



Article

Groundwater and River Interaction Parameter Estimation in Saigon River, Vietnam

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Abstract. The Saigon River system is one of the largest resources contributing water supply for domestic and industrial fields in the Ho Chi Minh City and Binh Duong Province where the drought issue is occurring at downstream area in recent years [1]. To manage the water resources in Saigon Basin effectively, the groundwater and river interaction parameter needs to be assessed systematically. However, in the past researches, the parameters seem to be less described with full understandings. In this study, a groundwater modeling of the main stream of Saigon River was applied to analyze groundwater and river interaction parameter along the river. The interaction layer was defined as a combined layer by materials of riverbed and materials of aquitard or aquifer. The values of conductance, through groundwater model calibration by piezometric 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 ratio of wetted length (R_w) was developed to estimate interaction parameter at each cross-section along Saigon River.

When river cross-sections has no penetration to the aquifer and the materials of interaction layer consists of materials of riverbed and aquitard, the value of interactions is equal to 0.0003 d^{-1} . In the other hand, the value will be reach to 0.254 d^{-1} when river cross-section has fully penetration to the aquifer. The interaction parameter function developed was applied to investigate the flow in and out between river and aquifer in the study area. In the upper part of Saigon River, river gained water from inflow of groundwater through riverbed (river gain) and lost water to groundwater (river loss) by outflow through the riverbed in the lower part during 2000 to 2007 and the river recharge to the first aquifer supplies to the second aquifer to supplement the aquifer storage discharged from the pumping.

Keywords: Interaction parameter, function, interaction pattern and volume, Saigon River.

ENGINEERING JOURNAL Volume 22 Issue 1

Received 14 September 2017

Accepted 28 October 2017

Published 31 January 2018

Online at <http://www.engj.org/>

DOI:10.4186/ej.2018.22.1.257

This article is based on the presentation at the THA 2017 International Conference on "Water Management and Climate Change towards Asia's Water-Energy-Food Nexus" in Bangkok, Thailand, 25th-27th January 2017.

1. Introduction

In the hydrologic cycle, the groundwater and river interaction is one of important parts and the interactions take many forms [2]. The process of groundwater and surface water interaction is generally complex and rates of exchange are highly variable, being dependent upon a range of parameters including geology, geomorphology and climate [3].

Groundwater pumping is response to quantify hydraulic properties of riverbed and aquifer material and to estimate quantity of river water entering the aquifer on the Susquehanna River in Broome County, New York [4]. On a similar note, Fox (2011) [5] demonstrated that pumping wells located adjacent to streams can reduce streamflow, a result that is known as alluvial well depletion. 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 [6].

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 [7] due to the effect of water use and wastewater from industrial, domestic and agricultural activities. From the 2000s, the stable isotope contents of groundwater samples collected from **Pleistocene aquifer (qp₂₋₃)** showed that there was a skewed frequency distribution with the maximum frequency occurred for the δD and $\delta^{18}O$ indices estimated for recharge by infiltration of precipitation and river and there was not the direct interaction between Saigon River and the deeper aquifer as **Pliocene aquifer (n₂₂)** [8]. Boehmer (2000) [9] recognized that 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.

Chan (2008) [10] and Khai (2015) [11] applied MODFLOW model to estimate groundwater recharge and reserves in the Ho Chi Minh area, respectively. Both of them collected conductance value from Boehmer (2000) [9] to set up river boundaries conditions. The result of MODFLOW model showed that river recharge occupied 20% to 40% of total groundwater budget in Ho Chi Minh area in period from 1995 to 2015 and the river recharge depended mainly on groundwater abstraction [11].

This paper focuses on analyzing groundwater and river interaction parameter along Saigon River by using groundwater model (MODFLOW). This study was conducted for better understanding the volume and pattern of river recharge (gain and loss) in Saigon River.

2. Materials and Method

Study Area

Saigon River is located in the South of Viet Nam (see in Fig. 1), and is the second biggest river in Viet Nam, which contributes from the Dau Tieng Dam. The study area covers the Lower Saigon River with the area of about 567.3 km², about 20 % of the Saigon River Basin. . During 2000-2007, the annual rainfall varies from 1,400 – 2,400 mm/year with more than 90% of the annual rain falling during the rainy season from May to November, and less than 10% of the annual rain falling during the dry season from December – April. Open pan evaporation ranges from 800 to 1,300 mm/year with the lowest evaporation in October and the highest in March. The humidity is generally high varying from 75% during the dry season to more than 90% in the wet season. The temperature varies between 24-25.5oC in the coolest month (January) and 28-30oC in the hottest month (May). According to Vuong (2010) [12], there are seven aquifers in the Saigon River basin, namely Holocene (qh), Upper Pleistocene (qp₃), Upper- middle Pleistocene (qp₂₋₃), Lower Pleistocene (qp₁), Middle Pliocene (n₂₂), Lower Pliocene (n₂₁) and Upper Miocene (n₁₃). Generally, lithology of each aquifer consists of fine to coarse sand, gravel, and pebble.

Methodology

In order to estimate the river conductance values and assess the interaction between the qp aquifer and river, the steps were applied in this study as follow: (1) develop groundwater modelling, (2) estimate interaction parameter and develop function of interaction parameter, (3) interaction pattern and volume of qp₂₋₃ aquifer (See in Fig. 2). The hydrogeological conceptual model covered an area of 567.3 km² along

Saigon River as consists of four aquifers, namely q_h , q_{p3} , $q_{p2.3}$ and q_{p1} separated by four aquitards, namely Q_2 , Q_1^3 , Q_1^{2-3} and Q_1^1 to be used for this study [13].

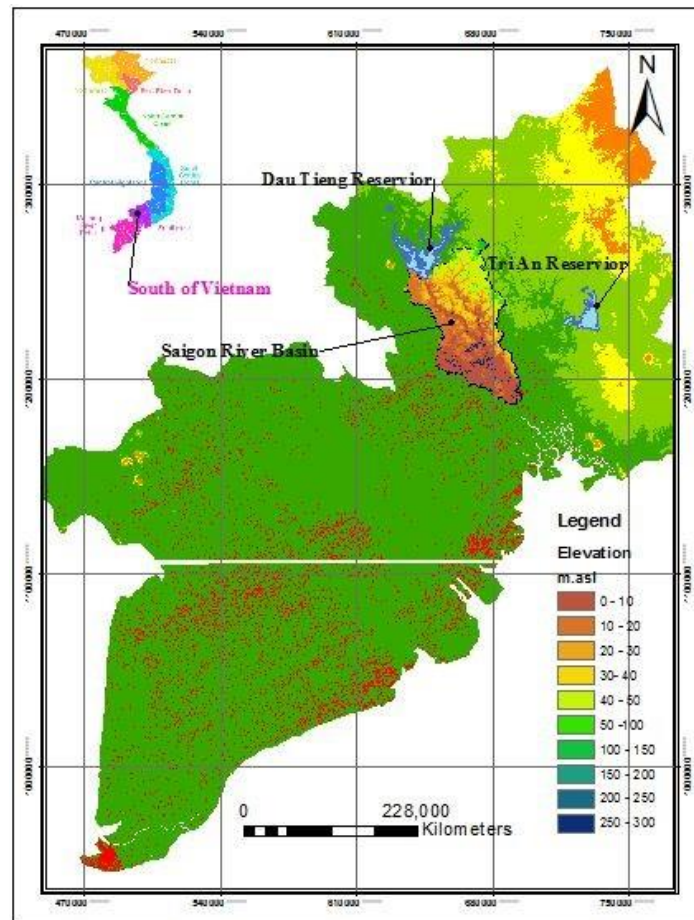


Fig. 1. Topography of the Saigon River Basin.

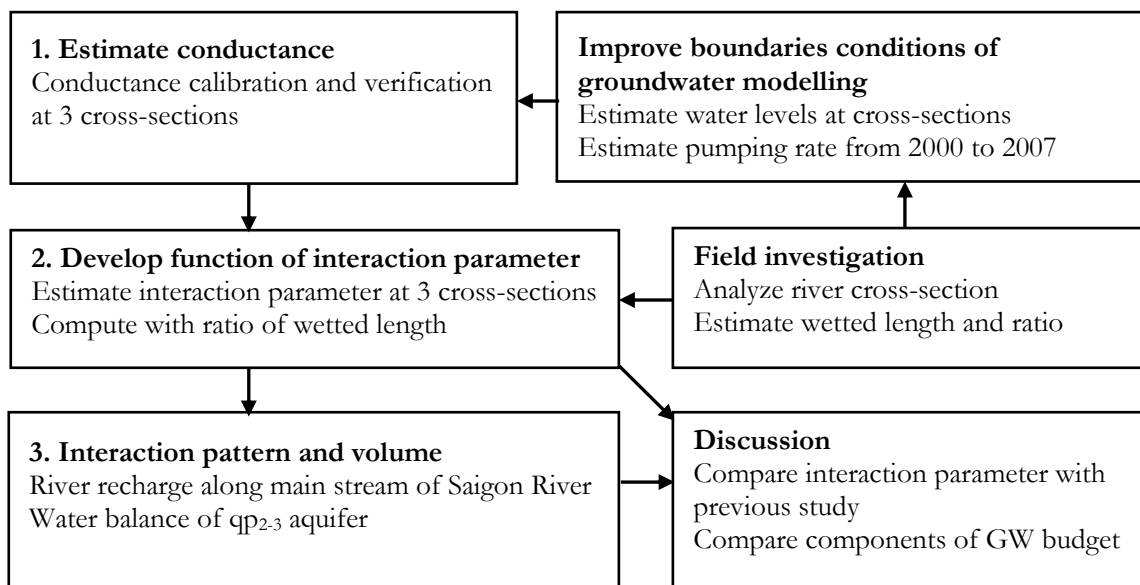


Fig. 2. Framework of this study.

Improve Groundwater Model Boundary Conditions

In this study, to improve river boundary, water levels at cross-section along Saigon river as TV1, TV3, TV7 and TV9 cross- sections (shown in Fig. 3) during 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. Ratio of population and pumping volume in two years, 2000 and 2007 were used to estimate the pumping rate from 2000 to 2007. Geostatistic tools (GMS) was applied to simulate hydraulic conductivity distribution of 8 layers by using the variogram of Long et al. (2017) [14]. The recharge rate is obtained from effective rainfall as Khai (2015) [11].

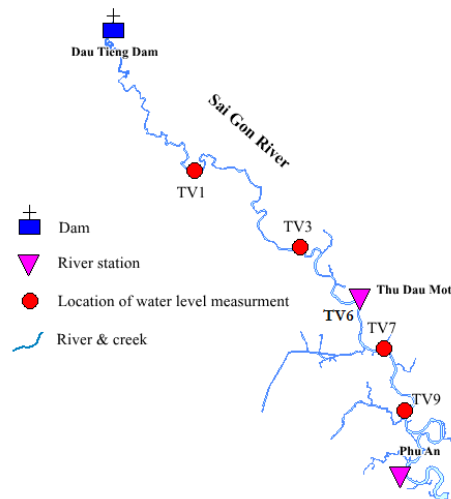


Fig. 3. Locations of water level measurement.

Field Investigation

From investigate results of the project on “Groundwater protection in Ho Chi Minh city” [15], 8 cross-sections along Saigon River were built to provide an overview of the spatial distribution of aquifer system and penetration at each cross-section along Saigon River. Through cross-section analysis, wetted length (W) of interaction layer and ratio of wetted length (R_w) at correlative cross-section was estimated by dividing wetted length under aquifer (W_u) for total of wetted length (W) as Eq. 3 (See results in Table 2).

Conductance Estimation

Conductance coefficient was calibrated and verified at 3 points associated with 3 cross-sections TV01, TV06, TV07 by using piezometric of observed wells near the cross-section which penetrate directly to qp₂₋₃ aquifer are N2, BD11 and Q00202A, respectively.

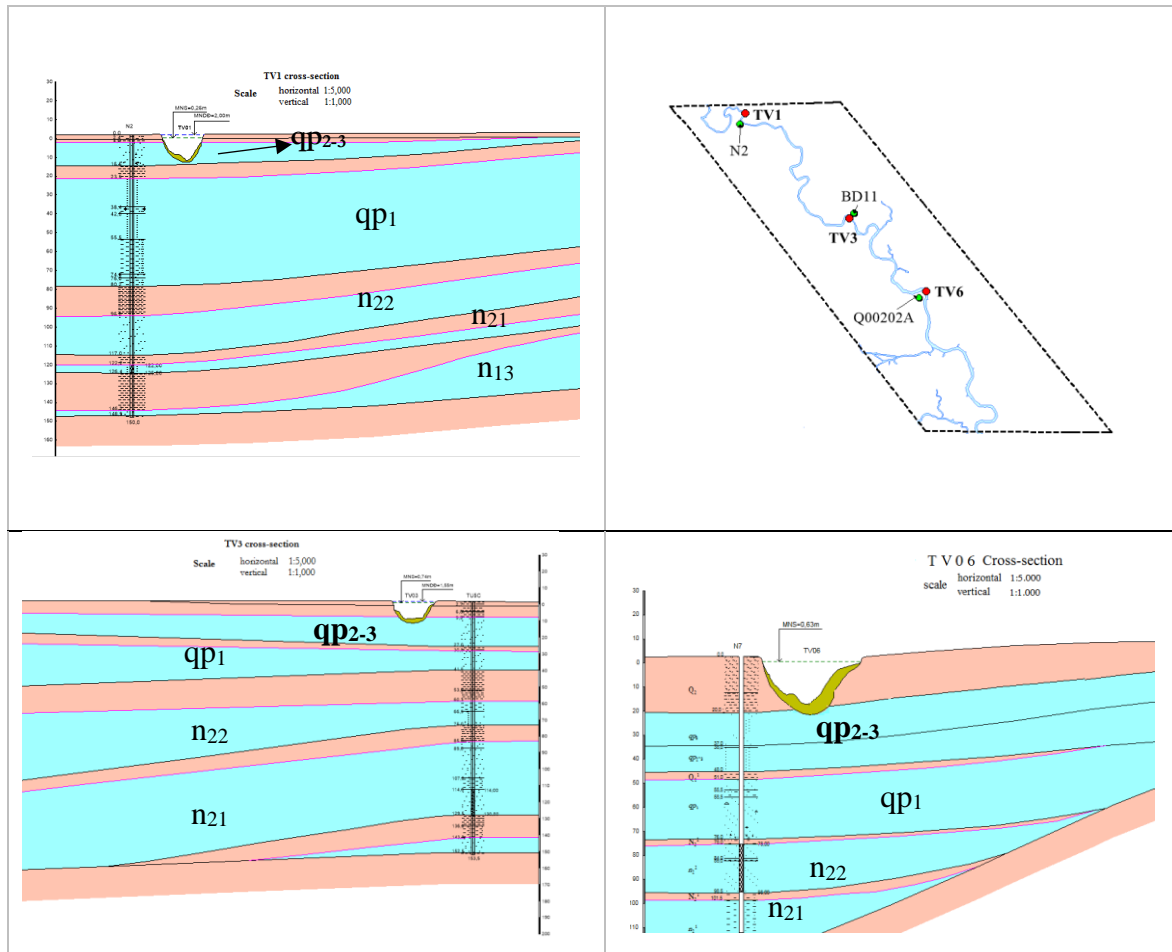


Fig. 4. Location and characteristic of 3 cross-sections in Saigon River.

3. Theories Used

Conductance Coefficient

In the case of a river boundary condition, the conductance is defined in MODFLOW as the hydraulic conductivity of riverbed materials divided by the vertical thickness (length of travel based on vertical flow), multiplied by the area (width times the length) of the river in the cell. To obtain river recharge through the interaction layer (L^3/T), the conductance is multiplied with the hydraulic head difference between the water level in the river and the water level in the aquifer.

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. Conductance for a given reach typically is conceptualized from interaction parameter value (Eq. (1)) as:

$$C = K_i M^{-1} \times W \quad (1)$$

where:

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

$K_i M^{-1}$ is interaction parameter f is separated into 2 parts: upper part is wetted parameter in aquitard (W_a) and lower part is wetted parameter in aquifer (W_u). Interaction parameter ($K_i M^{-1}$) is hydraulic conductivity (K_i) of the interaction layer (L/T) divided by the interaction layer thickness (M).

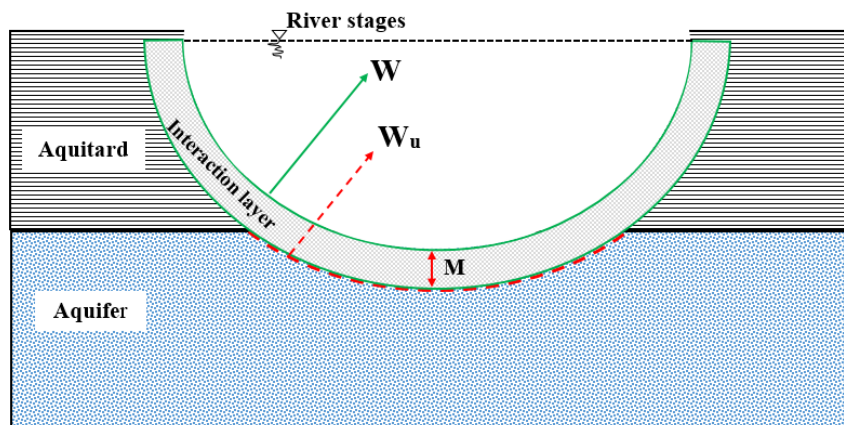


Fig. 5. Groundwater and river interaction layer simulation.

Interaction parameter is assumed as linear function with ratio of the wetted length at correlative cross-section.

$$K_i M^{-1} = a \times R_w + b \tag{2}$$

where:

- $K_i M^{-1}$ is interaction parameter [T^{-1}];
- a, b are coefficients of regression;
- R_w is ratio of wetted length and is calculated by dividing wetted length under aquifer (W_u) for total of wetted length (W):

$$R_w = W_u / W \tag{3}$$

4. Analysis Results

Estimate Interaction Parameter by GW Model

In model calibration process, 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 [16]. The selected value of conductance is the value with minimum RMSE and maximum R^2 (Fig. 6).

The selected conductance value at TV3 and TV6 cross-section were verified by computing calculated and observed groundwater level at observation well BD11 and Q00202A in the period from 3/2003 to 5/2005 and 4/2004 to 9/2007, respectively (See in Fig. 7). At TV3 cross-section, RMSE and R^2 were 0.34 and 0.66, respectively.

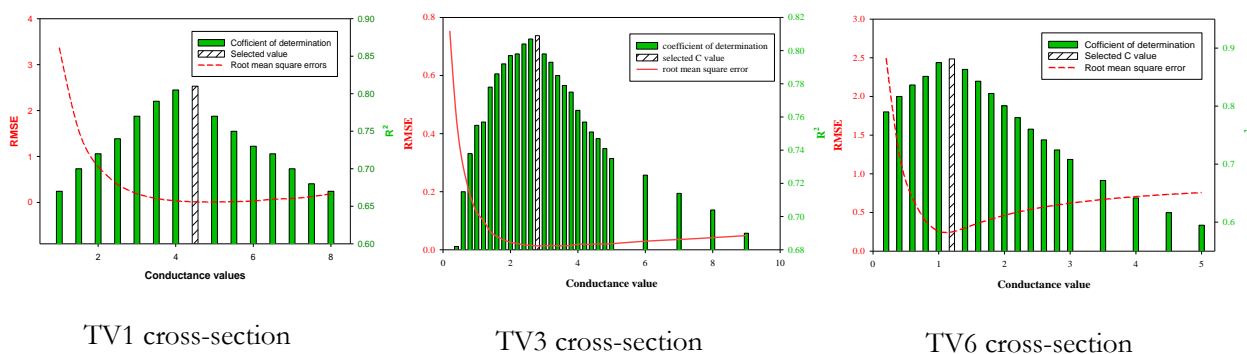


Fig. 6. Conductance calibration results at 3 cross-sections.

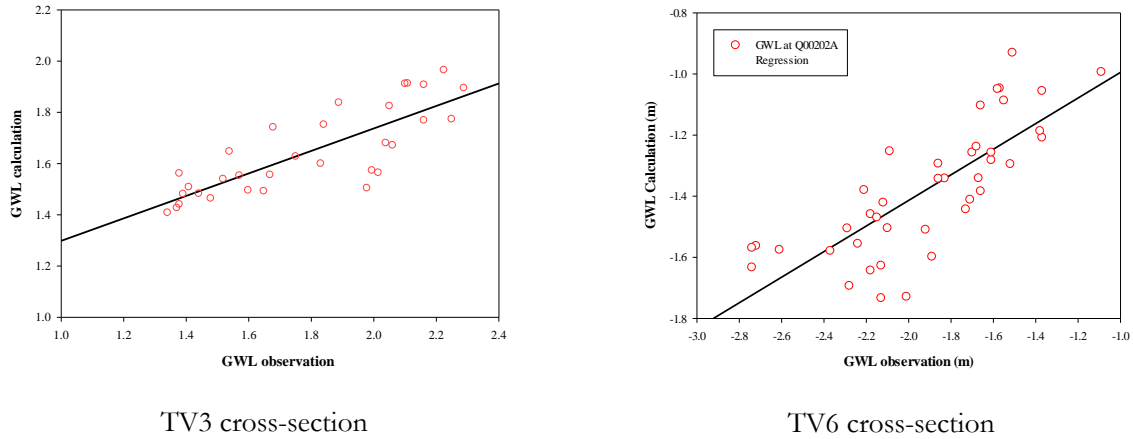


Fig. 7. Conductance verification results at TV3 and TV6 cross-section.

From Eq. (1), interaction parameter values were calculated based on selected conductance values from calibration and verification processes by multiplying with total wetted length of interaction layer at 3 cross-sections TV1, TV3 and TV6 (Table 1).

Table 1. Summary calculation of interaction parameter values and ratio of part of wetted length.

Cross-section	C (m/d)	W (m)	$K_i M^{-1}$ (d ⁻¹)	W_u (m)	R_w
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

The interaction parameter can be obtained from ratio of wetted length as linear function below:

$$K_i M^{-1} = 0.0254 \times R_w + 0.0003 \quad (4)$$

where:

$K_i M^{-1}$ is interaction parameter value [T⁻¹];
 R_w is the ratio of wetted length.

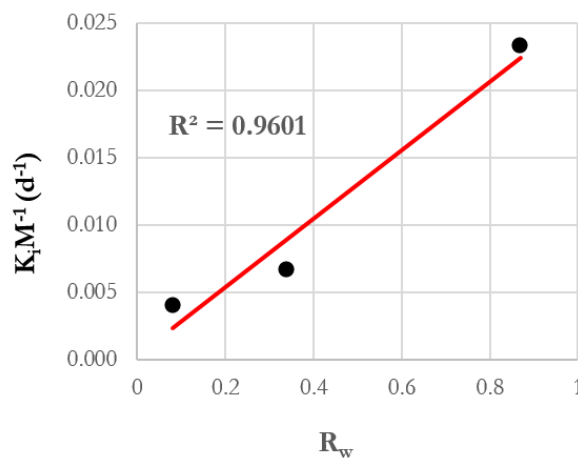


Fig. 8. Correlation of interaction parameter and ratio of wetted length.

Interaction parameter function (Eq. (3)) was applied to estimated interaction parameter value and conductance was calculated based on function (Eq. (1)) at other cross-sections along Sai Gon River. (See details of the result in Table 1).

Table 2. Calculation results of interaction parameter and conductance.

Cross-section	W_u (m)	W (m)	R_w	$K_i M^{-1}$	C (m/d)
SSG03	192	196	0.98	0.0252	4.94
TV01	169	194	0.87	0.0232	4.50
SSG12	131	225	0.58	0.0150	3.38
TV03	60	182	0.33	0.0066	2.80
SSG15	48	252	0.19	0.0051	1.29
TV06	18	306	0.60	0.0039	1.20
SSG20	74	309	0.24	0.0064	1.98
TV07	97	323	0.30	0.0079	2.56
TV09	0	285	0.00	0.0003	0.09
TV10	0	372	0.00	0.0003	0.11

Discussions

In the groundwater model, each cell presents for a river section, hence, cell width has effect on river recharge. In this study, cell width is 500 m and calibrated conductance is 1.2 at TV6 cross-section. To assess the cell width effect on river recharge, cell width was changed to 305 m equals to actual river width at TV6 cross-section and the conductance [9] was set to 2.2 as observed. The results showed that the average volume differential was 4.4 m³/d and average difference percentage was less than 4 percent. So, the difference of observed conductance [9] and calibrated conductance from this study came from the effect of cell width in the groundwater model.

The computed groundwater levels (GWL), when used $C_{initial}$ [9] and variable C (from the proposed interaction parameter function as in Table 2), were compared with observed groundwater level (GWL) at the cross-sections. Fluctuations of GWL calculation were much improved and more closed with observed GWL when applied the conductance values of this study.

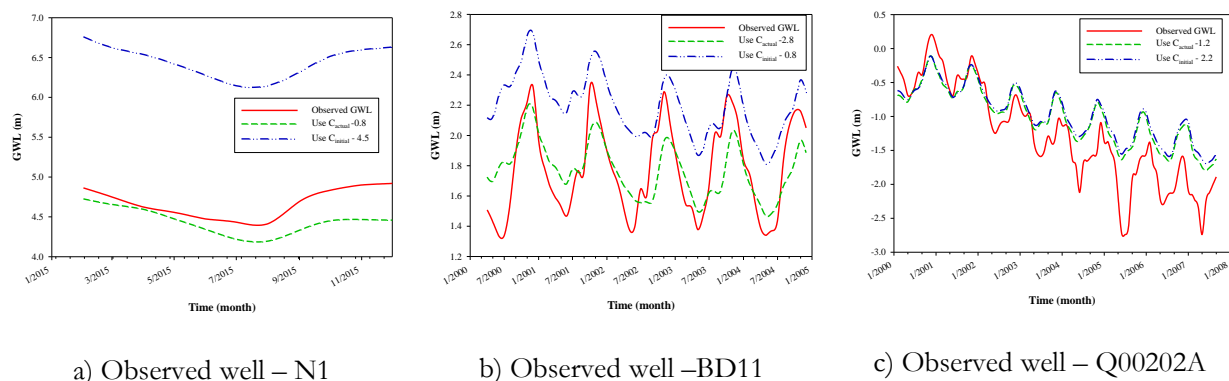


Fig. 9. Comparison of observed GWL observation with computed GWL at 3 observed wells.

In whole study area, all river recharge out (RRO) showed good correlations with rainfall during 2000 to 2007 (Fig. 10). RRO volume of qp₂₋₃ 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 m³/d and -22,355 m³/d, respectively. In contrast, RRI volume of qp₂₋₃ 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 m³/d

and 28,999 m³/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 m³/d to over 40,000 m³/d in 2000 and 2007, respectively (Fig. 11).

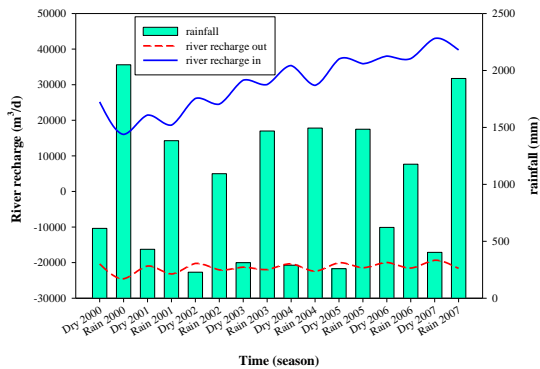


Fig. 10. Correlation between river recharge of qp₂₋₃ aquifer and rainfall.

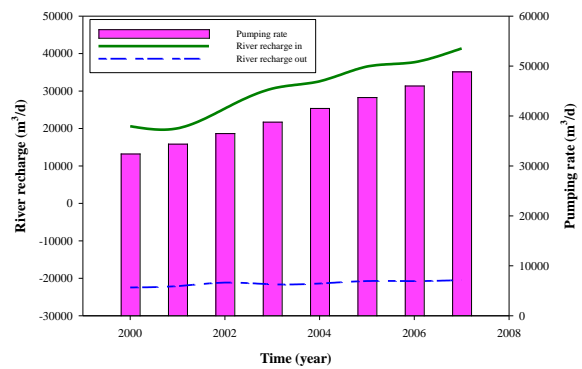


Fig. 11. Correlation between river recharge of qp₂₋₃ aquifer and pumping rate.

River recharge Pattern and Volume

From the groundwater model results, in the upper part of Saigon River, river gained water from qp₂₋₃ aquifer (RRO) through interaction layer with annual recharge volume at TV1 and TV3 cross-section were -2,896 m³/d and -1,497 m³/day respectively (Fig. 12). In contrast, river lost water to qp₂₋₃ aquifer (RRI) in lower part with annual recharge volume at TV6 and TV7 cross-section were 828 m³/d and 925 m³/day respectively. River recharge concentrated on qp₂₋₃ aquifer from 2000 to 2007, with RRO and RRI volume were -21,363 and 35,703, respectively. Although aquifer qp₂₋₃ absorbed until 96 percentages of river recharge and 77 percentages of land recharge in whole study area, however sum of discharge by pumping and filtration to below aquifer (qp₁ aquifer) was around 1.7 times total recharge of qp₂₋₃ aquifer consist of river recharge and land (Fig. 13). Therefore, pumping rate of both qp₂₋₃ aquifer and qp₁ aquifer need to be reduced and controlled better.

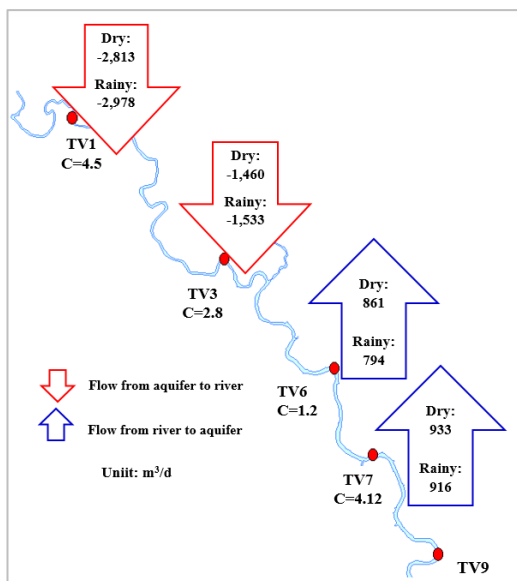


Fig. 12. River recharge pattern and volume.

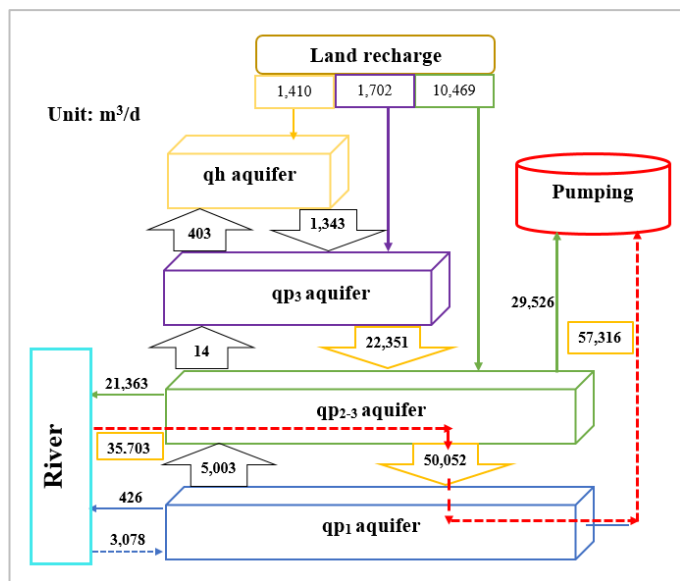


Fig. 13. Flow in and out of all aquifers in the study area.

5. Conclusions

The interaction parameter values at TV1, TV3, TV6 cross-section are 0.023 d⁻¹, 0.007 d⁻¹ and 0.004 d⁻¹, respectively and can be applied to groundwater and river interaction for future groundwater modeling in Saigon River area. A function of interaction parameter 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 the value of interaction parameter equals to 0.0003 d⁻¹. In the other hand, the value will reach to 0.033 d⁻¹ when river cross-section has fully penetration into aquifer.

In upper part of Saigon River, river gained water from inflow of groundwater through riverbed in the period from 2000 to 2007. Rate 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 m³/d and -1,496m³/d respectively. In lower part, river lost water to groundwater by out flow through the riverbed (river recharge in). By major impact of pumping of both aquifer qp₂₋₃ and qp₁, groundwater level in aquifer (qp₂₋₃) had been decreasing significantly although the aquifer was always absorbed most of river recharge and land recharge in this study area. This requires a better controlling of pumping distribution and rate. Under effect of increasing pumping rate, the volume of river recharge in grew up approximately 56% during 2000 to 2007 at TV6 cross-section and about 50 % at TV7 cross-section.

Acknowledgement

The authors would like to acknowledge the support from the Department of Water Resources Engineering, Chulalongkorn University. This paper is developed under a part of master scholarship funded by 72nd King's Birthday Scholarship of Chulalongkorn University. 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.

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