# Groundwater Model as a Tool for Sustainable Groundwater Management

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**Abstract:** Groundwater could be regarded as a vital water resource due to its high quality and perennial availability. However, lack of sustainable approach in groundwater management has induced a negative impact as evidenced by falling water tables, drying wetlands, increasing sea-water intrusion and deterioration of water quality. As groundwater cannot be renewed artificially on a large scale, sustainable management of this resource is vital. A number of scientific tools was applied for a number of applications such as assisting stakeholder in making decision, groundwater flow model, particle tracking and many more. In this paper, Semarang Urban Area case study will be used as example in illustrates the uses of groundwater modeling in achieving sustainable groundwater management. Three scenarios will be used to demonstrate the application of groundwater flow such as (i) interaction between surface water and groundwater, (ii) groundwater abstraction, and (iii) seawater intrusion. All the scenarios discussed with the aim to promote the advantages of groundwater modeling.

**Keywords:** groundwater modeling, aquifer characteristics, groundwater flow, urban recharge.

## 1. Introduction

Groundwater is one of the most widely distributed and important water resources which contribute about 20% of total fresh water in the world. Groundwater is suitable to be consumed as drinking water due to its quality and quantity but the importance of groundwater to the nation is not fully appreciated. Groundwater is more widely and easily available than surface water, and most groundwater is unpolluted and relatively safe from pollution. Apart from that, it is also cheaper compared to treated surface water. However, due to poor management, degradations of water quality and its quantity are the main problems many big cities [4, 5]. The growing population, excessive groundwater pumping, and poor sanitation of domestic sewage were the main factors contributing to these problems. In order to keep groundwater is sufficient as a drinking water and/or other purposes the groundwater management has to be implemented in a proper ways to protect this resource. However, groundwater is very complicated system which made it not really easy to manage. Groundwater is situated in subsurface layer that are known for its differences in properties from one place to another place [6, 11].

Many kinds of groundwater management have been implemented to manage the groundwater. Rapid development in computer technology is a very good opportunity in developing a groundwater model which can be a powerful tool to manage groundwater wisely. Ground water models are representative of reality and can be used to complement monitoring and laboratory studies in evaluating and forecasting groundwater flow system and mass transport [1, 7]. The groundwater result from the model simulation is expected to be a helpful data to support the groundwater management in this area.

This paper will show several applications of groundwater model with some assumptions and limitations because it is very difficult to simulate the subsurface condition accurately. Thus, the main objectives of this study are to share the advantages using computer software in modeling the groundwater problems. Secondly to promote the using of the groundwater model in assisting the decision maker in making their decision and last but not the least several scenarios will be used as an example to visualize the real application at the Semarang basin.

## 2. Research Methodologies

### 2.1 Study Area

Semarang city is located in the Central Java and it is also the capital city of Central Java. The population of this city has significantly increased from 503,780 people (1990) to approximately 1,450,000 people in (2005) [2]. The increases of the population in this city mostly due to the migration of the people from the country side to the city. As a result, the water demand in this city has increased proportionally with the increment of population. Surface water is the main source of the water supply in this city, however, due to high demand groundwater has been utilized as additional water to

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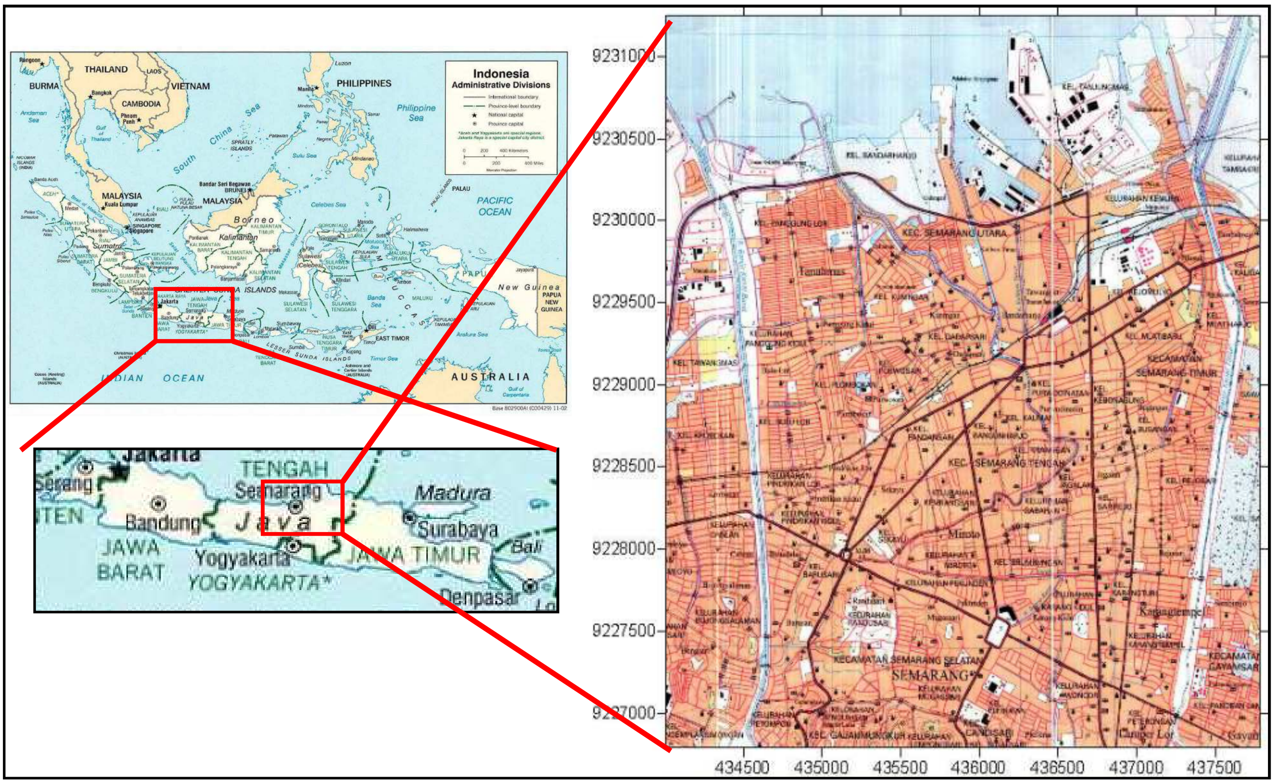



Fig. 1 Map of Study Area. *(Source of maps from Coordinate Survey and National Survey & Library of Texas University).*

support the water demand in this city. This situation has led to increases of pumping activities and poor management of pumping activities could lead to serious groundwater depletion.

The hydrogeological boundary of this study area is limited by Banjir Kanal Timur River on the east, Banjir Kanal Barat River on the west, Java Sea on the North, and at the border of different morphology on the south which also act as the boundary of the model area (Fig. 1). The research area located in the range between 922500m - 923300m North and 433500m – 438500m east. The study area also limited by the administrative border as follows:

- Semarang Utara on the north.
- Semarang Timur on the east.
- Semarang Barat on the west.
- Semarang Selatan on the south.

## 2.2 Investigation of Hydrogeological Conditions

The hydrogeological investigation of the study area was based on the following: (1) new data, including groundwater level measurements for the period 2006–2007 and pumping tests; and (2) existing hydrogeological data from previous studies. Marsudi [8] has study the effect of groundwater exploitation and additional loading on the embankment area in Semarang. Sihwanto et al. [12] has attempted to delineate the location of water resources for drinking water to support the water demand in Semarang. While, Pattikawa [10] has investigated the local condition of the Semarang basin (aquifer) and compare the result from borehole data to obtain a clear understanding of subsurface conditions. Moreover, extensive study of groundwater configuration and groundwater usage in Semarang-Demak, Subah and Karanganyar Boyolali Basin Central Java Province were executed by the Environmental Geology and Mining Area Directory [3] to evaluate the groundwater potential, aquifer configuration, aquifer parameter, land movement, land subsidence, recharge and pumping proses, and quality of groundwater at three different basins. Alpin Consult & P.T. Income has concluded a very important study in determining several important parameters such as transmissivity (T), hydraulic conductivity (K) and storativity (S). From their study, the young volcanic aquifer has the T value range 1- $4.10^{-3}$ $m^2$/s, K ranges 1- $4.10^{-5}$ m/s and S value varies from 1- $2.10^{-3}$.

A-time dependent and a time-independent head controlled boundary with a known potential or hydraulic head were used for the calculation. The southern boundary was set to be the head controlled boundary, the groundwater elevations of which were assumed to be time independent. Groundwater table elevations at the south boundaries were interpolated from observation well which assumed to be 0.5 m. The river reach located at the east and west were treated as head controlled boundary where the water elevations at these two rivers were time dependent. These boundary conditions are depends on the observation wells located scattered along these two river reach. In addition, when the calculated groundwater elevation exceeded the groundwater surface during the computation, it was set equal to the ground surface [13].

While the north boundary was treat as head independent flux boundary.

## 2.3 Groundwater Modelling

Darcy's Law was established by Henry Darcy based on the experimental study flow of water through sand as a medium [13]. In order to generate the flow equation in porous media, a relation between the groundwater velocity and hydraulic gradient are needed. The relationship is shown in Equation 1:

$$Q \alpha \Delta h \quad , \quad Q \alpha \frac{1}{\Delta s} \tag{1}$$

by introducing a proportionality constant K, the equation become

$$Q = -kA\frac{h_2 - h_1}{\Delta s} \quad = -kA\frac{\Delta h}{\Delta s} \tag{2}$$

The discharge velocity can be expressed as

$$q = \frac{Q}{A} = -K\frac{dh}{ds} = -Ki \tag{3}$$

where:

$q$ : Darcy flux or specific discharge in [L/T]
$K$ : hydraulic conductivity in [L/T]
$\Delta h$ : head difference in [L]
$\Delta s$ : length in [L]
$i$ : hydraulic gradient

Darcy has stated that the discharge velocity is proportional to the hydraulic gradient. Since the laminar flow is proportional to the hydraulic gradient. So, it can be inferred that the flow in porous media must be laminar for the Darcy's Law to be valid. Yet, hydraulic conductivity $K$ depends on other parameters such as the permeability of the porous media, physical properties of the fluid, density, and dynamic viscosity or kinematics viscosity, the general Darcy's law becomes:

$$q_i = -\frac{k_{ij}}{\mu}\left(\frac{\partial p}{\partial x_j} + \rho g \delta_j\right) \tag{4}$$

### 2.3.1 Conservation equation of mass:

The governing equations of groundwater flow in aquifer in all conditions whether homogeneous or heterogeneous aquifer by applying the conversation of mass principle. The principle is applied to the finite difference cell. The finite difference mathematical approach related specifically to the widely used groundwater flow modeling code [9]. According to this principle, the sum of inflow and outflow into the cell must be equal to the rate of change in storage within the cell. By assuming that the density of groundwater is constant, application of the conservation of mass principle for time period's $\Delta$ t for a cell gives;

$$-\nabla q - W = Ss\frac{\partial h}{\partial t} \tag{5}$$

With referred to Spitz and Moreno [13], the $\nabla$ is the gradient operator,

$$\nabla = \frac{\partial}{\partial x}i + \frac{\partial}{\partial y}j + \frac{\partial}{\partial z}k \tag{6}$$

in which *i, j, k* are represent in the *x, y, z* direction respectively. As a result, with the assumption that the density of water $\rho$ is constant, by substituting Equation 6 into Equation 5 the following equation can be written

$$\frac{\delta}{\delta x}\left(K_{xx}\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right) - W = 0 \tag{7}$$

where:

$K_{xx}$, $K_{yy}$, $K_{zz}$ : values of hydraulic conductivity in the x, y, z direction along Cartesian coordinate axes, which are assumed to align with principal direction of hydraulic conductivity.
$H$ : hydraulic head in [L]
$T$ : time [T]

Equation 7 describes the distribution of hydraulic head and flow throughout a continuous region. This equation is continuous in space and time, and generally cannot be solved analytically for practical applications involving complex system. This equation is called conservation of mass principle or generalization of Darcy's law [13].

## 2.3 Application of Groundwater Model

To demonstrate the effects of human activities to the groundwater in the study area, several scenarios were conducted to illustrate and simulate the model based on selected scenarios (Table 1). Three scenarios as follows:

i. Scenario 1: To determine the hydraulic interaction between the groundwater and surface water by calculating the water balance in this area and analyzing a water table fluctuation. Then, groundwater balance and water storage within the study area were determined.
ii. Scenario II: To simulate the effects of groundwater abstraction. Twenty additional pumping wells were placed scatter within the study area with the rates of 250 $m^3$/day.
iii. Scenario III: To simulate the sea water intrusion by assuming the particle tracking as the sources of saline water by placing the particle on the north side of the border of the sea and the land. Twenty pumping wells were placed scatter within the study area with the rates of 250 $m^3$/day.

Table 1 The parameters input for each scenarios

| Parameters | Scenario I | Scenario II | Scenario III |
|---|---|---|---|
| Pumping rate ($m^3$/day) | 250 | 250 | 250 |
| Particle tracking (day) | - | - | 1095 |
| Recharge (mm/a) | 550 | 550 | 550 |
| Number of pumping well | 20 | 20 | 20 |
| **GOALS** | **Water balance assessment** | **Water table drawdown** | **Sea water Intrusion** |

## 3. Results and Discussion

### 3.1 Morphology

The morphology of Semarang catchment can be divided into five types (Fig. 2). The study area is located at the flat plain area which is also known as alluvial plain. The lithology of alluvial deposit consists of river deposit, marine deposit, and the delta deposit which overlay and interfingering each other's. The process of sedimentation that continuously happened will caused the border between the sea and land to move further to the sea. According to Marsudi [8], the sea border between sea and land will propagate 4-6m per year as a resulted from the sedimentation process. The borelog data have shown that the existence of a shell and other small creature where life in the sea in the lithology units. This finding revealed that the possibility of the border between sea and land is located around this area. On the other hands, it is also indicated that the process of sedimentation of alluvium deposits in this area is influenced by the tidal rise.

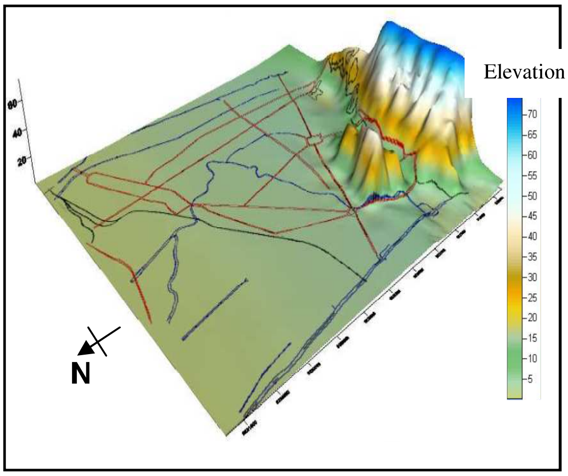



Fig. 2 Morphology condition in study area

The elevation varies from 0-75m from the sea level. However, the average values are ranging between 0-8m which increases from the north to the south with the inclination of slope between 0-5 percent (0-3°). At the southern part, the elevation is higher due to difference in morphology (flat plain area to the hilly area). Lithology at the southern area is quite difference with the lithology at the northern part, where, the lithology of this area consists of coarse sand, lenses of clay, and breccias which derived from Damar Formation.

The stratigraphy of the study area was defined from the bore log data which is based on Magelang-Semarang Geological Map sheets Thanden et al. [14]. Most of the study area is composed of alluvium deposits which forms a coastal plain, river and lake deposit which is connected by interfingering with each other to form this deposit. River deposits are composed of sand, pebbles, gravel, and sandstone. The thickness of the deposits ranges between 1-3m. While for coastal deposits, it consists of sand, silt, and clay with the thickness of this deposit varies from 0-30m according to the location of deposit, where, it becomes thicker as it closer to the north. At the southern part, the breccias can be found at the depth of 40 m while to the north there are no present of breccias in this area (Fig. 3). From the correlation result, it shows that the grain size changing from the south to the north, where, at the southern part the grain size is bigger than the grain size at the north.

### 3.2 Aquifer System

The type of aquifer system that's being modeled is unconfined aquifer which consists of sand, sandy clay, silt, lenses of clay, and breccias. Groundwater flowing from the south to the north coincide with the hydraulic gradient which getting smaller to the north. To generate the initial condition of water table in the study area and to prove that the groundwater is flowing from the south to north, groundwater table measurements are needed.

To determine the geometry of the aquifer accurately is very difficult due to lack of data and also the location of borehole spreading outspread. Fig. 3 shows the hydrogeology of study area, which is dominated by the sediment sand, sandy clay, silt and lenses of clay. However in some part of the southern part, breccia was found. Breccia was assumed as the basement of unconfined aquifer at the southern part. According to Sihwanto et al. [12], the depths of the confined aquifer range from 30m to 90 m on the west (Bulu and Kalibanteng area) while on the east side (Tambak – Lorok area) the depth more than 90m. By referring to previous studies and the correlation between the existing boreholes, the bottom aquifer in the study area approximately ranges from 30m to 40m.

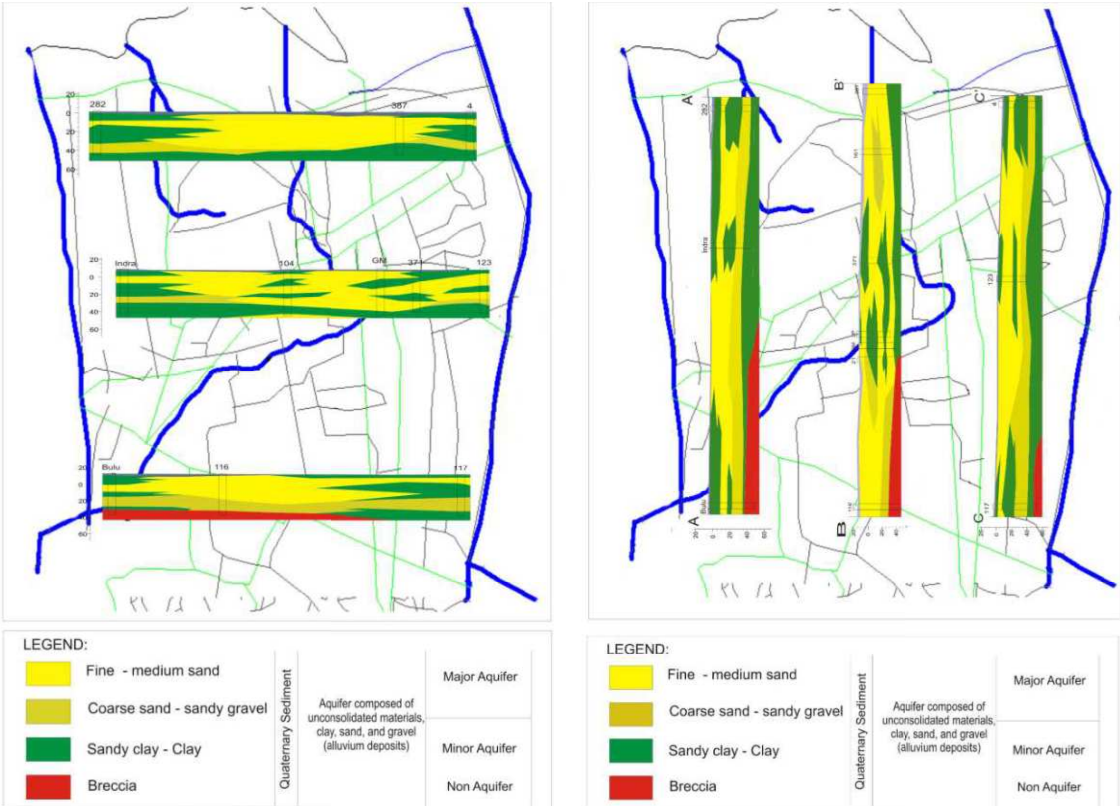



Fig. 3 Hydrogeological Fence Diagram of the Study Area

Hydraulic conductivity map was created using the K value which derived from the mathematical calculation. The calculations of K values are based on the Equation 8. Hydraulic conductivity value (K) based on grain size [12]. The calculated hydraulic conductivity (K) values show a small difference with the reported values in the previous report. This indicated that the calculated value ranges from 0.864 – 7.78 m/day is acceptable. Table 2 shows the value of K for each bore log. The calculated hydraulic conductivity for average value for each well log was derived by using the following formula:

$$K = \frac{\left(K_1 b_1 + K_2 b_2 + K_3 b_3 + \ldots + K_n b_n\right)}{b_1 + b_2 + b_3 + \ldots + b_n} \qquad (8)$$

where;

K= hydraulic conductivity from the chart (m/day)

b= thickness of each lithology (m)

Based on the values in Table 2 the map of K was generated (Fig. 4). From the generated K map, the values of hydraulic conductivity are getting smaller towards the north. Based on the report from the Department of Mining and Energy, the value of hydraulic conductivity (K) and transmissivity (T) for unconfined aquifers varies depend on the types of deposit. The aquifer in the study area consists of alluvium deposit, the value of K, T and Q varies from 2.2-7.2 m/day, 2.89-7.16 $m^2$/day, and 2.37-9.51 $m^3$/day/m respectively.

Table 2 Hydraulic conductivity value (K) in the study area.

| Location | K value (m/day) |
|---|---|
| 387 | 0.442 |
| 161 | 0.367 |
| 371 | 0.097 |
| 21 | 4.259 |
| 116 | 1.961 |
| 123 | 0.881 |
| 104 | 4.242 |
| 117 | 3.931 |
| GM | 1.555 |
| JP | 1.331 |
| Bulu | 3.983 |
| 282 | 0.351 |
| 4 | 0.528 |
| Indraprasta | 0.976 |

## 3.2 Groundwater Flow Pattern

Being the most important parameters in generating the initial conditions of groundwater flow pattern in this area, seventy dug well have been measured. Beside the water table measurement, several others parameters have been recorded as well such as pH, TDS, EC and coordinate of well. The elevation data has been extracted from the GPS as well on site measurement. The elevation level is so indispensable to utilize as a surface elevation to calculate the elevation of water table.

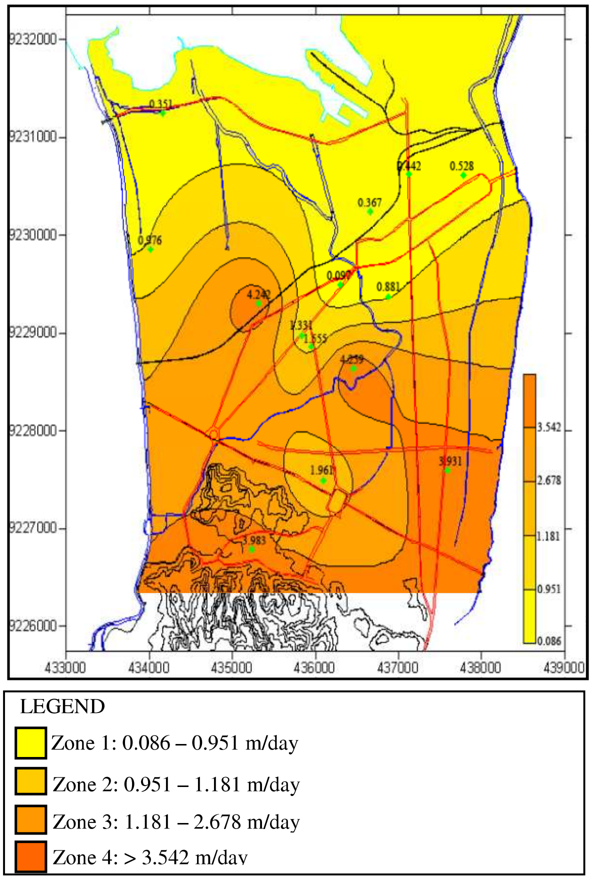



Fig. 4 Hydraulic Conductivity Zone.

Response to that problem, the digital topography map 1:10000 from geodesy department has been used as a solution to this problem to acquire the ground surface of each dug well.

Seventy dug well have been measured within the area to generate the contour map of the water table. Measurement of water table is wide spread in the model area, where the lowest water table was recorded in the northern part (0.1m) while the highest water table was recorded in the southern part (4.5m). This finding prove that, the groundwater has flow from the south to the north (Fig. 5). The depths of groundwater table generally control by the local topography differences. Therefore, higher elevation areas locally have a deeper groundwater table than the lower area. Normally, groundwater flow from high elevation to the lowest elevation or on the other word, groundwater flows from high hydraulic head to low hydraulic head.

### 3.2.1 Scenario 1 (Interaction between groundwater and surface water)

Fig. 6 shows the calculated water level within the study area. The highest water level (4.5m) was recorded in the southern part of the study area while the low water table (0.1m) was recorded at the northern part. Within the study area, two types of stream where identified; gaining stream and losing stream.

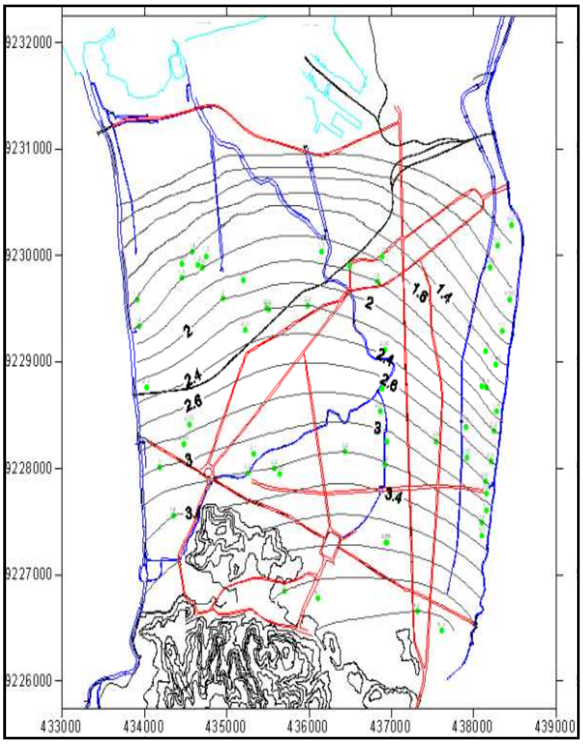


Fig. 5 Observed Groundwater Flow Pattern (Sept 2006 – Oct 2007)

*Before pumping activities:* Fig. 7(a) shows the cross section from AA'. Both rivers Banjir Kanal Barat and Banjir Kanal Timur have the same type of stream; both are gaining steam. From the calculated water balance, the discharge volume of groundwater to the river is 0.3435 $m^3$/day. For Banjir Kanal Barat River, the groundwater discharge from the aquifer to the river is 0.1345 $m^3$/day, while for Banjir Kanal Timur River the discharge is 0.2290$m^3$/day. Meanwhile, in Fig. 7(b) shows the cross section from BB'.

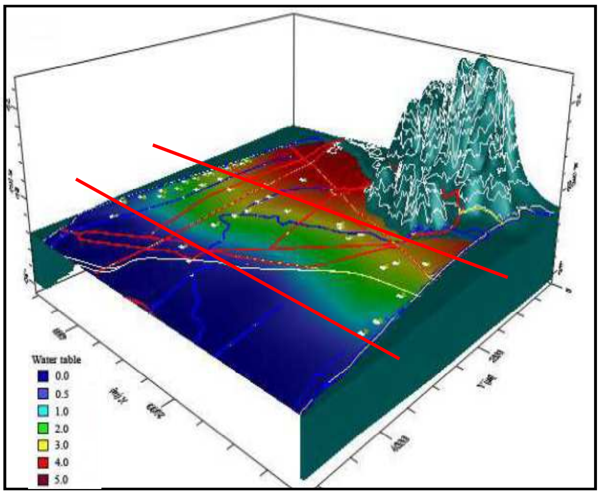
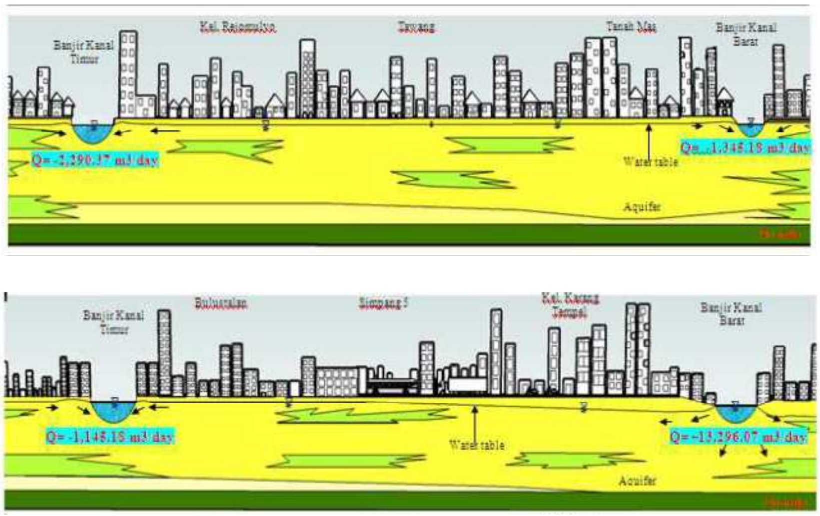


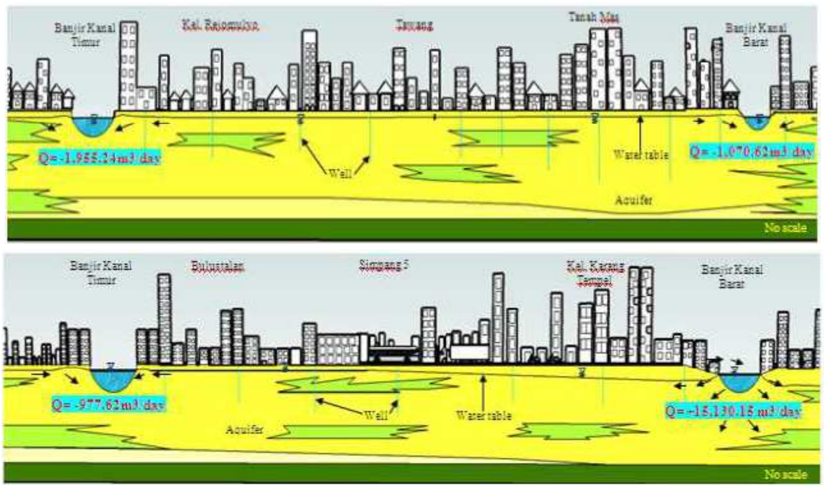

Fig. 6 Calculated water level in Semarang Urban Area.




(a)

(b)

Fig. 7 The illustration of surface water and groundwater interaction **before** groundwater abstraction activities




(a)

(b)

Fig. 8 The illustration of surface water and groundwater interaction **after** groundwater abstraction activities

This figure shows that the Banjir Kanal Barat and Banjir Kanal Timur rivers have different types of stream. For Banjir Kanal Timur River, the stream is gaining stream, while for Banjir Kanal Barat River type is losing stream.

*After pumping activities:* Fig. 8(a) shows the cross section from AA'. Based on the calculated water balance from the model, the discharge volume of groundwater to the river is 0.2932 $m^3$/day. This indicated that the groundwater supply the water to the river. For Banjir Kanal Barat River, the groundwater discharge from the aquifer to the river is 0.1070$m^3$/day, while for Banjir Kanal Timur River the discharge is 0.1955$m^3$/day. Meanwhile, in Fig. 8(b) shows the cross section from BB'.

The changing of the river type has been identified by groundwater flow pattern and also the elevation of the water table. In this area, the groundwater table a little bit lower than the river water level which caused the water from the river flowing out to the aquifer (groundwater). On the other hand, it can be concluded that the river has supplied the water to the groundwater. The volumes of river water leakage to the aquifer are 1.513 $m^3$/day. Kollet and Maxwell [15] in their study also concluded that the interaction between surface and groundwater are a key component of the hydrologic budget on the watershed scale.

## 3.2.2 Scenario 2 (Groundwater abstraction)

The impacts of groundwater over abstraction and water level declines have been reported widely within the study area for the last couple years [2, 3, 8, 15]. It is sufficient to note that over abstraction of groundwater could lead to a wide array of social, economics, and environmental consequences such as critical changes in groundwater flow patterns to and from adjacent aquifer systems [20].

Figure 9 shows the condition of groundwater table before groundwater abstraction activities were applied onto the aquifer system. With the increasing of population, the water demand will be increased. Due to the lack of water supply from the local government or water consortium who manages the water supply in this area (PDAM Semarang), the people tend to construct their own well to fulfill their needs. Marsudi [8] has mentioned that the land in the Semarang Urban area will be subside more or less 0.3m per year either caused by the decreasing of the water table or less soil compacted.

In order to minimize and mitigate the effects from groundwater abstraction, the local government should imply the groundwater regulation in this area by limited the pumping rate of each installed wells and set up the distance between one well to another well to prevent the lowering of groundwater too drastically.

To simulate the effects of groundwater abstraction on the groundwater system in this area, 20 pumping well were installed with the pumping rate of 250m$^3$/day for each pump. Fig. 9(a) and Fig. 9(b) show the groundwater table elevation conditions before and after groundwater abstraction in the study area. These two figures clearly show that, the differences of groundwater table elevation before and after groundwater abstraction activities. With the simulated result, the groundwater table has drop range between 0.3 – 1.65 m depends on the locations.

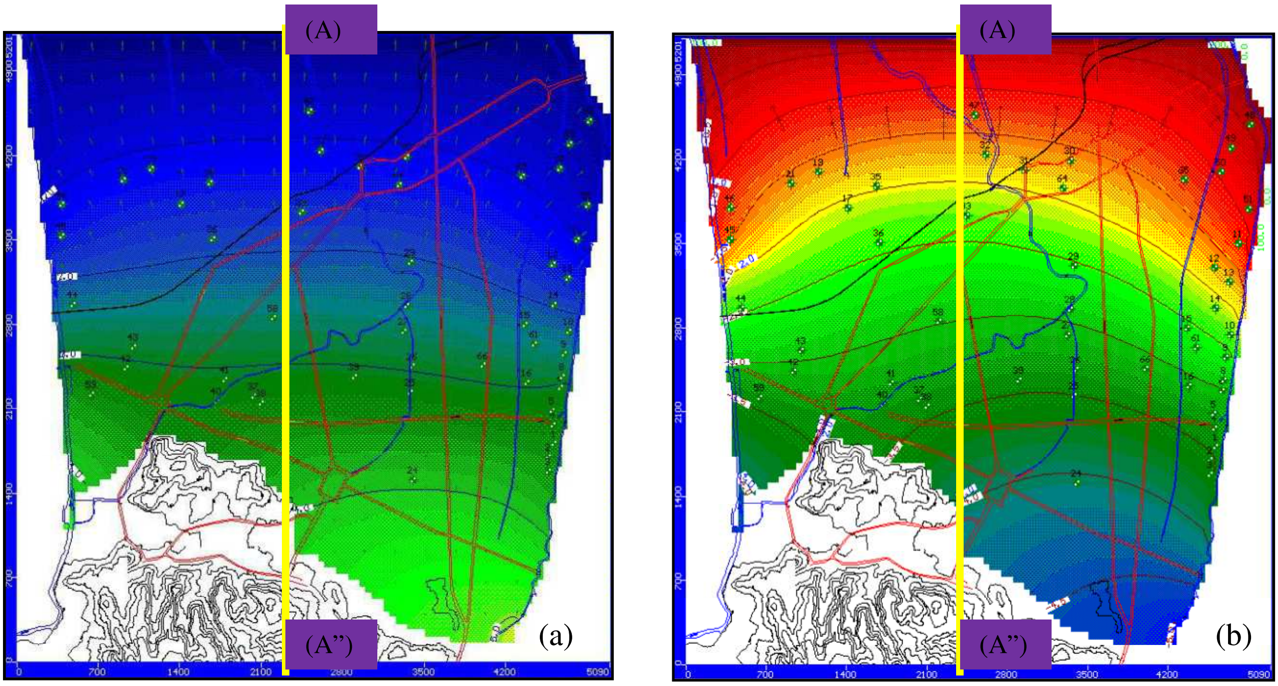



Fig. 9 Groundwater table elevation before and after groundwater abstraction activities.

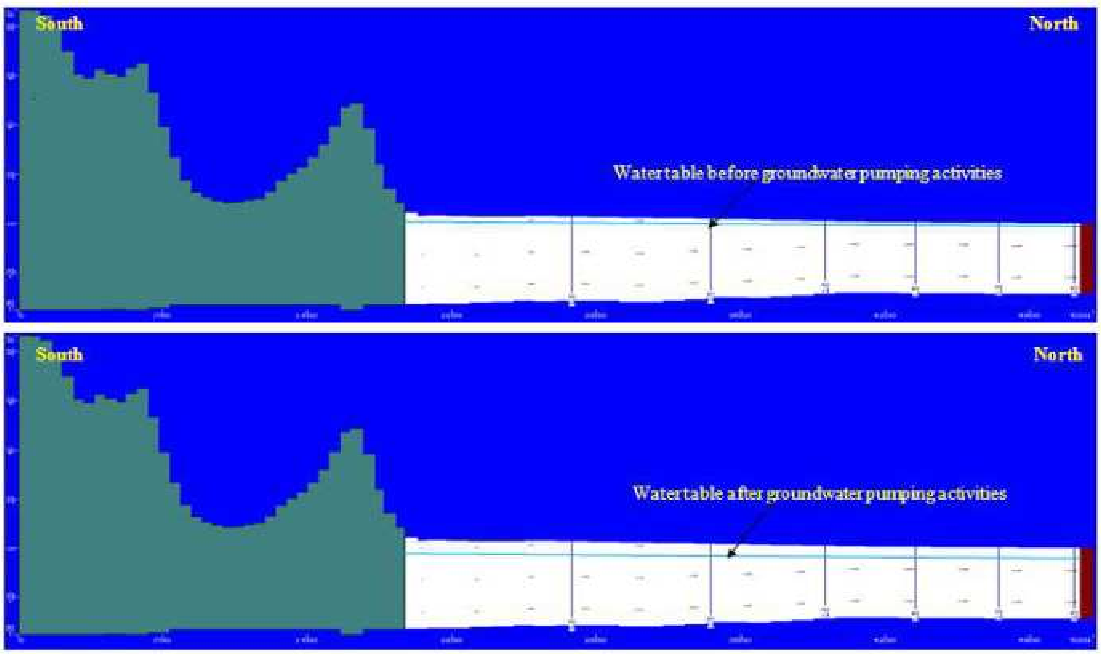



Fig. 10: Groundwater table elevation before and after groundwater abstraction activities (cross section A-A')

### 3.2.3 Scenario 3 (Sea water Intrusion)

Being located close to the sea has made this area is vulnerable to sea water intrusion if there is no monitoring and controlling activities were carried out to manage the groundwater in this area. The sea water intrusion occurred when the volume of fresh water is lesser than the saline water. Due to the small volume of fresh water, the saline water will push the fresh water and make the interface line will move towards the fresh water. When this condition occurred, it will polluted the fresh water by changing the freshwater to brackish water, which made this water is no longer suitable to be consumed as a drinking water [16-19].

By using groundwater model, assuming the particle tracking as the sources (in this case saline water), simulations were carried out to estimate how far the saline water was intrude into the fresh water within a specific time. In this simulation, the particle were placed at the upper part (north) of the study area. Fig. 11(a) and Fig. 11(b) show the result of particle tracking travel within 1 year and 3 years respectively. This result clearly shows that the area is very vulnerable to seawater intrusion. The extensions of area contaminated by the sea water intrusion depended on the pumping rate and the locations of pumping wells.

In addition, from the measurement of the TDS in this area, the initial sea water intrusion border in this area already reaches Tawang, Jalan Pemuda, and the adjacent area around 1 km from the Java Sea. When the sea water intrudes onto the land, it has not only polluted the fresh water which makes the water not suitable for drinking water, but also give a bad effect to construction activities where the steel was used for the foundation can be easily eroded [18]. Additionally, Fig. 11(a) shows the depth of the particle tracking within 1 year where the groundwater abstraction activities continuously applied in this area, the depth of sea water intrusion already reach until -8 m below the land surface. This interface will move further if the volume of fresh water is lesser compared with the volume of saline water. This phenomenon also related to the density of seawater which denser than fresh water makes this water have more strength to push the interface.

While, Fig. 11(b) shows the depth of the particle tracking within 3 years where the groundwater abstraction activities continuously applied in this area, the depth of sea water intrusion already reaches to -16 m below the land surface. This interface will move further if the volume of fresh water is lesser compared with the volume of saline water. This phenomenon also related to the density of seawater which denser than fresh water makes this water have more strength to push the interface.

By referring to Fig. 11(a) and Fig. 11(b), the distance of particle movement within 3 years was intruded more than Tawang area. This result inferred that, the movements of particle tracking from 1-3 year are around 0–500 meter. This finding can be very useful information for local government to control and/or to stop this phenomenon. If there is no groundwater management implied to mitigate this phenomenon, it is causes negative impacts to the groundwater system in this area.

## 3.3 Parameter Sensitivity Analysis (PSA)

After the modeling process, the calibration stage was carried out to determine the model result can be accepted or not. From the model result, the results are still not satisfied to be used as a final product. Responding to this problem, the parameter sensitivity analyses were conducted. The purpose of a parameter sensitivity analysis is to find the best and acceptable input parameters which can be used as a representation of real condition in the field. However, the model response to these variations of parameters must be valid as a calibrated model. The evaluated parameters are generally the parameters which give the most significant differences when the value was changed. As mentioned earlier, the most sensitive parameters are net recharge and hydraulic conductivity. However, in this paper, only hydraulic conductivity values were changed due to the ambiguities of K values, the values were obtained from the mathematical calculation instead of direct field measurement at the field. Five scenarios were set up to find the best input values and assess its impacts of each possible variation. The sensitivity analyses that were conducted are:

- PSA 1- Hydraulic conductivity value was multiplied with 10 while the recharge value remains the same as initial condition.
- PSA 2- Hydraulic conductivity value was multiplied with 100 while the recharge value remains the same as initial condition.
- PSA 3- Hydraulic conductivity value was multiplied by 1/10 while the recharge value remains the same as initial condition.
- PSA 4- Hydraulic conductivity value was multiplied by 1/100 while the recharge value remains the same as initial condition.
- PSA 5- Hydraulic conductivity value was assigned as shown in the Table 5.1, while the recharge value remains the same as initial conditions.

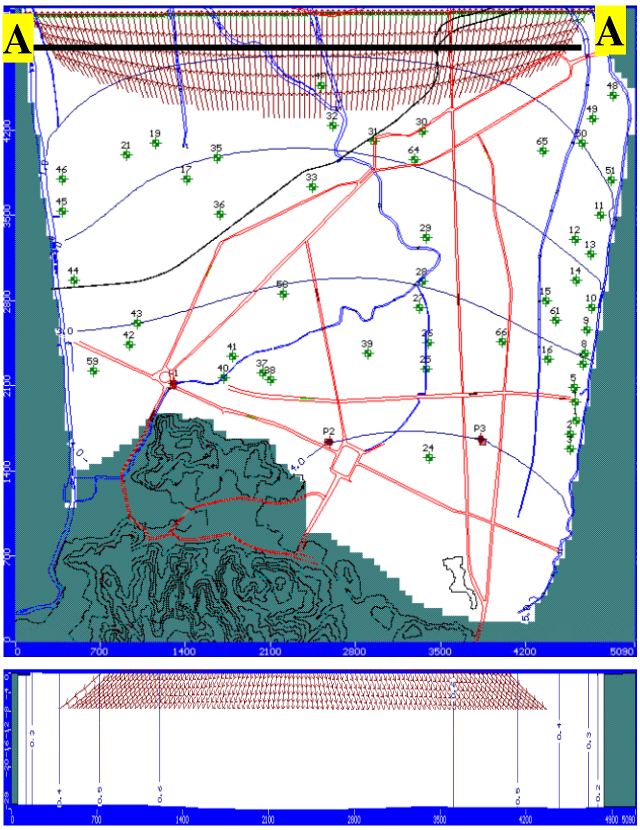


Fig. 11 (a) Simulation result for particle tracking within 1 year

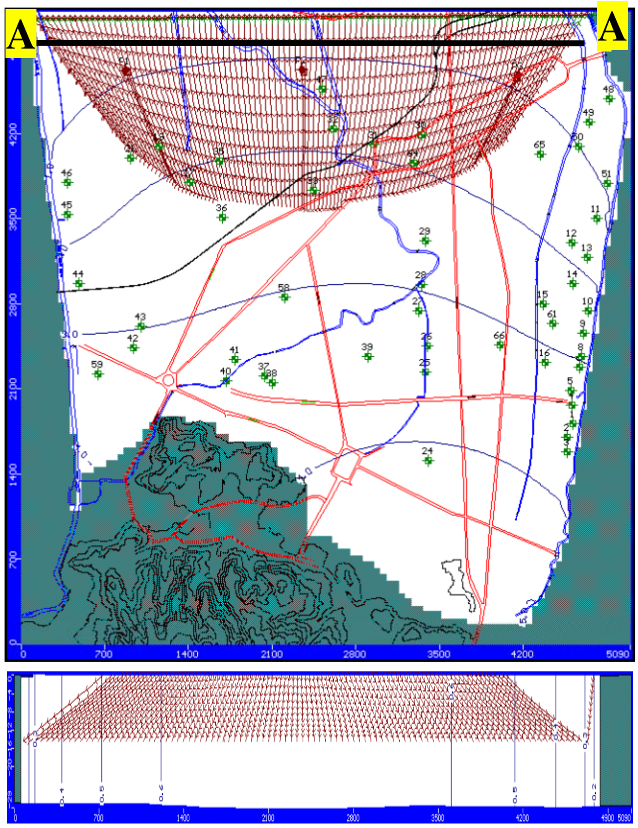


Fig. 11 (b) Simulation result for particle tracking within 3 year

Table 3 Parameter assigned in model for each PSA

| Parameter | Recharge (mm) | | Hydraulic conductivity (m/day) |
|---|---|---|---|
| | Zone 1 | Zone 2 | |
| PSA1 | 550 | 510 | $K_1$: 4.19<br>$K_2$:22.032<br>$K_3$:35.59<br>$K_4$:38.88<br>$K_5$:50.11 |
| PSA2 | 550 | 510 | $K_1$: 41.9<br>$K_2$:220.032<br>$K_3$:355.97<br>$K_4$:397.44<br>$K_5$:501.12 |
| PSA3 | 550 | 510 | $K_1$: 0.042<br>$K_2$:0.220<br>$K_3$:0.356<br>$K_4$:0.397<br>$K_5$:0.51 |
| PSA4 | 550 | 510 | $K_1$: 4.19x10$^{-3}$<br>$K_2$:0.022<br>$K_3$:0.0356<br>$K_4$:0.0397<br>$K_5$:0.050 |
| PSA5 | 550 | 510 | $K_1$: 3<br>$K_2$:4<br>$K_3$:4.5<br>$K_4$:6<br>$K_5$:7 |

**(i) PSA 1**

For the first parameter sensitivity analysis (PSA 1), the K values used as shown in Table 3, the net recharge value remain the same as the initial conditions. The model result shows that the model result still has a big error which is not acceptable to be used as calibrated model. The errors from PSA 1 are as follows; RMS error is 2.589 m and RM 2.563m. The result shows a small number of errors, but it is still cannot be used as the best result.

**(ii) PSA 2**

For the second parameter sensitivity analysis (PSA 2), the K values used as shown in Table 3, the net recharge value remain the same as the initial conditions. The model result shows that the model result is still having a big error which cannot be used as calibrated model. The errors from PSA 2 are as follows; RMS error is 5.687 m and RM 2.547 m. The result shows that the error still big, thus it cannot be used as the best result.

**(iii) PSA 3**

For the third parameter sensitivity analysis (PSA 3), the K value will assign as shown in Table 3, the net recharge value remain the same as the initial conditions. The model result shows that the model result still experiencing big errors which present the fact that it cannot be used as calibrated model. The errors from PSA 3 are as follows; RMS error is 1.056 m and RM 1.024. The result shows that the error consider small compare to

PSA1 and PSA2, but still it is not applicable to be used as the best result.

**(iv) PSA4**

For the forth parameter sensitivity analysis (PSA 4), the K values used as shown in Table 3, the net recharge value remain the same as the initial conditions. The model result shows that the model result still has a big error which cannot be used as calibrated model. The error from PSA 4 as follows; RMS error is 1.204 m and RM 1.187 m. The result shows that the error is small compare to PSA1 and PSA2 but still cannot be considered as the best result.

**(v) PSA 5**

For the fifth parameter sensitivity analysis (PSA 5), the K value will assign as shown in Table 3, the net recharge value remain the same as the initial conditions. The model result shows the small error which can be used as calibrated model. The error from PSA 6 as follows; RMS error is 0.149m and RM 0.064m. The result shows the smallest error comparisons to other PSA and this PSA5 was selected as it clearly produced the best result needed for this analysis.

### 3.3.1 Comparison between all PSA.

After all scenarios were carried out, the PSA5 has been chosen as the best result because it has the smallest error compared to the others. From the results of each PSA case, the changing of hydraulic value shows that it will give a significant or significant influenced on the model result. However, due to recharge value remain the same, the water balance in this area has not change so much. Table 4 shows the results for all scenarios.

Table 4: The errors result from each scenario.

| PSA/Error | RMS (m) | RM (m) |
|---|---|---|
| PSA 1 | 4.589 | 4.563 |
| PSA 2 | 7.687 | 7.547 |
| PSA 3 | 1.056 | 1.024 |
| PSA 4 | 1.204 | 1.187 |
| PSA 5 | 0.149 | 0.064 |

From Table 4, PSA 5 has been selected as the best parameter sensitivity analysis (PSA) because this PSA has the lowest error. The acceptance of the model result is depending on the error analysis. The smallest error that can be achieved is indicated reliability of the model result.

### 3.3.2 Model Calibration

Calibration is the process by which the independent variable parameters of a model are adjusted, within realistic limits, to produce the best match between simulated and measured data. In other words, calibration methods solve a problem inversely by adjusting the parameters until the solution matches the heads. This process involves with refining the hydrogeological framework, hydraulic properties, and boundary conditions of the model to achieve the desired degree of confidence in a model prediction. A calibration sensitivity analysis should also be undertaken to assess the relative importance of model parameter in achieving the calibration result. The trial and error is one of the processes to determine which parameter is the most sensitive.

The acceptability of a calibration process can be assessed by looking at the scatter diagram (Fig. 12). This figure shows the graphical representation of observed head and calculated heads for this study. The indication of high quality of the model result, all plotted points falls on the 45$^{o}$ straight line. This indicated that the measurement values is more or less same with the calculated value. The less scatter point in the graph shows a high quality of the result

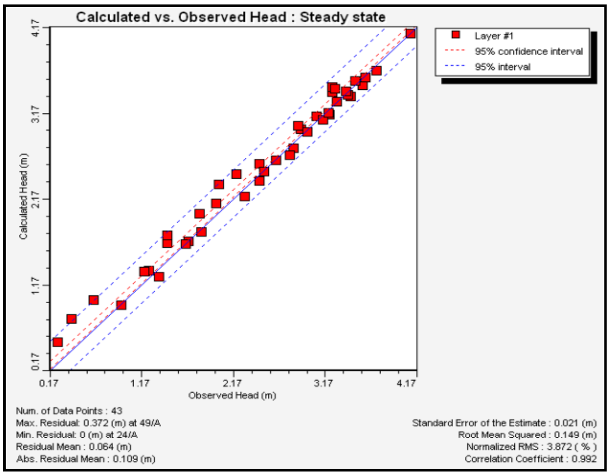



Fig. 12 Evaluation of Model Error

## 4. Summary

The sustainable management of aquifers is a burning problem in many countries. New scientific tools can assist in its solution, both in the analysis of assessing the present management is sustainable or not and in the definition of strategies and measures to achieve sustainability. A computer simulation model could be regarded as the best approach because the model integrated several data such as environmental tracers, remote sensing and geophysical data. Moreover, it not only simulate an average deterministic situation but also analyze the uncertainty of its predictions by stochastic approach in order to remain credible. From this study, all scenarios used shows that the groundwater flow model could be used as reference in deciding a groundwater management in this area.

The availability of water resources in the study area was estimated through first scenario. Second scenario shows the effect of groundwater abstraction on the groundwater table and the result can be used in setting up the permissible volume for groundwater abstraction. While, the third scenario has explains the effect of groundwater-seawater interaction. The seawater was already intruded into the freshwater and quick action should be carried out to minimize the effect of this phenomenon. All the scenarios used show is only example of groundwater model application. Thus, the use of groundwater flow model in groundwater management is expected.

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