การประมาณพารามิเตอร์ปฏิสัมพันธ์ระหว่างน้ำใต้ดินและน้ำในแม่น้ำไซง่อน ประเทศเวียดนาม

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GROUNDWATER AND RIVER INTERACTION PARAMETER ESTIMATION
ALONG SAIGON RIVER, VIET NAM

Mr. Tuan Pham Van

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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Thesis Title	GROUNDWATER AND RIVER INTERACTION PARAMETER ESTIMATION ALONG SAIGON RIVER, VIET NAM
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Field of Study	Water Resources Engineering
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ตวน พราม แวน : การประมาณพารามิเตอร์ปฏิสัมพันธ์ระหว่างน้ำใต้ดินและน้ำในแม่น้ำไซง่อน ประเทศเวียดนาม (GROUNDWATER AND RIVER INTERACTION PARAMETER ESTIMATION ALONG SAIGON RIVER, VIET NAM) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: สุจริต คูณธนกุลวงศ์, 102 หน้า.

ระบบแม่น้ำไซง่อนเป็นแหล่งน้ำใหญ่แห่งหนึ่งที่จ่ายน้ำกินน้ำใช้ให้กับภาคครัวเรือนและอุตสาหกรรมในเมืองโฮจิมินห์และจังหวัดบินดอง และประสบปัญหาภัยแล้งในช่วงเวลาที่ผ่านมาในพื้นที่ท้ายน้ำในการจัดการน้ำในลุ่มน้ำไซง่อนให้มีประสิทธิผล พารามิเตอร์การปฏิสัมพันธ์ระหว่างน้ำใต้ดินและแม่น้ำควรมีการประเมินอย่างเป็นระบบ.

การศึกษาครั้งนี้ได้ประยุกต์ใช้แบบจำลองน้ำใต้ดินและการสำรวจภาคสนามเพื่อวิเคราะห์หาพารามิเตอร์ของการปฏิสัมพันธ์ของน้ำใต้ดินและแม่น้ำ พารามิเตอร์ปฏิสัมพันธ์ (K_iM^{-1}) ถูกกำหนดจากค่าความนำทางชลศาสตร์หารด้วยความหนของชั้นปฏิสัมพันธ์ซึ่งจะมีทั้งวัสดุท้องน้ำและวัสดุของชั้นทึบน้ำหรือชั้นน้ำ ค่าวิเคราะห์ที่ได้จากการสอบเทียบแบบจำลองโดยค่าพารามิเตอร์ปฏิสัมพันธ์จากข้อมูลสนามสามหน้าตัดของแม่น้ำไซง่อนในช่วงปี 2000 ถึง 2007 และสร้างเป็นสมการพารามิเตอร์ปฏิสัมพันธ์ตามเปอร์เซนต์ของความกว้างชั้นน้ำแต่ละแบบ และถูกนำไปประมาณค่าพารามิเตอร์ปฏิสัมพันธ์ในหน้าตัดอื่นตลอดลำน้ำไซง่อน

ค่าพารามิเตอร์ปฏิสัมพันธ์ที่ได้แสดงผลจากภูมิสัณฐานของแม่น้ำ โดยถ้าหน้าตัดแม่น้ำไม่สัมผัสกับชั้นน้ำ มีเฉพาะวัสดุก้นน้ำและชั้นทึบน้ำ ค่าพารามิเตอร์ปฏิสัมพันธ์มีค่า 0.0003 ต่อวัน ในทางกลับกัน ถ้าหน้าตัดแม่น้ำสัมผัสกับชั้นน้ำทั้งหมด ค่าพารามิเตอร์ปฏิสัมพันธ์มีค่า 0.033 ต่อวัน

ในพื้นที่ต้นน้ำของแม่น้ำไซง่อน แม่น้ำได้รับน้ำจากน้ำใต้ดินผ่านท้องแม่น้ำ และไหลกลับสู่ชั้นน้ำใต้ดินในบริเวณท้ายน้ำผ่านท้องแม่น้ำเช่นกันในช่วงปี 2000-2007 จากการวิเคราะห์ทั้งพื้นที่ศึกษาพบว่า การเติมน้ำจากชั้นน้ำสู่แม่น้ำในช่วงปี 2000-2007 เพิ่มขึ้น 26,129 ลบมต่อวัน และเป็นสัดส่วน 34 % ของปริมาณน้ำไหลเข้าชั้นน้ำทั้งหมดเทียบกับปริมาณน้ำเติมจากพื้นที่ 10.1 % และปริมาณเก็บกัก17.7 % ผลจากการสูบน้ำใต้ดินเพิ่ม ทำให้ปริมาณน้ำไหลเข้าชั้นน้ำจากแม่น้ำที่หน้าตัด TV6 และ TV7 มีเพิ่มขึ้น 56% และ 50 % ตามลำดับ ดังนั้น จากการศึกษาครั้งนี้ ปัจจุบันอัตราการสูบน้ำในชั้นน้ำที่ ๒ (qp_{2-3}) และ ๓ (qp_1) มีมากกว่าอัตราการเติมน้ำของชั้นน้ำในพื้นที่ศึกษาจำต้องลดการสูบและปรับปรุงการจัดการน้ำใต้ดิน

ภาควิชา	วิศวกรรมแหล่งน้ำ	ลายมือชื่อนิสิต	....
สาขาวิชา	วิศวกรรมแหล่งน้ำ	ลายมือชื่อ อ.ที่ปรึกษาหลัก	....
ปีการศึกษา	2559		

5870337121 : MAJOR WATER RESOURCES ENGINEERING
KEYWORDS: INTERACTION PARAMETER, FUNCTION, INTERACTION PATTERN, INTERACTION VOLUME, SAIGON RIVER

TUAN PHAM VAN: GROUNDWATER AND RIVER INTERACTION PARAMETER ESTIMATION ALONG SAIGON RIVER, VIET NAM. ADVISOR: ASSOC. PROF. SUCHARIT KOONTANAKULVONG, D.Eng., 102 pp.

The Saigon River Basin is one of the largest water resources contributing water supply for domestic and industrial fields at Ho Chi Minh City and Binh Duong Province, and has been facing the drought issue at downstream in recent years. To manage the water resources in Saigon Basin effectively, the groundwater and river interaction parameters need to be assessed systematically

In this study, a groundwater modeling of the main stream of Saigon River and river cross-section investigations were applied to analyze groundwater and river interaction parameter along the river. The interaction parameter (K_iM^{-1}) was defined as hydraulic conductivity divide by thickness of interaction layer which is a combined layer by materials of riverbed with materials of aquitard or aquifer. The values of conductance through groundwater model calibration by peizometric heads during 2000 to 2007 at three cross-sections in Saigon River were used to estimate the interaction parameter (K_iM^{-1}) at correlative cross-section. A function of interaction parameter with percentage of interaction layer width under aquifer was developed to estimate interaction parameter at another cross-section along Saigon River.

The results showed the effect of river cross-section morphology on interaction parameter. When river cross-section has no penetration with aquifer, the materials of interaction layer consists of materials of riverbed and aquitard with value of interactions is equal to 0.0003 d^{-1}. In the other hand, the value will be reached to 0.033 d^{-1} when river cross-section has fully penetration with aquifer.

In the upper part of Saigon River, river gained water from groundwater inflow through riverbed (river recharge out) and lost water to groundwater (river recharge in) by out flow through the riverbed in lower part during 2000 to 2007. In the whole study area, river recharge volume increased 26,129 m^3/d from 2000 to 2007, and occupied average 34% of total flow in of water budget of qp_{2-3} aquifer in the study area, compared with 10.1% of land recharge and 17.7 % of storage in. With the effect of increasing pumping rate, the volume of river recharge in grew up approximately 56% from 2000 to 2007 at TV6 cross-section and about 50 % at TV7 cross-section. Hence, from the study, pumping rate of both qp_{2-3} and qp_1 aquifer exceeded total groundwater recharge so, groundwater in the study area needs to be reduced and better managed.

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

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I would like to thank the experts who were involved in the validation survey for this research project: Assoc. Prof. Dr. Tuantan Kitpaisalsakul, Assoc. Prof. Chaiyuth Sukhsri, Asst. Prof. Sunthorn Pumjan and Asst. Prof. Dr. Anurak Sriariyawat for their insightful comments and encouragement, but also for the hard question which incented me to widen my research from various perspectives.

A very special gratitude goes out to all down at 72nd King's Birthday Scholarship and also Department of Water Resources Engineering, Chulalongkorn University for helping and providing the funding for the work

This research cannot be concluded without data from the Division for Water Resources Planning and Investigation for the South of Vietnam (DWRPIS) and therefore we would like to extend appreciation to DWRPIS for the support.

I also give many thanks to Dr.Ngo Duc Chan who let me gain experiences the research of groundwater in Vietnam and help me developing my background in mapping, modelling. Special thanks goes to Dr.Bui Tran Vuong, who always give chances to participate in international workshops and trips. My research would not have been possible without their helps.

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CONTENTS

Page

Page

Page

List of Figures

List of Tables

List of Abbreviations

GWL	Groundwater level
HCMC	Ho Chi Minh City
MSL	Mean sea level
n_{2-2}	Middle Pliocene
n_{2-1}	Lower Pliocene
qh	Holocene
qp_3	Upper Pleistocene
qp_{2-3}	Upper - Middle Pleistocene
qp_1	Lower Pleistocence
RRI	River recharge in
RRO	River recharge out
RWL	River water level
Obs	Observation

CHAPTER 1: INTRODUCTION

1.1. Background of problem

In hydrologic cycle, the groundwater and river interaction is one of important parts. The interconnection of river and groundwater take many forms. In many situations, river gains water and solutes from groundwater systems and in others. The river is a source of groundwater recharge and causes changes in groundwater quality (Thomas et al., 1998).

Lateral flow and transportation between groundwater and river water through the subsurface interaction zone, in particular, are major pathway energy, water and gas to transfer terrestrial and aquatic systems. Pollution of surface water can cause degradation of groundwater quality and conversely pollution of groundwater can degrade surface water. So, the effective land and water management requires a clear understanding of the linkages between groundwater and surface water as it applies to any given hydrologic settings.

In Vietnam, groundwater and river system are two main parts of water resources systems. So, issues related to water supply, water quality, and degradation of aquatic environments are importance concerns of both nation or region. The Saigon River system is the second largest river supplying domestic water to Ho Chi Minh City (HCMC) after the Dong Nai River, which has been in high pressure on water quantity and quality (Vuong, 2013) due to the effect of water use and wastewater from industrial, domestic and agricultural activities.

Especially, the effect of salt water intrusion is being an extremely serious problem of the South of Viet Nam, and Saigon basin is one of regions most affected. Thus, groundwater and river interaction has been shown to be a significant concern in water quantity and quality management in Saigon River basin.

The understanding about groundwater and river interaction parameter plays a key part in water resources management at Saigon River. Therefore, the purpose of this study is to analyze groundwater and river interaction parameter along Saigon River by using groundwater model (GMS). This study conducted for better understanding the relationship between the groundwater and river.

1.2. Objectives of the study

This study set the main objective and specific objectives as follow.

The main objective:

- Investigate the groundwater and river interaction parameter along Saigon River.

The specific objectives:

- Estimate interaction parameter at three cross-sections on Saigon River
- Develop interaction parameter function
- Analyze groundwater and river interaction volume and pattern of Saigon River

1.3. Scope and limitations of the study

1.3.1. Scope of the study

The scope of the study involves general information of the study area and the tools/materials and techniques used, and the data needed for the model to be completed.

Study area

The Saigon River is a river located in southern Vietnam that rises near Phum Daung in southeastern Cambodia, flows south and south-southeast for about 230 kilometers (140 mi) and empties into the Nha Be River. Saigon river together with orchards in Thuan An town will be one of the province's highlights of absorbing tourists. The birth great groups, namely Lotte Mart, Aeon, Metro, Nguyen Kim etc. in the province shows that the local trade-service potential is very great. If waterway traffic is tapped well, Binh Duong province and Ho Chi Minh city will create great opportunities for socio-economic development.

A groundwater model covered the main stream of Saigon River from Bensuc, Cuchi District to Binhloi Bridge, Binhthanh District, HCMC with total length of river is 48 km. The domain of the model has an area of 567.3km^2 and is limited as Figure 1.1.

Figure 1.1. Study area

Groundwater model:

- Apply GMS software version 9.1 to build Groundwater flow model and to estimate interaction parameter.
- Interaction parameter function will be derived from the penetration ratio of interaction layer into aquifer.
- Apply multiple linear regression method to estimate river water level 4 cross-section.

Data usage

In this study, Division for Water Resources Planning and Investigation for the South of Vietnam provided all of groundwater data as hydrogeology map, borehole data, geophysical data and observed groundwater levels. Besides, other data, also known as climate, dam release, exploitation and river survey data were collected from other orgnizations and institutions as shown in Table 1.1.

Table 1.1. Data usage of the study

No.	Data	Period of data	Sources
1	Hydrogeology map	2015	Division for Water resources Planning and Investigation for the South of Vietnam
2	Borehole strata	2015	
3	Geophysical survey	2000-2013	
4	Groundwater levels	2000-2013	
5	Groundwater exploitation	2000-2007	Department of Resources and Environmental
6	River water levels	2000-2014	Southern Institute of Water Resources Research
7	Cross-sections	2013-2014	
8	Dam release (Dau Tieng)	2000-2015	
9	Climate	1980-2010	Southern Regional Hydrometeorology Center

1.3.2. Limitations of the study

The limitations from this study would be as follows:

- The study is based on the secondary data collection;
- This study only assesses the quantity of groundwater and river exchange with no assessment about quality;
- This study does not include the assessment of the impact of climate change.

1.4. Methodology

This section discusses the methods that have been used in investigation and analysis of data to answer the primary and secondary research questions of the study. It explains the improvement of boundaries condition of groundwater modeling; and describes how data collected from the investigation has been analyzed and compute with results of groundwater model. Both qualitative and quantitative research methods have been used in carrying out this research.

1.4.1. Frame work of the study

The main objective of this study was to estimate interaction parameter along Saigon River. Firstly, this required developing groundwater model calibration and verification to estimate conductance value. Secondly, a function of interaction parameter (K_iM^{-1}) with wetted length ratio of interaction layer (R_u) was developed to estimate K_iM^{-1} at each cross-sections in Saigon River. Finally, the values of interaction parameter were applied for the groundwater model to determine interaction volume and pattern in Saigon river. The general framework of the study is shown in Figure 1.2.

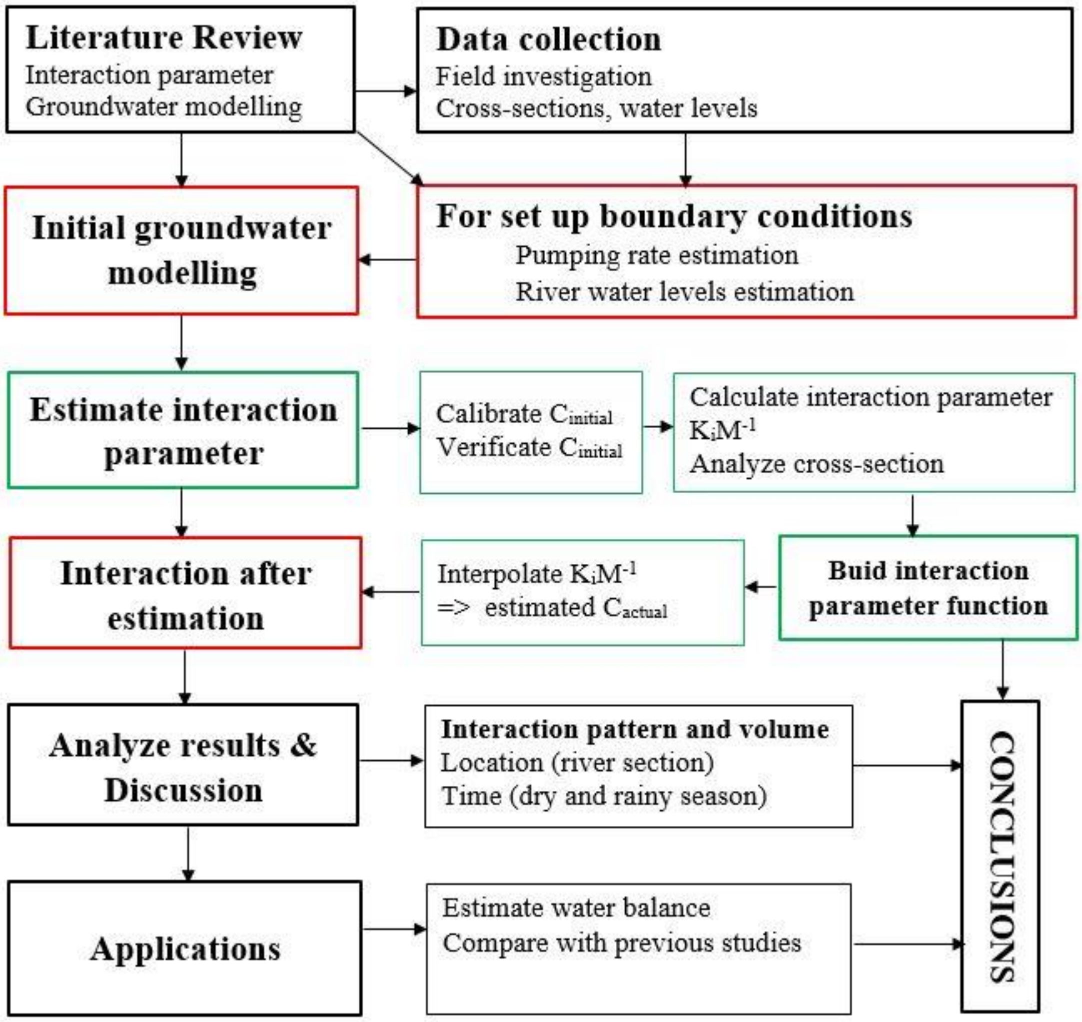


Figure 1.2. Framework of the study

1.4.2. Estimate conductance using model calibration and verification

Build a initial groundwater flow model by using GMS software version 9.0.5

From bore logs data, a groundwater model was developed to simulate the distribution of 8 top layers in the study area. The layers of 1, 3, 5 and 7 represented for aquitards or impervious layers. Layers of 2, 4, 6 and 8 represented for aquifers qh, qp_3, qp_{2-3} and qp_1, respectively. Besides, boundaries conditions of the groundwater model was improved from the previous study (Chan, 2008) by estimating pumping volume from

2000 to 2007 via population and water levels at cross-sections in Saigon River via dam release data.

Conductance calibration and verification:

Conductance coefficient was calibrated and verified at 3 points associated with 3 cross-sections TV01, TV03, TV06 by using piezometric of observed wells near the cross-section which penetrate directly to qp_{2-3} aquifer are N2, BD11 and Q00202A, respectively (see Figure 1.3).

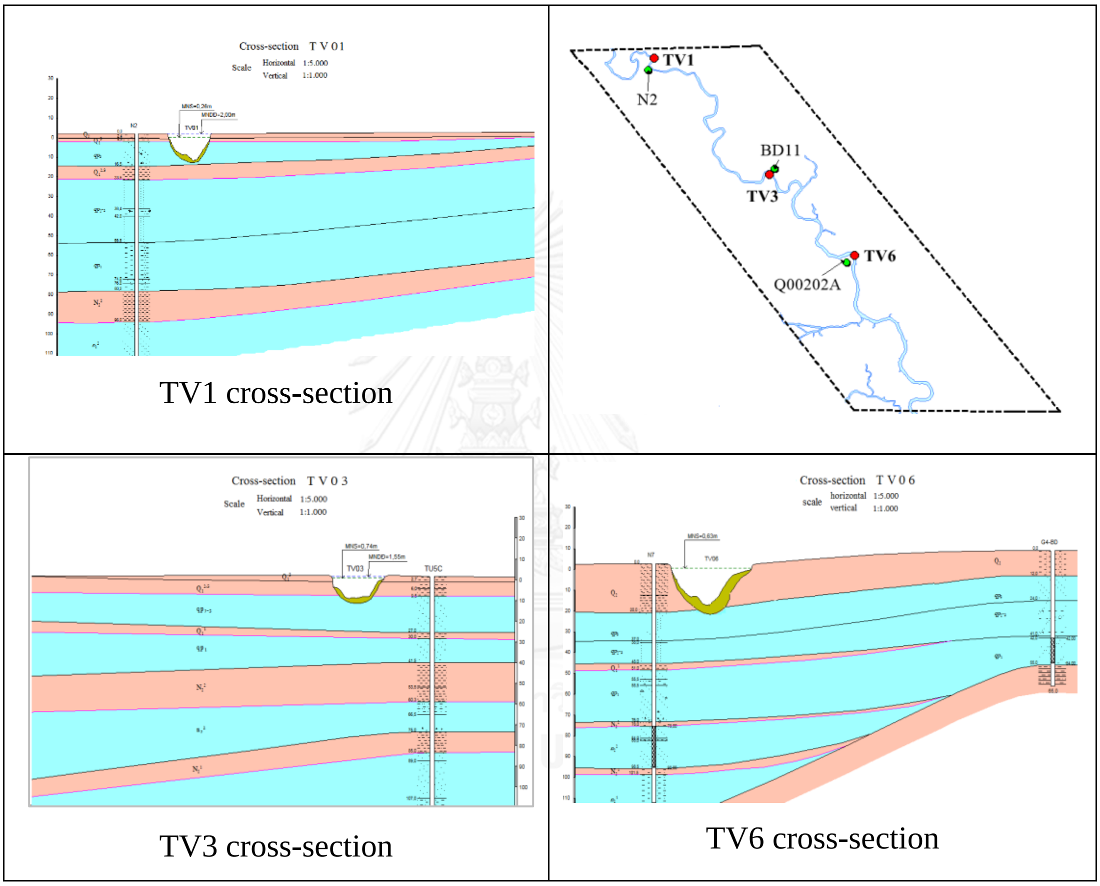


Figure 1.3. Cross-sections were used for calibrate and verify conductance

1.4.3. Develop function of interaction parameter

From result of conductance estimation, three values of conductance were selected correlative with three cross-sections in Saigon River. Besides, river cross-section analysis showed the results of wetted length and wetted length ratio of interaction layer. three values of interaction parameter (K_iM^{-1}) at three cross-sections were calculated and computed with wetted length ratio at three correlative cross-sections to develop functions of interaction parameter. Process of estimating interaction parameter and developing function of interaction parameter is summarized details in Figure 1.4 below.

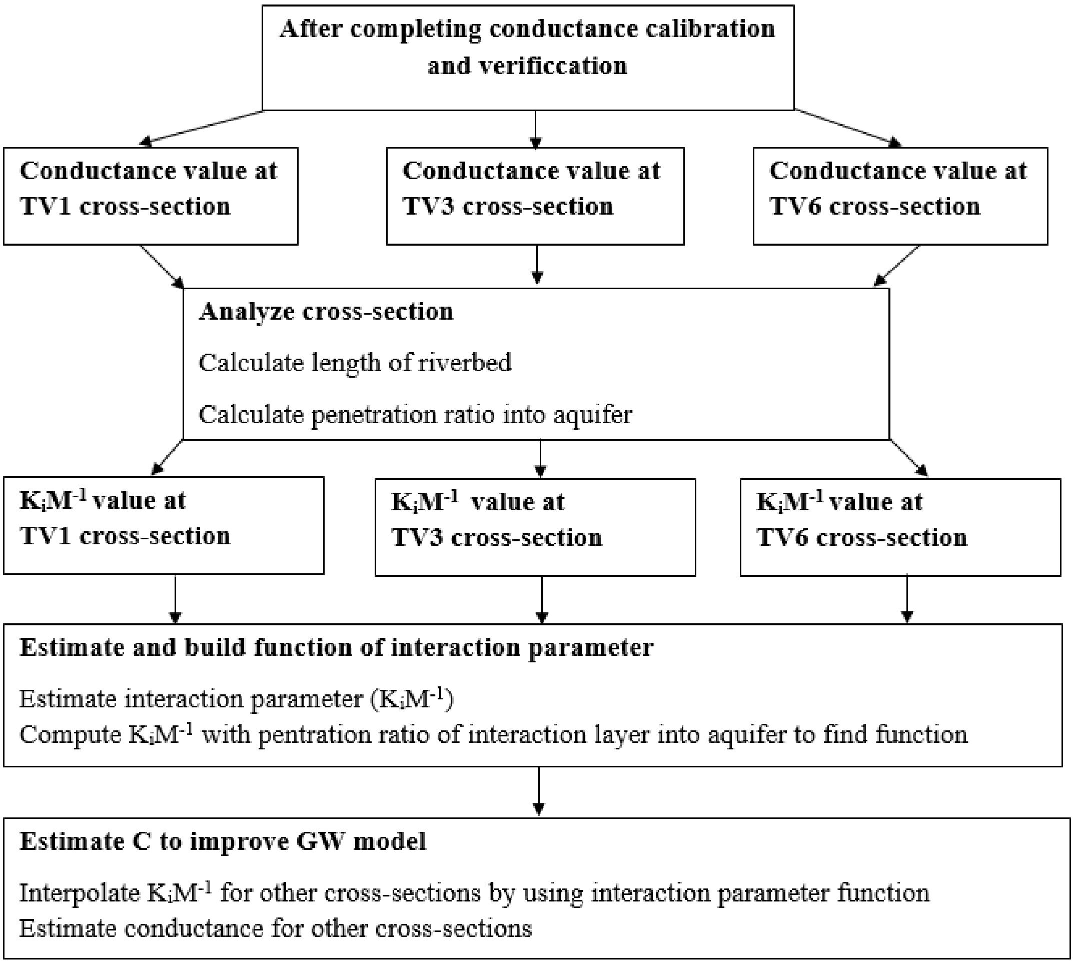


Figure 1.4. Process of interaction parameter estimation

1.4.4. Interaction volume and pattern estimation

The output of water budget of cells in same location with cross-sections in Saigon River presented the river recharge in and out by seasonal from 2000 to 2007 at each correlative cross-section. At TV6 cross-section, the effect of initial conductance and actual conductance on river recharge was calculated by change cell width to actual rive width. The output of water budget of qp_{2-3} aquifer was used to estimate water balance of the aquifer during the period from 2000 to 2007.

1.5. Expected outputs of the study

The expected outputs from this study were:

- Understand interaction parameter better
- Improve groundwater levels and river stages simulation
- Improve the storage and water balance calculation
- Interpolate interaction parameter value from interaction parameter function

CHAPTER 2: LITERATURE REVIEW AND THEORIES USED

2.1. Literature review

In my literature review, a good representative literature presented the need for assessment of groundwater and river interaction. However, little is written in detail estimation of interaction parameter. I am grateful to some authors as Chen, Xunhong and Chen (2003), Fox et al. (2011), Pérez-Paricio et al. (2010) who identified some of the factors that have effect to interaction between groundwater and river, and some case study in the South of Vietnam as Boehmer (2000), Chan (2008). By studying the relevant literature, it will help me understand more fully how other factors play a big role in groundwater and river interaction.

2.1.1. Groundwater and river interaction

A combination of detailed geophysical survey, water level monitoring and conceptual modeling were conducted to give an deep overview about alluvial aquifer and stream interaction in the Hadejia-Jama'are-Yobe River basin in Northern Nigeria (Alkali, 1995). He recognized that where the thickness of clay layer covered the flood plain surface is less than 1 meter, the flood water will infiltrate into the underlying aquifer. He also documented that the hydraulic continuity with the adjacent alluvial aquifer and variations in the aquifer storage is important factors to assess groundwater and river interaction at the study site.

When the hydraulic conductivity of geologic formations is high, the gradients between the stream and the groundwater system generally are not large, but the GW-SW exchange flow is substantial. In contrast, with the low hydraulic conductivity and the gradients generally are large, then the SW-GW exchange flow rate usually is small (Winter, 1998). He also documented that a stream originating in an extensive, highly permeable aquifer commonly will have a relatively stable supply of water in its headwater area and large recession indexes.

A HEC-RAS model was built to simulate the surface water flow in Lehn river, Germany (Saenger et al., 2005). Besides, Saenger linked HEC-RAS with MODFLOW, MODPATH, and MT3DMS to reproduce the transport in the groundwater. The results showed that the GW-SF exchange will increase in case of raising surface water flow rate. They also documented that although the flow controls the hyporheic exchange of river and groundwater, the effect of the sediment properties on the exchange is higher.

Both hydrological analysis and tracer - based approaches used to assess the interactions between groundwater and surface water in the Heihe River basin, China (Akiyama et al., 2007). The result underlined the GW-SW interaction has a significant difference in the irrigation and non-irrigation periods. Besides, Akiyama et al. (2007) also documented that the river water was mostly derived from the groundwater in the middle reaches in the non-irrigation period, and recharged the groundwater in the lower reaches throughout the period.

Two domains computational code, MODFLOW and HEC-RAS were combined to simulate the hydraulic profiles in drain channels within a regional groundwater flow system in the Choele Island, Argentina (Rodriguez et al., 2008). More sound hydraulic profiles along drain canals were calculated by the approach from coupling two models. According to Rodriguez et al. (2008), when apply the approach, the stream and aquifer interaction scenario can replace the drain package by river package.

The change in electrical conductivity (EC) of river water at downstream of Maules Creek can only be caused by the mixed with groundwater or with hyporheic different zones (Andersen and Acworth, 2009). Besides, it is a highly possibility that the river recharge is significant in the regional abstraction of groundwater.

Major ions, stable isotopes (deuterium and oxygen-18) and a radioactive isotope (radon-222) were used as environmental tracers to better understand groundwater and surface water interactions in the Border Rivers catchment, Australia (Baskaran et al., 2009). He showed that significant chemical and biological processes occur at the hyporheic zone that affects both surface water and groundwater chemistry. They also documented that the recharge of the alluvial aquifers by surface water occurs by bank infiltration, with diffuse recharge during high-rainfall events more dominant further away from the river.

MODFLOW model and HEC-RAS model were applied as a tool to assess river seepage and groundwater loss due to the rubber dam constructions in the Baihe River, China (Chen, Xi et al., 2012). From the sensitivity analysis of two models, he underlined that the combination of the river bed composition and infiltration capacity is a primary factor controlling amount of the river water seepage.

2.1.2. Interaction parameter

Boehmer (2000) mentioned that river conductance of rivers and canals is a very important parameter for calculating the seepage of water from/to underlying aquifer. He used hydraulic conductivity from pumping tests of whole Nambo plain to estimate conductance value at all hydraulic stations of river system in Nambo plain, consist of Saigon River.

Another approach from river interaction parameter was introduced by using river coefficient concept. A proxy coefficient from stream deposits properties was estimated to simulate river and aquifer interaction in the Lower Llobregat river (Barcelona, NE Spain) (Pérez-Paricio et al., 2010). By assuming that all measurable aquifer-river head losses are due to the streambed itself, Pérez-Paricio et al. (2010) combined formula 2.1 and 2.2 to develop a linear relationship between channel slope and the river conductance.

$$C_e = \frac{K_e L W}{M} \tag{2.1}$$

where K_e (LT^{-1}) is the hydraulic conductivity of the bed material, M (L) is the river bed thickness and L (L) and W (L) define the length and width of the river cell for the node. Since these are geometrically defined by the mesh, calibration of the aquifer-river interaction focuses on the factor K_eM^{-1} (river coefficient)

$$s \approx \theta_i R D M^{-1} \tag{2.2}$$

where θ_i (-) is the Shields parameter depending on the mode of transport (suspended load, mixed load and bed load), R (-) is the relative excess density of sediment particles, and D (L) is median grain size of channel bed material as shown in Figure 2.1.

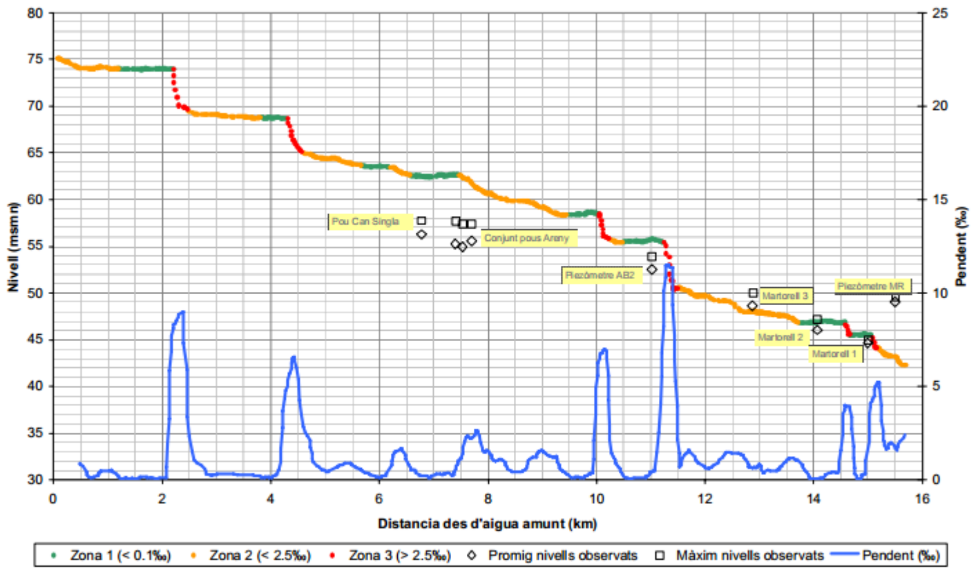


Figure 2.1. Zonation of the river coefficient depending on the river slope

The hydraulic parameters of a stream-aquifer, including horizontal hydraulic conductivity (Kx); aquifer anisotropy (Ka); streambed leakance l; aquifer specific storage Ss; and specific yield Sy were calculated by a nonlinear regression method (Chen, Xunhong and Chen, 2003). Streambed leakance can be inversely calculated from pumping test also in case appropriately designed and conducted near streams. A sensitivities for stream leakance shown that the stream leakance increase with time.

Fox et al. (2011) used a stream –aquifer analysis (SAA) as a pumping test adjacent to a stream to estimate reach-scale streamed conductance at the North Canadian River in central Oklahoma. Predicted drawdown by an analytical solution was fit to the observed drawdown to inversely estimate the transmissivity (790 to 950 m^2 d^{-1}), specific yield (0.19 to 0.28), and streambed conductance (600 to 1500 $m.d^{-1}$), which was compared to values derived from in-stream measurements (i.e., grain-size analyses on streambed sediment samples and in-stream falling-head permeameter tests). Fox et al. (2011) also concluded that the simpler analytical solutions can be adequate to inversely estimate the aquifer and streambed hydrologic parameters.

The streambed conductance is a parameter that effects to the head difference between the stream and aquifer to flow across the stream channel and it impacted on accuracy of the models (Lackey et al., 2015). He also estimated the streambed conductance by a sensitivity of depletion. The authors also used numerical simulations to demonstrate that a range of streambed conductance values depend on aquifer properties.

2.1.3. Groundwater modeling

Valerio et al. (2007) developed groundwater model MODFLOW and combined with Riverware model to calculate for the relatively rapid groundwater and surface water interactions in riparian zones on the Rio Grande near Albuquerque, New Mexico. He also suggested that in the lower portion of the model was less than river flows would produce drastically reduced seepage from the river to the aquifer at projected future groundwater conditions, and could contribute to a lowered water table.

Brunner et al. (2010) focused on analyzing the well-known assumption about surface water and groundwater interaction in the conceptualization of MODFLOW. The results shown that (1) the negative pressure gradient is an important factor of infiltration flux estimation, (2) the infiltration flux result of the model is only true with disconnected systems, (3) the size of the single grid cell a river impacted on the infiltration flux results, and (4) the infiltration flux is affected by the vertical discretization of the aquifer.

Bejranonda et al. (2013) used MODFLOW to determine the potential conjunctive use and explain the relationship between groundwater and river in the Plaichumpol, Thailand. The results of MODFLOW model showed that the recharge from two rivers and irrigation canals occupied 64% of total groundwater recharge in dry season. He also underlined the importance of the relationship between river and canals recharge to increase groundwater levels.

Rassam et al. (2013) applied MODFLOW to identify the role of the interaction between groundwater and river in river management model in the predominately gaining Boggabri-Narrbri reach of Nam Moi River in East Australia. The results of model emphasized the various groundwater closed to and away from the river. In addition, they combined MODFLOW with river model to calculate account for GW-SW interactions. From this, he demonstrated that groundwater system connected hydraulically with surface water system and there are continuous a number of exchange water between two systems.

Lackey et al. (2015) used numerical simulations to demonstrate that the stream depletion estimates are sensitive to a range of streambed conductance values depending on aquifer properties. He compared the stream depletion estimates by using various spatial patterns of streambed conductance to show that modeling streambed conductance as a homogeneous property can lead to errors in stream depletion estimates.

2.1.4. Water resources in Saigon River area

Chan (2008) built a groundwater flow model in HCMC and its vicinity. The model divided strata of this area into 15 layers, including 8 aquifers and used water withdrawal data to estimate water demand in 2007, 2015, 2020 and three scenarios of groundwater withdrawal by 398,047 m^3/day, 1,205,306 m^3/day, and 1,396,953 m^3/day. The result of model showed details the rate of 4 sources of groundwater recharge as: Surface, leaky, flow from neighborhood area and changing storage.

Pham et al. (2009) used the harmonic analysis method to simulate the water level for Saigon – Dong Nai river system based on the tidal and non-tidal constituents. The non-tidal constituent results showed that the rainfall and wind are two main factors of the water level variation on the river. Pham, D.M. et al. (2009) also documented that the water level simulation quality increased after supplementing the non-tidal elements.

Sajor and Minh Thu (2009) focused on organizational issues particular to water resources in Saigon River. They also showed the challenges and opportunities for an alternative integrated management approach in Vietnam, particularly in the context of its political legacy, current development goal, and Doi Moi reforms.

Vuong (2013) applied the groundwater sustainability infrastructure index (GSII) to evaluate the groundwatersustainability in Ho Chi Minh area which is *a delta city on* the bank of Saigon River. The results showed that all index components are approximately 'medium'. He also suggested that overall situation of 'groundwater sustainability infrastructure' in HCMC can be rated as sustainable.

Viet (2014) extended area of model to around 18,210 km^2 to simulate for Saigon River basin area by 3,870 km^2, and model grid size by 1000x1000m with eight aquifers. The results of calibration and verification follow two cases: steady and transient stages shown that the flow in of groundwater consists of five components as rainfall, surface, leaky, flow from the besides area and changing storage. In this, the river recharge occupied until 18.54% to 21.41% of the flow in.

Minh et al. (2015) focused on an advanced PSI (persistent scatters interferometry) analysis to provide a spatial extent and continuous temporal coverage of the subsidence in HCMC from 2006 to 2010. The results showed that subsidence is most severe in the Holocene silt loam areas along the Saigon River and in the southwest of the city. Minh et al. (2015) recognized that the major cause of the subsidence were groundwater extraction resulting from urbanization and urban growth.

Khai (2015) applied MODFLOW model to estimate land recharge in Ho Chi Minh area. The result of MODFLOW model showed that the land recharge provided from 0 to 30% for flow budget from 1998 to 2015 in Ho Chi Minh area. Khai (2015) also documented that river recharge provided 20%-40% to water budget and the river recharge depended mainly on groundwater abstraction.

In summary, river recharge has a important role in providing water to groundwater system in Saigon River area, however the previous research seems to less fully understanding about groundwater and river interaction. Conductance was only estimated at two locations in Saigon river and then was interpolated to other locations. Ten river cross-sections along Saigon River were investigated and analyzed to estimate conductance in this study.

Some previous research mentioned that river slope and river bed properties, are main factors of groundwater and river interaction. In this study, morphology of river cross-section can be computed to find linear relationship with interaction parameter. Therefore, this study tried to estimate interaction parameter along Saigon river to have a more clearly overview about groundwater and river interaction in Saigon River area.

2.2. Theories used

A groundwater model is used to assess the exchange flow of groundwater system and river in Saigon River area. The aim is to determine interaction parameter at cross sections along the river and relationship with morphology of river cross-section. So, this section provides details the theories to improve boundaries condition of groundwater water model and estimate interaction parameter as below:

- Groundwater modeling (groundwater level, river recharge, interaction parameter).
- Distribution of pumping rate and hydraulic conductivity
- River water levels

2.2.1. Groundwater modeling

2.2.1.1. Groundwater levels.

GMS is the most intuitive and capable software platform used to create groundwater and subsurface simulations in a 3D environment. MODFLOW is a three-dimensional (3D) finite-difference groundwater model (GMS).

MODFLOW model is used to predict aquifer response, in terms of head (groundwater level) and fluxes into and out of an aquifer. All variations of groundwater level are described by a derivative equation 4.1 below:

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)+q_s=S_s\frac{\partial h}{\partial t} \qquad (2.3)$$

Where:

K_{xx}, K_{yy} and K_{zz} are the values of hydraulic conductivity along the x, y, and z coordinate axes and may be function of space [L/T];

h is the hydraulic head [L];

q_s is the volumetric flux of groundwater sources and sinks per unit volume [1/T] with positive values indicating flow into the groundwater system

S_s is the specific storage of the porous material and may be function of space [1/L], t is time [T]

Figure 2.2 describes the process of spatial discrete and hydrogeological region which are divided by vertical direction into the aquifer.

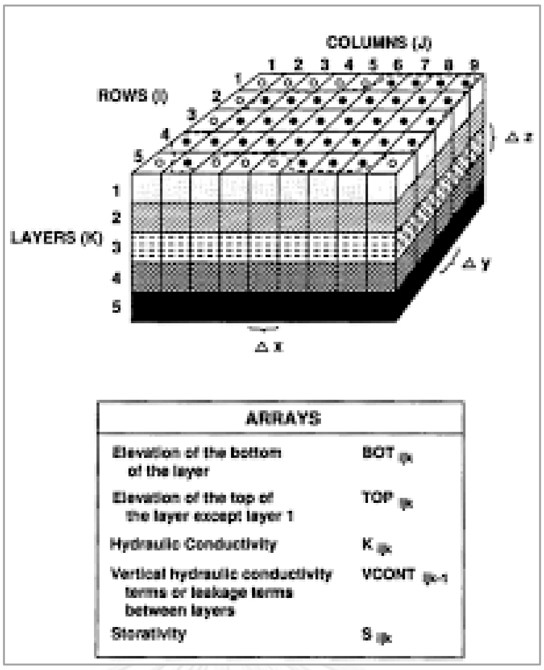


Figure 2.2. Generic MODFLOW grid (McDonald and Harbaugh, 1988)

The difference set of equations was formed from Equation 2.4 based on water balance rule as below:

$$\sum_i Q_i = S_s \frac{\Delta h}{\Delta t} \Delta V \tag{2.4}$$

Where:

Q_i is flow in the cell (choose minus value for flow out)

S_s is the specific storage of the porous material and may be function of space [1/L]

ΔV is the volume of the cell [L].

Δh is variable value of h in the time Δt at the cell.

The equation, together with specification of flow and head conditions at the boundaries of aquifer system and specification of initial head conditions, constitues a mathematical representation of groundwater flow system. Figure 2.3 describes the flow from one cell (i, j, k) to six next cells : (i-1,j,k), (i+1,j,k), (i,j-1,k), (i,j+1,k), (i,j,k-1), (i,j,k+1).

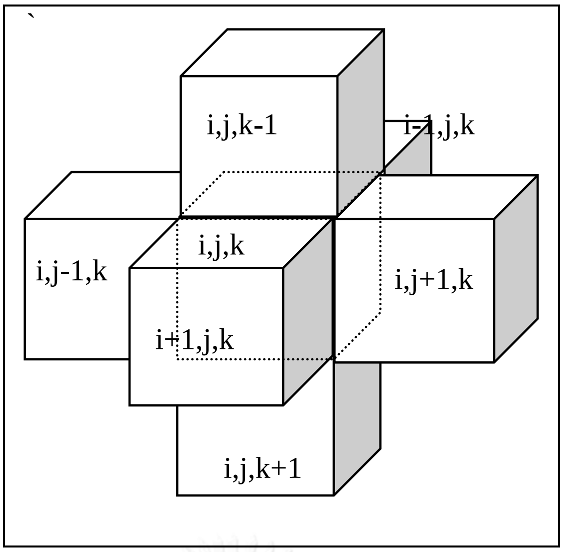


Figure 2.3. Water balance calculation of one cell

Applying Darcy Law to calculate the flow from one cell to next cell, we have the formula as below:

$$q_{i,j-1/2,k} = KR_{i,j-1/2,k} \Delta c_i \Delta v_k \frac{(h_{i,j,k} - h_{i,j-1,k})}{\Delta r_{j-1/2}} \quad (2.5)$$

Where:

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

$q_{i,j-1/2,k}$ the flow rate through the interface between two cells (i,j,k) and (i,j-1,k)

$KR_{i,j-1/2,k}$ is the hydraulic conductivity of the flow through two nodes (i,j,k) and (i,j-1,k)

$\Delta c_i \Delta v_k$ is the area of interface.

$\Delta r_{j-1/2}$ is the distance between two nodes (i,j,k) and (i,j-1,k)

So, combining the equation for six next cell, the finite-difference equation for the cell is presented as below :

$CR_{i,j-1/2,k}(h_{mi,j-1,k}-h_{mi,j,k})+CR_{i,j+1/2,k}(h_{mi,j+1,k}-h_{mi,j,k})+$

$+CC_{i-1/2,j,k}(h_{mi-1,j,k}-h_{mi,j,k})+CC_{i+1/2,j,k}(h_{mi+1,j,k}-h_{mi,j,k})+$

$+CV_{i,j,k-1/2}(h_{mi,j,k-1}-h_{mi,j,k})+CV_{i,j,k+1/2}(h_{mi,j,k+1}-h_{mi,j,k})+$

$+ P_{i,j,k}h_{mi,j,k-1}+Q_{i,j,k}=SS_{i,j,k}(\Delta r_j \Delta c_j \Delta v_k)(h_{mi,j,k}-h_{m-1i,j,k})/(t_m - t_{m-1})$

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 Qi,j,k< 0.0 for flow out of the groundwater system, and Qi,j,k> 0.0 for flow in (L^3/T);

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

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

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

Δi,j,k is the vertical thickness of cell i,j,k (L);

t_m is the time at time step m (T).

2.2.1.2. River recharge

The river recharge is calculated by MODFLOW model. The calculations based on stage in the river, hydraulic head in the part of the groundwater system underlying the river, river bed bottom elevation, and hydraulic conductance of the river bed. The equation is presented to calculate the exchange flow rate as follow:

$$Q_r = C(S\text{-}H) \qquad \text{when } H \geq RBOT \tag{2.6a}$$

$$Q_r = C(S\text{-}RBOT) \qquad \text{when } H < RBOT \tag{2.6b}$$

Where:

Q_r is the river recharge [L^3/T], when river gains water from aquifer, the exchange flow is defined as river recharge out (RRO). In contrast, when river lost water to aquifer, the exchange flow is defined as river recharge in (RRI).

C is the hydraulic conductance of the river bed,

S is the stage in the river reach (L),

H is the hydraulic head in the GW system underlying the river reach (L);

RBOT is the elevation of the river bed bottom (m).

For initial model, the conductance from research of Boehmer (2000) was applied for inputting river boundary condition. Conductance coefficient was used to calibrate by piezometric head at three cross-sections. Root mean square and coefficient of determination of regression were used to find the best value of conductance.

In the case of a river boundary condition, the conductance is defined in MODFLOW as the hydraulic conductivity of materials of interaction layer divided by the vertical thickness (length of travel based on vertical flow) of the river bed materials, multiplied by the area (width times the length) of the river in the cell. The last term, area, is the hardest parameter to determine by hand since it varies from cell to cell.

GMS can automatically calculate the lengths of arcs and areas of polygons. Therefore, when a conductance is entered for an arc, it should be entered in terms of conductance per unit length. Hydraulic conductance of the interaction layer for a given reach typically is conceptualized from interaction parameter value (function 2.7) as:

$$C = K_i M^{-1} \times W \tag{2.7}$$

Where:

C is conductance per unit of interaction layer [L/T];

K_i is hydraulic conductivity of interaction layer [L/T];

W is total wetted length of interaction layer [L];

M is thickness of interaction layer [L].

2.2.1.2. Interaction parameter

As mention of Lackey et al. (2015), aquifer properties have significant impact on range of streambed leakance. So, with each morphology of river section, stream bed leakance has difference values. In this study, the interaction layer was defined as a combined layer by materials of riverbed with materials of aquitard or aquifer as Figure 2.4 below.

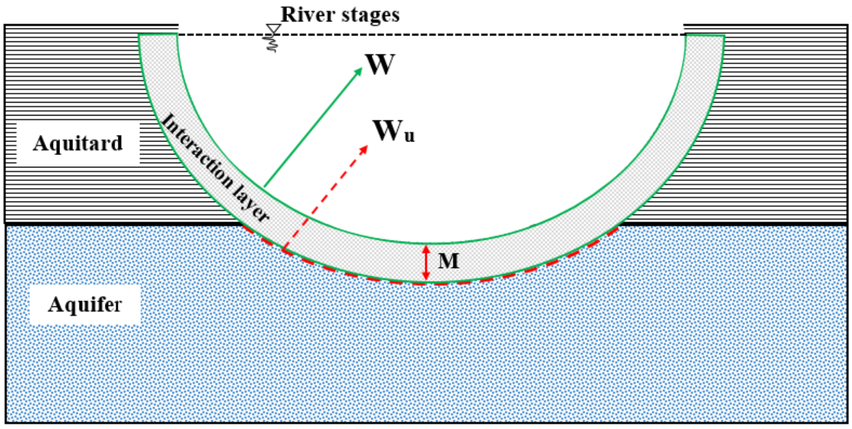


Figure 2.4. Groundwater and river interaction layer simulation

Where:

W is total of wetted length [L]

W_u is wetted length under aquifer [L]

M is thickness of interaction layer [L]

Wetted length ratio of interaction layer (R_u) is calculated as function below:

$$R_u = \frac{W_u}{W} \tag{2.8}$$

Interaction parameter is defined as hydraulic conductivity of interaction layer divide by thickness of interaction layer. Change of morphology of river cross-section will bring about the change of ratio aquifer properties and aquitard properties of interaction layer (Figure 2.4). In other words, interaction parameter values depend on morphology of river cross-section. In this study, interaction parameter was assumed as linear function with ratio of wetted length ratio at correlative cross-section.

$$K_i M^{-1} = a \times R_u + b \tag{2.9}$$

Where:

K_iM^{-1} is interaction parameter of the interaction layer [T^{-1}];

R_u is wetted length ratio of interaction layer;

a,b are coefficients of regression.

2.2.2. Pumping rate estimation

Distribution of pumping concentrated Thuan An district and Thu Dau Mot city area, and occupied until over 85% of total pumping rate of the study area (See Figure 2.5). The groundwater abstraction in Thuan An district and Thu Dau Mot city is used mainly for industry. As industry growth, the population of the area increased significantly from 272,176 people in 2000 to 409,792 people in 2007.

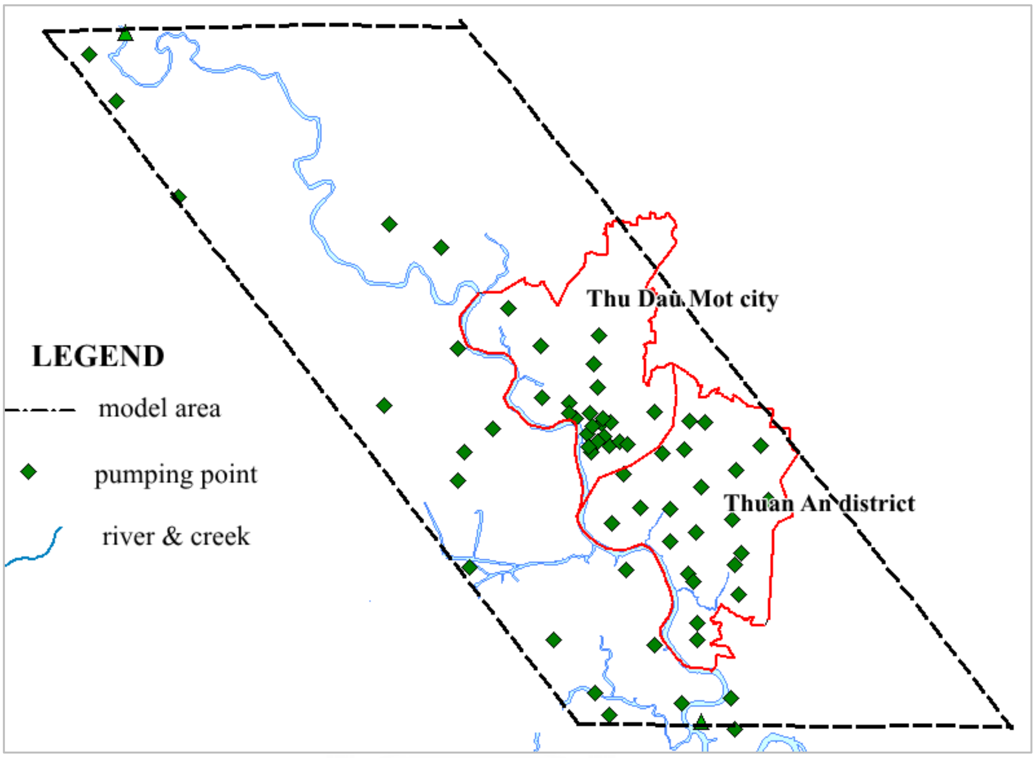


Figure 2.5. Distribution of pumping wells of $qp_{2\text{-}3}$ aquifer

Ratio of pumping volume of the study area per one person from 2001 to 2006 was calculated and was used to interpolate for other years based on population.

$$R_Q = (Q_{2000} + Q_{2007})/(P_{2000} + P_{2007}) \qquad (2.10)$$

Where:

R_Q is ratio of pumping volume per one person

Q_{2000} is pumping volume of aquifer in 2000

Q_{2007} is pumping volume of aquifer in 2007

P_{2000} is population of Thu Dau Mot and Thuan An area in 2000

P_{2007} is population of Thu Dau Mot and Thuan An area in 2007

The pumping rate of $qp_{2\text{-}3}$ aquifer and qp_1 aquifer were estimated using ratio of pumping volume per one person (eq. 2.10) and population of Thu Dau Mot and Thu An area in same year as function below

$$Q_x = R_Q \times P_x \qquad (2.11)$$

Where:

x: year

Q_x is pumping rate in year x (m^3/d)

P_x is population in year x (person)

2.2.3. River water levels

In project on "Groundwater protection in Ho Chi Minh city" (2014), water levels at cross-section along Saigon river as TV1, TV3, TV7 and TV9 cross sections were measured by hourly. (See location in Figure 2.6)

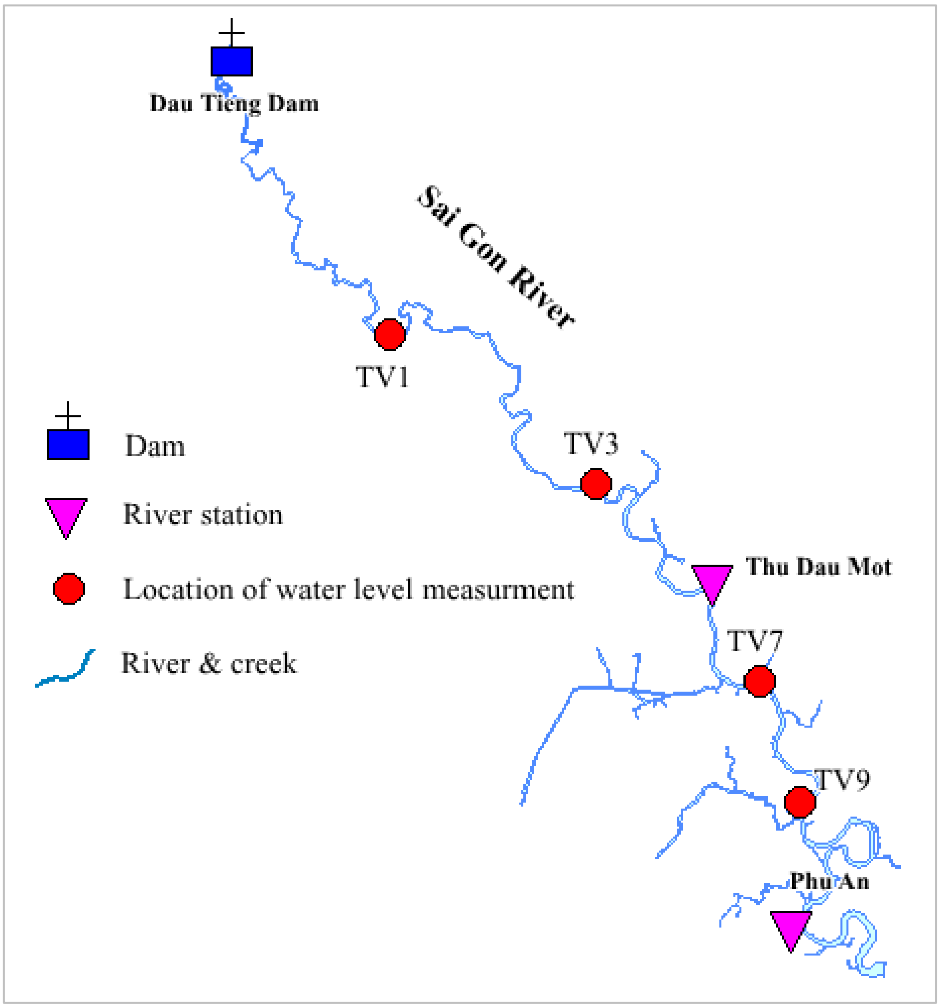


Figure 2.6. Location of water level measurement along Saigon River

In this study, to improve river boundary water levels at cross-section along Saigon river as TV1, TV3, TV7 and TV9 cross sections January 2000 to September 2007 were estimated by using correlation and regression analysis to compute water level measurement by hourly in 2014 with dam release from Dau Tieng Dam or river stages at Thu Dau Mot station and Phu An station.

$$Y = a \times X + b \tag{2.12}$$

Where:

Y is water level at cross-section [L]

X are water levels [L] at Thu Dau Mot station or Phu An station

a, b are coefficients of regression

$$Y = a \times R_d + \mathrm{b} \tag{2.13}$$

Where:

Y is water level at cross-section (L)

R_d is release at Dau Tieng Dam [L^3/T]

a, b are coefficients of regression

2.2.4. Distribution of hydraulic conductivity

143 pumping test data of 3 aquifers as qp_3, qp_{2-3} and qp_1 were collected from project on "Groundwater protection in Ho Chi Minh city" (2014).

As mentioned Long (2017), the Kriging is the good method to interpolate hydraulic conductivity of all aquifers in Saigon basin. The geostatistical estimation technique (Kriging) uses a linear combination of surrounding sampled values to make such predictions.

The process of Kriging interpolated values for a grid of points based on the weighted grades of points surrounding it. The Kriging weights are based on the variogram model parameters and the anisotropy factors for the search ellipsoid.

Kriging system solves problem following steps as below:

- A linear estimator for Rev. or spatially correlated data
- Estimation based on point data available => yields either point estimated or block average
- Variogram/spatial correlated required for spatial correlation incorporated into the estimation

The mean grade Z_∇ of the block ∇ is estimated as linear combination of the N data values in Kriging:

$$Z_\nabla = \sum \lambda_i Z_i \tag{2.14}$$

The N weight λI are determined to hold the following two points;

- The estimation is unbiased: $E(Z_\nabla - Z_\nabla^*) = 0$
- The variance of estimation is minimal: $\sigma_E^z = E\{[Z_\nabla - Z_\nabla^*]^2\}$ => minimum

Variogram relationship based on the measured points is as follows:

$$\gamma(h) = \frac{1}{2n(h)} \sum_{i=1}^{n(h)} [z(x+h) - z(x)]^2 \tag{2.15}$$

Where:

γ(h) is the variogram for a distance (lag) h between observations z(x) and z(x+h).

n (h) is the number of pairs of observations which are at distance h.

z(x) is the observed variable.

z (x+h) is the observed variable is the h distance from z (x) and variogram γ(h).

The variogram in this study was applied for all aquifers excepted the top aquifer (qh) because of lacking pumping test data of this aquifer. Figure 2.7, Figure 2.8 and Figure 2.9 show the variograms were applied for interpolating hydraulic conductivity of qp_3, qp_{2-3} and qp_1 aquifer, respectively.

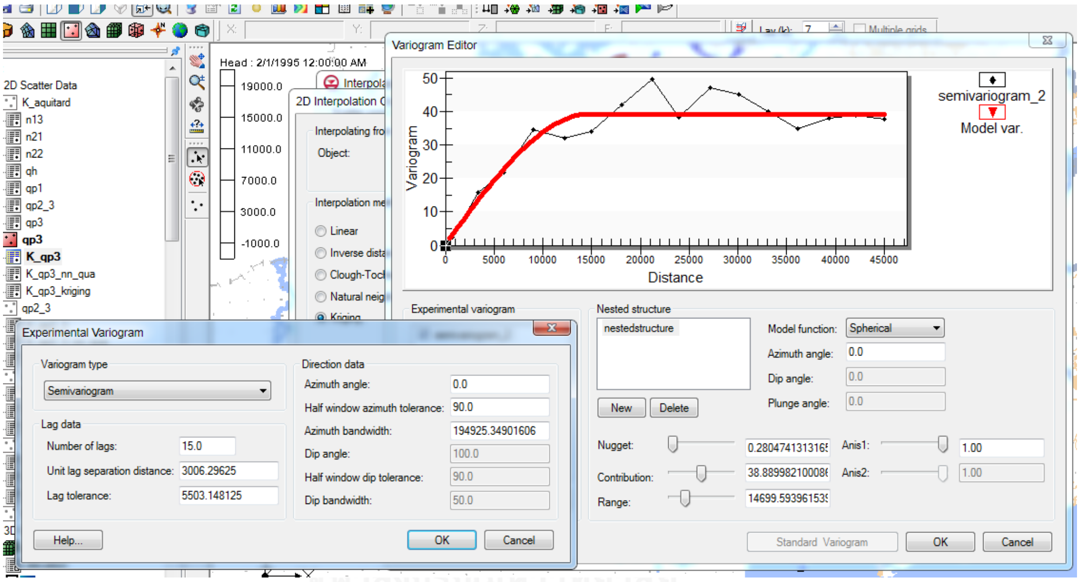


Figure 2.7. Variogram application for qp_3 aquifer (Long, 2017)

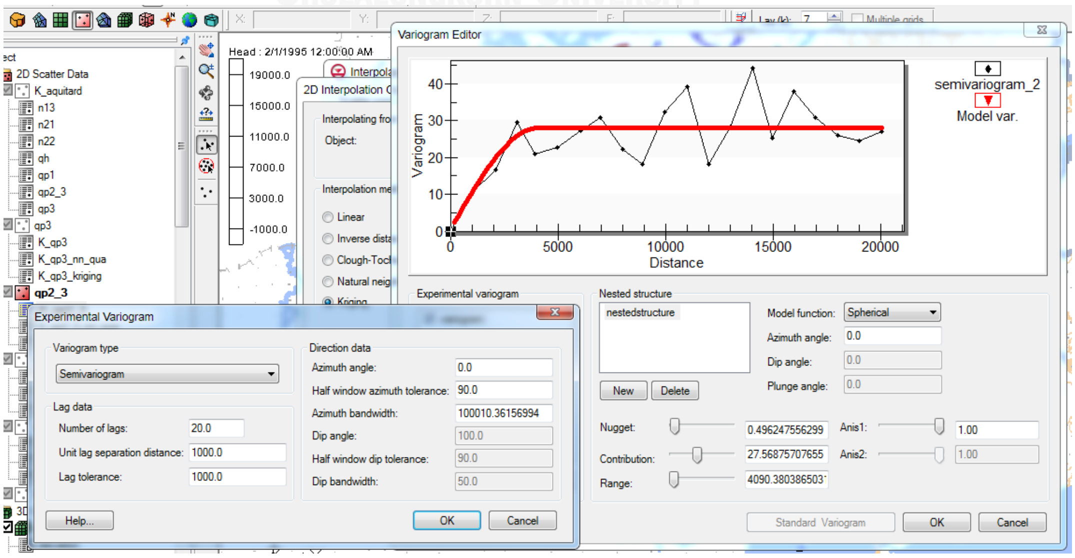


Figure 2.8.. Variogram application for qp_{2-3} aquifer (Long, 2017)

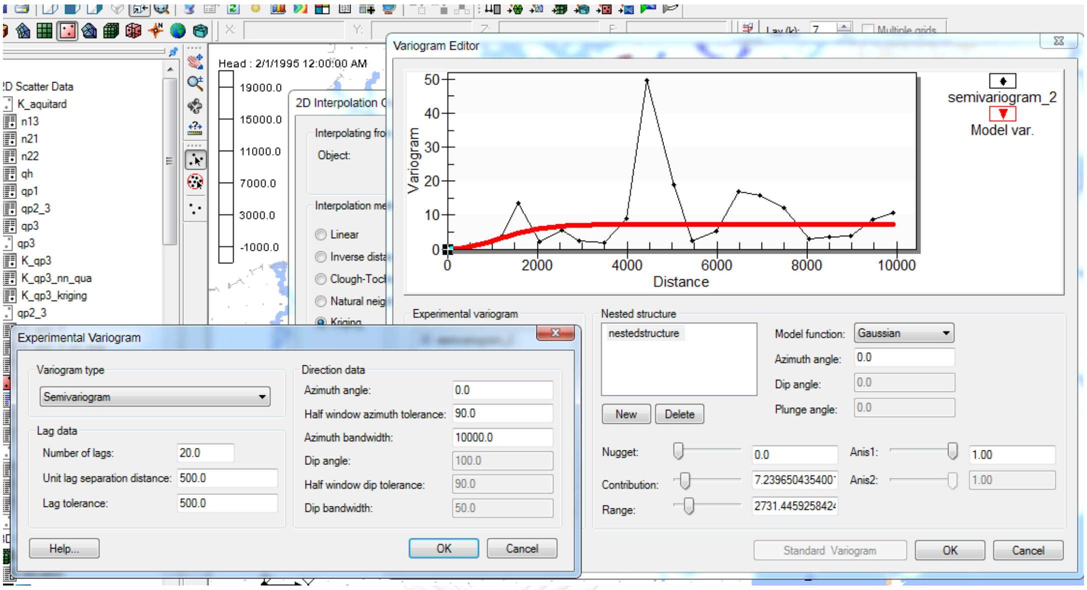


Figure 2.9. Variogram application for qp_1 aquifer (Long, 2017)

CHAPTER 3: STUDY AREA CONDITIONS

Most water resources researches begin by defining the study area. Sometimes, study areas follow governmental boundaries such as city limits, but most often there are river basin or sub-basin. As part of Saigon River basin, the study area cover only a part of Saigon River along main stream of Saigon River to improve the water management especially groundwater resources. However, to have a macro picture, this chapter describes main hydrological factors such as climate, hydrology, hydrogeology in whole Saigon basin and also includes groundwater exploitation in the study area.

3.1. Location

Saigon River, Vietnamese Song Saigon, river in southern Vietnam that rises near Phum Daung, southeastern Cambodia, and flows south and south-southeast for about 140 miles (225 km). In its lower course it embraces Ho Chi Minh City (formerly Saigon) on the east and forms an estuary at the head of Ganh Rai Bay, an outlying part of the Mekong delta. The Saigon is joined 18 miles (29 km) northeast of HCMC by the Dong Nai River, an important stream of the central highlands, and just above HCMC it is joined by the Thi Tinh River as shown in Figure 3.1.

Figure 3.1. Location of Saigon River

3.2. Topography

Saigon basin topography is gradually lower from the north to the south and from the west to the east (Figure 3.2). Average elevation is from 2 to 5.2 m, except for some high hills in the northern delta province. Along the Saigon River, elevation is from the 0.1 to 6.0 m high, then lower to the central plains in the 1.0 to 1.5 m high, and only 0 0.3 to 0,7 m in the tidal, coastal area. The geology of Saigon basin consists of two main types of sedimentary faces which are Pleistocene and Holocene exposed on the surface.

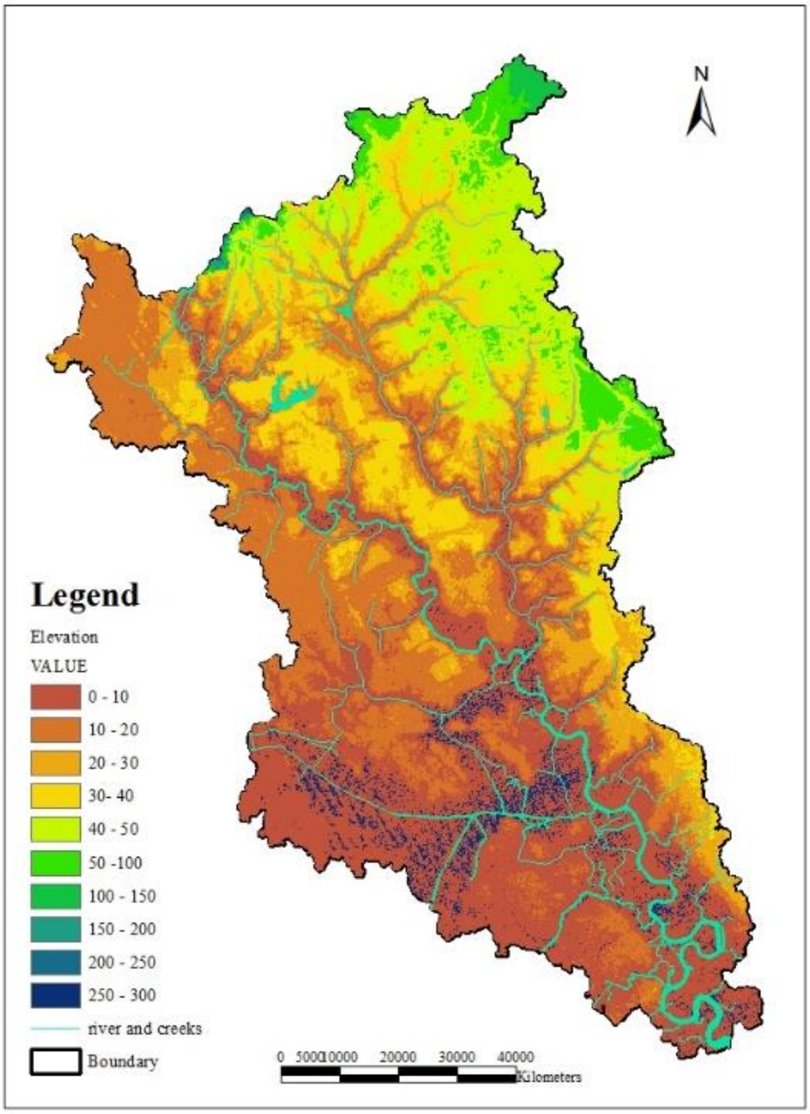


Figure 3.2. Topography of Saigon River basin

3.3. Hydrology

The Saigon River system consists of the natural river systems and the manmade canal systems. The system of manmade canal in the Saigon Basin was developed primarily during the past century, with the primary purpose to develop agriculture and transportation (Figure 3.3).

Dau Tieng reservoir affects a large area of Saigon River basin (2,700 km^2). Its volume is 105 million m^3. It supplies water for irrigation and a clean water supply in Tay Ninh (north of Dau Tieng reservoir) Province and HCMC. The irrigation canal system is also a significant freshwater recharge source for the groundwater aquifers in the Saigon River basin, located in the west and southwest of HCMC (Tai, 2015). Moreover, the reservoir also contributes to push back the salinity point because it discharges water to the downstream of Saigon River at a rate of 20 m^3/s to control a salinity of 4% at Phu An station.

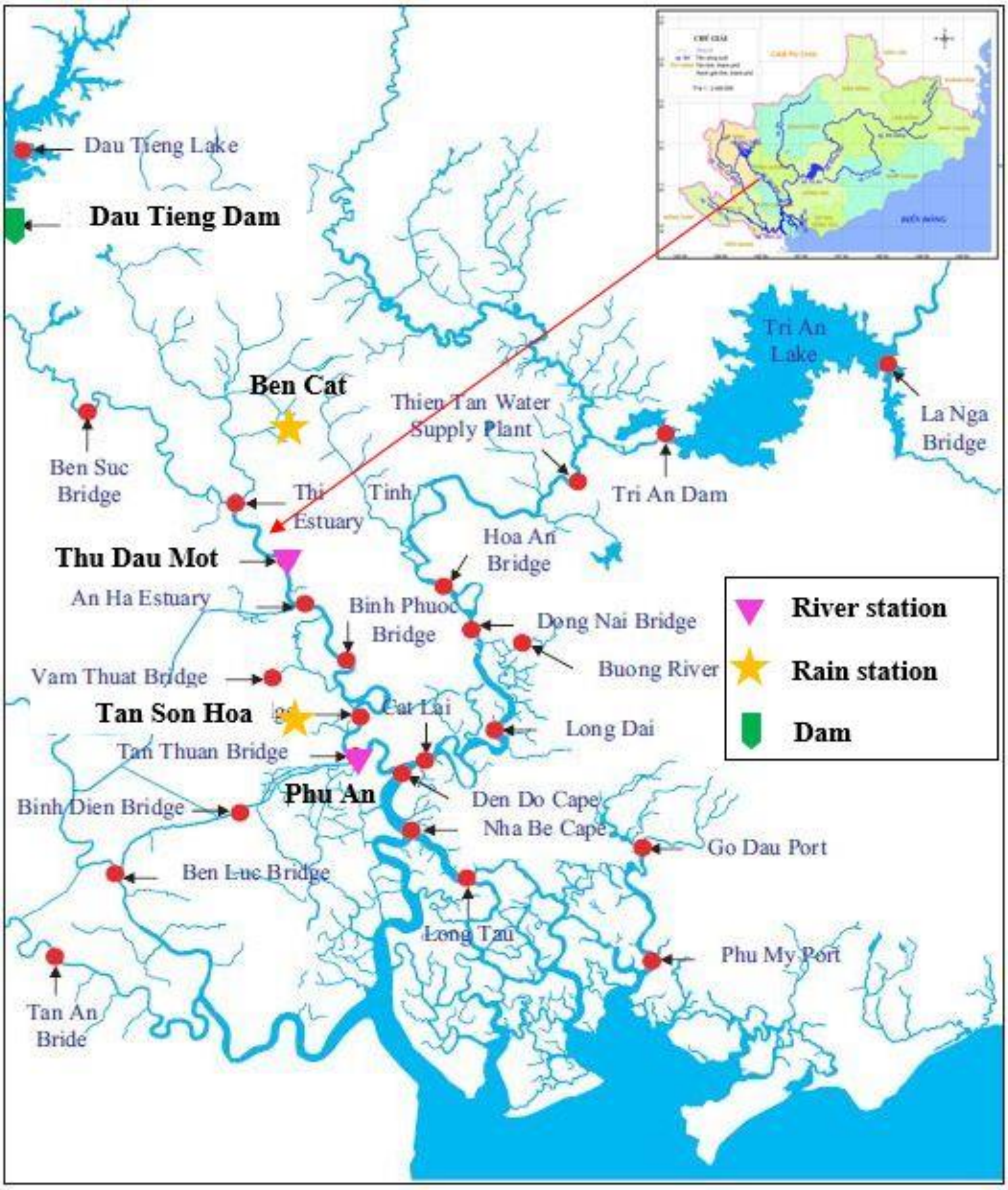


Figure 3.3. Saigon – Dongnai River system (Ohgaki et al., 2006).

The river depth and river width are 10-20 m and 250 - 350 m, respectively. Maximum flow rate was 84 m^3/s in October, 1986 (recorded at Thu Dau Mot station, Binh Duong Province) and minimum flow rate was 22.5 m^3/s in August, 1986. Maximum and minimum water level were 1.18 m (10th October, 1990) and -0.34 m (20th October, 1990). Saigon River is affected by semi-diurnal tidal flow regime. The changes of water level in Saigon rivers is very low between 1960 and present time. The variation of water level of Saigon River at Phu An is low (only 10 cm) as shown in Figure 3.4.

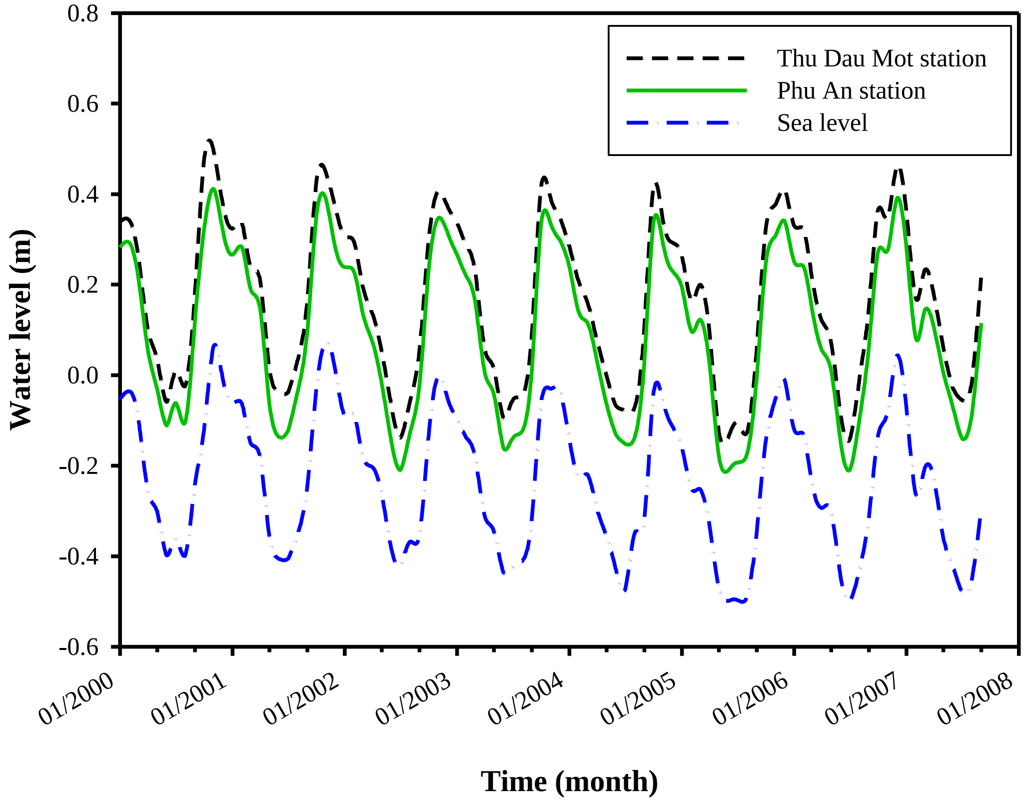


Figure 3.4. Relationship sea level and water levels at two river stations

3.4. Climate

The climate of Saigon River basin is equatorial monsoon climate and is divided in two seasons: the rainy season and dry season. The distribution of rainfall, temperature and evaporation are described as below:

Rainfall

The annual rainfall varies from 1,400 – 2,400 mm/year. Rainfall distributes very unevenly in the year, more than 90% of the annual rainfall is in rainy season from May to November, and less than 10% of the annual rainfall is in dry season from December – April. Figure 3.5 shows monthly rainfall at Tan Son Hoa station (Figure 3.3) in Saigon basin during period of 1999-2010.

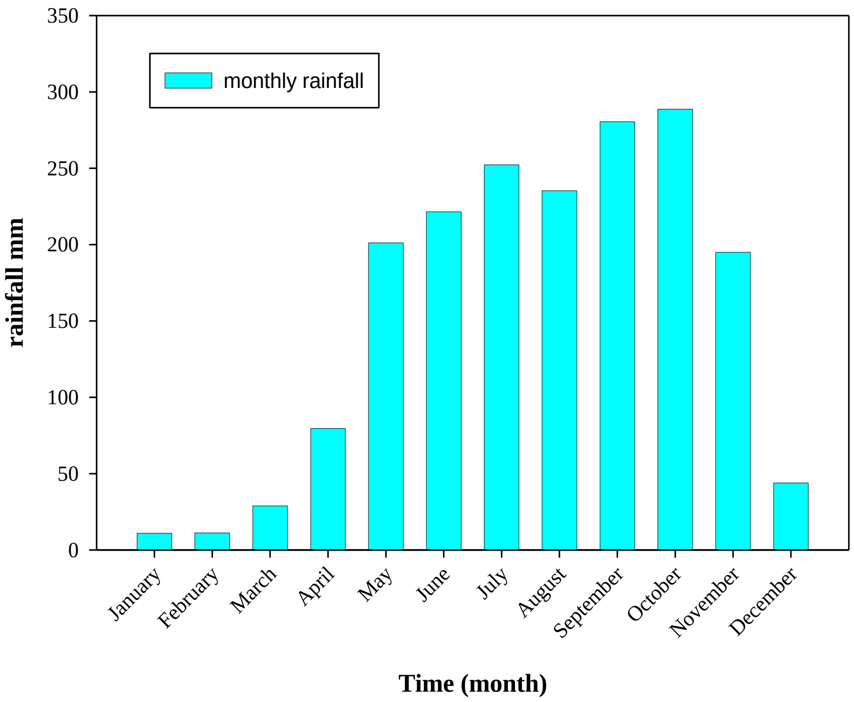


Figure 3.5. Monthly rainfall at Tan Son Hoa station

Temperature and evaporation

The temperatures are highest on average in April, at around 29.5 °C. In December, the average temperature is 25.9 °C. It is the lowest average temperature of the whole year (see Figure 3.6) (Southern Regional Hydrometeorology Center). The open pan evaporation is from 800 to 1,300 mm/year with the lowest evaporation in October and the highest in March.

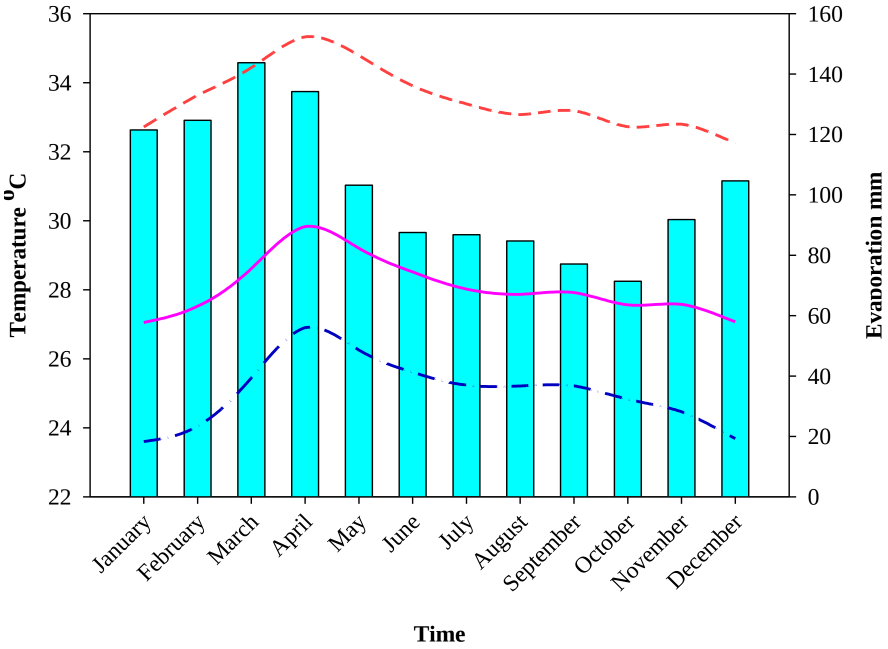


Figure 3.6. Monthly temperature and evaporation at Tan Son Hoa station

3.5. Hydrogeology

There are six distinguished aquifers in Saigon basin, namely Holocene (qh), Upper Pleistocene (qp_3), Upper- middle Pleistocene (qp_{2-3}), Lower Pleistocene (qp_1), Middle Pliocene (n_{2-2}) and Lower Pliocene (n_{2-1}). Generally, lithology of each aquifer consists of fine to coarse sand, gravel, and pebble.

The two cross sections (Figure 3.7) illustrated in Figure 3.8 and Figure 3.9 provides an overview of the spatial distribution and interconnection of aquifer system of the Deltas' subsurface. Basically, the aquifer system in Saigon basin has an artesian basin structure. A brief characterization of the aquifers and their composition is summarized below.

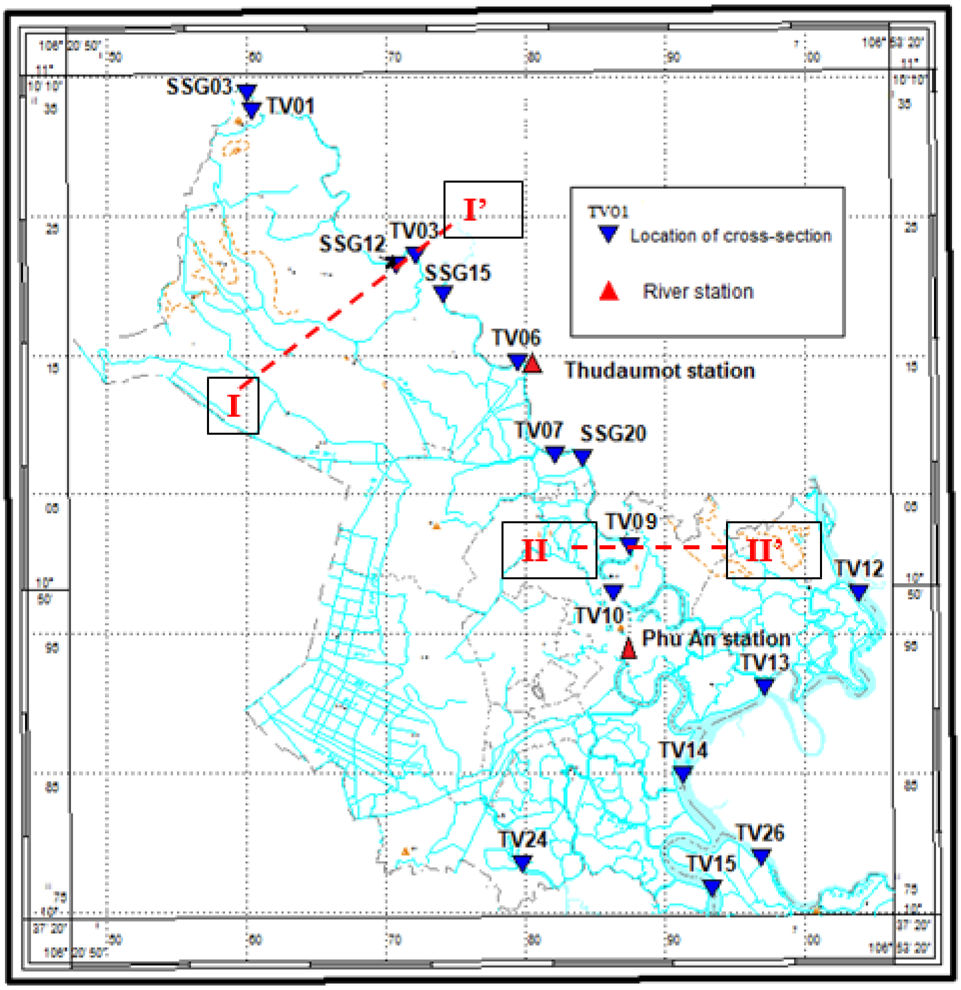


Figure 3.7. Cross-section layout (Tai, 2015)

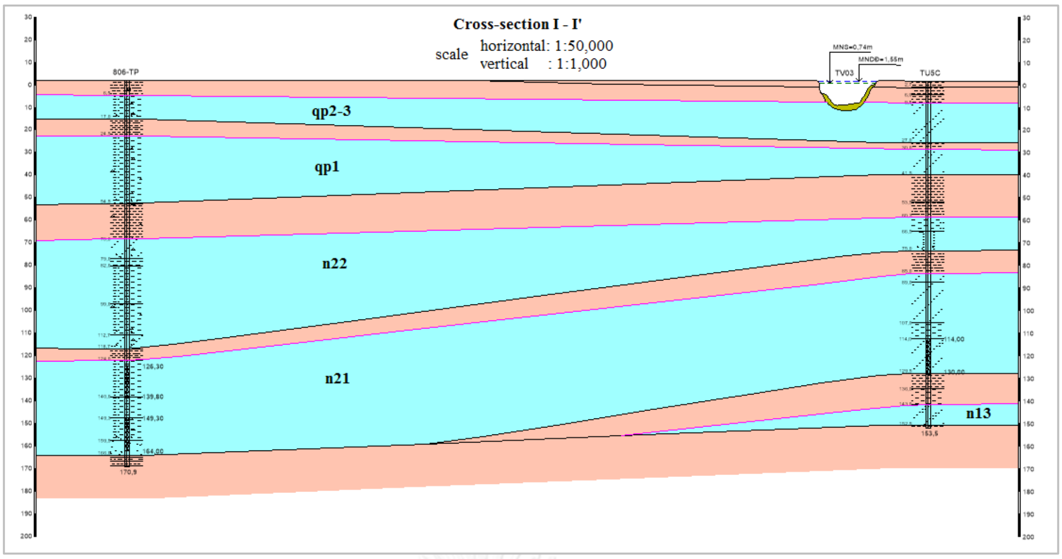


Figure 3.8. Cross-section I-I' (Tai, 2015)

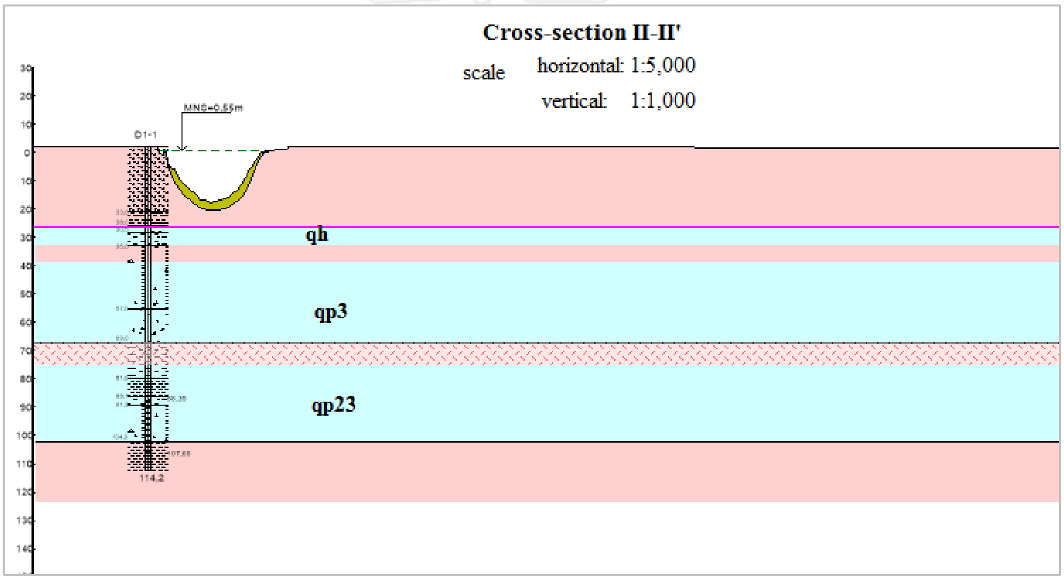


Figure 3.9. Cross-section layout - TV06 (Tai, 2015)

Intergranular Upper Pleitocene aquifer (qh)

Upper Pleistocene aquifer distributes widely on the area of 213.15 km^2. The aquifer is composed of upper Pleistocene sediments of alluvial and marine origin (amQ_1^3) consisting of fine medium sand, somewhere is coarse sand, silty sand, sandy silt.

The depth to the top of the aquifer varies from 0.7m to 63.4m, the depth to the bottom of the aquifer ranges from 4.5m to 111.6m; the thickness if from 1.0m to 90.0m., the average is 42.5m.

The pumping tests show the results as below:

The productivity aquifer change from poor to high

Initial groundwater level range from 0.5 to 9.39 MSL

Groundwater discharge range from 0.01 to 7.92l/s

Groundwater level drawdown range from 1.09 to 12.81 MSL

Specific discharge range from 0.0027 to 5.044l/sm.

Intergranular Upper – Middle Pleitocene aquifer (qp_{2-3})

Upper - Middle Pleistocene aquifer covers the area of 1,756 km^2. The aquifer is composed of upper-middle Pleistocene sediments of alluvial and marine origin consisting of fine to coarse sand, gravel.

The depth to the top of the aquifer varies from 0.0m to 134m, the depth to the bottom of the aquifer ranges from 2.5m to 157 m; the thickness if from 0.5m to 99.8m., the average is 64.7m.

The pumping tests show the results as below:

The productivity aquifer change from poor to high

Initial groundwater level range from 0.7 to 13.0 m

Groundwater discharge range from 0.008 to 18.0/s

Groundwater level drawdown range from 1.977 to 23.84 m

Specific discharge range from 0.018 to 5.501l/sm.

Intergranular Lower Pleitocene aquifer (qp_1)

Lower Pleistocene aquifer distributes widely on the area of 1856.3km^2. The aquifer is composed of lower Pleistocene sediments of alluvial and alluvial-marine origin consisting of fine to coarse sand.

The depth to the top of the aquifer varies from 0.5m to 179m, the depth to the bottom of the aquifer ranges from 2.5m to 206 m; the thickness if from 0.7m to 68.9m., the average is 25.9m.

The pumping tests show the results as below:

The productivity aquifer change from poor to high

Initial groundwater level range from +0.18 to 17.86 m

Groundwater discharge range from 0.07 to 27.77l/s

Groundwater level drawdown range from 1.177 to 38.45 m

Specific discharge range from 0.004 to 5.623l/sm.

Intergranular Middle Pliocene aquifer (n_{2-2})

Middle Pliocene aquifer distributes widely on the area of 2014.5 km^2. The aquifer is composed of middle Pliocene sediments of alluvial and alluvial-marine origin consisting of fine sand somewhere is coarse sand and Gravel sand

The depth to the top of the aquifer varies from 0.0 m to 240m, the depth to the bottom of the aquifer ranges from 15m to 274 m; the thickness if from 1.1m to 112.0m., the average is 35.4m.

The pumping tests show the results as below:

The productivity aquifer change from poor to high

Initial groundwater level range from +3.8 to 38.6m

Groundwater discharge range from 0.017 to 27.77l/s

Groundwater level drawdown range from 1.04 to 34.8m

Specific discharge range from 0.001 to 6.722l/sm.

Intergranular Lower Pliocene aquifer (n_{2-1})

Lower Pliocene aquifer distributes widely on the area of 2,213 km^2. The aquifer is composed of lower Pliocene sediments of alluvial and alluvial-marine origin consisting of coarse sand and somewhere is gravel sand.

The depth to the top of the aquifer varies from 39.5 to 288.5m, the depth to the bottom of the aquifer ranges from 50.5 to 380.0m; the thickness if from 3.5 to 109.0m., the average is 38.3m.

The pumping tests show the results as below:

The productivity aquifer change from poor to high

Initial groundwater level range from +3.8 to 38.6m

Groundwater discharge range from 0.017 to 27.77l/s

Groundwater level drawdown range from 1.04 to 34.8m

Specific discharge range from 0.001 to 6.722l/sm.

3.6. Groundwater use

Groundwater has been used in Saigon Basin since 1920 and focus on supplying HCMC (Table 3.1).Rapid increase of groundwater use started in 1990 when the economic policies of Viet Nam opened. High industrialization and urbanization resulted in the quick increase of water demands. The expansion of surface water works in Saigon Basin has not met this rapid increase. Besides, free of charge groundwater and uncontrolled exploitation has increasingly augmented the exploitation rate.

Table 3.1. Groundwater exploitation at Saigon basin (DWPRIS 2008 and 2014)

Sub-basin	**Groundwater exploitation (m^3/d)**			
	2000	**2007**	**2014**	**Predict 2020**
Dau Tieng	2,500	9,600	25,160	37,047
Thu Dau Mot	27,565	42,033	171,377	402,240
Saigon River Mouth	204,450	311,856	1,170,137	1,424,744
Total	**234,515**	**363,489**	**1,366,674**	**1,864,031**

The dynamic potential of groundwater is the difference between water volume in porous pores in rainy season and that in dry season. The static potential includes:

- Static gravity potential is the amount of water contained in porous pores of aquifer. This potential depends on the depth of aquifer, exploitation time and aquifer area, etc.
- Static elastic potential is the amount of water released from the compressed aquifers as the water pressure of this aquifer decreases. Elastic static potential depends on water release coefficient and elastic volume coefficient.

Groundwater still plays a non-replaceable role in water supply for HCMC or Saigon Basin at present, and will do so into the future. However, the groundwater is under threat due to salt water intrusion, water table descent and contamination of the shallow aquifer that have already been observed in some monitoring wells. Some papers reported that land subsidence had occurred at few areas with large exploitation capacity wells. Until now, no surveys on land subsidence have been done in Saigon River Basin and HCMC.

CHAPTER 4: STUDY RESULTS

This chapter describes an process of the characterization of the spatial variability of groundwater flow data to the groundwater. Section 4.1 gives a detail procedure of groundwater modeling consisting of input data, calibration process and deviation result. The conductance calibration process is explained in section 4.2. In section 4.2, the investigation data also analyzed to estimate interaction parameter based on conductance calibration result of groundwater modeling. The effect of mesh size which depict river width is illustrated in section 4.3. In other part of this section, deviation of the initial model (in section 4.1) compared with errors of the model which applied interaction parameter result in section 4.2 by groundwater levels and volume of river recharge.

4.1. Initial groundwater modeling

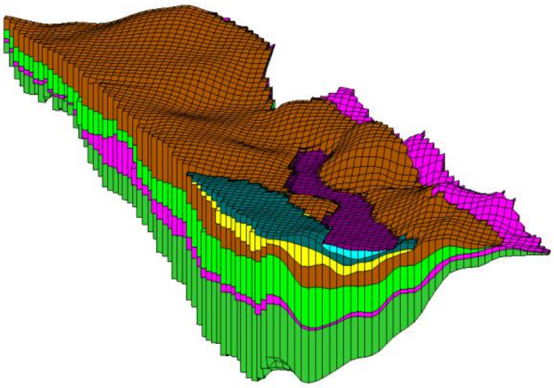
To achieve a better understanding of the groundwater system contributing exchange flow between groundwater and river in Saigon River area, a numerical groundwater model was created representing simulation of aquifers and river system. This model was the first attempt for this study and is the foundation for further groundwater modeling and exploration of the factors contributing to groundwater and river interaction. Many of the parameters, such as land recharge, conductance were approximated using previous studies of the river basin and other areas similar to the basin. Besides, distribution of hydraulic conductivity, pumping rate and river water levels were estimated to improve boundaries conditions of groundwater model. The most reliable data were used wherever possible

4.1.1. Numerical model set-up

The procedure of groundwater flow modeling is the construction of a conceptual model of the problem and the relevant aquifer domain. The conceptual model consists of defining the extent and characteristic of the aquifer system and developing an understanding of groundwater flow directions, sources and sinks. Integrating the available data on hydro-stratigraphy, well and geophysical logs, geologic map, geologic cross–section, pumping test data and boundaries conditions improvement from previous studies was applied to develop the conceptual model of the area.

4.1.1.1. Aquifer characteristic and model grid

The absolute elevations of top and bottom of 8 layers in the model were created based on well-log data from 83 wells with reliable stratigraphy information in Saigon river basin. Borehole information includes its name, coordinates, elevation Z. The values in the columns bot1, bot3, bot5 and bot7 are the absolute elevation of the bottom of aquitard layers or impermeable layers Q_2, Q_1^3, Q_1^{2-3} and Q_1^1, respectively. The value in the columns bot2, bot4, bot6 and bot8 are the absolute elevations of the bottom of aquifers qh, qp_3, qp_{2-3} ad qp_1, respectively (see detail in Apendix 1). The model grid consists of 49 rows and 86 columns with a uniform grid size of 500 x 500 m. The layers of 1, 3, 5 and 7 represented for aquitards or impervious layers. Layers of 2, 4, 6 and 8 represented for aquifers qh, qp_3, qp_{2-3}, qp_1 respectively as shown in Figure 4.1.



Layer colour	Name	Layer	Type
	Q_2	1	aquitard
	qh	2	aquifer
	Q_3	3	aquitard
	qp^3	4	aquifer
	Q_{2-3}	5	aquitard
	qp_{2-3}	6	aquifer
	Q_1	7	aquitard
	qp_1	8	aquifer

Figure 4.1. Aquifer system simulation by GMS software

4.1.1.2. Boundary conditions

General head boundaries were assigned at the distribution boundaries of aquifers qh, qp_3, qp_{2-3} and qp_1. The absolute average elevations of groundwater level (in month of each year) at the points on the general head boundaries were interpolated from absolute average groundwater level at the nearest observation wells (Figure 4.3). No flow boundaries were assigned at the boundaries where the aquifers qh, qp_3, qp_{2-3} and qp_1 were not existed. In Figure 4.2, the straight lines indicate general head boundary, dot lines indicate no flow boundary and red points indicated the absolute average groundwater level in each time step. Pink points are observation wells to interpolate general head boundary and green points are observation wells to use for calibration.

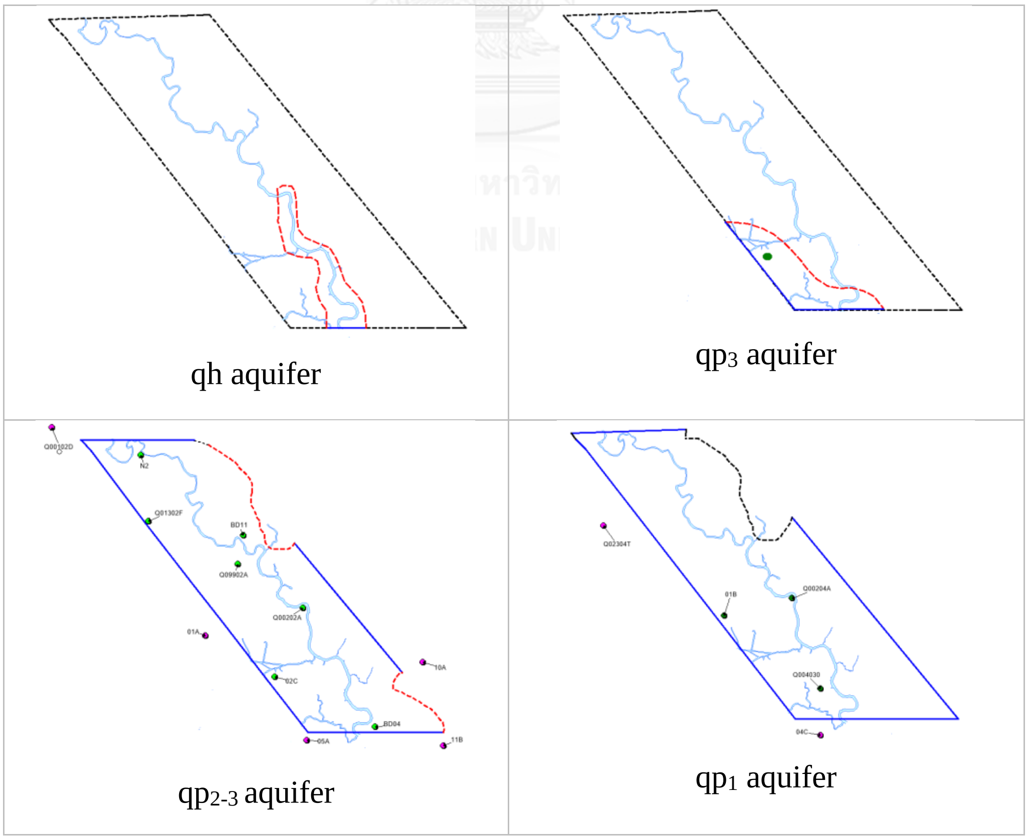


Figure 4.2. General head and no flow boundary of 4 aquifers

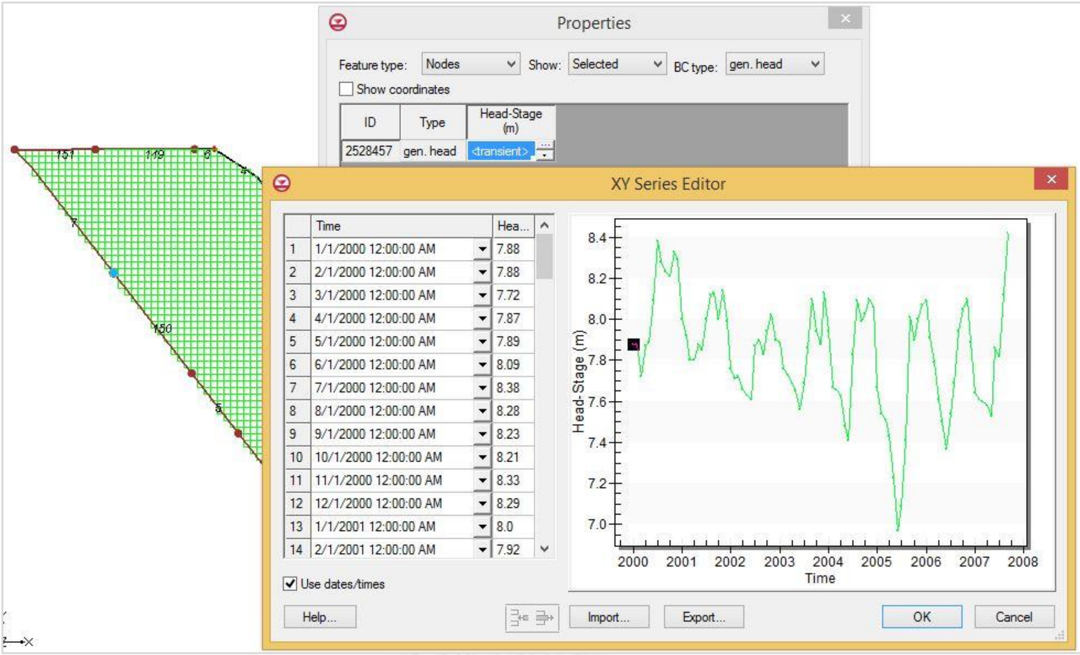
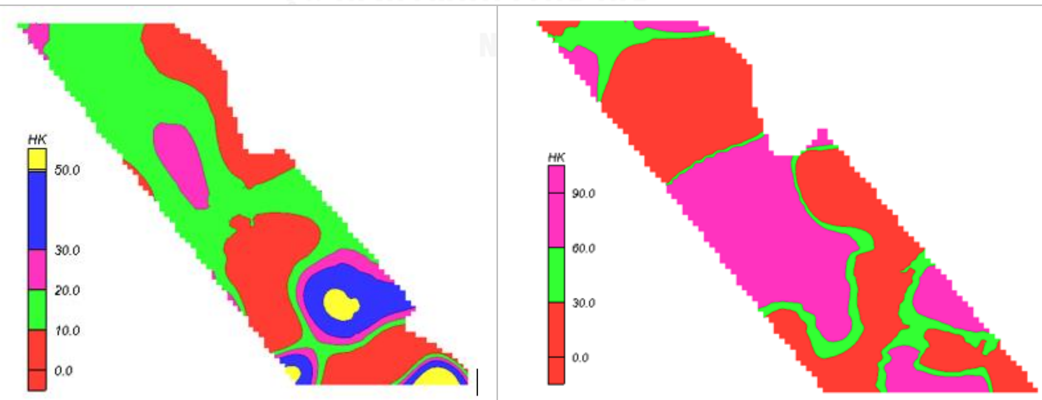


Figure 4.3. Input general head in the model

4.1.1.2. Hydraulic conductivity

Hydraulic conductivities were calculated from 143 pumping tests of whole Saigon basin. Kriging method, as a geostatistic tool in GMS software version 9.0, was applied to distribute hydraulic conductivity of qp_{2-3} and qp_1 aquifer based on the variogram application (Long, 2017). The tool was used to simulate hydraulic conductivity distribution of 2 main aquifers, qp_{2-3} and qp_1 aquifer,and assigned to parameter zones. Figure 4.4 shows distribution of hydraulic conductivity of two main aquifers in this study area.



qp_{2-3} aquifer (unit m/d) — qp_1 aquifer (unit m/d)

Figure 4.4. Hydraulic conductivity distribution of qp_{2-3} aquifer and qp_1 aquifer

4.1.1.3. River water levels

Linear regression method was applied to build function of daily water level at TV1 cross-section and hourly water level at TV3 cross-section, TV7 cross-section and TV9 cross-section. Daily water levels at TV1 cross-section showed a good relationship with daily release from Dau Tieng Dam with coefficient of determination is 0.65. Fluctuation of water levels at TV3 and TV7 cross-section were significant closed with the fluctuation of water level at Thu Dau Mot station. Values of R-square of linear regression at TV3 and TV7 cross-section were 0.94 and 0.86, respectively. Similarly, water levels at TV9 cross-section fluctuated very closely with water level at Phu An station (R-square equal 0.94, as shown in Table 4.1).

Table 4.1. Function of water levels at 4 cross-sections

Cross-section	Function	Correlation R-square
TV1	**$Y = 1.1607\ R_d + 136.24$ (4.1)** Y is daily water level (m) R_d is daily release at Dau Tieng Dam (m_3/s)	0.65
TV3	**$Y = 1.0052\ X + 16.857$ (4.2)** Y is hourly water level at TV3 cross-section (cm) X is hourly water level at Thu Dau Mot station (cm)	0.94
TV7	**$Y = 0.6845\ X + 14.166$ (4.3)** Y is hourly water level at TV3 cross-section (cm) X is hourly water level at Thu Dau Mot station (cm)	0.86
TV9	**$Y = 0.9375\ X + 9.8269$ (4.4)** Y is hourly water level at TV3 cross-section (cm) X is hourly water level at Phu An station (cm)	0.94

TV1 cross-section:

A measurement data of water level at TV1 cross section was computed with the dam release at Dau Tieng Dam in same time (as shown in Table 4.2). Fluctuation of water level at TV1 cross-section presented a good correlation with the dam release (see in Figure 4.1). Daily water levels from January 1st, 2000 to September 30th, 2007 at TV1 cross-section were estimated by using linear function (Table 4.1and Eq. 4.1) between water levels measurement and dam release.

Table 4.2. Summary daily water level measurement and dam release

Time	Dam release m^3/s	Water level m	Time	Dam release m^3/s	Water level m	Time	Dam release m^3/s	Water level m
8/2/06	83	229.4	20/3/07	67	240.6	24/4/08	89	242.0
9/2/06	78	226.7	21/3/07	86	249.1	25/4/08	72	239.8
10/2/06	97	231.9	22/3/07	99	259.2	21/5/08	75	213.0
11/2/06	95	228.1	18/4/07	84	224.8	22/5/08	75	212.6
10/3/06	68	196.5	19/4/07	83	225.4	23/5/08	78	214.8
11/3/06	65	187.5	20/4/07	89	227.6	24/5/08	79	220.1
12/3/06	70	190.8	21/4/07	92	229.0	25/2/09	79.8	230.8
13/3/06	75	203.7	18/5/07	65	239.0	26/2/09	81.6	232.0
8/4/06	22	132.5	19/5/07	62	222.4	27/2/09	83.5	235.5

Time	Dam release m^3/s	Water level m	Time	Dam release m^3/s	Water level m	Time	Dam release m^3/s	Water level m
9/4/06	22	137.6	20/5/07	54	220.5	28/2/09	87.1	233.8
10/4/06	20	134.8	21/5/07	54	220.0	25/3/09	60.4	198.6
11/4/06	25	154.0	22/2/08	74	231.2	26/3/09	61.1	209.8
8/5/06	53	204.9	23/2/08	76	233.7	27/3/09	63.4	216.9
9/5/06	55	212.2	24/2/08	75	235.1	28/3/09	65.2	222.7
10/5/06	57	221.7	25/2/08	74	229.8	24/4/09	76.9	208.5
11/5/06	59	229.7	24/3/08	58	208.4	25/4/09	72.4	208.4
17/2/07	65	212.0	25/3/08	62	226.1	26/4/09	73.5	209.2
18/2/07	69	221.0	26/3/08	61	226.7	27/4/09	74.3	209.5
19/2/07	69	225.1	27/3/08	63	219.3	24/5/09	82.8	223.3
20/2/07	65	220.0	22/4/08	98	245.5	25/5/09	81.2	225.1
19/3/07	65	232.1	23/4/08	96	243.2	26/5/09	71.1	223.5

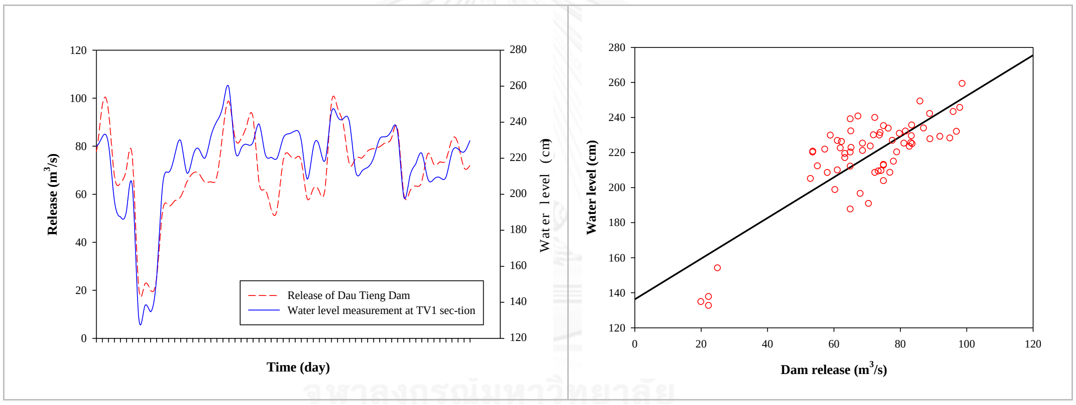


Figure 4.5. Computed water levels at TV1 with dam release

TV3 cross-section

A measurement data of water level at TV3 cross section correlated with the water levels at Thu Dau Mot station in same time (Table 4.3). Fluctuation of water level at TV3 cross-section presented a good correlation with the river stages at Thu Dau Mot station (see Table 4.3). Hourly water levels from January 1st, 2000 to September 30th, 2007 at TV3 cross-section were estimated by using linear function (Table 4.1 and Eq. 4.2) between water levels measurement and water levels observation at Thu Dau Mot station.

Table 4.3. Summary hourly water level at TV3 and Thu Dau Mot station

Time (hour) (15/9/2014)	Water level (cm MSL)	
	Thu Dau Mot station	TV3
0	53	58.1
2	73	82.1
4	66	94.1

Time (hour) (15/9/2014)	Water level (cm MSL)	
	Thu Dau Mot station	TV3
6	22	61.1
8	-34	9.1
10	-99	-82.9
12	-78	-82.9
14	18	9.1
16	84	79.1
18	114	124.1
20	100	129.1
22	59	90.1
24	34	63.1

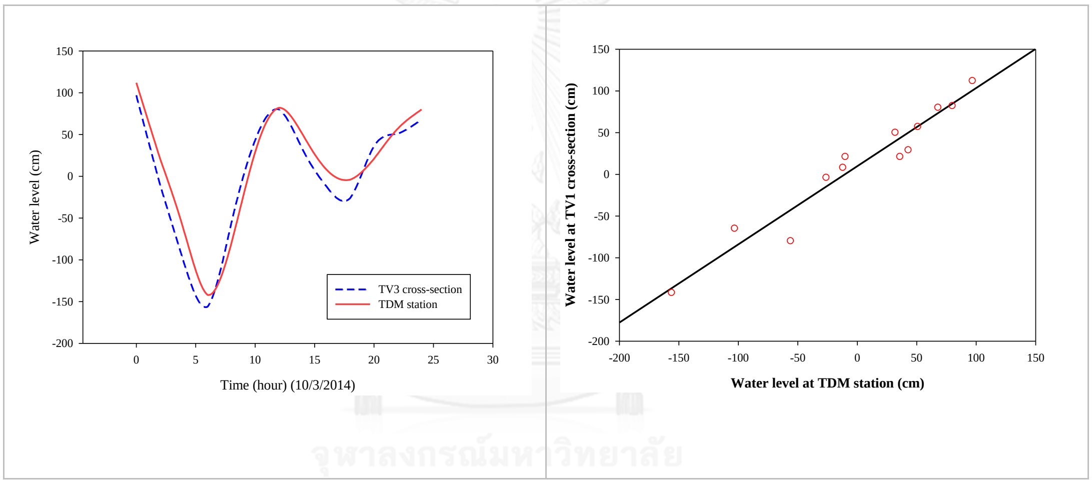


Figure 4.6. Computed water level at TV3 cross-section

TV7 cross-section

A measurement data of water level at TV7 cross section (Table 4.4) was correlated with the water levels at Thu Dau Mot station in same time. Fluctuation of water level at TV3 cross-section presented a good correlation with the river stages at Thu Dau Mot station (see Figure 4.7). Hourly water levels from January 1st, 2000 to September 30th, 2007 at TV7 cross-section were estimated by using linear function (Table 4.1 and Eq. 4.3) between water levels measurement and water levels observation at Thu Dau Mot station.

Table 4.4. Summary hourly water levels at TV7 and Thu Dau Mot station

Time (hour) (15/9/2014)	Water level (cm MSL)	
	Thu Dau Mot station	TV7
0	101	96
2	101	107
4	19	46

Time (hour) (15/9/2014)	Water level (cm MSL)	
	Thu Dau Mot station	TV7
6	-24	-18
8	-97	-86
10	-59	-47
12	16	39
14	106	85
16	106	64
18	-19	22
20	-65	-3
22	26	39
24	154	90

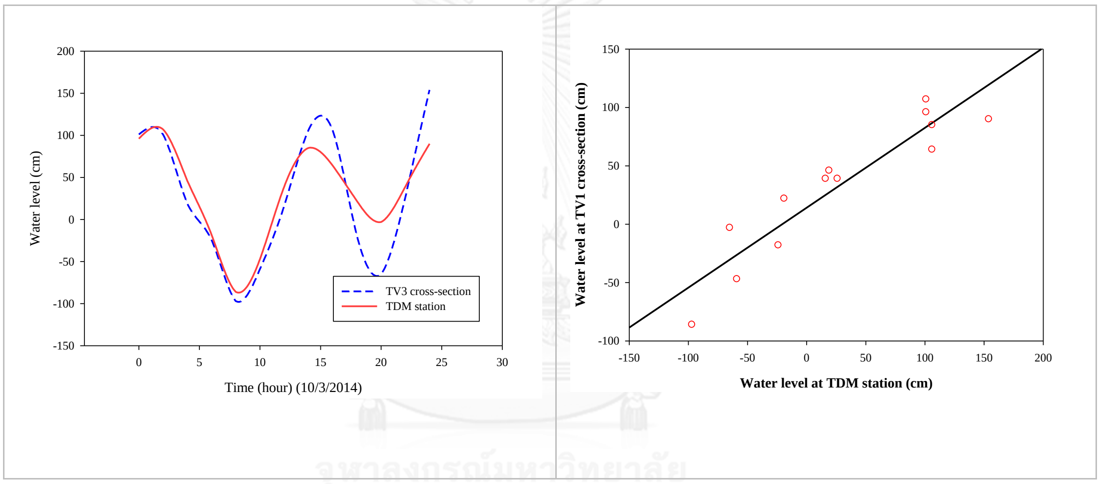


Figure 4.7. Computed water levels at TV7 and Thu Dau Mot station

TV9 cross-section

A measurement data of water level at TV9 cross was computed with the water levels at Thu Dau Mot station in same time (Table 4.5). Fluctuation of water level at TV3 cross-section presented a good correlation with the river stages at Phu An station (see Figure 4.8). Hourly water levels from January 1st 2000 to September 30th, 2007 at TV9 cross-section were estimated by using linear function (Table 4.1 and Eq. 4.4) between water levels measurement and water levels observation at Phu An station.

Table 4.5. Summary hourly water levels at TV9 cross-section and Phu An station

Time (hour) (15/9/2014)	Water level (cm)	
	Phu An station	TV9
0	97	112
2	-10	21
4	-103	-65
6	-156	-142
8	-56	-80

Time (hour) (15/9/2014)	Water level (cm)	
	Phu An station	TV9
10	43	29
12	80	82
14	32	50
16	-12	8
18	-26	-4
20	36	21
22	51	57
24	68	80

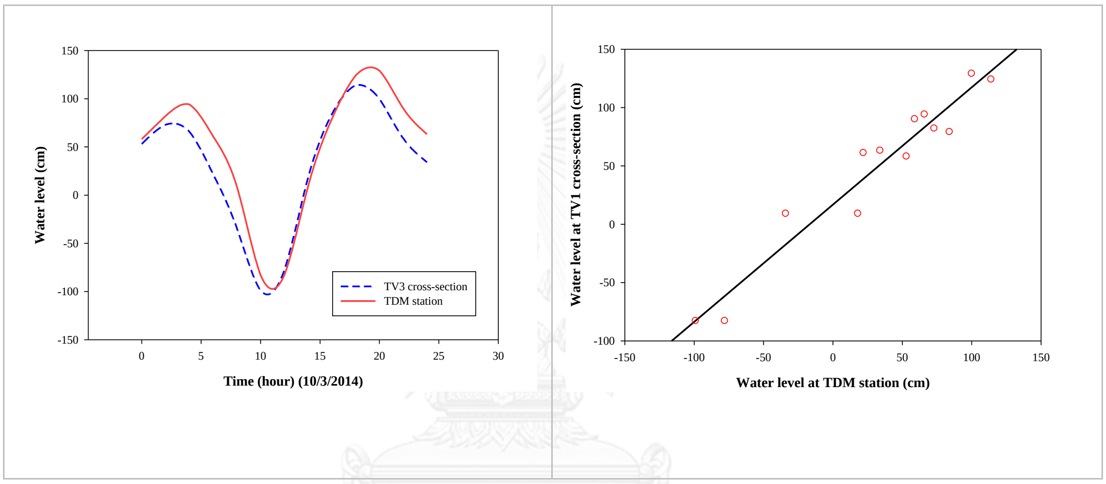


Figure 4.8. Computed water levels at TV9 and Phu An station

Hourly or daily water levels from January 1st, 2000 to September 30th, 2007 at 4 cross-sections in river were interpolated by using linear function in Table 4.1. From this, monthly water levels from 1/2000 to 9/2007 were estimated and input into nodes of river and canal system in groundwater model (see in Figure 4.9).

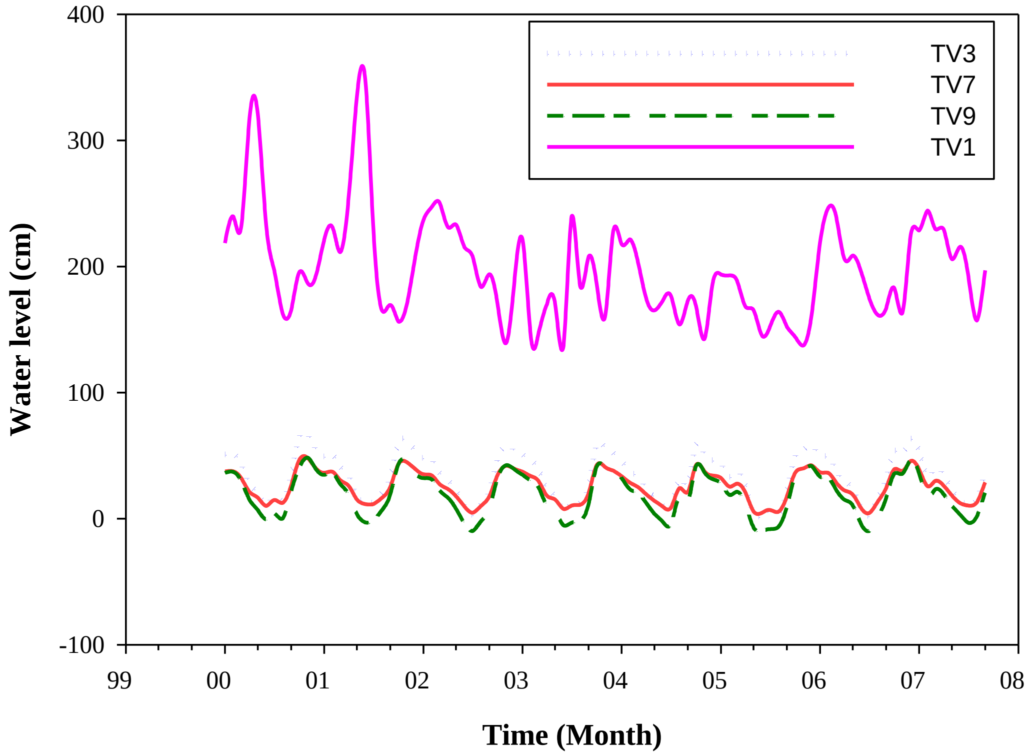


Figure 4.9. Monthly water levels at 4 cross-sections

4.1.1.4. Pumping rate

Groundwater abstraction data of two main aquifers, qp_{2-3} and qp_1 aquifer, and population of Thu Dau Mot and Thuan An area were from the results of an investigation done by DWRPIS in 2000 and 2008. In 2000, when population of total Thu Dau Mot and Thuan An were 272,156 people and groundwater pumping was 68,616 m^3/d. However, the population increased 1.5 times from 2000 to 2007 and brought out 1.6 times increase of groundwater pumping in the study area as shown in Table 4.6.

Table 4.6. Summary of pumping rate and population

Time	Pumping rate (m^3/d)		Population (person)
	qp_{2-3} aquifer	qp_1 aquifer	
2000	-23,418	-45,198	272,156
2007	-37,680	-73,252	409,792

Ratio of pumping rate of two aquifers was calculated using function 5.7 (mentioned in section 5.2.3) as below:

qp_{2-3} aquifer: R_Q = (23,418+37,680)/ (272,156+409,792) = 0.090

qp_1 aquifer: R_Q = (45,198+73,252)/ (272,156+409,792) = 0.163

Table 4.7 shows pumping rates distribution of qp_{2-3} aquifer and qp_1 aquifer from 2000 to 2007. There were estimated by computing the increase of pumping in 2000 and 2007 with population growth of Thu Dau Mot and Thuan An area.

Table 4.7. Pumping rates distribution of qp_{2-3} and qp_1 aquifer from 2000 to 2007

Time	**Population** (person)	**qp2-3 aquifer**		**qp1 aquifer**	
		Ratio m^3/d/person	**Pumping rate** (m^3/d)	**Ratio m^3/d/person**	**Pumping rate** (m^3/d)
2000	272,156	0.086	23,418	0.166	45,198
2001	272,307	0.090	24,397	0.174	4,245
2002	298,092	0.090	26,707	0.174	4,647
2003	326,262	0.090	29,231	0.174	5,086
2004	326,643	0.090	29,265	0.174	5,092
2005	351,090	0.090	31,456	0.174	5,473
2006	380,056	0.090	34,051	0.174	5,925
2007	409,792	0.092	37,680	0.179	73,252

Locations of abstraction wells and total amount of groundwater abstraction per aquifer as mentioned in the section 3.6 were input per aquifer (Figure 4.10)

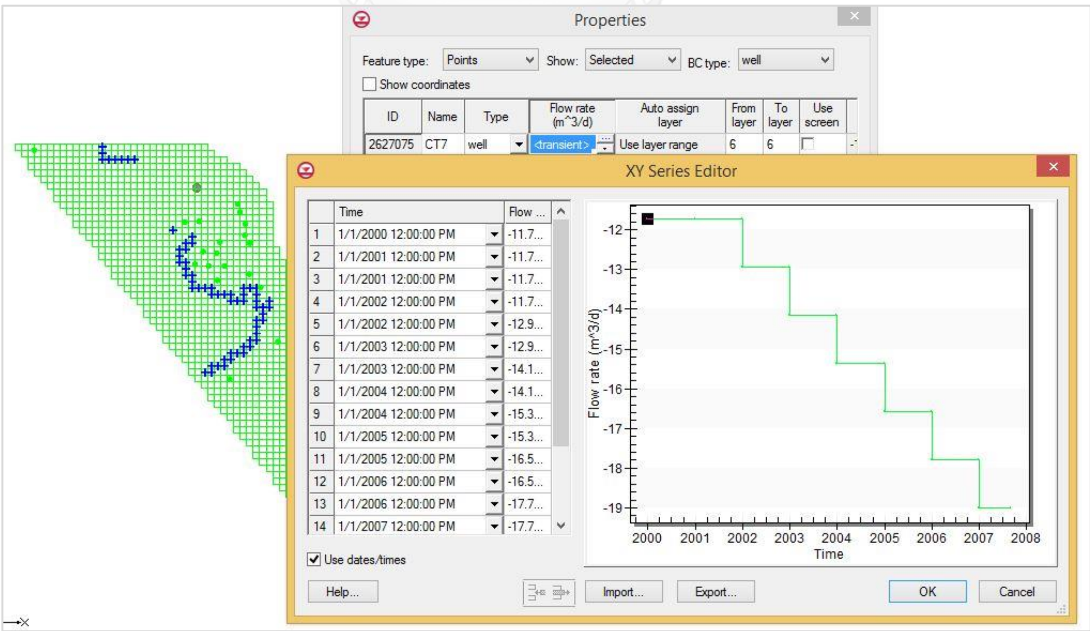
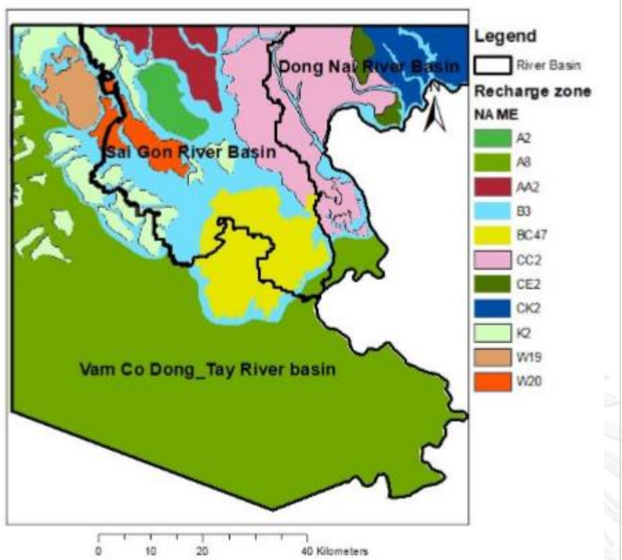


Figure 4.10. Input pumping rate at one abstraction well

4.1.1.5. Land recharge

The recharge rate is obtained from effective rainfall and recharge rate can set as linear function of effective rainfall (Khai, 2015). Recharge zone was created based on hydrogeological map and effective rainfall is defined as the difference between total rainfall and actual evapotranspiration as in Figure 4.11.



No	Zone	Function
1	A2	I = 0.0074x + 5E-06
2	K2	I = 0.0072x + 5E-06
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 4.11. Land recharge map and zone's function (Khai, 2015)

Value of recharges that were calculated as mentioned in the section 6.1 for each time steps were input per zone (Figure 4.12). There are 8 zones as land recharge map of Khai (2015) in this model area.

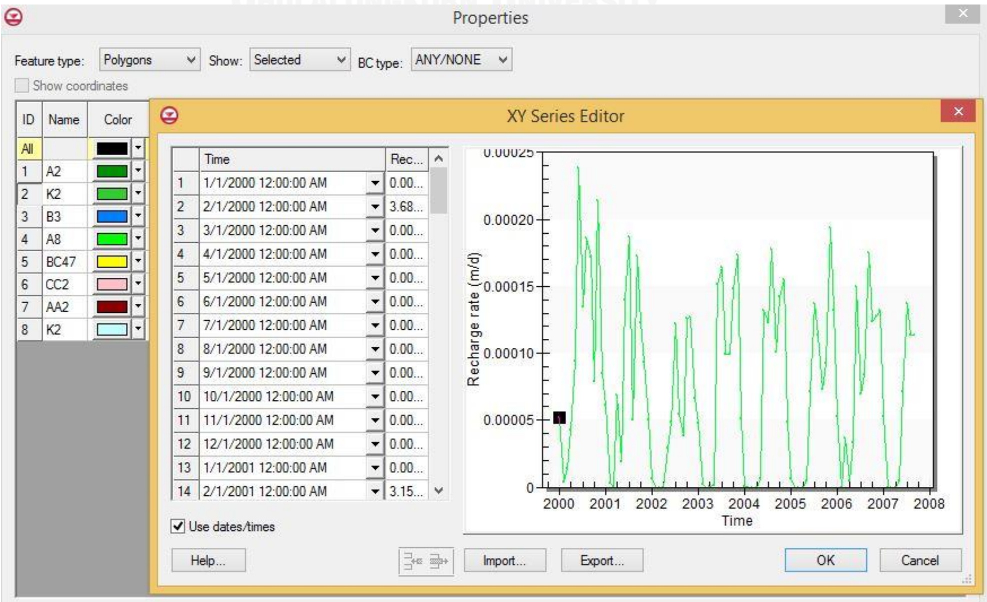


Figure 4.12. Land recharge values

4.1.1.6. Conductance

For initial model, conductance values were input by using the results of field calculation results of Boehmer (2000). In Saigon River system, Boehmer (2000) only estimated conductance value at Thu Dau Mot station and Phu An station. For other nodes of river system, he interpolated river width and calculated conductance values base on geology age. Figure 4.13 shows node of canals or rivers to input water level and conductance for groundwater model.

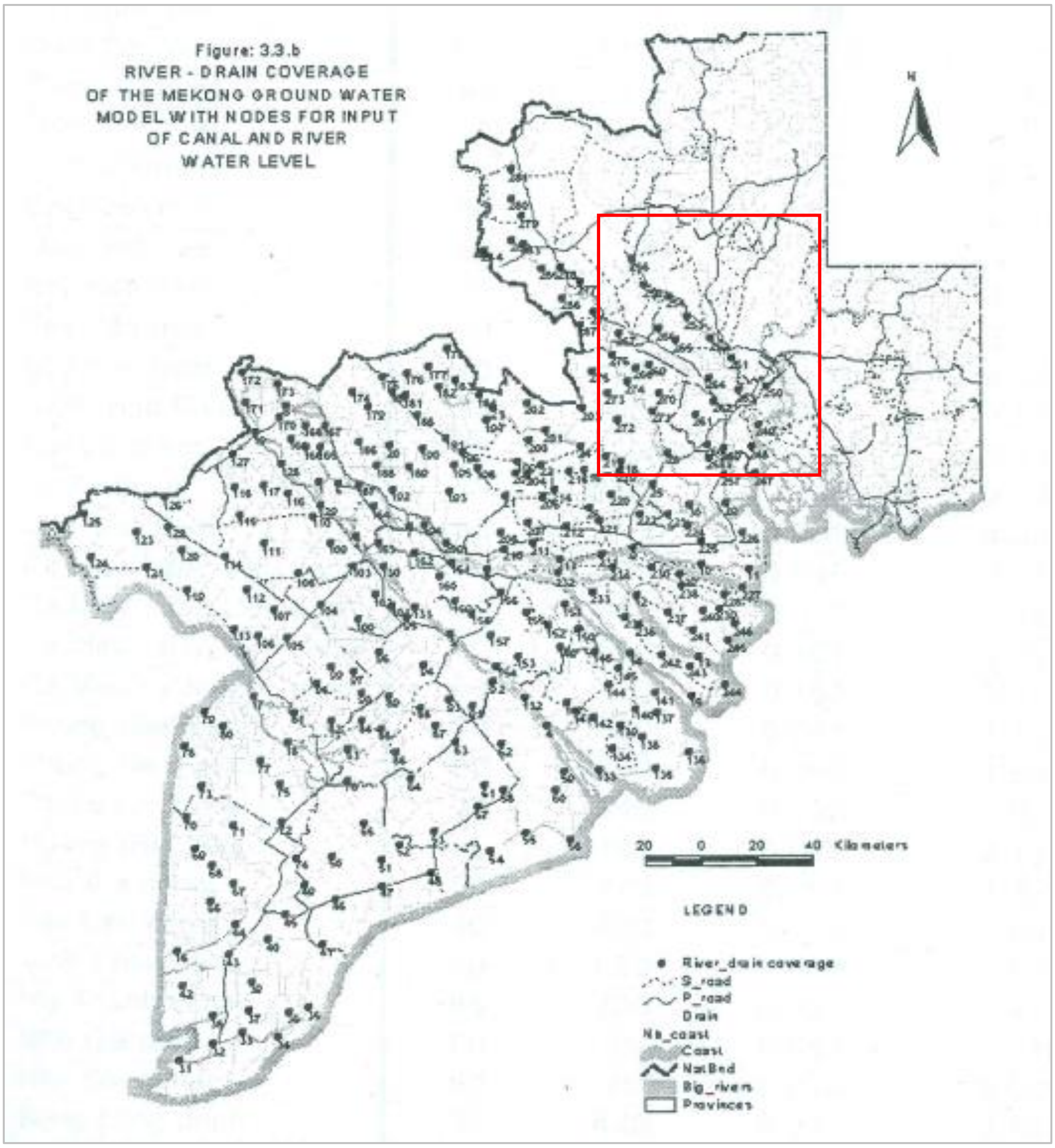


Figure 4.13. River –drain coverage of Mekong groundwater model with nodes for input of canal and river water level (Boehmer, 2000)

Table 4.8. Initial conductance value of drain and canal in Saigon River

No of stations	Width (m)	Hydraulic resistance (d)	Conductance W/d(m/d)
247	365	530	0.689
248	320	650	0.492
249	385	410	0.939
250	45	210	0.214
251	105	185	0.568
251	98	150	0.653
253	75	120	0.625
254	65	105	0.619
255	60	90	0.667
256	60	75	0.8
263	140	160	0.875

4.1.1.7. Observation wells

The absolute average elevations of groundwater level for each time step per well at 11 observed wells were input directly in the model. Observation well N2, BD11 and Q00202A of qp2-3 aquifer were used for conductance calibration at TV1, TV3 and TV6 cross-section, respectively. Figure 4.14 shows the locations of observation wells in each aquifer.

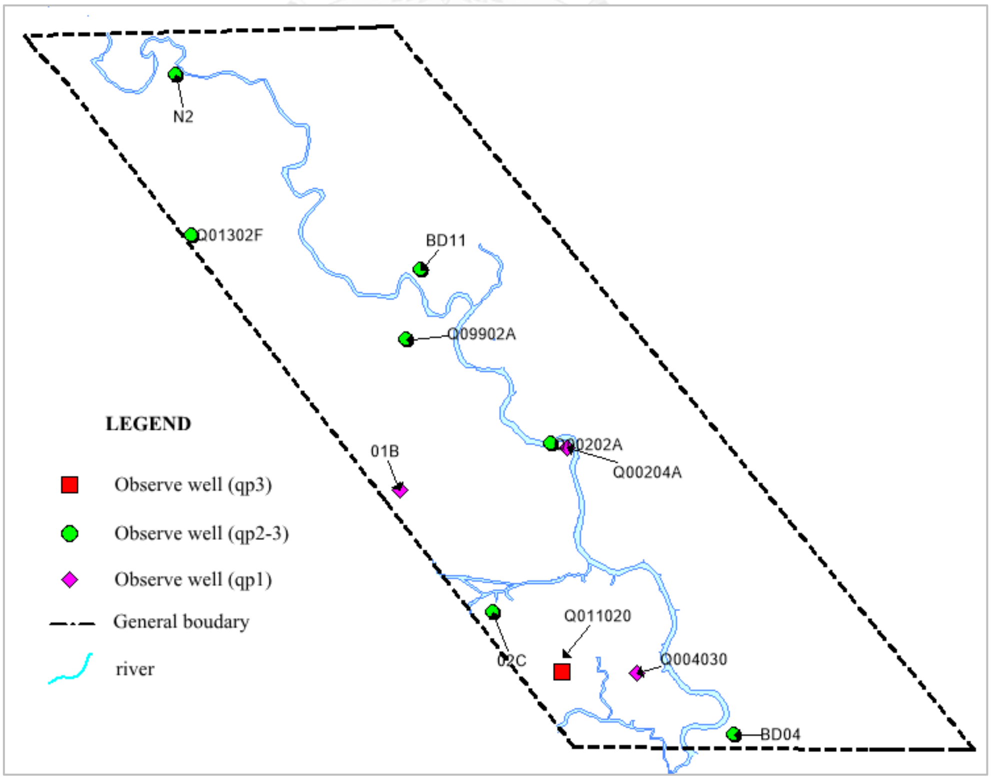


Figure 4.14. Location of observation wells in each aquifer

The calibration time is 7 years from 2000 to 2007 and was divided into monthly stress period resulting 93 stress periods. Figure 4.15 shows the absolute groundwater level data were input at one observation well in the model.

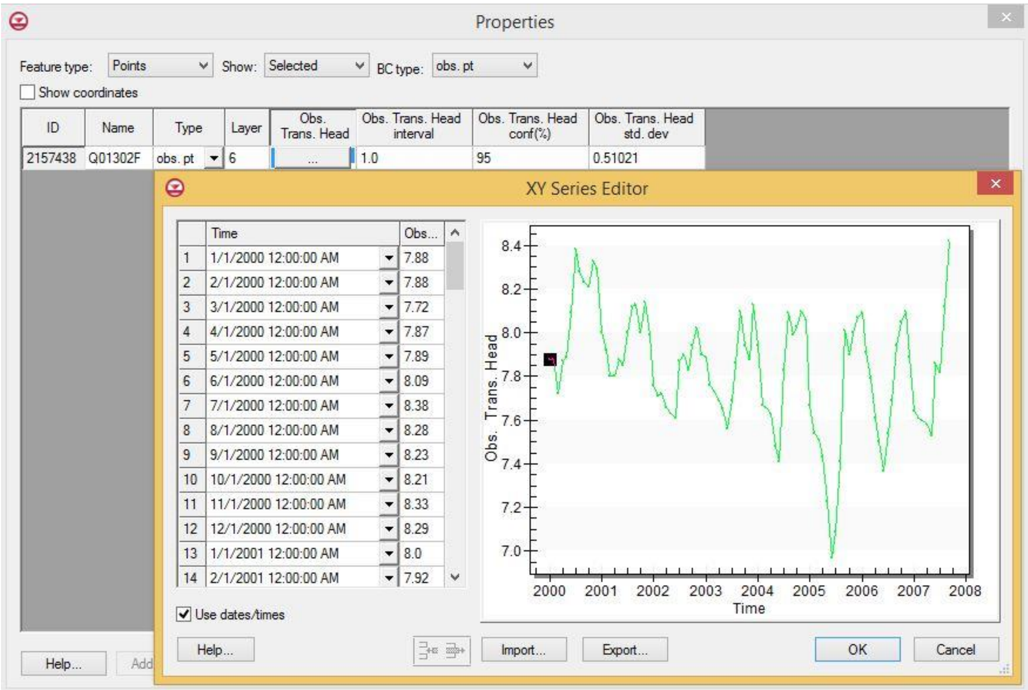


Figure 4.15. Input absolute groundwater level elevation at one observation well

4.1.2. Model calibration

4.1.2.1. Calibration procedures

The model was calibrated using trial and error method to reduce the differences between the observed and calculated groundwater level at 11 observation wells. During the calibration process, hydraulic conductivity, specific yield, specific storage and specified head at specified boundaries were modified. The accuracy of the model after calibrated was evaluated by two approaches:

1- Comparing the differences between the calculated and observed groundwater level at 11 observation wells of 3 aquifers (Figure 4.14). If the difference is between ± 0,5m, the model is reliable. The reason to choose the value of ± 0,5m is that, the observed groundwater levels at each time step of each observation well were the monthly groundwater levels.

2- Reducing (as much possible) three type of errors: i) mean error (ME); ii) mean absolute error; and iii) root mean square
   a. Mean error (ME) is the residual mean between observed value and calculated value.

$$ME = \sum_{i=1}^{n} (h_m - h_s)_i / n$$

b. Mean absolute error is mean of absolute value of deviation between observed value and calculated value: $MAE = (\sum_{i=1}^{n} /(h_m - h_s)_i /) / n$

c. Root mean square error: $RMSE = [\sum_{i=1}^{n} (h_m - h_s)_i^2 / n]^{0,5}$

where

- h_m: observed groundwater level
- h_s: calculated groundwater level

4.1.2.2. Calibration results

Table 4.9 summarizes the minimum, maximum and mean values of the three types of errors at the observation wells in each aquifer. Mean errors (ME) of aquifers are from 0.17 to 1.11m; Mean absolute errors (MAE) are from 0.28 to 1.11 and Root Mean Square Error is form 0.08 to 1.5m. These errors are reasonable and the model is acceptable to do further simulations for future.

Table 4.9. Error results of 3 aquifers in transient state

Obs well	**Aquifer**	**ME**	**MAE**	**RMSE**
Q011020	qp_3	0.40	0.42	0.50
Q01302F	qp_{2-3}	0.59	0.59	0.38
Q00902A	qp_{2-3}	0.17	0.28	0.08
BD11	qp_{2-3}	-0.35	0.35	0.15
Q00202A	qp_{2-3}	-0.35	0.43	0.28
BD4	qp_{2-3}	-0.16	0.58	0.49
02C	qp_{2-3}	0.71	0.51	0.30
Q00204A	qp_1	0.86	0.67	0.52
Q040300	qp_1	0.51	0.44	0.41
01B	qp_1	1.02	0.82	0.55

Figure 4.16 to Figure 4.18 present the graphs of calculated and observed groundwater levels at some observation wells representing for three aquifers. It may be seen that the calculated groundwater levels and the observed groundwater levels at 93 time steps are rather corresponding.

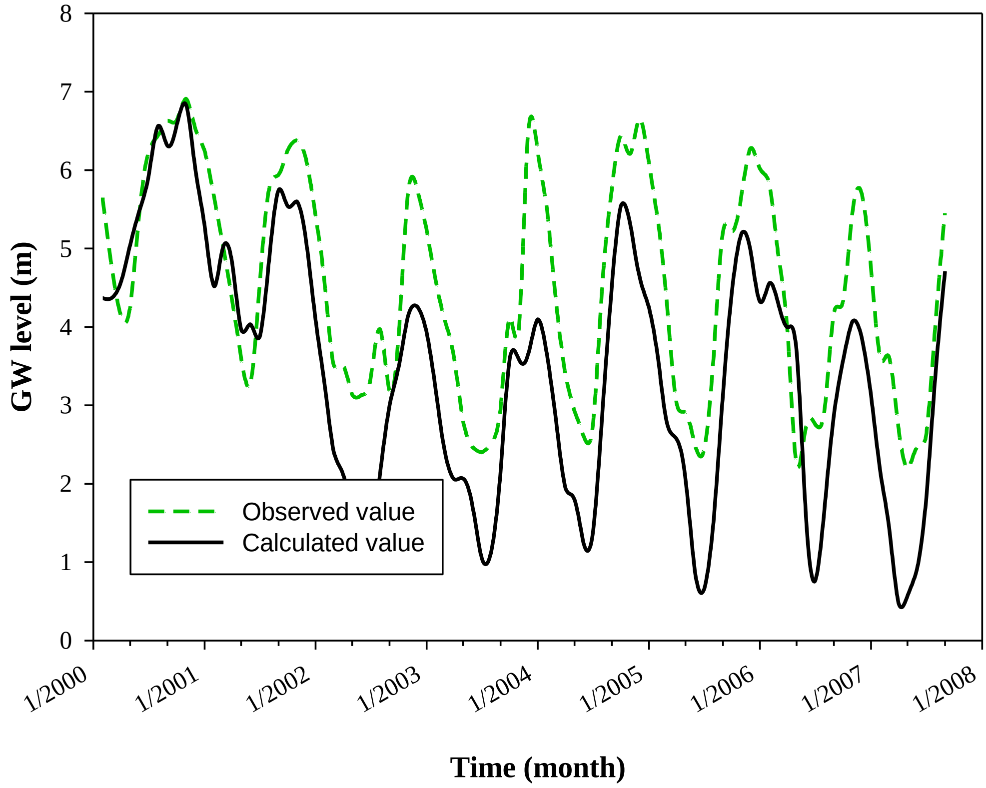


Figure 4.16. Computed and observed GWL at obs.well Q011020 (qp_3 aquifer)

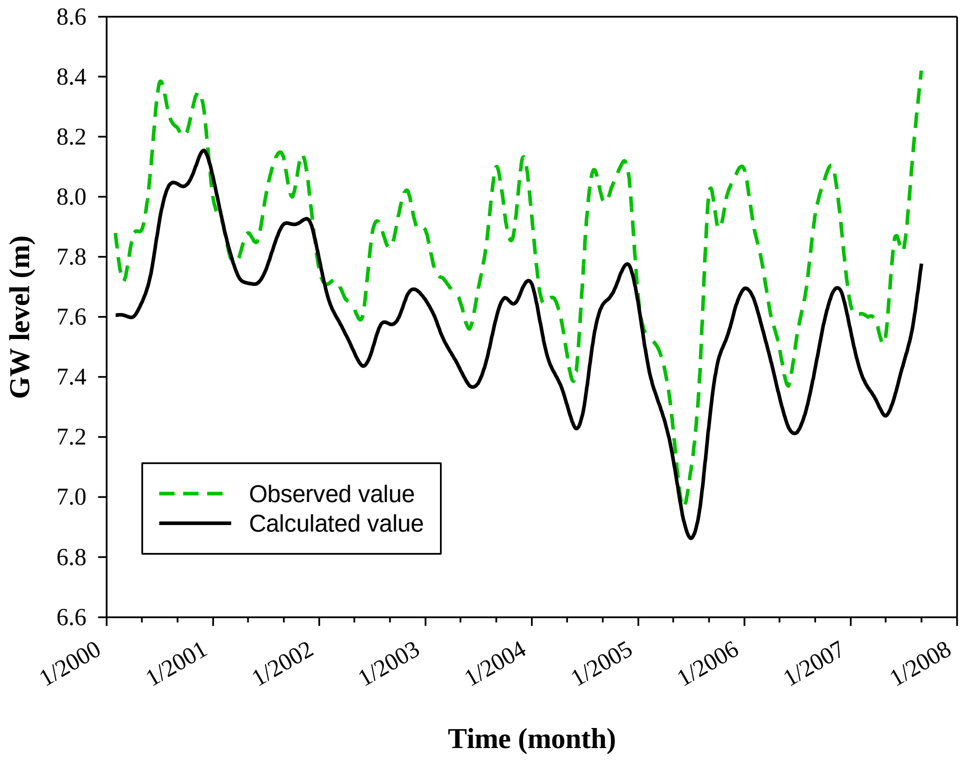


Figure 4.17. Computed and observed GWL at obs.well Q01302F ($qp_{2\text{-}3}$ aquifer)

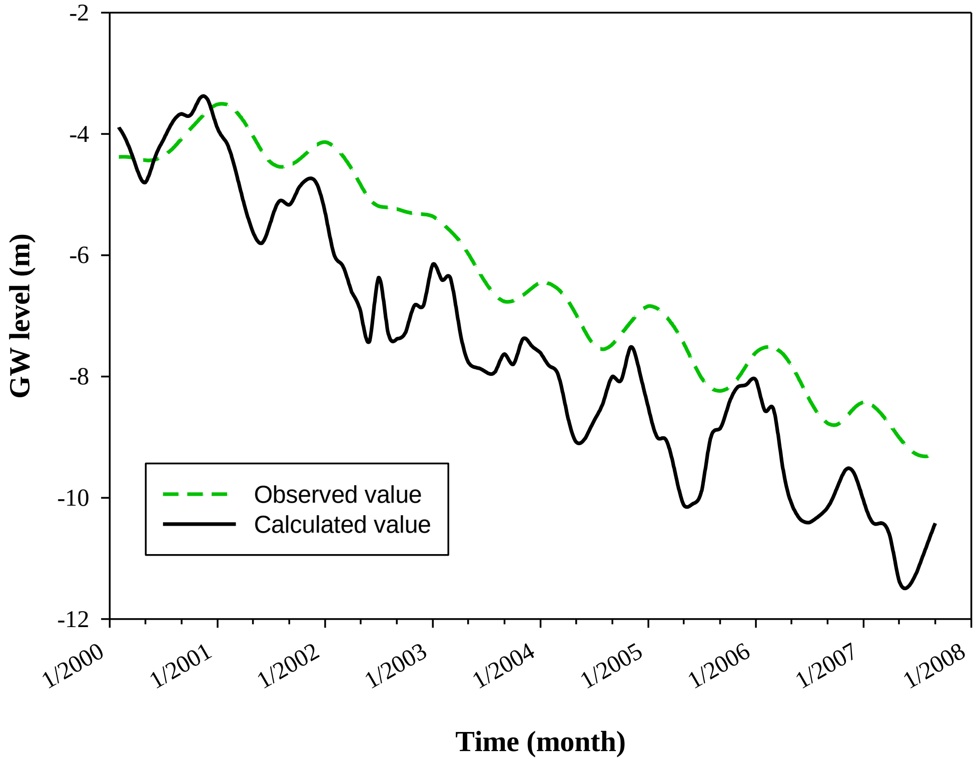


Figure 4.18. Computed and observed GWL at obs.well Q01302F (qp_1 aquifer)

4.2. Interaction parameter estimation

In groundwater model calibration, root mean square error (RMSE) and coefficient of determination of regression (R^2) were estimated by computing the calculated and observed groundwater levels at 3 cross-sections was applied to calibrate conductance. The selected value was the value which has min RMSE and max R^2.

From investigate results of the project on “Groundwater protection in Ho Chi Minh City”, 8 cross-sections along Saigon River were built to estimate wetted length of interaction layer and wetted length ratio at correlative cross-section.

4.2.1. Conductance calibration and verification

TV1 cross section.

Root mean square error and coefficient of determination of computing the calculated and observed groundwater level at observation wells N2 were used to calibrate conductance of TV1 cross-section in the period from January 2015 to December 2015.

Figure 4.19 shows fluctuation of RMSE and R^2 when changed conductance from 0.5 to 8. With conductance equal 4.5, RMSE and R^2 of GWL at observation well N2 reached minimum and maximum, respectively.

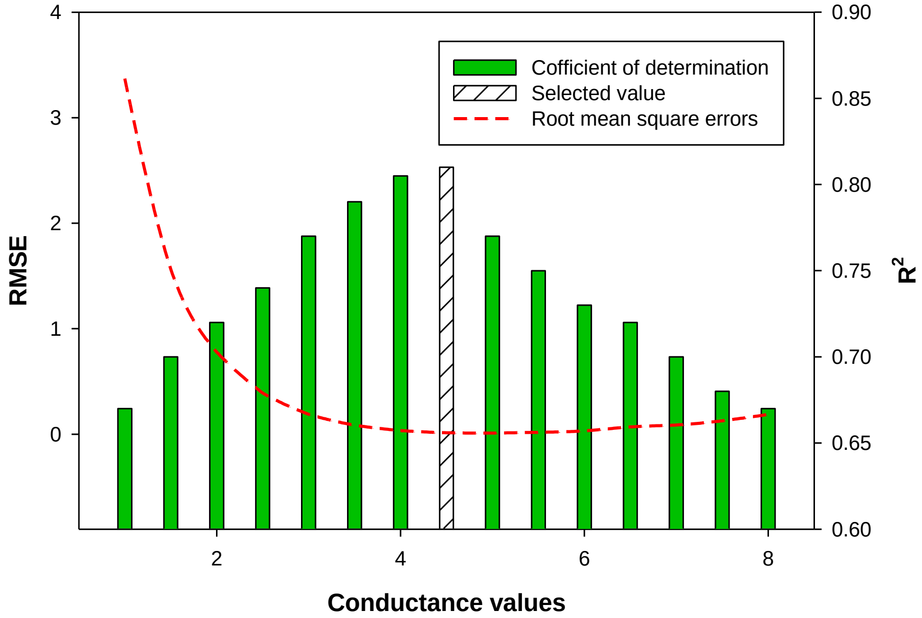


Figure 4.19. Conductance calibration at TV1 cross-section

TV3 cross-section:

Root mean square error and coefficient of determination of computing the calculated and observed groundwater levels at observation well BD11 were used to calibrate conductance of TV3 cross-section in the period from March 2001 to May 2003.

Figure 4.20 shows fluctuation of RMSE and R^2 when changed conductance from 0.2 to 9. With conductance equal 2.8, RMSE and R^2 of GWL at BD11 observation well reached minimum and maximum, respectively.

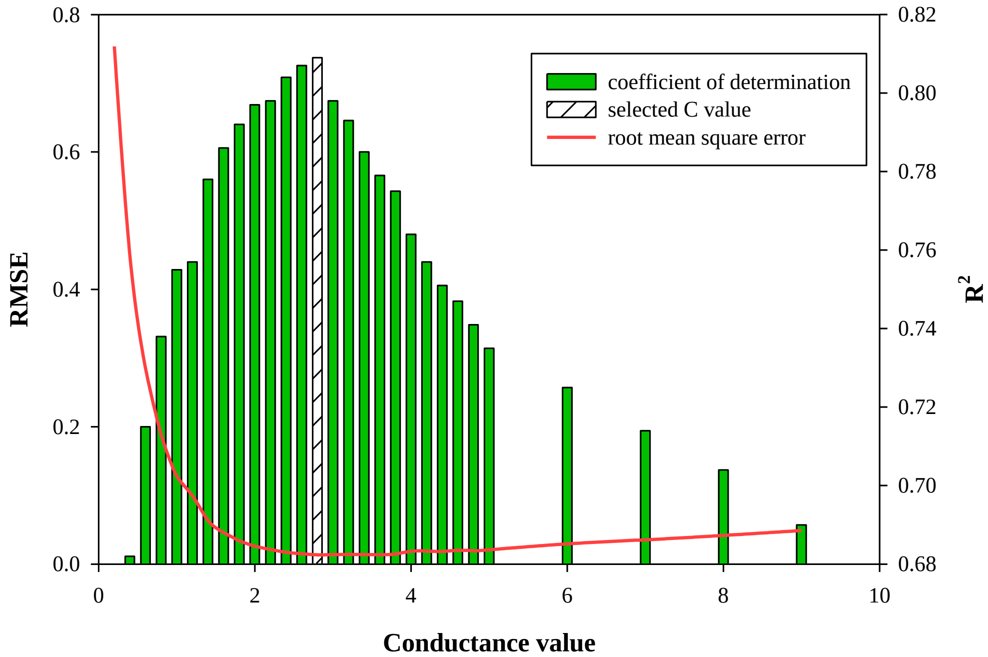


Figure 4.20. Conductance calibration at TV3 cross-section

The selected conductance value of TV3 cross-section was verified by computing calculated and observed groundwater level at observation well Q00202A in the period from April 2004 to September 2007. Figure 4.21 shows verification of conductance at cross-section TV6 in next period (from 3/2003 to 12/2005) with RMSE and R^2 were 0.34 and 0.66, respectively

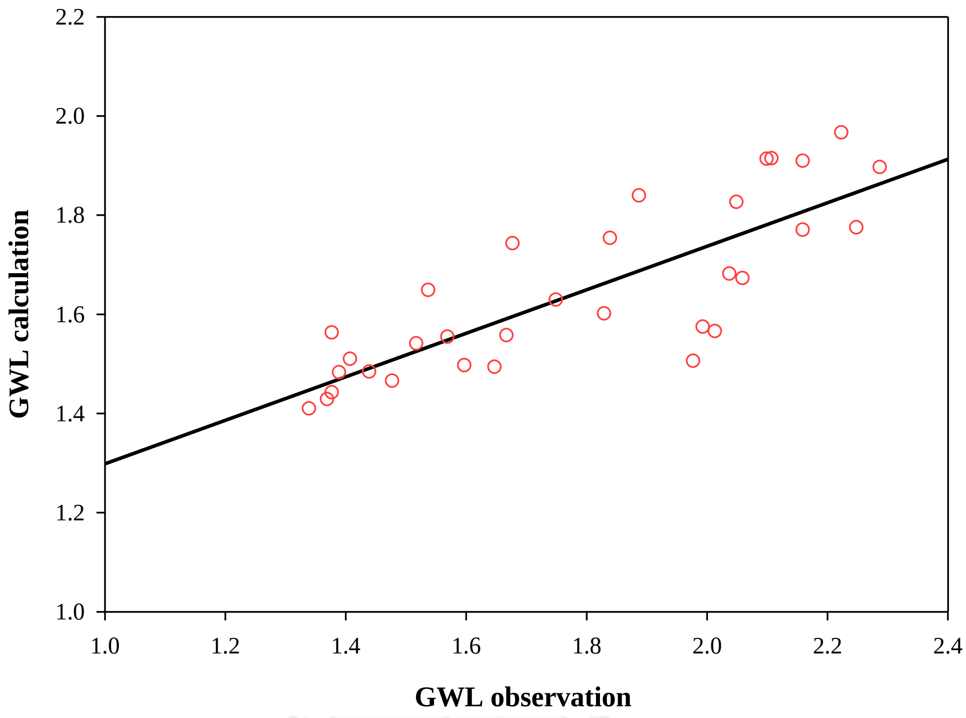


Figure 4.21. Conductance verification at TV3 cross-section

TV6 cross-section:

Root mean square error and coefficient of determination of computing the calculated and observed groundwater level at observation wells Q00202A were used to calibrate conductance of TV6 cross-section in the period from January 2000 to April 2004 (Tuan and Koontanakulvong, 2017)

Figure 4.22 shows fluctuation of RMSE and R^2 when changed conductance from 0.2 to 5. With conductance equal 1.2, RMSE and R^2 of GWL at Q00202A observation well reached minimum and maximum, respectively

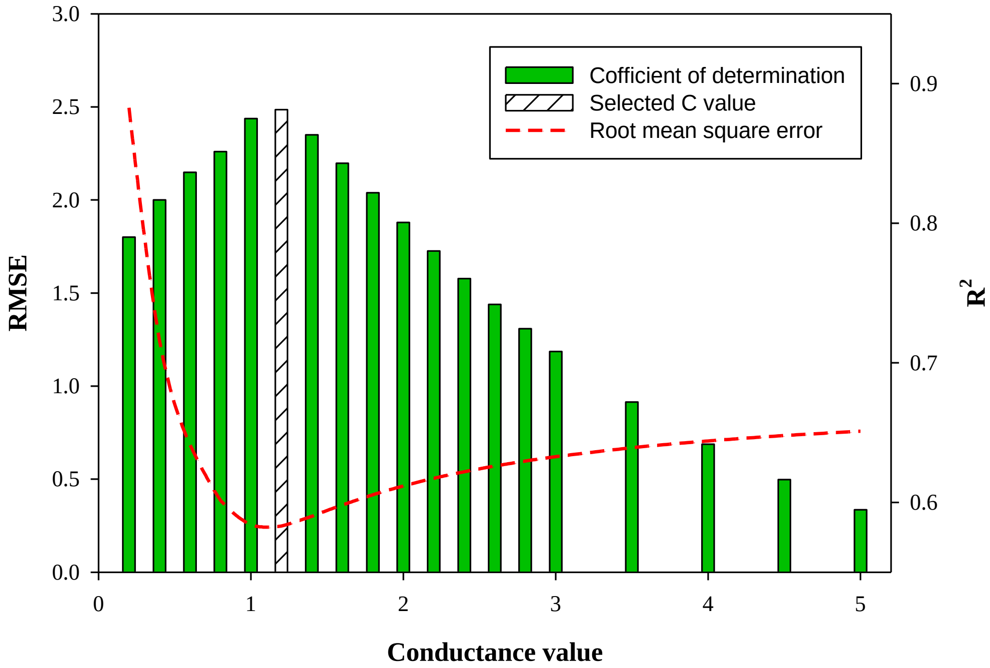


Figure 4.22. Conductance calibration at TV6 cross-section

The selected conductance value of TV6 cross-section was verified by computing calculated and observed groundwater level at observation well Q00202A in the period from April 2004 to September 2007 (Figure 4.23). Verification of conductance at cross-section TV6 in next period (from 4/2004 to 9/2007) with RMSE and R^2 were 0.6 and 0.61, respectively

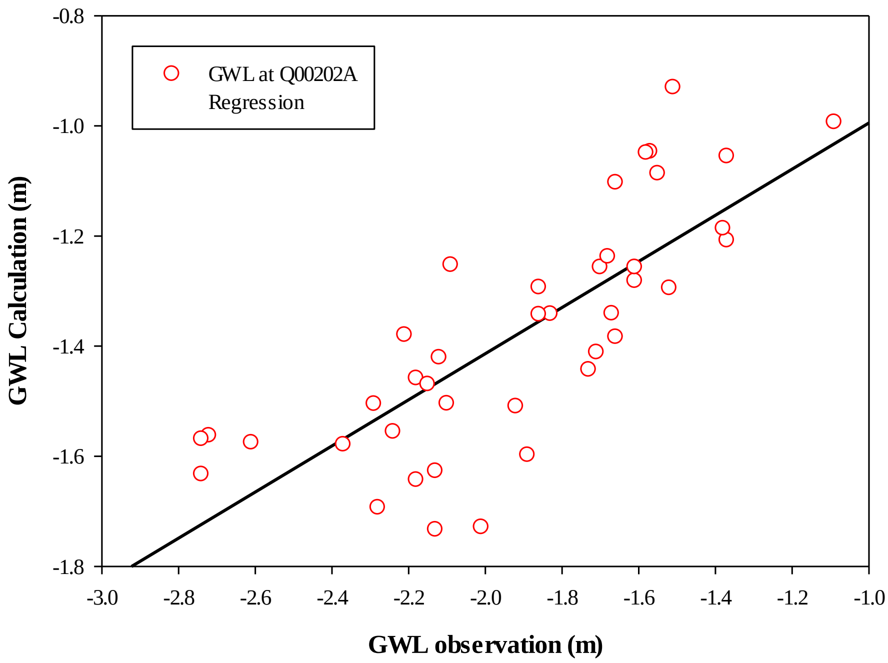


Figure 4.23. Conductance verification at TV6 cross-section

RMSE, R^2 and the selected value of conductance at 3 cross-sections were summarized in Table 4.10. After conductance calibration, result of both RMSE and R^2 at three cross-sections as TV1, TV3 and TV6 were improved significantly.

Table 4.10. Summary of conductance calibration results

Cross-section	**Selected C value**	**Use $C_{calibration}$**		**Use $C_{initial}$**	
		RMSE	**R^2**	**RMSE**	**R^2**
TV1	4.5	0.110	0.810	1.35	0.68
TV3	2.8	0.014	0.809	0.25	0.73
TV6	1.2	0.248	0.881	0.46	0.78

4.2.2. Function of interaction parameter

4.2.3.1. Cross-section analysis results

The eight cross sections (Figure 4.24) were illustrated by Figure 4.25 to Figure 4.31 provide an overview of the spatial distribution of aquifer system and penetration at each cross-section along Saigon River. Table 4.11 shows results of wetted length of interaction layer and wetted length ratio at 10 cross-sections along Saigon River. Values of wetted length ratio are from 0.19 to 0.89, depend on penetration level of interaction layer into aquifer except TV9 and TV10 cross-section which have no penetration into aquifer.

Table 4.11. Cross-section analysis results

Cross-section	**W_u(m)**	**W (m)**	**$R_u = W_u/W$**
SSG03	192	196	0.98
TV01	169	194	0.87
SSG12	131	225	0.58
TV03	60	182	0.33
SSG15	48	252	0.19
TV06	18	306	0.60
SSG20	74	309	0.24
TV07	97	323	0.30
TV09	0	285	0.00
TV10	0	372	0.00

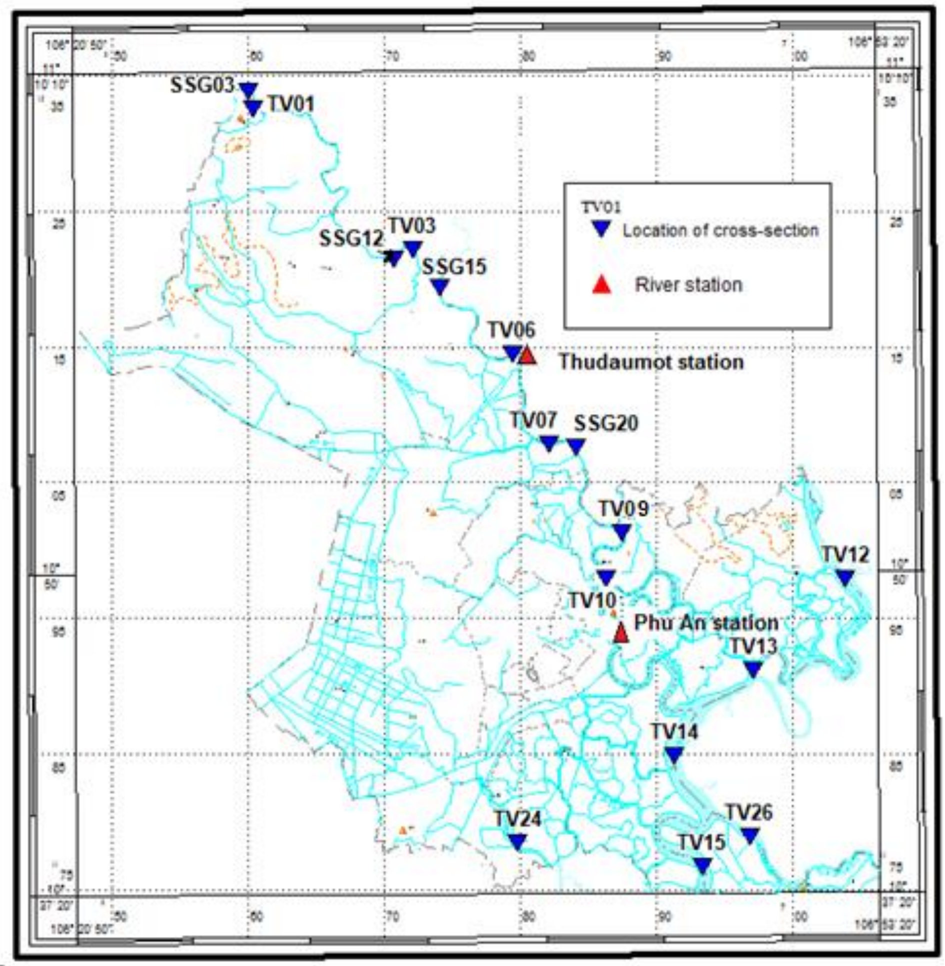


Figure 4.24. Location of river cross-section along Saigon River

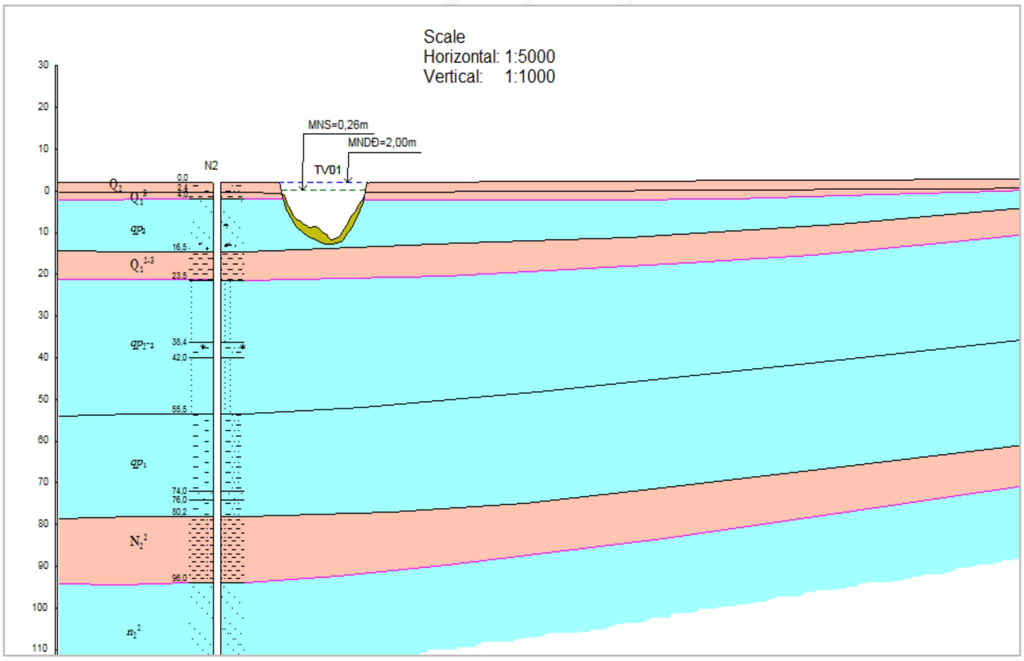


Figure 4.25. Cross-section at TV1

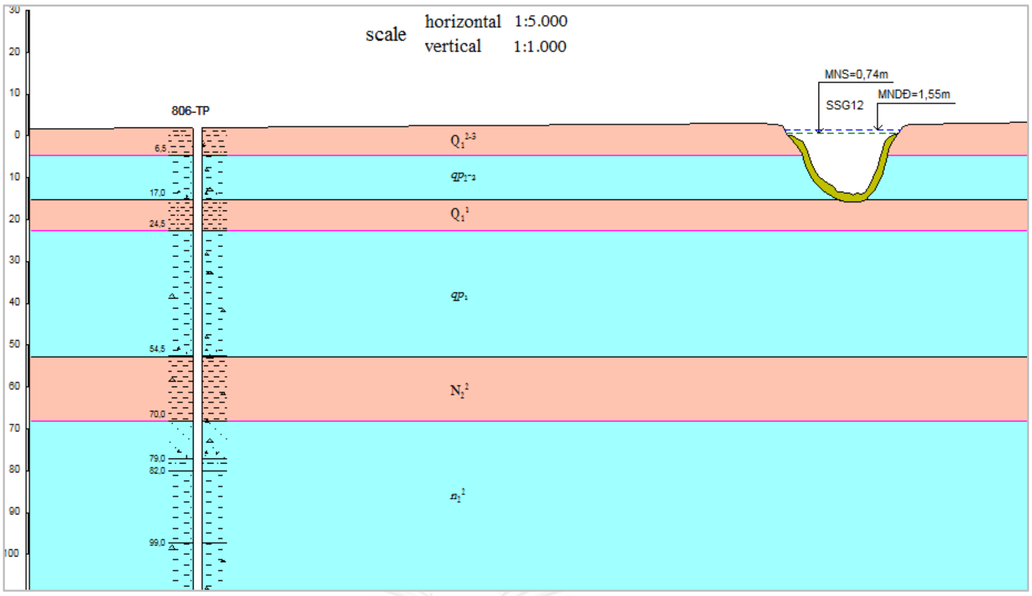


Figure 4.26. Cross-section at SSG12

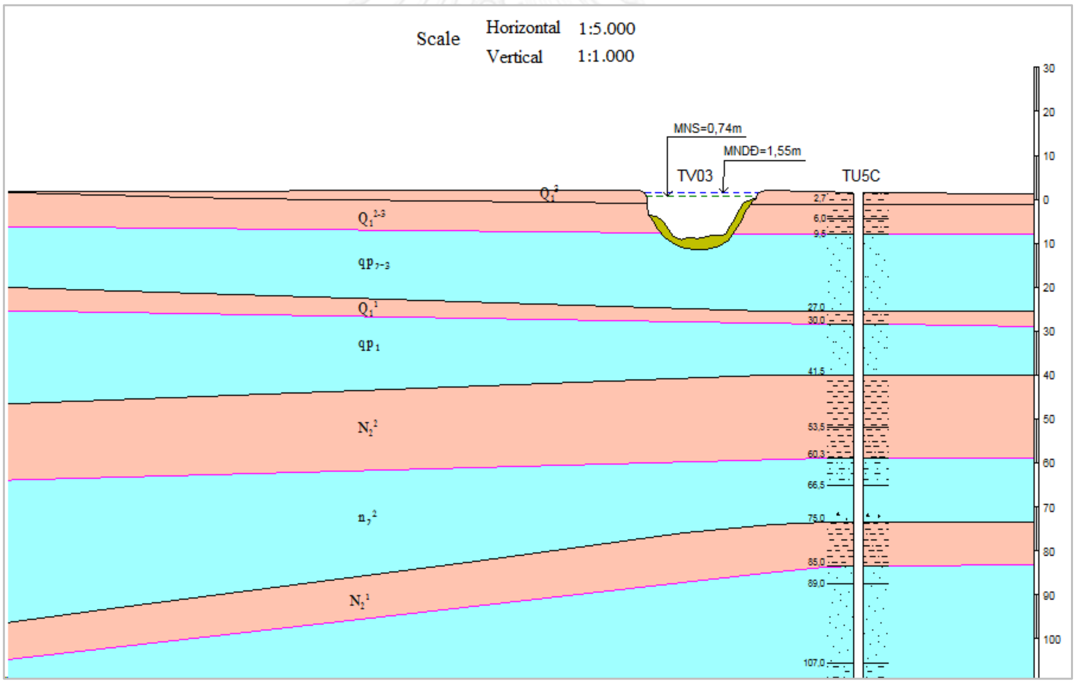


Figure 4.27. Cross-section at TV03

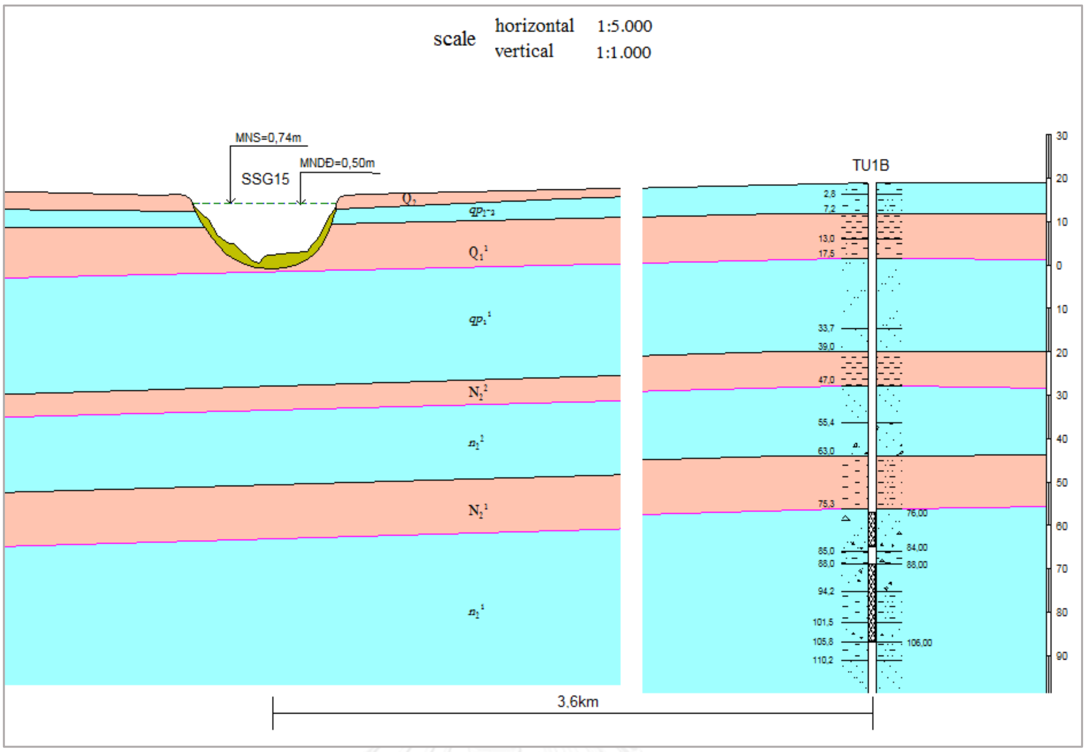


Figure 4.28. Cross-section at SSG20

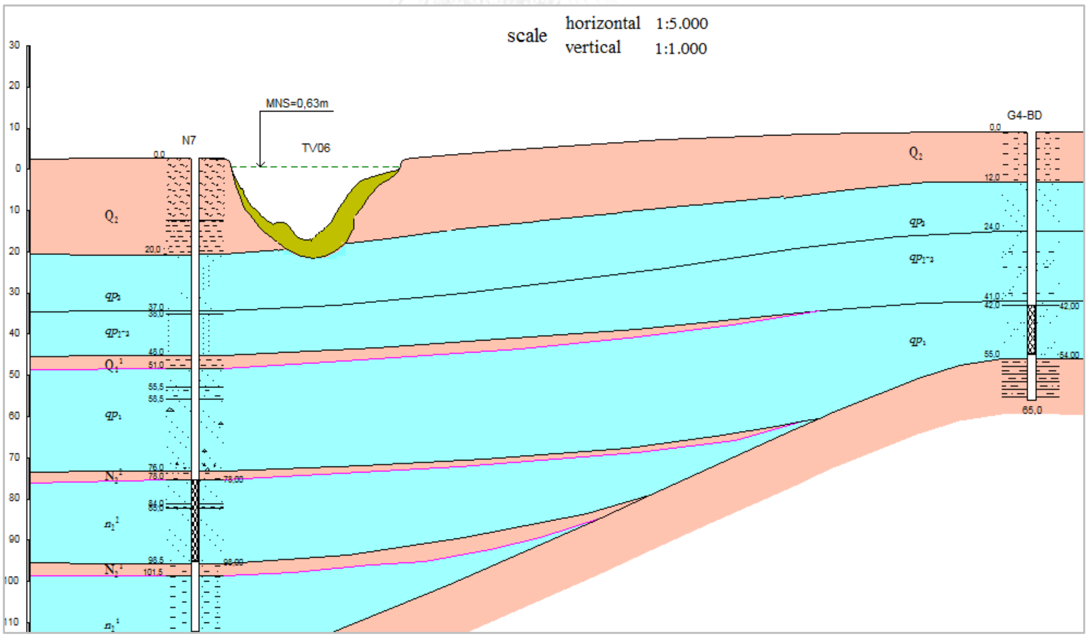


Figure 4.29. Cross-section at TV06

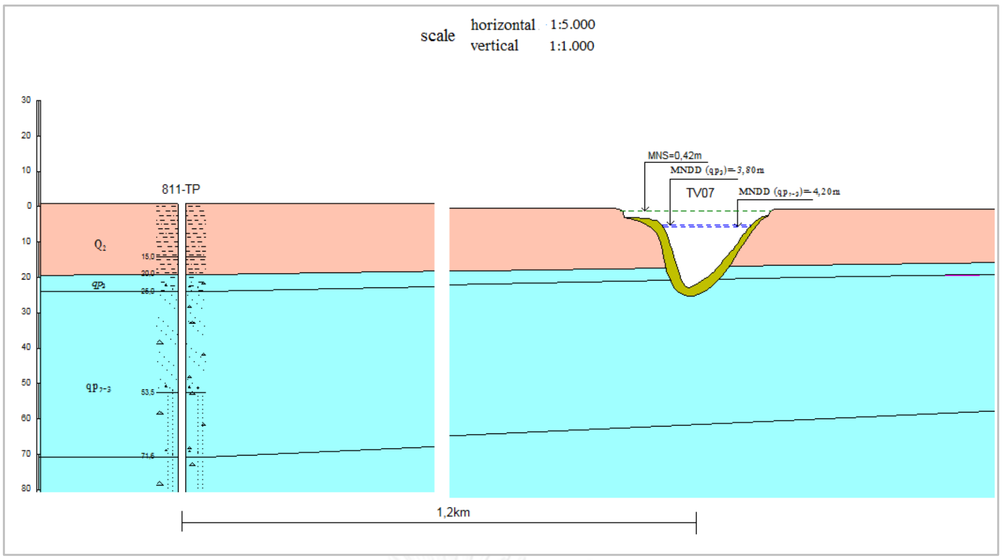


Figure 4.30. Cross-section at TV07

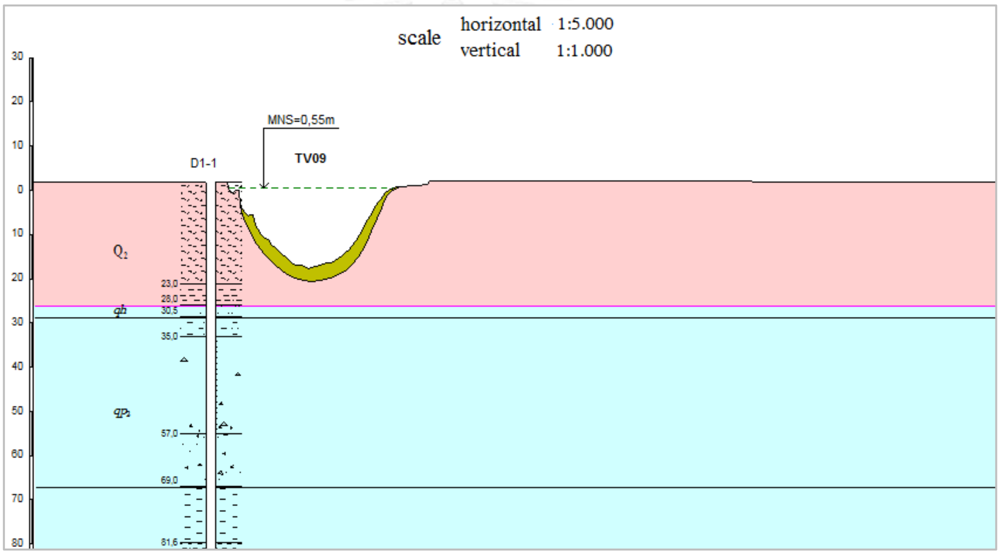


Figure 4.31. Cross-section at TV09

4.2.3.2. Function setup

From function 2.7 as mentioned in section 2.2.1.2, interaction parameter values were calculated based on conductance values (Table 4.10) and wetted length of interaction layer at 3 cross-sections TV1, TV3 and TV6. Besides, wetted length ratio (R_u) is calculated based on function 2.8. See calculation results in Table 4.12.

Table 4.12. Summary calculation of interaction parameter values penetration ratio

Cross-section	C (m/d)	W (m)	K_iM^{-1} (d^{-1})	Wu (m)	R_u
TV1	4.5	194	0.023	169	0.87
TV3	2.8	182	0.007	94	0.34
TV6	1.2	305	0.004	50	0.08

Figure 4.32 shows computation of the interaction parameter (**K_iM^{-1}**) and wetted length ratio of interaction layer. The computation result showed a good relationship between interaction parameter and wetted length ratio with R-squared is 0.96. So, interaction parameter can be obtained from wetted length ratio of interaction layer as linear function (function 2.6) below:

$$K_iM^{-1} = 0.0254 \times R_u + 0.0003 \quad (5.1)$$

Where:

K_iM^{-1} is interaction parameter value [T^{-1}]

R_u is wetted length ratio of interaction layer.

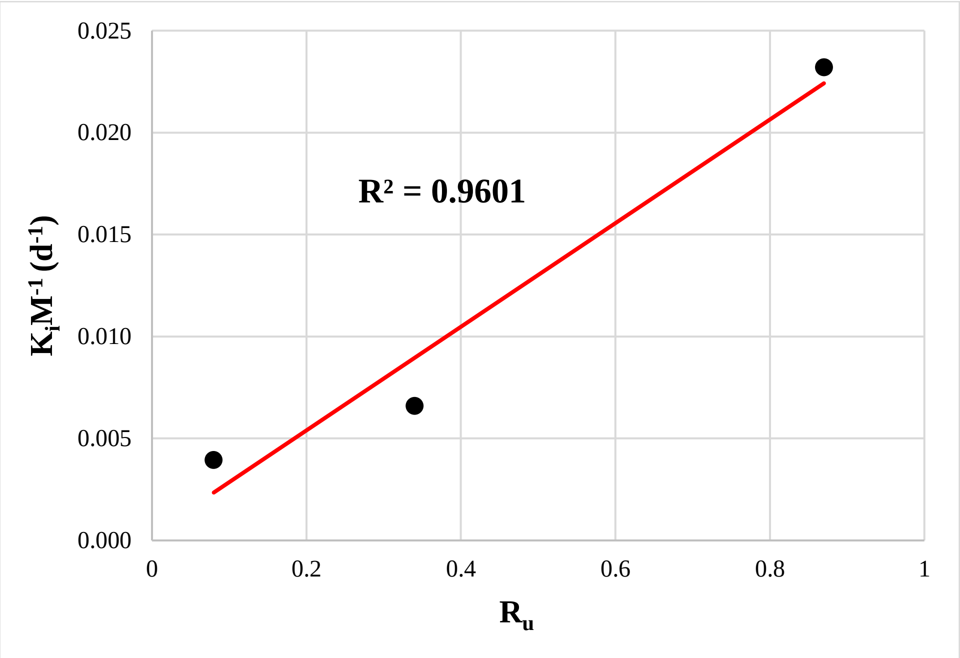


Figure 4.32. Correlation between interaction parameter and wetted length ratio.

Interaction parameter function (5.1) was applied to estimate interaction parameter value and conductance was calculated based on function 2.7 as mentioned in section 2.2.1.2 at other cross-section along Saigon River. In upper part of Saigon River, all cross sections have high ratio of wetted length and got high value of interaction parameter or conductance too. For example, correlative with high ratio of wetted length at SSG03 cross-section, interaction parameter and conductance value are 0.298 d^{-1} and 5.84 respectively. In contrast, when ratio of wetted length equals zero, interaction parameter value is 0.0003 and conductance values only depend on wetted length of interaction layer or riverbed. See more details in Table 4.13.

Table 4.13. Interaction parameter and conductance value estimation

Cross-section	**R_u**	**$K_iM^{-1}(d^{-1})$**	**W (m)**	**Conductance**
SSG03	0.98	0.0298	196	5.84
SSG12	0.58	0.0178	225	4.01

Cross-section	R_u	$K_iM^{-1}(d^{-1})$	W (m)	Conductance
SSG15	0.19	0.0061	252	1.54
SSG20	0.24	0.0076	309	2.35
TV07	0.30	0.0094	323	3.04
TV09	0.00	0.0003	285	0.11
TV10	0.00	0.0003	372	0.15

4.3. Discussions

4.3.1. Effect of mesh size

In the groundwater model, each cell presents for a river section. So, cell width has effect on river recharge. In this study, cell width is 500 m and actual conductance is 1.2 at TV6 cross-section. To assess the cell width effect on river recharge, cell width was changed to 305 m equal river width at TV6 cross-section and initial conductance (Boehmer 2000) was set 2.2 again.

Figure 4.33 shows change of river recharge and percentage during time period from 1/2000 to 9/2007. Average volume differential was 4.4 m^3/d and average changing percentage was always less than 4 percent. So, the difference of initial conductance (Boehmer 2000) and actual conductance (this study) came from the effect of cell width in the model.

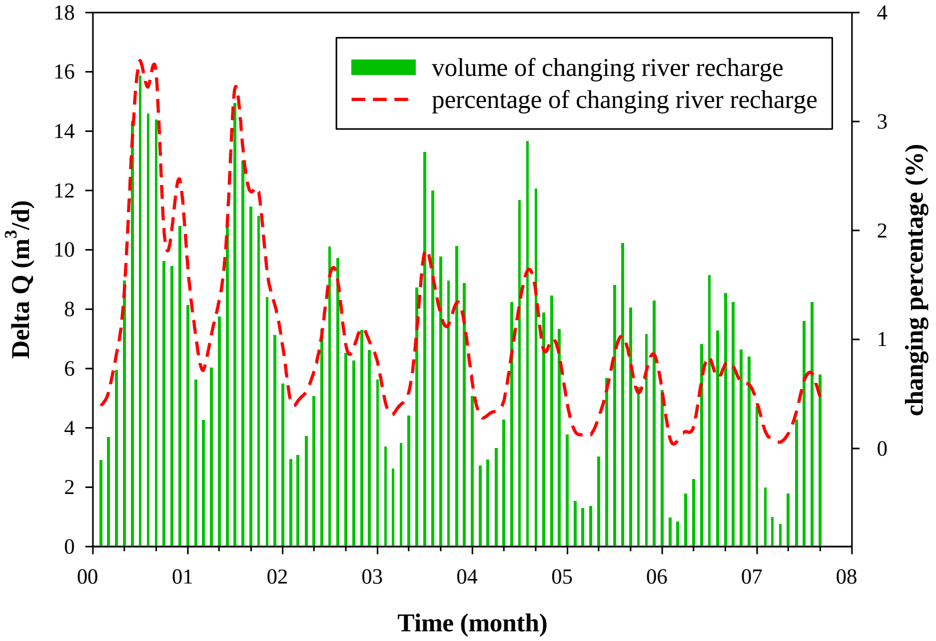


Figure 4.33. Effect of grid and initial conductance

4.3.2. Comparison with initial model.

Groundwater level and river recharge results at three cross-sections TV1, TV3 and TV6 were used to compare with the result of initial model which use conductance of **Boehmer (2000)**($C_{initial}$)

Groundwater levels

Figure 4.34 to Figure 4.36 shows the change of GWL when use $C_{initial}$ (same previous model) and variable C following interaction parameter function (mentioned in section 6.2.3.2) with observed groundwater level (GWL) at the cross-section. Fluctuation of GWL calculation was much more closed with observed GWL when apply conductance of this study.

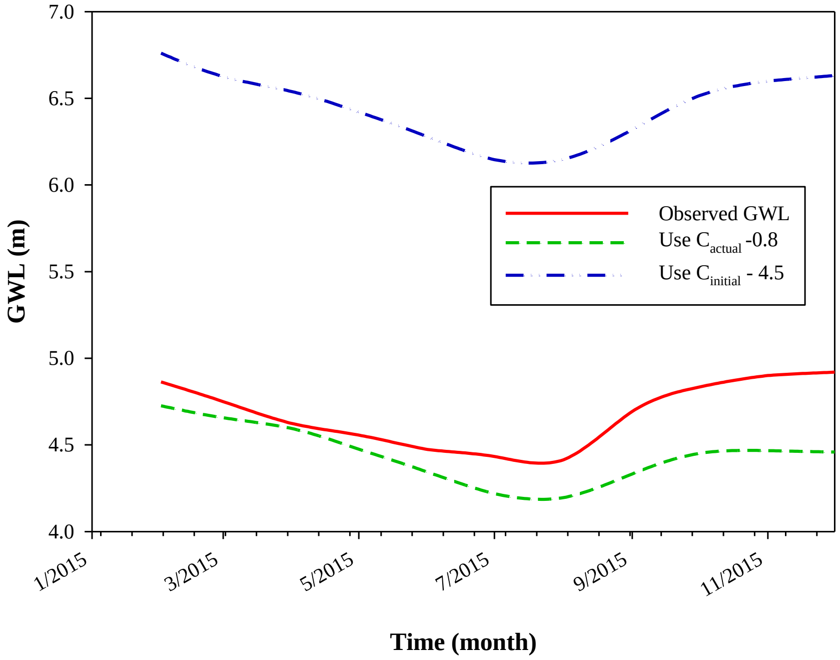


Figure 4.34. Comparison of GWL at TV1 cross-section

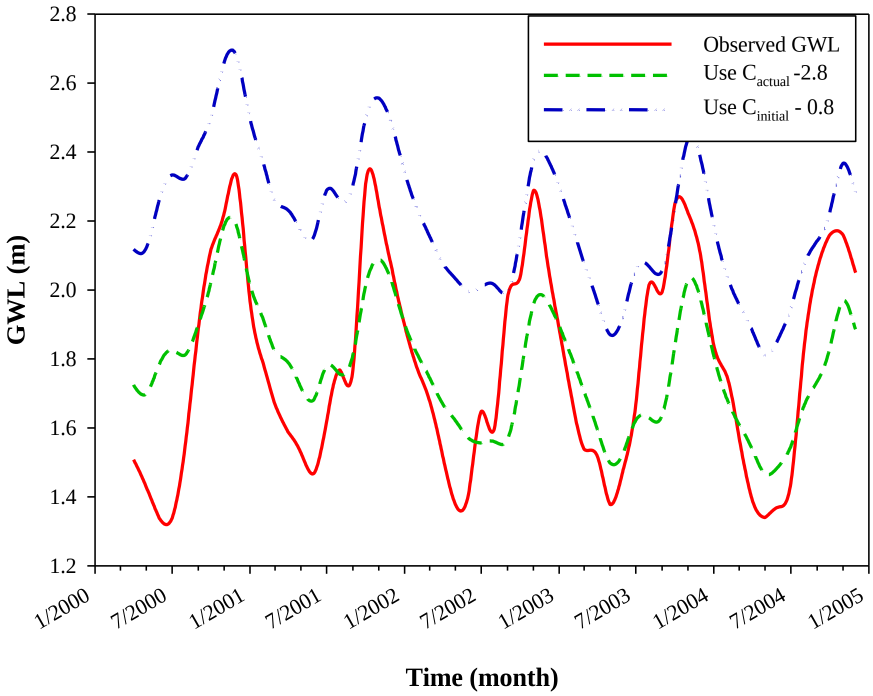


Figure 4.35. Comparison of GWL at TV3 cross-section

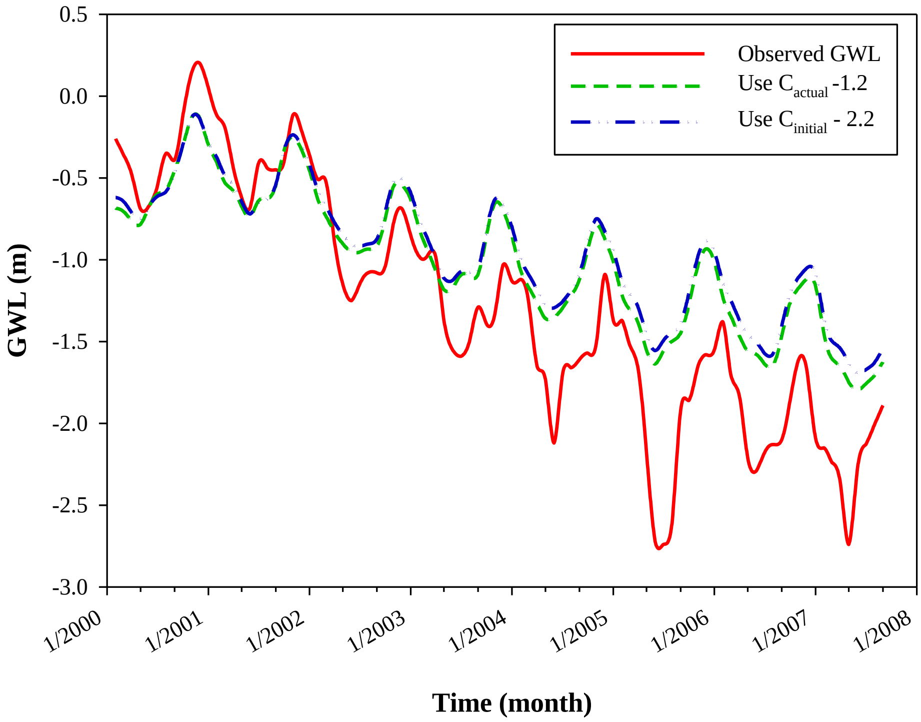


Figure 4.36. Comparison of GWL at TV6 cross-section

By applying interaction parameter results (in section 4.2), the groundwater level result from groundwater model showed a more closed fluctuation with observed groundwater level. Especially, at TV1 and TV3 cross-section which high ratio of wetted length of interaction layer, groundwater level changed 1.5 m and 0.4 m to close with observed GWL respectively.

River recharge volume

Figure 4.37 to Figure 4.39 show the change of river recharge when used fix C (same as initial model) and variable C following interaction parameter function (mentioned in section 5.2.3.2). At cross-section TV1, TV3 and TV6 the average increasing volumes were 1,234 m^3/d, 576 m^3/d and 239 m^3/d associated with using interaction parameter function to change C value from 0.8 to 4.5, from 0.8 to 2.8 and from 2.2 to 1.2, respectively.

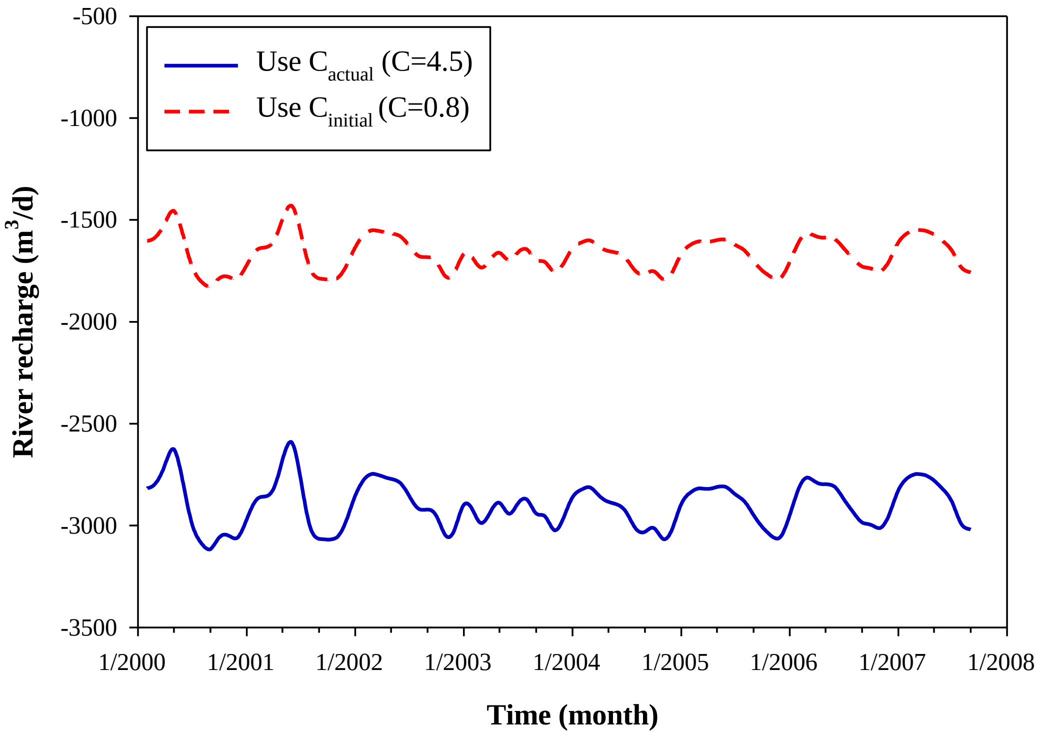


Figure 4.37. Comparison of river recharge at TV1 cross-section

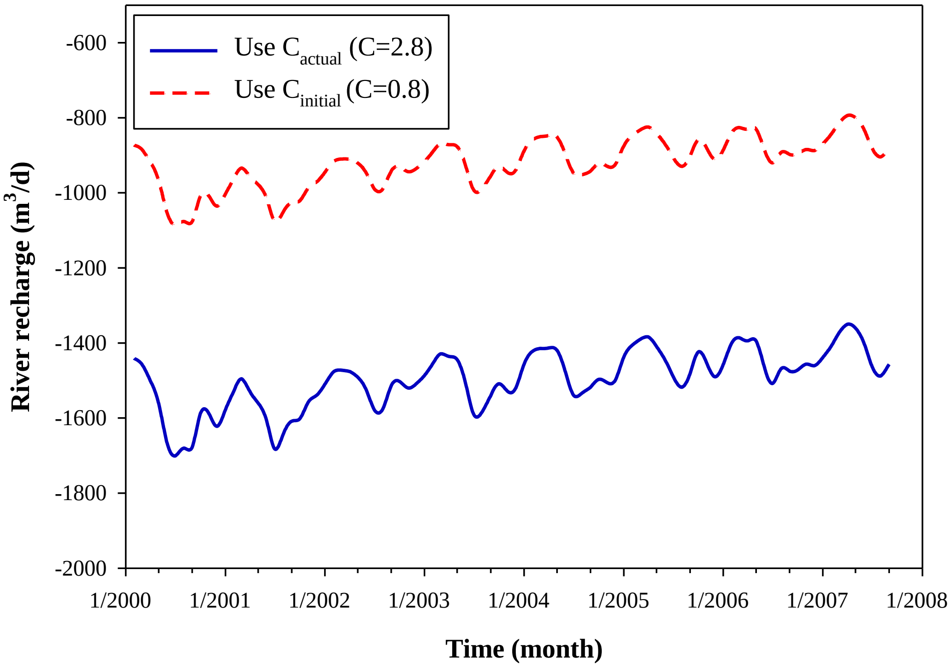


Figure 4.38. Comparison river recharge at TV3 cross-section

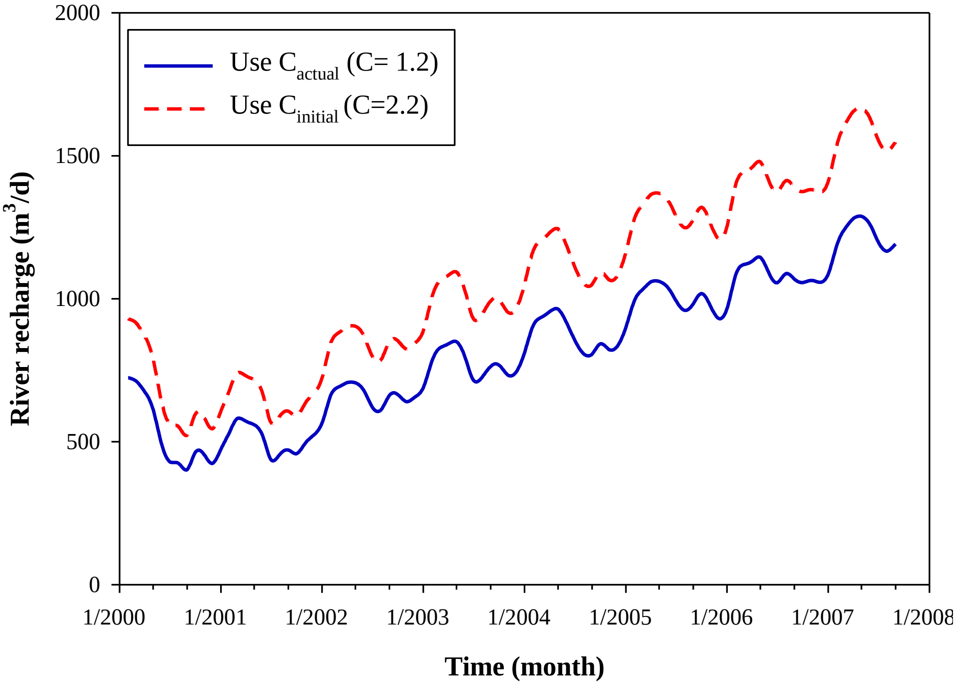


Figure 4.39. Comparison of river recharge at TV6 cross-section

Absolutely, the improvements of groundwater levels brought out changes of river recharge to more close with the fact. In particularly, interaction parameter of this study improved the underestimation about the gaining flow of river in upper part of Saigon River (TV1 and TV3 cross-section). This thing is very important because it can help water resources managers to have more clearly view on leakage of groundwater.

CHAPTER 5: AQUIFER WATER BALANCE RESULTS

In addition to carry conductance calibration to better understand the interaction between groundwater and river, this study has also considered the application of interaction parameter to simulations. This chapter presents the application of groundwater modeling to describe river recharge volume and pattern along Saigon River. Groundwater balance of four aquifers were also estimated to present exchange flow volume of all components of groundwater budget. A comparison of river recharge with flow rate of river was implemented to assess river loss in this study area.

5.1. Volume and pattern of river recharge

River recharges at 4 cross-sections were calculated directly by exporting groundwater budget at correlative cell in GMS software. River recharge is separated into two components: river recharge out (RRO) and river recharge in (RRI). RRO presents the volume of flow from aquifer to river with plus value and RRI presents the volume of flow from river to aquifer with minus value.

Figure 5.1 shows detail of the river volume and qp_{2-3} aquifer exchange flow in – out at 4 cross-sections along Saigon river. In upper part of Saigon River, river gained water from qp_{2-3} aquifer (RRO) through interaction layer with annual recharge volume at TV1 and TV3 cross-section were -2,896 m^3/d and -1,497 m^3/day respectively. In contrast, river lost water to qp_{2-3} aquifer (RRI) in lower part with annual recharge volume at TV6 and TV7 cross-section were 828 m^3/d and 925 m^3/day respectively.

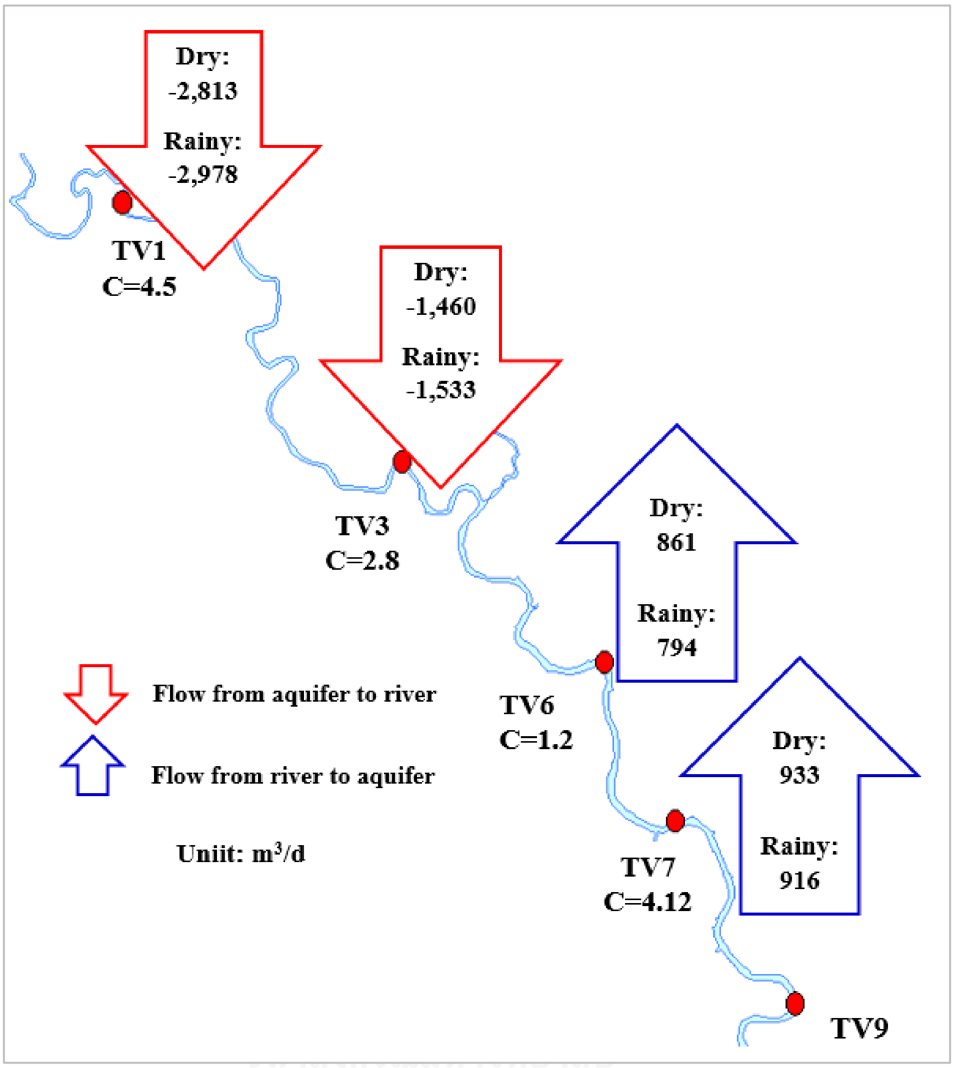


Figure 5.1. River recharge pattern along Saigon River

In whole study area, all river recharge out (RRO) shown a good correlation with rainfall from 2000 to 2007 (Figure 5.2). RRO volume of qp_{2-3} aquifer in rainy season is always higher than in dry season during the time period from 2000 to 2007 with average RRO volume in dry season and rain season were -20,313 m^3/d and -22,355 m^3/d, respectively. In contrast, RRI volume of qp_{2-3} aquifer in rainy season is always lower than in dry season in the time period with average RRI volume in dry season and rain season were 32,026 m^3/d and 28,999 m^3/d, respectively. While the RRO kept stable during the period from 2000 to 2007 and the volume of river recharge out grew up from around 20,000 m^3/d to over 40,000 m^3/d in 2000 and 2007 respectively as in Figure 5.3.

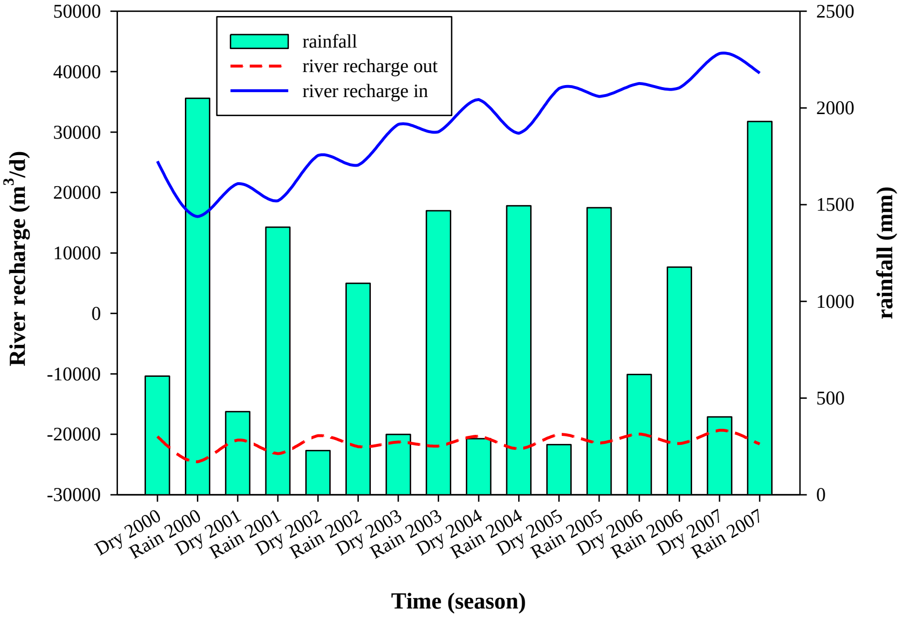


Figure 5.2. Correlation between river recharge of qp_{2-3} aquifer and rainfall

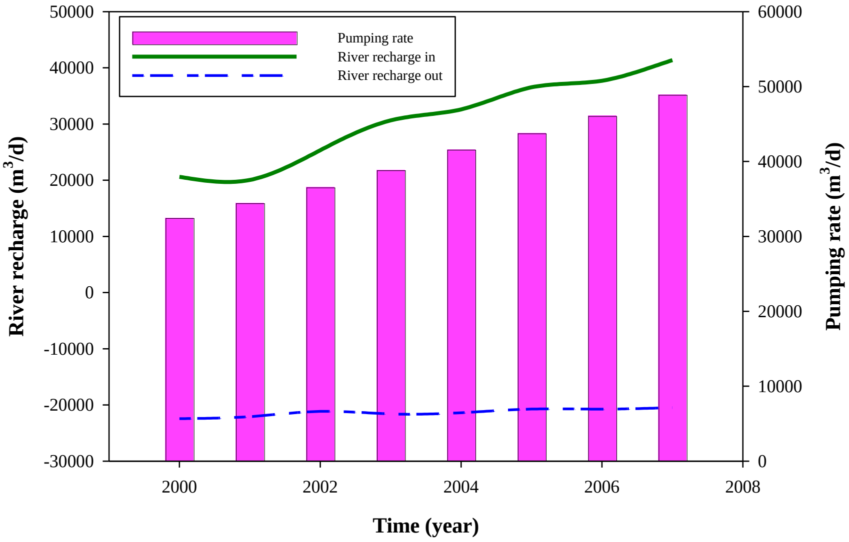
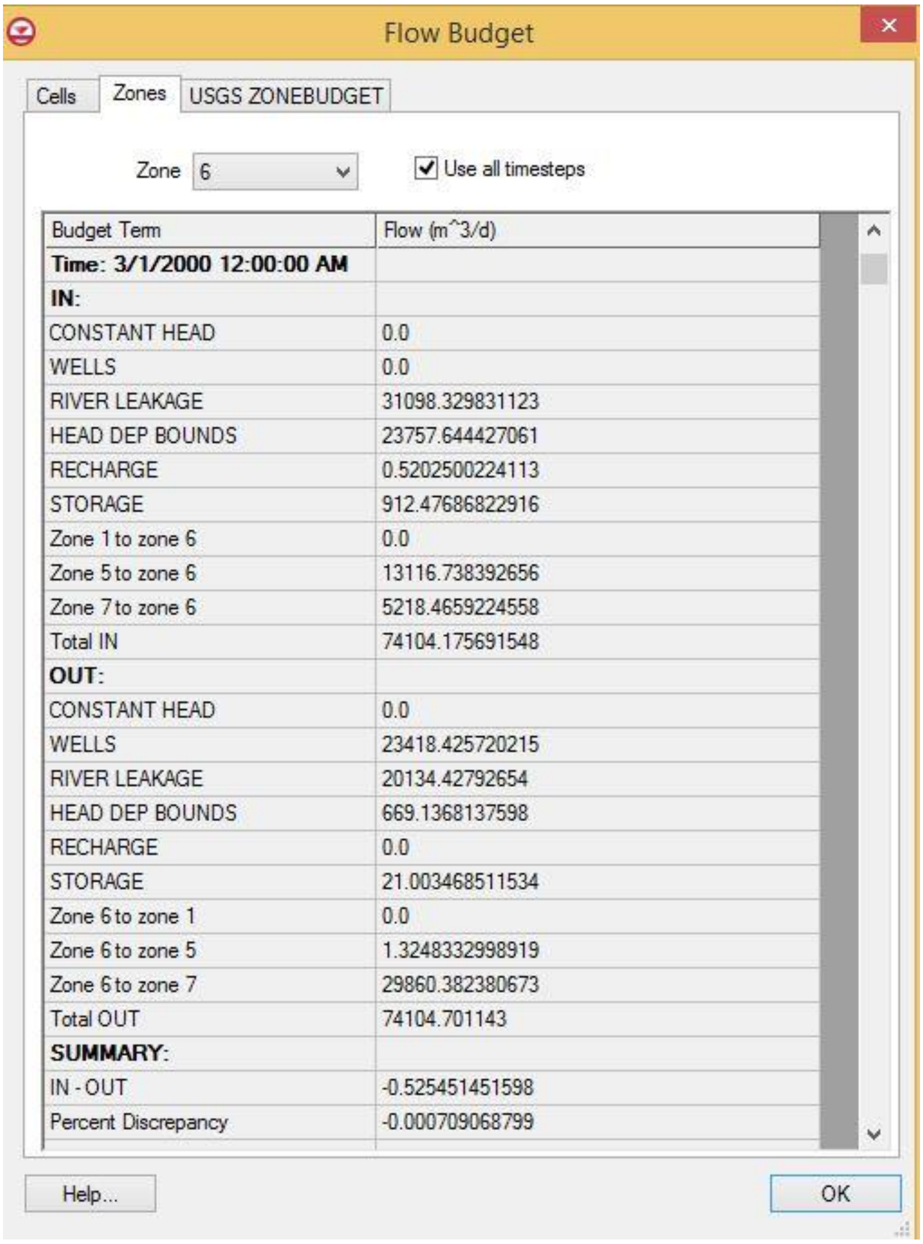


Figure 5.3. Correlation between river recharge of qp_{2-3} aquifer and pumping rate

5.2. Water balance of qp_{2-3} aquifer

Groundwater budget tools in GMS software provides the in and out volume at each cell or whole aquifer of all components as: river recharge, pumping discharge, boundaries flow, land recharge and storage (see in Figure 5.4)



Flow Budget

Cells | Zones | USGS ZONEBUDGET

Zone 6 — Use all timesteps

Budget Term	Flow (m^3/d)
Time: 3/1/2000 12:00:00 AM	
IN:	
CONSTANT HEAD	0.0
WELLS	0.0
RIVER LEAKAGE	31098.329831123
HEAD DEP BOUNDS	23757.644427061
RECHARGE	0.5202500224113
STORAGE	912.47686822916
Zone 1 to zone 6	0.0
Zone 5 to zone 6	13116.738392656
Zone 7 to zone 6	5218.4659224558
Total IN	74104.175691548
OUT:	
CONSTANT HEAD	0.0
WELLS	23418.425720215
RIVER LEAKAGE	20134.42792654
HEAD DEP BOUNDS	669.1368137598
RECHARGE	0.0
STORAGE	21.003468511534
Zone 6 to zone 1	0.0
Zone 6 to zone 5	1.3248332998919
Zone 6 to zone 7	29860.382380673
Total OUT	74104.701143
SUMMARY:	
IN - OUT	-0.525451451598
Percent Discrepancy	-0.000709068799

Help... | OK

Figure 5.4. Groundwater budget output of qp2-3 aquifer

Table 5.1 shows water balance of qp_{2-3} aquifer in the period from 2000 to 2007. In 2000, the model estimated total inflows to be 17.6 % groundwater recharge, 38.3% boundary recharge and 27 % river recharge. In the meanwhile, the model estimated outflows to be 26.7% river recharge, 27.5 % pumping discharge, 44 % boundaries discharge as in Table 5.2. In the period from 2000 to 2007, while ratio of pumping rate was 27.9% in 2004 and 29.5% in 2006, ratio of the river recharge went up to 34.8% in 2004 and 37% in 2006 respectively.

Table 5.1. Water balance of aquifer qp_{2-3} from 2000 to 2007

Components unit mi.m^3/d	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Boundaries in	32.6	33.4	38.4	33.8	42.8	44.2	44.6	45.3
RRI	23.3	23.2	29.4	35.5	38.0	42.4	44.3	49.4
Land recharge	14.9	11.1	6.9	10.5	10.0	8.8	11.1	7.6
Total in	70.8	67.7	74.6	79.9	90.8	95.4	100.1	102.3
Boundaries out	37.4	38.3	44.2	48.2	56.3	60.0	62.6	64.4
RRO	22.7	22.2	21.2	21.6	21.4	20.9	20.8	20.1
Pumping rate	23.4	24.4	26.7	29.2	29.3	31.5	34.1	37.7
Total out	83.5	84.9	92.1	99.1	107.0	112.4	117.4	122.3
Change storage	-13.8	-16.2	-16.4	-17.0	-17.4	-18.4	-18.6	-20.0

Table 5.2. Budget components ratio of qp_{2-3} aquifer from 2000 to 2007

Components unit %	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Boundaries in	38.3	39.5	42.0	34.3	39.1	38.4	37.3	36.8
River recharge in	27.4	27.5	32.1	36.0	34.8	36.9	37.0	40.1
Land recharge	17.6	13.1	7.5	10.7	9.1	7.6	9.3	6.1
Total in	100	100	100	100	100	100	100	100
Boundaries out	44.0	45.3	45.8	48.9	51.5	52.2	52.3	52.3
River recharge out	26.7	26.2	21.9	21.9	19.6	18.2	17.4	16.3
Pumping rate	27.5	27.7	26.8	28.4	27.9	28.6	29.5	30.6
Total out	100	100	100	100	100	100	100	100

In the period from 2000 to 2007, flow in components consist of recharge 10,105 cubic meter per day (10% of total in), river recharge in 35,703 cubic meter per day (34% of total in), water from boundaries in 39,392 cubic meter per day (38.2% of total in) and water supply from storage in 18,183 cubic meter per day (17.8% of total). Flow out components consists of: groundwater pumping 29,615 (28% of total out), groundwater discharge to river (river recharge out) 21,363 cubic meter per day (21% of total out), groundwater discharge to boundary (boundary out) 51,439 cubic meters per day (49% of total out), and water supply to groundwater reserve (storage out) 837 cubic meters per day (1% of total out) as shown in Figure 5.5.

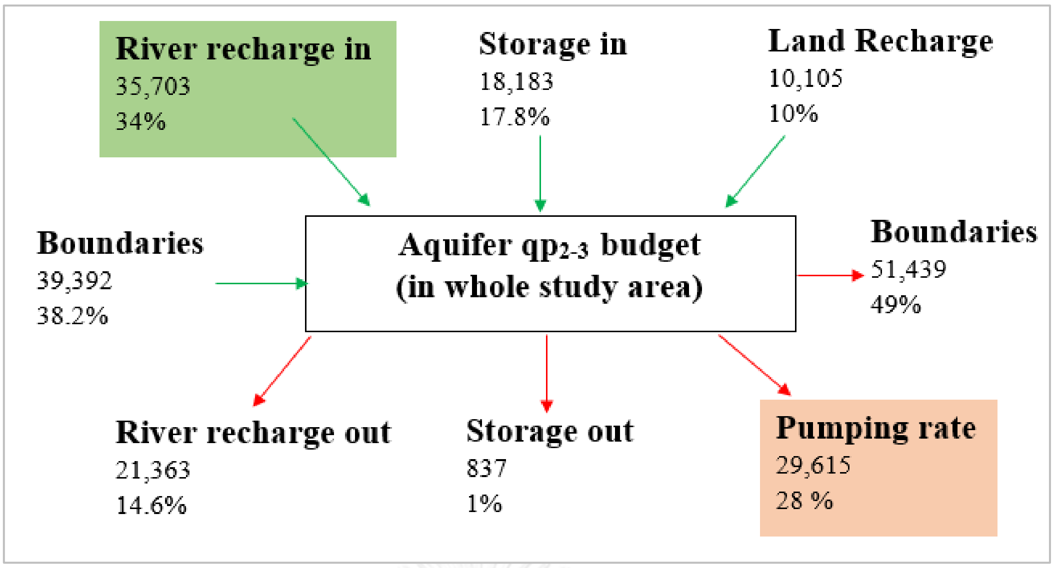


Figure 5.5. Groundwater budget of aquifer $qp_{2\text{-}3}$ from 2000 to 2007

A summary of water balance of 4 aquifers shows an overview about how water in and out in each aquifer and volume of all flow components i.e., river recharge, pumping rate, land recharge and exchange flow between two continuous aquifer also. River recharge concentrated on $qp_{2\text{-}3}$ aquifer from 2000 to 2007, with RRO and RRI volume were -21,363 and 35,703, respectively. For $qp_{2\text{-}3}$ aquifer, total recharge was 68,523 m^3/d, however total infiltration rate to below aquifer (qp_1 aquifer) and pumping rate were 79,578 m^3/d. So, pumping rate of both $qp_{2\text{-}3}$ aquifer and qp_1 aquifer need to be reduced and controlled better as shown in Figure 5.6.

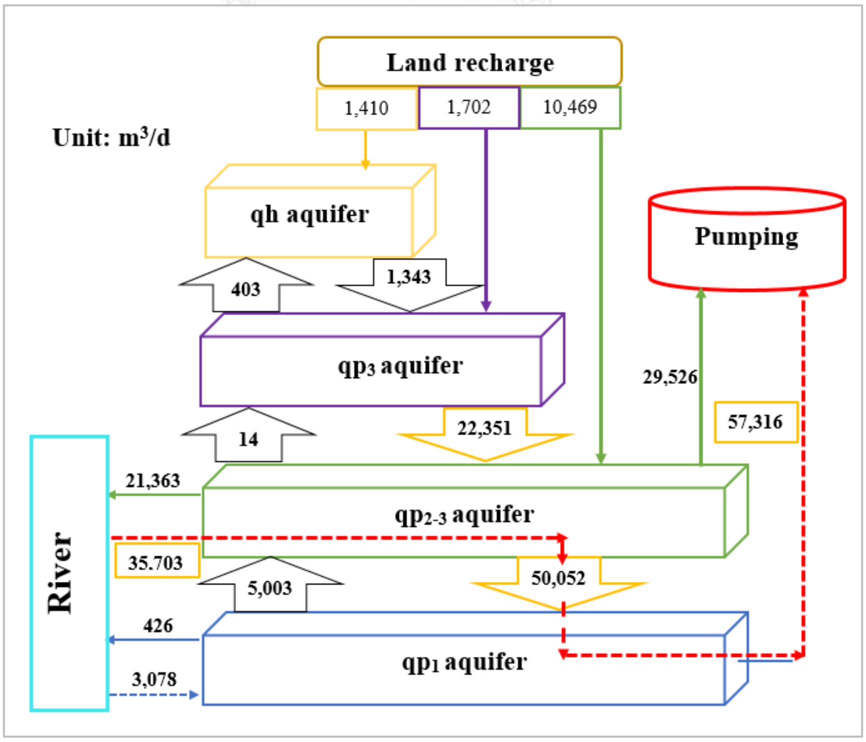


Figure 5.6. Flow in and out of 4 aquifers

5.3. Analysis of groundwater budget component

Figure 5.7 shows the depletion of yearly groundwater storage. Changes of groundwater storage of qp_{2-3} aquifer in 2000 of the whole study area was -13,777 m^3/d, and that of 2007 is -19,969 m^3/d resulting the average rate of depletion of groundwater storage is -17,221 m^3/d per year. The change in storages in qp2-3 aquifer was of negative values from 2000 to 2007, meaning that groundwater is being declined significantly. The changing storage in qp_{2-3} aquifer had effect from rapid pumping growth.

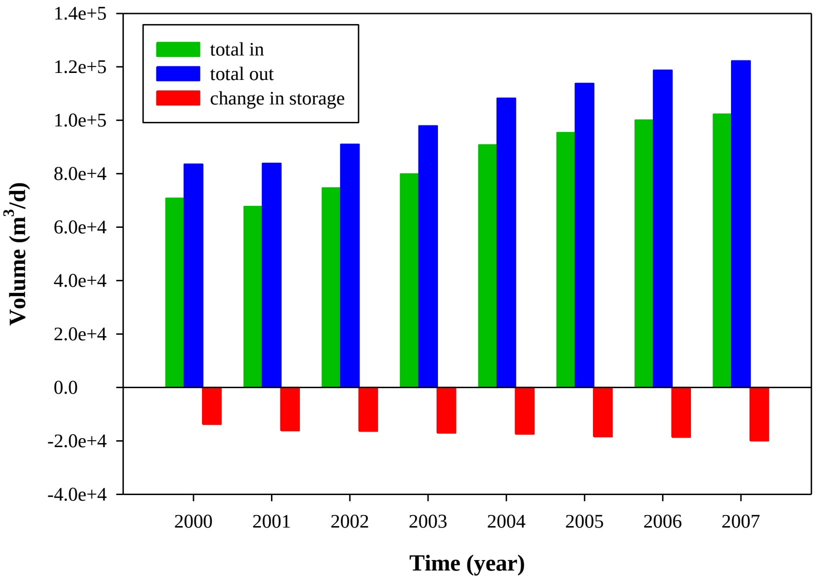


Figure 5.7. Changes of groundwater storage from 2000 to 2007 in qp_{2-3} aquifer

Pumping induced more river recharge and gave the same tendency to increase rapidly from 2000 to 2007. The river recharge in rainy season always was higher the one in dry season in the period from 2002 to 2007 with average difference ratio between two seasons approximately 7%. In contrast, the land recharge in dry season was lower the one in rainy season (see in Figure 5.8)

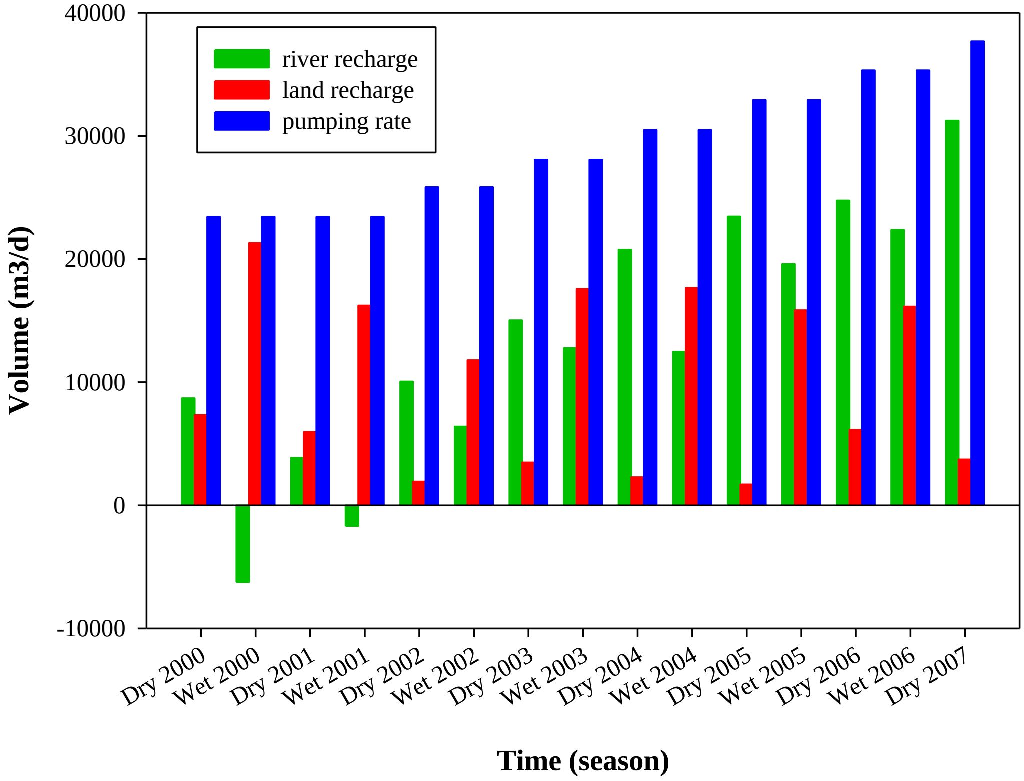


Figure 5.8. Correlation recharge components and pumping rate of qp_{2-3} aquifer

5.4. Assessment of river loss

River recharge at Thu Dau Mot station (TV6 cross-section) was computed with flow rate of river to assess the river loss (Table 5.3). There was only average 0.03 % of flow rate loss to qp_{2-3} aquifer. During the period from 2000 to 2007, the river loss was too small compared with flow rate of river at Thu Dau Mot station, so river water levels kept steady fluctuation in this time period but groundwater levels decreased rapidly, about 0.15m/year because of increasing pumping rate (see in Figure 5.9).

Table 5.3. Estimation of river loss ratio at Thu Dau Mot station

Time	Flow rate (m^3/s)	River recharge (m^3/d)	% rate loss
Feb-05	25.2	994	0.05
Mar-05	20.1	1,031	0.06
Apr-05	26.6	1,059	0.05
May-05	21.4	1,061	0.06
Feb-06	97.0	1,082	0.01
Mar-06	80.2	1,119	0.02
Apr-06	63.4	1,131	0.02
May-06	113.1	1,145	0.01
Feb-07	72.1	1,187	0.02
Mar-07	65.7	1,243	0.02

Time	Flow rate (m^3/s)	River recharge (m^3/d)	% rate loss
Apr-07	60.7	1,280	0.02
May-07	79.2	1,288	0.02
Average	**60.4**	**1,135**	**0.03**

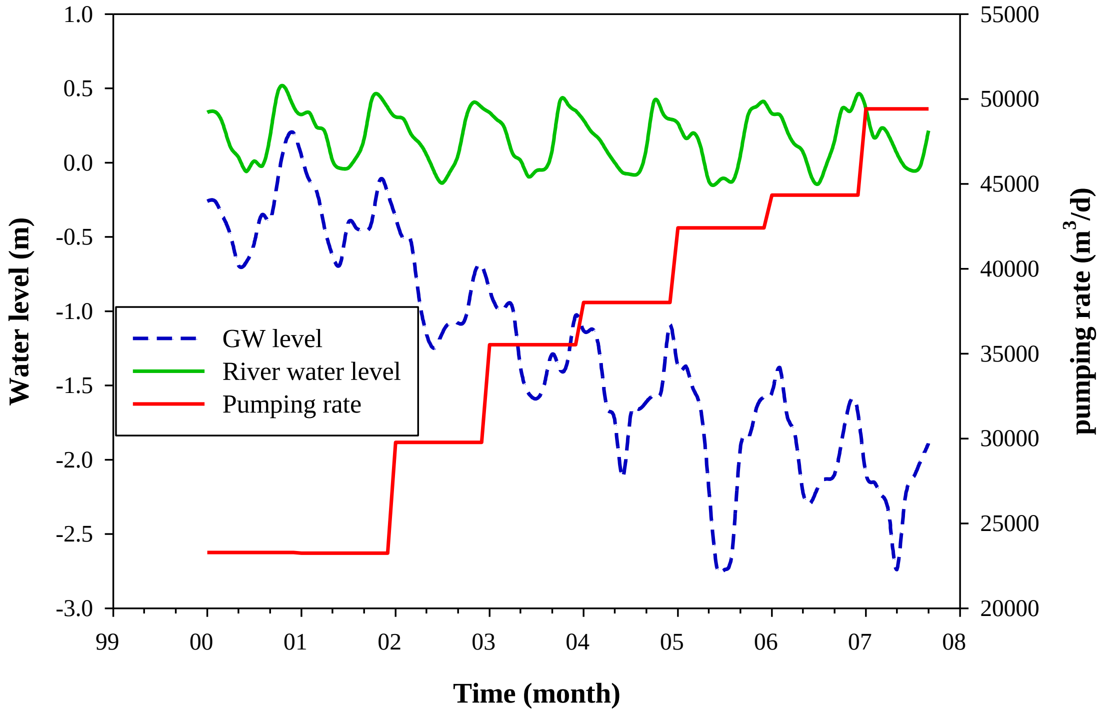


Figure 5.9. Effect of pumping rate on fluctuation trend of GWL and RWL

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

The interaction parameter value at TV1, TV3, TV6 cross-section is 0.023 d^{-1}, 0.007 d^{-1} and 0.004 d^{-1}, respectively and can be applied to groundwater and river interaction for groundwater modeling in Saigon River area. A linear function of interaction parameter with wetted length ratio of interaction layer ($K_i M^{-1} = 0.0254 \times R_u + 0.0003$) was developed to estimate the interaction parameter at other locations along Saigon River. When river cross-section has no penetration with aquifer, the materials of interaction layer consists of materials of riverbed and aquitard with value of interaction parameter equal 0.0003 d^{-1}. In the other hand, the value will reach to 0.033 d^{-1} when river cross-section has fully penetration with aquifer.

In upper part of Saigon River, river gained water from inflow of groundwater through riverbed in the period from 2000 to 2007. Volume of RRO showed a closed relationship with rainfall and the volume in rainy season. The average RRO volume at TV1 cross-section and TV6 cross-section were -2,899 m^3/d and -1,496m^3/d respectively. In lower part, river lost water to groundwater by out flow through the riverbed (river recharge in). Under effect of increasing pumping rate, the volume of river recharge in grew up approximately 56% from 2000 to 2007 at TV6 cross-section and about 50 % at TV7 cross-section. However, pumping rate of both qp_{2-3} and qp_1 aquifer exceeded total groundwater recharge so, they need to be reduced and controlled better.

In whole study area, river recharge volume increased 26,129 m^3/d from 2000 to 2007, and the recharge volume occupied in average 34% of total flow in water budget of qp_{2-3} aquifer in the study area compared with 10.1% of land recharge and 17.7 % of storage in. The river loss was insignificant when compared with flow rate of river, not over 0.06%. Groundwater flow model in period of 2000-2007 showed that groundwater resource was under declining and the existing development of groundwater resources was unsustainable. The impact of groundwater abstraction to groundwater resources was significant through increase change of storage with the average rate of depletion of groundwater storage is -17,221 m^3/d.

6.2. Recommendations

More field tests at cross-sections along Saigon River, i.e., observed groundwater level and river water level, should be implemented to improve the estimate of the interaction parameter function developed from this study.

Besides, an abstraction investigation needs to add more to see more exactly the impact of abstraction on river recharge and change of ground storage also. Pumping rate of two aquifers (qp2-3 and qp1) need to be controlled better. Water quality of river needs to be monitored and managed much better because it has been effecting directly to groundwater quality in lower part of Saigon River.

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APPENDIX

APPENDIX 1

Absolute elevation of the top and bottom of aquifers

Well ID	X	Y	Z	Q_2	qh	Q_1^3	qp_3	Q_1^{2-3}	qp_{2-3}	Q_1^1	qp_1
				Bot_1	Bot_2	Bot_3	Bot_4	Bot_5	Bot_6	Bot_7	Bot_8
807	665503	1211359	8.0	8.0	8.0	-14.5	-18.0	-46.8	-63.0	-69.0	-119.0
810	675593	1200293	7.7	7.7	7.7	-0.3	-22.3	-37.8	-71.2	-76.3	-128.3
9617	641930	1204838	0.6	0.6	0.6	-18.9	-52.3	-52.3	-86.2	-98.2	-102.3
801-TP	658210	1220645	9.9	9.9	9.9	-17.1	-17.1	-37.6	-63.6	-65.6	-84.6
802-TP	658750	1210129	0.3	-20.8	-22.8	-22.8	-42.5	-42.5	-69.3	-75.5	-120.8
806-TP	670694	1221347	2.0	2.0	2.0	-8.0	-13.0	-22.5	-29.0	-29.0	-52.5
816-B-TP	686851	1197414	2.7	-11.3	-11.3	-15.8	-26.3	-36.3	-54.3	-55.3	-86.8
817-TP	693654	1200082	28.9	28.9	28.9	28.9	28.9	27.9	1.3	1.3	1.3
BK1	715775	1227391	36.1	36.1	36.1	36.1	36.1	36.1	36.1	36.1	36.1
BK10	712587	1207899	42.0	42.0	42.0	42.0	42.0	38.7	38.7	38.7	36.0
BK11	715033	1204843	51.0	51.0	51.0	51.0	51.0	44.9	44.9	37.0	27.0
BK12A	714396	1200521	33.6	33.6	33.6	33.6	33.6	28.3	28.3	28.3	20.6
BK14	718261	1199289	30.0	30.0	30.0	30.0	30.0	23.1	23.1	17.5	6.0
BK17	697192	1216478	5.9	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7
BK18	708670	1205436	26.5	26.5	26.5	26.5	26.5	22.9	20.9	20.9	20.9
BK2	712633	1219740	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
BK3	708450	1218382	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5
BK4	705632	1214643	31.9	31.9	31.9	31.9	31.9	27.1	27.1	27.1	27.1
BK5	702051	1208611	3.0	3.0	3.0	3.0	3.0	-0.4	-5.6	-5.6	-5.6
BK6	701490	1206009	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
BK7	694236	1211207	2.8	2.8	2.8	1.0	-0.3	-1.4	-5.3	-8.8	-15.4
BK8A	698604	1221419	11.2	11.2	11.2	11.2	11.2	11.2	11.2	3.0	-2.2
BK9	705586	1208996	34.4	34.4	34.4	34.4	34.4	29.5	25.7	24.6	20.9
DD11	676517	1258378	47.7	47.7	47.7	47.7	47.7	47.7	47.7	40.7	24.7
D12	699916	1200965	8.0	8.0	8.0	-6.1	-24.1	-40.1	-66.1	-75.1	-122.1
D302	670765	1200704	5.1	5.1	5.1	-12.9	-34.9	-44.9	-79.7	-84.9	-127.0
D4	683333	1203447	1.5	1.5	1.5	-5.5	-8.5	-10.5	-55.0	-56.1	-94.7
D4A	681649	1201979	2.6	2.6	2.6	-1.9	-4.2	-7.9	-40.9	-49.4	-100.4
Đ8	690729	1274340	63.4	63.4	63.4	63.4	63.4	63.4	63.4	63.4	63.4
ĐT1	638129	1225675	5.0	5.0	5.0	-7.0	-33.0	-56.0	-74.0	-98.0	-151.0
DucH	666635	1203268	0.9	-10.1	-34.4	-50.1	-88.1	-90.1	-129	-137	-157.1
G13A	677616	1197255	5.0	5.0	5.0	-7.0	-30.0	-44.0	-70.0	-86.0	-123.0
LN	638079	1247356	13.0	13.0	13.0	6.0	-1.0	-4.0	-7.0	-34.0	-41.0
NB12	660232	1234427	8.0	8.0	8.0	8.0	8.0	6.5	-7.5	-17.5	-36.5

Well ID	X	Y	Z	Q_2	qh	Q_1^3	qp_3	Q_1^{2-3}	qp_{2-3}	Q_1^1	qp_1
				Bot_1	Bot_2	Bot_3	Bot_4	Bot_5	Bot_6	Bot_7	Bot_8
PSI	694216	1259562	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	72.0
Q023050	648158	1219680	5.9	5.9	5.9	-4.4	-8.4	-13.1	-24.1	-24.1	-42.4
Q225060	689225	1242864	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5
Q80404Z	664170	1215218	10.4	10.4	10.4	2.4	-17.6	-20.6	-31.1	-38.1	-54.4
QTBD1A	683755	1214696	29.8	29.8	29.8	29.8	29.8	24.8	4.8	-0.2	-13.2
QTBD2A	690086	1212907	34.2	34.2	34.2	34.2	34.2	26.2	24.2	19.2	-2.8
QTBD3A	691578	1205018	31.3	31.3	31.3	31.3	31.3	21.3	12.3	3.3	-0.7
QTBD4A	685539	1203095	1.5	-25.5	-49.0	-48.5	-48.5	-50.5	-66.0	-69.5	-80.5
QTBD5A	685925	1211647	27.9	27.9	27.9	27.9	27.9	18.9	11.7	-3.1	-6.1
QTBD6A	669368	1225961	19.0	19.0	19.0	19.0	19.0	7.0	-10.5	-18.5	-40.5
SB101	680067	1214519	1.4	-17.7	-17.7	-17.7	-17.7	-17.7	-20.7	-26.2	-48.7
TU10	687658	1247796	35.0	35.0	35.0	35.0	35.0	35.0	35.0	33.8	30.7
TU11	667493	1249008	41.0	41.0	41.0	41.0	41.0	39.0	37.4	28.3	27.0
TU12	698928	1250745	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0
TU1B	677509	1220463	16.0	16.0	16.0	16.0	16.0	13.2	8.8	3.0	-23.0
TU2B	691514	1222884	28.9	28.9	28.9	28.9	28.9	28.9	28.9	21.3	14.9
TU3	708171	1230965	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
TU4	691480	1229338	46.0	46.0	46.0	46.0	46.0	46.0	46.0	38.0	20.6
TU5C	672179	1222240	2.0	2.0	2.0	-0.7	-0.7	-7.5	-25.0	-28.0	-39.5
TU6	693023	1238631	50.0	50.0	50.0	50.0	50.0	50.0	50.0	44.4	43.7
TU7	704354	1243880	52.0	52.0	52.0	52.0	52.0	52.0	52.0	52.0	52.0
TU8	710618	1250252	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0
TU9B	672405	1233910	25.0	25.0	25.0	25.0	25.0	25.0	25.0	12.7	10.0
T_MĐ1	675584	1253610	40.0	40.0	40.0	40.0	40.0	31.0	31.0	26.0	20.0
T_TCN	678532	1255010	45.0	45.0	45.0	45.0	45.0	45.0	45.0	40.0	21.0
NT6-1	674715	1242593	40.0	40.0	40.0	40.0	40.0	27.0	24.0	7.0	-3.0
LH	677664	1240624	40.0	40.0	40.0	40.0	40.0	35.0	28.0	24.0	8.0
NTLS_2	686484	1210524	25.0	25.0	25.0	25.0	25.0	15.0	-10.2	-18.1	-24.5
AP1a	687818	1214880	31.8	31.8	31.8	31.8	31.8	31.2	26.6	23.7	2.2
DA_1	683852	1227981	35.0	35.0	35.0	35.0	35.0	30.0	16.5	8.3	-3.2
TanLong	682604	1253033	50.0	50.0	50.0	50.0	50.0	50.0	50.0	47.0	45.7
VRG	674865	1243749	40.0	40.0	40.0	40.0	40.0	26.0	22.0	10.0	3.0
MHO	677830	1248880	50.0	50.0	50.0	50.0	50.0	36.0	32.0	21.0	12.5
CH_1	688210	1223730	30.0	30.0	30.0	30.0	30.0	24.0	22.5	14.5	10.0
CTDT	681068	1215823	15.0	15.0	15.0	15.0	15.0	10.0	-10.0	-15.0	-28.0
TNTU	690403	1222210	30.0	30.0	30.0	30.0	30.0	30.0	30.0	24.0	14.0

Well ID	X	Y	Z	Q_2	qh	Q_1^3	qp_3	Q_1^{2-3}	qp_{2-3}	Q_1^1	qp_1
				Bot_1	Bot_2	Bot_3	Bot_4	Bot_5	Bot_6	Bot_7	Bot_8
HH_G1	682671	1239477	15.0	15.0	15.0	15.0	15.0	15.0	15.0	7.0	-22.0
VN2	690117	1242688	40.0	40.0	40.0	40.0	40.0	40.0	40.0	22.0	20.0
MiP	692340	1221061	18.0	18.0	18.0	18.0	18.0	14.0	12.2	7.2	5.7
MaiThao2	669426	1269231	44.0	44.0	44.0	44.0	44.0	43.0	40.5	38.7	37.7
LongTan	670250	1245750	40.0	40.0	40.0	40.0	40.0	34.0	29.0	21.0	13.0
MinhTan	656250	1257750	40.0	40.0	40.0	40.0	40.0	39.0	38.5	35.8	23.8
AL1	687250	1251250	45.5	45.5	45.5	45.5	45.5	45.5	45.5	45.5	45.5
BTram	695250	1239250	50.0	50.0	50.0	50.0	50.0	50.0	50.0	48.0	47.0
BB_mia	684250	1241750	50.0	50.0	50.0	50.0	50.0	50.0	50.0	46.0	35.0
KhaiHoan	674865	1243749	40.0	40.0	40.0	40.0	40.0	40.0	40.0	26.0	22.0
Food_KC	695750	1210750	8.0	8.0	8.0	8.0	8.0	7.0	6.0	-3.0	-13.5
VietHuong	669011	1227206	18.0	18.0	18.0	18.0	18.0	13.0	5.0	-10.0	-13.0

APPENDIX 2
Water levels estimation at TV3, TV7 and TV9 cross-section

Time	Observed water level (m)		Release (m^3/s)	Interpolated water level (m)			
	Thu Dau Mot	Phu An	Dau Tieng	TV1	TV3	TV7	TV9
Jan-00	0.34	0.28	70.9	2.19	0.51	0.37	0.36
Feb-00	0.34	0.29	89.1	2.40	0.51	0.37	0.37
Mar-00	0.26	0.21	82.0	2.31	0.43	0.32	0.30
Apr-00	0.10	0.05	156.8	3.18	0.27	0.21	0.15
May-00	0.04	-0.03	159.3	3.21	0.21	0.17	0.07
Jun-00	-0.06	-0.11	83.3	2.33	0.11	0.10	-0.01
Jul-00	0.01	-0.06	52.0	1.97	0.18	0.15	0.04
Aug-00	-0.02	-0.10	22.5	1.62	0.15	0.13	0.00
Sep-00	0.18	0.12	25.0	1.65	0.35	0.26	0.21
Oct-00	0.47	0.32	51.0	1.95	0.65	0.47	0.40
Nov-00	0.50	0.41	43.4	1.87	0.67	0.48	0.48
Dec-00	0.38	0.32	48.6	1.93	0.55	0.40	0.40
Jan-01	0.32	0.27	73.3	2.21	0.49	0.36	0.35
Feb-01	0.34	0.28	81.3	2.31	0.51	0.37	0.36
Mar-01	0.24	0.19	64.8	2.11	0.41	0.30	0.28
Apr-01	0.17	0.10	102.5	2.55	0.34	0.26	0.19
May-01	0.02	-0.06	170.7	3.34	0.18	0.15	0.04
Jun-01	-0.04	-0.14	182.9	3.49	0.13	0.11	-0.03
Jul-01	-0.04	-0.12	80.0	2.29	0.13	0.12	-0.02
Aug-01	0.03	-0.04	25.1	1.65	0.20	0.16	0.07
Sep-01	0.16	0.10	28.5	1.69	0.33	0.25	0.19
Oct-01	0.43	0.35	17.2	1.56	0.60	0.43	0.43
Nov-01	0.45	0.39	29.0	1.70	0.62	0.45	0.46
Dec-01	0.37	0.28	60.3	2.06	0.54	0.40	0.36
Jan-02	0.31	0.24	86.6	2.37	0.48	0.35	0.32
Feb-02	0.29	0.23	95.6	2.47	0.46	0.34	0.31
Mar-02	0.20	0.14	98.8	2.51	0.36	0.27	0.23
Apr-02	0.14	0.07	81.9	2.31	0.31	0.23	0.17
May-02	0.05	-0.02	83.6	2.33	0.22	0.18	0.08
Jun-02	-0.07	-0.15	68.1	2.15	0.10	0.10	-0.04
Jul-02	-0.14	-0.21	62.0	2.08	0.03	0.05	-0.10
Aug-02	-0.06	-0.13	40.9	1.84	0.11	0.10	-0.02
Sep-02	0.05	-0.02	49.6	1.94	0.22	0.18	0.08
Oct-02	0.30	0.24	29.3	1.70	0.47	0.35	0.32
Nov-02	0.41	0.35	2.5	1.39	0.58	0.42	0.42

Time	Observed water level (m)		Release (m^3/s)	Interpolated water level (m)			
	Thu Dau Mot	Phu An	Dau Tieng	TV1	TV3	TV7	TV9
Dec-02	0.37	0.32	42.3	1.85	0.54	0.40	0.39
Jan-03	0.34	0.27	73.4	2.21	0.51	0.37	0.35
Feb-03	0.29	0.22	6.3	1.44	0.46	0.34	0.30
Mar-03	0.23	0.16	9.4	1.47	0.40	0.30	0.25
Apr-03	0.06	0.01	29.1	1.70	0.23	0.18	0.10
May-03	0.02	-0.04	29.9	1.71	0.18	0.15	0.06
Jun-03	-0.09	-0.16	0.8	1.37	0.07	0.08	-0.05
Jul-03	-0.06	-0.14	89.2	2.40	0.11	0.10	-0.03
Aug-03	-0.05	-0.12	41.8	1.85	0.12	0.11	-0.02
Sep-03	0.09	0.01	61.4	2.08	0.25	0.20	0.11
Oct-03	0.41	0.33	43.2	1.86	0.58	0.42	0.41
Nov-03	0.39	0.34	20.4	1.60	0.56	0.41	0.41
Dec-03	0.35	0.30	79.1	2.28	0.52	0.38	0.38
Jan-04	0.29	0.24	70.1	2.18	0.46	0.34	0.32
Feb-04	0.21	0.14	73.5	2.22	0.38	0.29	0.23
Mar-04	0.16	0.11	58.1	2.04	0.33	0.25	0.21
Apr-04	0.07	0.03	32.8	1.74	0.24	0.19	0.12
May-04	0.00	-0.06	24.9	1.65	0.17	0.14	0.04
Jun-04	-0.07	-0.13	31.6	1.73	0.10	0.09	-0.03
Jul-04	-0.08	-0.15	34.7	1.77	0.09	0.09	-0.04
Aug-04	0.15	0.08	15.2	1.54	0.32	0.24	0.17
Sep-04	0.10	0.03	31.5	1.73	0.27	0.21	0.13
Oct-04	0.42	0.34	27.8	1.68	0.59	0.43	0.42
Nov-04	0.34	0.29	5.3	1.42	0.51	0.38	0.37
Dec-04	0.29	0.23	43.3	1.87	0.46	0.34	0.31
Jan-05	0.26	0.19	49.4	1.94	0.43	0.32	0.28
Feb-05	0.16	0.10	48.8	1.93	0.33	0.25	0.19
Mar-05	0.20	0.12	45.2	1.89	0.37	0.28	0.21
Apr-05	0.10	0.02	27.4	1.68	0.27	0.21	0.12
May-05	-0.12	-0.18	25.0	1.65	0.04	0.06	-0.07
Jun-05	-0.14	-0.21	7.6	1.45	0.03	0.05	-0.10
Jul-05	-0.11	-0.19	14.1	1.53	0.06	0.07	-0.08
Aug-05	-0.13	-0.17	24.0	1.64	0.04	0.05	-0.06
Sep-05	0.05	-0.01	13.7	1.52	0.22	0.18	0.09
Oct-05	0.32	0.25	6.8	1.44	0.49	0.36	0.33
Nov-05	0.38	0.31	0.9	1.37	0.55	0.40	0.39
Dec-05	0.41	0.34	22.2	1.62	0.58	0.42	0.42

Time	Observed water level (m)		Release (m^3/s)	Interpolated water level (m)			
	Thu Dau Mot	**Phu An**	**Dau Tieng**	**TV1**	**TV3**	**TV7**	**TV9**
Jan-06	0.33	0.25	71.5	2.19	0.50	0.37	0.33
Feb-06	0.32	0.24	95.2	2.47	0.49	0.36	0.32
Mar-06	0.21	0.14	89.2	2.40	0.38	0.29	0.23
Apr-06	0.12	0.06	60.0	2.06	0.29	0.22	0.15
May-06	0.07	0.01	62.4	2.09	0.24	0.19	0.11
Jun-06	-0.08	-0.15	51.2	1.96	0.08	0.08	-0.04
Jul-06	-0.14	-0.21	33.3	1.75	0.03	0.04	-0.10
Aug-06	-0.01	-0.10	21.9	1.62	0.16	0.13	0.01
Sep-06	0.15	0.06	26.1	1.67	0.32	0.24	0.16
Oct-06	0.37	0.27	40.3	1.83	0.54	0.39	0.36
Nov-06	0.35	0.28	23.6	1.64	0.52	0.38	0.36
Dec-06	0.46	0.39	76.8	2.25	0.63	0.46	0.46
Jan-07	0.36	0.28	79.5	2.29	0.53	0.39	0.36
Feb-07	0.17	0.08	93.2	2.44	0.34	0.26	0.17
Mar-07	0.23	0.14	80.5	2.30	0.40	0.30	0.23
Apr-07	0.18	0.10	80.3	2.29	0.34	0.26	0.19
May-07	0.06	0.01	59.9	2.06	0.23	0.18	0.10
Jun-07	-0.03	-0.07	68.4	2.16	0.14	0.12	0.03
Jul-07	-0.06	-0.14	48.1	1.92	0.11	0.10	-0.03
Aug-07	-0.02	-0.09	18.0	1.57	0.15	0.13	0.01
Sep-07	0.22	0.11	52.3	1.97	0.38	0.29	0.21

APPENDIX 3
Hydraulic conductivity values from pumping test data

qp3 aquifer

ID	X	Y	K (m/d)	ID	X	Y	K (m/d)
325	656,691	1,170,529	20.0	**DT**	647,685	1,246,974	21.7
327	640,723	1,174,698	12.0	**DT2**	651,976	1,205,538	26.6
328	650,419	1,160,451	20.0	**DT3**	657,422	1,198,825	12.0
329	652,066	1,163,761	12.0	**GD1_LA**	664,876	1,175,717	11.0
330	660,248	1,167,082	12.0	**GD2_LA**	664,399	1,176,075	30.0
333	637,159	1,158,666	30.0	**GD3**	637,740	1,227,641	4.0
334	665,894	1,170,690	20.0	**GD5_LA**	663,654	1,177,029	21.4
336	653,573	1,171,765	20.0	**LK1-TP**	660,926	1,215,040	12.0
9614	699,546	1,151,527	4.0	**M1**	693,801	1,192,460	20.0
9615	658,979	1,179,260	31.0	**M10**	629,104	1,226,981	50.0
9617	641,930	1,204,838	10.1	**M15**	629,490	1,229,218	12.0
01C	668,226	1,210,122	0.3	**M20**	627,199	1,227,824	6.3
02D	675,643	1,205,279	12.0	**M7C**	628,529	1,228,628	50.0
03D	677,900	1,200,857	6.1	**MH01**	594,689	1,185,500	30.0
04D	682,593	1,195,454	11.5	**MH03**	614,624	1,193,052	30.0
05C	680,688	1,191,184	13.4	**MH07**	593,897	1,193,804	30.0
08C	672,767	1,189,821	30.0	**MH724**	612,695	1,186,518	30.0
11A	693,899	1,192,554	4.0	**MH728B**	610,527	1,180,567	20.0
12A	700,290	1,166,015	4.0	**MH729**	604,762	1,199,784	30.0
28-III	602,106	1,191,145	12.0	**MH751**	606,678	1,187,199	30.0
6T	683,412	1,186,281	20.0	**MH758**	597,619	1,187,019	30.0
801-TP	658,210	1,220,645	0.25	**Q003340**	670,744	1,200,785	31.6
802-TP	658,750	1,210,129	65.0	**Q004030**	683,161	1,202,870	4.0
803-TP	661,741	1,213,463	8.4	**Q007030**	671,460	1,197,976	4.0
804-II-TP	664,170	1,215,218	50.4	**Q011340**	676,393	1,201,418	4.0
807-TP	668,308	1,210,417	0.01	**Q015030**	675,719	1,186,400	50.0
810-TP	675,593	1,200,293	36.4	**Q017030**	679,966	1,203,434	20.0
812-A-TP	673,296	1,182,807	46.8	**Q018030**	673,936	1,191,044	42.1
813-TP	675,965	1,185,138	30.0	**Q022050**	627,769	1,178,176	12.0
814-TP	678,059	1,192,111	43.2	**Q023050**	648,158	1,219,680	1.2
815-B-TP	679,230	1,193,962	12.0	**Q027050**	585,591	1,204,189	4.0
816-B-TP	686,851	1,197,414	50.0	**Q220050**	607,681	1,282,531	4.0
819-TP	686,561	1,187,838	65.0	**Q22104Z**	618,328	1,250,384	9.5
826-TP	680,806	1,182,401	12.0	**Q222050**	604,748	1,245,783	0.2500
827-TP	700,201	1,166,157	4.0	**Q32604Z**	667,330	1,159,841	53.5

ID	X	Y	K (m/d)	ID	X	Y	K (m/d)
A1	676,312	1,185,950	20.0	**Q808050**	665,373	1,192,989	42.6
A10	689,075	1,189,714	12.0	**Q821040**	694,807	1,178,140	17.3
A11	668,079	1,188,272	12.0	**Q822040**	709,889	1,149,819	46.6
A2	674,494	1,182,902	50.0	**S209**	628,660	1,178,089	10.3
A3	667,572	1,176,799	50.0	**S210**	600,504	1,192,279	4.0
A4	680,940	1,185,790	12.0	**S211**	592,015	1,207,019	20.0
A5	680,743	1,178,441	12.0	**S224**	612,038	1,250,720	4.0
A6	680,942	1,177,770	12.0	**S225**	628,842	1,227,824	7.9
A7	682,585	1,172,944	20.0	**S228**	615,774	1,252,243	4.0
A8	669,857	1,173,536	17.9	**S237**	630,928	1,215,449	0.25
A9	677,481	1,177,890	12.0	**S238**	577,542	1,216,081	12.0
BK14	716,840	1,201,245	0.25	**S243**	593,540	1,285,980	8.8
BSG1	681,368	1,190,802	17.9	**SB101**	680,067	1,214,519	4.0
Cauxang	665,750	1,194,592	12.0	**Tantru**	664,762	1,162,484	30.0
D13-1	675,389	1,203,801	8.1	**TN1**	610,206	1,249,099	4.0
D14-1	677,836	1,198,165	11.4	**TN5**	622,401	1,243,791	4.0
D402ATD	681,649	1,201,979	20.0	**TN7**	633,272	1,245,850	0.20
DetDA	667,171	1,207,024	30.0	**TN8**	621,701	1,231,506	25.1
DH-18	660,444	1,209,055	10.0	**TP1**	689,282	1,193,747	4.0
DH3-1	659,261	1,206,541	6.3	**TP2**	690,464	1,184,515	50.0
DH3-10	657,077	1,211,142	9.3	**TU9B**	672,405	1,233,910	0.25
DH3-14	655,623	1,212,266	50.0	**Tuahai**	616,685	1,254,449	20.1
DHCS	691,699	1,201,106	12.0	**VITANS**	687,803	1,183,540	12.0
ĐN29	702,487	1,188,293	12.0	**XBG**	599,814	1,243,666	20.1
ĐN30	716,230	1,180,206	4.0				

Hydraulic conductivity values from pumping test data (continue)

qp_{2-3} aquifer

ID	X	Y	K (m/d)	ID	X	Y	K (m/d)
327	640,723	1,174,698	4.0	**LK1**	725,500	1,174,649	20.0
328	650,419	1,160,451	20.0	**LK1-TP**	660,926	1,215,040	12.0
329	652,066	1,163,761	20.0	**Longhoa**	661,596	1,251,959	4.0
330	660,248	1,167,082	30.0	**M1**	693,801	1,192,460	12.0
333	637,159	1,158,666	50.0	**M10**	629,104	1,226,981	12.0
334	665,894	1,170,690	17.5	**M15**	629,490	1,229,218	12.0
336	653,573	1,171,765	4.0	**M20**	627,199	1,227,824	27.0
9614	699,546	1,151,527	20.0	**M7C**	628,529	1,228,628	50.0
9615	658,979	1,179,260	30.0	**MH01**	594,689	1,185,500	30.0
9617	641,930	1,204,838	52.7	**MH03**	614,624	1,193,052	30.0
01C	668,226	1,210,122	12.0	**MH07**	593,897	1,193,804	30.0
02D	675,643	1,205,279	4.0	**MH724**	612,695	1,186,518	16.7
04D	682,593	1,195,454	18.7	**MH728B**	610,527	1,180,567	20.0
05C	680,688	1,191,184	7.0	**MH729**	604,762	1,199,784	30.0
08C	672,767	1,189,821	4.0	**MH751**	606,678	1,187,199	30.0
09-02A	693,658	1,202,219	4.0	**MH758**	597,619	1,187,019	30.0
10B	695,553	1,201,187	4.0	**MP1**	673,658	1,233,553	4.0
10-TH	713,503	1,186,167	28.5	**MX1**	723,252	1,177,400	1.0
12A	700,290	1,166,015	8.1	**MX12**	724,945	1,175,575	0.25
12-NB	655,688	1,236,237	20.0	**MX13**	725,236	1,174,649	58.1
25-TH	713,210	1,193,321	12.0	**MX14**	725,024	1,173,327	9.4
28-III	602,106	1,191,145	20.0	**MX17**	726,082	1,172,903	0.25
6T	683,412	1,186,281	20.0	**MX19**	725,871	1,173,776	0.01
7-TH	700,798	1,181,817	4.0	**MX20**	724,072	1,172,242	39.0
801-TP	658,210	1,220,645	12.5	**MX21**	725,024	1,178,088	43.4
802-TP	658,750	1,210,129	59.1	**Q00204A**	679,491	1,214,370	4.0
803-TP	661,741	1,213,463	24.2	**Q003340**	670,744	1,200,785	59.0
804-II-TP	664,170	1,215,218	4.0	**Q004030**	683,161	1,202,870	20.0
806-TP	670,661	1,221,399	20.0	**Q007030**	671,460	1,197,976	10.5
807-TP	668,308	1,210,417	12.0	**Q011340**	676,393	1,201,418	30.0
809-TP	672,427	1,195,981	53.1	**Q015030**	675,719	1,186,400	10.5
810-TP	675,593	1,200,293	48.2	**Q017030**	679,966	1,203,434	4.0
811-B-TP	682,677	1,206,831	50.0	**Q018030**	673,936	1,191,044	27.7
812-A-TP	673,296	1,182,807	4.0	**Q019340**	678,152	1,199,309	39.8
812-BS-TP	672,508	1,182,863	9.3	**Q022050**	627,769	1,178,176	4.0
813-TP	675,965	1,185,138	38.0	**Q023050**	648,158	1,219,680	4.0

ID	X	Y	K (m/d)	ID	X	Y	K (m/d)
814-TP	678,059	1,192,111	24.8	**Q027050**	585,591	1,204,189	23.1
815-B-TP	679,230	1,193,962	54.4	**Q220050**	607,681	1,282,531	12.0
817-TP	693,654	1,200,082	66.2	**Q22104Z**	618,328	1,250,384	23.8
819-TP	686,561	1,187,838	32.1	**Q222050**	604,748	1,245,783	24.2
820-TP	693,742	1,193,141	0.25	**Q22404Z**	676,610	1,228,816	0.67
826-TP	680,806	1,182,401	17.9	**Q32604Z**	667,330	1,159,841	50.0
827-TP	700,201	1,166,157	12.0	**Q808050**	665,373	1,192,989	41.3
8-TH	705,653	1,181,457	12.0	**Q821040**	694,807	1,178,140	35.0
9-TH	709,470	1,184,017	15.4	**Q822040**	709,889	1,149,819	9.8
A1	676,312	1,185,950	12.0	**BD1A**	683,755	1,214,696	15.6
A10	689,075	1,189,714	20.0	**BD2A**	690,298	1,212,986	0.25
A11	668,079	1,188,272	20.0	**BD3A**	691,472	1,204,965	11.3
A2	674,494	1,182,902	4.0	**S209**	628,660	1,178,089	12.0
A3	667,572	1,176,799	20.0	**S210**	600,504	1,192,279	12.0
A4	680,940	1,185,790	4.0	**S211**	592,015	1,207,019	20.0
A5	680,743	1,178,441	20.0	**S224**	612,038	1,250,720	11.6
A6	680,942	1,177,770	9.4	**S225**	628,842	1,227,824	12.0
A7	682,585	1,172,944	20.0	**S228**	615,774	1,252,243	5.5
A8	669,857	1,173,536	20.0	**S238**	577,542	1,216,081	26.3
A9	677,481	1,177,890	50.0	**S243**	593,540	1,285,980	12.0
BH1	697,667	1,212,821	6.1	**S73**	591,384	1,199,959	12.0
BH4	703,038	1,208,641	4.0	**Tantru**	664,762	1,162,484	25.3
BK12-B-II	714,396	1,200,521	12.0	**TN1**	610,206	1,249,099	12.0
BK16	711,808	1,196,865	18.4	**TN10**	633,062	1,237,304	41.2
BK17-II	697,192	1,216,478	14.1	**TN11**	628,574	1,225,034	50.0
BK7A	694,236	1,211,207	3.2	**TN13**	613,839	1,257,145	12.0
BK9	705,586	1,208,996	38.8	**TN2**	621,552	1,252,168	4.0
BSG1	681,368	1,190,802	19.8	**TN3**	624,925	1,253,247	20.0
BV_BD	679,186	1,215,699	12.0	**TN4-I**	613,275	1,243,308	50.0
Cauxang	665,750	1,194,592	15.5	**TN5**	622,401	1,243,791	50.0
D13-1	675,389	1,203,801	20.0	**TN7**	633,272	1,245,850	4.0
D14-1	677,836	1,198,165	15.4	**TN8**	621,701	1,231,506	43.9
D402ATD	681,649	1,201,979	22.0	**TN9**	630,848	1,235,519	8.8
DetDA	667,171	1,207,024	20.0	**TP1**	689,282	1,193,747	86.0
DH-18	660,444	1,209,055	4.0	**TP2**	690,464	1,184,515	50.0
DH3-1	659,261	1,206,541	31.0	**TU11**	667,531	1,249,021	4.0
DH3-10	657,077	1,211,142	28.0	**TU1B**	677,554	1,220,461	0.25
DH3-14	655,623	1,212,266	37.9	**TU5C**	672,179	1,222,240	12.0
DHCS	691,699	1,201,106	12.6	**Tuahai**	616,685	1,254,449	5.4

ID	X	Y	K (m/d)	ID	X	Y	K (m/d)
ĐN24	697,541	1,188,233	0.25	**TV1**	720,536	1,182,578	4.0
ĐN25	702,415	1,185,272	43.7	**TV10**	727,073	1,165,752	69.9
ĐN27	710,865	1,186,259	0.25	**TV13**	727,005	1,158,008	0.92
ĐN29	702,487	1,188,293	4.0	**TV2**	725,193	1,186,374	4.0
ĐN30	716,230	1,180,206	7.4	**TV21**	727,458	1,181,310	50.0
DT1	638,129	1,225,674	12.0	**TV4**	716,027	1,168,325	4.0
DT2	651,976	1,205,538	12.0	**TV5**	722,842	1,172,707	17.6
DT3	657,422	1,198,825	12.0	**TV6**	732,367	1,177,366	0.01
G1_Sonadezi	709,079	1,196,319	0.25	**Viethong**	668,872	1,231,594	4.0
G2_Sonadezi	709,422	1,196,208	0.25	**Vinakyoel**	721,374	1,177,876	4.0
G3_Sonadezi	709,785	1,196,119	0.25	**VITANS**	687,803	1,183,540	12.0
GD1_LA	664,876	1,175,717	19.9	**VT1A**	732,908	1,178,329	4.0
GD2_LA	664,399	1,176,075	30.0	**VT2A**	728,438	1,177,426	4.0
GD3	637,740	1,227,641	20.0	**VT3A**	724,355	1,171,793	12.0
GD5_LA	663,654	1,177,029	15.2	**VT4A**	723,158	1,167,526	10.0
LD28	723,596	1,178,379	4.0	**VT5A**	734,708	1,174,805	4.0
LD34	720,719	1,179,063	4.0	**VT5B**	734,905	1,172,296	12.0

Hydraulic conductivity values from pumping test data (continue)

qp_1 aquifer

ID	X	Y	K (m/d)	ID	X	Y	K (m/d)
325	656,691	1,170,529	50.0	**G2_Sonadezi**	709,422	1,196,208	12.0
327	640,723	1,174,698	12.0	**G3_Sonadezi**	709,785	1,196,119	12.0
328	650,419	1,160,451	4.0	**GD1_LA**	664,876	1,175,717	14.4
329	652,066	1,163,761	30.0	**GD2_LA**	664,399	1,176,075	30.0
330	660,248	1,167,082	20.0	**GD3**	637,740	1,227,641	15.5
333	637,159	1,158,666	30.0	**GD5_LA**	663,654	1,177,029	20.0
334	665,894	1,170,690	3.7	**LK1-TP**	660,926	1,215,040	4.0
336	653,573	1,171,765	20.0	**Longhoa**	661,596	1,251,959	0.3
9614	699,546	1,151,527	4.0	**Longtan**	708,093	1,182,734	4.0
9615	658,979	1,179,260	27.1	**M1**	693,801	1,192,460	12.0
9617	641,930	1,204,838	52.8	**M10**	629,104	1,226,981	50.0
01C	668,226	1,210,122	4.0	**M15**	629,490	1,229,218	12.0
02D	675,643	1,205,279	3.8	**M20**	627,199	1,227,824	11.8
03D	677,900	1,200,857	16.1	**M7C**	628,529	1,228,628	50.0
04D	682,593	1,195,454	18.2	**MH01**	594,689	1,185,500	30.0
05C	680,688	1,191,184	12.9	**MH03**	614,624	1,193,052	30.0
08C	672,767	1,189,821	2.0	**MH07**	593,897	1,193,804	30.0
09-02A	693,658	1,202,219	2.9	**MH724**	612,695	1,186,518	20.0
10B	695,553	1,201,187	20.0	**MH728B**	610,527	1,180,567	20.0
10-TH	713,503	1,186,167	18.8	**MH729**	604,762	1,199,784	30.0
11A	693,899	1,192,554	3.3	**MH751**	606,678	1,187,199	16.5
11-TH	716,975	1,188,049	50.0	**MH758**	597,619	1,187,019	30.0
12A	700,290	1,166,015	10.0	**MP1**	673,658	1,233,553	3.2
12-NB	655,688	1,236,237	12.0	**Phuocsang_1**	694,216	1,259,562	4.0
25-TH	713,210	1,193,321	30.0	**Q003340**	670,744	1,200,785	57.1
28-III	602,106	1,191,145	12.0	**Q004030**	683,161	1,202,870	10.7
6T	683,412	1,186,281	17.7	**Q007030**	671,460	1,197,976	8.0
7-TH	700,798	1,181,817	41.2	**Q011340**	676,393	1,201,418	30.0
801-TP	658,210	1,220,645	31.8	**Q015030**	675,719	1,186,400	36.2
802-TP	658,750	1,210,129	69.3	**Q017030**	679,966	1,203,434	47.9
804-II-TP	664,170	1,215,218	44.5	**Q018030**	673,936	1,191,044	24.8
806-TP	670,661	1,221,399	64.8	**Q019340**	678,152	1,199,309	10.8
807-TP	668,308	1,210,417	69.4	**Q022050**	627,769	1,178,176	30.4
809-TP	672,427	1,195,981	50.0	**Q023050**	648,158	1,219,680	5.2
810-TP	675,593	1,200,293	70.9	**Q027050**	585,591	1,204,189	17.6
811-B-TP	682,677	1,206,831	50.0	**Q039340**	709,617	1,184,072	13.6

ID	X	Y	K (m/d)	ID	X	Y	K (m/d)
812-A-TP	673,296	1,182,807	60.2	**Q040040**	715,412	1,189,425	12.0
812-BS-TP	672,508	1,182,863	4.0	**Q220050**	607,681	1,282,531	35.9
814-TP	678,059	1,192,111	48.2	**Q22104Z**	618,328	1,250,384	40.6
815-B-TP	679,230	1,193,962	68.6	**Q222050**	604,748	1,245,783	30.0
816-B-TP	686,851	1,197,414	60.9	**Q22404Z**	676,610	1,228,816	19.1
819-TP	686,561	1,187,838	61.9	**Q32604Z**	667,330	1,159,841	50.0
820-TP	693,742	1,193,141	64.0	**Q714040**	720,423	1,193,674	0.3
826-TP	680,806	1,182,401	23.7	**Q808050**	665,373	1,192,989	49.2
827-TP	700,201	1,166,157	30.0	**Q821040**	694,807	1,178,140	54.3
8-TH	705,653	1,181,457	11.2	**Q822040**	709,889	1,149,819	49.2
A1	676,312	1,185,950	12.0	**S209**	628,660	1,178,089	10.9
A10	689,075	1,189,714	20.0	**S210**	600,504	1,192,279	12.0
A11	668,079	1,188,272	4.0	**S211**	592,015	1,207,019	2.6
A2	674,494	1,182,902	12.0	**S224**	612,038	1,250,720	12.0
A3	667,572	1,176,799	50.0	**S225**	628,842	1,227,824	12.0
A4	680,940	1,185,790	20.0	**S228**	615,774	1,252,243	12.0
A5	680,743	1,178,441	20.0	**S237**	630,928	1,215,449	33.8
A6	680,942	1,177,770	10.5	**S238**	577,542	1,216,081	14.9
A7	682,585	1,172,944	43.2	**S243**	593,540	1,285,980	10.5
A8	669,857	1,173,536	20.0	**S302**	617,080	1,300,978	20.0
A9	677,481	1,177,890	5.4	**S73**	591,384	1,199,959	30.0
BD1A	683,755	1,214,696	13.8	**SB101**	680,067	1,214,519	50.0
BD2A	690,298	1,212,986	20.0	**Tanthanh**	701,253	1,233,204	4.0
BD3A	691,472	1,204,965	42.7	**Tantru**	664,762	1,162,484	24.5
BK12-B-II	714,396	1,200,521	38.0	**TN1**	610,206	1,249,099	12.0
BK14	716,840	1,201,245	2.0	**TN10**	633,062	1,237,304	12.0
BK15	715,940	1,195,857	51.3	**TN11**	628,574	1,225,034	46.6
BK16	711,808	1,196,865	7.9	**TN13**	613,839	1,257,145	12.0
BK7A	694,236	1,211,207	12.0	**TN2**	621,552	1,252,168	4.0
BK9	705,586	1,208,996	65.0	**TN3**	624,925	1,253,247	4.0
BSG1	681,368	1,190,802	30.0	**TN4-I**	613,275	1,243,308	4.0
BV_BD	679,186	1,215,699	16.9	**TN5**	622,401	1,243,791	4.0
Cauxang	665,750	1,194,592	5.1	**TN7**	633,272	1,245,850	12.0
Đ10	665,942	1,254,305	50.0	**TN8**	621,701	1,231,506	20.0
Đ11	676,296	1,257,923	12.0	**TN9**	630,848	1,235,519	9.7
D13-1	675,389	1,203,801	12.0	**TP1**	689,282	1,193,747	8.2
D14-1	677,836	1,198,165	16.0	**TP2**	690,464	1,184,515	30.0
D402ATD	681,649	1,201,979	12.0	**TU10**	687,708	1,247,805	0.1

ID	X	Y	K (m/d)	ID	X	Y	K (m/d)
DetDA	667,171	1,207,024	30.0	**TU11**	667,531	1,249,021	65.0
DH-18	660,444	1,209,055	31.0	**TU1B**	677,554	1,220,461	33.6
DH3-1	659,261	1,206,541	25.7	**TU2B**	691,550	1,222,887	7.3
DH3-10	657,077	1,211,142	15.8	**TU4**	691,480	1,229,338	10.7
DHCS	691,699	1,201,106	20.0	**TU5C**	672,179	1,222,240	12.0
ĐN24	697,541	1,188,233	48.1	**TU6**	692,814	1,238,973	0.1
ĐN27	710,865	1,186,259	14.7	**TU9B**	672,405	1,233,910	50.0
DT	647,685	1,246,974	15.3	**Tuahai**	616,685	1,254,449	1.6
DT1	638,129	1,225,674	12.0	**Viethong**	668,872	1,231,594	4.0
DT2	651,976	1,205,538	12.1	**Vinhhoa**	695,826	1,244,713	4.0
DT3	657,422	1,198,825	12.0	**VITANS**	687,803	1,183,540	16.2
G1_Sonadezi	709,079	1,196,319	4.0	**XBG**	599,814	1,243,666	30.0

APPENDIX 4
Conductance calibration results

Observation well N2 (TV1 cross-section)

Time step	Obs GWL(m)	Computed (m) GWL with correlative conductance value						
		C=1	C=1.5	C=2	C=2.5	C=3	C=3.5	C=4
Jan-15	4.89	6.74	6.09	5.71	5.44	5.25	5.10	4.98
Feb-15	4.86	6.64	6.04	5.68	5.42	5.23	5.08	4.97
Mar-15	4.75	6.56	5.97	5.61	5.36	5.17	5.02	4.91
Apr-15	4.62	6.48	5.92	5.56	5.31	5.12	4.98	4.86
May-15	4.56	6.41	5.86	5.52	5.27	5.09	4.95	4.84
Jun-15	4.47	6.30	5.77	5.42	5.18	5.00	4.86	4.75
Jul-15	4.43	6.28	5.73	5.38	5.13	4.95	4.80	4.69
Aug-15	4.41	6.33	5.76	5.38	5.12	4.93	4.78	4.66
Sep-15	4.69	6.47	5.88	5.49	5.21	5.01	4.85	4.73
Oct-15	4.83	6.68	6.08	5.70	5.42	5.22	5.06	4.94
Nov-15	4.90	6.72	6.12	5.72	5.44	5.24	5.08	4.95
Dec-15	4.92	6.76	6.15	5.74	5.46	5.25	5.09	4.96
Time step	Obs GWL(m)	Computed (m) GWL with correlative conductance value						
		C=4.5	C=5	C=5.5	C=6	C=6.5	C=7	C=7.5
Jan-15	4.89	4.88	4.80	4.73	4.67	4.62	4.58	4.54
Feb-15	4.86	4.87	4.79	4.73	4.67	4.62	4.58	4.55
Mar-15	4.75	4.82	4.74	4.67	4.62	4.57	4.53	4.49
Apr-15	4.62	4.77	4.69	4.63	4.57	4.53	4.48	4.45
May-15	4.56	4.75	4.67	4.61	4.55	4.51	4.47	4.43
Jun-15	4.47	4.66	4.59	4.53	4.47	4.43	4.39	4.35
Jul-15	4.43	4.60	4.52	4.46	4.41	4.36	4.32	4.28
Aug-15	4.41	4.56	4.48	4.42	4.36	4.31	4.27	4.23
Sep-15	4.69	4.63	4.55	4.48	4.42	4.36	4.32	4.28
Oct-15	4.83	4.84	4.76	4.69	4.63	4.58	4.53	4.49
Nov-15	4.90	4.85	4.76	4.69	4.63	4.58	4.53	4.49
Dec-15	4.92	4.85	4.77	4.69	4.63	4.58	4.53	4.49

Conductance calibration results (continue)

Observation well BD11 (TV3 cross-section)

Time step	Obs GWL m	computed GWL (m) with correlative conductance									
		0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2
Apr-01	1.51	2.84	2.56	2.37	2.22	2.11	2.04	1.95	1.89	1.84	1.79
May-01	1.43	2.87	2.57	2.37	2.22	2.11	2.04	1.94	1.87	1.82	1.77
Jun-01	1.34	3.04	2.73	2.51	2.35	2.22	2.15	2.04	1.97	1.91	1.86
Jul-01	1.34	3.13	2.8	2.57	2.41	2.28	2.21	2.09	2.02	1.96	1.91
Aug-01	1.55	3.1	2.78	2.55	2.39	2.26	2.19	2.07	2	1.94	1.89
Sep-01	1.89	3.19	2.87	2.64	2.48	2.35	2.28	2.16	2.09	2.03	1.98
Oct-01	2.12	3.25	2.94	2.73	2.57	2.45	2.38	2.27	2.2	2.15	2.1
Nov-01	2.22	3.41	3.1	2.89	2.73	2.61	2.54	2.43	2.37	2.31	2.26
Dec-01	2.33	3.43	3.12	2.9	2.74	2.62	2.55	2.44	2.37	2.31	2.26
Jan-02	1.97	3.23	2.93	2.71	2.56	2.44	2.37	2.26	2.2	2.14	2.09
Feb-02	1.79	3.09	2.79	2.59	2.44	2.32	2.25	2.15	2.09	2.04	1.99
Mar-02	1.67	2.96	2.67	2.47	2.33	2.22	2.15	2.05	1.99	1.94	1.89
Apr-02	1.59	2.95	2.66	2.46	2.31	2.19	2.12	2.02	1.96	1.91	1.86
May-02	1.53	2.9	2.6	2.4	2.25	2.13	2.06	1.96	1.89	1.84	1.79
Jun-02	1.47	2.9	2.6	2.38	2.23	2.11	2.04	1.93	1.86	1.81	1.76
Jul-02	1.62	3.07	2.74	2.52	2.35	2.23	2.16	2.04	1.97	1.91	1.86
Aug-02	1.77	3.02	2.7	2.48	2.32	2.19	2.12	2.01	1.94	1.88	1.83
Sep-02	1.77	3.05	2.74	2.52	2.36	2.24	2.17	2.06	1.99	1.94	1.89
Oct-02	2.31	3.24	2.93	2.72	2.56	2.44	2.37	2.26	2.19	2.14	2.09
Nov-02	2.25	3.29	2.98	2.78	2.62	2.5	2.43	2.33	2.27	2.21	2.16
Dec-02	2.07	3.21	2.91	2.7	2.55	2.43	2.37	2.26	2.2	2.15	2.1
Jan-03	1.90	3.05	2.76	2.56	2.42	2.3	2.23	2.14	2.07	2.02	1.97
Feb-03	1.77	2.93	2.65	2.45	2.31	2.2	2.13	2.04	1.98	1.92	1.88
Mar-03	1.68	2.86	2.58	2.38	2.24	2.13	2.06	1.97	1.91	1.86	1.81
Apr-03	1.52	2.78	2.5	2.31	2.16	2.05	1.98	1.89	1.83	1.78	1.74
May-03	1.38	2.74	2.46	2.27	2.12	2.01	1.94	1.85	1.79	1.74	1.69
Jun-03	1.41	2.72	2.43	2.23	2.08	1.97	1.9	1.8	1.74	1.69	1.64
Jul-03	1.65	2.75	2.45	2.24	2.09	1.97	1.9	1.8	1.73	1.68	1.63
Aug-03	1.60	2.76	2.46	2.25	2.09	1.97	1.9	1.8	1.74	1.68	1.63
Sep-03	1.98	2.71	2.42	2.22	2.08	1.96	1.89	1.8	1.73	1.68	1.64
Oct-03	2.04	2.87	2.59	2.39	2.25	2.13	2.06	1.97	1.91	1.86	1.81
Nov-03	2.29	3.1	2.82	2.62	2.47	2.35	2.28	2.19	2.13	2.07	2.03
Dec-03	2.11	3.11	2.83	2.63	2.48	2.37	2.3	2.2	2.14	2.09	2.04
Jan-04	1.89	3.02	2.74	2.54	2.4	2.29	2.22	2.12	2.06	2.01	1.97
Feb-04	1.68	2.89	2.62	2.43	2.29	2.18	2.11	2.02	1.96	1.91	1.87

Time step	Obs GWL m	computed GWL (m) with correlative conductance									
		0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2
Mar-04	1.54	2.77	2.5	2.32	2.18	2.07	2	1.92	1.86	1.81	1.77
Apr-04	1.52	2.66	2.4	2.21	2.07	1.97	1.9	1.81	1.75	1.71	1.66
May-04	1.38	2.57	2.3	2.12	1.98	1.87	1.8	1.72	1.66	1.61	1.57
Jun-04	1.48	2.65	2.37	2.17	2.03	1.92	1.85	1.75	1.69	1.64	1.59
Jul-04	1.67	2.82	2.52	2.31	2.16	2.04	1.97	1.86	1.8	1.74	1.7
Aug-04	2.01	2.82	2.52	2.32	2.16	2.04	1.97	1.87	1.81	1.75	1.7
Sep-04	1.99	2.79	2.5	2.3	2.15	2.04	1.97	1.87	1.81	1.75	1.71
Oct-04	2.25	2.97	2.68	2.49	2.34	2.23	2.16	2.06	2	1.95	1.91
Nov-04	2.22	3.17	2.89	2.69	2.54	2.43	2.36	2.26	2.2	2.14	2.1
Dec-04	2.10	3.11	2.83	2.63	2.48	2.37	2.3	2.2	2.14	2.09	2.04
Jan-05	1.84	2.9	2.62	2.44	2.3	2.19	2.12	2.03	1.97	1.92	1.88
Feb-05	1.75	2.74	2.47	2.29	2.15	2.05	1.98	1.9	1.84	1.79	1.75
Mar-05	1.57	2.65	2.39	2.21	2.08	1.97	1.9	1.82	1.76	1.72	1.67
Apr-05	1.39	2.57	2.32	2.14	2	1.9	1.83	1.75	1.69	1.64	1.6
May-05	1.34	2.51	2.25	2.07	1.93	1.83	1.76	1.68	1.62	1.57	1.53
Jun-05	1.37	2.58	2.3	2.12	1.97	1.87	1.79	1.71	1.65	1.6	1.55
Jul-05	1.44	2.69	2.4	2.21	2.06	1.94	1.87	1.78	1.72	1.66	1.62
Aug-05	1.83	2.81	2.52	2.32	2.18	2.06	1.99	1.9	1.83	1.78	1.73
Sep-05	2.06	2.87	2.59	2.39	2.24	2.13	2.06	1.96	1.9	1.85	1.8
Oct-05	2.16	2.95	2.67	2.47	2.33	2.22	2.15	2.06	2	1.94	1.9
Nov-05	2.16	3.09	2.81	2.62	2.47	2.36	2.29	2.2	2.14	2.08	2.04
Dec-05	2.05	3	2.72	2.53	2.39	2.27	2.21	2.11	2.05	2	1.95

Time step	Obs GWL m	computed GWL (m) with correlative conductance									
		2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4
Apr-01	1.51	1.76	1.72	1.69	1.66	1.64	1.62	1.6	1.58	0.96	1.56
May-01	1.43	1.74	1.7	1.66	1.64	1.61	1.59	1.57	1.55	1.05	1.53
Jun-01	1.34	1.83	1.78	1.75	1.72	1.69	1.66	1.64	1.62	1.23	1.6
Jul-01	1.34	1.87	1.82	1.79	1.76	1.73	1.7	1.68	1.66	1.31	1.64
Aug-01	1.55	1.85	1.81	1.77	1.74	1.71	1.69	1.67	1.65	1.29	1.63
Sep-01	1.89	1.94	1.9	1.86	1.83	1.8	1.78	1.75	1.73	1.29	1.71
Oct-01	2.12	2.06	2.02	1.99	1.96	1.93	1.91	1.89	1.87	1.15	1.85
Nov-01	2.22	2.23	2.18	2.15	2.12	2.1	2.07	2.15	2.13	0.94	2.11
Dec-01	2.33	2.22	2.18	2.15	2.12	2.09	2.07	2.04	2.14	0.95	2.11
Jan-02	1.97	2.06	2.01	1.98	1.95	1.93	1.9	1.88	1.86	1.13	1.84
Feb-02	1.79	1.95	1.91	1.88	1.85	1.89	1.81	1.79	1.77	1.05	1.75
Mar-02	1.67	1.86	1.82	1.79	1.76	1.74	1.72	1.7	1.68	0.99	1.66
Apr-02	1.59	1.83	1.79	1.76	1.73	1.7	1.68	1.66	1.64	1.03	1.62

Time step	Obs GWL m	computed GWL (m) with correlative conductance									
		2.2	**2.4**	**2.6**	**2.8**	**3**	**3.2**	**3.4**	**3.6**	**3.8**	**4**
May-02	1.53	1.76	1.72	1.68	1.66	1.63	1.61	1.59	1.57	1.08	1.55
Jun-02	1.47	1.72	1.68	1.65	1.62	1.59	1.57	1.55	1.53	1.15	1.42
Jul-02	1.62	1.82	1.78	1.74	1.71	1.68	1.66	1.63	1.61	1.28	1.59
Aug-02	1.77	1.8	1.75	1.72	1.69	1.66	1.59	1.61	1.59	1.23	1.58
Sep-02	1.77	1.85	1.81	1.77	1.74	1.72	1.69	1.67	1.65	1.18	1.63
Oct-02	2.31	2.05	2.01	1.97	1.95	1.92	1.9	1.87	1.85	1.17	1.84
Nov-02	2.25	2.13	2.09	2.05	2.03	2	1.98	1.96	1.94	1.1	1.92
Dec-02	2.07	2.06	2.02	1.99	1.96	1.94	1.92	1.9	1.88	1.06	1.86
Jan-03	1.90	1.94	1.9	1.87	1.84	1.82	1.8	1.78	1.76	1.01	1.74
Feb-03	1.77	1.85	1.81	1.78	1.75	1.73	1.71	1.69	1.67	0.96	1.65
Mar-03	1.68	1.78	1.74	1.71	1.69	1.66	1.64	1.62	1.6	0.94	1.59
Apr-03	1.52	1.7	1.67	1.64	1.61	1.59	1.57	1.55	1.53	0.94	1.51
May-03	1.38	1.66	1.62	1.59	1.56	1.54	1.52	1.5	1.48	0.96	1.46
Jun-03	1.41	1.61	1.57	1.54	1.51	1.48	1.46	1.44	1.42	1.01	1.41
Jul-03	1.65	1.59	1.55	1.52	1.49	1.47	1.44	1.42	1.4	1.1	1.39
Aug-03	1.60	1.6	1.56	1.52	1.5	1.47	1.45	1.43	1.41	1.1	1.39
Sep-03	1.98	1.6	1.56	1.53	1.5	1.48	1.46	1.44	1.42	1.01	1.4
Oct-03	2.04	1.78	1.74	1.71	1.68	1.66	1.63	1.61	1.6	0.99	1.58
Nov-03	2.29	1.99	1.95	1.92	1.9	1.87	1.85	1.83	1.81	1.01	1.79
Dec-03	2.11	2.01	1.97	1.94	1.91	1.89	1.87	1.85	1.83	1	1.81
Jan-04	1.89	1.93	1.9	1.87	1.84	1.81	1.79	1.77	1.75	0.96	1.74
Feb-04	1.68	1.83	1.8	1.77	1.74	1.72	1.7	1.68	1.66	0.91	1.64
Mar-04	1.54	1.74	1.7	1.67	1.65	1.62	1.6	1.59	1.57	0.87	1.55
Apr-04	1.52	1.63	1.59	1.57	1.54	1.52	1.5	1.48	1.46	0.88	1.44
May-04	1.38	1.53	1.5	1.47	1.44	1.42	1.4	1.38	1.36	0.88	1.34
Jun-04	1.48	1.56	1.52	1.49	1.46	1.44	1.42	1.4	1.38	0.98	1.36
Jul-04	1.67	1.66	1.62	1.59	1.56	1.53	1.51	1.49	1.47	1.11	1.45
Aug-04	2.01	1.67	1.63	1.59	1.56	1.54	1.52	1.49	1.47	1.1	1.46
Sep-04	1.99	1.67	1.63	1.6	1.57	1.55	1.53	1.51	1.49	1.03	1.47
Oct-04	2.25	1.87	1.83	1.8	1.77	1.75	1.73	1.71	1.69	0.99	1.67
Nov-04	2.22	2.06	2.02	1.99	1.97	1.94	1.92	1.9	1.88	1.02	1.86
Dec-04	2.10	2.01	1.97	1.94	1.91	1.89	1.87	1.84	1.83	1.01	1.81
Jan-05	1.84	1.84	1.81	1.78	1.75	1.73	1.71	1.69	1.67	0.91	1.65
Feb-05	1.75	1.71	1.68	1.65	1.63	1.61	1.58	1.57	1.55	0.85	1.53
Mar-05	1.57	1.64	1.61	1.58	1.55	1.53	1.51	1.49	1.47	0.84	1.46
Apr-05	1.39	1.57	1.53	1.51	1.48	1.46	1.44	1.42	1.4	0.83	1.39
May-05	1.34	1.49	1.46	1.43	1.41	1.39	1.37	1.35	1.33	0.84	1.31
Jun-05	1.37	1.52	1.48	1.45	1.43	1.4	1.38	1.36	1.34	0.92	1.33

Time step	Obs GWL m	computed GWL (m) with correlative conductance									
		2.2	**2.4**	**2.6**	**2.8**	**3**	**3.2**	**3.4**	**3.6**	**3.8**	**4**
Jul-05	1.44	1.58	1.54	1.51	1.48	1.46	1.44	1.42	1.4	1.02	1.38
Aug-05	1.83	1.7	1.66	1.63	1.6	1.58	1.55	1.53	1.51	1.02	1.5
Sep-05	2.06	1.77	1.73	1.7	1.67	1.65	1.62	1.6	1.59	1	1.57
Oct-05	2.16	1.86	1.83	1.8	1.77	1.74	1.72	1.7	1.68	0.97	1.67
Nov-05	2.16	2	1.97	1.94	1.91	1.88	1.86	1.84	1.82	0.98	1.81
Dec-05	2.05	1.92	1.88	1.85	1.82	1.8	1.78	1.76	1.74	0.97	1.72

Time step	Obs GWL m	computed GWL (m) with correlative conductance									
		1.55	1.53	1.52	1.51	1.5	1.49	1.44	1.41	1.38	1.36
Apr-01	1.51	1.51	1.5	1.49	1.47	1.46	1.45	1.4	1.37	1.34	1.31
May-01	1.43	1.58	1.57	1.55	1.54	1.53	1.51	1.46	1.43	1.39	1.37
Jun-01	1.34	1.62	1.6	1.59	1.57	1.56	1.55	1.5	1.46	1.42	1.4
Jul-01	1.34	1.61	1.59	1.58	1.56	1.55	1.54	1.49	1.55	1.42	1.39
Aug-01	1.55	1.7	1.68	1.67	1.65	1.64	1.63	1.57	1.53	1.5	1.48
Sep-01	1.89	1.83	1.82	1.8	1.79	1.78	1.76	1.72	1.68	1.65	1.5
Oct-01	2.12	2.04	2.06	2.1	2.1	2.09	2.09	1.98	1.88	1.91	1.89
Nov-01	2.22	2.02	2.04	2.1	2.09	2.09	2.09	1.99	1.87	1.9	1.88
Dec-01	2.33	1.83	1.81	1.8	1.79	1.77	1.76	1.71	1.78	1.65	1.62
Jan-02	1.97	1.73	1.72	1.71	1.69	1.68	1.67	1.62	1.69	1.56	1.54
Feb-02	1.79	1.64	1.63	1.62	1.6	1.59	1.58	1.54	1.5	1.48	1.45
Mar-02	1.67	1.61	1.59	1.58	1.57	1.56	1.54	1.5	1.46	1.43	1.41
Apr-02	1.59	1.53	1.52	1.5	1.39	1.49	1.47	1.42	1.38	1.46	1.23
May-02	1.53	1.42	1.48	1.3	1.31	1.31	1.32	1.3	1.24	1.31	1.18
Jun-02	1.47	1.58	1.56	1.55	1.53	1.42	1.36	1.45	1.42	1.32	1.36
Jul-02	1.62	1.56	1.54	1.53	1.51	1.5	1.49	1.34	1.4	1.32	1.34
Aug-02	1.77	1.42	1.6	1.59	1.57	1.56	1.55	1.4	1.46	1.43	1.31
Sep-02	1.77	1.82	1.8	1.79	1.78	1.76	1.75	1.7	1.66	1.53	1.61
Oct-02	2.31	1.9	1.77	1.87	1.86	1.85	1.84	1.79	1.65	1.72	1.7
Nov-02	2.25	1.84	1.83	1.82	1.8	1.79	1.78	1.73	1.7	1.67	1.64
Dec-02	2.07	1.72	1.78	1.7	1.68	1.67	1.66	1.62	1.58	1.65	1.73
Jan-03	1.90	1.64	1.62	1.61	1.6	1.59	1.58	1.53	1.5	1.43	1.55
Feb-03	1.77	1.57	1.56	1.55	1.53	1.52	1.51	1.47	1.43	1.41	1.38
Mar-03	1.68	1.5	1.48	1.47	1.46	1.45	1.44	1.39	1.36	1.33	1.31
Apr-03	1.52	1.45	1.43	1.42	1.41	1.4	1.38	1.34	1.31	1.28	1.26
May-03	1.38	1.39	1.38	1.36	1.35	1.34	1.33	1.28	1.25	1.22	1.19
Jun-03	1.41	1.37	1.35	1.34	1.33	1.31	1.3	1.26	1.22	1.19	1.17
Jul-03	1.65	1.37	1.36	1.34	1.33	1.32	1.31	1.26	1.22	1.19	1.17
Aug-03	1.60	1.39	1.37	1.36	1.35	1.33	1.32	1.28	1.24	1.21	1.19

Time step	Obs GWL m	computed GWL (m) with correlative conductance									
		1.55	1.53	1.52	1.51	1.5	1.49	1.44	1.41	1.38	1.36
Sep-03	1.98	1.56	1.55	1.54	1.52	1.51	1.5	1.46	1.42	1.39	1.37
Oct-03	2.04	1.78	1.76	1.75	1.74	1.72	1.71	1.67	1.63	1.6	1.58
Nov-03	2.29	1.8	1.78	1.77	1.76	1.74	1.73	1.69	1.65	1.62	1.6
Dec-03	2.11	1.72	1.71	1.7	1.68	1.67	1.66	1.62	1.58	1.55	1.53
Jan-04	1.89	1.63	1.62	1.6	1.59	1.58	1.57	1.53	1.49	1.47	1.44
Feb-04	1.68	1.54	1.52	1.51	1.5	1.49	1.48	1.44	1.4	1.38	1.36
Mar-04	1.54	1.43	1.42	1.4	1.39	1.38	1.37	1.33	1.29	1.27	1.25
Apr-04	1.52	1.33	1.32	1.3	1.29	1.28	1.27	1.23	1.19	1.17	1.15
May-04	1.38	1.35	1.33	1.32	1.31	1.3	1.29	1.24	1.21	1.18	1.15
Jun-04	1.48	1.43	1.42	1.4	1.39	1.38	1.37	1.32	1.28	1.25	1.23
Jul-04	1.67	1.44	1.43	1.41	1.4	1.39	1.37	1.33	1.29	1.26	1.24
Aug-04	2.01	1.45	1.44	1.43	1.41	1.4	1.39	1.34	1.31	1.28	1.26
Sep-04	1.99	1.66	1.64	1.63	1.62	1.6	1.59	1.55	1.51	1.49	1.46
Oct-04	2.25	1.85	1.83	1.82	1.81	1.79	1.78	1.74	1.7	1.67	1.65
Nov-04	2.22	1.79	1.78	1.77	1.75	1.74	1.73	1.68	1.65	1.62	1.6
Dec-04	2.10	1.64	1.63	1.61	1.6	1.59	1.58	1.54	1.5	1.48	1.45
Jan-05	1.84	1.52	1.51	1.49	1.48	1.47	1.46	1.42	1.39	1.36	1.34
Feb-05	1.75	1.44	1.43	1.42	1.41	1.4	1.39	1.35	1.31	1.29	1.27
Mar-05	1.57	1.37	1.36	1.35	1.34	1.33	1.32	1.27	1.24	1.22	1.2
Apr-05	1.39	1.3	1.29	1.27	1.26	1.25	1.24	1.2	1.17	1.14	1.12
May-05	1.34	1.31	1.3	1.29	1.27	1.26	1.25	1.21	1.17	1.15	1.13
Jun-05	1.37	1.36	1.35	1.34	1.32	1.31	1.3	1.25	1.22	1.19	1.17
Jul-05	1.44	1.48	1.47	1.45	1.44	1.43	1.42	1.37	1.33	1.31	1.28
Aug-05	1.83	1.55	1.54	1.53	1.51	1.5	1.49	1.44	1.41	1.38	1.36
Sep-05	2.06	1.65	1.64	1.63	1.61	1.6	1.59	1.55	1.51	1.48	1.46
Oct-05	2.16	1.79	1.78	1.76	1.75	1.74	1.73	1.68	1.65	1.62	1.6
Nov-05	2.16	1.79	1.78	1.76	1.75	1.74	1.73	1.68	1.65	1.62	1.60
Dec-05	2.05	1.71	1.69	1.68	1.67	1.66	1.65	1.60	1.57	1.54	1.52

Conductance calibration results (continued)

Observation well Q00202A (TV6 cross-section)

Time step	Obs. GWL m	computed GWL (m) with correlative conductance value								
		0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8
Feb-00	-0.26	-2.63	-1.55	-1.05	-0.77	-0.58	-0.45	-0.35	-0.28	-0.22
Mar-00	-0.36	-2.63	-1.55	-1.05	-0.77	-0.58	-0.45	-0.35	-0.28	-0.22
Apr-00	-0.49	-2.60	-1.56	-1.08	-0.81	-0.64	-0.51	-0.42	-0.35	-0.30
May-00	-0.69	-2.53	-1.55	-1.10	-0.84	-0.68	-0.57	-0.48	-0.42	-0.37
Jun-00	-0.67	-2.49	-1.55	-1.12	-0.88	-0.72	-0.61	-0.53	-0.47	-0.42
Jul-00	-0.55	-2.48	-1.56	-1.14	-0.89	-0.74	-0.63	-0.55	-0.49	-0.44
Aug-00	-0.35	-2.44	-1.53	-1.11	-0.87	-0.72	-0.61	-0.53	-0.47	-0.42
Sep-00	-0.39	-2.40	-1.48	-1.06	-0.82	-0.66	-0.55	-0.47	-0.40	-0.35
Oct-00	-0.12	-2.26	-1.31	-0.88	-0.62	-0.46	-0.34	-0.26	-0.19	-0.14
Nov-00	0.14	-2.11	-1.16	-0.72	-0.46	-0.30	-0.18	-0.10	-0.03	0.02
Dec-00	0.20	-2.13	-1.19	-0.75	-0.50	-0.33	-0.22	-0.13	-0.07	-0.02
Jan-01	0.05	-2.26	-1.30	-0.86	-0.60	-0.44	-0.32	-0.23	-0.17	-0.11
Feb-01	-0.12	-2.49	-1.47	-1.00	-0.72	-0.54	-0.42	-0.32	-0.25	-0.19
Mar-01	-0.19	-2.56	-1.53	-1.05	-0.77	-0.59	-0.46	-0.36	-0.29	-0.23
Apr-01	-0.44	-2.60	-1.57	-1.09	-0.81	-0.63	-0.51	-0.42	-0.34	-0.29
May-01	-0.62	-2.70	-1.67	-1.19	-0.92	-0.74	-0.61	-0.52	-0.45	-0.39
Jun-01	-0.68	-2.76	-1.74	-1.28	-1.01	-0.83	-0.71	-0.62	-0.55	-0.50
Jul-01	-0.41	-2.82	-1.80	-1.33	-1.06	-0.88	-0.76	-0.67	-0.59	-0.54
Aug-01	-0.44	-2.83	-1.80	-1.32	-1.04	-0.86	-0.73	-0.64	-0.57	-0.51
Sep-01	-0.45	-2.74	-1.71	-1.23	-0.95	-0.77	-0.64	-0.55	-0.47	-0.42
Oct-01	-0.40	-2.66	-1.60	-1.10	-0.81	-0.62	-0.49	-0.39	-0.31	-0.25
Nov-01	-0.12	-2.60	-1.50	-0.99	-0.70	-0.50	-0.37	-0.27	-0.19	-0.13
Dec-01	-0.20	-2.64	-1.54	-1.02	-0.72	-0.53	-0.39	-0.29	-0.21	-0.15
Jan-02	-0.36	-2.77	-1.64	-1.12	-0.81	-0.61	-0.48	-0.37	-0.29	-0.23
Feb-02	-0.51	-3.06	-1.86	-1.30	-0.97	-0.76	-0.61	-0.49	-0.41	-0.34
Mar-02	-0.52	-3.23	-1.99	-1.41	-1.07	-0.85	-0.69	-0.58	-0.49	-0.42
Apr-02	-0.89	-3.32	-2.07	-1.48	-1.14	-0.92	-0.76	-0.65	-0.56	-0.49
May-02	-1.15	-3.37	-2.12	-1.53	-1.20	-0.98	-0.82	-0.71	-0.62	-0.55
Jun-02	-1.25	-3.41	-2.17	-1.59	-1.26	-1.04	-0.89	-0.78	-0.70	-0.63
Jul-02	-1.15	-3.49	-2.25	-1.68	-1.35	-1.13	-0.98	-0.87	-0.79	-0.72
Aug-02	-1.08	-3.56	-2.30	-1.72	-1.38	-1.17	-1.01	-0.90	-0.81	-0.74
Sep-02	-1.08	-3.54	-2.26	-1.67	-1.32	-1.10	-0.94	-0.83	-0.74	-0.67
Oct-02	-1.04	-3.44	-2.14	-1.53	-1.18	-0.95	-0.79	-0.67	-0.58	-0.51
Nov-02	-0.77	-3.34	-2.01	-1.39	-1.03	-0.80	-0.64	-0.52	-0.42	-0.35
Dec-02	-0.69	-3.34	-2.00	-1.37	-1.01	-0.77	-0.61	-0.48	-0.39	-0.31
Jan-03	-0.85	-3.40	-2.04	-1.41	-1.04	-0.81	-0.64	-0.52	-0.42	-0.35
Feb-03	-0.98	-3.68	-2.26	-1.59	-1.20	-0.95	-0.77	-0.64	-0.54	-0.46

Time step	Obs. GWL m	computed GWL (m) with correlative conductance value								
		0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8
Mar-03	-0.98	-3.89	-2.41	-1.72	-1.32	-1.06	-0.87	-0.73	-0.63	-0.54
Apr-03	-0.98	-4.08	-2.57	-1.87	-1.46	-1.19	-1.00	-0.86	-0.75	-0.67
May-03	-1.37	-4.16	-2.65	-1.95	-1.54	-1.27	-1.09	-0.95	-0.84	-0.76
Jun-03	-1.55	-4.16	-2.67	-1.97	-1.57	-1.31	-1.13	-1.00	-0.89	-0.81
Jul-03	-1.59	-4.23	-2.73	-2.03	-1.63	-1.37	-1.18	-1.05	-0.94	-0.86
Aug-03	-1.50	-4.30	-2.77	-2.06	-1.65	-1.38	-1.19	-1.05	-0.95	-0.86
Sep-03	-1.29	-4.25	-2.72	-2.00	-1.59	-1.32	-1.13	-0.99	-0.88	-0.79
Oct-03	-1.39	-4.05	-2.50	-1.78	-1.37	-1.10	-0.91	-0.77	-0.66	-0.57
Nov-03	-1.33	-3.92	-2.36	-1.64	-1.22	-0.95	-0.76	-0.62	-0.51	-0.42
Dec-03	-1.03	-3.96	-2.40	-1.67	-1.25	-0.98	-0.79	-0.64	-0.54	-0.45
Jan-04	-1.13	-4.06	-2.48	-1.75	-1.32	-1.05	-0.85	-0.71	-0.60	-0.51
Feb-04	-1.12	-4.38	-2.73	-1.96	-1.51	-1.22	-1.01	-0.86	-0.74	-0.65
Mar-04	-1.25	-4.60	-2.90	-2.10	-1.64	-1.34	-1.12	-0.97	-0.84	-0.75
Apr-04	-1.65	-4.75	-3.01	-2.20	-1.73	-1.42	-1.21	-1.05	-0.92	-0.83

Time step	Obs GWL m	computed GWL (m) with correlative conductance value								
		2.0	2.2	2.4	2.6	2.8	3.0	3.5	4.0	4.5
Feb-00	-0.26	-0.17	-0.14	-0.10	-0.07	-0.05	-0.03	0.01	0.05	0.07
Mar-00	-0.36	-0.17	-0.14	-0.10	-0.07	-0.05	-0.03	0.01	0.05	0.07
Apr-00	-0.49	-0.25	-0.22	-0.19	-0.16	-0.14	-0.12	-0.08	-0.05	-0.02
May-00	-0.69	-0.32	-0.29	-0.26	-0.24	-0.22	-0.20	-0.16	-0.13	-0.11
Jun-00	-0.67	-0.38	-0.35	-0.32	-0.30	-0.28	-0.26	-0.23	-0.20	-0.18
Jul-00	-0.55	-0.40	-0.37	-0.34	-0.32	-0.30	-0.28	-0.24	-0.22	-0.20
Aug-00	-0.35	-0.38	-0.35	-0.32	-0.30	-0.28	-0.26	-0.22	-0.20	-0.18
Sep-00	-0.39	-0.31	-0.28	-0.25	-0.23	-0.21	-0.19	-0.15	-0.13	-0.10
Oct-00	-0.12	-0.10	-0.06	-0.03	-0.01	0.02	0.03	0.07	0.10	0.13
Nov-00	0.14	0.06	0.10	0.13	0.15	0.18	0.20	0.23	0.26	0.29
Dec-00	0.20	0.02	0.06	0.09	0.11	0.14	0.15	0.19	0.22	0.24
Jan-01	0.05	-0.07	-0.04	-0.01	0.02	0.04	0.06	0.10	0.13	0.15
Feb-01	-0.12	-0.15	-0.11	-0.07	-0.05	-0.02	0.00	0.04	0.07	0.10
Mar-01	-0.19	-0.19	-0.15	-0.11	-0.09	-0.06	-0.04	0.00	0.03	0.06
Apr-01	-0.44	-0.24	-0.20	-0.17	-0.14	-0.12	-0.10	-0.05	-0.02	0.00
May-01	-0.62	-0.35	-0.31	-0.28	-0.25	-0.23	-0.20	-0.16	-0.13	-0.11
Jun-01	-0.68	-0.45	-0.41	-0.38	-0.36	-0.33	-0.31	-0.27	-0.24	-0.22
Jul-01	-0.41	-0.49	-0.46	-0.42	-0.40	-0.37	-0.35	-0.31	-0.28	-0.26
Aug-01	-0.44	-0.47	-0.43	-0.40	-0.37	-0.34	-0.32	-0.28	-0.25	-0.23
Sep-01	-0.45	-0.37	-0.33	-0.30	-0.27	-0.25	-0.23	-0.18	-0.15	-0.13
Oct-01	-0.40	-0.21	-0.17	-0.13	-0.10	-0.08	-0.06	-0.01	0.02	0.05
Nov-01	-0.12	-0.08	-0.04	0.00	0.03	0.05	0.08	0.12	0.16	0.18

Time step	Obs GWL m	computed GWL (m) with correlative conductance value								
		2.0	**2.2**	**2.4**	**2.6**	**2.8**	**3.0**	**3.5**	**4.0**	**4.5**
Dec-01	-0.20	-0.10	-0.06	-0.02	0.01	0.03	0.05	0.10	0.13	0.16
Jan-02	-0.36	-0.18	-0.14	-0.10	-0.07	-0.05	-0.02	0.02	0.06	0.08
Feb-02	-0.51	-0.28	-0.24	-0.20	-0.16	-0.14	-0.11	-0.06	-0.02	0.01
Mar-02	-0.52	-0.36	-0.31	-0.27	-0.24	-0.21	-0.18	-0.13	-0.09	-0.06
Apr-02	-0.89	-0.43	-0.38	-0.34	-0.31	-0.28	-0.25	-0.20	-0.16	-0.13
May-02	-1.15	-0.49	-0.44	-0.40	-0.37	-0.34	-0.32	-0.26	-0.22	-0.19
Jun-02	-1.25	-0.57	-0.53	-0.49	-0.45	-0.43	-0.40	-0.35	-0.31	-0.28
Jul-02	-1.15	-0.67	-0.62	-0.58	-0.55	-0.52	-0.50	-0.45	-0.41	-0.38
Aug-02	-1.08	-0.68	-0.64	-0.60	-0.56	-0.53	-0.51	-0.46	-0.42	-0.39
Sep-02	-1.08	-0.61	-0.56	-0.52	-0.48	-0.45	-0.43	-0.38	-0.34	-0.30
Oct-02	-1.04	-0.45	-0.40	-0.36	-0.32	-0.29	-0.26	-0.21	-0.17	-0.14
Nov-02	-0.77	-0.29	-0.24	-0.19	-0.16	-0.13	-0.10	-0.05	0.00	0.03
Dec-02	-0.69	-0.25	-0.20	-0.16	-0.12	-0.09	-0.06	-0.01	0.03	0.07
Jan-03	-0.85	-0.29	-0.24	-0.19	-0.16	-0.13	-0.10	-0.04	0.00	0.03
Feb-03	-0.98	-0.39	-0.34	-0.29	-0.25	-0.22	-0.19	-0.13	-0.08	-0.04
Mar-03	-0.98	-0.47	-0.42	-0.37	-0.33	-0.29	-0.26	-0.20	-0.15	-0.12
Apr-03	-0.98	-0.60	-0.54	-0.49	-0.45	-0.41	-0.38	-0.32	-0.27	-0.23
May-03	-1.37	-0.69	-0.63	-0.58	-0.54	-0.51	-0.48	-0.41	-0.37	-0.33
Jun-03	-1.55	-0.74	-0.69	-0.64	-0.60	-0.57	-0.54	-0.48	-0.43	-0.39
Jul-03	-1.59	-0.79	-0.74	-0.69	-0.65	-0.61	-0.58	-0.52	-0.48	-0.44
Aug-03	-1.50	-0.79	-0.74	-0.69	-0.65	-0.61	-0.58	-0.52	-0.47	-0.43
Sep-03	-1.29	-0.72	-0.67	-0.62	-0.58	-0.54	-0.51	-0.45	-0.40	-0.36
Oct-03	-1.39	-0.50	-0.44	-0.39	-0.35	-0.32	-0.28	-0.22	-0.17	-0.14
Nov-03	-1.33	-0.35	-0.29	-0.24	-0.20	-0.16	-0.13	-0.07	-0.02	0.02
Dec-03	-1.03	-0.38	-0.32	-0.27	-0.23	-0.19	-0.16	-0.10	-0.05	-0.01
Jan-04	-1.13	-0.44	-0.38	-0.33	-0.29	-0.25	-0.22	-0.16	-0.11	-0.07
Feb-04	-1.12	-0.57	-0.51	-0.46	-0.41	-0.37	-0.34	-0.27	-0.22	-0.18
Mar-04	-1.25	-0.67	-0.60	-0.55	-0.50	-0.46	-0.42	-0.35	-0.30	-0.26
Apr-04	-1.65	-0.75	-0.68	-0.62	-0.58	-0.54	-0.50	-0.43	-0.37	-0.33

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2013 graduated bachelor degree on Hydrogeology at Department of Hydrogeology, Faculty of Geology in Ha Noi University of Mining and Geology, Vietnam.

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2015 enrolled in Master program of Water Resources Engineering, Faculty of Engineering, Chulalongkorn University under Scholarship of 72nd King's Birthday Scholarship.

2015 presented poster on "Modelling shallow aquifer and river interactions by MODFLOW in downstream of Sai Gon river, Viet Nam" at International Conference on

"Resilience of Groundwater system to Climate Change and Human Development", 6 - 9 February 2016, Bangkok, Thailand.

2017 Presented the paper on "Estimation of river conductance values along Saigon River, Vietnam" at THA 2017 International Conference on "Water Management and Climate Change Towards Asia's Water-Energy-Food Nexus" 25 - 27 January 2017, Bangkok, Thailand.

2017 Participated the trainging workshop on "Monitoring of groundwater salinity and related socio-economic parameters", 21 - 23 March 2017, IHE-DELFT, Netherlands.

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