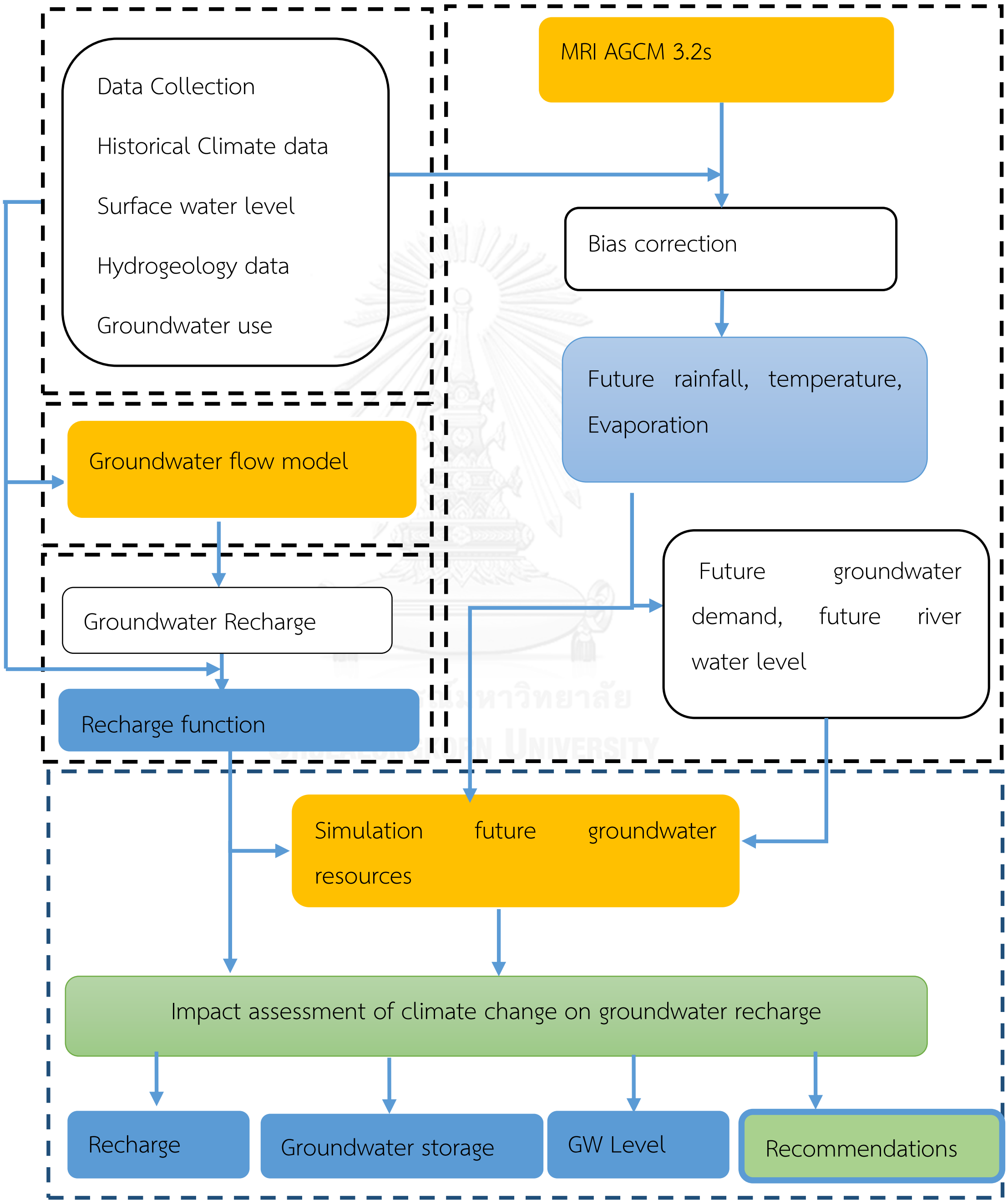


Figure 32: The methodological framework for processing of impact assessment of climate change on groundwater recharge

IV.1 Bias correction method

The statistic Bias correction method used in this thesis was called Gamma Gamma Transformation (Ines & Hansen, 2006). This method is widely used in impact assessment on hydrological process. The detail of procedures is modified by Chaowiwat (2014) as follows:

1) Correct the empirical distribution probability of observed daily rainfall data (CDFobs), the threshold or minimum rainfall value was defined as 0.1. Thus, the observed rainfall values under 0.1 would be truncated.

2) Calculate the alpha (α) and beta (β) parameters in each month for observation data and GCM data by using maximum likelihood method.

3) Correct the empirical distribution probability of raw GCM data by truncating value smaller than 0.1.

4) Map the GCM rainfall data onto the probability of observed rainfall data (CDFobs).

5) Correct the gamma distribution of mapping GCM rainfall (CDFgcm’) by using alpha and beta parameters from step 2. Thus, the alpha and beta parameters were used to correct the raw GCM rainfall data.

6) Transform the CDFgcm’ to the bias corrected GCM rainfall data by inversing the gamma probability of CDFgcm’ from step 5.

7) Evaluate the result of bias corrected rainfall by the goodness of fit test.

IV.2 Groundwater Modeling

IV.2.1. Theories

Groundwater-flow models are used to simulate aquifer response, in terms of head (ground water level) and fluxes into and out of an aquifer.

Numerical groundwater modeling can be performed in steady state or transient state conditions. Fluxes are constant during the simulation period in the steady state whilst they vary both in space and time in fully transient modeling.

3D groundwater flow through a porous medium is governed by the following equation

$$\frac{\partial}{\partial x}\left[K_{xx}\frac{\partial h}{\partial x}\right]+\frac{\partial}{\partial y}\left[K_{yy}\frac{\partial h}{\partial y}\right]+\frac{\partial}{\partial z}\left[K_{zz}\frac{\partial h}{\partial z}\right]+W=S_s\frac{\partial h}{\partial t} \qquad (4.1)$$

where:

K_{xx}, K_{yy} and K_{zz} are the hydraulic conductivity values along the x, y, and z coordinate axes and may be function of space. Kzz is assumed equal 10% of Kxx.

h is the potentiometric head (hydraulic head)

W is a volumetric flux per unit volume representing sources and sinks of water, where negative value is water extraction, and positive value is injection.

S_s is the specific storage of the porous material and may be function of space,

t is time.

Equation 4.1, together with specification of flow and head conditions at the boundaries of aquifer system and specification of initial head conditions, constitutes a mathematical representation of groundwater flow system (Harbaugh, 2005).

The ground-water flow process solves equation 4.1 using the finite-difference method in which the groundwater flow system is divided into a grid of cells. For each cell, there is a single point, called a node, at which head is calculated. The finite-difference equation (McDonald & Harbaugh, 1988) for a cell is:

$$
\begin{aligned}
&CR_{i,j-1/2,k}(h_{mi,j-1,k}-h_{mi,j,k})+CR_{i,j+1/2,k}(h_{mi,j+1,k}-h_{mi,j,k})+\\
&+CC_{i-1/2,j,k}(h_{mi-1,j,k}-h_{mi,j,k})+CC_{i+1/2,j,k}(h_{mi+1,j,k}-h_{mi,j,k})+\\
&+CV_{i,j,k-1/2}(h_{mi,j,k-1}-h_{mi,j,k})+CV_{i,j,k+1/2}(h_{mi,j,k+1}-h_{mi,j,k})+\\
&+P_{i,j,k}h_{mi,j,k-1}+Q_{i,j,k}=SS_{i,j,k}(\Delta r_j \Delta c_j \Delta v_k)(h_{mi,j,k}-h_{m-1i,j,k})/(t_m - t_{m-1}).
\end{aligned}
\tag{4.2}
$$

where:

$h_{mi,j,k}$ is head at cell i,j,k at time step m (L);

CV, CR, and CC are hydraulic conductance, or branch conductance, between node i,j,k and a neighboring node (L^2/T);

$P_{i,j,k}$ is the sum of coefficients of head from source and sink terms (L^2/T);

$Q_{i,j,k}$ is the sum of constants from source and sink terms, with $Q_{i,j,k} < 0.0$ for flow out of the ground-water system, and $Q_{i,j,k} > 0.0$ for flow in (L^3/T);

$SS_{i,j,k}$ is the specific storage (L^{-1});

Δj is the cell width of column j in all rows (L);

ΔCi is the cell width of row i in all columns (L);

Δi,j,k is the vertical thickness of cell i,j,k (L); and t_m is the time at time step m (T).

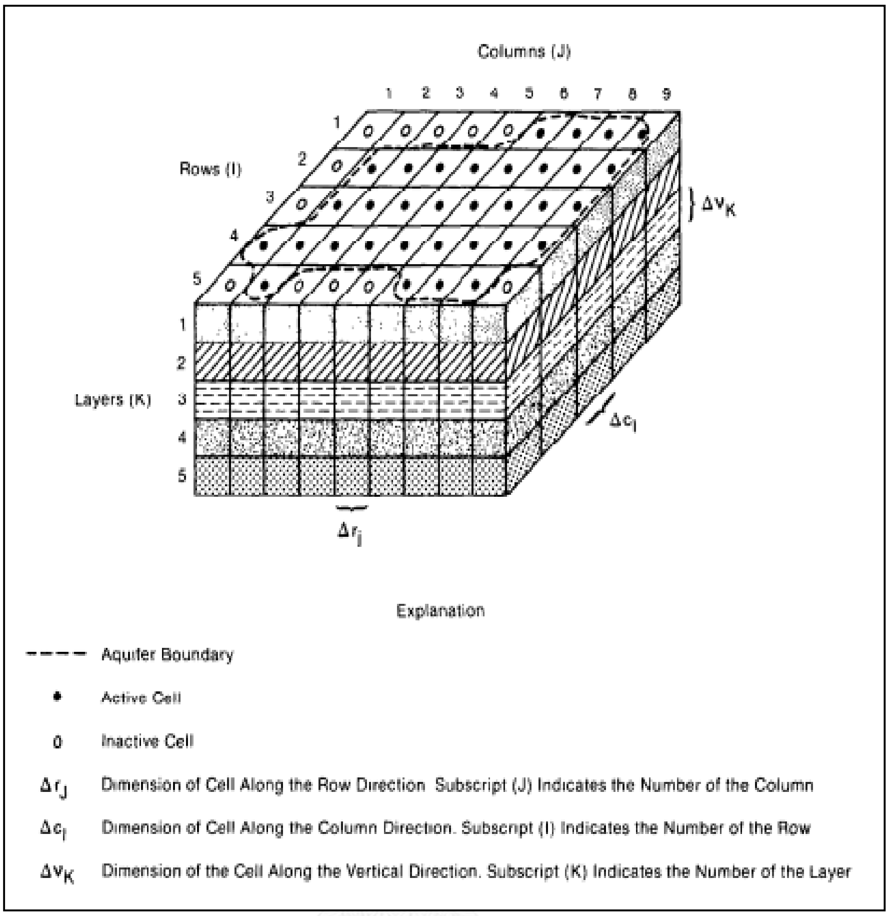


Figure 33: A discretized hypothetical aquifer system. (Michael G. McDonald and Arien W. Harbaugh, 1988).

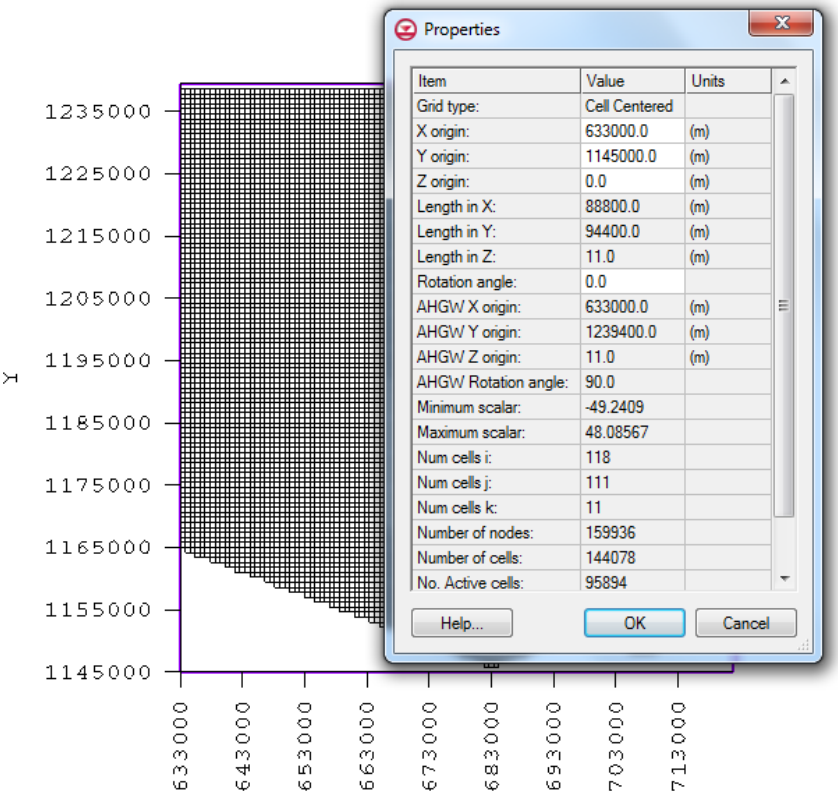
IV.2.2. Tools approach

To solve equation 4.1, there are some code written on a computer and commonly code used today in the field of underground water resources as MODFLOW 2000 (USGS). GMS software of AQUAVEO has integrated this code along with the other code as geo-statistics, GIS to give customers easy to use and more effective in simulating groundwater system.

IV.2.3. Development of groundwater model

IV.2.3.1. Develop a conceptual model

The model was developed for an area involve Ho Chi Minh City and Binh Duong Province and Tay Ninh and Long an. The model simulate 11 layers with grid 800x800m.



Item	Value	Units
Grid type:	Cell Centered	
X origin:	633000.0	(m)
Y origin:	1145000.0	(m)
Z origin:	0.0	(m)
Length in X:	88800.0	(m)
Length in Y:	94400.0	(m)
Length in Z:	11.0	(m)
Rotation angle:	0.0	
AHGW X origin:	633000.0	(m)
AHGW Y origin:	1239400.0	(m)
AHGW Z origin:	11.0	(m)
AHGW Rotation angle:	90.0	
Minimum scalar:	-49.2409	
Maximum scalar:	48.08567	
Num cells i:	118	
Num cells j:	111	
Num cells k:	11	
Number of nodes:	159936	
Number of cells:	144078	
No. Active cells:	95894	

Figure 34: Model domain

a. *Topography*

Using scatter point elevation data of topography map was collected as second data at DWRPIS.

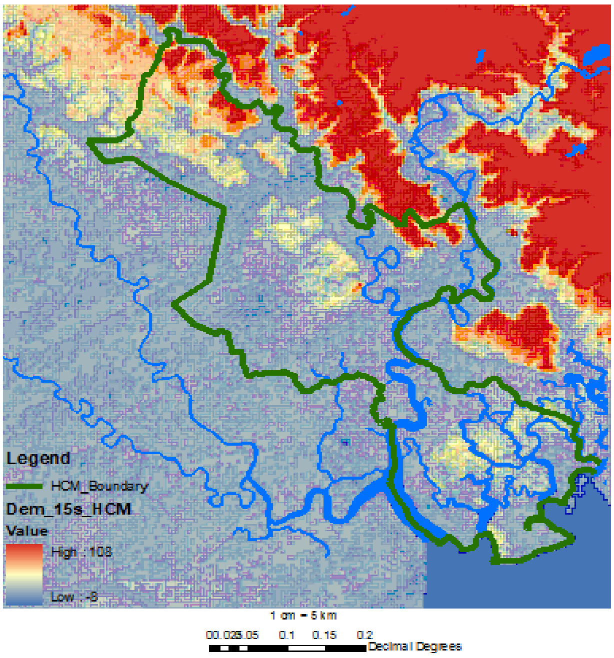


Figure 35: Topographical map

b. Hydrogeological strata

Interpolation top and bottom of each layers to the model was based on data of 300 borehole around area.

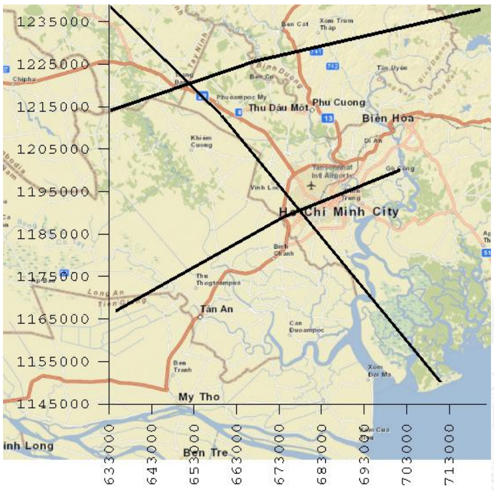


Figure 36: Location of cross-section

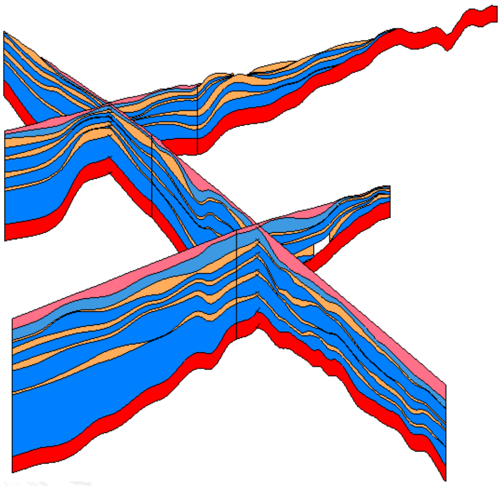


Figure 37: Aquifers cross-section

c. Boundary condition

The flow per unit area from a boundary into an aquifer is given by Darcy's law as:

$$q = -K\frac{\Delta h}{\Delta l} \qquad (4.3)$$

Where q is specific discharge (m/day), K is hydraulic conductivity of the aquifer (m/day), h is hydraulic head (L), and n is distance normal to the boundary (m).

The function of the General-Head Boundary (GHB) Package (Harbaugh, 2005) is to simulate flow into or out of a cell from an external source in proportion to the difference between the head in the cell and the head assigned to the external source. The constant of proportionality is called the boundary conductance. Thus a linear relation between flow into the cell and head in the cell is established:

QB=CB(HB-h) (4.4)

where:

QB: is flow into cell from the boundary (m^3/day),

CB: is the boundary conductance (m^3/day),

HB: is head assigned to the external source (m), h: is the head in cell (m).

In this study, specify head was assigned for boundaries in the north and southern of model and general head was assigned for boundaries in the western and eastern of model.

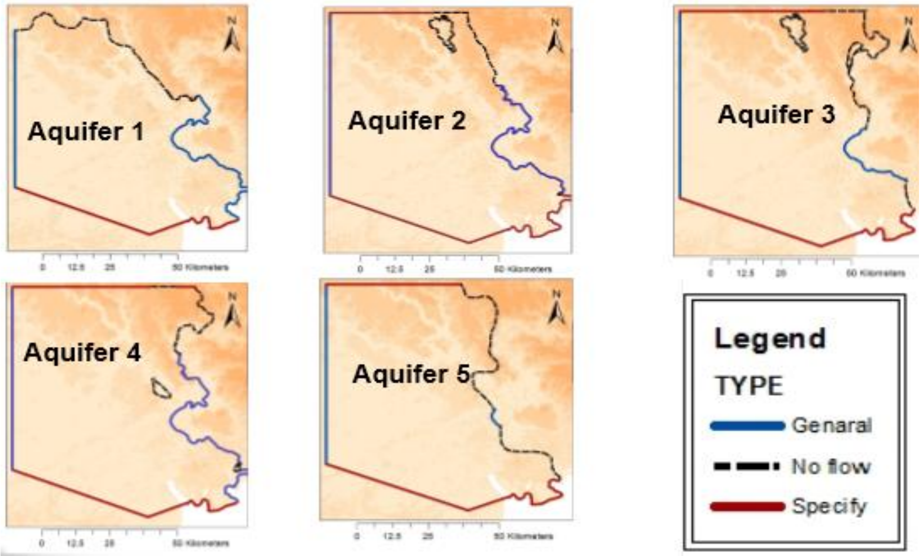


Figure 38: Boundaries condition of groundwater model

d. *Hydrogeology parameter*

Hydraulic conductivity, specific storage and specific yield: all of parameters will be selected based of the previous reports as (Chan N D, 2011) and (Khai, 2011).

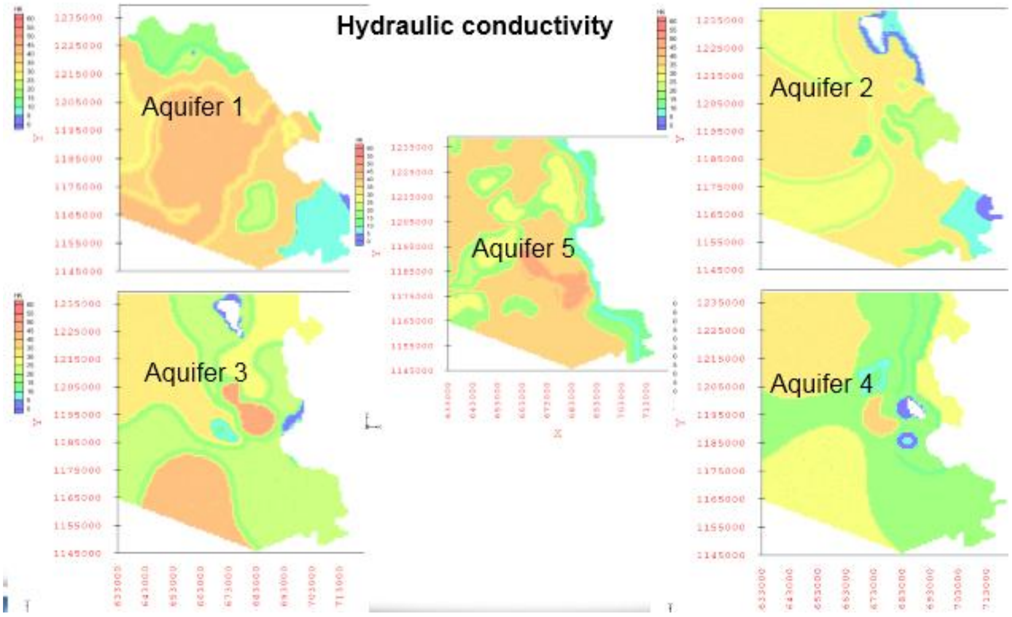


Figure 39: Hydraulic conductivity map

e. River

Rivers and streams contribute water to or drain water from the ground-water system, depending on the head gradient between the river and the ground-water regime. The purpose of the River (RIV) Package (Harbaugh, 2005) is to simulate the effects of flow between surface-water features and ground-water systems. To accomplish this purpose, terms representing seepage to or from the surface features must be added to the ground-water flow equation for each cell affected by the seepage.

The assumption is made that measurable head losses between the river and the aquifer are limited to those across the riverbed layer itself—that is, that no substantial head loss occurs between the bottom of the riverbed layer and the point represented by the underlying model node. Further, an assumption is made that the underlying model cell remains fully saturated—that is, the water level does not drop below the bottom of the riverbed layer. Under these assumptions, flow between the river and the ground-water system for reach n is given by:

$$QRIV = CRIV(HRIV - h) \qquad (4.5)$$

Where:

QRIV: is the flow between the river and the aquifer, taken as positive if it is directed into the aquifer (m^3/day),

HRIV is the water level (stage) in the river (m),

CRIV is the hydraulic conductance of the river-aquifer interconnection,

h is the head at the node in the cell underlying the river reach (m).

In the study, river water level at each river was collected and assigned on the river line of model then simulated by river package. Conductance coefficient was collected from previous model (Boehmer, 2000) . Water level at small river was automatically calculated by model. Sea water level was collected with monthly data at Vung Tau station.

f. Groundwater exploitation

Groundwater withdrawal is collected from Division for Water Resources Planning and Investigation of the south of Vietnam (DWRPIS) and Department of Natural Resources and Environmental of Ho Chi Minh City (DONRE).

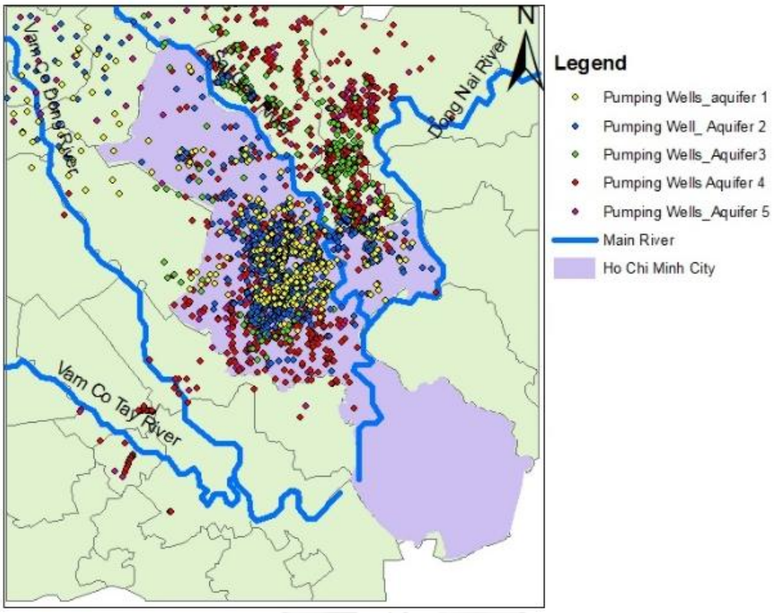


Figure 40: Groundwater abstraction map

IV.2.3.2. Calibration and Verification process

a. Calibration

Calibration of a flow model refers to a demonstration that the model is capable of producing filed measured heads and flows which are the calibration values. Calibration is accomplished by finding a set of parameters, boundary conditions, and stresses that produce simulated heads and fluxes that match field measured values within a pre-established range of error. Finding this set of values amounts to solving what is known as the inverse problem as details show in Figure 41. In an inverse problem the objective is to determine values of the parameters and hydrologic stresses from information about heads, whereas in the forward problem system parameters such as hydraulic conductivity, specific storage, and hydrologic stresses such as recharge rate are specified and the model calculates heads.

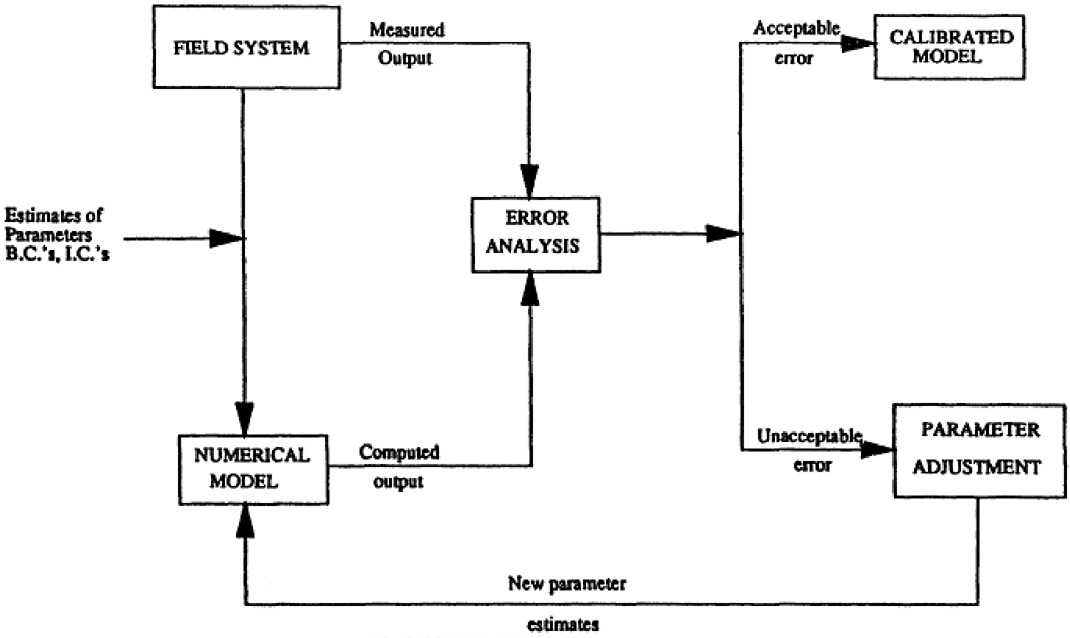


Figure 41: Trial and error calibration procedures (Anderson & Woessner, 1992)

In this study calibration process was divided into 2 step, as steady state and transient step. In order to improve model steady state was simulated for two time during 1/1995 and 1/2007. And, transient process was simulated for monthly time step during 1/1995 to 12/2007.

b. *Verification*

Owing to uncertainties in the calibration, the set of parameter values used in the calibrated model may not accurately represent field values. Consequently, the calibrated parameters may not accurately represent the system under a different set of boundary conditions or hydrologic stresses.

Verification of this model will be run from 1/2008 to 12/2012 to check result of calibrated process above.

IV.3 Recharge function development

The Recharge (RCH) Package (Harbaugh, 2005) is designed to simulate areally distributed recharge to the ground-water system. Recharge applied to the model is defined as:

$$QR = I * DELR * DELC \qquad (4.6)$$

where

QR is the recharge flow rate applied to the model at horizontal cell expressed as a fluid volume per unit time (m^3/day), I is the recharge flux (in units of length per time m/day) applicable to the map area DELR*DELC (cell area),

Values of recharge flux, I, are specified by the user at each stress period

In this study, initial recharge map was created based on hydrogeological map which is showed in section III.5. Initial recharge rate in each zone were assumed as linear function with effective rainfall (P-E).

$$I = aX+b$$

where, I is recharge flux (m/day), x is effective rainfall (m/day),

a and b coefficients of each recharge zone will get during calibration of groundwater model process by applying trial error method.

Effective rainfall is here defined as the difference between total rainfall and actual evapotranspiration (Misstear et al., 2009).

$$X= P - ET$$

where P is average daily rainfall (m/day),

ET is average daily evapotranspiration which was calculated by Penman-Monteith equation (m/day)

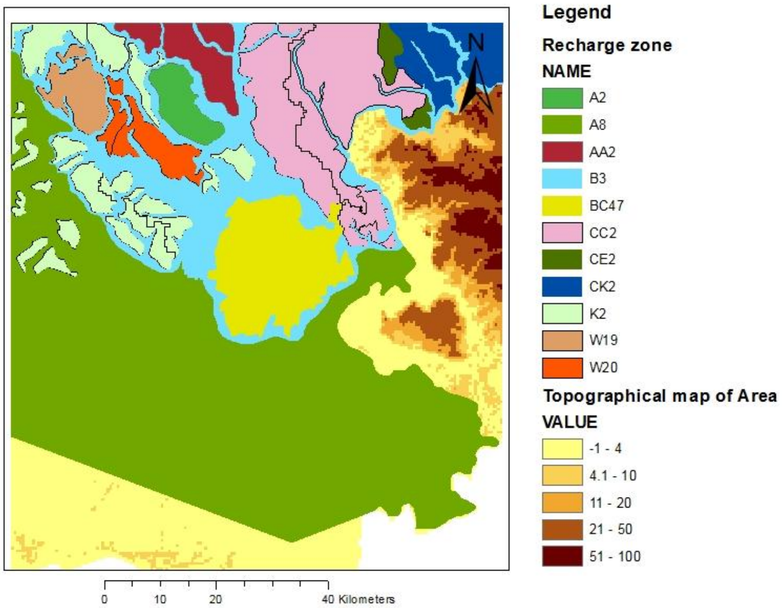


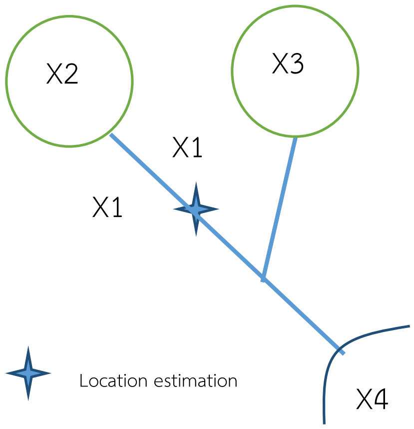
Figure 42: Recharge zone distribution map

IV.4 Simulation of future groundwater resources

IV.4.1. Future river water level estimation

Regression analysis is a statistical technique that efforts the relationship between two variables using a straight line. The variables are Criterion Variable (Y) and Predictor Variables (X) from rainfall and water level related to one criteria variable: therefore, multiple linear regression can be written in the mathematical equation as:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_{2,3} + \beta_3 X_4 + \varepsilon \qquad (4.7)$$



Where, Y is monthly water level in river

X_1 monthly rainfall in sub river basin.

$X_{2,3}$ monthly water release from reservoir

X4 monthly sea water level

$\beta_0, \beta_1, \beta_2$ …., β_3 is coefficients can be estimated by least square method, and ε is an error. In the least square model, the best-fitting line for observation data is calculated by minimizing the sum of the squares of the vertical deviations from each data point to the line. The residuals, ε are difference between the observed and fitted values; hence, the sum of residuals equal to zero.

IV.4.2. Future groundwater exploitation

Future groundwater abstraction was obtained from "Ho Chi Minh water supply master plan 2025". In order to calculate water demand for Ho Chi Minh City, water use was divided into 5 sectors as human activities, industrial, public services, services and tourist:

a. Water for human activities

Water for human activities was calculated based on numbers of population in the city and water demand standard per person. Ho Chi Minh City Population in 2015 and 2025 was predicted at 8,220,000 and 10,000,000 people, respectively. And standard for water demand in the City is shown in the Table 4.

Table 4: Standard of Water demand per person and percentage of people use water

No	Area	2015		2025	
		%	Lit/person/ day	%	Lit/person/ day
I1. Center areas					
1	District 1	100%	180	100%	180
2	District 3	100%	180	100%	180
3	District 4	100%	180	100%	180
4	District 5	100%	180	100%	180
5	District 6	100%	180	100%	180
6	District 8	100%	180	100%	180
7	District 10	100%	180	100%	180
8	District 11	100%	180	100%	180
9	Go Vap district	100%	180	100%	180
10	Tan Binh district	100%	180	100%	180
11	Tan Phu district	100%	180	100%	180
12	Binh Thanh District	100%	180	100%	180
13	Phu Nhuan District	100%	180	100%	180
14	District 2	90%	180	100%	180
15	Thu Duc District	90%	180	100%	180
16	District 9	90%	180	100%	180
17	District 7	90%	180	100%	180
18	District 12	90%	180	100%	180
19	Binh Tan District	90%	180	100%	180
I3. Suburban areas					
20	Cu Chi	80%	130	100%	150
21	Hoc Mon	80%	130	100%	150
22	Binh Chanh	80%	130	100%	150

Table 4: Standard of Water demand per person and percentage of people use water (continue)

No	Area	2015		2025	
		%	Lit/person/ day	%	Lit/person/ day
23	Nha Be	80%	130	100%	150
24	Can Gio	80%	130	100%	150
%: percentage of people use water					

b. *Water demand for industrial zone*

- Water demand for industrial zone was calculated with standard 35-45 m3/ha/day. And industrial area in Ho Chi Minh City was 4707ha in 2015, 7042 ha in 2025.

- Water demand for small industrial was calculated by 5% to 10% water demand for human activities.

c. *Water demand for public services sector*

Public services was such as military, hospital, school.... According to Vietnam construction standard number 33-2006 name “water supply for pipe network systems and construction-standard for architect”, then water for public services by 5% to 10% water demand for human activities

d. *Water demand for services sector*

Service sector was involved such as market, hotel,.. was calculated by 5% to 10% water demand for human activities.

e. *Water demand for tourist*

Water demand for tourist was calculated by 15% to 25% water demand for human activities.

IV.4.3. Impact assessments of climate change on Groundwater recharge

Climate change will impact direct on groundwater resources through recharge and impact indirect on groundwater through surface water and groundwater exploitation. Therefore, to assess impact of climate change on groundwater recharge need to element steps as follows:

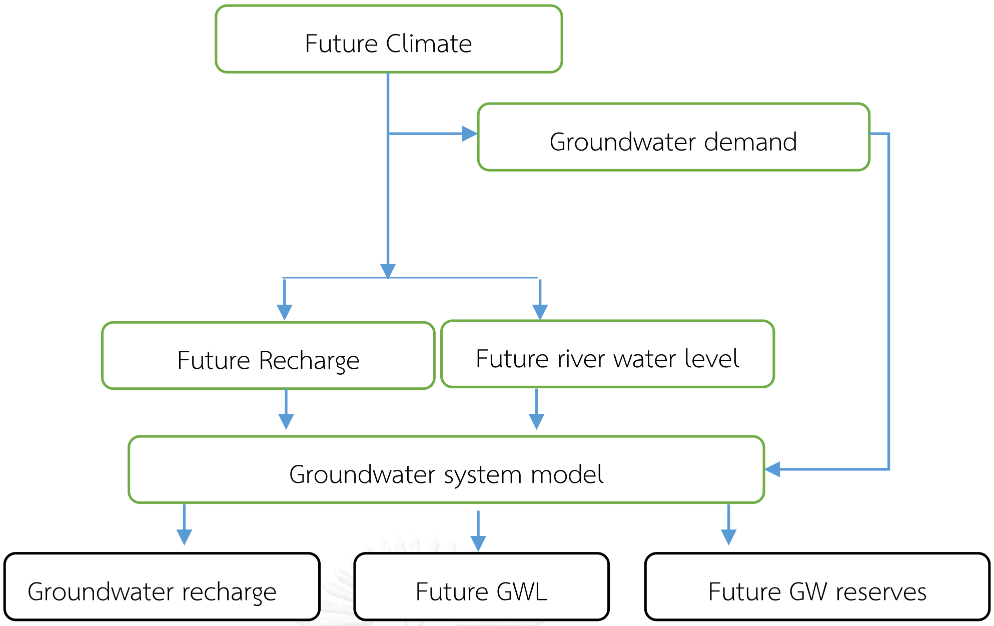


Figure 43: Flowchart to assess the impact of climate change on groundwater resources

IV.4.4. Groundwater management recommendations

Based on the groundwater recharge impact assessment, the groundwater management options will be considered in cases, i.e., changing groundwater use based on the groundwater exploitation plan of Ho Chi Minh City in 2015 and 2025, control groundwater use at the certain rate. The comparison of these options was studied and compared the recharge impact towards to the groundwater. The recommendations for groundwater conservation was made based on the analysis results.

CHAPTER V
RESULTS AND DISSCUSSION

This chapter shows the results of this thesis, and some discussion. At section V.1 the thesis shows results of projected climate change. Section V.2 was results of groundwater model. Section V.3 shows the result of developing recharge function. Impact assessment of climate change on groundwater and recommendations for groundwater management were shown in section V.4 and V.5, respectively.

V.1Climate change projection

V.1.1. Bias-Correction

Rainfall data and temperature data were collected from Southern Regional Hydrometeorology Center during 1980 to 2007. Data of 18 stations (Figure 44) was used to interpolation from observation points to GCM grids. IDW method was used to interpolate daily data.

GCM data named MRI_AGCM3.2s with grid size 20x20km was chose to project future climate for the area. Comparing observation rainfall data with MRI GCM3.2s data in Figure 45 shown that MRI_AGCM3.2s was suitable for the area with high correlation at R = 0.77. However, when comparing average monthly rainfall data of MRI ACGM3.2s with average monthly observation rainfall data during 1980-2007, it is found that rainfall from GCM model seem to be overestimate in dry season and underestimate in rainy season. A comparison spatial distribution of average rainfall of MRI AGCM3.s data during 1980-2007 in Figure 46 and observation Figure 48 also show that GCM model produced overestimate rainfall in area near the sea. Therefore, in order to correct GCM data, this thesis used Gamma Gamma transformation method to bias correction.

Bias correction method was applied with daily data from 1980-2007. Results from bias correction method when compared with observation data show good relationship (Figure 45). When compared spatial distribution of bias corrected results in Figure 47 with observation data in Figure 48, the results showed good match between two maps.

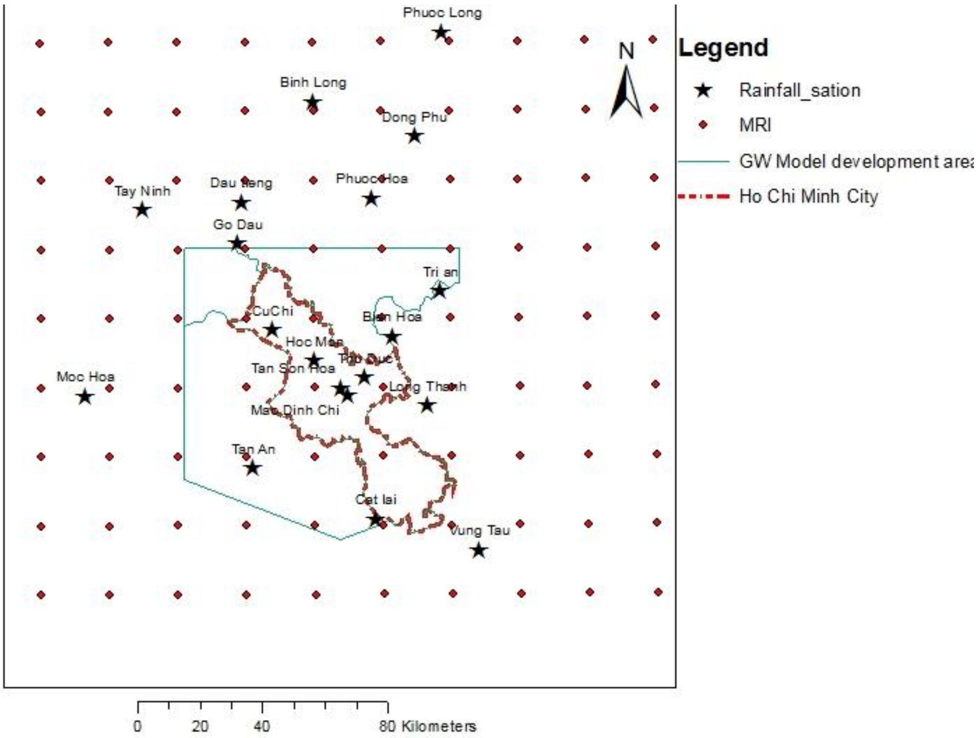


Figure 44: MRI AGCM 3.2s point data and rain gauge stations used in this study

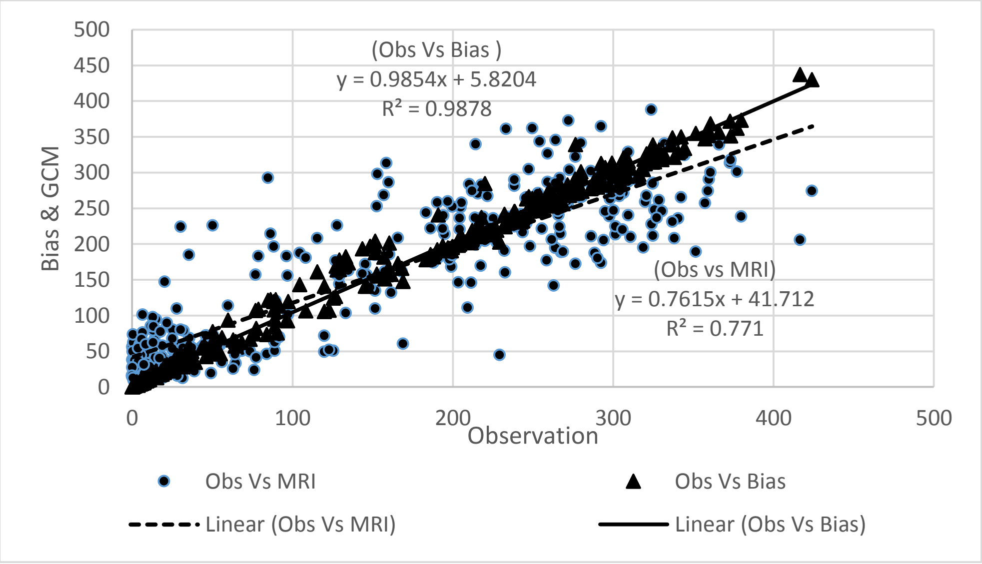


Figure 45: Correlation among precipitation observations, raw GCM and bias corrected data

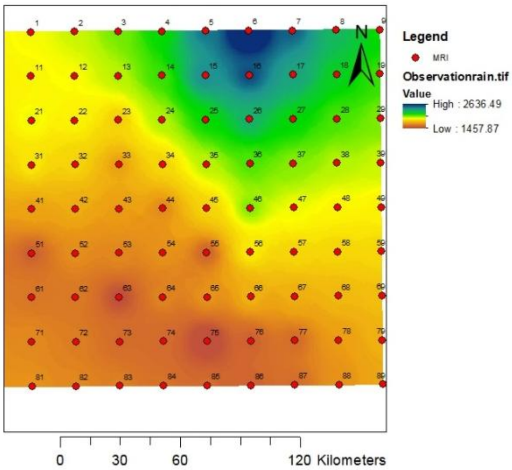


Figure 48: Average annual observation rainfall distribution in Ho Chi Minh City area during 1980-2007

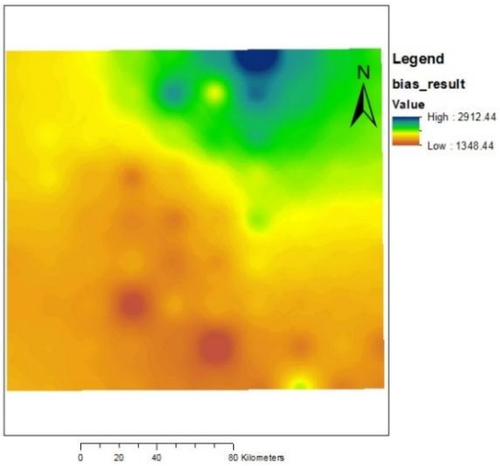


Figure 47: Average annual bias corrected rainfall distribution in Ho Chi Minh City area during 1980-2007

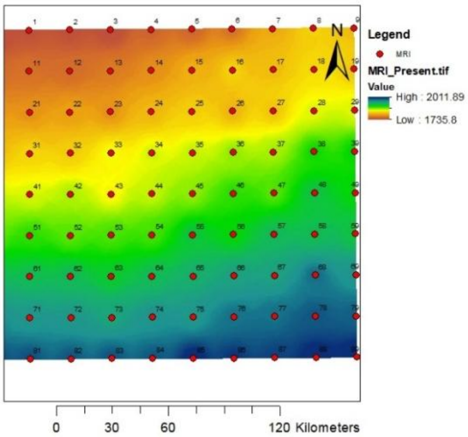


Figure 46: Average annual rainfall distribution MRI AGCM3.2s data for Ho Chi Minh City area during 1980-2007

Statistical parameters, which indicating the correspondence of bias-corrected GCM and observation data with R^2, are greater than 0.9 and average monthly rainfall bias corrected was nearly the same with observation data (Table 5). Consequently, GG method could be applied to bias correction MRI AGCM 3.2s for the area.

Table 5: Statistic analysis of observation rainfall and result of Bias correction method during 1980-2007

Month	Average (mm)		Max (mm)		Min (mm)		SD (mm)	
	Obs	Bias	Obs	Bias	Obs	Bias	Obs	Bias
January	8.51	12.00	55.93	68.90	0.02	0.22	11.77	14.87
February	6.97	8.20	31.42	35.82	0.00	0.08	9.16	10.70
March	20.75	20.41	76.04	74.32	0.01	0.26	21.37	21.23
April	68.55	62.82	229.26	202.67	15.33	13.01	49.48	44.38
May	196.98	192.39	290.33	289.97	96.33	92.71	56.44	55.00
June	252.91	248.75	357.34	347.46	152.54	157.44	51.57	50.40
July	266.05	266.84	372.85	372.23	153.05	155.63	55.72	56.53
August	271.13	266.52	379.84	373.31	186.15	185.31	56.65	54.51
September	303.18	298.31	424.04	429.98	190.23	192.29	53.67	51.96
October	275.59	288.96	416.63	437.14	156.92	181.82	44.66	43.69
November	117.99	157.36	276.49	339.37	27.84	44.39	56.56	67.39
December	32.41	41.71	119.93	141.25	0.53	0.82	31.08	36.89

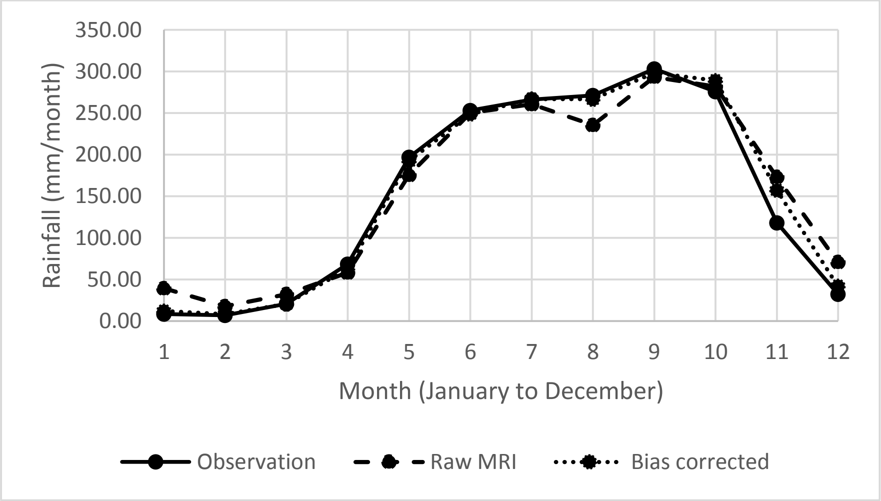


Figure 49: Average monthly rainfall of observation, raw MRI and Bias corrected during 1980-2007

V.1.2. Future climate

V.1.2.1. Precipitation

Comparison between average rainfall in present periods (1980-2007) and near future (2015-2039) and far future (2075-2099) in Figure 50 shows that there will be more rain in dry season and less rain in rainy season during near future period, however in far future there will have more rain in rainy season.

When comparing annual rainfall data (Figure 51), although in present rainfall tend to increase and it will have more rain at beginning of near future period, but, in years after, then annual rainfall gradually decrease. During far future period, rainfall is clearly higher than present and tend to increase until the end of century.

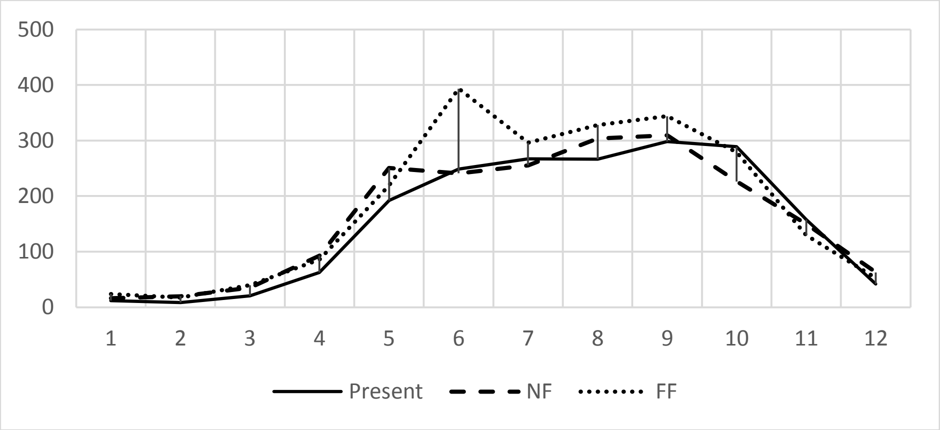


Figure 50: Average monthly rainfall for Present, near future and far future

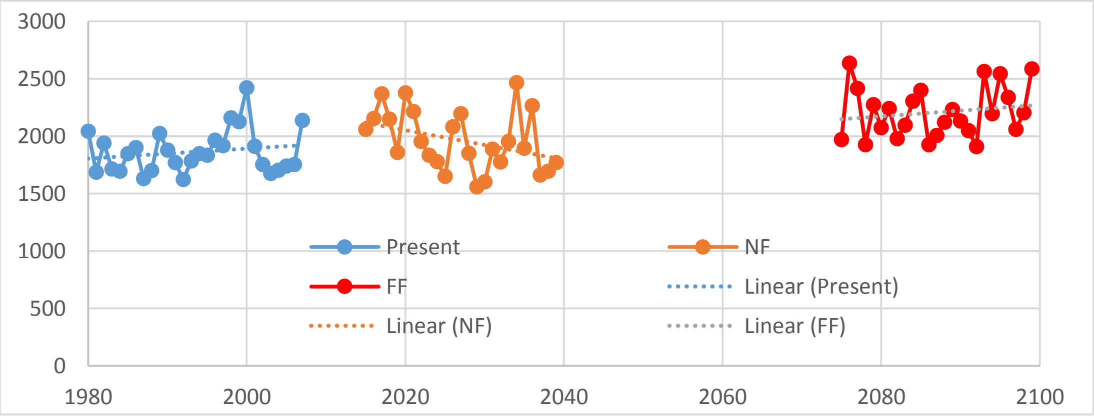


Figure 51: Annual rainfall in present (1980-2007), near future (2015-2039), and far future (2075-2099) periods

So, projected precipitation increases in future periods. Average annual precipitation is projected to increase 5% in near future period and 13% in far future periods as shown in Figure 52.

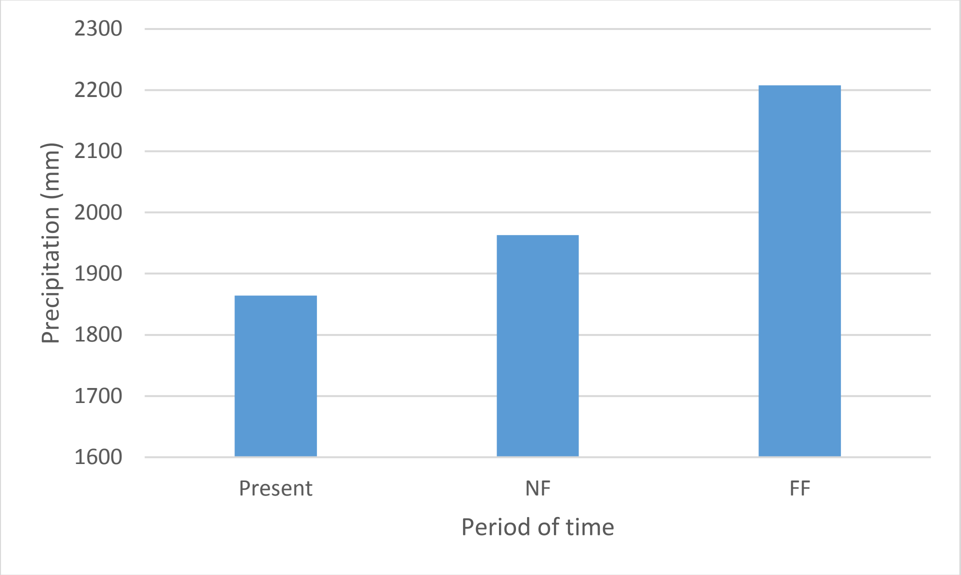


Figure 52: Average annual rainfall in present, near future and far future periods

V.1.2.2. Temperature

Monthly temperature was projected gradually to increase in near future period and far future period as shown in Figure 53. Average monthly temperature will increase at 1.1°C in near future period and around 2.4°C in far future period as Figure 54. Highest temperature in the year is during April and lowest during December.

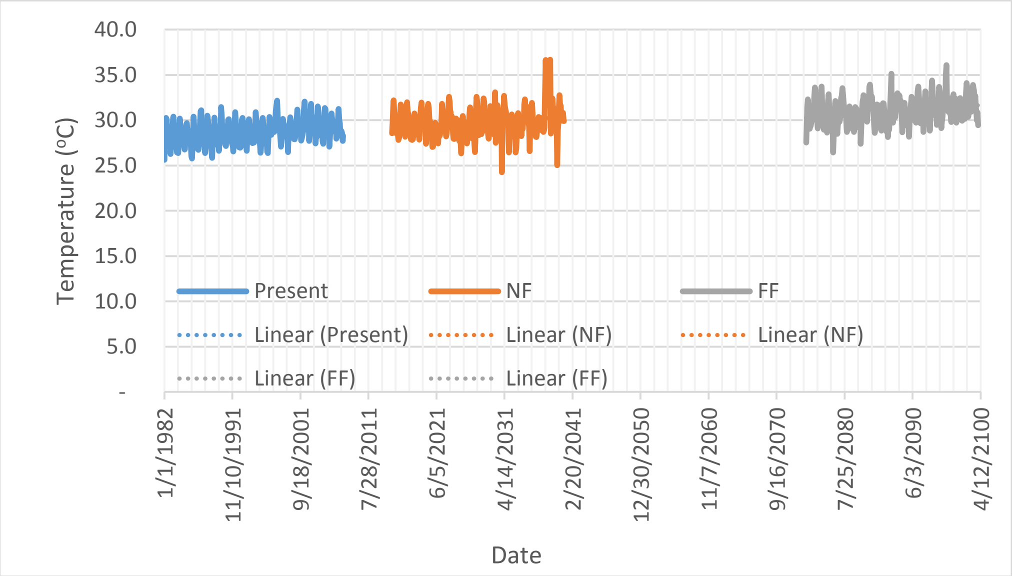


Figure 53: Monthly temperature in present (1980-2007), near future (2015-2039), and far future (2075-2099)

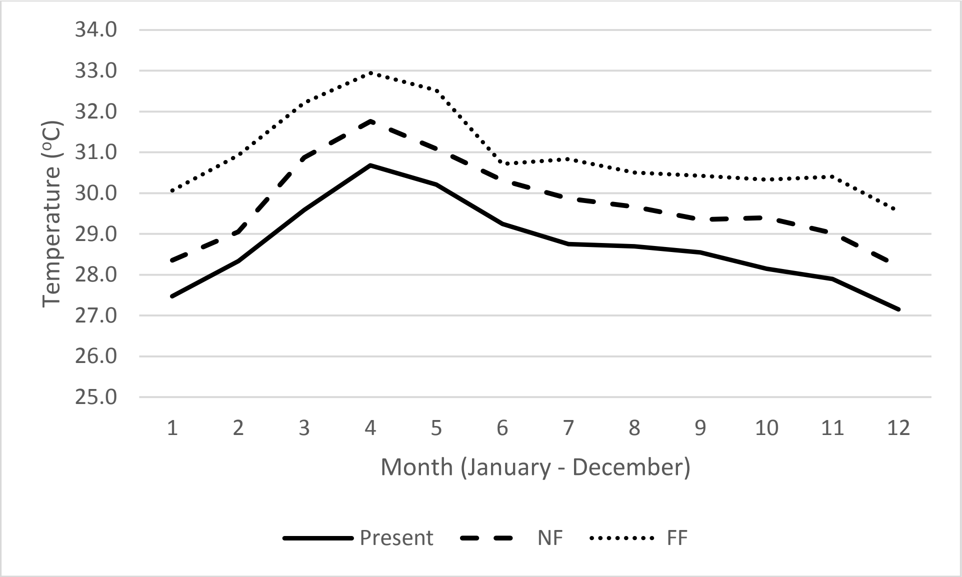


Figure 54: Average monthly temperature

V.1.2.3. Evapotranspiration (E)

Evapotranspiration during the period 1982-2007 was collected from the Project on "Integrated Management and Water Resources Reasonable Usage on Dong Nai River system" (Lanh Do T, 2010). A comparison of evapotranspiration (ET) and temperature (T) show that two variables have relation as linear function with R^2 =0.53 in rainy season and 0.68 in dry season.

Table 6: Evapotranspiration function

No	River Basin	Season	Function	Correlation (R^2)
1	Sai Gon	Dry	ET = 13.312T - 269.68	0.69
		Rainy	ET = 15.021T - 319.37	0.60
2	Vam Co Dong	Dry	ET=13.609T-279.84	0.69
		Rainy	ET=15.274T-327.06	0.61
3	Dong Nai	Dry	ET = 13.551T - 270.06	0.67
		Rainy	ET = 16.036T - 347.69	0.62

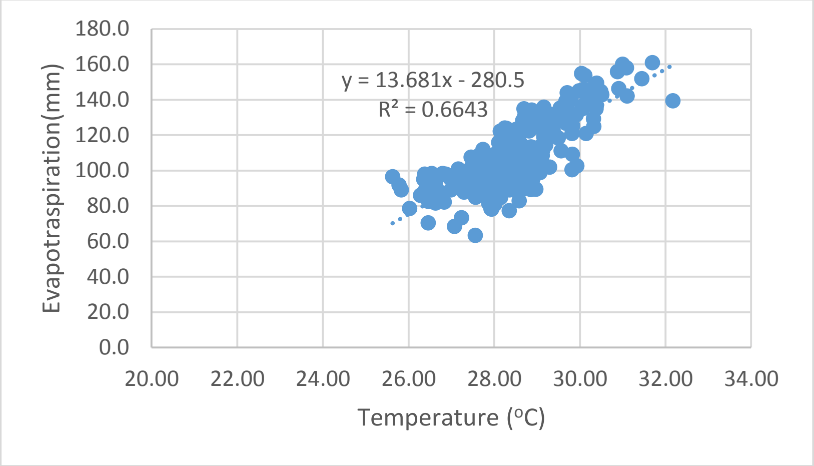


Figure 55: Comparison between evapotranspiration with temperature at Sai Gon River Basin in dry season during 1982-2000

Verification was conducted by using data from 2001 to 2007 to compare calculated evapotranspiration by temperature with observed evapotranspiration.

Table 7: Correlation between calculated evapotranspiration and observed evapotranspiration

No	Basin	Correlation (R^2)
1	Sai Gon River basin	0.72
2	Vam Co Dong	0.73
3	Dong Nai	0.70

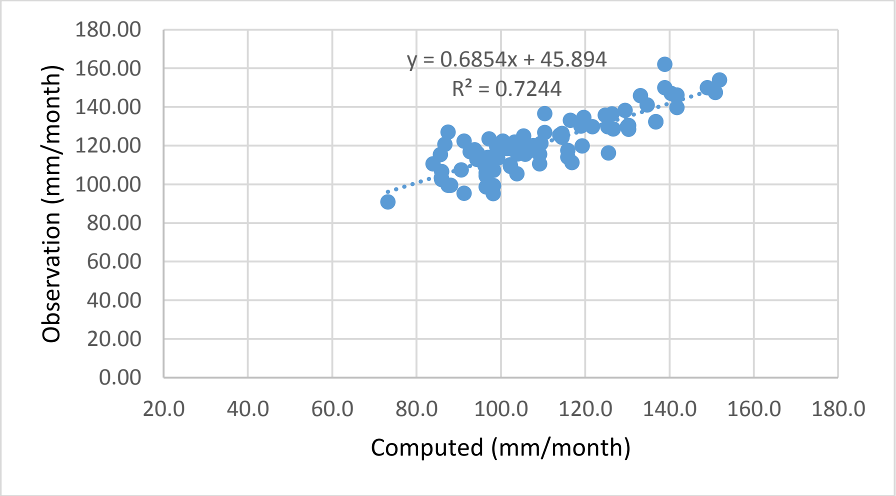


Figure 56: Comparison between calculated evapotranspiration and observed evapotranspiration

Result of calculated evapotranspiration show that annual evapotranspiration increases in future period as Figure 57. Average annual evapotranspiration increases 16% in the near future period and 32% in far future period as Table 8.

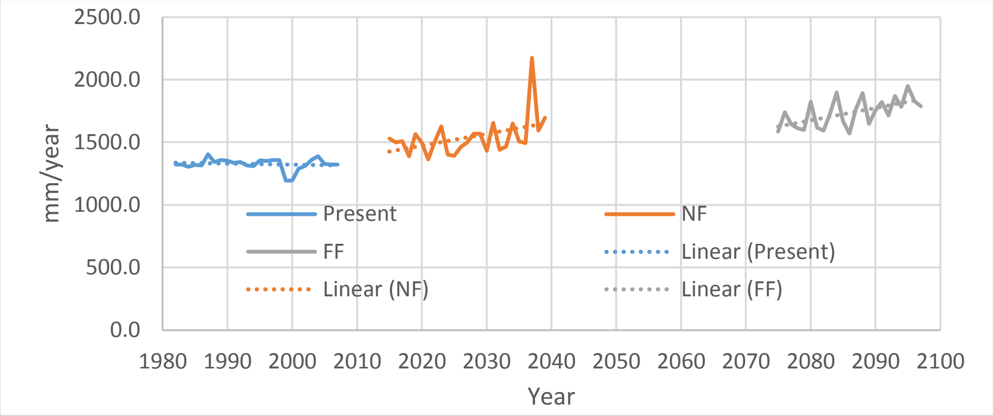


Figure 57: Annual Evapotranspiration

Table 8: Average monthly evapotranspiration in past, near future and far future

Month	Present	NF	FF	NF Diff%	FF Diff%
1	98.10	109.31	132.37	11%	35%
2	99.85	118.80	144.07	19%	44%
3	131.81	143.25	161.35	9%	22%
4	145.07	155.22	171.23	7%	18%
5	136.76	148.68	170.87	9%	25%
6	115.05	136.85	142.95	19%	24%
7	116.30	129.95	144.84	12%	25%
8	108.37	126.82	139.75	17%	29%
9	98.94	121.97	138.53	23%	40%
10	98.06	122.61	137.00	25%	40%
11	89.58	118.35	136.93	32%	53%
12	87.67	107.34	125.56	22%	43%
Sum/average	**1325.6**	**1539.2**	**1745.5**	**16%**	**32%**

V.2Groundwater model

This section provides results of calibration and verification process and also provides a comparison between two models to choose appropriated recharge rate.

V.2.1. Calibration process

Calibration process involved two steps as calibrating model in steady-state conditions and calibrating model in transient condition.

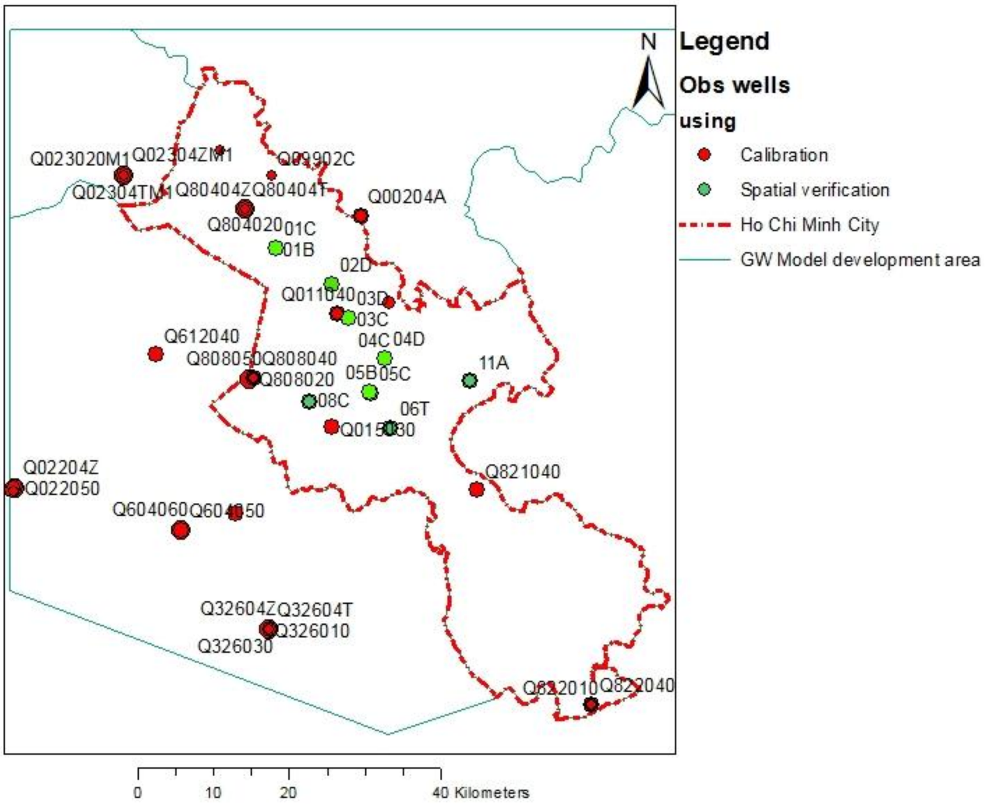


Figure 58: Observation wells map

V.2.1.1 Steady-state

Calibration was performed on a steady-state model using of hydraulic properties of the materials, and boundary conditions described in section IV.2.3. The model was calibrated iteratively by modifying independent hydraulic properties, recharge rate distribution, and taking note of the model error between observed and simulated hydraulic heads from 27 observation wells, and their locations within the modeling domain. The calibrated steady-state model is evaluated using residuals between computed and observed heads, where out of 27 wells. The residual mean (E) is 0.21 m in 1995 and 0.53 in 2007, the mean absolute residual (MAE) is 0.96 m and 1.33 in 1995 and 2007 respectively, and the root mean squared error (RMSE) is also respectively 1.58 m and 2.13 in 1995 and 2007. A plot of the residuals is shown in Figure 59.

Table 9: Monitoring wells

No	Name	Monitoring period	Task	Aquifer
1	Q01302a - Observed	1995-2012	Calibration	1
2	Q09902C - Observed	1995-2012	Calibration	1
3	Q804020 - Observed	1995-2012	Calibration	1
4	Q808020 - Observed	1995-2012	Calibration	1
5	Q00202A - Observed	1995-2012	Calibration	2
6	Q004030 - Observed	1995-2012	Calibration	2
7	Q011340 - Observed	1995-2012	Calibration	2
8	Q02202ZM1 - Observed	1995-2012	Calibration	2
9	Q808030 - Observed	1995-2012	Calibration	2
10	Q822030 - Observed	1995-2012	Calibration	2
11	Q00204A - Observed	1995-2012	Calibration	3
12	Q015030 - Observed	1995-2012	Calibration	3
13	Q02204T - Observed	1995-2012	Calibration	3
14	Q02304TM1 - Observed	1995-2012	Calibration	3
15	Q821040 - Observed	1995-2012	Calibration	3
16	Q011040 - Observed	1995-2012	Calibration	4
17	Q02204Z - Observed	1995-2012	Calibration	4
18	Q22404T - Observed	1995-2012	Calibration	4
19	Q32604T - Observed	2010-2012	Calibration	4
20	Q80404T - Observed	1995-2012	Calibration	4
21	Q808040 - Observed	1995-2012	Calibration	4
22	Q822040 - Observed	1995-2012	Calibration	4
23	Q022050 - Observed	1995-2012	Calibration	5
24	Q02304ZM1 - Observed	1995-2012	Calibration	5
25	Q22404Z - Observed	1995-2012	Calibration	5
26	Q80404Z - Observed	1995-2012	Calibration	5
27	Q808050 - Observed	1995-2012	Calibration	5

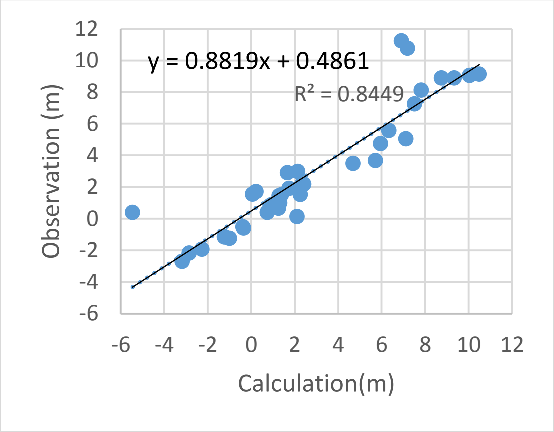


Figure 59: Scatter point of observation and model value

Table 10: Errors of steady state model in comparing with observation data (1/1/1995)

Parameter	ME	MAE	RMSE
Average	0.21	0.96	1.58
Max	5.87	5.87	
Min	-2.05	0.04	

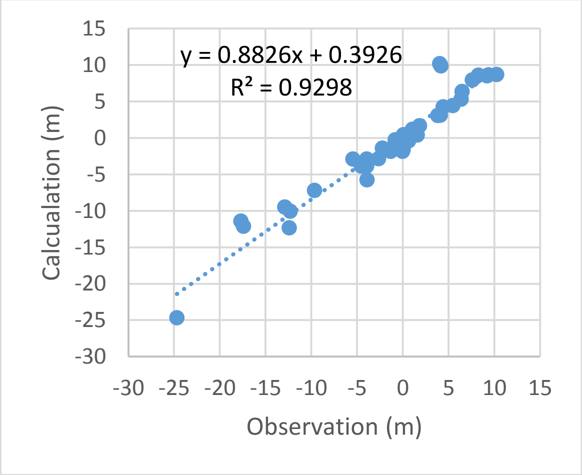


Figure 60: Result of steady state model in 1/1/2007

Table 11: Errors of steady state model in comparing with observation data (1/1/2007)

Parameter	ME	MAE	RMSE
Average	0.53	1.33	2.13
Max	6.27	6.27	
Min	-1.83	0.01	

V.2.1.2 Transient step

Transient simulations were undertaken using the heads from the steady-state solution as an initial condition. The twelve year transient simulation for monthly time step using the heads of the previous simulation as the starting heads for the next. This looping of simulation allows the model to settle into a monthly pattern.

Groundwater level in the model are compared with groundwater level in observation wells at the same location to check the fitting of groundwater simulation, for example in Figure 61. At the same time, indicators of error such as mean error (ME), mean absolute error (MAE), and root mean square error (RMSE) are also calculated to check the fitting of groundwater model.

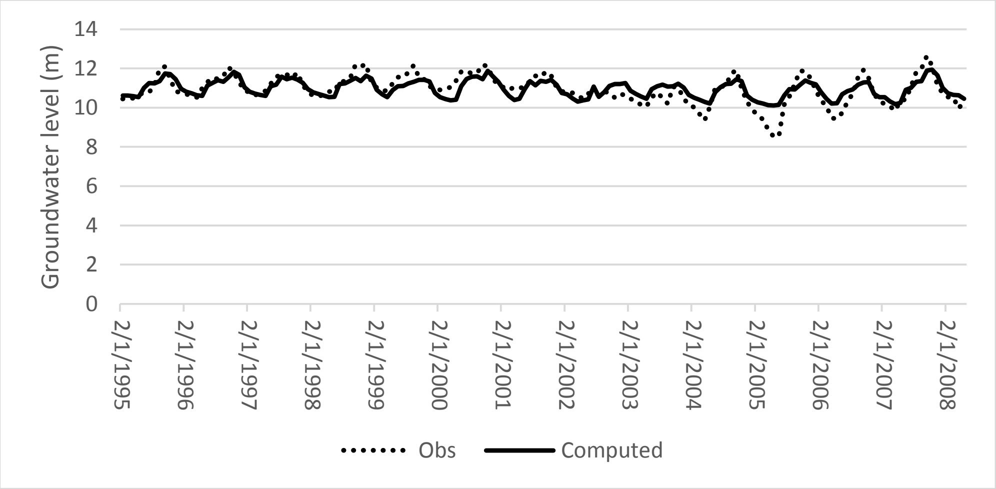


Figure 61: Computed groundwater level and observed groundwater level in well name Q01302a

Results of calibration model show that computation values have close relations with observation data and expressed by average RMSE range from 1.12 m in aquifer 2 as shown in Table 13 to 2.13 m in aquifer 3 as shown in Table 14.

Table 12: Error in aquifer 1

No	Observation wells	ME	Max of E	Min of E	MAE	RMSE
1	Q01302a - Observed	0.02	1.62	-0.95	0.36	0.45
2	Q09902C - Observed	-0.90	1.40	-3.41	1.26	1.52
3	Q804020 - Observed	-2.56	-0.33	-4.39	2.56	2.65
4	Q808020 - Observed	0.27	2.49	-1.30	0.67	0.85
Average		-0.79	1.30	-2.51	1.21	1.60

Table 13: Error in aquifer 2

No	Row Labels	ME	Max of E	Min of E	MEA	RMSE
1	Q00202A - Observed	1.12	2.07	0.37	0.37	1.17
2	Q004030 - Observed	0.68	3.49	-1.07	0.00	1.27
3	Q011340 - Observed	-0.29	3.32	-3.55	0.01	1.60
4	Q808030 - Observed	0.59	4.35	-1.05	0.00	1.24
5	Q822030 - Observed	-0.29	-0.10	-0.42	0.10	0.29
Average		0.36	2.63	-1.14	0.10	1.12

Table 14: Error in aquifer 3

No	Observation wells	ME	Max of E	Min of E	MAE	RMSE
1	Q00204A - Observed	1.12	2.20	0.24	1.12	1.18
2	Q015030 - Observed	3.40	7.57	-0.30	3.41	3.97
3	Q02204T - Observed	-1.77	-1.47	-2.28	1.77	1.78
4	Q02304TM1 - Observed	1.40	2.57	-1.04	1.45	1.61
Average		1.04	2.72	-0.85	1.94	2.13

Table 15: Error in aquifer 4

No	Observation wells	ME	Max of E	Min of E	MAE	RMSE
1	Q011040 - Observed	0.97	3.50	-1.82	1.35	1.62
No	Observation wells	ME	Max of E	Min of E	MAE	RMSE
2	Q22404T - Observed	-1.74	1.83	-2.89	1.83	1.93
3	Q80404T - Observed	-0.96	0.50	-2.02	0.99	1.12
4	Q808040 - Observed	2.01	5.51	-0.65	2.03	2.47
5	Q822040 - Observed	-0.15	-0.04	-0.21	0.15	0.15
Average		0.02	2.26	-1.52	1.27	1.46

Table 16: Error in aquifer 5

No	Well	ME	Max of E	Min of E	MAE	RMSE
1	Q022050 - Observed	-0.3	0.5	-1.1	0.4	0.5
2	Q02304ZM1 - Observed	0.4	1.6	-1.1	0.5	0.6
3	Q22404Z - Observed	-1.7	1.2	-2.5	1.7	1.8
4	Q32604Z - Observed	1.3	2.2	-0.1	1.3	1.4
5	Q80404Z - Observed	0.0	1.5	-1.7	0.5	0.6
6	Q808050 - Observed	2.4	7.1	-2.2	2.6	3.1
Average		0.3	2.4	-1.4	1.2	1.3

V.2.2. Verification step

Verification step was performed after completed transient step with new data from 2008 to 2012. The step was implemented to verify simulation of model parameters and model can be used for predicting.

Verification was divided into two steps as verifying spatial model distribution and verifying prediction of model.

Verifying spatial model was used new observation wells data (Table 17) to compare with model values, for examples in Figure 62. Observation wells in this step were monitored with monthly data in the period of 2000 to 2006.

Table 17: Observation wells for verification

No	Name	Monitoring period	Task	Aquifer
1	06D - Observed	2000-2006 & 2010-2012	Verification	2
2	08B - Observed	2000-2006 & 2010-2012	Verification	2
3	11B - Observed	2000-2006 & 2010-2012	Verification	2
4	01B - Observed	2000-2006 & 2010-2012	Verification	3
5	03C - Observed	2000-2006 & 2010-2012	Verification	3
6	04C - Observed	2000-2006 & 2010-2012	Verification	3
7	05B - Observed	2000-2006 & 2010-2012	Verification	3
8	08C - Observed	2000-2006 & 2010-2012	Verification	3
9	11A - Observed	2000-2006 & 2010-2012	Verification	3
10	01C - Observed	2000-2006 & 2010-2012	Verification	4
11	02D - Observed	2000-2006 & 2010-2012	Verification	4
12	03D - Observed	2000-2006 & 2010-2012	Verification	4
13	04D - Observed	2000-2006 & 2010-2012	Verification	4
14	05C - Observed	2000-2006 & 2010-2012	Verification	4

Results of verifying spatial distribution of model shown that model produced overestimate water water level at most observation wells (Figure 62) with mean residual value (ME) vary in range of 0.84 in aquifer 3 as

Table 19 to 7.79m in aquifer 4 as Table 20. Mean absolute residual (MAE) values range from 1.82 to 3.16 and root mean square error (RMSE) values range from 2.08 to 3.39. In the City center (wells name 8B, 5B, 5C) the error values was highest. It may be affected by groundwater exploitation data input to model. Likely, groundwater exploitation in the area higher than the records at Department of Natural Resources and Environment. ‘

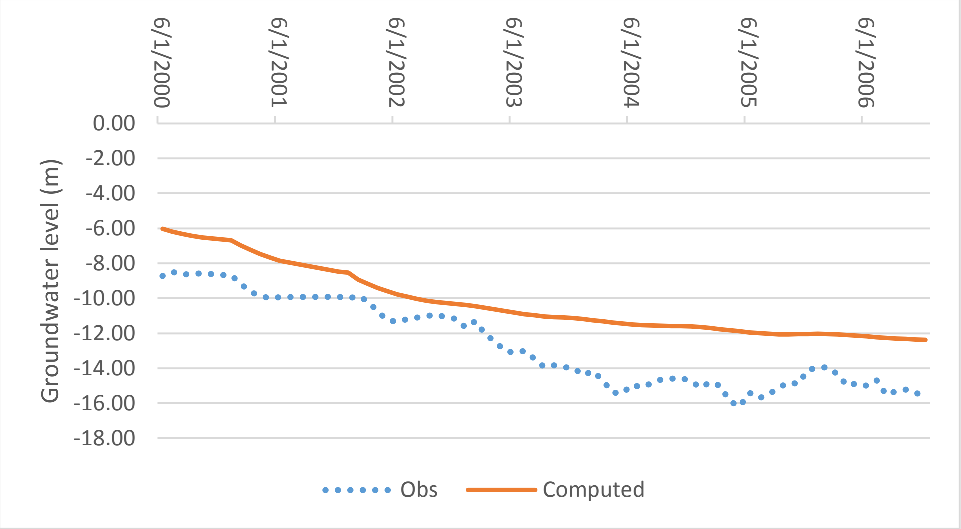


Figure 62: Observed groundwater level and computed groundwater level in observation wells named 06D.

Table 18: Error value in aquifer 2

No	Observation wells	ME	Max of E	Min of E	MAE	RMSE
1	06D - Observed	2.46	4.3	0.71	2.46	2.61
2	08B - Observed	3.61	6.76	1.05	3.61	3.85
3	11B - Observed	0.78	1.67	-0.36	0.79	0.86
Average		2.28	4.24	0.46	2.29	2.44

Table 19: Error values in aquifer 3

No	Observation wells	ME	Max of E	Min of E	MAE	RMSE
1	01B - Observed	-0.68	0.74	-1.89	0.84	1.00
2	03C - Observed	0.27	2.85	-1.99	1.21	1.40
3	04C - Observed	1.22	3.24	-2.51	1.37	1.59
4	05B - Observed	3.39	5.16	-0.27	3.4	3.58
5	08C - Observed	-0.01	2.93	-7.09	2.26	2.84
Average		0.84	2.99	-2.75	1.82	2.08

Table 20: Error values in aquifer 4

No	Observation wells	ME	Max of E	Min of E	MAE	RMSE
1	01C - Observed	1.32	2.49	0.27	1.32	1.44
2	02D - Observed	0.65	3.75	-0.95	0.94	1.25
3	03D - Observed	0.83	3.67	-1.8	1.67	1.89
4	04D - Observed	3.92	6.39	0.85	3.92	4.14
5	05C - Observed	7.97	10.77	4.88	7.97	8.2
Average		2.94	5.42	0.65	3.16	3.39

Verifying prediction of model was performed with data of next periods of time after calibration period from 2008-2012. In order to assess the model verification, groundwater level at observation wells location are compared groundwater level observation, for example in Figure 63. After that, some indicators such as mean residual value (ME), mean absolute residual values (MAE) and root mean square error values (RMSE) are calculated for checking the fitting of model. The indicators of aquifer 1 are showed in Table 21, errors of aquifer 2 are showed in Table 22, and Table 23, Table 24, Table 25 show error values of aquifer 3, aquifer 4 and aquifer 5, respectively.

Results of model verification show that the model generally have appropriate prediction when compared model value with observation. The mean residual value stay in range from 0.06m (aquifer 4) to 1.62m (aquifer 3) and mean absolute residual (MAE) range from 0.98m (aquifer 2) to 4.43m (aquifer 5). Root mean square error value (RMSE) also shown a good appropriation of model, RMSE value range from 1.13m (aquifer 2) to 4.53 (aquifer 5). However, when look at mean error value at individual wells. It shows that 25 wells have negative mean error (ME) value and 18 wells have positive value of mean error. Positive values of mean error (ME) mean the model overestimate water level and negative values mean the model underestimate water level.

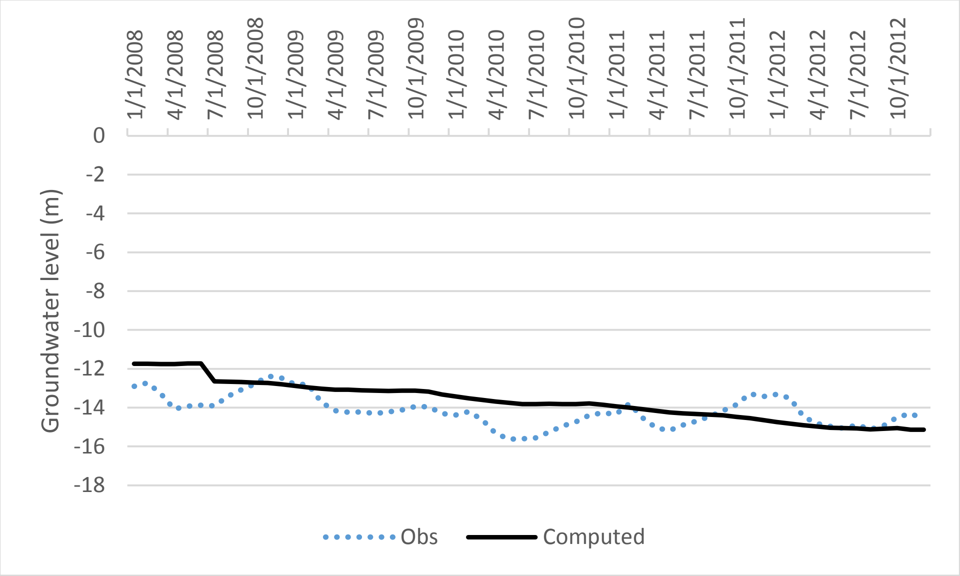


Figure 63: Groundwater level observation and computed groundwater level in observation well name Q004030

Table 21: Error value in aquifer 1

No	Observation wells	ME	MAE	RMSE
1	Q01302a - Observed	0.26	0.44	0.54
2	Q022010 - Observed	0.71	0.71	0.73
3	Q023020M1 - Observed	0.15	0.37	0.45
4	Q09902C - Observed	-1.72	1.85	2.14
5	Q326010 - Observed	-2.19	2.19	2.20
6	Q804020 - Observed	-2.82	2.82	2.90
7	Q808020 - Observed	-0.51	0.73	0.88
8	Q822010 - Observed	-0.05	0.18	0.21
average		-0.77	1.16	1.26

Table 22: Error values in aquifer 2

No	Observation wells	ME	MAE	RMSE
1	Q00202A - Observed	-0.38	0.48	0.64

Table 22: Error values in aquifer 2 (continue)

No	Observation wells	ME	MAE	RMSE
2	Q004030 - Observed	0.51	0.85	1.03
3	Q011340 - Observed	-1.74	1.77	2.07
4	Q02202ZM1 - Observed	0.00	0.13	0.20
5	Q326020 - Observed	2.77	2.77	2.82
6	Q808030 - Observed	0.65	0.70	0.87
7	Q822030 - Observed	-0.18	0.18	0.21
Average		0.23	0.98	1.12

Table 23: Error value in aquifer 3

No	Observation wells name	ME	MAE	RMSE
1	01B	-2.16	2.16	2.29
2	03C	0.51	0.77	0.92
3	04C	-2.54	2.54	2.65
4	05B	-3.28	3.28	3.35
5	08C	1.84	1.84	1.93
6	11A	0.25	0.36	0.43
7	Q00204A	-0.71	0.75	0.92
8	Q015030	4.17	4.17	4.47
9	Q02204T	-1.55	1.55	1.63
10	Q02304TM1	-1.13	1.14	1.28
11	Q326030	2.29	2.29	2.29
12	Q612040	1.80	1.80	1.83
13	Q616040	-1.99	1.99	2.06
14	Q821040	1.62	1.62	1.71
Average		1.62	1.62	1.71

Table 24: Error values in aquifer 4

No	Observation Wells	ME	MAE	RMSE
1	01C - Observed	-0.82	0.98	1.16
2	02D - Observed	-1.39	1.55	1.76
3	03D - Observed	-0.88	1.09	1.40
4	04D - Observed	-1.68	1.68	1.99
5	05C - Observed	3.10	3.10	3.27
7	Q011040 - Observed	-1.03	1.24	1.68
8	Q02204Z - Observed	0.25	0.34	0.40
9	Q22404T - Observed	-2.80	2.91	3.43
10	Q32604T - Observed	2.21	2.21	2.22
11	Q604050 - Observed	2.75	2.75	2.77
12	Q80404T - Observed	-2.33	2.33	2.45
13	Q808040 - Observed	3.55	3.55	3.65
14	Q822040 - Observed	-0.22	0.22	0.23
Average		0.06	1.84	2.03

Table 25: Error values in aquifer 5

No	Row Labels	ME	MAE	RMSE
1	Q022050 - Observed	1.21	3.95	4.13
2	Q02304ZM1 - Observed	-0.96	0.92	1.06
3	Q22404Z - Observed	-3.08	1.03	1.19
4	Q32604Z - Observed	1.69	4.19	4.27
5	Q604060 - Observed	8.04	6.10	6.13
6	Q80404Z - Observed	-1.27	3.52	3.60
7	Q808050 - Observed	4.33	11.32	11.36
Average		1.42	4.43	4.53

V.2.3. Groundwater balance

V.2.3.1 Groundwater balance during 1995-2007

Groundwater inflow is mainly from model boundary (boundaries in 1,412,093 cubic meter per day), direct recharge of rainfall (138,684.6 cubic meter per day), river leakage in (231,910.4 cubic meter per day) where the water table is below river-bed elevation. Groundwater outflow is from discharge to river (river leakage out 152,548.7), discharge to model boundary (boundaries out 1,302,831), and groundwater abstraction (wells out 398,088.2 cubic meter per day). Groundwater balance Table 26 is established by equating components of inflow and outflow with any change in storage (-70779.6 cubic meter per day), that is:

$$Inflow\ (boundary, recharge, river) - outflow\ (Pumping, river, boundary) = \Delta storage(storage\ out - storage\ in) \quad (5.1)$$

Table 26: Groundwater balance in the study area during 1995-2007

Components in	Flow rate (m^3/day)	Components out	Flow rate (m^3/day)
Boundaries In	1,412,093	Boundaries Out	1,302,831
RECHARGE In	138,684.6	RIVER LEAKAGE Out	152,548.7
RIVER LEAKAGE In	231,910.4	WELLS Out	398,088.2
Total in	1,782,688	Total out	1,853,468
Change in Storage (ΔS)	-70779.6 (m^3/day)		

V.2.3.2. Groundwater balance in 2012

In 2012, Groundwater flow balance in the area consists of 2 components as flow in and out, details show in Figure 64:

Flow in components consist of recharge 145,508.2 cubic meter per day (7% of total in), river leakage flow in 623,247 cubic meter per day (29% of total in), water from boundaries in 1,219,220 cubic meter per day (56% of total in) and water supply from storage in 227,871.7 cubic meter per day (11% of total).

Flow out components consist of: groundwater pumping 1,006.784 (47% of total out), groundwater discharge to river (River leakage out) 96,745.7 cubic meter per day (4% of total out), groundwater discharge to boundary (boundary out) 1,037,234.6 cubic meter per day (48% of total out), and water supply to groundwater reserve (storage out) 79,047.5 cubic meter per day (4% of total).

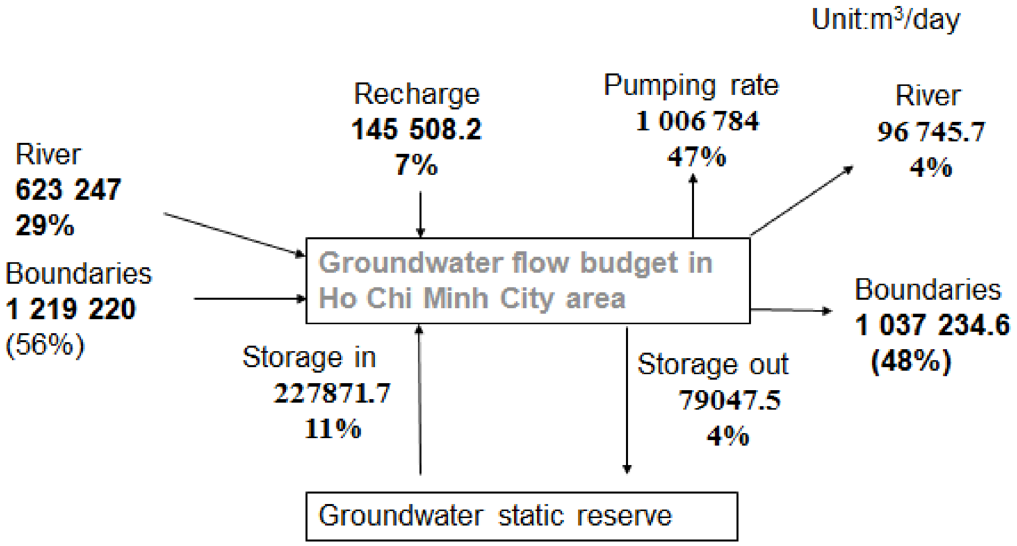


Figure 64: Water flow balance in the area in 2012

V.3Recharge function

V.3.1. Developing recharge function

As mentioned in section IV.3 then recharge zone map was created by using hydrogeological map, and recharge rate as linear function of effective rainfall:

$$I= aX+b \qquad (5.2)$$

where: Y is recharge rate (m/day)

X is effective rainfall (m/day)

a and b factors were got during calibration and verification process by applying trial error method, result is showed in Table 27.

The results of model calibration and verification above showed that the computed values of the model are matched with observation values. It mean that recharge rate can be obtained from effective rainfall and recharge rate can be linear function of effective rainfall (Table 27).

Table 27: Recharge zone's function

No	Zone	Function
1	A2	I = 0.0074x + 5E-06
2	K2	I = 0.0072x + 5E-06

Table 27: Recharge zone's function (continue)

No	Zone	Function
3	B3	I =0.0029x + 8e-10
4	A8	I = 0.0024x + 1E-07
5	BC47	I = 0.01x + 8E-07
6	CC2	I = 0.0027x + 3E-07
7	AA2	I = 0.0093x +8E-07
8	CK2	I = 0.034x + 2E-06
9	CE2	I = 0.0024x + 6E-08
10	W19	I = 0.019x + 1E-05
11	W20	I =0.036x +4E-6

*Where: y is recharge rate (m/day) and x is effective rainfall (m/day)

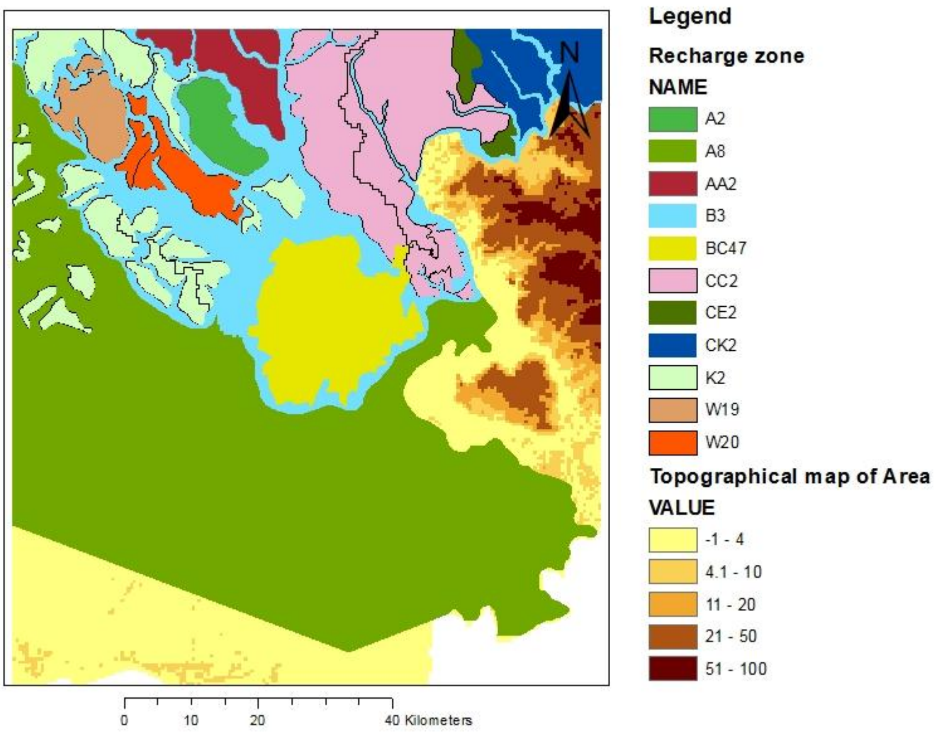


Figure 65: Recharge zone's map

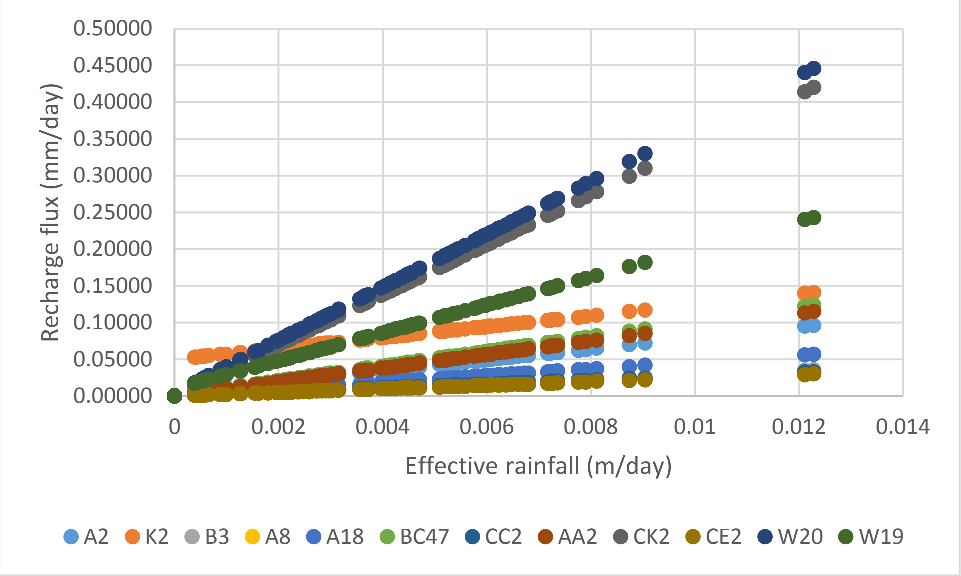


Figure 66: Scattered point of relation between recharge flux and effective rainfall

V.3.2. Verification of recharge rate

When built groundwater model for the area, due to calculated groundwater recharge are quite complex, hence modelers normally assumed recharge equal 10% of rainfall. Also, Khai (2011), built groundwater model for area between two river Vam Co Dong River and Sai Gon River assumed that recharge rate equal 10% of rainfall to input to model and calibrated for 5 years from 2006-2010. However, in order to compare two models with different boundary conditions was not reasonable. Therefore, this study will use recharge rate got from Khai (2011) to input to model and compare result with results of model used recharge rate from effective rainfall. The results of two models show that the model used recharge as function of effective rainfall was better with all indicators such as average residual error (ME) and mean absolute error (MAE) as well as RMSE were smaller than model used recharge as percentage of rainfall (Table 28).

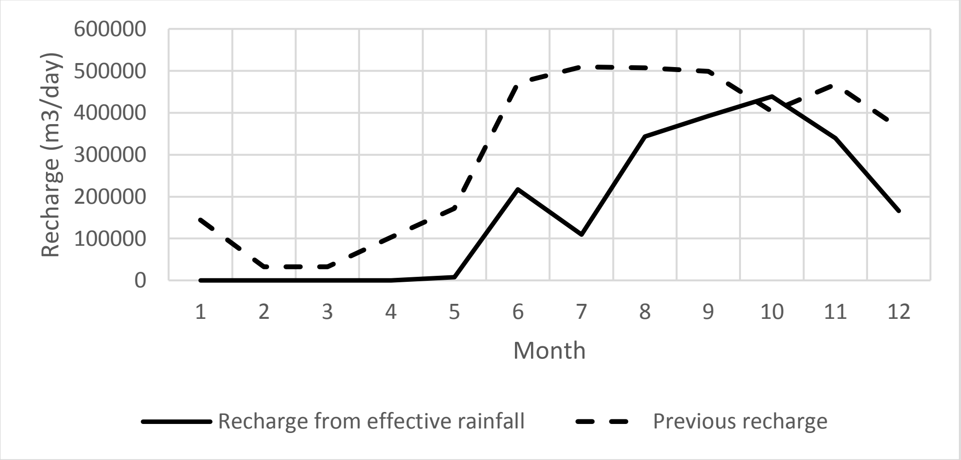


Figure 67: Average monthly recharge from 2006-2010

Table 28: Comparison error of models

Aquifer	Model with recharge from rainfall			Model with recharge from effective rainfall		
	ME (m)	MAE (m)	RMSE (m)	ME (m)	MAE (m)	RMSE (m)
Aquifer 1	-0.33	1.00	1.45	-0.47	0.96	1.40
Aquifer 2	0.93	1.15	1.53	0.67	0.99	1.31
Aquifer 3	1.48	2.18	3.12	1.31	2.02	2.89
Aquifer 4	0.34	1.39	1.95	0.17	1.34	1.87
Aquifer 5	0.94	1.65	2.50	0.83	1.69	2.50
Average	0.67	1.47	2.11	0.50	1.40	1.99

In conclusion, calibrating and verifying model shown reasonable of model and comparing model show an appropriable of choosing recharge rate. Hence, further steps of this thesis is going to use recharge rate obtained from effective rainfall as one boundary condition for future groundwater modeling.

V.4Future groundwater resource simulation

Future groundwater resource simulation by using Modflow code, need to have initials input to the model such as recharge rate obtained from function as in the Table 27, river water level, groundwater abstraction…

V.4.1. Projected groundwater recharge

Future groundwater recharge rates were input to groundwater model to simulate future groundwater resources. The results in the Figure 68 showed that recharge will decrease in the near future and increase in the far future periods.

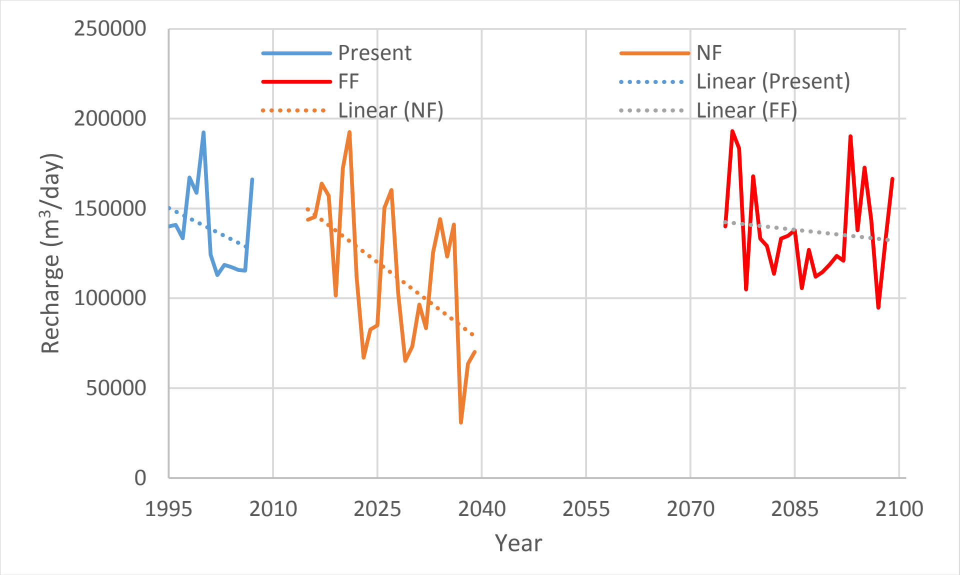


Figure 68: Average annual recharge rate in the past period (1995-2007), near future period (2015-2039) and far future period (2075-2099).

The comparison between average monthly recharge show that recharge in the dry season in future will reduce and recharge increase in the rainy season in far future (Figure 69). Average recharge rate will decrease 17% in near future periods and it will recover as rate of present period in far future period. And when comparing total cumulative recharge in three periods show that near future recharge seem to be less than present and far future recharge will be higher than present periods as Figure 70.

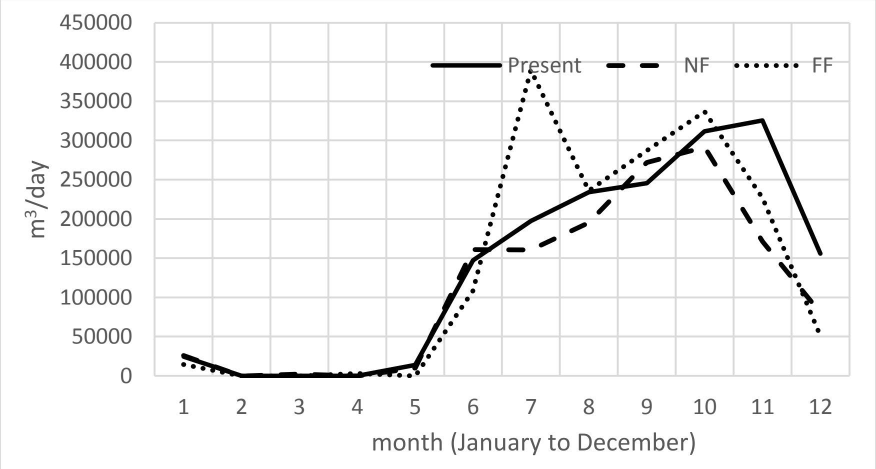


Figure 69: Average monthly recharge rate in the past, near future, and far future period

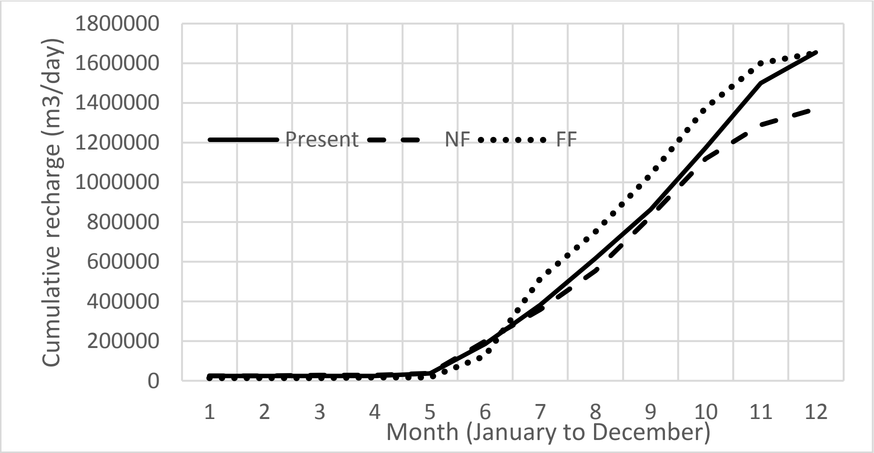


Figure 70: Cumulative average monthly of recharge during periods of Present (1995-2007), near future (2015-2039), far future (2075-2099)

A comparison of future recharge, climate variables in Figure 71 found that climate factors were strongly impact on groundwater recharge. In near future period, rainfall will increase 5% and when temperature increase 1.1°C then evapotranspiration will also increase 16%. All of these climate factors will make groundwater recharge reduce around 17%. At the same time, in far future period, rainfall is projected to increase 13%, temperature will increase 2.4°C and evapotranspiration increase 32%. Meanwhile, groundwater recharge rate will recover nearly the same rate in present period.

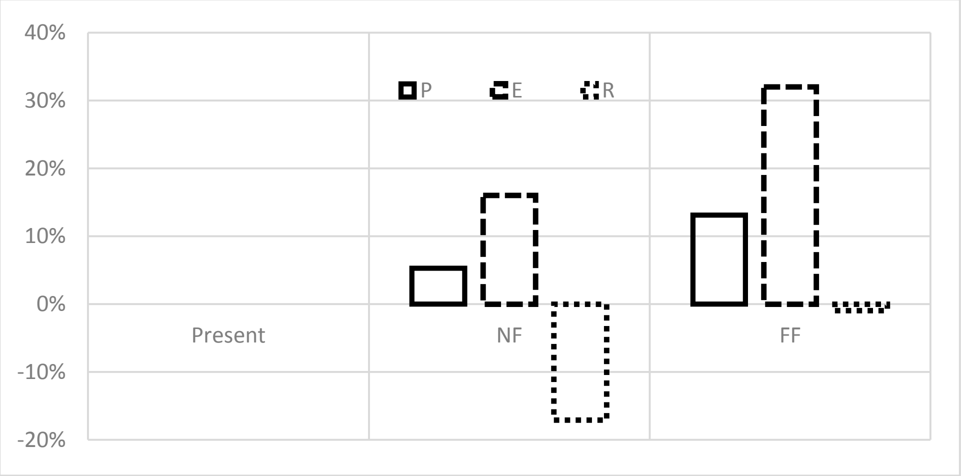


Figure 71: Difference value of average recharge rate, rainfall and evapotranspiration in near future period and far future period

V.4.2. Future river water level

Multiple linear regression method was applied to develop function of water level at each station. Monthly water level data from 1980 to 2000 was used to develop function and using data from 2000 to 2007 for verification. Details in the Table 29.

The results show positive correlation value R square range from 0.6 to 0.97. From water level formulas, Sai Gon River water level mainly impacted by sea water level and rainfall in Saigon river basin. Similarly, water level in Dong Nai River is also influenced by Tri An dam release and rainfall. Water level on Vam Co Dong River and Vam Co Tay River is mainly affected by sea water level and partly by rainfall.

Table 29: Function of water level at river station

River	**Station**	**Function**	**Correlation (R^2)**
Dong Nai River	Tri An	Y=0.0036*Qr+0.5956	R=0.94
		Qr = (from January to April) Qr=0.4381Qin+224.34 (1) (May to August) Qr=0.8293Qin+131.48 (2) (August to December)	R_1=0.90 R_2 = 0.95
		Qin=2.3453*R+52.826	R=0.6
	Bien Hoa	Y = 0.367 + 0.000408Qr + 0.983S	R=0.97
	Nha Be	C1 = 0.288 + 1.12S + 0.000016Qr	R=0.97
Sai Gon River	Thu Dau Mot	Y = 0.399 + 0.000065 R + 1.01S	R=0.85
	Phu An	Y = 0.340 + 1.05S + 0.0000379R	R=0.87
Vam Co Dong	Go Dau Ha	Y=0.579 + 0.00124R + 1.76S	R=0.83
	Ben Luc	Y = 0.369 + 1.12S + 0.000172R	R=0.85
Vam Co Tay	Tuyen Nhon	Y = 0.758 + 0.0002R + 2.32S	R=0.61
	Tan An	Y = 0.451 + 0.000694 R + 1.48S	R=0.85

**where: Y is water level at river station (m), S is sea water level (m), and R was monthly rainfall (m), and Qr is average monthly water release from dam (m^3/s), Qin is monthly water inflow to the reservoir.*

V.4.2.1 Water level in Saigon river

There are three stations on Saigon river including Dau Tieng station, Thu Dau Mot station and Phu An station. Results of each station were calculated for two cases i.e., sea level rise and no sea level rise.

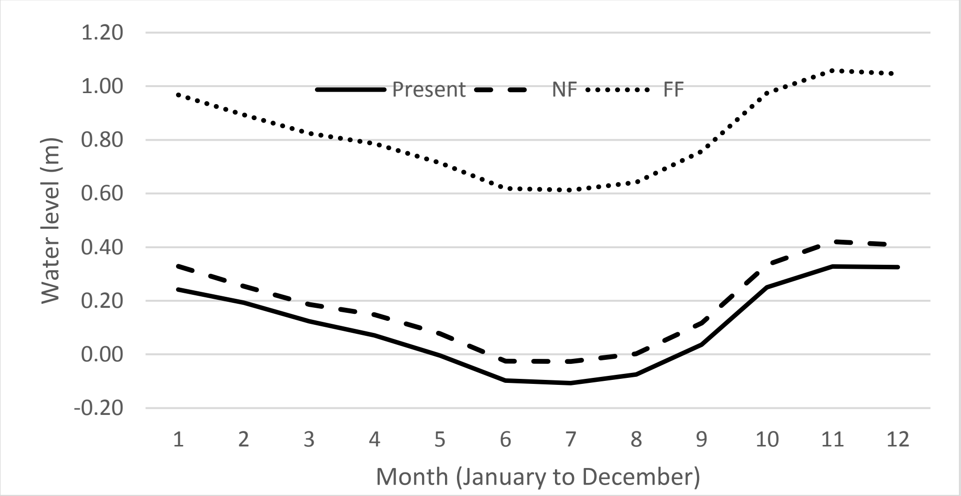


Figure 72: Average monthly river water level at Phu An station in case of sea level rise

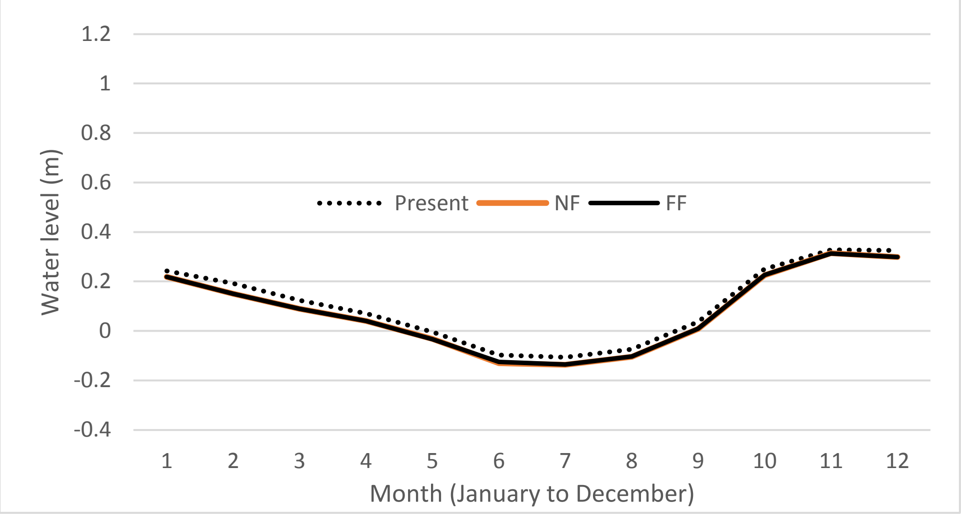


Figure 73: Average monthly river water level at Phu An station in case of fixed sea level

V.4.2.2 Water level in Dong Nai river

There are three station on Dong Nai river included Tri An station, Bien Hoa Station and Nha Be station.

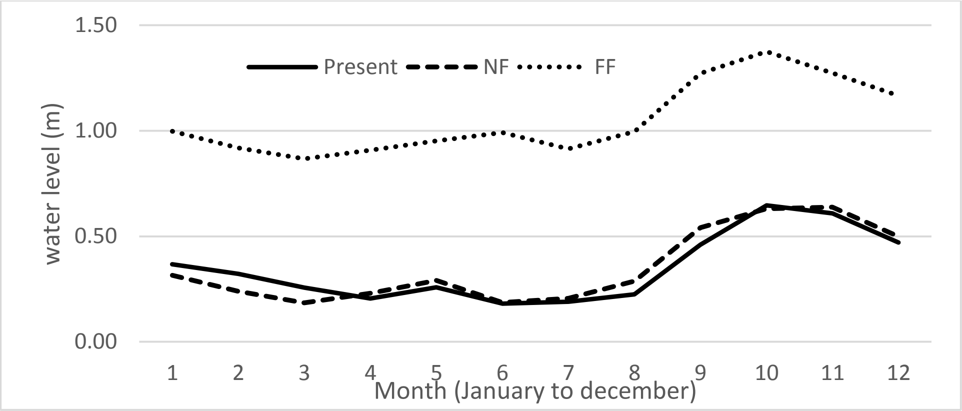


Figure 74: Average monthly river water level at Bien Hoa station in case of sea level rise

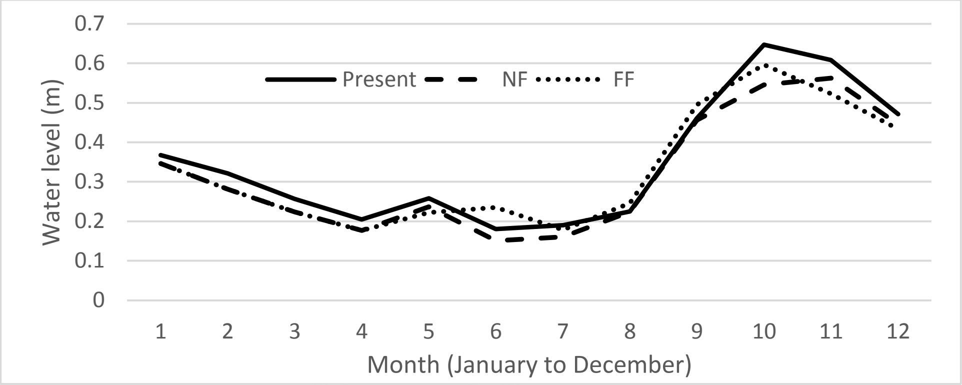


Figure 75: Average monthly river water level at Bien Hoa station in case of no sea level rise

V.4.2.3 Water level in Vam Co Dong River

There are two station on Vam Co Dong river included Ben luc and Go Dau. Result of calculation water level at these station in two case as details in Figure 76 and Figure 77.

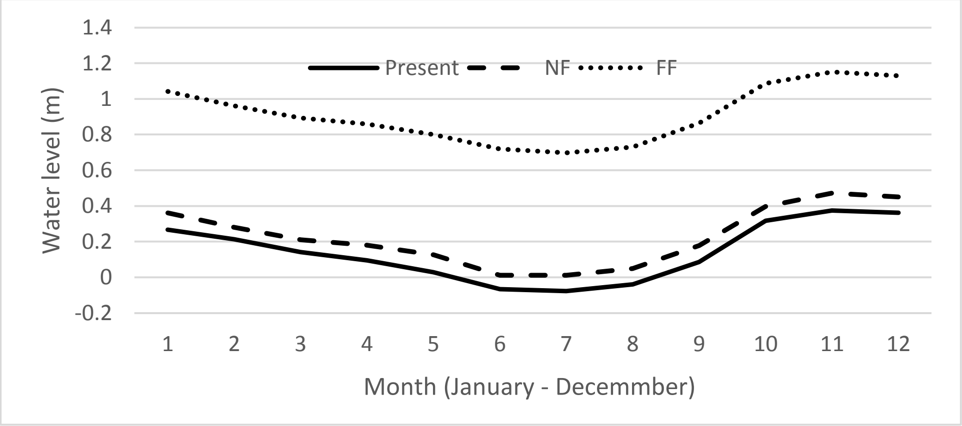


Figure 76: Average monthly water level in Vam Co Dong river at Ben luc Station in case of sea level rise

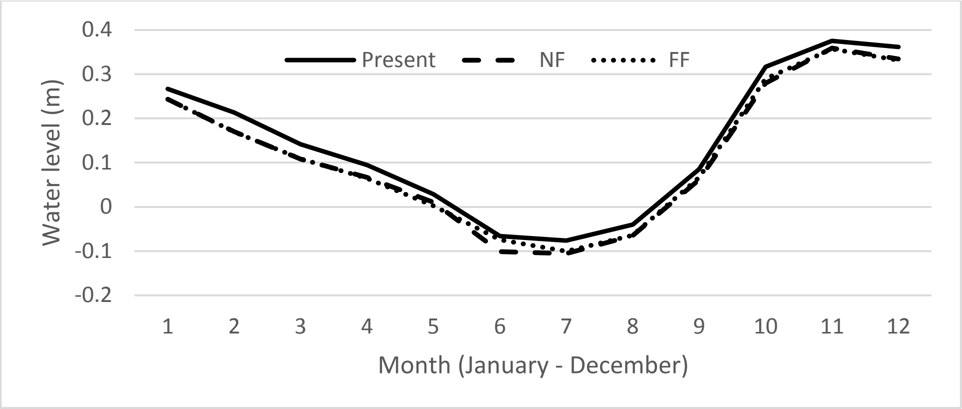


Figure 77: Average monthly water level in Vam Co Dong river at Ben luc Station in case of no sea level rise

V.4.2.4 Water level in Vam Co Tay river

There are two station on Vam Co Tay river as Tan an station and Tuyen Nhon station. Result of calculation water level at these stations in two cases as details

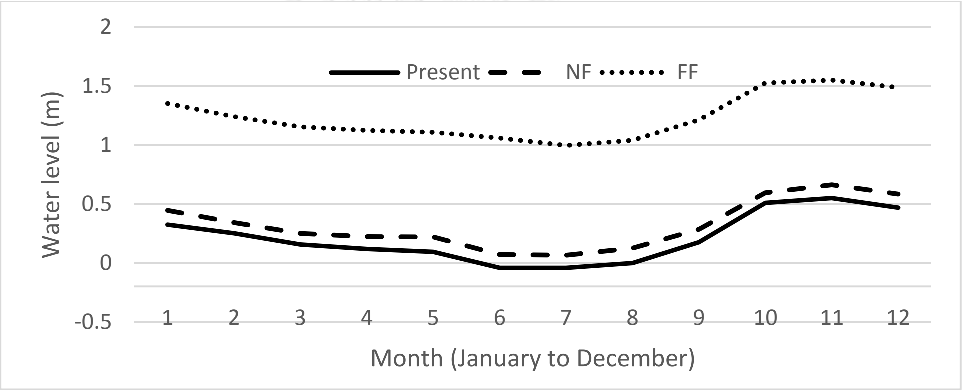


Figure 78: Average monthly water level in Vam Co Tay river at Tan an Station in case of sea level rise

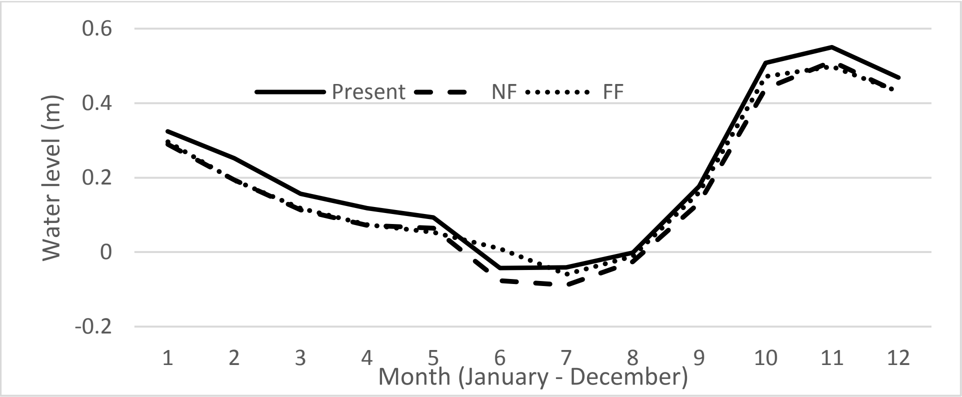


Figure 79: Average monthly water level in Vam Co Tay river at Tan an Station in case of no sea level rise.

V.4.3. Water demand and water supply plan

V.4.3.1 Water demand

According to Ho Chi Minh City Water Supply Master Plan 2025 then water demand was divided into 5 sectors as in Table 30.

Table 30: Water demand in Ho Chi Minh City

Sector	2015 (m^3/day)	2025 (m^3/day)
Human activities	1.353.594	1.763.025
tourist	36.244	72.087
Public	94.751	123.411
Industrial zone	122.220	191.135
Small industrial	88.246	123.387
Services	94.751	123.411
Total without loss	1.789.806	2.396.458
Loss	782.827	788.440
Total	2.580.000	3.296.000

V.4.3.2 Water supply plan

Up to 2025, water will supply to all people in the area and major sources was surface water from Dong Nai and Sai Gon rivers with capacity up to 4 million cubic meter per day. And groundwater pumping in the area will reduce to 100 000 cubic meter per day in 2025 and groundwater only will exploit at some industrial wells. Small wells and private wells will be closed. Details shown in Table 31 below:

Table 31: Water supply master plan 2025

Number	Water Plant	Capacity (m^3/day)		
		2010	2015	2025
I	Sources from Dong Nai Rivers			
1	Thu Duc Plant	750 000	750,000	750,000

Table 31: Water supply master plan 2025 (continue)

Number	Water Plant	Capacity (m^3/day)		
		2010	**2015**	**2025**
2	Thu Duc II Plant	300 000	300,000	300,000
3	Thu Duc III Plant		300,000	300,000
4	Thu Duc IV Plant			300,000
5	Thu Duc V Plant			500,000
6	Binh An Plant	100,000	100,000	100,000
Total		1,150,000	1,450,000	2,250,000
II	Sai Gon River			
1	Tan Hiep 1 Plant	300,000	300,000	300,000
2	Tan Hiep 2 plant		300,000	300,000
3	Tan Hiep 3 Plant			300,000
4	Kenh dong I plant		200,000	200,000
5	Kenh Dong 2 plant		150,000	250,000
Total		300,000	950,000	1,350,000
III	Groundwater			
1	Tan Binh Plant	65,000	75,000	75,000
2	Small wells in center	2,000	0	0
3	Go Vap Plant	10,000	10,000	10,000
4	Binh Tri Dong Plant	8,000	8,000	0
5	Social wells	3,000	2,000	0
6	Binh Hung Plant		15,000	15,000
7	Industrial wells	350,861	190,000	0
8	Private wells	256,000	140,000	0
Total		694,861	440,000	100,000
Sum total		2,144,861	2,840,000	3,700,000

V.4.4. Impact assessment of climate change on groundwater recharge

Since, groundwater in the area was impacted by climate factor and sea water level. Hence, to assess the impact of climate change on groundwater resources the study were simulated in two cases. Firstly, groundwater simulation assumed that no sea level rise. Secondly, groundwater simulation with sea level rise (as scenarios of Ministry of Natural Resources and Environment 2012). Future groundwater resources change in two cases was described in details as below:

V.4.4.1 No sea level rise

The simulation future groundwater resources by groundwater model need some of boundary conditions data such as water level, recharge rate, and groundwater abstraction. River water level is obtained in section V.4.2 in case of no sea level rise and recharge used result of section V.4.1. Groundwater abstraction used the same with year 2013. Future groundwater flow model run with monthly steps for future periods as near future (NF) period (2015-2039) far future (FF) period (2075-2099).

a. Flow budget

Results of the model were compared with flow budget in 2012 to see the change of flow budget components in future as well as the change in historical period, as Table 32. The result shown that when groundwater exploitation is nearly the same as present then groundwater flow from boundaries increase 16% in near future periods 18% in far future period. Groundwater discharge to boundaries decrease around 14%, 15% in periods of near future and far future, respectively. At the same time, recharge from surface also decreases 21% and 6% in near future period and far future period. However, recharge from river (leakage) and discharge to river increases in near future and more increases in far future period.

Table 32: Change of water budget components in case of no sea level rise when compared with parameters in 2012

Components	Past		2012		NF %		FF %	
	In	Out	In	Out	In	Out	In	Out
CONSTANT HEAD BOUNDARY	-9%	-1%	-	-	13%	-10%	15%	-11%
GENERAL HEAD BOUNDARY	29%	38%	-	-	3%	-4%	3%	-4%
RECHARGE	-5%		-	-	-21%		-6%	
RIVER LEAKAGE	-63%	70%	-	-	14%	2%	15%	5%

Table 32: Change of water budget components in case of no sea level rise when compared with parameters in 2012 (continue)

Components	Past		2012		NF %		FF %	
	In	Out	In	Out	In	Out	In	Out
STORAGE IN/OUT	-29%	14%	-	-	-63%	-31%	-72%	-11%
Total Source/Sink	-9%	-9%	-	-	2%	2%	3%	3%
WELLS		-60%	-	-		7%		7%

b. Groundwater level

Assumed that if no sea level rise, groundwater abstraction change 7% in comparing with 2012 and recharge change due to climate change then average groundwater level will decline in future. Average groundwater level will decline 2 m in near future period and 2.09 m in far future period when compared with groundwater level in 2012. The highest decline of groundwater level in aquifer 5 with 3.06 m and 3.23 m in near future and far future respectively. The lowest decline in aquifer 1 with 0.7 m in near future and 0.64 m in far future. Table 33 show a slightly increase of groundwater level in far future period in compared with near future period in aquifer 1.

Table 33: Average groundwater level in each aquifers during past period (1995-2007), 2012, near future period and far future in case of no sea level rise

Aquifer	Average water level (m)				Difference value (m)			
	Past	2012	NF	FF	Past	2012	NF	FF
Aquifer 1	4.42	3.42	2.72	2.78	1.01	0.00	-0.70	-0.64
Aquifer 2	-3.10	-9.11	-10.03	-10.09	6.01	0.00	-0.92	-0.98
Aquifer 3	-4.48	-8.30	-11.88	-11.99	3.82	0.00	-3.58	-3.69
Aquifer 4	-4.56	-13.29	-15.04	-15.21	8.73	0.00	-1.74	-1.92
Aquifer 5	0.16	-4.12	-7.18	-7.35	4.28	0.00	-3.06	-3.23
Average	-1.51	-6.28	-8.28	-8.37	4.77	0.00	-2.00	-2.09

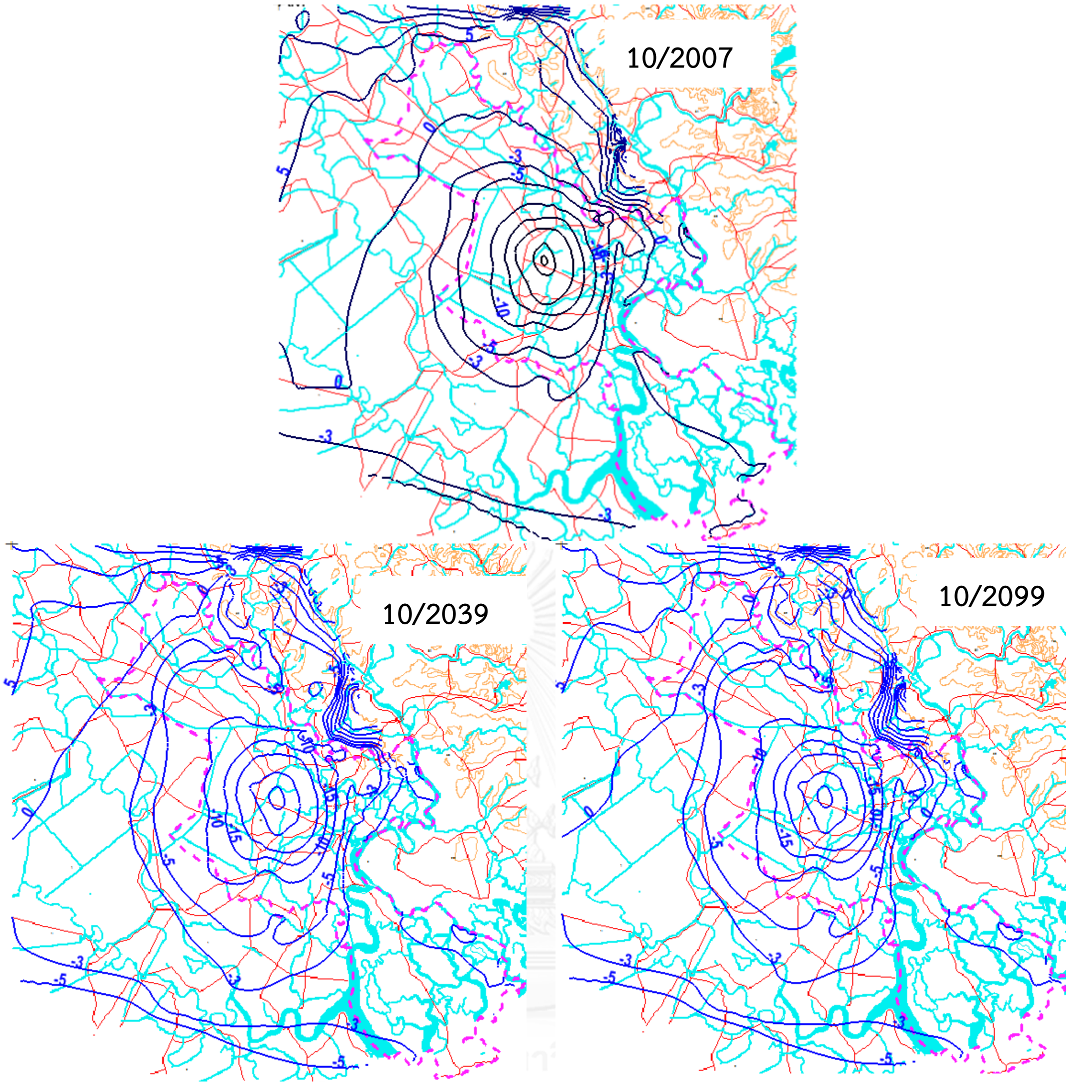


Figure 80: Future Groundwater level contour map in case of no sea level rise (aquifer 2)

V.4.4.2 With sea level rise

Simulating future groundwater resources in the area under climate change condition and sea level rise was based on groundwater recharge calculation in section V.4.1, water level under climate change conditions and sea level rise in section V.4.2. Groundwater abstraction was assumed no change and steps and time of model was the same with previous section.

a. Flow budget

In case of sea level rise, future groundwater flow budget in comparison with groundwater budget in 2012 was described in Table 34. In this case when climate change and sea level rise, thus, average groundwater flow come from boundaries increase 13% in near future, 9% in far future period. Groundwater discharge to boundaries decrease 13% to 10% in near future and far future periods. Meanwhile, river recharge increases 16% in near future and 22% in far future period.

However, water flow into groundwater storage (storage out) decreases amount of 30% and 9% in near future period and far future period, respectively.

Table 34: Change of water budget components in case of sea level rise

Components	Past		2012		NF %		FF %	
	In	Out	In	Out	In	Out	In	Out
CONSTANT HEAD BOUNDARY	-9%	-1%	-	-	10%	-10%	9%	-8%
GENERAL HEAD BOUNDARY	29%	38%	-	-	3%	-3%	0%	-2%
RECHARGE	-5%		-	-	-21%		-6%	
RIVER LEAKAGE	-63%	70%	-	-	16%	-13%	22%	-27%
STORAGE IN/OUT	-29%	14%	-	-	-64%	-30%	-72%	-9%
Total Source/Sink	-9%	-9%	-	-	2%	2%	3%	3%
WELLS In		-60%	-	-		7%		7%

b. Groundwater level

When sea water level rise and groundwater abstraction not change much, thus, groundwater level is projected to decline in near future period, but it can slightly recovered in far future period. Average decline value of groundwater level in near future is 1.97 m and far future period is 1.76m. Groundwater level will recover 0.21 m in far future period due to sea level rise.

Table 35: Groundwater level in case of sea level rise

Aquifer	Average water level (m)				Difference value (m)			
	Past	2012	NF	FF	Past	2012	NF	FF
Aquifer 1	4.42	3.42	2.72	3.02	1.01	0.00	-0.69	-0.40
Aquifer 2	-3.10	-9.11	-9.97	-9.61	6.01	0.00	-0.86	-0.50
Aquifer 3	-4.48	-8.30	-11.83	-11.56	3.82	0.00	-3.54	-3.26
Aquifer 4	-4.56	-13.29	-15.00	-14.85	8.73	0.00	-1.71	-1.56
Aquifer 5	0.16	-4.12	-7.16	-7.22	4.28	0.00	-3.05	-3.10
Average	-1.51	-6.28	-8.25	-8.04	4.77	0.00	-1.97	-1.76

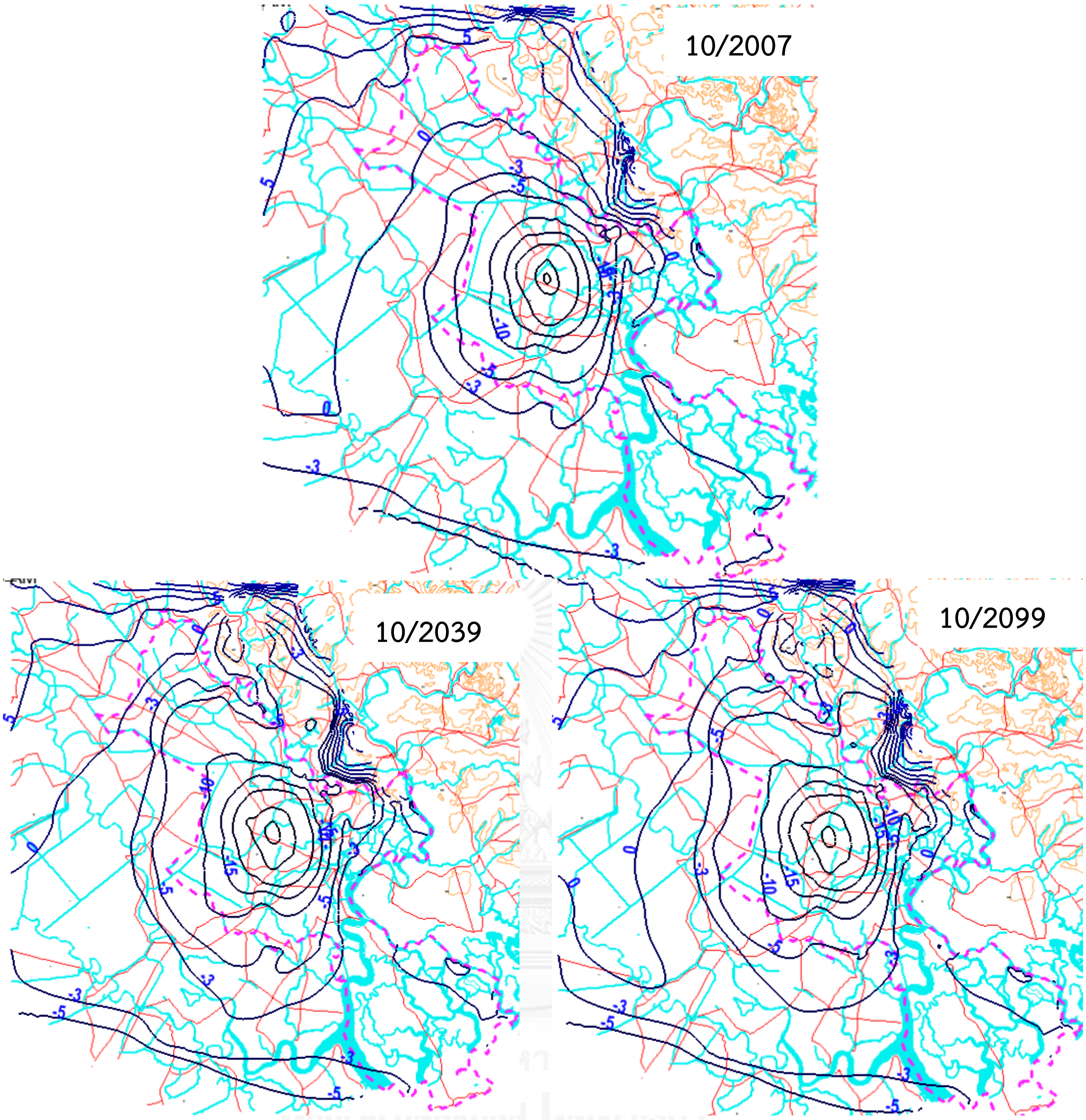


Figure 81: Groundwater level contour map of aquifer 2 in case of sea level rise

V.4.4.3 Conclusions

Average recharge rate will decrease 17% in near future period and it will recover in far future period in comparing with past period (1995-2007).

a) In case of climate change and no sea level rise.

Water from river leakage will increase 14% in near future period and 15% in far future period

Water in to groundwater reserve (storage out) will decrease 31% in near future and decrease 11% in far future period

Groundwater level will decrease 2 m and 2.09 m in near future and far future period respectively

b) In case of climate change with sea level rise

Water come from river increases 16% in near future period and 22% in far future period

Water in to groundwater reserve (storage out) decreases 30% in the near future and 9% in far future period

Groundwater level decreases 1.97 m and 1.76 m in near future and far future period, respectively.

V.5Recommendations on groundwater management

There are many ways to manager groundwater resources to cope with groundwater problems such as set up groundwater safe yield (Arlai et al., 2006), conjunctive groundwater and surface water use (Werapol Bejranonda et al., 2013), reallocation groundwater (Candela et al., 2009) etc.

In this section the study will base on groundwater model to study case of changing groundwater pumping. Results of the model will give a solution to cope with climate change impact. Groundwater pumping rate is assumed the same with plan of Ho Chi Minh City in 2015 and 2025. In neighborhood provinces will fix at the same rate with 2012. The results of model are analyzed on the change of groundwater storage, groundwater level, and possible groundwater salt intrusion.

V.5.1. Flow water budget

Result of comparison between future groundwater budget with present groundwater budget are described in the Table 36. In this case, near future groundwater exploitation was reduced amount of 41% and 56% in far future period. So when reduction groundwater abstraction, thus, groundwater come from all boundaries also decrease and groundwater discharge to river also decreases 5% in near future period and 14% in far future period

Table 36: Change of water budget components in case of GW exploitation change

	Past		2012		NF %		FF %	
Components	In	Out	In	Out	In	Out	In	Out
CONSTANT HEAD BOUNDARY	-9%	-1%	-	-	1%	-7%	-7%	-3%
GENERAL HEAD BOUNDARY	29%	38%	-	-	-2%	1%	-7%	5%
RECHARGE	-5%		-	-	-21%		-6%	

Table 37: Change of water budget components in case of GW exploitation change (continue)

Components	Past		2012		NF %		FF %	
	In	Out	In	Out	In	Out	In	Out
RIVER LEAKAGE	-63%	70%	-	-	-32%	-5%	-48%	-14%
STORAGE IN/OUT	-29%	14%	-	-	-70%	9%	-72%	-9%
Total Source/Sink	-9%	-9%	-	-	-16%	-16%	-23%	-23%
WELLS	-	-60%	-	-	-	-39%	-	-56%

V.5.2. Groundwater level

Reduction of groundwater exploitation make groundwater level increase more in future period. Average groundwater level recovers at 2.58m and 4.65m in near future and far future, respectively. The highest value is projected at aquifer 2 with 4.84 m in near future and 7.49 m in far future period.

Table 38: Change of groundwater level in case of GW exploitation change and sea level rise

Aquifer	Average water level (m)				Difference value (m)			
	Past	2012	NF	FF	Past	2012	NF	FF
Aquifer 1	4.42	3.42	3.88	4.65	1.01	0.00	0.46	1.24
Aquifer 2	-3.10	-9.11	-4.27	-1.62	6.01	0.00	4.84	7.49
Aquifer 3	-4.48	-8.30	-5.23	-2.29	3.82	0.00	3.06	6.01
Aquifer 4	-4.56	-13.29	-7.39	-4.24	8.73	0.00	5.91	9.05
Aquifer 5	0.16	-4.12	-5.50	-4.64	4.28	0.00	-1.38	-0.53
Average	-1.51	-6.28	-3.70	-1.63	4.77	0.00	2.58	4.65

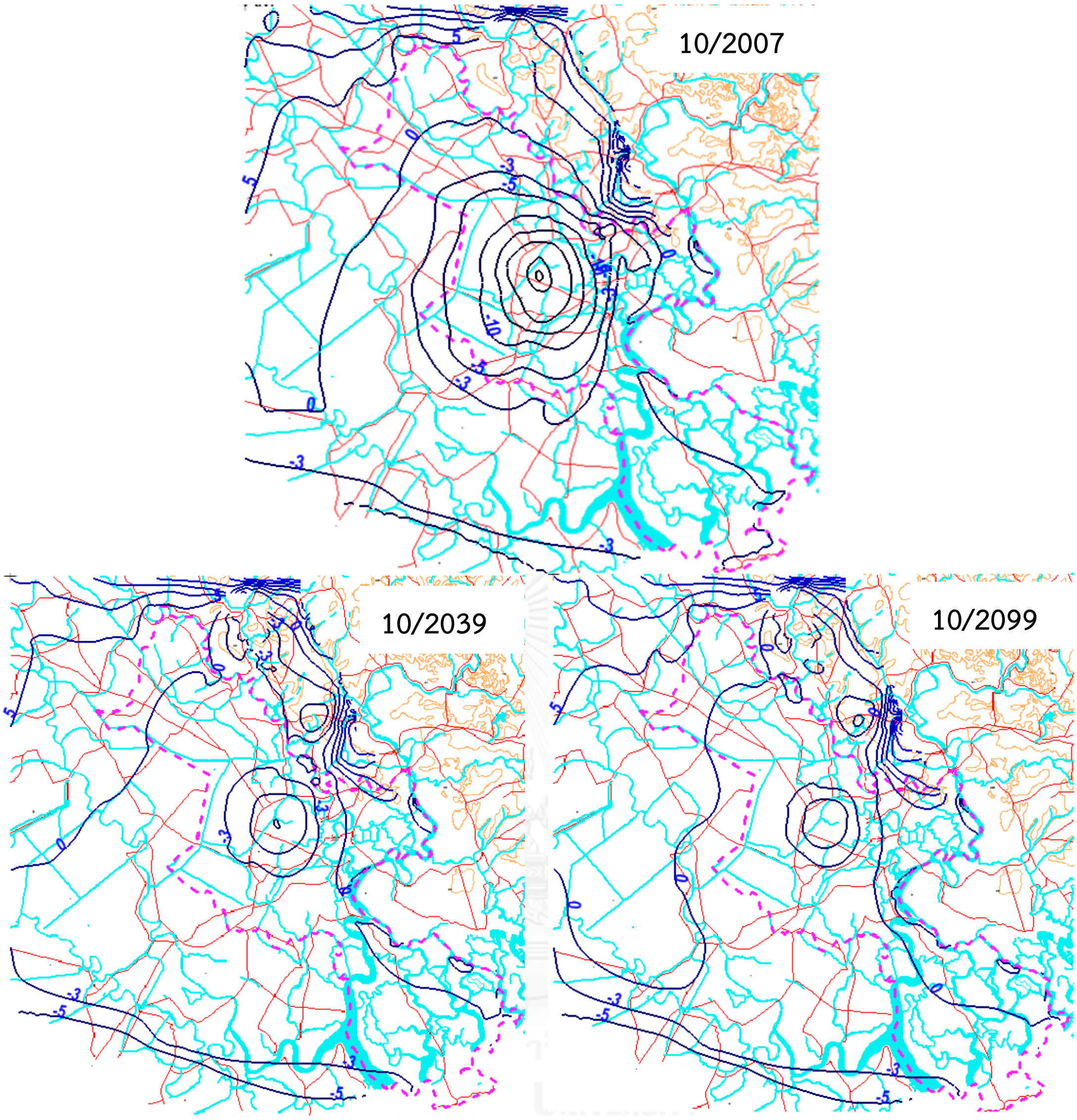


Figure 82: Groundwater level contour map of aquifer 2 in case of groundwater exploitation change

In conclusion, if groundwater pumping reduces 41% in near future and 56% in far future then future groundwater storage out will increase 9% in near future period and decrease 9% in far future period, but river water leakage will decrease 32% in near future and 48% in far future period. As a result, groundwater level will increase 2.58 m in near future period and 4.56 m in far future period.

V.5.3. Salt water intrusion

Based on hydrogeology map and saline boundaries (1 mg/l) of aquifers can divide aquifers into 2 part as fresh water zone and salt water zone

In order to assess possible salt water intrusion based on assess flow rate from salt water zone (SA) to fresh water zone (FA)

V.5.3.1 No sea level rise

In case of no sea level rise, results of future groundwater model show that total salt water flow in to fresh water zone will increase 7% in near future and increase 8% in far future, details show in Table 39.

Table 39: Salt water flow rate from salt water zone to fresh water zone (in case of no sea water level rise)

Period	Salt water flow rate (m^3/day)	Difference value (%)	Groundwater Pumping rate (m^3/day)
Past	345,059.74	-57%	398,088.16
2012	806,103.81	-	1,006,783.57
NF	864,392.58	7%	1,075,347.43
FF	869,659.77	8%	1,075,347.43

V.5.3.2 With sea level rise

In case of sea level rise, results of future groundwater model show that total salt water flow in to fresh water zone will increase 7% in near future and increase 8% in far future as details shown in Table 40.

Table 40: Salt water flow rate from salt water zone to fresh water zone (in case of with sea water level rise)

Period	Salt water flow rate (m^3/day)	Difference value (%)	Groundwater Pumping rate (m^3/day)
Past	345,059.12	-57%	398,088.16
2012	806,103.81	-	1,006,783.57
NF	864,506.33	7%	1,075,347.43
FF	870,386.88	8%	1,075,347.43

V.5.3.3. Change of groundwater pumping

If groundwater pumping rate change to 596,121 cubic meter per day in near future and 441,008 cubic meter per day in far future period then salt water flow rate from salt water area will reduce 30% in near future and reduce 42% in far future in compared with salt water flow rate in 2012, as details in Table 41.

Table 41: Salt water flow rate from salt water zone to fresh water zone (in case of change groundwater pumping)

Period	Salt water flow rate (m^3/day)	Difference salt water flow rate (%)	Groundwater Pumping rate (m^3/day)
Past	344,919.66	-58%	398,088.16
2012	830,900.02	-	1,006,783.57
NF	583,479.01	-30%	596,121.83
FF	479,405.36	-42%	441,008.76

In conclusion, climate change and sea level rise will increase 7% salt water flow rate from salt water zone to fresh water zone in near future period and increase 8% in far future period. However, when groundwater pumping rate is reduced, then salt water flow rate from salt water area decrease 30% in near future and reduce 42% in far future in compared with salt water flow rate in 2012.

V.5.4. Preliminary conclusions

Groundwater overexploitation is main cause of groundwater level decrease in the past as well as it is also main cause of groundwater salt intrusion.

In the future under climate change impacts, groundwater level will decrease 1.96m in the near future period and decrease 1.76m in the far future period as well as salt water flow rate from salt water area to fresh water area also increase 7% in the near future period and 8% in the far future.

Control groundwater pumping rate is a good solution for groundwater problems in the area. Actually, when groundwater pumping rate is reduced 41% in near future and 56% in far future then future groundwater storage out will increase 9% in near future period and decrease 9% in far future period, but river water leakage will decrease 32% in near future and 48% in far future period.

As a result, groundwater level will increase 2.58 m in near future period and 4.56 m in far future period. At the same time, when groundwater pumping rate is reduced, then it also make to decrease 30% salt water flow rate from salt water area in near future and reduce 42% in far future in compared with salt water flow rate in 2012.

However, controlling groundwater pumping rate as plan of Ho Chi Minh City still make salt water intrusion. Therefore, reallocation of groundwater exploitation wells should be studied for further study.

CHAPTER VI

CONCLUSIONS AND RECOMENDATIONS

VI.1 Conclusions

GCM model named MRI AGCM3.2s provided a good match with observation rainfall in Ho Chi Minh City area. However, it still exist some difference as more rainfall in dry season and less in rainy season. Gamma-gamma transformation method helped to improve result of GCM model. Result of Bias correction indicated good corresponding with observation data.

Result of projected future climate show that annual precipitation will increase 5% in near future period and increased 13% in far future. Also, temperature gradually increase in the future and increase about 2.4°C at the far future period. Annual evapotranspiration calculated by using temperature, will increase 16% in near future period and 32% in far future period compared with evapotranspiration in the past 1982-2007.

Groundwater model was developed based historical data and it is the first groundwater model in the area calibrated with long time data for the area. It is conducted by 2 steps, i.e., calibration step used data from 1995-2007 and verification step from 2008-2012. Result of these step show that simulated groundwater model was appropriated with observation data in both spatial and temporal.

By using recharge rate from effective rainfall in linear function improved model results when compared with result of model used recharge obtained as 10% of rainfall. Using recharge function can simulate the impact of climate change on groundwater clearly.

Results of groundwater model during 1995-2007 shown that recharge provided 0-30% for flow budget in the area. Meanwhile, river also provide 20%-40% to water budget and this amount of river leaky depend mainly on groundwater abstraction. At the same time, thus, changing groundwater storage during this time was negative value. It seem to be main cause of groundwater level decline.

Climate change will make groundwater recharge rate reduce 17% in near future and recovered in far future period in compared with past period

River leakage in will increase in future and storage out will decrease in future.

Groundwater pumping and climate change make groundwater level decrease 2.0 m in near future period and decrease 2.09 m in far future period compared with present

If pumping reduce rate at the of 41% in near future period and 56% in far future period as in the water supply plan, then groundwater level will increase 2.58 m and 4.65m in near future and far future respectively.

Groundwater pumping is main cause to lead groundwater level decrease and it also increase possibility of groundwater salinization

Groundwater pumping rate control is a good solution for groundwater level in the area.

VI.2 Recommendations

Estimate groundwater recharge is based on empirical formula which may have uncertainties due to complexion of groundwater and theological estimation. It should also be confirmed with site investigation in the future.

Salt water intrusion is the most important issue in the area. And climate change will make the problem more seriously. Therefore, the area need to have more study to solve problem on groundwater salt intrusion under climate change condition.

Each GCM data will have different results. Hence, further study should use more GCMs data to see impact of uncertainty of GCMs to estimate recharge.

A couple model should be applied to improve assessment impact of climate change on groundwater resources

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APPENDIX

APPENDIX 1

Bias Correction Results

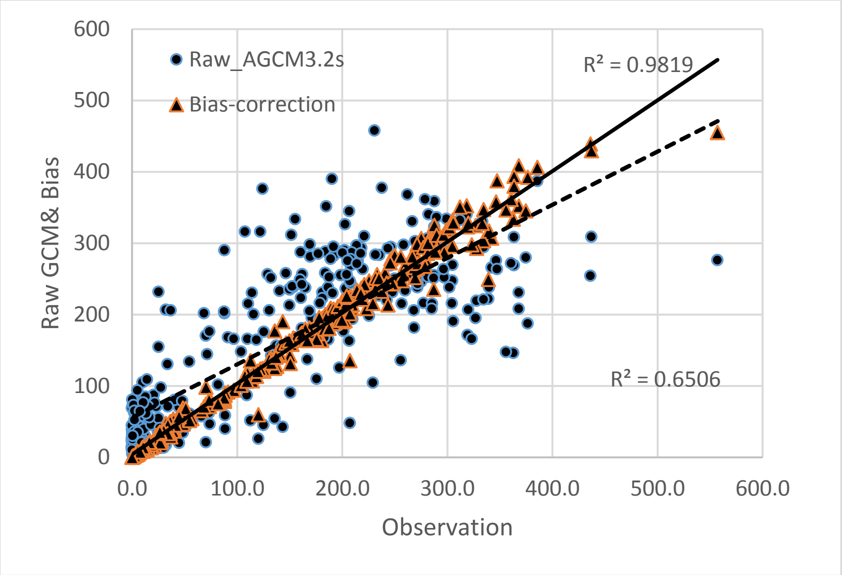


Figure 83: Correlation between observation rainfalls with bias corrected results and raw MRI at GRID 54

Table 42: Monthly rainfall data in present period at Grid 54

Monthly rainfall data in present period at Grid 54 (mm)			
Time	Observation	Bias-corrected	Raw_AGCM3.2s
1/1/1980	33.8	39.5	27.3
2/1/1980	5.7	4.2	12.8
3/1/1980	0.1	0.7	30.3
4/1/1980	3.5	4.9	52
5/1/1980	268.2	262.0	205.8
6/1/1980	275.0	306.4	246.2
7/1/1980	268.5	288.0	273.7
8/1/1980	271.2	298.7	249.4
9/1/1980	218.2	236.9	293.3

Table 42: Monthly rainfall data in present period at Grid 54 (continue)

Monthly rainfall data in present period at Grid 54 (mm)			
Time	Observation	Bias-corrected	Raw_AGCM3.2s
10/1/1980	267.9	270.0	253.6
11/1/1980	180.4	163.8	161.1
12/1/1980	39.4	38.4	51
1/1/1981	7.0	6.6	32.4
2/1/1981	0.1	0.5	24.4
3/1/1981	2.7	3.2	37.4
4/1/1981	4.8	6.2	69.2
5/1/1981	202.5	212.5	201.4
6/1/1981	222.9	208.6	227.9
7/1/1981	436.1	439.0	254.1
8/1/1981	206.7	224.1	344.5
9/1/1981	124.2	124.5	376
10/1/1981	161.9	164.6	256.2
11/1/1981	149.9	142.6	234.76
12/1/1981	27.6	24.0	30.1
1/1/1982	0.0	0.0	38.8
2/1/1982	1.1	1.0	15.3
3/1/1982	10.3	10.7	29
4/1/1982	23.6	29.8	47.1
5/1/1982	110.5	109.8	215
6/1/1982	282.2	303.8	340.3
7/1/1982	295.1	290.6	291.1

Table 42: Monthly rainfall data in present period at Grid 54 (continue)

Monthly rainfall data in present period at Grid 54 (mm)			
Time	Observation	Bias-corrected	Raw_AGCM3.2s
8/1/1982	234.4	251.7	242.5
9/1/1982	342.2	307.1	265.6
10/1/1982	198.3	198.9	255.1
11/1/1982	150.6	131.4	90.7
12/1/1982	1.7	2.1	46.5
1/1/1983	0.5	1.2	32.9
2/1/1983	0.0	0.2	18.9
3/1/1983	0.0	0.0	44.9
4/1/1983	0.9	1.9	74.1
5/1/1983	70.1	74.3	170.2
6/1/1983	203.3	219.8	236.2
7/1/1983	277.3	294.1	216.1
8/1/1983	304.3	297.6	215.7
9/1/1983	180.9	194.9	230.6
10/1/1983	169.4	168.2	281.2
11/1/1983	125.3	120.4	175.5
12/1/1983	9.8	9.6	104.7
1/1/1984	5.8	6.3	44.4
2/1/1984	0.0	0.1	26.5
3/1/1984	0.9	1.7	36.3
4/1/1984	44.5	59.4	70.5
5/1/1984	186.7	200.5	164.7

Table 42: Monthly rainfall data in present period at Grid 54 (continue)

Monthly rainfall data in present period at Grid 54 (mm)			
Time	Observation	Bias-corrected	Raw_AGCM3.2s
6/1/1984	186.6	203.0	237.9
7/1/1984	287.4	294.3	254.9
8/1/1984	140.1	144.8	232.9
9/1/1984	201.9	216.7	289.9
10/1/1984	304.8	295.8	247.2
11/1/1984	114.3	106.9	115.1
12/1/1984	48.7	46.7	51.7
1/1/1985	0.1	0.3	35.3
2/1/1985	14.1	10.1	11.6
3/1/1985	1.7	2.2	21.4
4/1/1985	135.5	177.0	54
5/1/1985	152.2	158.0	161.7
6/1/1985	153.2	166.9	238.6
7/1/1985	271.4	265.0	237.9
8/1/1985	149.8	160.4	235.3
9/1/1985	287.7	312.0	358.7
10/1/1985	266.5	259.6	251.7
11/1/1985	137.6	127.2	137.5
12/1/1985	65.8	65.2	57.4
1/1/1986	10.2	8.6	24.2
2/1/1986	3.9	3.1	24.9
3/1/1986	0.2	0.6	32.2

Table 42: Monthly rainfall data in present period at Grid 54 (continue)

Monthly rainfall data in present period at Grid 54 (mm)			
Time	Observation	Bias-corrected	Raw_AGCM3.2s
4/1/1986	9.4	12.9	68.7
5/1/1986	256.5	247.3	215.2
6/1/1986	334.5	303.3	293.9
7/1/1986	169.2	169.6	298.1
8/1/1986	240.7	258.2	236.3
9/1/1986	287.7	324.9	322.9
10/1/1986	184.2	189.1	288.4
11/1/1986	175.5	173.0	174.6
12/1/1986	25.2	24.7	154.6
1/1/1987	0.0	0.1	69
2/1/1987	0.0	0.4	14.1
3/1/1987	1.1	1.6	36.1
4/1/1987	3.7	5.4	54.4
5/1/1987	71.5	74.8	144.3
6/1/1987	339.7	316.7	238
7/1/1987	243.8	242.9	242.2
8/1/1987	207.8	226.0	243.6
9/1/1987	208.1	224.5	269.1
10/1/1987	214.4	223.0	227
11/1/1987	135.5	124.7	136.4
12/1/1987	20.6	18.7	87.3
1/1/1988	9.3	10.0	73.7

Table 42: Monthly rainfall data in present period at Grid 54 (continue)

Monthly rainfall data in present period at Grid 54 (mm)			
Time	Observation	Bias-corrected	Raw_AGCM3.2s
2/1/1988	21.3	15.9	20.2
3/1/1988	0.4	1.1	36.6
4/1/1988	39.3	53.8	40.1
5/1/1988	137.1	145.1	156.2
6/1/1988	128.9	132.8	256.5
7/1/1988	193.1	191.5	289.6
8/1/1988	181.1	194.8	222.6
9/1/1988	368.1	408.6	230.8
10/1/1988	262.2	269.3	368.2
11/1/1988	201.1	189.9	176.6
12/1/1988	16.3	14.5	52.9
1/1/1989	12.8	12.4	28.5
2/1/1989	1.7	1.5	14.1
3/1/1989	48.4	69.1	34.6
4/1/1989	73.9	82.2	46.6
5/1/1989	191.6	187.9	282
6/1/1989	225.5	247.0	198.3
7/1/1989	297.0	287.2	251.9
8/1/1989	367.9	351.9	208
9/1/1989	246.3	277.8	294.4
10/1/1989	374.7	345.1	279.5
11/1/1989	54.5	53.8	134.1

Table 42: Monthly rainfall data in present period at Grid 54 (continue)

Monthly rainfall data in present period at Grid 54 (mm)			
Time	Observation	Bias-corrected	Raw_AGCM3.2s
12/1/1989	0.2	0.3	80.8
1/1/1990	0.0	0.2	21.9
2/1/1990	0.0	0.0	12.3
3/1/1990	0.5	1.1	20.3
4/1/1990	10.3	14.3	56.8
5/1/1990	91.1	91.4	168.1
6/1/1990	213.7	233.3	296.6
7/1/1990	235.1	243.1	283.1
8/1/1990	305.0	332.0	269.5
9/1/1990	385.6	406.0	386.8
10/1/1990	260.0	268.8	233.3
11/1/1990	87.8	78.3	201.5
12/1/1990	1.3	1.5	73.2
1/1/1991	12.0	12.7	29.8
2/1/1991	0.4	0.7	12.7
3/1/1991	4.8	5.5	22.5
4/1/1991	39.5	51.3	52.3
5/1/1991	109.8	117.7	165.6
6/1/1991	189.0	209.1	277.9
7/1/1991	299.0	318.7	333.9
8/1/1991	177.0	190.7	285.2
9/1/1991	221.0	242.0	309.9

Table 42: Monthly rainfall data in present period at Grid 54 (continue)

Monthly rainfall data in present period at Grid 54 (mm)			
Time	Observation	Bias-corrected	Raw_AGCM3.2s
10/1/1991	230.5	234.7	457.6
11/1/1991	25.0	21.9	231.8
12/1/1991	10.6	9.4	82.4
1/1/1992	9.5	9.1	58
2/1/1992	0.0	0.2	13.1
3/1/1992	0.3	0.8	23.9
4/1/1992	22.7	30.7	45
5/1/1992	161.5	174.4	180.5
6/1/1992	362.7	333.7	146.1
7/1/1992	214.8	228.8	274.8
8/1/1992	339.0	249.2	221.7
9/1/1992	178.6	190.6	216.2
10/1/1992	190.2	198.4	389.8
11/1/1992	27.2	22.5	97.7
12/1/1992	12.6	12.4	84.5
1/1/1993	2.5	2.4	5.6
2/1/1993	0.1	0.3	5
3/1/1993	120.1	59.5	25.9
4/1/1993	16.2	21.7	50.9
5/1/1993	73.4	71.1	176
6/1/1993	346.3	357.8	275.8
7/1/1993	279.7	275.7	260.2

Table 42: Monthly rainfall data in present period at Grid 54 (continue)

Monthly rainfall data in present period at Grid 54 (mm)			
Time	Observation	Bias-corrected	Raw_AGCM3.2s
8/1/1993	233.0	255.9	238.7
9/1/1993	318.2	352.2	340.2
10/1/1993	285.4	303.6	215.3
11/1/1993	96.7	94.2	165.8
12/1/1993	23.1	21.7	70.6
1/1/1994	10.8	9.0	24
2/1/1994	1.2	1.1	10.8
3/1/1994	32.1	47.3	16.8
4/1/1994	31.3	37.9	45.1
5/1/1994	141.9	155.9	156
6/1/1994	347.4	387.1	263.5
7/1/1994	151.6	158.7	311.5
8/1/1994	189.8	203.2	189.8
9/1/1994	311.9	350.6	332.1
10/1/1994	281.2	285.5	306.6
11/1/1994	32.1	28.7	206.7
12/1/1994	40.2	37.5	80
1/1/1995	14.1	13.6	109
2/1/1995	0.0	0.2	22.1
3/1/1995	11.2	15.0	39.3
4/1/1995	21.5	27.4	76
5/1/1995	192.1	198.3	186.7

Table 42: Monthly rainfall data in present period at Grid 54 (continue)

Monthly rainfall data in present period at Grid 54 (mm)			
Time	Observation	Bias-corrected	Raw_AGCM3.2s
6/1/1995	183.7	199.7	258
7/1/1995	285.2	302.6	208.1
8/1/1995	326.8	324.5	194.9
9/1/1995	231.6	251.1	246.6
10/1/1995	209.0	208.5	286.7
11/1/1995	87.9	80.5	289.82
12/1/1995	56.9	54.0	54.5
1/1/1996	10.9	9.4	20.9
2/1/1996	0.2	0.9	14.2
3/1/1996	1.9	2.2	62.8
4/1/1996	47.7	64.0	78.8
5/1/1996	247.8	243.3	231.1
6/1/1996	152.3	163.5	239.5
7/1/1996	218.1	228.9	219.2
8/1/1996	160.6	170.5	223
9/1/1996	191.8	207.4	294.9
10/1/1996	269.2	251.7	302.4
11/1/1996	183.0	179.6	167.7
12/1/1996	38.8	36.5	46.5
1/1/1997	1.1	0.9	43.3
2/1/1997	18.1	13.5	11.8
3/1/1997	0.9	1.4	32.4

Table 42: Monthly rainfall data in present period at Grid 54 (continue)

Monthly rainfall data in present period at Grid 54 (mm)			
Time	Observation	Bias-corrected	Raw_AGCM3.2s
4/1/1997	50.9	68.7	43
5/1/1997	206.6	204.1	162.9
6/1/1997	160.4	172.7	287.1
7/1/1997	437.1	429.4	308.6
8/1/1997	159.8	170.4	248.7
9/1/1997	249.7	282.5	249.9
10/1/1997	202.6	191.5	326.26
11/1/1997	103.6	100.7	147.7
12/1/1997	15.2	14.0	71.3
1/1/1998	4.4	3.6	17.3
2/1/1998	0.0	0.1	15.6
3/1/1998	0.3	0.8	20.4
4/1/1998	36.1	49.7	39.5
5/1/1998	170.8	175.4	195.4
6/1/1998	363.4	393.6	269
7/1/1998	231.7	236.1	283.9
8/1/1998	281.6	299.8	252.9
9/1/1998	363.4	379.8	308.5
10/1/1998	207.9	212.0	277.4
11/1/1998	319.2	322.7	171.1
12/1/1998	125.1	123.3	45.4
1/1/1999	88.4	87.1	39.7

Table 42: Monthly rainfall data in present period at Grid 54 (continue)

Monthly rainfall data in present period at Grid 54 (mm)			
Time	Observation	Bias-corrected	Raw_AGCM3.2s
2/1/1999	27.8	33.3	18.9
3/1/1999	41.4	45.3	31.3
4/1/1999	143.3	190.1	42.7
5/1/1999	169.0	181.2	204.8
6/1/1999	164.8	179.7	237.4
7/1/1999	235.0	250.6	226.2
8/1/1999	196.0	211.7	184.1
9/1/1999	146.4	159.8	257.9
10/1/1999	219.4	221.5	263.7
11/1/1999	268.4	265.6	181.6
12/1/1999	54.5	51.3	60.8
1/1/2000	24.6	23.1	36.5
2/1/2000	26.8	20.5	12.8
3/1/2000	44.7	57.1	20.2
4/1/2000	207.2	135.5	48.1
5/1/2000	320.0	328.1	206.6
6/1/2000	271.9	271.7	242.9
7/1/2000	360.8	361.1	271.5
8/1/2000	327.8	292.6	219.3
9/1/2000	155.0	166.1	333.4
10/1/2000	376.5	392.0	187.5
11/1/2000	175.5	165.5	109.9

Table 42: Monthly rainfall data in present period at Grid 54 (continue)

Monthly rainfall data in present period at Grid 54 (mm)			
Time	Observation	Bias-corrected	Raw_AGCM3.2s
12/1/2000	88.4	90.0	58.6
1/1/2001	36.0	33.2	28.8
2/1/2001	3.7	3.4	15.8
3/1/2001	70.3	97.9	20.9
4/1/2001	33.9	45.3	71.2
5/1/2001	229.0	215.5	104.3
6/1/2001	278.8	267.6	361.3
7/1/2001	122.1	123.5	316
8/1/2001	289.8	311.2	336.1
9/1/2001	200.2	219.6	286.6
10/1/2001	190.8	193.3	229.7
11/1/2001	115.4	117.9	200.5
12/1/2001	18.1	17.8	45.7
1/1/2002	0.0	0.0	44.1
2/1/2002	0.0	0.0	12.4
3/1/2002	0.4	0.7	31.9
4/1/2002	25.3	33.6	54.7
5/1/2002	68.3	70.8	201.6
6/1/2002	288.6	287.6	297.1
7/1/2002	107.5	114.0	315.8
8/1/2002	113.9	113.0	230.5
9/1/2002	287.0	235.4	251
10/1/2002	258.4	255.9	297.4
11/1/2002	118.3	113.2	164.5

Table 42: Monthly rainfall data in present period at Grid 54 (continue)

Monthly rainfall data in present period at Grid 54 (mm)			
Time	Observation	Bias-corrected	Raw_AGCM3.2s
12/1/2002	73.1	80.3	62.2
1/1/2003	1.7	1.2	29
2/1/2003	0.0	0.1	23.3
3/1/2003	3.5	4.4	35.7
4/1/2003	5.2	6.5	93.4
5/1/2003	209.7	213.9	193.5
6/1/2003	207.2	201.3	246.8
7/1/2003	203.7	216.4	215.7
8/1/2003	149.8	163.3	213
9/1/2003	237.8	232.6	377.6
10/1/2003	266.6	281.1	330.2
11/1/2003	87.6	83.4	203.9
12/1/2003	2.2	2.6	52.5
1/1/2004	2.3	2.1	35.7
2/1/2004	0.0	0.0	13.8
3/1/2004	0.2	0.6	17.3
4/1/2004	16.5	20.9	55.8
5/1/2004	255.5	280.5	135.7
6/1/2004	205.0	224.0	275
7/1/2004	333.4	327.5	330.4
8/1/2004	161.5	173.1	242
9/1/2004	213.9	234.1	271.2

Table 42: Monthly rainfall data in present period at Grid 54 (continue)

Monthly rainfall data in present period at Grid 54 (mm)			
Time	Observation	Bias-corrected	Raw_AGCM3.2s
10/1/2004	242.2	244.2	219.9
11/1/2004	81.7	75.1	101.9
12/1/2004	13.3	11.5	61.5
1/1/2005	0.0	0.0	26.2
2/1/2005	0.0	0.0	14.6
3/1/2005	0.4	0.9	25.6
4/1/2005	5.5	8.3	35.1
5/1/2005	166.9	163.4	137.3
6/1/2005	243.3	213.3	292.5
7/1/2005	184.8	195.2	351.2
8/1/2005	131.9	138.7	251.5
9/1/2005	204.1	225.8	255.9
10/1/2005	296.5	311.5	263.4
11/1/2005	197.2	191.9	125.6
12/1/2005	109.3	106.7	87.1
1/1/2006	0.4	0.8	29.8
2/1/2006	30.1	37.3	13.2
3/1/2006	9.1	10.5	20.5
4/1/2006	112.6	135.2	51.6
5/1/2006	199.5	192.2	197.9
6/1/2006	130.4	137.3	205.9
7/1/2006	187.5	180.8	252.5

Table 42: Monthly rainfall data in present period at Grid 54 (continue)

Monthly rainfall data in present period at Grid 54 (mm)			
Time	Observation	Bias-corrected	Raw_AGCM3.2s
8/1/2006	301.8	321.7	237.8
9/1/2006	245.6	272.6	268.5
10/1/2006	217.6	228.7	285.3
11/1/2006	36.6	28.7	205.7
12/1/2006	33.8	33.1	130.3
1/1/2007	2.3	2.4	64.9
2/1/2007	0.0	0.1	10.2
3/1/2007	26.4	35.4	40.7
4/1/2007	10.6	14.0	76.6
5/1/2007	323.2	297.5	165.6
6/1/2007	177.9	195.8	193.3
7/1/2007	355.9	346.3	147.3
8/1/2007	305.6	328.5	190.4
9/1/2007	557.2	454.9	275.9
10/1/2007	334.5	346.7	220.9
11/1/2007	132.2	132.3	142.5
12/1/2007	7.6	7.4	64.3

APPENDIX 2

Groundwater model calibration and verification

2.1. Aquifer depth

In the study, groundwater model layers are created by using boreholes data, these data will separate into layers as details in the Table 43.

Table 43: Statistic parameters of aquifer depth before and after simulation

Aquifers	Raw data (304 bore holes) (m)				Results of model (m)			
	Max	Min	Average	SD	Max	Min	Average	SD
Top	75	0.4	5.3	9.1	100.2	-2.1	8.2	15.4
Aquitad 1	75	-74.1	-15.2	21.4	100.4	-61.6	-10.3	26.6
Aquifer 1	75	-89.5	-35.4	28.3	100.4	-89.4	-28.6	38
Aquitad 2	75	-119.5	-47.9	31.9	100.7	-119	-40.4	41.6
Aquifer 2	91	-144	-72.6	40.7	100.7	-143.9	-63	52.7
Aquitad 3	75	-159.5	-83.3	43.6	100.8	-159.5	-73	55.3
Aquifer 3	119	-185.5	-109.8	51.3	100.8	-186.1	-96	64.4
Aquitad 4	75	-221.1	-121.8	54.3	100.9	-209.5	-106.9	65.3
Aquifer 4	75	-252.4	-159.2	63.4	100.9	-265	-145	80.9
Aquitad 5	75	-275.2	-168.5	68.6	100.9	-278.9	-153.7	84.2
Aquifer 5	75	-487.9	-212.3	104	100.9	-487.4	-227.1	132.5

2.2. Hydraulic conductivity (K)

Initial hydraulic conductivities were collected from previous studies in the area (Chan N D 2011) based on pumping test results of more than 100 bore holes in the area. Details are shown in the Table 44.

Table 44: Statistical parameter of aquifer hydraulic conductivities

Aquifer	Aquifer 5	Aquifer 4	Aquifer 3	Aquifer 2	Aquifer 1
Number of Wells	60	119	108	98	71
Average	22.5	23.5	25.9	19.2	21.1
Max	78.7	119	108	98	71
Min	0.1809	0.0002	0.005	0.25	0.005

Hydraulic conductivity after calibration as Figure 84: Hydraulic conductivity maps

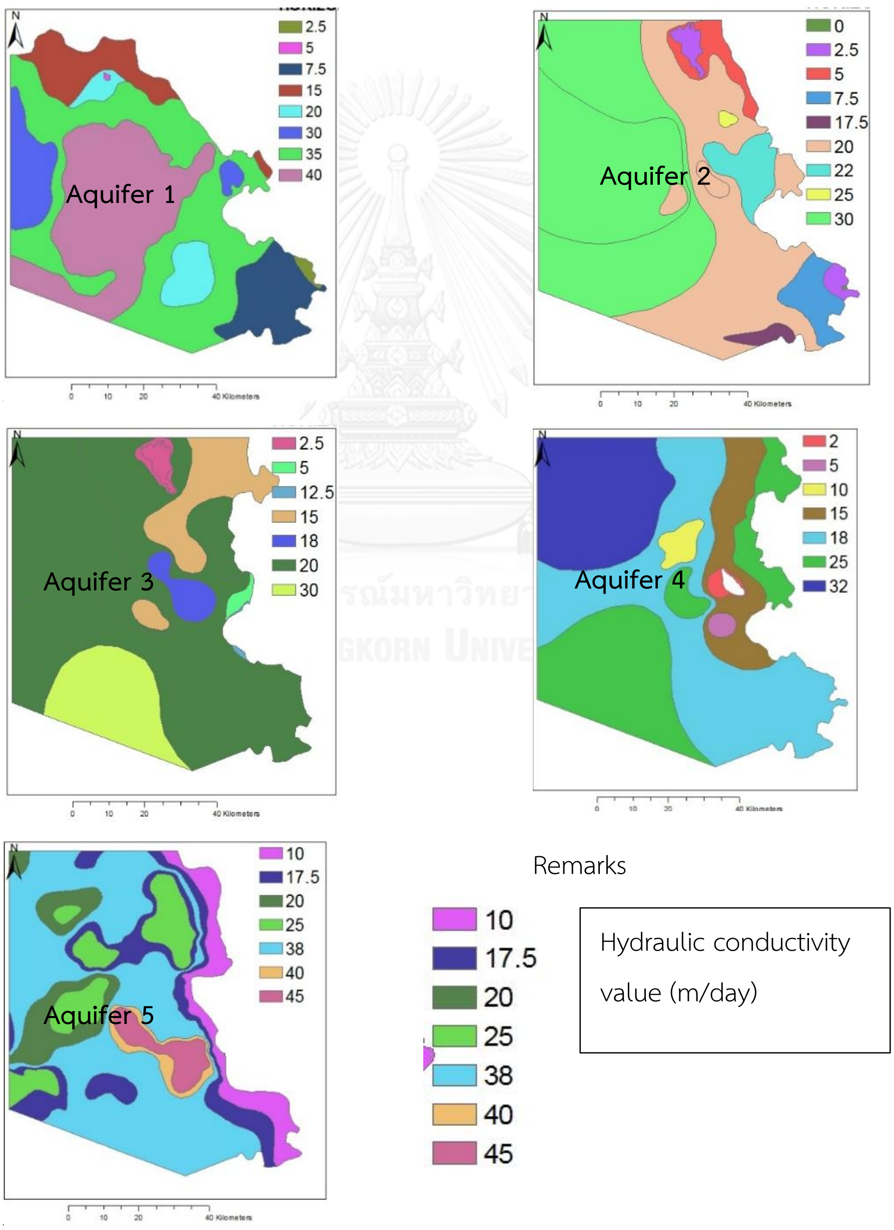


Figure 84: Hydraulic conductivity maps

APPENDIX 3

Calibration of Recharge Flux Results

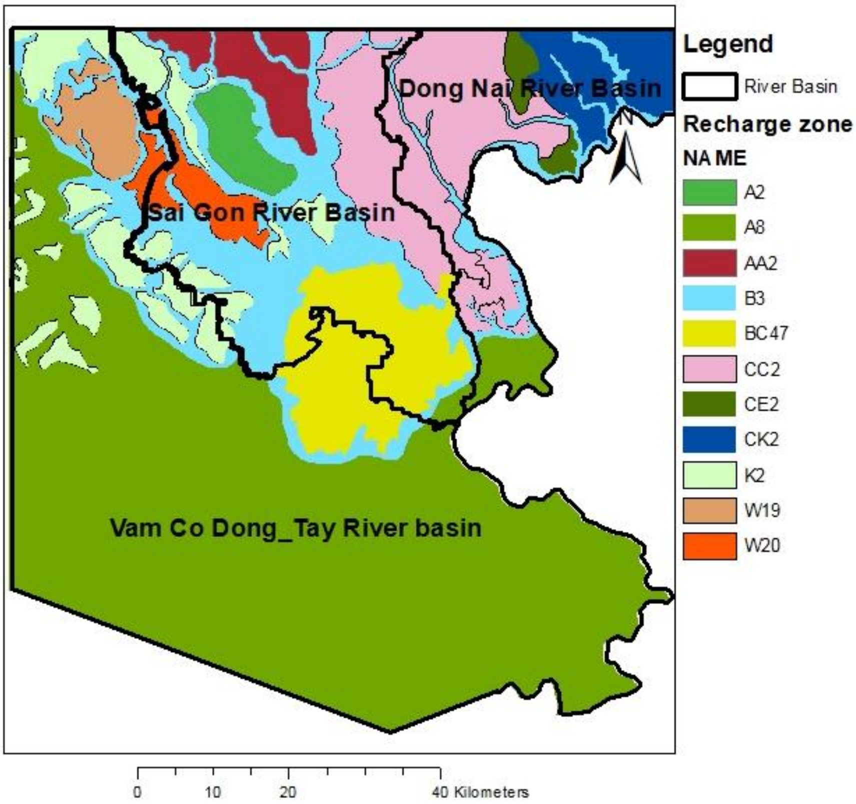


Figure 85: Recharge map input to model

Table 45: Monthly recharge flux on Sai Gon river basin

Monthly recharge flux on Sai Gon river basin (mm/day)										
Date	A2	K2	B3	A8	A18	BC47	CC2	AA2	W20	W19
1/1/1995	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2/1/1995	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3/1/1995	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4/1/1995	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5/1/1995	0.019	0.064	0.006	0.005	0.009	0.020	0.005	0.019	0.074	0.047
6/1/1995	0.026	0.071	0.008	0.007	0.013	0.029	0.008	0.027	0.106	0.064
7/1/1995	0.028	0.073	0.009	0.008	0.015	0.032	0.009	0.030	0.117	0.070

Table 45: Monthly recharge flux on Sai Gon river basin (continue)

Monthly recharge flux on Sai Gon river basin (mm/day)										
Date	A2	K2	B3	A8	A18	BC47	CC2	AA2	W20	W19
8/1/1995	0.043	0.088	0.015	0.013	0.024	0.053	0.014	0.049	0.191	0.109
9/1/1995	0.065	0.110	0.024	0.020	0.037	0.082	0.022	0.076	0.296	0.164
10/1/1995	0.038	0.083	0.013	0.011	0.021	0.046	0.012	0.042	0.165	0.095
11/1/1995	0.012	0.057	0.003	0.002	0.004	0.010	0.002	0.009	0.036	0.027
12/1/1995	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1/1/1996	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2/1/1996	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3/1/1996	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4/1/1996	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5/1/1996	0.033	0.078	0.011	0.009	0.017	0.038	0.010	0.035	0.138	0.081
6/1/1996	0.025	0.070	0.008	0.007	0.013	0.028	0.007	0.026	0.102	0.062
7/1/1996	0.032	0.077	0.010	0.009	0.017	0.037	0.010	0.034	0.134	0.079
8/1/1996	0.022	0.067	0.007	0.006	0.011	0.024	0.006	0.023	0.089	0.055
9/1/1996	0.043	0.088	0.015	0.013	0.024	0.053	0.014	0.049	0.191	0.109
10/1/1996	0.059	0.104	0.021	0.018	0.034	0.074	0.020	0.069	0.269	0.150
11/1/1996	0.032	0.077	0.011	0.009	0.017	0.038	0.010	0.035	0.137	0.080
12/1/1996	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1/1/1997	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2/1/1997	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3/1/1997	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4/1/1997	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5/1/1997	0.023	0.068	0.007	0.006	0.011	0.025	0.006	0.023	0.090	0.055

Table 45: Monthly recharge flux on Sai Gon river basin (continue)

Monthly recharge flux on Sai Gon river basin (mm/day)										
Date	A2	K2	B3	A8	A18	BC47	CC2	AA2	W20	W19
6/1/1997	0.009	0.054	0.002	0.001	0.003	0.006	0.002	0.006	0.024	0.021
7/1/1997	0.063	0.108	0.023	0.019	0.036	0.080	0.021	0.074	0.289	0.160
8/1/1997	0.024	0.069	0.008	0.006	0.012	0.027	0.007	0.025	0.098	0.059
9/1/1997	0.055	0.100	0.019	0.016	0.031	0.068	0.018	0.063	0.246	0.138
10/1/1997	0.054	0.099	0.019	0.016	0.030	0.067	0.018	0.062	0.242	0.135
11/1/1997	0.012	0.057	0.003	0.002	0.005	0.011	0.003	0.010	0.040	0.029
12/1/1997	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1/1/1998	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2/1/1998	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3/1/1998	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4/1/1998	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5/1/1998	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6/1/1998	0.048	0.093	0.017	0.014	0.027	0.058	0.016	0.054	0.211	0.119
7/1/1998	0.026	0.071	0.008	0.007	0.013	0.029	0.008	0.027	0.104	0.063
8/1/1998	0.051	0.096	0.018	0.015	0.029	0.063	0.017	0.059	0.229	0.129
9/1/1998	0.070	0.115	0.025	0.021	0.040	0.088	0.024	0.082	0.319	0.176
10/1/1998	0.039	0.084	0.013	0.011	0.021	0.046	0.012	0.043	0.167	0.096
11/1/1998	0.072	0.117	0.026	0.022	0.042	0.091	0.024	0.085	0.330	0.182
12/1/1998	0.021	0.066	0.006	0.005	0.010	0.022	0.006	0.020	0.080	0.050
1/1/1999	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2/1/1999	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3/1/1999	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 45: Monthly recharge flux on Sai Gon river basin (continue)

Monthly recharge flux on Sai Gon river basin (mm/day)										
Date	A2	K2	B3	A8	A18	BC47	CC2	AA2	W20	W19
4/1/1999	0.020	0.065	0.006	0.005	0.009	0.021	0.005	0.019	0.076	0.048
5/1/1999	0.031	0.076	0.010	0.009	0.016	0.036	0.010	0.034	0.132	0.078
6/1/1999	0.022	0.067	0.007	0.005	0.010	0.023	0.006	0.022	0.085	0.053
7/1/1999	0.038	0.083	0.013	0.011	0.020	0.045	0.012	0.042	0.164	0.094
8/1/1999	0.028	0.073	0.009	0.008	0.015	0.032	0.009	0.030	0.118	0.070
9/1/1999	0.021	0.066	0.006	0.005	0.010	0.023	0.006	0.021	0.083	0.051
10/1/1999	0.044	0.089	0.015	0.013	0.024	0.054	0.014	0.050	0.194	0.110
11/1/1999	0.043	0.088	0.015	0.012	0.023	0.052	0.014	0.048	0.187	0.107
12/1/1999	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1/1/2000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2/1/2000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3/1/2000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4/1/2000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5/1/2000	0.035	0.080	0.012	0.010	0.019	0.041	0.011	0.038	0.150	0.087
6/1/2000	0.058	0.103	0.021	0.017	0.033	0.073	0.020	0.068	0.264	0.147
7/1/2000	0.059	0.104	0.021	0.018	0.034	0.074	0.020	0.069	0.269	0.150
8/1/2000	0.059	0.104	0.021	0.018	0.033	0.073	0.020	0.068	0.265	0.148
9/1/2000	0.038	0.083	0.013	0.011	0.021	0.046	0.012	0.043	0.166	0.095
10/1/2000	0.095	0.140	0.035	0.029	0.056	0.122	0.033	0.113	0.440	0.240
11/1/2000	0.036	0.081	0.012	0.010	0.020	0.043	0.012	0.040	0.157	0.091
12/1/2000	0.008	0.053	0.001	0.001	0.002	0.005	0.001	0.005	0.019	0.018
1/1/2001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 45: Monthly recharge flux on Sai Gon river basin (continue)

Monthly recharge flux on Sai Gon river basin (mm/day)										
Date	A2	K2	B3	A8	A18	BC47	CC2	AA2	W20	W19
2/1/2001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3/1/2001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4/1/2001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5/1/2001	0.021	0.066	0.006	0.005	0.010	0.023	0.006	0.021	0.084	0.052
6/1/2001	0.055	0.100	0.020	0.016	0.031	0.069	0.018	0.064	0.249	0.139
7/1/2001	0.008	0.053	0.001	0.001	0.002	0.005	0.001	0.004	0.018	0.017
8/1/2001	0.050	0.095	0.018	0.015	0.028	0.062	0.016	0.057	0.223	0.126
9/1/2001	0.034	0.079	0.012	0.010	0.018	0.040	0.011	0.038	0.147	0.085
10/1/2001	0.044	0.089	0.015	0.013	0.024	0.053	0.014	0.049	0.192	0.109
11/1/2001	0.009	0.054	0.002	0.001	0.002	0.006	0.001	0.006	0.023	0.020
12/1/2001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1/1/2002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2/1/2002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3/1/2002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4/1/2002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5/1/2002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6/1/2002	0.049	0.094	0.017	0.014	0.027	0.060	0.016	0.056	0.219	0.123
7/1/2002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8/1/2002	0.021	0.066	0.006	0.005	0.010	0.023	0.006	0.021	0.084	0.052
9/1/2002	0.052	0.097	0.018	0.015	0.029	0.065	0.017	0.060	0.233	0.131
10/1/2002	0.049	0.094	0.017	0.014	0.027	0.060	0.016	0.056	0.218	0.123
11/1/2002	0.027	0.072	0.009	0.007	0.014	0.031	0.008	0.029	0.112	0.067

Table 45: Monthly recharge flux on Sai Gon river basin (continue)

Monthly recharge flux on Sai Gon river basin (mm/day)										
Date	A2	K2	B3	A8	A18	BC47	CC2	AA2	W20	W19
12/1/2002	0.009	0.054	0.002	0.001	0.003	0.007	0.002	0.006	0.025	0.021
1/1/2003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2/1/2003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3/1/2003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4/1/2003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5/1/2003	0.025	0.070	0.008	0.007	0.013	0.028	0.007	0.026	0.102	0.062
6/1/2003	0.021	0.066	0.006	0.005	0.010	0.023	0.006	0.021	0.083	0.052
7/1/2003	0.032	0.077	0.011	0.009	0.017	0.037	0.010	0.035	0.136	0.079
8/1/2003	0.026	0.071	0.008	0.007	0.013	0.029	0.008	0.027	0.106	0.064
9/1/2003	0.040	0.085	0.014	0.011	0.022	0.048	0.013	0.044	0.173	0.099
10/1/2003	0.058	0.103	0.021	0.017	0.033	0.073	0.019	0.067	0.262	0.146
11/1/2003	0.010	0.055	0.002	0.002	0.003	0.007	0.002	0.007	0.028	0.023
12/1/2003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1/1/2004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2/1/2004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3/1/2004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4/1/2004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5/1/2004	0.040	0.085	0.014	0.011	0.022	0.048	0.013	0.045	0.174	0.099
6/1/2004	0.039	0.084	0.013	0.011	0.021	0.046	0.012	0.043	0.168	0.097
7/1/2004	0.048	0.093	0.017	0.014	0.027	0.059	0.016	0.055	0.214	0.121
8/1/2004	0.027	0.072	0.008	0.007	0.013	0.030	0.008	0.028	0.109	0.065
9/1/2004	0.037	0.082	0.013	0.011	0.020	0.044	0.012	0.041	0.161	0.093

Table 45: Monthly recharge flux on Sai Gon river basin (continue)

Monthly recharge flux on Sai Gon river basin (mm/day)										
Date	A2	K2	B3	A8	A18	BC47	CC2	AA2	W20	W19
10/1/2004	0.036	0.081	0.012	0.010	0.019	0.042	0.011	0.039	0.153	0.089
11/1/2004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12/1/2004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1/1/2005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2/1/2005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3/1/2005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4/1/2005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5/1/2005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6/1/2005	0.023	0.068	0.007	0.006	0.011	0.025	0.007	0.024	0.092	0.057
7/1/2005	0.037	0.082	0.013	0.011	0.020	0.044	0.012	0.041	0.161	0.093
8/1/2005	0.016	0.061	0.004	0.004	0.007	0.016	0.004	0.015	0.060	0.039
9/1/2005	0.045	0.090	0.016	0.013	0.025	0.055	0.015	0.051	0.200	0.113
10/1/2005	0.053	0.098	0.019	0.016	0.030	0.066	0.018	0.061	0.237	0.133
11/1/2005	0.027	0.072	0.009	0.007	0.014	0.031	0.008	0.028	0.111	0.066
12/1/2005	0.014	0.059	0.004	0.003	0.006	0.014	0.003	0.013	0.050	0.034
1/1/2006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2/1/2006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3/1/2006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4/1/2006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5/1/2006	0.014	0.059	0.004	0.003	0.006	0.013	0.003	0.012	0.049	0.034
6/1/2006	0.018	0.063	0.005	0.004	0.008	0.019	0.005	0.017	0.069	0.044
7/1/2006	0.021	0.066	0.006	0.005	0.010	0.023	0.006	0.021	0.084	0.052

Table 45: Monthly recharge flux on Sai Gon river basin (continue)

Monthly recharge flux on Sai Gon river basin (mm/day)										
Date	A2	K2	B3	A8	A18	BC47	CC2	AA2	W20	W19
8/1/2006	0.046	0.091	0.016	0.013	0.026	0.057	0.015	0.053	0.205	0.116
9/1/2006	0.045	0.090	0.016	0.013	0.025	0.054	0.015	0.051	0.197	0.112
10/1/2006	0.036	0.081	0.012	0.010	0.020	0.043	0.011	0.040	0.157	0.091
11/1/2006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12/1/2006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1/1/2007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2/1/2007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3/1/2007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4/1/2007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5/1/2007	0.036	0.081	0.012	0.010	0.019	0.042	0.011	0.039	0.154	0.089
6/1/2007	0.024	0.069	0.007	0.006	0.012	0.027	0.007	0.025	0.097	0.059
7/1/2007	0.062	0.107	0.023	0.019	0.036	0.078	0.021	0.073	0.283	0.157
8/1/2007	0.051	0.096	0.018	0.015	0.029	0.063	0.017	0.059	0.228	0.128
9/1/2007	0.096	0.141	0.036	0.030	0.057	0.124	0.033	0.115	0.446	0.243
10/1/2007	0.050	0.095	0.018	0.015	0.028	0.061	0.016	0.057	0.221	0.125
11/1/2007	0.017	0.062	0.005	0.004	0.008	0.017	0.004	0.016	0.062	0.041
12/1/2007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

APPENDIX 4

Future River Water Level

1. Release from reservoirs

1.1 Tri An Reservoirs

1.1.1. Methodology

In order to calculate water level at downstream, then water flow data to Tri an reservoir were collected during 2002 to 2012 and water release from dam to Dong Nai River from 1984 to 2012. Comparing between inflow and rainfall river in upstream show good relationship with R^2 = 0.6 (Figure 87) from that we can use this equation to calculate future inflow of reservoir. At the same time, future water release from the dam can be derived from the function of water inflow during May to August (Figure 88), and September to December (Figure 89). Future water release during January, February, March, and April were used the same average historical water release in each month.

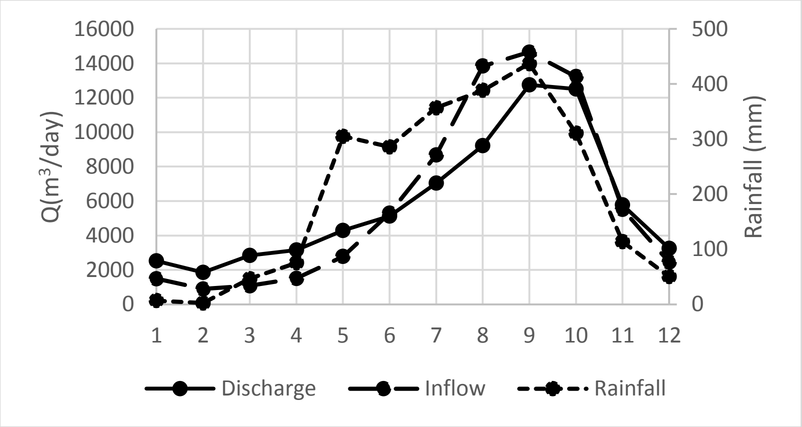


Figure 86: Average monthly rainfall, inflow and discharge at Tri An reservoir during 2002-2012

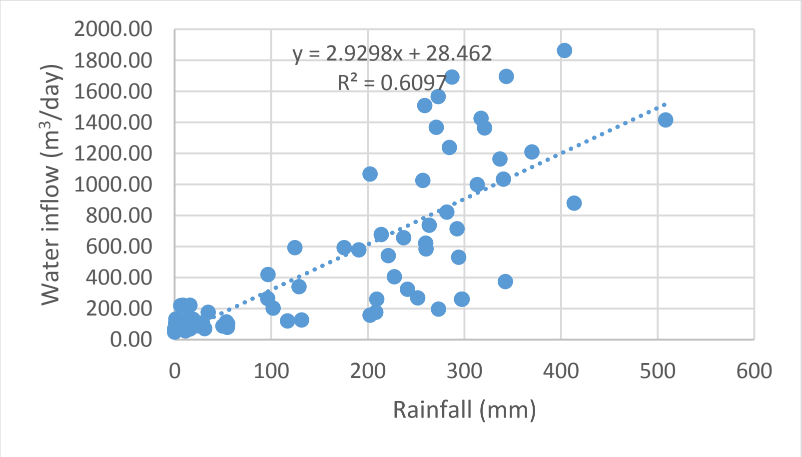


Figure 87: Relation between inflow to Tri An reservoir and rainfall (2002-2007)

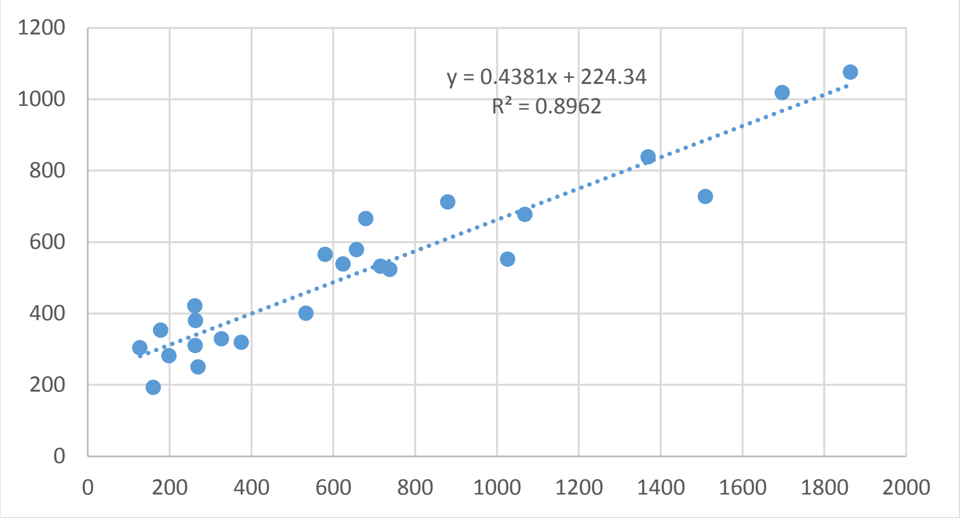


Figure 88: Inflow and dam release from Tri An Dam in May to August during 2002-2007

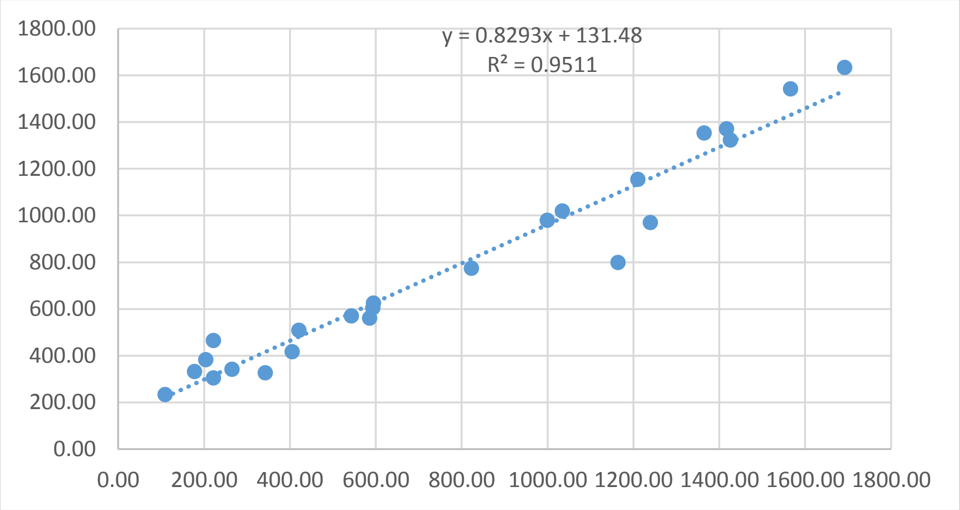


Figure 89: Inflow and discharge from Tri An Dam during September to December

Table 46: Function to calculate water release from Tri An Dam

No	Volume	Function	Correlation (R^2)
1	Dam release	Qr = 77.36 m^3/s (January) Qr = 80.76 m^3/s (February) Qr = 121.08 m^3/s (March) Qr = 292.75 m^3/s (April) Qr=0.4381Qin+224.34 (1) (May to August)	R_1=0.90 R_2 = 0.95

No	Volume	Function	Correlation (R^2)
		Qr=0.8293Qin+131.48 (2) (August to December)	
2	Water flow into reservoir	Qin=2.3453*R+52.826	R=0.6

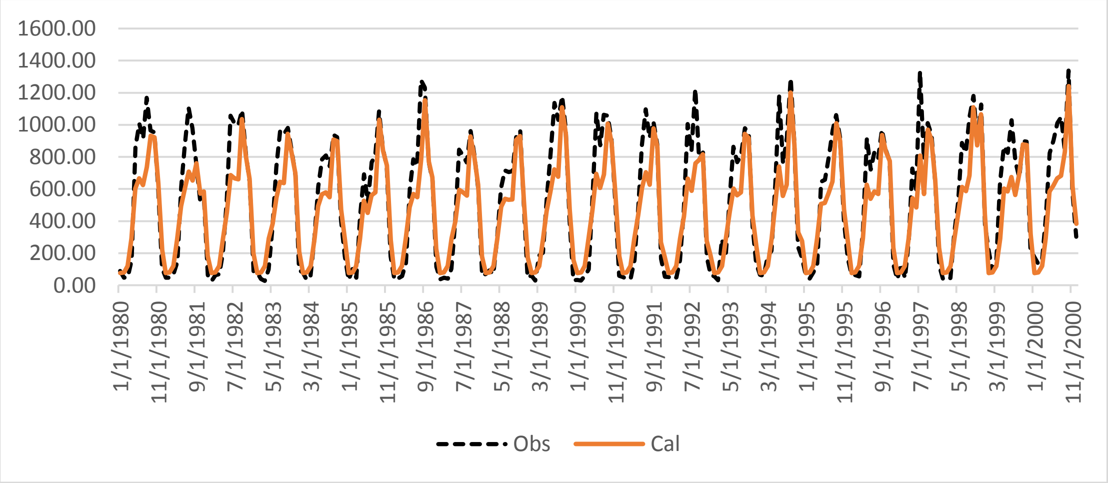


Figure 90: Observation and computed water release from Tri An Dam during 1980-2000

1.1.2. Water release from Tri An Dam

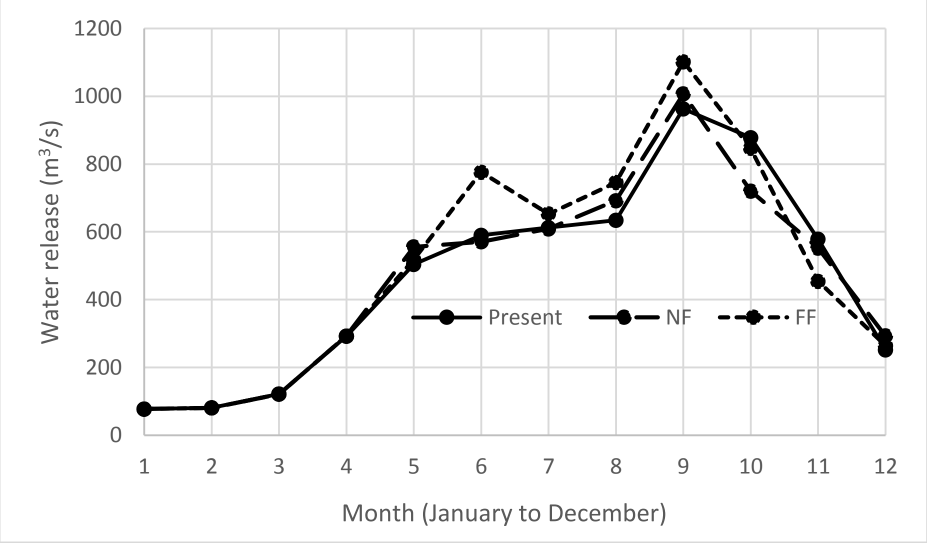


Figure 91: Average water release from Tri An dam during past period (1980-2007), near future (2015-2039) and Far Future (2075-2099).

1.2. Dau Tieng Reservoir

1.2.1. Methodology

The study did not have enough data such as water supply for irrigation, for supply as well as future water demand. Therefore, the study assumed that water release from dam to Saigon River was in the ratio with commutative rainfall at the Saigon River upstream to calculate future water release from dam, as details shown in Table 47.

Table 47: Monthly ratio of Dau Tieng dam release with commutative rainfall

Month	Release (m^3/s)	Rain (mm)	Ratio
1	4.1205	14.24702	0.29
2	10.0285	23.6721	0.42
3	20.4255	57.54407	0.35
4	39.9025	141.4746	0.28
5	62.058	324.7781	0.19
6	88.04	582.9515	0.15
7	109.3335	861.6524	0.13
8	119.3585	1156.327	0.10
9	132.7865	1501.383	0.09
10	167.949	1825.307	0.09
11	182.4695	1983.915	0.09
12	191.7935	2032.241	0.09

1.2.2. Water release from Dau Tieng Dam

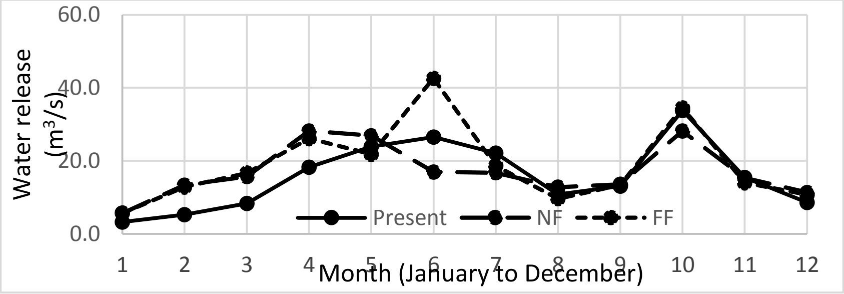
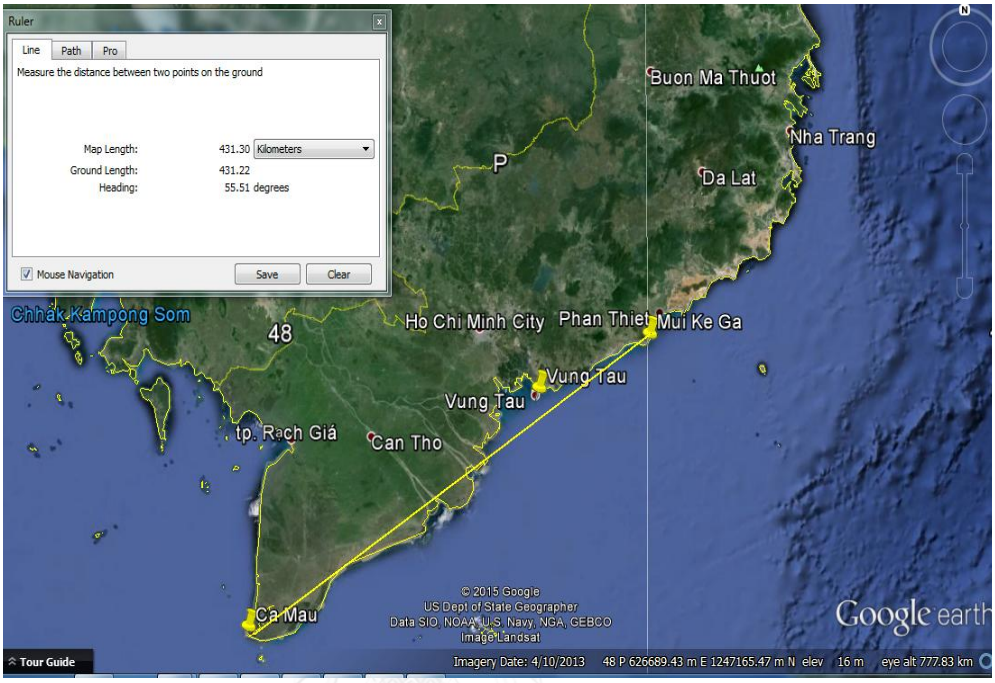


Figure 92: Average water release from Dau Tieng Dam during past period (1980-2007), near future (2015-2039) and far future (2075-2099)

2. Sea water level

Sea water level rise scenarios for Vietnam was built in 2012 by Ministry of Natural Resources and Environment.



Measure the distance between two points on the ground

Map Length: 431.30 Kilometers
Ground Length: 431.22
Heading: 55.51 degrees

Figure 93: Location of Ca Mau and Mui Ke Ga stations

Table 48: Sea level rise under a high emissions scenario (Quang, 2012)

Area	Year (cm)								
	2020	2030	2040	2050	2060	2070	2080	2090	2100
From Ke Ga to Ca Mau	8-9	13-14	19-21	26-30	35-41	45-53	56-68	68-83	79-99

In this scenarios show that sea water level will rise up to 0.8m in the end of this century.

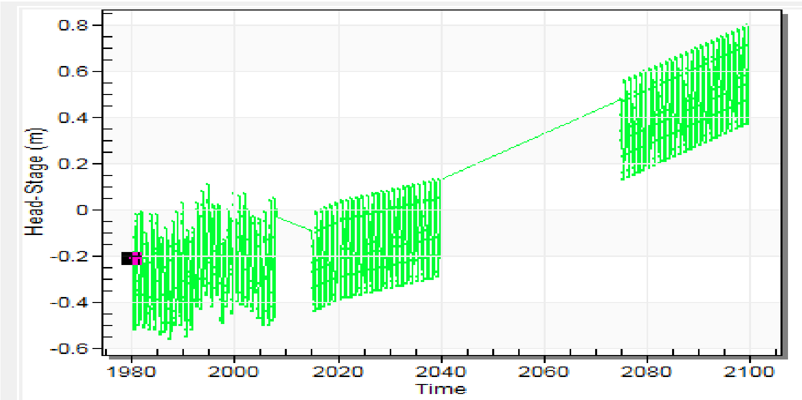


Figure 94: Future sea water level (according sea level rise scenarios)

3. River water level

3.1. Develop function

Multiple linear regression method was applied to develop function of water level at each station. Monthly water level data from 1980 to 2000 was used to develop function and used data from 2000 to 2007 for verification. While seawater level used scenarios of MONRE 2012.

Result of applied multiple linear regression method for developing the function of water level in river station was shown in details as in the Table 49. The results were also shown positive correlation value R square range from 0.6 to 0.97.

Table 49: Function of water level at river station

River	Station	Function	Correlation (R^2)
Dong Nai River	Tri An	$Y=0.0036*Qr+0.5956$	0.94
	Bien Hoa	$Y = 0.367 + 0.000408Qr + 0.983S$	0.97
	Nha Be	$C1 = 0.288 + 1.12S + 0.000016Qr$	0.97
Sai Gon River	Thu Dau Mot	$Y = 0.399 + 0.000065 R + 1.01S$	0.85
	Phu An	$Y = 0.340 + 1.05S + 0.0000379R$	0.87
Vam Co Dong	Go Dau Ha	$Y=0.579 + 0.00124R + 1.76S$	0.83
	Ben Luc	$Y = 0.369 + 1.12S + 0.000172R$	0.85
Vam Co Tay	Tuyen Nhon	$Y = 0.758 + 0.0002R + 2.32S$	0.61
	Tan An	$Y = 0.451 + 0.000694 R + 1.48S$	0.85

**where: Y is water level at river station (m), S is sea water level (m), and R was monthly rainfall (m), and Qr is average monthly water release from dam (m3/s),*

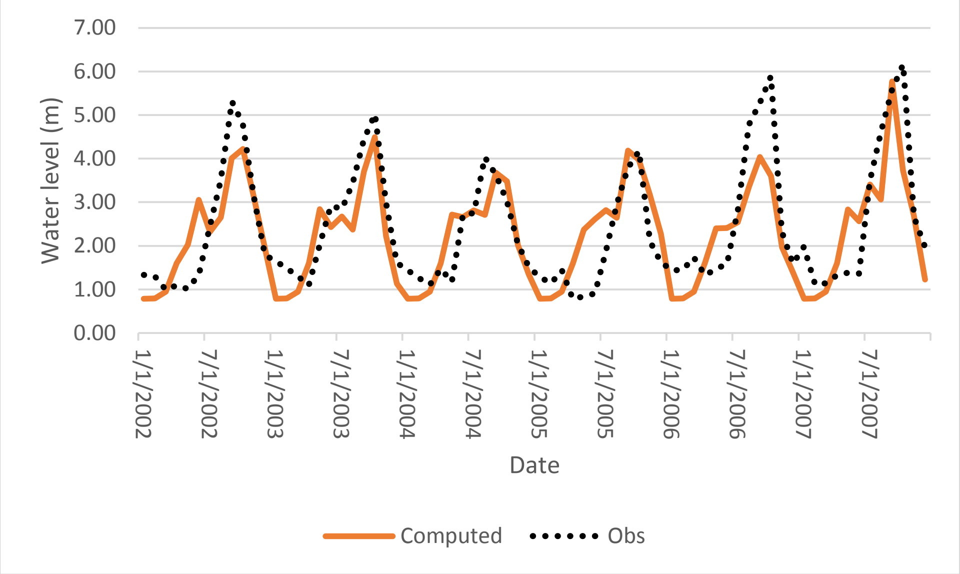


Figure 95: Computed monthly water level and observed water level at Tri an station during 2002-2007

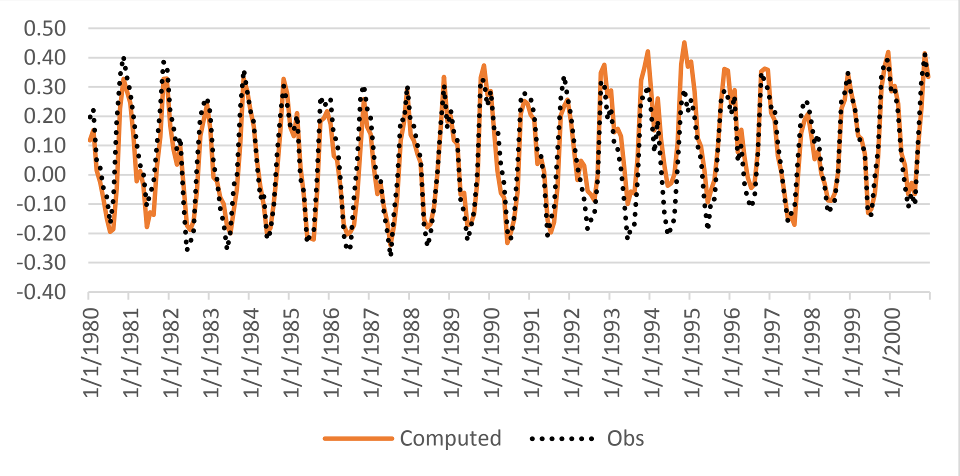


Figure 96: Computed and observed water level at Phu An station during 1980-2000

3.2. Verification function

Verification step was conducted with data from 2000 to 2007. The result of verification step shown good relationship between calculation values with observation value. It was expressed by correlation coefficient R-square in range from 0.9 to 0.96, and mean residual value was almost zero. Details shown in the Table 50.

Table 50: Result of verification step for river water level

No	Station	ME (m)	Max of E (m)	Min of E (m)	Correlation
1	Ben luc	-0.01	0.12	-0.21	0.90
2	Thu Dau Mot	0.00	0.13	-0.16	0.94
3	Bien Hoa	-0.09	0.11	-0.39	0.96
4	Dau Tieng	0.02	0.17	-0.25	0.95
5	Nha Be	-0.02	0.10	-0.10	0.96
6	Phu An	0.00	0.12	-0.12	0.96

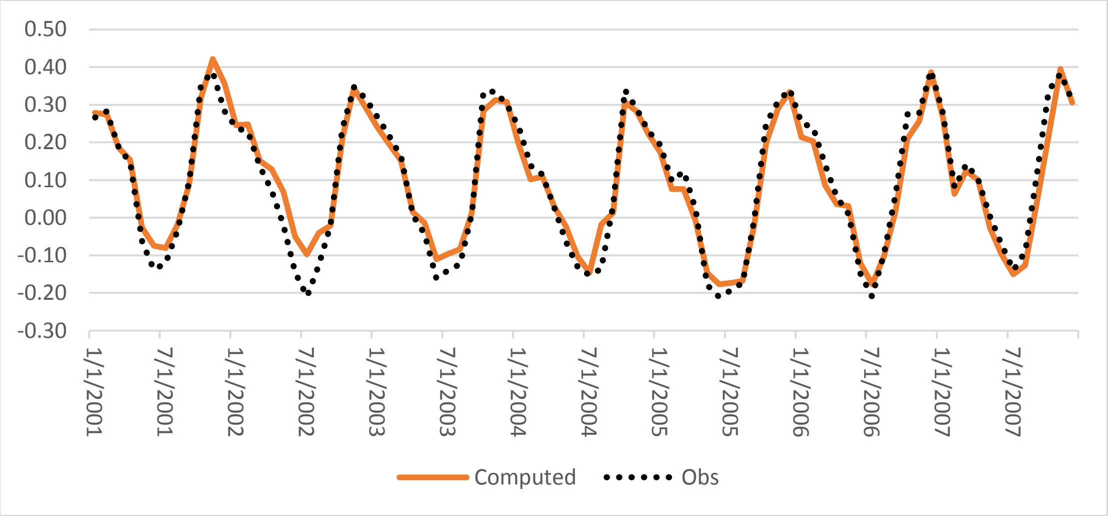


Figure 97: Computed and observation monthly water level at Phu an station during 2001 to 2007

APPENDIX 5

Groundwater budget in Ho Chi Minh City Area

Table 51: Present groundwater budget in Ho Chi Minh City

Year	Boundaries in	Boundaries Out	RECHARGE In	RIVER LEAKAGE In	RIVER LEAKAGE Out	Storage Change	WELLS Out
1995	1517007	1398715	139980	113350	159760	69379	142481
1996	1483284	1375208	140798	115852	173358	20497	170870
1997	1500285	1403897	133393	118826	189360	-39248	198495
1998	1439702	1380403	167321	132627	170374	-27608	216480
1999	1444350	1357394	158660	143299	178567	-48424	258771
2000	1518745	1398780	192411	169096	176618	-46966	351821
2001	1473429	1368864	124231	212051	168585	-150237	422500
2002	1423244	1327912	112870	265145	143613	-164449	494183
2003	1399176	1292563	118586	307271	137550	-153097	548015
2004	1342141	1226022	117276	334433	128240	-124384	563972
2005	1315289	1192571	115795	355503	116080	-95109	573044
2006	1271762	1124830	115463	366131	120166	-78413	586773
2007	1228800	1089642	166116	381252	120861	-82074	647740
2008	1257512	1010292	34237	501959	96083	19913	723633
2009	1150412	964650	132190	504499	101755	-87716	798468
2010	1142874	1005760	128935	540662	99237	-126234	877938
2011	1193129	1003036	146534	572705	99742	-169474	941466
2012	1219220	1037235	145508	620247	96746	-148824	1006784

Table 52: Future groundwater budget in Ho Chi Minh City in case of NO sea level rise

Future groundwater budget in Ho Chi Minh City in case of NO sea level rise							
Year	Boundaries in (m^3/day)	Boundaries Out (m^3/day)	RECHARGE In (m^3/day)	RIVER LEAKAGE In (m^3/day)	RIVER LEAKAGE Out (m^3/day)	Storage Change (m^3/day)	WELLS Out (m^3/day)
2015	1235406	1106542	143820	610817	102303	-190654	1063123
2016	1262171	1111438	145293	654584	104255	-113575	1075347
2017	1272295	1115049	163864	671684	106685	-64184	1075347
2018	1279991	1116914	157163	682888	106520	-46993	1075347
2019	1291705	1120284	101543	701447	100094	-58684	1075347
2020	1294052	1122487	172295	705905	100513	17781	1075347
2021	1286630	1120427	192645	684586	114414	-8729	1075347
2022	1295557	1122050	112112	702452	102708	-44028	1075347
2023	1304955	1125744	66981	721551	95205	-48208	1075347
2024	1308757	1128227	82581	727805	93514	-19899	1075347
2025	1310590	1128845	84922	729148	93514	-13486	1075347
2026	1306017	1128127	150299	721107	98441	30141	1075347
2027	1300369	1124876	160343	709400	102903	16666	1075347
2028	1302861	1124624	102713	714646	100597	-28282	1075347
2029	1310869	1127583	65218	730661	92959	-29973	1075347
2030	1313562	1129340	73082	735114	91430	-12697	1075347
2031	1312832	1129893	96583	733829	92586	6898	1075347
2032	1312791	1130140	83261	731572	93517	-9767	1075347
2033	1308318	1128343	125492	724934	97161	15194	1075347
2034	1305865	1127993	144023	722088	98161	26042	1075347

Table 52: Future groundwater budget in Ho Chi Minh City in case of NO sea level rise (continue)

Future groundwater budget in Ho Chi Minh City in case of NO sea level rise							
Year	Boundaries in (m^3/day)	Boundaries Out (m^3/day)	RECHARGE In (m^3/day)	RIVER LEAKAGE In (m^3/day)	RIVER LEAKAGE Out (m^3/day)	Storage Change (m^3/day)	WELLS Out (m^3/day)
2035	1303462	1127183	123160	711007	102761	-13578	1075347
2036	1301895	1127187	141100	710691	104086	-172	1075347
2037	1314791	1130659	30748	734195	90867	-53355	1075347
2038	1318538	1132566	63521	742203	88242	-5265	1075347
2039	1317775	1132869	70175	740047	89744	-3423	1075347
2075	1321568	1138837	139950	738276	89708	66903	1075347
2076	1307515	1133316	193161	718599	102648	66173	1075347
2077	1297675	1127775	183555	700487	111600	16691	1075347
2078	1305538	1127543	104827	717001	100001	-20045	1075347
2079	1302698	1126402	167959	713737	102164	31990	1075347
2080	1301751	1124889	133274	708580	103065	-8304	1075347
2081	1301865	1125663	129125	711295	102561	-9330	1075347
2082	1305266	1126446	113591	718976	98855	-8359	1075347
2083	1303572	1125764	133139	716115	100536	3725	1075347
2084	1304195	1125882	134822	717719	100052	8690	1075347
2085	1302239	1126086	137917	713739	101482	3132	1075347
2086	1304399	1126965	105562	718299	100297	-19978	1075347
2087	1304917	1126755	127052	718898	99825	3102	1075347
2088	1305478	1126787	112094	720091	99209	-8735	1075347
2089	1306652	1127634	114640	723047	97589	22	1075347

Table 52: Future groundwater budget in Ho Chi Minh City in case of NO sea level rise (continue)

Future groundwater budget in Ho Chi Minh City in case of NO sea level rise							
Year	Boundaries in (m^3/day)	Boundaries Out (m^3/day)	RECHARGE In (m^3/day)	RIVER LEAKAGE In (m^3/day)	RIVER LEAKAGE Out (m^3/day)	Storage Change (m^3/day)	WELLS Out (m^3/day)
2090	1306208	1127630	118821	720899	98272	383	1075347
2091	1305758	1127478	123589	718640	99610	901	1075347
2092	1306369	1127545	120851	717224	99560	-2197	1075347
2093	1299266	1125659	190282	707066	105625	38576	1075347
2094	1299793	1124469	137858	709339	103647	-7302	1075347
2095	1297115	1123683	172809	705115	106571	15524	1075347
2096	1297775	1123256	143302	706841	105619	-9190	1075347
2097	1304023	1125138	94660	719763	98555	-27352	1075347
2098	1303783	1125950	131819	717706	99643	5357	1075347
2099	1296693	1124683	166461	706189	107966	8400	1075347

Table 53`: Future groundwater budget in Ho Chi Minh City in case of sea level rise

Future Groundwater budget in Ho Chi Minh City in case of sea level rise							
Year	Boundaries in (m^3/day)	Boundaries Out (m^3/day)	RECHARGE In (m^3/day)	RIVER LEAKAGE In (m^3/day)	RIVER LEAKAGE Out(m^3/day)	Storage Change (m^3/day)	WELLS Out (m^3/day)
2015	1222338	1018068	143820	614945	89754	-189840	1063123
2016	1248826	999115	145293	659363	91312	-112291	1075347
2017	1258813	993665	163864	677063	93381	-62653	1075347
2018	1266300	989358	157163	688711	92916	-45446	1075347
2019	1276919	981858	101543	707989	86154	-56907	1075347

Table 53: Future groundwater budget in Ho Chi Minh City in case of sea level rise (continue)

Future Groundwater budget in Ho Chi Minh City in case of sea level rise							
Year	Boundaries in (m^3/day)	Boundaries Out (m^3/day)	RECHARGE In (m^3/day)	RIVER LEAKAGE In (m^3/day)	RIVER LEAKAGE Out(m^3/day)	Storage Change (m^3/day)	WELLS Out (m^3/day)
2020	1278721	982913	172295	713024	86363	19416	1075347
2021	1271826	988056	192645	691388	100169	-7711	1075347
2022	1279914	980944	112112	709584	88210	-42891	1075347
2023	1288047	975320	66981	729230	80665	-47074	1075347
2024	1291302	974382	82581	735857	78905	-18892	1075347
2025	1292872	973666	84922	737371	78766	-12613	1075347
2026	1288673	978647	150299	729470	83634	30815	1075347
2027	1283372	980930	160343	717808	87742	17504	1075347
2028	1285440	978233	102713	723330	85309	-27406	1075347
2029	1292216	973388	65218	739902	77567	-28966	1075347
2030	1294397	972683	73082	744705	75983	-11829	1075347
2031	1293423	973608	96583	743729	77010	7770	1075347
2032	1293170	973911	83261	741624	77808	-9010	1075347
2033	1288949	977028	125492	735161	81253	15974	1075347
2034	1286185	978435	144023	732475	82197	26704	1075347
2035	1283694	979402	123160	721708	86488	-12674	1075347
2036	1281835	980827	141100	721513	87731	543	1075347
2037	1293538	972596	30748	745864	74428	-52220	1075347
2038	1296809	971748	63521	754142	71848	-4471	1075347
2039	1295851	972345	70175	752260	73171	-2578	1075347
2075	1281590	983872	139950	785379	61598	86101	1075347
2076	1266282	994712	193161	758479	74470	73394	1075347
2077	1256493	999212	183555	738550	82962	21078	1075347
2078	1262303	992461	104827	755704	71475	-16450	1075347
2079	1259078	996098	167959	752608	73545	34655	1075347
2080	1257569	995035	133274	747743	74092	-5888	1075347
2081	1257042	995623	129125	750940	73365	-7228	1075347

Table 53: Future groundwater budget in Ho Chi Minh City in case of sea level rise (continue)

Future Groundwater budget in Ho Chi Minh City in case of sea level rise							
Year	Boundaries in (m^3/day)	Boundaries Out (m^3/day)	RECHARGE In (m^3/day)	RIVER LEAKAGE In (m^3/day)	RIVER LEAKAGE Out(m^3/day)	Storage Change (m^3/day)	WELLS Out (m^3/day)
2082	1259389	993779	113591	759439	69550	-6257	1075347
2083	1257492	995697	133139	757055	71009	5633	1075347
2084	1257485	995337	134822	759199	70314	10508	1075347
2085	1255304	997235	137917	755775	71427	4986	1075347
2086	1256681	995999	105562	760947	70048	-18204	1075347
2087	1256614	996229	127052	762163	69421	4833	1075347
2088	1256653	995752	112094	763931	68621	-7041	1075347
2089	1257207	995541	114640	767667	66837	1789	1075347
2090	1256322	996479	118821	766049	67305	2061	1075347
2091	1255403	997017	123589	764291	68318	2601	1075347
2092	1255381	996806	120851	763480	68080	-521	1075347
2093	1248919	1003563	190282	753618	73813	40096	1075347
2094	1248949	1001981	137858	756514	71622	-5629	1075347
2095	1246042	1004895	172809	752841	74266	17186	1075347
2096	1246201	1003723	143302	755156	73069	-7480	1075347
2097	1250973	998898	94660	769091	66008	-25528	1075347
2098	1250245	1000408	131819	767635	66930	7014	1075347
2099	1243837	1006493	166461	756390	74937	9913	1075347

Table 54: Future groundwater budget in Ho Chi Minh city in case of change groundwater pumping

Future groundwater budget in Ho Chi Minh city in case of change groundwater pumping							
Year	Boundaries in (m^3/day)	Boundaries Out (m^3/day)	RECHARGE In (m^3/day)	RIVER LEAKAGE In (m^3/day)	RIVER LEAKAGE Out (m^3/day)	Storage Change (m^3/day)	WELLS Out (m^3/day)
2015	1222222	1018145	143820	613167	89776	-189835	1061123
2016	1237429	1003111	145293	597125	92473	55838	828426
2017	1231615	1004669	163864	542756	96167	45738	791661
2018	1228981	1005480	157163	525810	96425	18389	791661
2019	1232604	1001490	101543	531627	89414	-16791	791661
2020	1229753	1004916	172295	530085	90050	45506	791661
2021	1219912	1011690	192645	505655	105143	9719	791661
2022	1225942	1005499	112112	520389	92211	-30927	791661
2023	1232668	1000423	66981	537728	83930	-38635	791661
2024	1234990	999851	82581	543316	82163	-12789	791661
2025	1225409	1003566	84922	467317	84797	183199	506083
2026	1203303	1017175	150299	372657	94305	173770	441009
2027	1185563	1026701	160343	325081	101651	101626	441009
2028	1179142	1029251	102713	313279	99188	25687	441009
2029	1180176	1027862	65218	319042	89663	5902	441009
2030	1178649	1029482	73082	318628	88111	11757	441009
2031	1175349	1032023	96583	315065	89807	24159	441009
2032	1173596	1033423	83261	311192	90943	2675	441009
2033	1168422	1037313	125492	304642	95721	24513	441009
2034	1165112	1039339	144023	301259	96915	33132	441009
2035	1162338	1040822	123160	291203	102589	-7719	441009
2036	1160220	1042553	141100	291047	104336	4469	441009
2037	1171438	1034241	30748	310849	86792	-49005	441009

Table 54: Future groundwater budget in Ho Chi Minh city in case of change groundwater pumping (continue)

Future groundwater budget in Ho Chi Minh city in case of change groundwater pumping							
Year	Boundaries in (m^3/day)	Boundaries Out (m^3/day)	RECHARGE In (m^3/day)	RIVER LEAKAGE In (m^3/day)	RIVER LEAKAGE Out (m^3/day)	Storage Change (m^3/day)	WELLS Out (m^3/day)
2038	1174350	1033335	63521	318273	83573	-1771	441009
2039	1173255	1034021	70175	316678	85383	-305	441009
2075	1159573	1047242	139950	347543	72481	86335	441009
2076	1144879	1058671	193161	323461	88521	73300	441009
2077	1135582	1063606	183555	305717	99196	21045	441009
2078	1141314	1056722	104827	319301	84044	-16333	441009
2079	1138210	1060449	167959	317233	87082	34864	441009
2080	1136804	1059459	133274	312447	87695	-5639	441009
2081	1136386	1060143	129125	315304	86592	-6928	441009
2082	1138684	1058245	113591	322592	81543	-5929	441009
2083	1136850	1060223	133139	320856	83659	5954	441009
2084	1136863	1059880	134822	322609	82569	10836	441009
2085	1134821	1061918	137917	319639	84139	5311	441009
2086	1136213	1060702	105562	324086	82024	-17874	441009
2087	1136127	1060917	127052	325349	81449	5155	441009
2088	1136179	1060455	112094	326924	80465	-6730	441009
2089	1136749	1060265	114640	330201	78210	2106	441009
2090	1135916	1061262	118821	328816	78922	2361	441009
2091	1135043	1061847	123589	327267	80151	2893	441009
2092	1135055	1061673	120851	326492	79953	-237	441009
2093	1128825	1068661	190282	318877	87976	40339	441009
2094	1128896	1067111	137858	320411	84449	-5403	441009

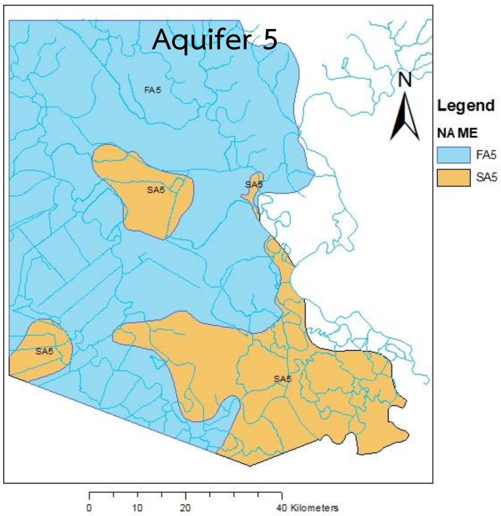
Table 54: Future groundwater budget in Ho Chi Minh city in case of change groundwater pumping (continue)

Future groundwater budget in Ho Chi Minh city in case of change groundwater pumping							
Year	Boundaries in (m^3/day)	Boundaries Out (m^3/day)	RECHARGE In (m^3/day)	RIVER LEAKAGE In (m^3/day)	RIVER LEAKAGE Out (m^3/day)	Storage Change (m^3/day)	WELLS Out (m^3/day)
2095	1126108	1070141	172809	317703	88060	17412	441009
2096	1126302	1068998	143302	319297	86143	-7249	441009
2097	1130950	1064051	94660	331057	76871	-25263	441009
2098	1130259	1065607	131819	330253	78430	7285	441009
2099	1124103	1071946	166461	321486	88956	10141	441009

APPENDIX 6

Possibility saltwater intrusion impact to groundwater resources

When sea level rise, it seem to have impact on groundwater reserves such as increase water level, but it have problem with salt water intrusion. To estimate the possibility of saline intrusion was not objective of this study. However, to get an overview of possibility salinization due to climate change and sea level rise then the study will divide aquifers into two part as fresh water zone and salt water zone. And then using 3 case model mentioned above to calculate water balance of each fresh water zone. If water from salt water contribute to flow budget of fresh water it mean that possible to salt water intrusion.



Remark

FA: Fresh water zone

SA: Salt water zone

Figure 98: Fresh water and salt water zone map of aquifer 5

Table 55: Future salt water flow rate from salt water zone to fresh water zone

Year	Future salt water flow rate (m^3/day)		
	Case of no sea level rise	Case of sea level rise	Case of change GW pumping
2015	830889	831067	830889
2016	842844	843057	763867
2017	849414	849638	709760
2018	854004	854235	696110

Table 5556: Future salt water flow rate from salt water zone to fresh water zone (continue)

Year	Future salt water flow rate (m^3/day)		
	Case of no sea level rise	Case of sea level rise	Case of change GW pumping
2019	858951	859169	692106
2020	861589	861803	689765
2021	861827	862047	687386
2022	863683	863827	686945
2023	866918	867026	688596
2024	868607	868703	689314
2025	869044	869128	609916
2026	868563	868651	536063
2027	867012	867104	508509
2028	867809	867896	495994
2029	869981	870042	489875
2030	870942	871001	486369
2031	871206	871260	484071
2032	871063	871113	482468
2033	870103	870169	480893
2034	870421	870480	480424
2035	869538	869619	479487
2036	869781	869874	479382
2037	871024	871080	479122
2038	872218	872251	479718
2039	872381	872421	479948

Table 5557: Future salt water flow rate from salt water zone to fresh water zone (continue)

Year	Future salt water flow rate (m^3/day)		
	Case of no sea level rise	Case of sea level rise	Case of change GW pumping
2075	872967	874832	482411
2076	870728	872562	481685
2077	869004	870430	480332
2078	869135	870120	478886
2079	868902	869690	478848
2080	868538	869241	478377
2081	869281	869913	478864
2082	869736	870278	478895
2083	869245	869775	478724
2084	869684	870183	478923
2085	869749	870291	479216
2086	870450	870970	479706
2087	870034	870538	479327
2088	870082	870598	479327
2089	870654	871147	479644
2090	870354	870862	479615
2091	870321	870843	479634
2092	869993	870519	479385
2093	868600	869191	479066
2094	868374	868962	478520
2095	868292	868914	478757

Table 5558: Future salt water flow rate from salt water zone to fresh water zone (continue)

Year	Future salt water flow rate (m^3/day)		
	Case of no sea level rise	Case of sea level rise	Case of change GW pumping
2096	868391	869022	478613
2097	869909	870472	479183
2098	870037	870609	479542
2099	869033	869710	479655

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