Simulation of Groundwater Movement for Nuclear Research Center at Al-Tuwaitha Area in Baghdad City, Iraq

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ABSTRACT

The simulation of groundwater movement has been carried out by using MODFLOW model in order to show the impact of change of water surface elevation of the Tigris river on layers of the aquifer system for Nuclear Research Center at Al-Tuwaitha area, in addition to evaluate the ability of the proposed pumping well to collect groundwater and change the direction of flow at steady-state. The results of the study indicated that there is a good match between the values of groundwater levels that calculated in the model and measured in the field, where mean error is 0.09 m.

The study also showed that the increasing of water surface elevation of the Tigris river led to increase in the hydraulic head of observed wells, while the use proposed pumping well reduced the hydraulic head and intercepted the movement of groundwater flow. The flow direction is toward the Tigris river, and the velocity of flow is clear in the third layer identified medium sand which is 0.0015 m/day. The using of the proposed pumping well has changed the direction of groundwater, especially in the area around the well.

Key words: groundwater, MODFLOW, Al-Tuwaitha, and Tigris River.

محاكاة حركة المياه الجوفية لمركز البحوث النووي في منطقة التويثة، مدينة بغداد، العراق

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الخلاصة

تم محاكاة حركة المياه الجوفية باستخدام نموذج MODFLOW لبيان تأثير تغيير منسوب الماء السطحي لنهر دجلة على الطبقة الجوفية لمركز البحوث النووي في منطقة التويثة اضافة الى تقيم قدرة بئر الضخ المقترح لتجميع الماء الجوفي وتغير اتجاه الجريان بالحالة المستقرة مع الزمن. أشارت نتائج الدراسة الى وجود توافق جيد بين قيم مناسيب الماء الجوفي المحسوبة في الموديل والقيم المقاسة، حيث معدل الخطأ كان 0.09 م .

كما بينت الدراسة ان زيادة منسوب الماء السطحي لنهر دجلة ادى الى زيادة المنسوب الهيدروليكي لإبار المراقبة ، بينما استخدام بئر الضخ ادى الى تقليل المنسوب الهيدروليكي واعتراض حركة الجريان .

اتجاه التدفق كان باتجاه نهر دجلة ، والسرعة تكون واضحة بالطبقة الثالثة المميزة (رملية متوسط) 0.005 م/يوم . استخدام بئر الضخ غير اتجاه التدفق وخاصة بالمنطقة حول البئر .

1. INTRODUCTION

Groundwater is predominantly a new able resource which ensures the supply for a long term to meet the increasing requests and mitigate the impacts of anticipated climate change, and it is closely interrelated with other components of the environment, **Guzha, 2008**. The movement of groundwater may be overlapping with each other, or the direction of flow may be in the river or the sea. Therefor the effective management of water sources requires a comprehensive knowledge of hydrologic processes.

The model of groundwater flow is a clear representation for a groundwater system (a real phenomenon) and simplified it with maintaining the required accuracy and ensuring high reliability of the results. The models incorporated restrictive assumptions, such as spatial variability, dimensionality, and interaction of various components of flow and transport processes.

The modeling of groundwater flow applied by several researchers in Iraq for different purposes, for example : **Al-Ajaaj, 2007**, studied the impact of the environmental of Badush dam on groundwater flow by using Visual MODFLOW. The results showed that the dam has a negative impact on the foundation of the nearby building after 20 years after construction. **Attea, et al, 2007**, used Processing MODFLOW software to describe the behavior of groundwater flow at sandy Dibdiba formation in Safwan region. The results showed enhancing in the water elevation for wells and using artificial recharge for rehabilitation of formation for an aquifer. **Al-Maimuri, and Mohammed, 2009**, developed the mathematical model for groundwater motion by applying the theory of superposition. The superposition gave a good concordance between the time and distance drown down the curves of theoretical and numerical solution in heterogeneous hydrogeologic media. **Al-Dabbas, et al, 2016**, explained the impact of the climatic change on the groundwater. They found that the climatic change led to decrease the water table in the unconfined aquifer in Salah Din.

In this research, the modeling of groundwater flow is applied for Nuclear Research Center at Al-Tuwaitha area to determine the distribution of the hydraulic head and to evaluate the impact of the proposed pumping well on groundwater levels. Processing MODFLOW software version 5.3.1 is used to simulate groundwater flow, MODFLOW model is used to calculate and distribute the hydraulic heads, and PMPATH model is used to show the flow direction of the aquifer in Al-Tuwaitha.

2. MATERIALS AND METHODS

2.1 Site Description

The Nuclear Research Center is located in Al-Tuwaitha site about 18 kilometers (km) south of the southern edge of Baghdad Governorate, between (44°27'-44°35') Longitude and (33°10'-33°15) Latitude. It is characterized by a flat floor surface, surrounded by earthen dikes and ranging from 30-32m above mean sea level and the topography factor has no significant impact on water level and groundwater movement, **Copland, and Cochran, 2013**.The Tigris river passes near it about 1km from it, **Fig. 1**. The typical lithology of the site is a loamy clay from 0 to 16 m bls (below land surface), silt fine sand from 16 to 30 m bls, and medium sand from 30 to 50 m bls, **Al-Daffaie, 2014**. It has a hot, dry climate, vassal to Baghdad climate that's considered one of the hottest cities in the world. The warmest month is July with an average high of 44 °C and an average low of 25.5°C, while the coolest month is January with an average high of 16°C and an average low of 3.8°C.

2.2 Data Collection

Water level data for six observation wells located at Al-Twaitha area is used for ground water modeling, as in **Table 1**. The recharge is applied to top grid layer and the input parameter is assumed to be constant during the time stress period, and the principal source is the rainfall. The value of recharge rate was 2 x 10^{-5} m/day, **Bashoo, et al, 2005**. Aquifer properties for each layer were given as input to the model in **Table 2**.

2.3 Groundwater Flow Equation

The process of groundwater flow is based on Darcy's law and the conservation of mass, which describes the three dimensional movement of groundwater flow of constant density through the porous media is, **Rushton, 2004**.

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(k_z \frac{\partial h}{\partial z}\right) = S_S \frac{\partial h}{\partial t} - W \qquad (1)$$

Where:

Kx, Ky & Kz are components of the hydraulic conductivity $[LT^{-1}]$, *Ss* is the specific storage $[L^{-1}]$, *W(x,y,z,t)* is the rate of ground water discharge/recharge per unit area $[LT^{-1}]$ general sink/source term that is intrinsically positive and defines the volume of inflow to the system per unit volume of aquifer per unit of time $[T^{-1}]$, *h* is the ground water head [L], *x, y, z* are Cartesian coordinate directions [L] and *t* is time [T].

In this research the groundwater flow ran at steady-state, where the term $S_S \frac{\partial h}{\partial t}$ was equal to zero.

2.4 Numerical Model

The finite-difference flow code existed within processing MODFLOW software, is used to perform this simulation. Processing MODFLOW for Windows (PMWIN) is designed with a professional graphical user-interface, the supported models and programs and several other useful modeling tools. The graphical user-interface allows to simulate and create models with ease. It handles models with up to 1,000 stress periods, 80 layers and 250,000 cells in each layer. The output of simulation included hydraulic heads, draw downs, subsidence, Darcy velocities, concentrations and mass terms, **Chiang, and Kinzelbach, 1998**.

The finite-difference is used to solve the groundwater flow equation in MODFLOW model, where the model domain is divided into a number of equal-sized cells-usually by specifying the number of rows and columns. Hydraulic properties are assumed to be uniform within each cell, and an equation is developed for each cell, based on the surrounding cells. Steady-state and transient flow conditions can simulate in MODFLOW. PMPATH Code is an advective transport model running to represent flow lines and paths lines of groundwater. It links with the groundwater models and outputs of the simulation from MODFLOW. It uses a semi-analytical particle tracking scheme, **Lu, 1994**, to calculate the groundwater paths and performs particle tracking with just a few clicks of the mouse. It gives different on screen graphical options involving head contours, and velocity vectors, **Chiang, 2005.**

2.5 Discretization of the Model

The model consists of 28 rows and 57 columns in each layer as in **Fig. 2** with cell size 80 m x 80 m. Based on the acquired information the model is divided into a three layered , top layer which has loam clay with a thickness of 16 m (approx.), the middle layer is 14 m thick silt fine sand and bottom layer is made up of predominantly medium sand with a thickness of 20 m. MODFLOW is used to estimate the distribution of hydraulic heads in steady-state, and PMPATH is used to calculate the ground water flow paths.

The boundaries of flow model were based on physical features and the hydraulic conditions, the cells that represent the Tigris river are defined as a constant head boundary and the neighbored cells for the Tigris river from the north-west are considered inactive cells, while other cells were defined as variable head boundaries, as in **Fig. 2**. The value of water surface elevation of the Tigris river is specified as a value of initial hydraulic head with 27.6 m.a.s.l, **Copland, and Cochran, 2013.**

3. STEADY STATE MODEL CALIBRATION

The model is operated with the initial conditions and hydraulic conductivities, which is adjusted during the calibration of the model using manual calibration. The final calibration process gave a good match between the observed and calculated head. **Table 3** and **Fig. 3** show a fairly good match between the calculated and observed heads. The model calibration error can be expressed qualitatively by mean error (ME), mean absolute error (MAE), root mean square error (RMSE), **Anderson, and Woessner, 2002.**

The ME error for observed head versus calculated head is 0.09 m, is very close to 0, and it is the best statistical value compared with MAE and RMSE which are 0.16 m and 0.24 m, respectively. Since it is impossible to obtain an exact match for calculated and observed heads therefore the model can be accepted with an acceptable error ratio.

4. THE RESULT AND DISCUSSION

The equipotential lines of groundwater flow in the first, second, and third layers are shown in **Fig. 4**. It has a high value in the eastern part of the aquifer of 27.82 m, while the smallest value of the area that neighboring the river is 27.61 m, which is the grade towards the river, therefore the groundwater will move toward the river.

It has been noticed when the groundwater flow is drawn by PMPATH model that groundwater movement of groundwater is slow, especially in the first layer identity type of loam clay, **Ou, 2006**, but its highest in the third layer, where the velocity of groundwater flow in the first, second, and third layer were 9.77×10^{-6}, 3.6×10^{-4}, and 0.0015 m/day, respectively. **Fig.5 (a,b,c**) shows the behavior of groundwater flow direction in the aquifer system, where water flow towards the river because the less head at area neighbored the river.

5. THE SCENARIOS OF GROUNDWATER FLOW

After the final calibration process, two scenarios are tested in order to check the influence of variation in water surface elevation of the Tigris river and pumping well proposed on the head of the aquifer system.

In the scenario1 is run with an average water surface elevation of the Tigris river of 28.7 m.a.s.l, to predict the impact of the Tigris river on groundwater aquifer, and also on hydraulic head of observation wells. The results shown that the increase of water elevation of the Tigris river creates to increase in the calculated head values of the groundwater levels as compared with the values of the observation wells, as **Fig. 6**.

While the model in the scenario 2 is run with an average of water surface elevation of the Tigris river of 28.7 m.a.s.l as in scenario 1 and used the proposed pumping well. The use of pumping well led to reduce the water level in the observed wells as compared with the value of the results in scenario 1, as **Fig. 6**. The direction of groundwater flow became toward the pumping well as shown in **Fig.7 (a,b,c**). So the movement of contaminant will follow the groundwater movement and it will be toward the pumping well and this is noted from the output of this scenario, which operated with proposed pumping well to limit the movement of water contaminant toward the Tigris river and thereby reducing the movement of contamination deposited to aquifer from the surface for Nuclear Research Center at Al-Tuwaitha area near the Tigris river. **Fig. 8** shows the effect of pumping well on the equipotential lines.

6. CONCLUSIONS AND RECOMMENDATION

The simulation of groundwater flow shows that there is a good result between the observed and calculated heads, where the value of mean error is 0.09 which is close to zero. Any increase in the water elevation of the Tigris river leads to increase the hydraulic heads aquifer, while the use of proposed pumping well leads to reduce the hydraulic heads, and also to capture the flow lines of groundwater. Groundwater flow movement is slowly toward the Tigris river which, influenced by soil type. This is more pronounced in the third layer due to its high permeability value, the velocity of groundwater is 0.0015 m/day in the third layer compared with the first and the second layer, the velocity are 0.00036 m/day and 0.00000977 m/day respectively. The recommendations may be taken into consideration for further, as using transient simulations to show the change of aquifer levels with time, also using more parameters and changing boundary conditions by making the water surface elevation of the Diyala River as a boundary condition.

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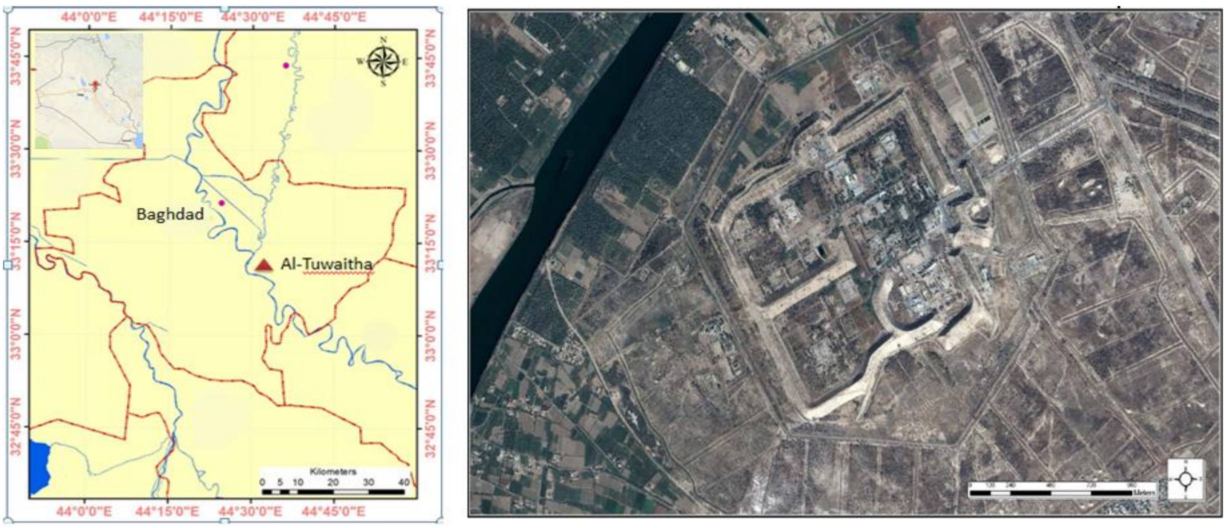

Figure 1. Location of Nuclear Research Center at Al-Tuwaitha site, **Al-Daffaie, 2014**.

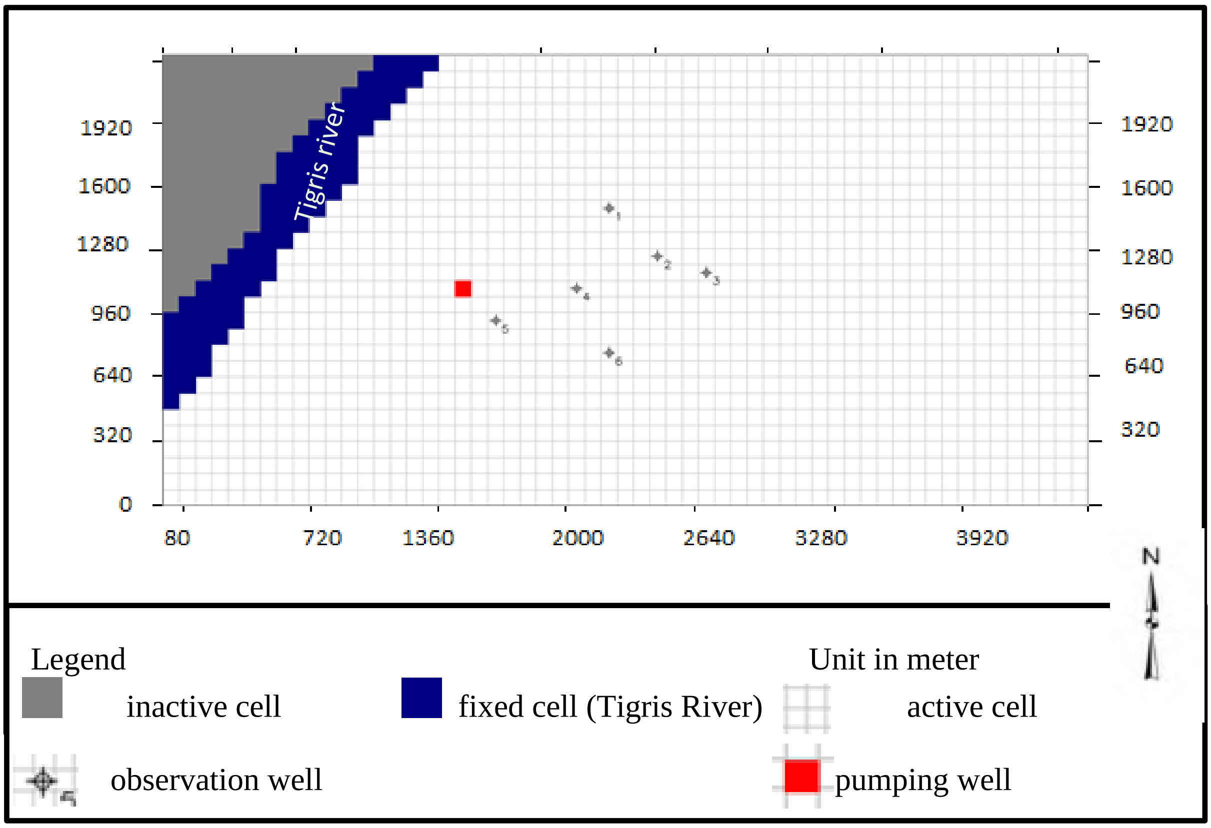

Figure 2. Plane view of the model.

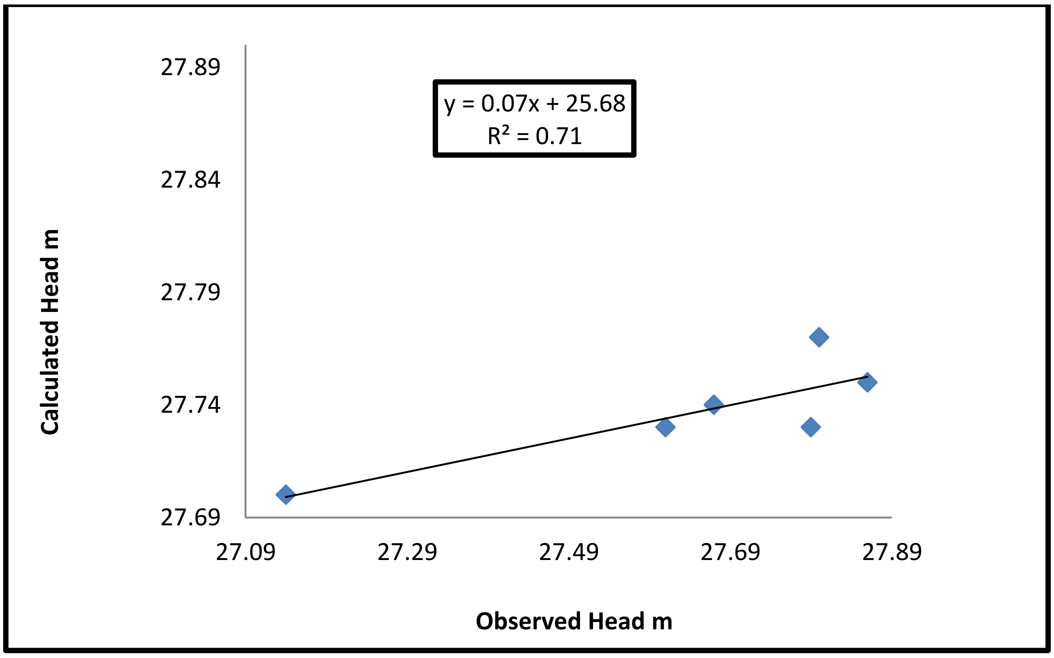

Figure 3. Calculated and observed heads (m) of Nuclear Research Center at Al-Tuwaitha site.

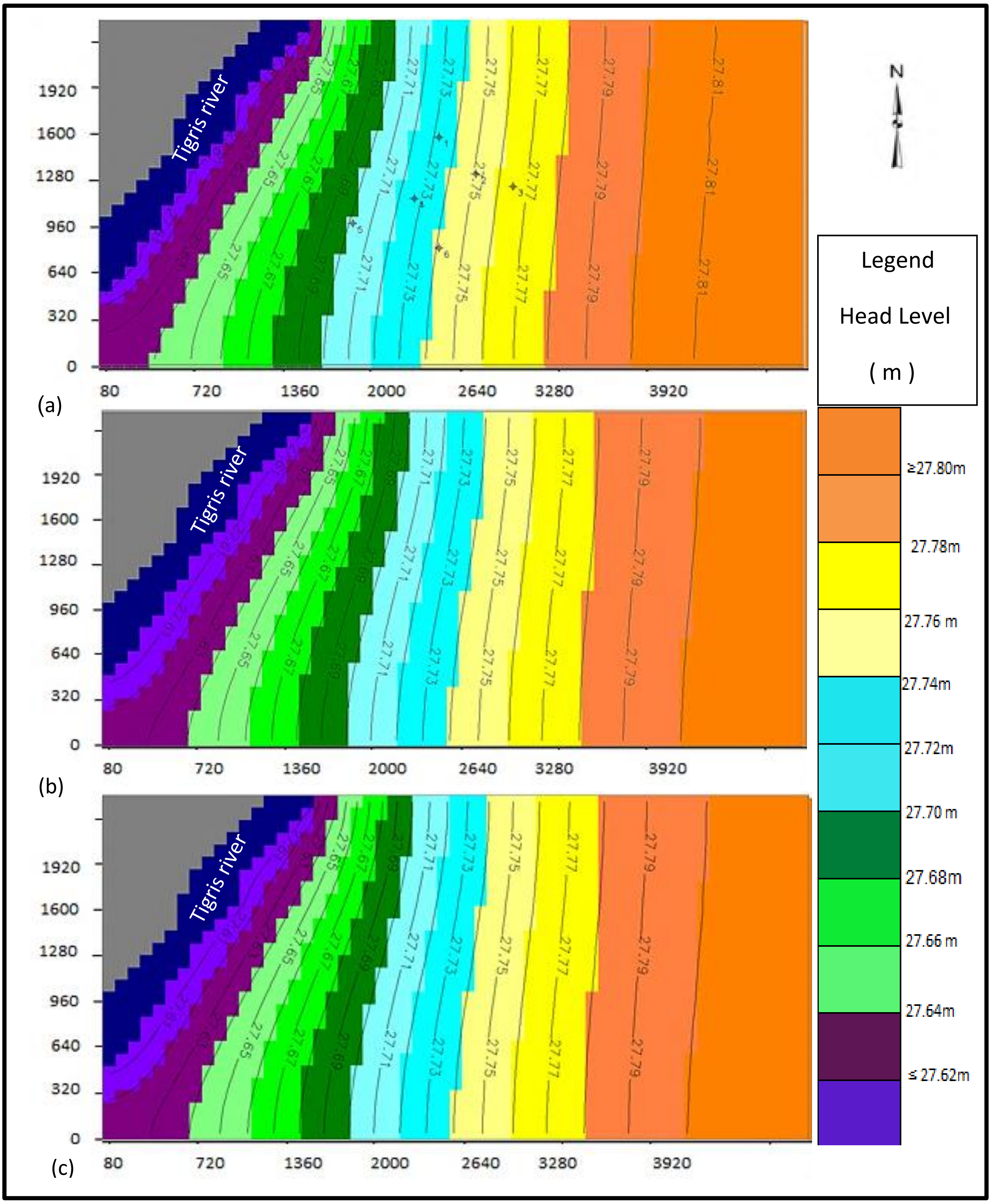

Figure 4. Simulated steady-state of the heads for the study area with 27.6 m as value of water surface elevation of the Tigris river, (a):contours of hydraulic heads in the first layer, (b): contours of hydraulic heads in the second layer, (c): contours of hydraulic heads in the third layer.

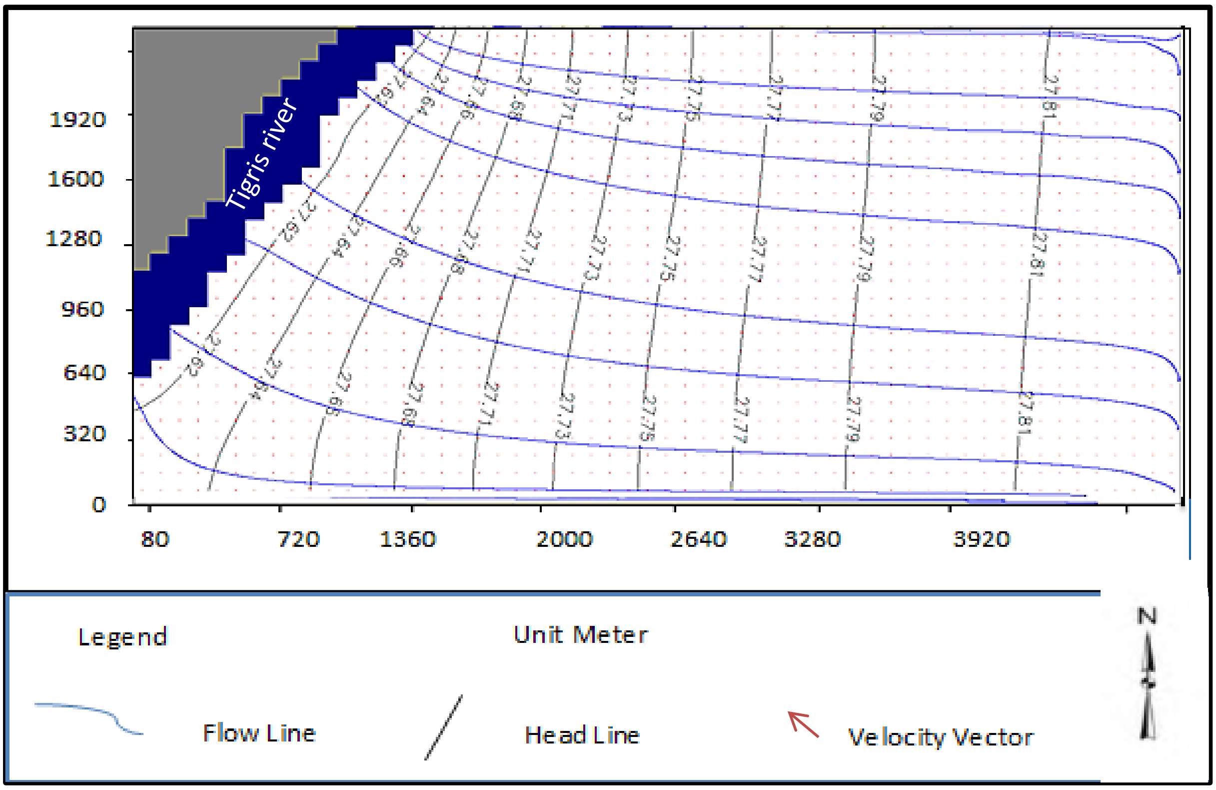

Figure 5a. Groundwater flow net direction in the first layer.

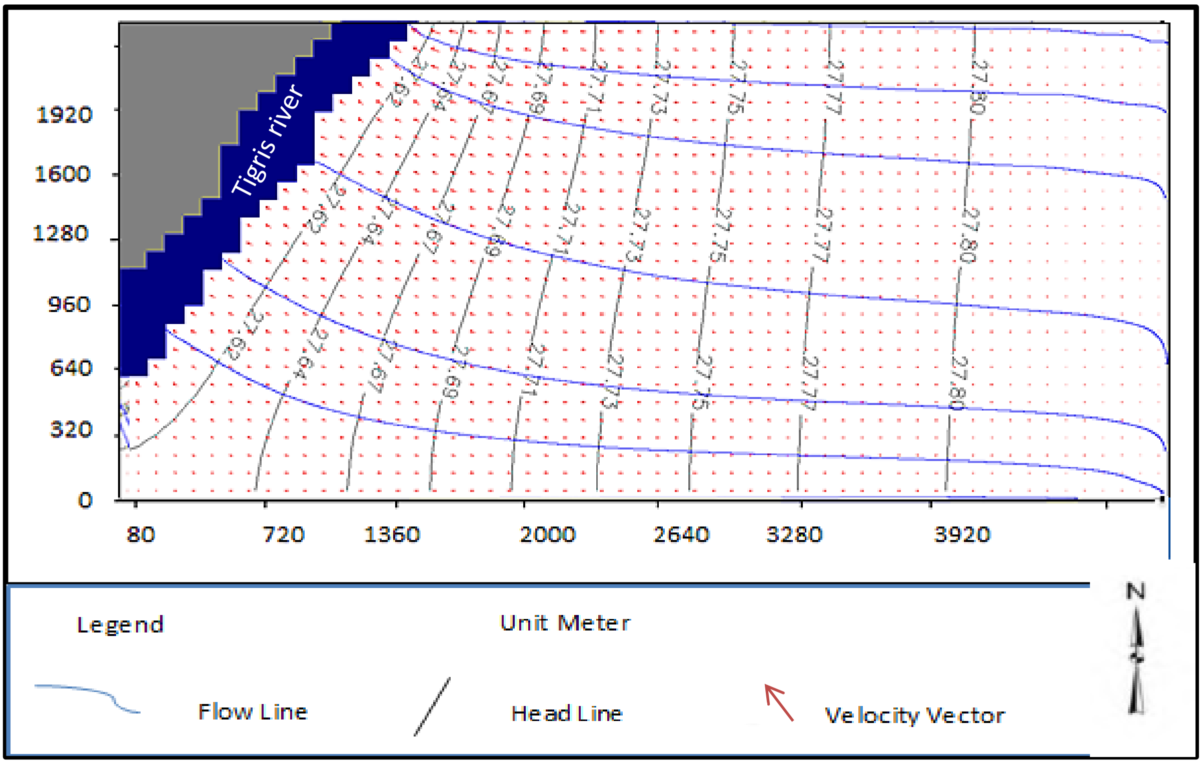

Figure 5b. Groundwater flow net direction in the second layer.

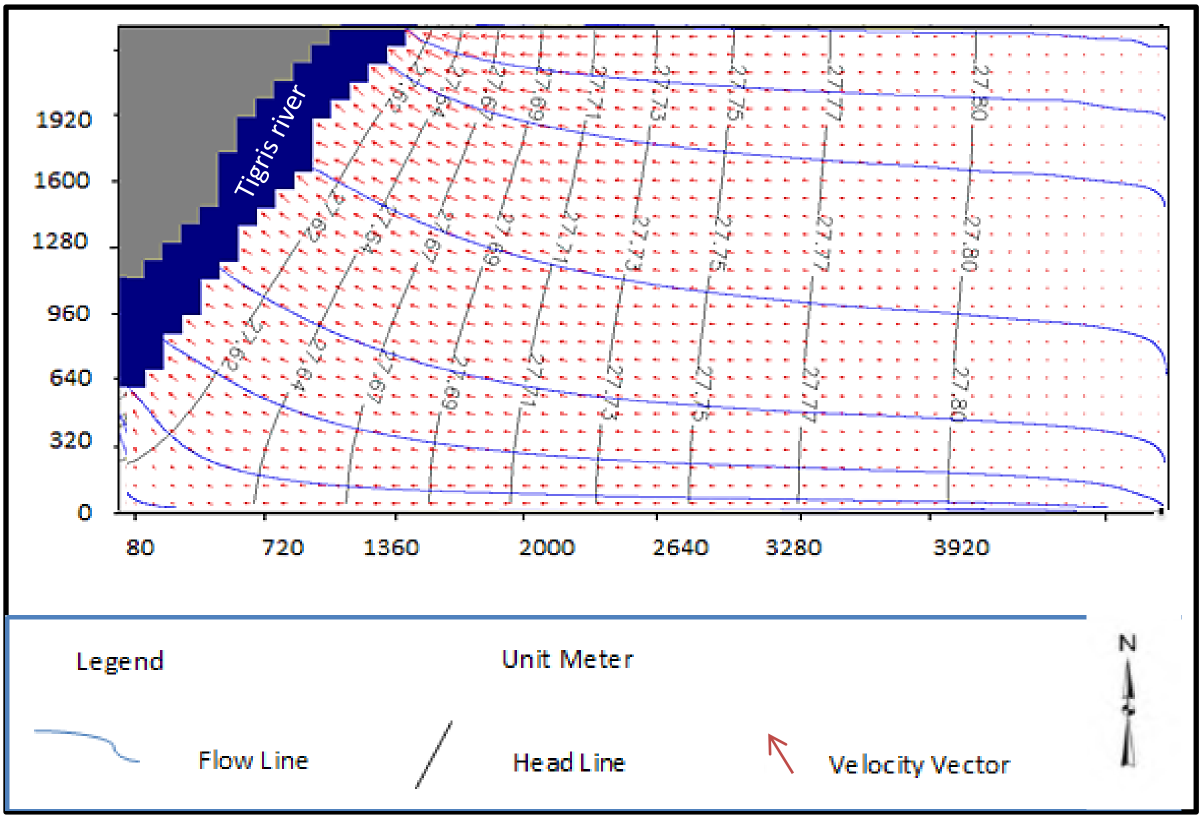

Figure 5c. Groundwater flow net direction in the third layer.

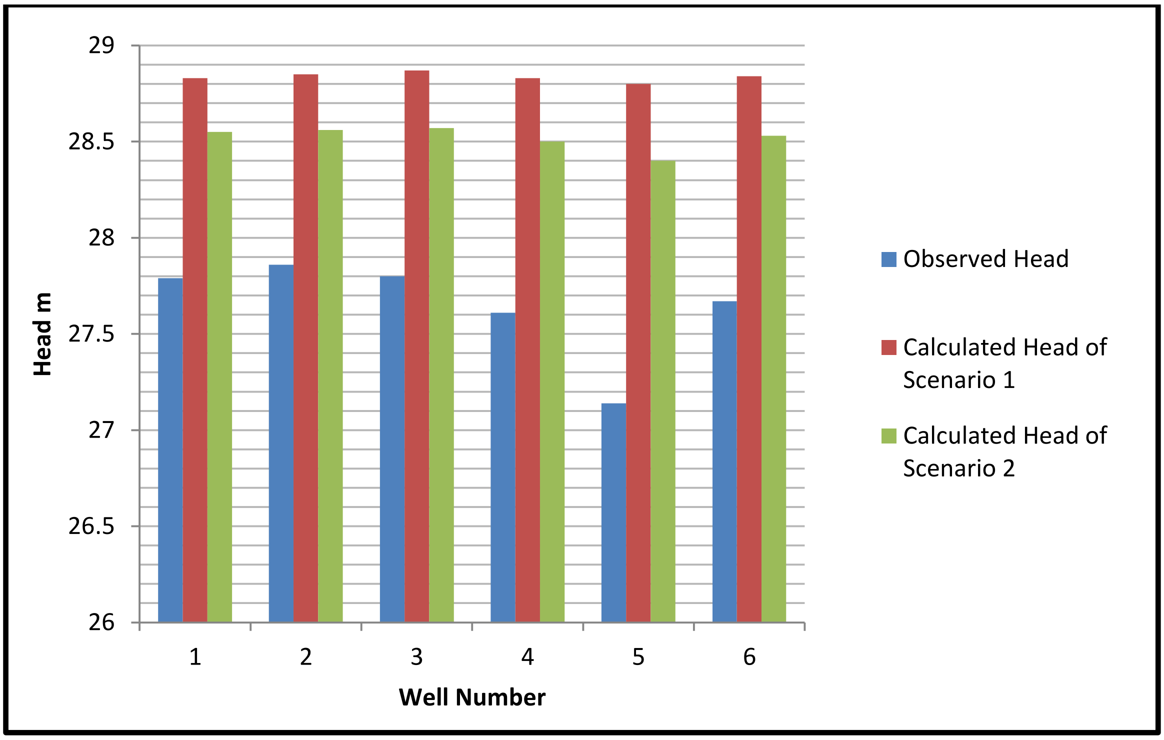

Figure 6. Calculated and observed heads (m) of Nuclear Research Center at Al-Tuwaitha site of scenario 1 and scenario 2.

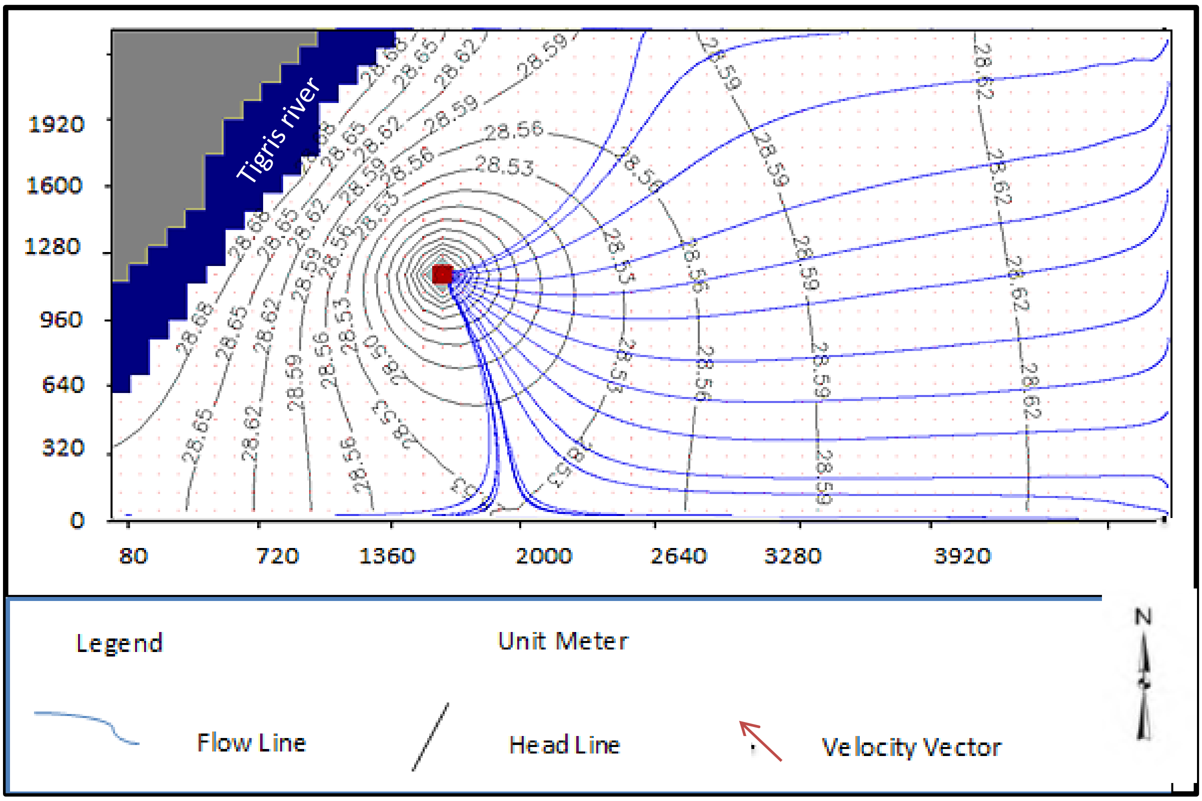

Figure 7a. Groundwater flow net direction in the first layer.

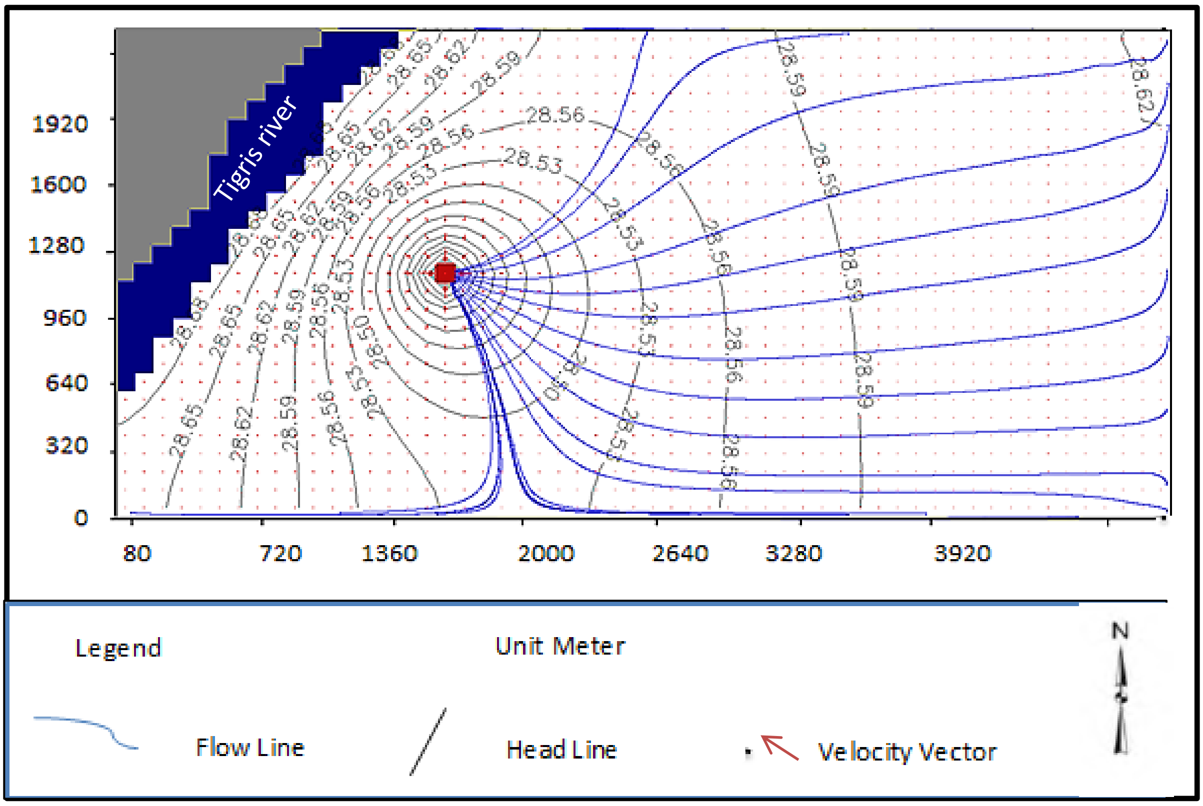

Figure 7b. Groundwater flow net direction in the second layer.

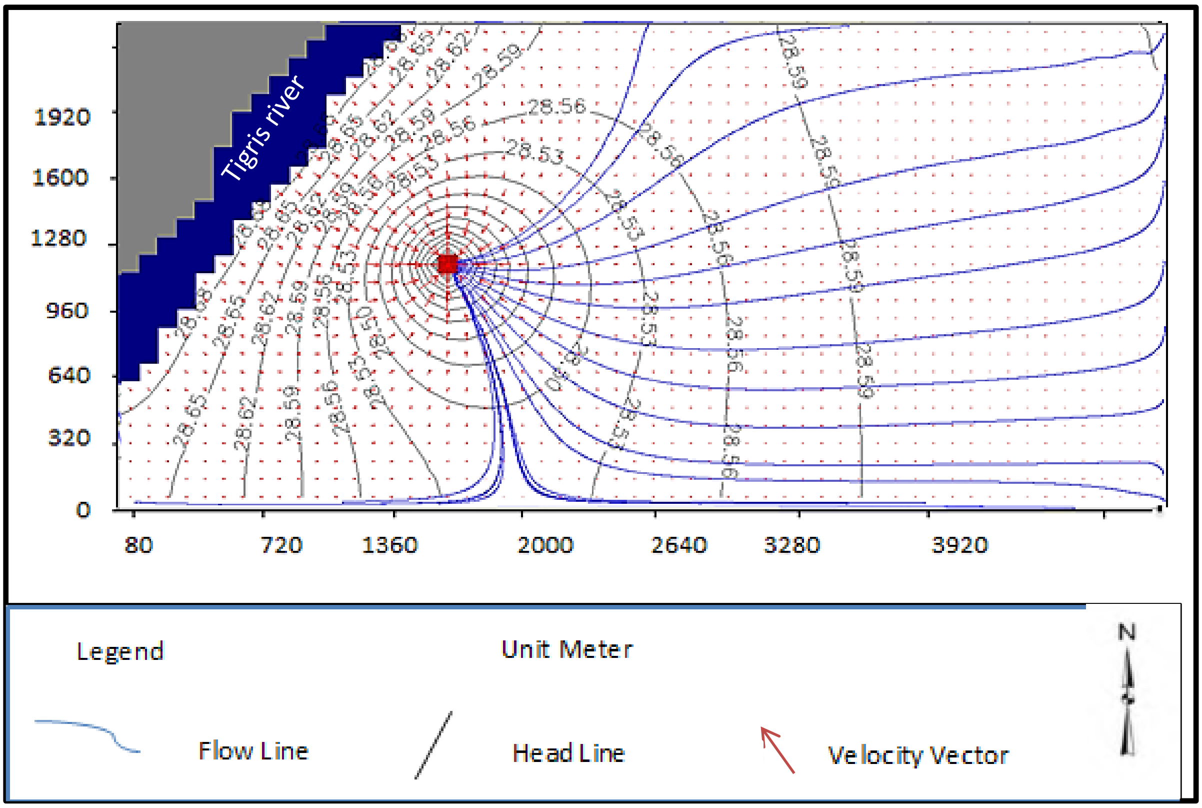

Figure 7c. Groundwater flow net direction in the third layer.

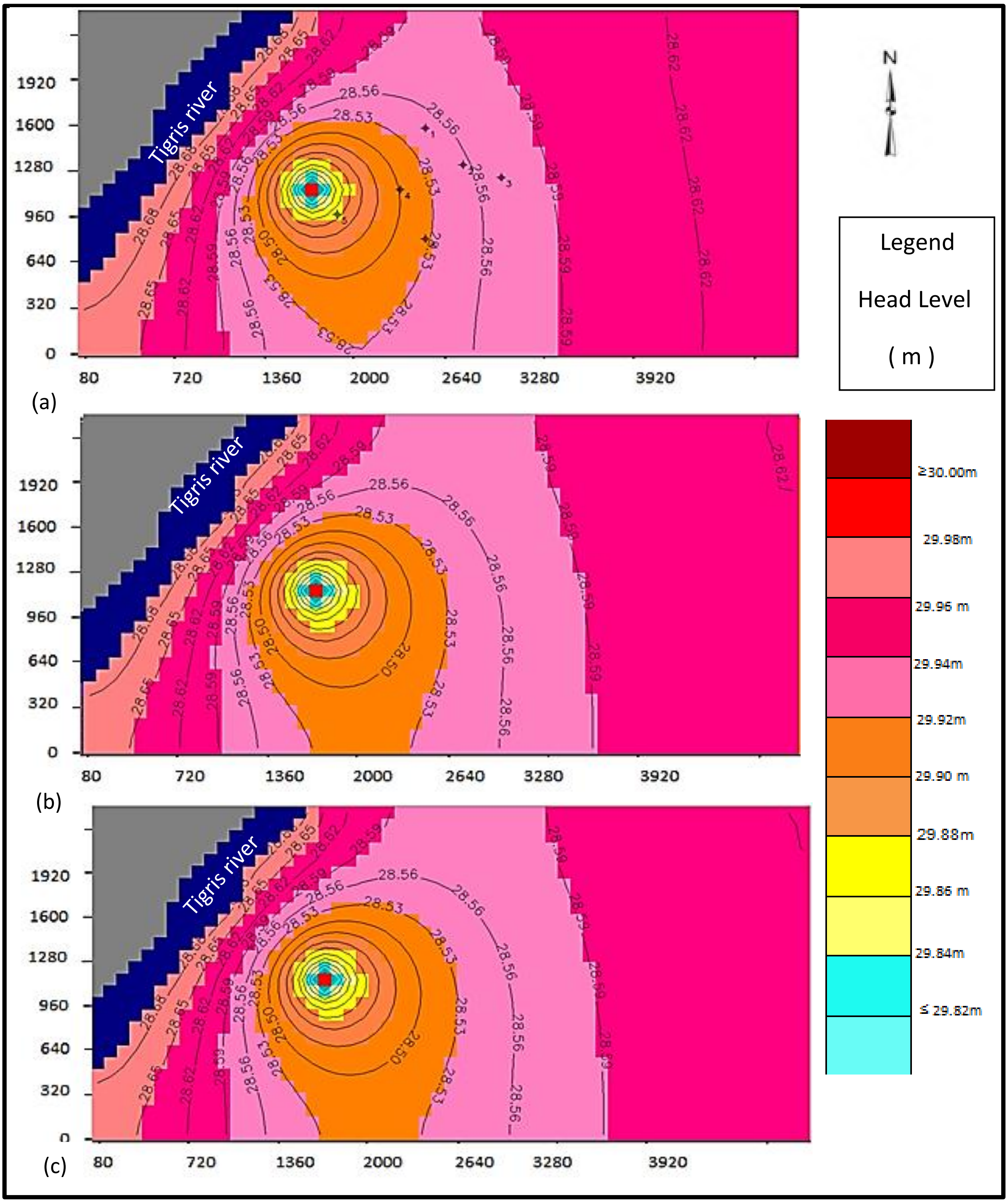

Figure 8. Simulated steady-state of the heads for the study area, (a): contours of hydraulic heads in the first layer, (b): contours of hydraulic heads in the second layer, (c): contours of hydraulic heads in the third layer.

Table 1. Water elevation of observation wells, **Copland, and Cochran, 2013.**

Observation Well	Ground Surface Elevation (m)	Water Table m.a.s.l.	Observation Well	Ground Surface Elevation (m)	Water Table m.a.s.l
W1	31.81	27.79	W4	31.56	27.61
W2	31.57	27.86	W5	31.14	27.14
W3	32.02	27.80	W6	31.88	27.67

Table 2. The aquifer properties.

No. Layer	Soil Type	Layer Type	Hydraulic Conductivity m/s	
			KH	KV
1	Loam /Clay	Unconfined	$2 \text{ x} 10^{-6}$	$2 \text{ x } 10^{-7}$
2	Silt /Fine sand	Confined / Unconfined, Transmissivity varies	$7 \text{ x } 10^{-5}$	$7 \text{ x } 10^{-6}$
3	Medium sand	Confined / Unconfined, Transmissivity varies	$3 \text{ x } 10^{-4}$	$3 \text{ x } 10^{-5}$
Source	Al-Daffaie, 2014	Ali, 2012	Osterbaan, 1986, and Heath, 1983.	Todd, 2005

Table 3. The values of calculated steady-state and observed heads (m) in Nuclear Research Center at Al-Tuwaitha site.

Well No.	Observed Head m.a.s.l	Calculated Head m.a.s.l	Well No.	Observed Head m.a.s.l	Calculated Head m.a.s.l
1	27.79	27.73	4	27.61	27.73
2	27.86	27.75	5	27.14	27.7
3	27.80	27.77	6	27.67	27.74