Effects of Heavy Pumping and Artificial Groundwater Recharge Pond on the Aquifer System of Langat Basin, Malaysia

R. May, K. Jinno, I. Yusoff

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***Abstract*—**The paper aims at evaluating the effects of heavy groundwater withdrawal and artificial groundwater recharge of an ex-mining pond to the aquifer system of the Langat Basin through the three-dimensional (3D) numerical modeling. Many mining sites have been left behind from the massive mining exploitations in Malaysia during the England colonization era and from the last few decades. These sites are able to accommodate more than a million cubic meters of water from precipitation, runoff, groundwater, and river. Most of the time, the mining sites are turned into ponds for recreational activities. In the current study, an artificial groundwater recharge from an ex-mining pond in the Langat Basin was proposed due to its capacity to store >50 million m^3 of water. The location of the pond is near the Langat River and opposite a steel company where >4 million gallons of groundwater is withdrawn on a daily basis. The 3D numerical simulation was developed using the Groundwater Modeling System (GMS). The calibrated model (error about 0.7 m) was utilized to simulate two scenarios (1) Case 1: artificial recharge pond with no pumping and (2) Case 2: artificial pond with pumping. The results showed that in Case 1, the pond played a very important role in supplying additional water to the aquifer and river. About 90,916 m^3/d of water from the pond, 1,173 m^3/d from the Langat River, and 67,424 m^3/d from the direct recharge of precipitation infiltrated into the aquifer system. In Case 2, due to the abstraction of groundwater from a company, it caused a steep depression around the wells, river, and pond. The result of the water budget showed an increase rate of inflow in the pond and river with 92,493m^3/d and 3,881m^3/d respectively. The outcome of the current study provides useful information of the aquifer behavior of the Langat Basin.

***Keywords*—**Groundwater and surface water interaction, groundwater modeling, GMS, artificial recharge pond, ex-mining site.

I. Introduction

GROUNDWATER is a very important source of drinking water in many countries. Due to the abundance of surface water, some parts of Malaysia have not yet disturbed this resource. The rapid development in the capital city Kuala Lumpur, and the surrounding states, e.g. the Selangor State contributes to the shortage of water. The quantity of surface water is not enough to supply water to the consumers, and the quality of surface water in the Langat River is slightly polluted [1]. Consequently, the groundwater is considered to be a potential alternative water resource, and some industries have altered their surface water utilization to groundwater [2]. The Langat Basin is one of the most potential groundwater basins in Malaysia. There are many factories in the area. One of them was permitted to abstract >22,000 m^3/d of groundwater for its company's production. There are several proposed projects involved in the abstraction of a great amount of groundwater. It is expected that the environmental impacts to the Langat Basin due to these activities are significant. In order to cope with the problems, the artificial recharge of groundwater is one of the options to ensure that the aquifer does not deteriorate. This choice could be applied in the mining activities in which the seepage from the groundwater is expected to pump out of the excavation sites as soon as possible. The water could be injected back into the aquifer through the artificial recharge pond, for instance.

This paper focuses on the effects of the heavy groundwater abstraction and artificial pond to the aquifer system through the 3D numerical simulation in GMS. The model can be used to predict the future water budget in the aquifer system, especially future projects related to groundwater artificial recharge in the study area.

II. Study Area

The study area is located in the central Langat Basin (Fig. 1), about 30km from the Kuala Lumpur City Center (KLCC) and 10km from the Kuala Lumpur International Airport (KLIA). The area is administratively a part of the Kuala Langat District. The boundary of the study area is limited to the middle of the Langat Basin which is the alluvium floodplain. The average elevation of the ground surface is about 15m above sea level (a.s.l.). The perimeter and area of the research vicinity area are 64.98km and 243.65km^2 respectively. The map in Fig. 2 is utilized as a base map in the study; therefore, it is visible enough to identify the landuse applications such as gas stations, lakes, houses, forests, factories, plantations, workshops, and hotels.

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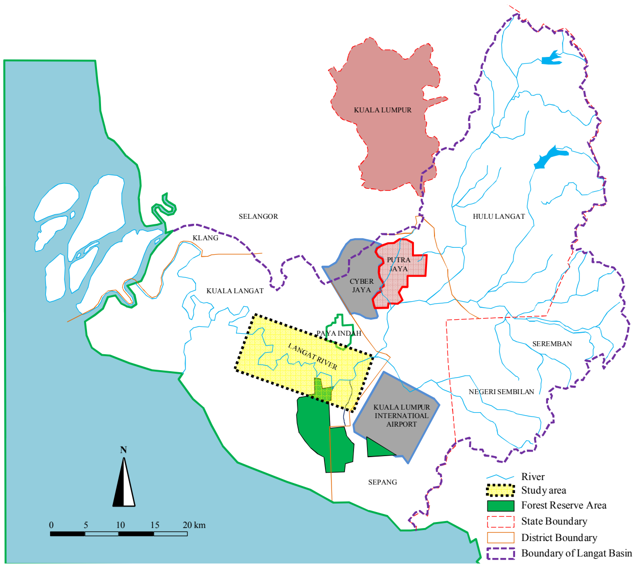

Fig. 1 Location of study area

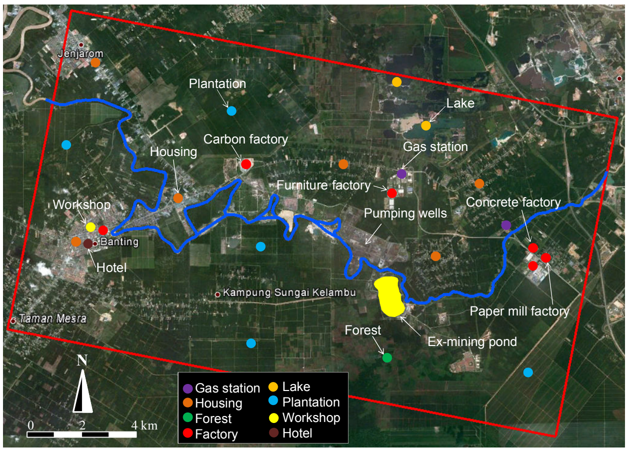

Fig. 2 Land use identification in study area

III. Model Development

GMS was used to simulate the groundwater flow in the study area. MODFLOW is one of the components of the software, and it was developed based on the principle equations of Darcy's Law and conservation mass equation. The finite different method was adopted to compute the groundwater flow movement numerically. The study area was heterogeneously discretized due to the inclusion of the pumping wells. Generally, a well causes steep incline of piezometric heads near the wells and characterizes a point of convergence in the groundwater flow movement. In order to accurately model the flow dynamics near the wells, the grid was refined in the vicinity of the wells by 50m and 150m for the base and maximum sizes respectively (Fig. 3). Therefore, the total cells for simulation were 15,856.

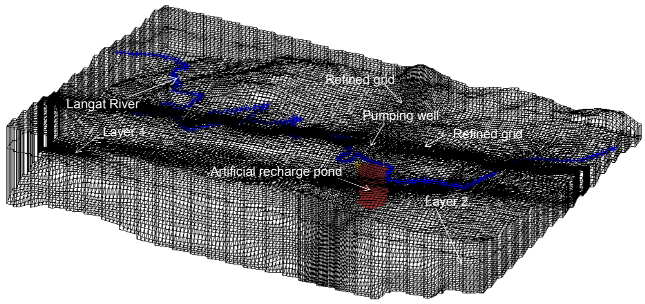

Fig. 3 Variable-spacing finite-difference grid of model area

A. Darcy's Law

Darcy's Law is the main equation in calculating the groundwater flow. This equation presents that the flow rate through a porous medium (such as an aquifer) is proportional to the cross sectional area perpendicular to flow and also proportional to the head loss per unit length in the direction flow. The Darcy's Law equation is given as follows [3]:

$$Q = -KA\frac{\partial h}{\partial l} \qquad (1)$$

where Q is the flow [m^3/s], K is the hydraulic conductivity [m/s], A is the area through which flow occurs [m^2] and dh/dl is the change in head (h) over a distance (l) [dimensionless]. The term dh/dl is commonly written as i, the hydraulic gradient.

B. Groundwater Flow Equation

The model is based on Darcy's Law and the equation of conservation of mass. The combination of both results in a partial differential equation for groundwater flow is given by [4] as follows:

$$S_s\frac{\partial h}{\partial t} = \frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial x}\left(K_{zz}\frac{\partial h}{\partial z}\right) - w \qquad (2)$$

where K_{xx}, K_{yy}, and K_{zz} are values of hydraulic conductivity along the x, y, and z coordinate axes, which are assumed to be parallel to the major axes of hydraulic conductivity (L/T); h is the potentiometric head (L); w is a volumetric flux per unit volume and represents sources and/or sinks of water, with $w<0$ for flow out of the groundwater system, and $w>0$ for flow in (1/T); S_s is the specific storage of the porous material (1/L); and t is time (T).

C. River-Aquifer Interaction

In the current simulation, two types of boundary conditions (river and pond) require a conductance parameter [4]. The amount of inflow and outflow water of the model due to the boundary condition stresses is determined by using this constant proportionality conductance (Fig. 4). The conductance is defined according to Darcy's Law as follows [5]:

$$Q = KiA \qquad (3)$$

where Q is the flow rate (L^3/T), K is the hydraulic conductivity (L/T), i represents the hydraulic gradient (L/L), and A represents the cross-sectional area of flow. $A = WL$ where W is the width of river (L) and L is the length of river reach (L). Therefore, Darcy's Law can be expressed as follows:

$$Q = K\frac{\Delta H}{B}A \tag{4}$$

where $\Delta H = H_1 - H_2$ is the head loss (L) and B is the length of flow (thickness of river bed sediment) (L). Another form of (4) can be written as follows:

$$Q = C\Delta H \tag{5}$$

where C is called conductance which represents the unknown on the right side of (4). The general definition for conductance is as follows:

$$C = \frac{K}{B}A \tag{6}$$

In the case of the river, conductance should be assigned in terms of conductance per unit length. Therefore, the hydraulic equation of conductance for the river is as follows:

$$C_{river} = \frac{\frac{K}{B}WL}{L} \tag{7}$$

$$C_{river} = \frac{K}{B}W \tag{8}$$

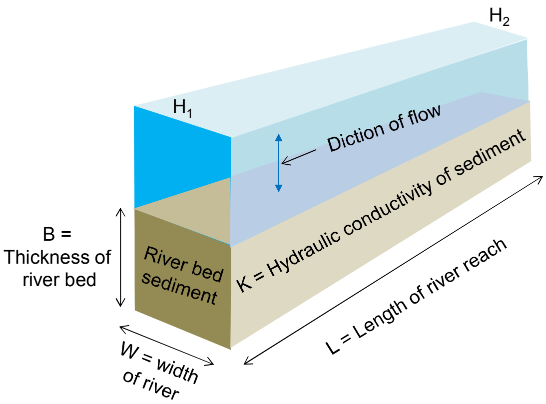

Fig. 4 Prism of river bed sediment and upper water illustrating Darcy's law

D.Lake-Aquifer Interaction

The artificial recharge pond will significantly influence the groundwater flow in the system; therefore, the boundary condition of this water body has to be properly defined. To simulate the pond behavior, the general heads of pond are specified by appointing a general head and a conductance to a set of cells representing the pond (Fig. 5). When the piezometric head increases above the general head, water flows out of the aquifer; water flows into the aquifer when the piezometric head decreases below the general head. The flow rate is proportionate to the head difference and the conductance in both cases. For the pond, conductance should be assigned in a conductance per unit area. From (6), the conductance of the pond has the following expression:

$$C_{pond} = \frac{\frac{K}{B}A}{A} \tag{9}$$

$$C_{pond} = \frac{K}{B} \tag{10}$$

where K represents the hydraulic conductivity of the pond bed sediment (L/T) and B represents the thickness of the sediment.

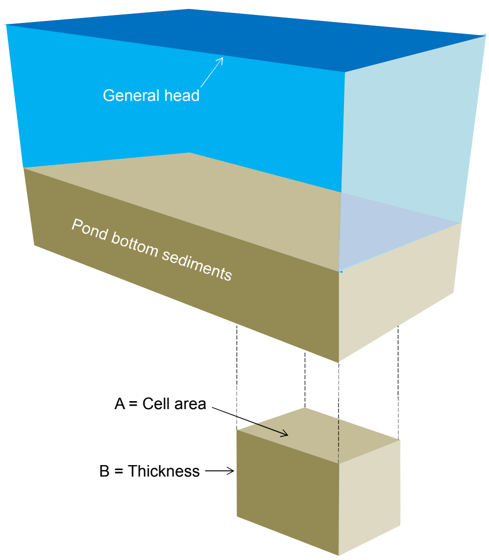

Fig. 5 Prism of pond bottom sediment illustrating conductance assignment

IV. Input Data

A data set prepared for the simulation included the following parameters. The input data representing the aquifer characteristics and boundary conditions were aquifer thickness, horizontal hydraulic conductivity, vertical anisotropy, recharge rate, river, river conductance, specific head of river water, no-flow boundary, pond conductance, and general head of the pond water. Table I summarizes the data input for simulation.

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TABLE I
INPUT PARAMETER FOR MODEL SIMULATION

Parameter	Symbol	Unit[a]	Value	Other
Horizontal hydraulic conductivity	K_{H1}	m/s	5.79×10^{-5}	Layer1
Vertical anisotropy	K_{H1}/K_{V1}	-	10	Layer1
Horizontal hydraulic conductivity	K_{H2}	m/s	3.24×10^{-4}	Layer2
Vertical anisotropy	K_{H2}/K_{V2}	-	30	Layer2
Recharge rate	w	mm/y	100.375	
Initial condition	h_0	m	Ground elevation	
Pumping wells	w	m^3/h	-787.5	Steel factory 3 production wells

[a] Units are m = meter, s = second, mm = millimeter, y = year, m^2 = square meter, h = hour, and m^3 = cubic meter.

A. Aquifer Characteristics

The stratigraphy of aquifer in the modeled area can be classified into two different layers, sandy clay at the upper layer (layer 1) and sand and gravel at the lower layer (layer 2). Layer 1 extended from northeast to southwest. The maximum elevation of the first aquifer bottom was -5 m a.s.l., and the minimum reached until -25 m a.s.l. The horizontal hydraulic conductivity was approximately 5.79×10^{-5} m/s, and the vertical anisotropy was 10 [2]. In layer 2, the aquifer bottom was shielded by the bedrock of sandstone, quartzite, and granite. The sand and gravel were dominantly found in this aquifer layer. The horizontal hydraulic conductivity was approximately 3.24×10^{-4} m/s and the vertical anisotropy was 30 [2]. The average depth of the second layer was 90 m. The 3D conceptual model in Fig. 6 illustrated the aquifer system in the study area. The recharge rate was estimated by the tank model [6]. It was assumed that the recharge distribution was homogeneous and covered the entire area with the rate of 100.375 mm/y.

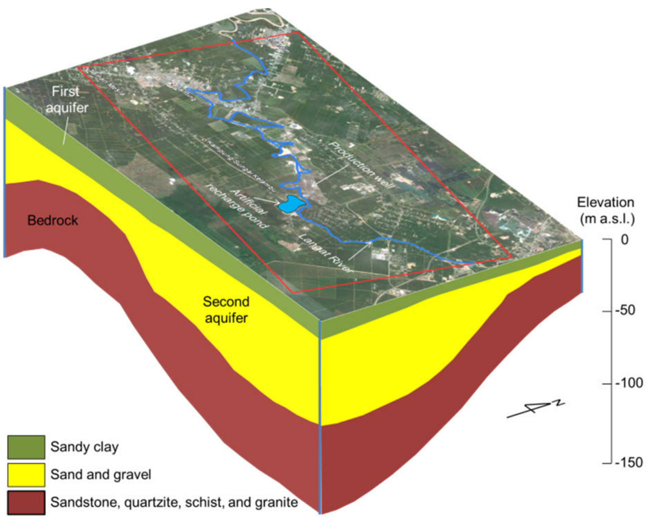

Fig. 6 3D conceptual model of the aquifer system (not to scale)

B. River

To simulate the interaction of the groundwater and surface water accurately, the river parameters such as river conductance, river water elevation, and river bed elevation had to be taken into consideration. The river conductance was adopted approximately at 6.25×10^{-3} $m^2/s/m$. The river water and bed elevations were interpolated linearly from one location to another. Fig. 7 and Table II show the locations and relevant parameters along the river. These data were derived from JICA [2] and DID's online hydrological website [7].

TABLE II
THE RIVER WATER AND BED ELEVATIONS INPUT IN THE SIMULATION

Location	River water elevation (m a.s.l.)	River bed elevation (m a.s.l.)
A	7.9	2.91
B	1.83	0.32
C	0.84	-6.03
D	0.78	-6.41
E	0.69	-7.13
F	0.61	-7.62
G	0.56	-7.98
H	0.50	-8.01
I	0.0	-8.94

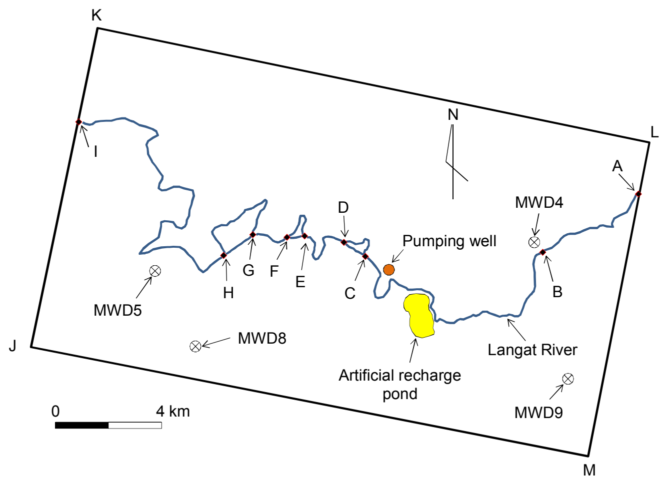

Fig. 7 Simplified map illustrating artificial pond, pumping location, monitoring wells, and locations along the river where the river water and bed elevations are known

C. Pond

The ex-mining area in the model area had the area of approximately 1,137,884 m^2 and the deepest depth of 70 m. In the current simulation, the area was assumed to be an artificial recharge pond for the Langat Basin. The hydraulic conductance of the pond was estimated to be equals to 3.47×10^{-4} $m^2/s/m^2$. The general head of the pond (or surface water elevation of pond) was constant at 5 m a.s.l.

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D. Boundary Condition

Boundary condition is a mathematical statement that depends on the variable e.g. water head, recharge rate, or concentration. In a steady-state simulation, the boundary condition is necessary to approximate the natural condition. Table III summarizes the selected boundary types for the simulation. The river, pond, and boundary of the study area were assigned to specific head, general head, and no-flow boundaries respectively.

TABLE III
BOUNDARY CONDITIONS SELECTED FOR SIMULATION

Boundary	Type	Unit	Value	Remark
JKLM	No-flow boundary	m a.s.l.	$\frac{\partial h}{\partial t} = 0$	Fig. 7
River (A to I)	Specific head	m a.s.l.	$\frac{\partial h}{\partial t} = h_r$	Fig. 7 and h_r represents the river water elevation
Artificial recharge pond	General head	m a.s.l.	5	Fig. 7
River conductance	Conductance	$m^2/s/m$	$C_{river} = 6.25\times10^{-3}$	The thickness of riverbed sediment was assumed to be 0.5 m [9].
Pond conductance	Conductance	$m^2/s/m^2$	$C_{pond} = 3.47\times10^{-4}$	The thickness of pond bottom sediment was assumed to be 0.5 m [9].

E. Initial Condition

The initial condition illustrates the specified value for the piezometric head at the beginning of the simulation. The ground elevations were utilized to be the initial condition in this modeling.

V. RESULTS AND DISCUSSION

A. Model Calibration

Four monitoring wells (Fig. 7) were prepared for the calibration process. The calibration target was set to have the estimated error interval of ±1.0 m of the observed value. The confident value to estimate the error was 95%. The achievement was confirmed by another statistical analysis i.e. the root mean square error (RMSE) which was given as follows [8]:

$$RMSE = \left[\frac{1}{n} \sum_{i=1}^{n} \left(h_m - h_s \right)^2 \right]^{1/2} \qquad (11)$$

where h_m is the observed piezometric head (L), h_s represents the simulated piezometric head (L), and n is the number of observed wells.

The observed and simulated piezometric heads from Table IV were used to calculate the RMSE. The error was approximately 0.699m. Therefore, the simulation was successfully achieved to demonstrate the aquifer behavior in the study area.

TABLE IV
THE CALIBRATION RESULTS

Observed well Fig. 7	Observed head (m)	Observed head interval (m)	Observed head confidence (%)	Computed head (m)	Residual head (m)
MWD4	2.31	1.0	95	2.411	-0.101
MWD9	3.856	1.0	95	3.772	0.084
MWD8	1.522	1.0	95	2.559	-1.037
MWD5	0.591	1.0	95	1.203	-0.612

B. Discussion

1. Artificial Recharge Pond without Pumping

The calibrated model was adopted to predict the groundwater dynamics in the aquifer system. In this case, the pumping rate was not applied in the simulation. The results of the piezometric head distribution are shown in Fig. 8. Almost the entire reach of the Langat River was a gaining stream. The direction of the groundwater flow headed from the northeast toward the southwest at the northern side of the river. The piezometric head varied from 8.5 m a.s.l. to 0.5 m a.s.l. At the southern side of the river, the groundwater flow influenced most of the reach from the direction of the southwest and southeast toward the river. However, the east reach of the river influenced the aquifer. The infiltrated water from the artificial recharge pond influenced much of the groundwater and river, especially to the west and east of the pond. Fig. 9 illustrates the close-up piezometric head in layer 1, particularly the interaction between the pond and river. The dense contour patterns near the river indicated the additional water supply from the artificial recharge pond where the piezometric head declined from 5 m a.s.l. to 1.5 m a.s.l. The observation of the pond-aquifer interactions in layer 2 was presented in Fig. 10. The local aquifer at the northern side of the river was continuously influenced by the artificial recharge pond without any interruption. It was noticed that the dry cells (DC) and flood cells (FC) were observed locally in the model area. The DC in Fig. 8 indicated the lower ground elevation in that particular location than the top elevation of layer 1. It was confirmed that the place was a hilly area with the crest of 30 m a.s.l. The DC zone was shown in the satellite image of Fig. 11; therefore, further investigation of this area would be necessary for the detailed geology and stratigraphy. The FC1 indicated the piezometric head above the ground elevation. It was a confirmation of a wetland area i.e. Paya Indah Wetland. Several artesian wells were found in the area according to a

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report from an officer in the Department of Minerals and Geoscience. Therefore, it was an important fact to confirm the success of the calibrated model. However, more investigations should be proposed to raise the high reliability of the results of the model. The FC2 specified another location where the piezometric head was higher than the ground elevation; however, further investigation to confirm the existing of spring or reclaimed land is necessary. The FC3 in Figs. 8 and 9 indicated the pond water elevation was above the ground elevation. Therefore, the precise topographic data input was essential to eliminate this particular matter.

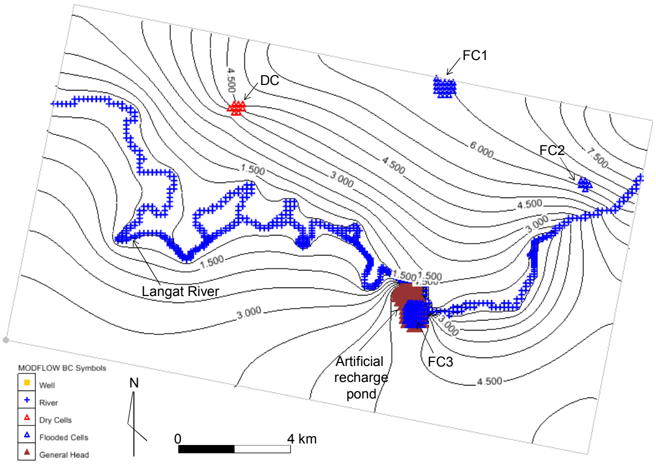

Fig. 8 Piezometric head in the aquifer with a condition of artificial recharge pond without pumping (0.5 m interval and m a.s.l. of unit of contour line)

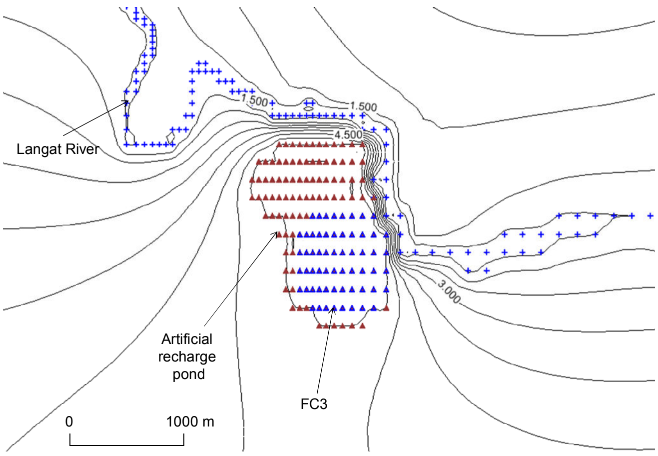

Fig. 9 Close-up of the piezometric head around the recharge pond in layer 1 (0.5 m interval of contour line)

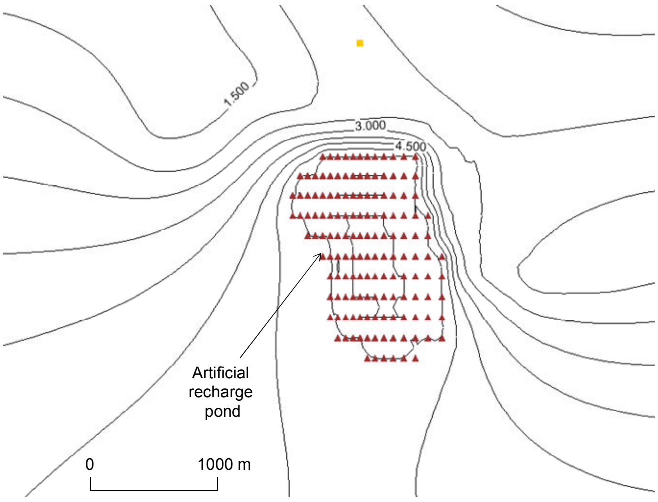

Fig. 10 Close-up of piezometric head around the recharge pond in layer 2 (0.5 m interval of contour line)

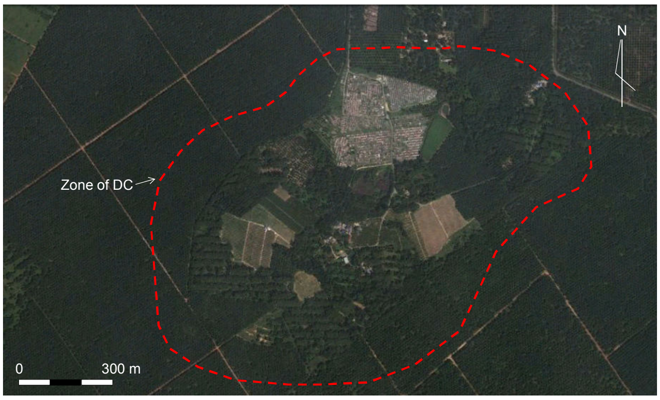

Fig. 11 The satellite image of the zone of DC

The water budget in the aquifer was summarized in Table V which included the total inflow and outflow. Three main components of inflow were the artificial recharge pond, river, and recharge rate from precipitation. The artificial recharge pond contributed approximately 90,916m^3/d, the river about 1,173m^3/d, and the recharge around 67,424m^3/d, into the aquifer. In contrast, the total outflow from the aquifer system was from the artificial recharge pond and river. The flux from the pond was very small, approximately 219m^3/d, compared to its portion of inflow. The flow rate from the river was around 159.51 m^3/d.

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TABLE V
WATER BUDGET IN THE AQUIFER SYSTEM IN CASE OF THE ARTIFICIAL RECHARGE POND WITHOUT PUMPING

Water budget	Flow (m^3/d)
Flow in:	
Artificial recharge pond	90,916.211
River	1,173.278
Wells	0.0
Recharge	67,423.935
Total IN	159,513.423
Flow out:	
Artificial recharge pond	219.663
River	159,292.136
Wells	0.0
Recharge	0.0
Total OUT	159,511.799

2. Artificial Recharge Pond with Pumping

The alteration of the aquifer behavior was observed in another case in which the calibrated model included the artificial recharge pond and pumping wells of the company. The total pumping rate was 18,900m^3/d (among three production wells). It was assumed that the wells fully penetrated only in layer 2. As a result, the patterns of the groundwater changed much around the pumping wells. The drawdown could be identified, and the lowest piezometric head was -3 m a.s.l. The FC1 zone in Fig. 12 reduced its size compared to the previous case. It indicated a drop of the piezometric head to approximately 0.5 m in depth in the area. Fig. 13 illustrated the river-aquifer interaction due to the pumping in layer 1 where the river water was forced to drain into the aquifer. It could be observed from the decline in the contour lines of the piezometric head. At the same time, the artificial recharge pond supplied much water to the river. Therefore, the impact of pumping activity to the pond was not significant in layer 1 due to the river barrier. However, the continuous flow declining from the artificial recharge pond toward the pumping wells indicated the substantial flow exchange. The outflow from the pond contributed much to the pumping rate. The piezometric head steeply declined from 5 m a.s.l. of pond surface water level to -3 m a.s.l. of the deepest elevation in the pumping zone (Fig. 14).

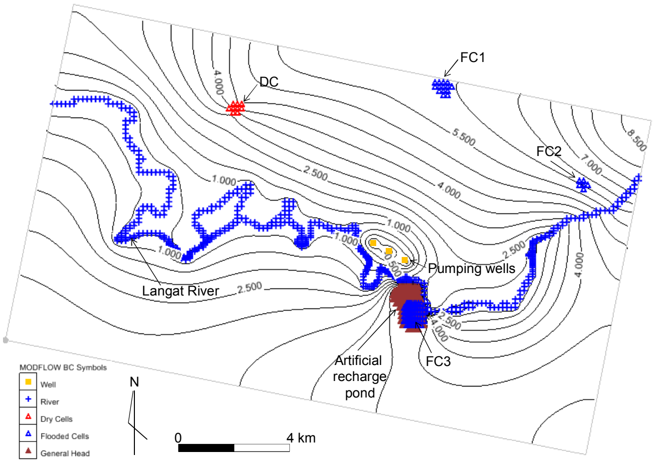

Fig. 12 Piezometric head when the artificial recharge pond with pumping (0.5 m interval and m a.s.l. of unit of contour line)

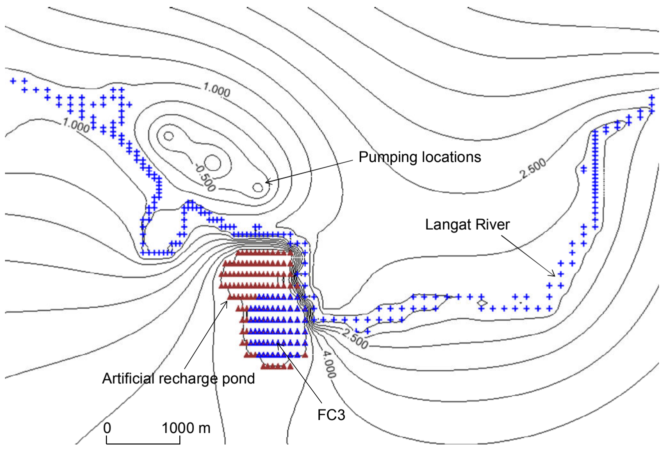

Fig. 13 Close-up of the piezometric head around the recharge pond and pumping locations in layer 1 (0.5 m interval of contour line)

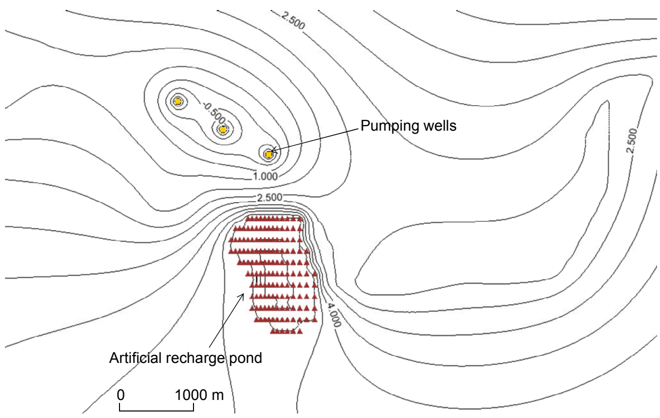

Fig. 14 Close-up of the piezometric head around the recharge pond and pumping wells in layer 2 (0.5 m interval of contour line)

The flow processes explained above could be quantified through the water budget in Table VI. The flux from the artificial recharge pond supplied approximately 92,493 m^3/d of water into the aquifer system. Similarly, the river provided around 3,881 m^3/d of the additional discharge to the

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subsurface. The direct recharge from precipitation contributed around 67,424m^3/d to the groundwater in the model area.

TABLE VI
WATER BUDGET IN THE AQUIFER SYSTEM IN CASE OF THE ARTIFICIAL RECHARGE POND WITH PUMPING

Water budget	Flow (m^3/d)
Flow in:	
Artificial recharge pond	92,493.155
River	3,881.338
Wells	0.0
Recharge	67,423.935
Total IN	163,798.427
Flow out:	
Artificial recharge pond	219.417
River	144,677.292
Wells	18,900.0
Recharge	0.0
Total OUT	163,796.708

On the other hand, the outflow of the aquifer was from the artificial recharge pond (219 m^3/d), river (144,677 m^3/d), and wells (18,900 m^3/d). Compared to the case of no pumping, it could be concluded that the additional flux from the artificial recharge pond and river reached approximately 4,285 m^3/d during the pumping process.

VI. CONCLUSION

The heavy groundwater abstraction and artificial recharge pond could alter the flow dynamics in the aquifer system. A proper methodology to handle the problem is indispensable to solving the environmental issue. The current paper is aimed at studying the impacts of the pumping activities and artificial recharge pond to the subsurface environment. The 3D numerical simulation was applied in GMS through the conceptual model representing the natural condition. The model results were calibrated by using four observation wells to achieve the error target. The accepted interval error was confirmed by the statistical analysis i.e. the RMSE was approximately 0.7m. The calibrated simulation was adapted to model with the effect of artificial recharge pond without pumping (case 1) and pumping (case 2). The results in case 1 showed that the river was influenced by the pond, specifically in layer 1 of aquifer. The aquifer of layer 2 continuously gained the water from the pond without any interruption. The inflow into the aquifer system from the artificial recharge pond, river, and natural recharge from precipitation were around 90,916 m^3/d, 1,173m^3/d, and 67,424m^3/d respectively. The results in case 2 demonstrated the decrease of the number of flooded cells representing the wetland i.e. Paya Indah Wetland. The drop of the piezometric head in this area was 0.5 m in depth. The drawdown could be observed around the pumping wells where the lowest head was -3 m a.s.l. In layer 1, the river water flowed into the aquifer system, especially into the pumping area. A portion of the pumping rate was from the pond in layer 2. The flow budget for case 2 could be summarized as follows: the inflow from the pond, river, and natural recharge were approximately 92,493m^3/d, 3,881m^3/d, and 67,424m^3/d respectively. If a comparison between the pumping and no pumping states was made, the total additional inflow from the pond and river of around 4,285m^3/d could be achieved. To sum up, the calibrated model successfully demonstrated the impacts from the artificial recharge pond and pumping activities to the aquifer system. The simulation results could be an important tool to prepare for future groundwater management projects within the study area.

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