Mathematical Model of Groundwater flow in Safwan Al – Zubair Area, South of Iraq

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Abstract

A two –dimensional mathematical model has been constructed by using finite difference method for representation the groundwater flow in both steady and unsteady states at the upper aquifer of Dibdibba formation. The hydraulic characteristics of this aquifer have been redistributed based on observed data for the period (1988-1989). A verification test is added to check the model correctness by matching the calculated levels with the ones observed for the year 2000.A model was set to predict the groundwater levels up to the year 2010. Results of prediction show a reduction in groundwater level about (1m) in the central parts of the study area compared to the level of this groundwater in the year 2000.On the other hand, this decrease is reaches (0.5m) in the western parts of this area.

النموذج الرياضي لجريان المياه الجوفية لمنطقة سفوان–الزبير، جنوب العراق

علي حسن العبودي   احمد مجيد الكاظمي   مجيد عبود الطائي

الخلاصة

تم إنشاء نموذج رياضي ثنائي البعد باستخدام الطريقة العددية (الفرو قات المحددة) لتمثيل حركة المياه الجوفية في الحالة المستقرة وغير المستقرة للخزان الأعلى لتكوين الدبدبة. وبالاعتماد على معلومات حقلية للفترة (1988–1989) ، أعيد توزيع الخصائص الهيدروليكية للمكمن المائي واجري التحقق من صحة للنموذج المُعد وذلك بمطابقة المناسيب المحسوبة مع تلك المقاسة في عام (2000).أستخدم النموذج لتنبؤ بمستوى المياه الجوفية حتى عام (2010) ، حيث تبين أن هناك انخفاض في مستوي تلك المياه يصل إلى (1م) تقريباً عما هو علية في عام (2000) في الأجزاء الوسطى من المنطقة، في حين إن قيمة هذا الانخفاض تقريبا (0.6م) في الأجزاء الغربية من المنطقة المدروسة.

Introduction

Mathematical models include analytical and numerical models. Usually assumptions necessary to solve mathematical model analytically are fairly restrictive. Many analytical solutions require that the medium should be homogeneous and isotropic, for this reason using numerical methods is very realistic solution. (Wang and Anderson, 1982) [10].

Al-Kubaisi, 1996, [4] introduced a new study about hydrogeological of Safwan AL-Zubair area, this study includes water balance in the water year (1995-1996), and determined some limits to the qualitative and quantitative consumption for aquatic source and also described the chemical characteristics for these waters in the region. Al-Manssori, 2000 [5] had done a research related to hydraulic and hydrogeochemical characteristics of the upper unconfined aquifer. He calculated its transmissivities by using 50% and 90% recovery test were ranged from 115 to 3255 (m2/day) and from 18 to 135 (m2/day) respectively. The calculated values using numerical method ranged from 235 to 5880 (m2/day).

A finite difference two dimensional model is used for modeling the groundwater flow for the upper aquifer in Safwan- Al- Zubair area, in order to describe the changes level of this groundwater after increasing numbers of wells have been used for agricultural purposes. A graphical interface (GUI) computer program namely Processing Modflow for windows (PMWIN v.5) is selected to simulate the aquifer behavior being studied. The study area is located in the south –west part of Basrah province in the south of Iraq, the area is about 1400 km^2 as shown in figure (1). This area is involved within the Dibdibba formation, which is mainly composed of sand and gravel with some cementing materials such as silt and clay. Dibdibba formation consists of two aquifers, the first aquifer has a changeable thickness up to 30m in Safwan area, while second aquifer can be penetrated by wells as it's depth increased more than the previous one. These two aquifers are separated by hard layer, which is locally called "Jaojab".

Where:

Kxx, Kyy:- values of hydraulic conductivity along x and y coordinate axes (L/T)

h:- potentiometric head (L)

w:- volumetric flux per unit volume representing sources and/ or sinks of water, with w<0.0 for flow out of the groundwater system, and w>0.0 for flow in (T^{-1}).

Ss:- specific storage of the porous material (L^{-1}).

T:- Time (T).

Equation (1), when combined with boundary and initial conditions, describes unsteady two – dimensional groundwater flow, provided that the principal axes of hydraulic conductivity are aligned with the coordinate directions.

Input Data

Input data may be introduced into the following classes.

1. Hydraulic Conductivity and Specific Yield.

Several field tests have been conducted to determine the hydraulic conductivity and specific yield of upper aquifer in Dibdibba formation; Atia's values (Atia, 2000) [2] are used as initial input data to the current model.

2. Boundary Conditions

Boundary conditions are defined along the edges of the simulation domain, including the top and bottom of this domain. Three types of boundary conditions-specified head, specified flow, and head-dependent flow are commonly specified in mathematical analyses of groundwater flow system. The boundary conditions determination along the edges of the domain is a difficult process as hydraulic heads or inflow and outflow rates can be poorly defined. To overcome this problem the model boundaries are placed along natural hydrogeologic boundaries, or parallel to the path lines. In the present model, the northern, southern west and southern boundaries of the study area almost coincident with the flow lines (see figure. 4), therefore, these boundaries were represented as no flow boundaries as shown in figure (2). The canal of Shatt Al-Basrah lies to the east of the model area, therefore, the eastern boundary represent constant head and the information concerning the canal head obtained from the General Faculty for the Operation of Al-Abbas

The western boundary was modeled as head-dependent boundary to allow inflow to the modeled region at a rate proportional to the head difference between the aquifer outside the simulated area and the model boundary.

3. Distribution of Wells and Pumping Rate

Statistical data about the number of wells in the study area is shown in table (2). It is worth noting that it was not possible to distribute the wells over the study area in 1988. According to the second edition of the map produced in 1990 by the Iraqi Military Forces, the researcher could find out how wells are distributed over that area as shown in figure (3).

The number of pumping hours is determined in the light of the agricultural season. In the study area there are three main pumping periods, as follows:-

1. Normal pumping periods have been almost in November up to May, they attain about twelve hours per day.
2. Extensive pumping periods are during the months of August, September and October, they attain about twenty hours per day.
3. Relaxation periods are during June and July months, where irrigation activities are stopped.

In this study, the pumping rate was taken to be 7 liter/sec. Since the soil in the study area does not reserve water except for a very short time period, Haddad and Hawa (1979) [7] estimated the percentage of irrigation water that percolates to the groundwater to be 84%. Propagation of the trickle irrigation scheme decreases this percentage because this system leads water to be evapotranspire instead of percolating into the groundwater. The number of farms using the trickle irrigation system is unknown though its user is increasing. In the present model, the percentage used for representing the percolated irrigation water that return to groundwater is equal to 70% and only 30% of water is consumed.

4. Initial condition

The initial condition is the hydraulic heads distribution at time zero. In other words, it reflects the state of the system before the modeling begins. Eight observations wells distributed over study area as shown in figure (1) were used to drive the initial water table, which was taken as initial water level for the simulation.

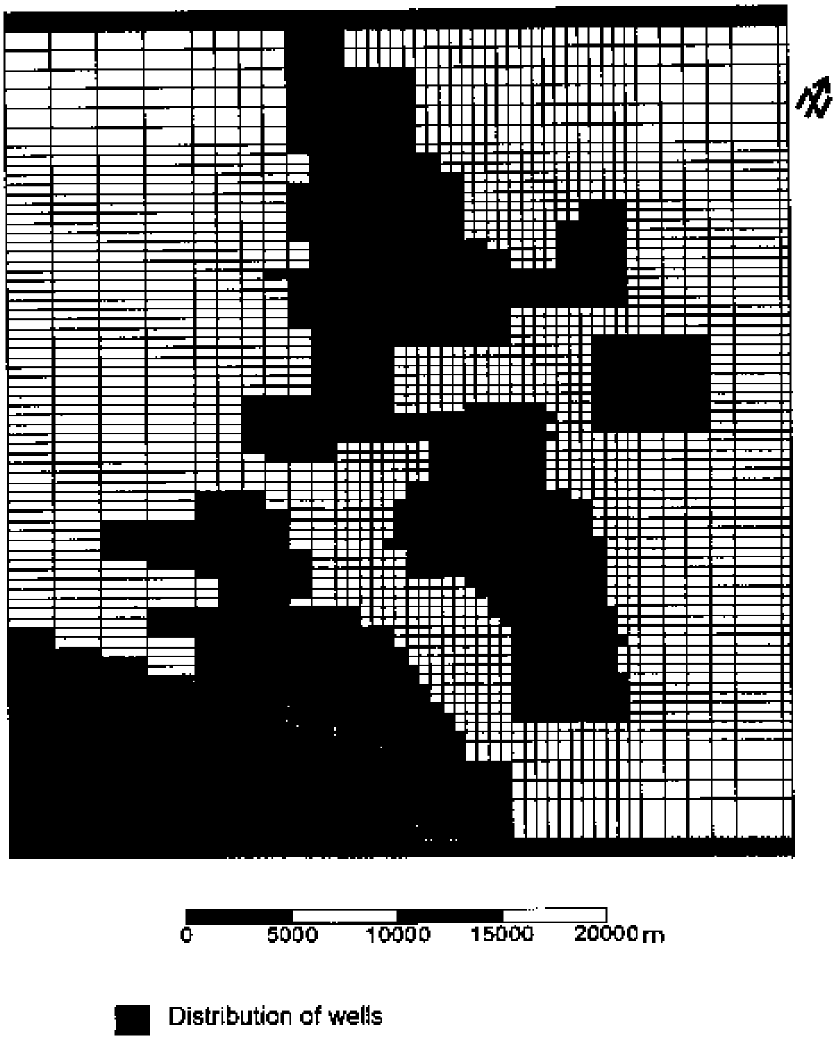


Fig. (3) Distribution of wells over study area

5. Direct Recharge

The previous studies that dealt with recharge arrived at different results and conclusion with reference to the percentage of rainfall, which percolates, to the groundwater. Haddad and Hawa (1979) [7] and Al-Rawi *et. al* (1983) [3] hypothesized that the percentage of recharge lies between 17-26% and 3.3-14.3% respectively.

Hydrological condition permits the adoption of a high percentage for the following reasons.

1. Haddad and Hawa made several field studies in 1979 on the amount of the irrigation water that might possibly return downward to the groundwater. The percentage was found to be more than 80%.
2. There have been no valleys that collect water in the study area with the exception of Al-Battin valley.
3. Owing to the nature of the sandy soil, it is believed that such soil does not remain wet for along period, as water either percolates to the groundwater or evaporates to the atmosphere. For this reason the saturation factor is neglected when calculating the component of water balance.

From what has been mention above one may assume that the percentage of the percolation water from rainfall is equal to 20%.

6. Historical Water Table Elevations

Eight observation wells represent historical groundwater elevations over the study area as shown in figure (1); these data were introduced for the period (January, 1988; September, 1989). And which was obtained from Al-Furat Center for studies and design of irrigation projections.

7. Network Configuration

The first step in groundwater modeling is to collect the necessary data, then develop a conceptual model of the ground water system and define the spatial discretization of the model domain. In the block-centered finite difference method, an aquifer system is replaced by a discretized domain consisting of an array of nodes and associated finite difference blocks (cells). Figure (2) shows a spatial discretization of the aquifer in the study area with a mesh of cells at which the hydraulic heads are calculated. The location of cells is described in term of columns, rows. Processing Modflow for windows (PMWIN) uses an index notation (J, I) for the locating the cells. The present model consists of 42 columns and 74 rows. It is good practice to use a smaller grid in areas where the hydraulic gradient is expected to be large (areas around the wells). Thus the area of cells in the middle of the zone is equal to (500×500m) because of increasing number of wells in this region. This dimension was increased toward the edges of model area.

Sensitivity Analysis

In the simulation of areal aquifer system, modelers are often faced with uncertainty as to the exact values assigned to the physical parameters of the system. Therefore, one must conduct a sensitivity analysis to establish the limits within which the values of the parameters of the physical system may vary without appreciably affecting the model results. A sensitivity analysis is conducted by introducing perturbations into the physical parameters of the system and observing the changes in systems response. Sensitivity analysis of the model can be divided into two types, and asfollows:

1. Sensitivity Analysis of Steady State

It becomes clear that changes in the values of hydraulic conductivity lead to great improvement in hydraulic heads. On the other hand it seems to be some direct effect of the change in the values of hydraulic conductivity imposes up on the values of hydraulic head, this is lead to a significant matching between observed and calculated heads. In steady state, the storage term in equation of groundwater flow is set to zero, therefore, this parameter is not participate in sensitivity analysis.

2. Sensitivity Analysis of Unsteady State

When there is unsteady flow the model will be improved to a large extent, as there are some great changes in the values of specific yield. The adjustment of these values related to this parameter has affects to some extent the matching between simulated heads and the measured ones. On the other hands, it has not been approved that there is any sensitivity concerning the changes in the values of hydraulic conductivity. As far as the effect of boundary conditions on the sensitivity analysis leads to specific changes in the northern and southern boundaries. These change stems from state of non-flow boundaries into variation heads, no change in the values of hydraulic heads has been noticed.

Calibration

Groundwater flow models need to be calibrated if they become reliable to simulate the observed hydrologic conditions. Model calibration is a process of adjusting model parameters so that the simulated and the observed hydrologic conditions become similar. Periodic and continuous water level data can be used in model calibration.

If differences between measured and simulated water level exceed an acceptable margin of error, then model parameters, such as aquifer hydraulic conductivity, stream bed hydraulic conductivity, locations and nature of simulated aquifer boundaries, or model stresses, such as recharge and boundary inflow, will be adjusted to provide a better calibration.

Adjustments to model parameters, stresses, and boundaries will be limited within reasonable ranges that are based on available information.

Most commonly, calibration method is accomplished by a trial and error adjustment of model parameters. This procedure involves the systematic variation of model parameters like hydraulic conductivity, specific yield, flows or boundary conditions. Automated inverse procedure like those in MODFLOW may speed up calibration (Hill, 1992) [8].

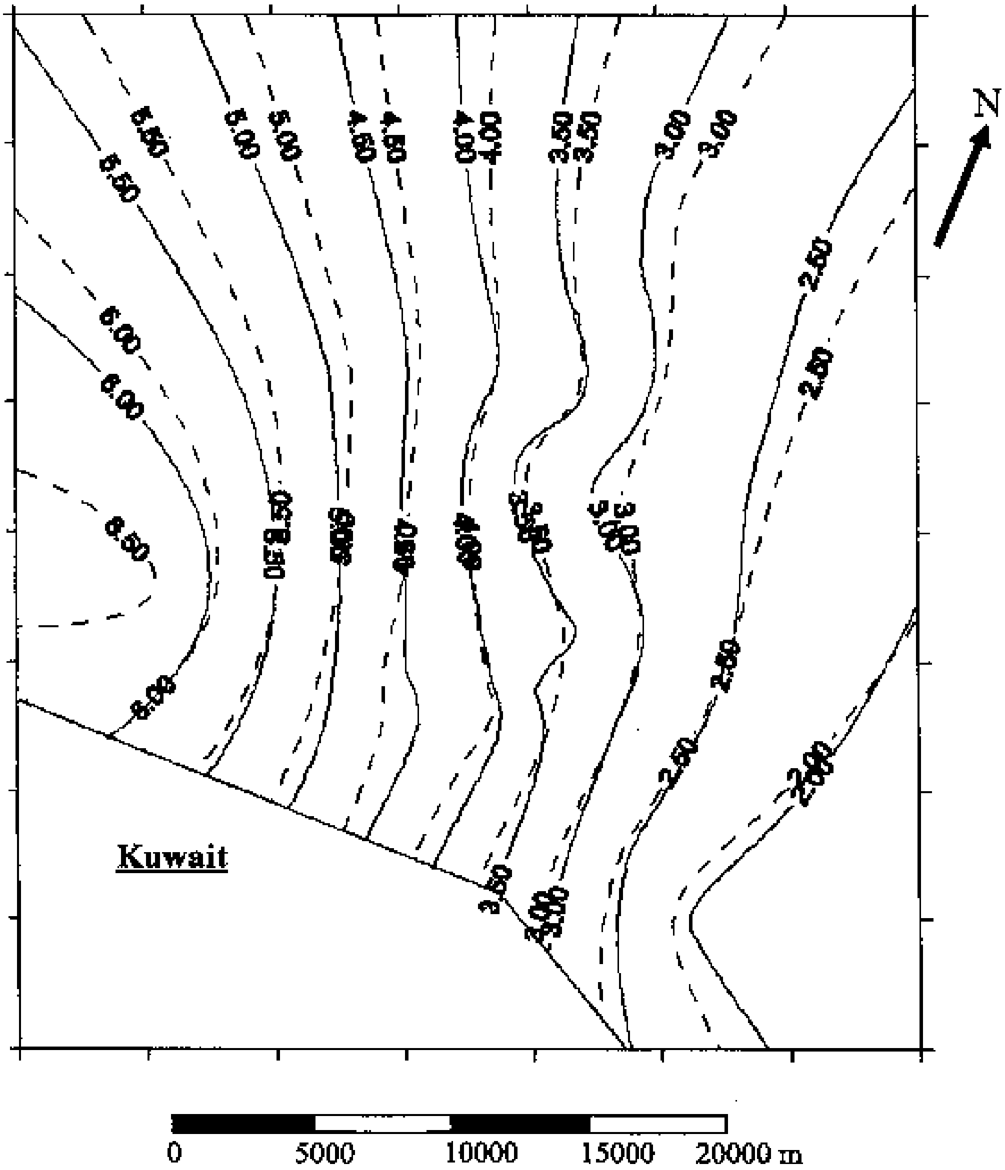
In the present model, a trial and error procedure was used to calibrate the model. Input parameters, such as hydraulic conductivity and specific yield, were suitable to adjust after each simulation run until a good match was obtained between computed and observed heads. Calibration of the model was carried out in two sequential stages, a steady state calibration followed by an unsteadycalibration.

1. Steady State Calibration

The process of the steady state calibration permits the adjustment of hydraulic conductivity in the aquifer without the added complication of specific yield, which becomes important only for unsteady simulations. The model was calibrated according to the peizometric heads of groundwater in the study area as shown in figure (4).

2. Unsteady Calibration

The unsteady calibration results were evaluated by comparing the temporal variations in simulated heads with those of observed water level data at certain locations (figures 5 & 6).Data used for calibration was obtained from Al-Furat Center for studies and design of irrigation projects.



Contour Interval=0.5m

Obs. hydraulic heads

Cal. hydraulic heads

Fig. (4) Comparison between observed and calculated heads in steady state

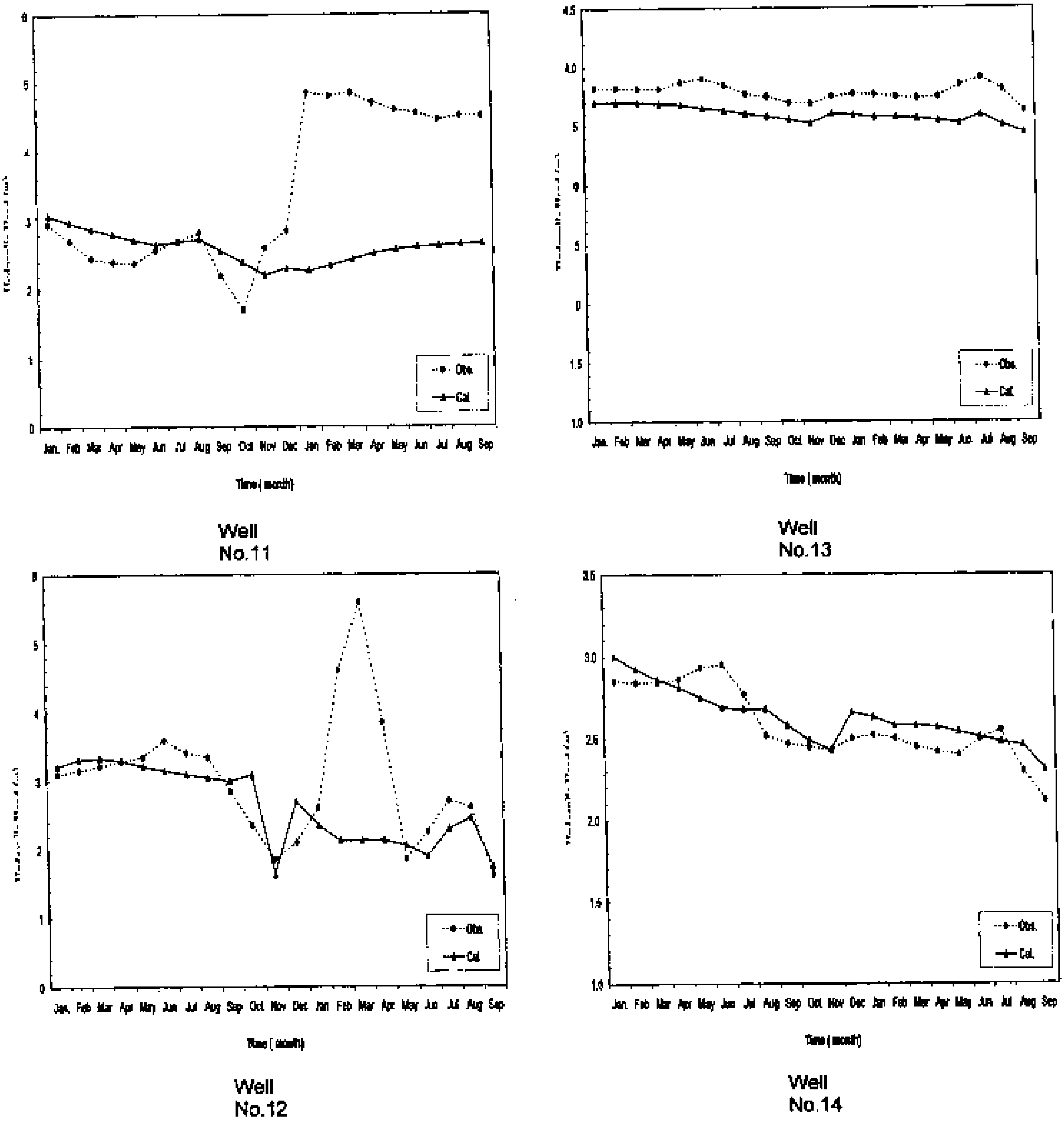


Fig.(5) Comparison between observed and calculated heads in unsteady state.

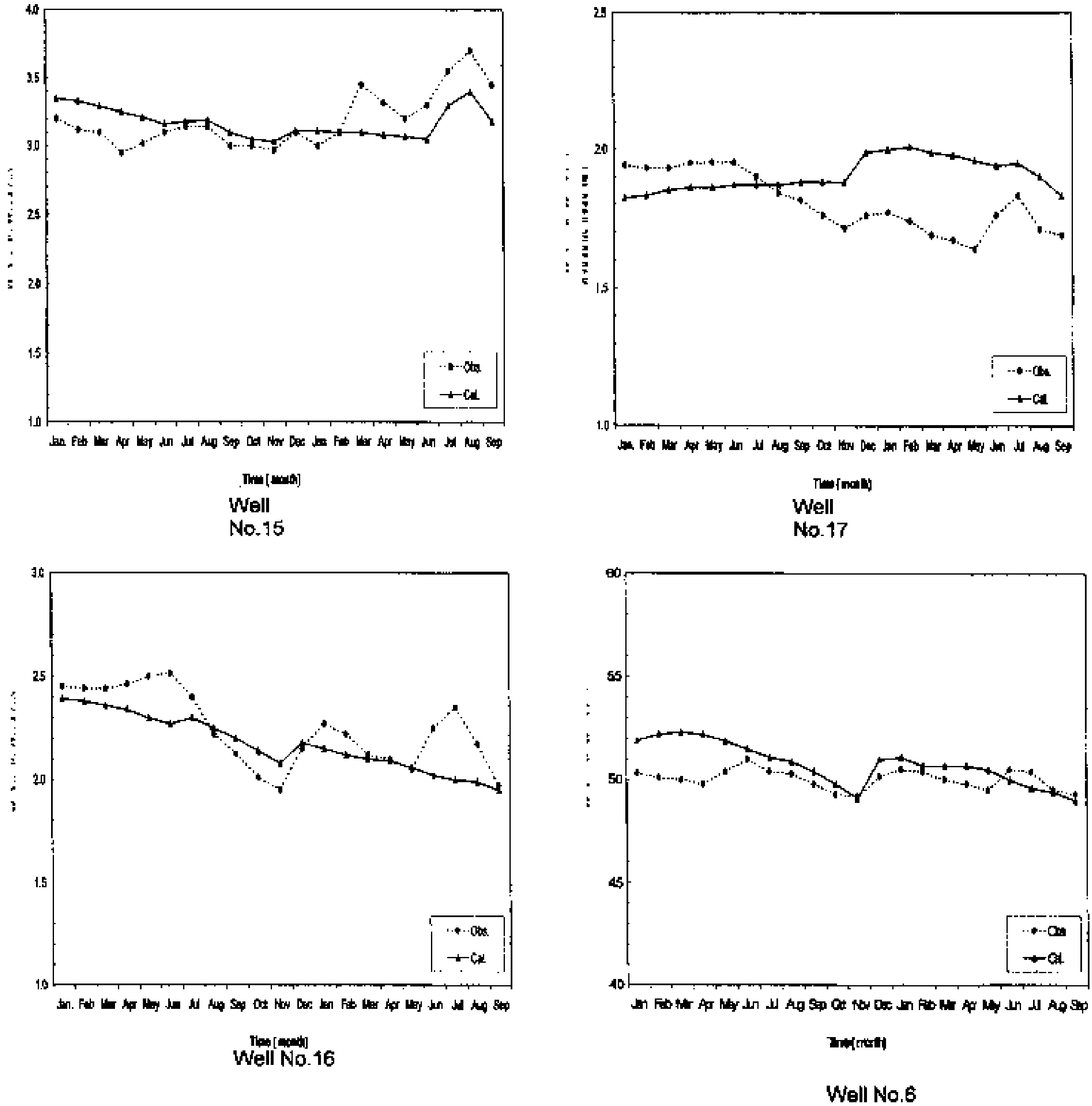


Fig.(6) Comparison between observed and calculated heads in unsteady state.

Verification of Model Performance

After the process of calibration, a verification test is commonly performed to check the model adequacy to represent the hydrogeolgic system. To verify applicability of the model prepared for the area under investigation, a comparison is made between the calculated heads and the measured heads of groundwater for June month in the year 2000 (Al-Abadi, 2002) [1] as shown in figure (7). To represent the increasing number of wells which be used for agricultural purpose and according to previous calculations of wells as shown in table (2), number of wells assumed to be increases at a rate of 200 wells per year. Also in representing the rainfall during the verification period, the values of these rainfalls are given in table (3) which is taken from the meteorological recording station in Basrah

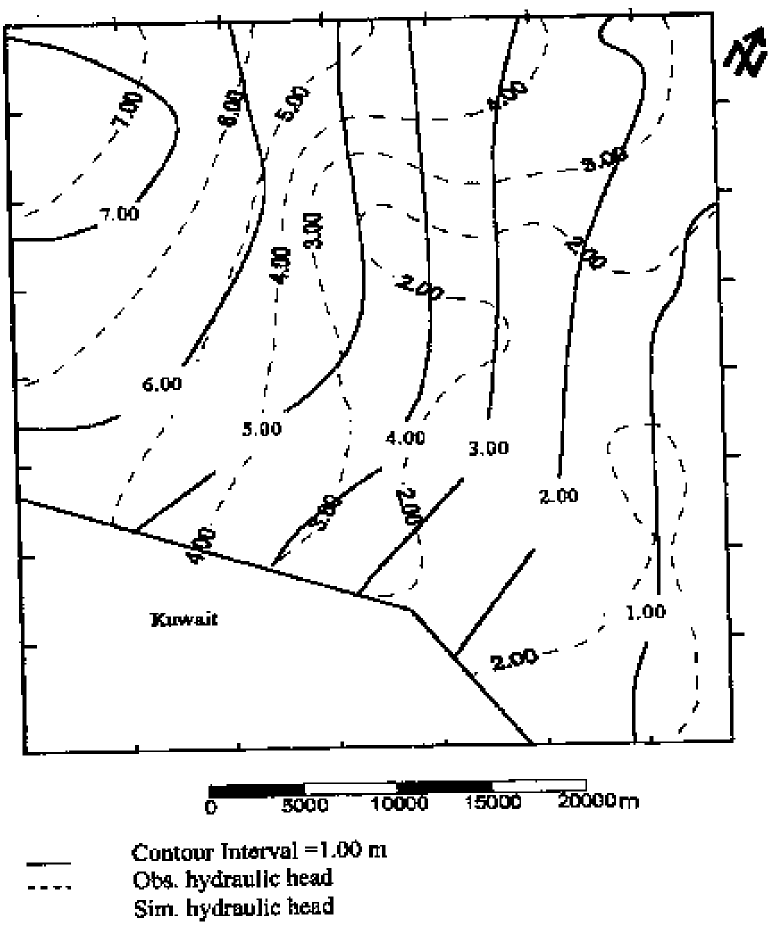


Fig. (7) Comparison between observed head with simulated head for the year 2000

Prediction

The main goal of simulation is to predict the value of the groundwater in Safwan. Al-Zubair area for the year 2010 and assessing the magnitude of changes in the level of groundwater in regard to the increasing demand for agricultural purposes, and regular distribution of wells. Rainfall quantities for the period (1990-2000) is used for representation the recharge quantities for prediction periods. Figure (8) shows a comparison between the levels of groundwater in the year 2000 and that of the year 2010

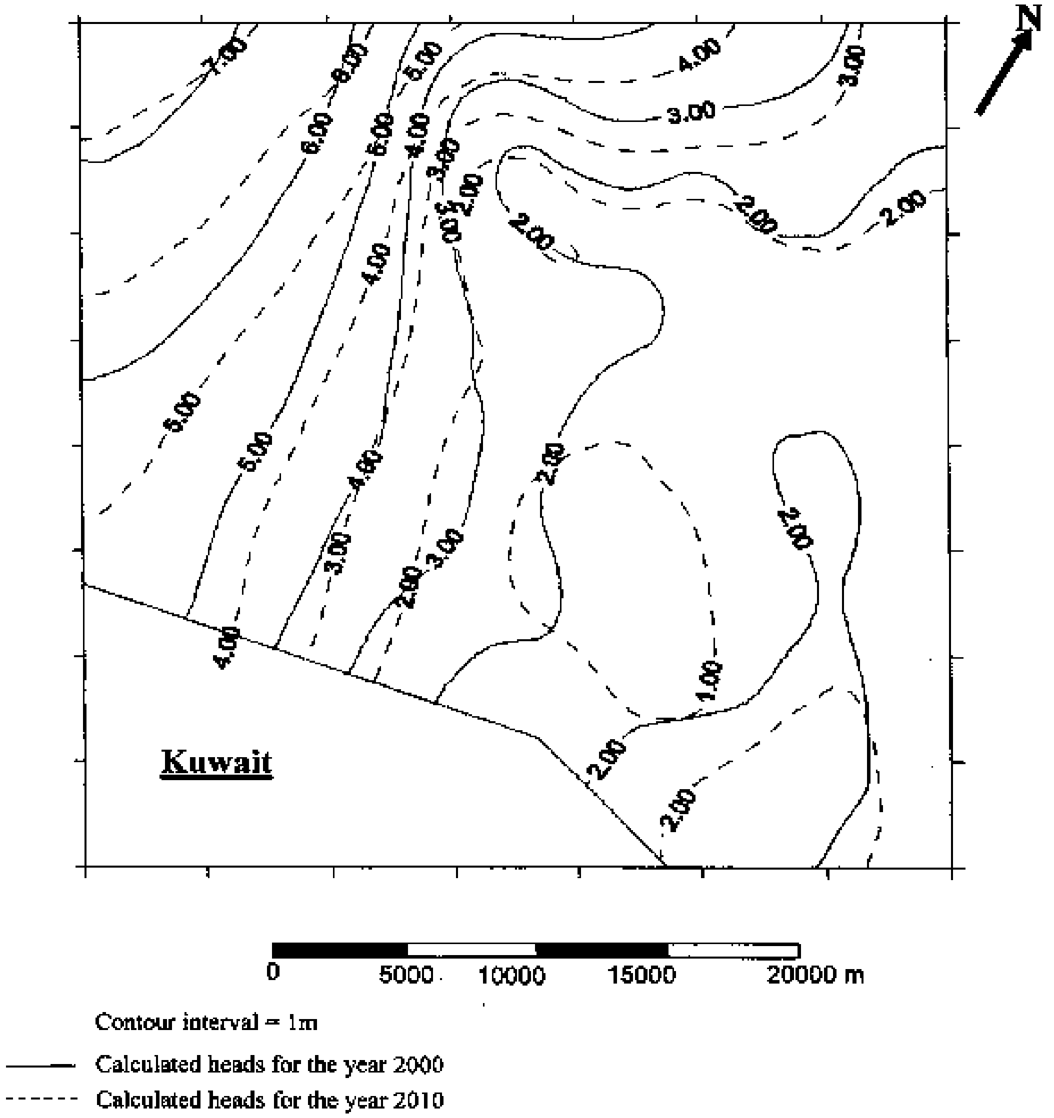


Fig. (8) Comparison between calculated heads for the year 2000 and the year 2010

Results and Discussion

1-There is great similarity between observed and simulated groundwater levels in the steady state flow. This is naturally depends on the extension of the area and sensitivity of hydraulic parameters such as hydraulic conductivity, Fig. (4).

2-A good degree of similarity appears between the observed and simulated heads of groundwater with the exception of wells No.(11), and No.(12). At well (11) some significant difference between the calculated and observed levels has been found to be (2.58m) in January and well (12) where the difference reads (3.47m) in March. This difference can be attributed to some error in the process of measurements so that there is no acceptable reason to have a rise in the groundwater level of (2.02m) in well (11) and (2.0m) in well (12).

3-According to figure (7) there is some differences between observed and simulated heads of groundwater for the year (2000). This difference is estimated to be about (1m) in the western parts as well as this difference may increases in the central parts. Difference can be attributed to the following reasons:

- There is no complete data concerning number of wells for the period (1990-2000)
- There is no maps showing the distribution of the wells, which were used for agriculture purposes.
- There is no enough data concerning the farms that make use of furrow irrigation and those farms using trickle irrigation. Similarly, there is no calculation concerning the number of farms that have changed from furrow irrigation to trickle irrigation. All these factors affect the percolation quantities from irrigation water into groundwater.
- The area has no enough observation wells to assess the initial level of groundwater.
- The simplicity of the tools which were used to measure the groundwater levels by (Al-Abadi, 2002) [1], which effect the accuracy of his measurement.

Conclusion

Figure (8) shows a comparison between the levels of groundwater in the year 2000 and that of the year 2010, it can notice there is a decrease of about (1m) in the central parts of the area under investigation. These decreases in levels due to presence of wells are installed in these parts. On other hand, the decrease in groundwater levels is about (0.5m) in the western parts of the study area. The predicted values of the groundwater in Safwan. Al-Zubair area for the year 2010 indicated that the dewatering of the aquifer being surveyed is expected to occur if the existing trend in growth of drilling wells will continue. The calibrated model can be used, if necessary data available, to establish the response of the aquifer to artificial recharge which is suggested to enhance the water availability and rebalance the aquifer in other context.

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Table (1) Water surface level of Shatt Al-Basrah canal in upstream and down stream of regulator (m).

[illegible]	[illegible]			[illegible]		
[illegible]	[illegible]			[illegible]		
Jan.	1.4	1.3	1.2	1.5	1.5	1.5
Feb.	1.4	1.3	1.1	1.7	1.6	1.5
Mar.	1.5	1.5	1.7	1.8	1.8	1.8
Apr.	1.4	1.4	1.6	1.7	1.8	1.7
May.	1.6	1.4	1.7	1.8	1.8	*
Jun.	1.5	1.5	*	1.8	2.0	*
Jul.	1.6	1.5	*	2.1	1.9	*
Aug.	1.6	1.5	*	2.0	1.8	*
Sep	0.9	1.4	*	2.2	1.7	*
Oct.	1.5	1.5	*	1.8	1.8	*
Nov.	1.5	1.4	*	1.7	1.7	*
Dec.	1.5	1.2	*	1.7	1.5	*

*** Data is not available**

Slope of water surface = 1.5 cm: 1 km.

Table (2) Number of wells in the study area for period (1989-1999)

[illegible]	[illegible]	Reference
3000	1989	Al-Jawad et.al (1989)
4000	1995	Al-Kubaisi, 1996
5000	1999	Atia, 2000

Table (3) monthly rainfall data (mm) for the period (1988-2000).

1988	29.3	26.0	19.4	11.51	0.00	0.00	0.00	0.00	0.00	0.00	30.00	19.5
1989	5.00	19.3	29.20	0.00	0.80	0.00	0.00	0.00	0.00	0.00	27.7	29.3
1990	8.60	15.40	9.30	1.80	0.60	0.00	0.00	0.00	0.00	0.00	11.60	1.00
1991	45.7	41.6	61.2	2.70	0.00	0.00	0.00	0.00	0.00	13.3	1.20	21.4
1992	51.1	16.1	37.0	0.00	1.50	0.00	0.00	0.00	0.00	0.00	25.10	34.4
1993	48.4	38.4	7.80	6.12	10.0	0.00	0.00	0.00	0.00	6.20	2.50	3.10
1994	6.90	0.70	40.3	8.20	4.30	0.00	0.00	0.00	0.20	41.10	23.71	27.60
1995	8.90	20.2	28.5	18.3	0.00	0.00	0.00	0.00	0.00	0.00	0.60	54.80
1996	67.5	47.0	22.9	58.4	8.40	0.00	0.00	0.00	0.00	0.00	4.70	5.30
1997	50.60	0.00	78.7	28.8	5.00	0.00	0.00	0.00	0.00	0.00	41.00	27.5
1998	47.00	4.30	20.0	2.20	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.10
1999	43.0	57.5	33.1	0.3	4.0	0.00	0.00	0.00	0.00	0.00	22.2	37.5
2000	41.1	25.0	36.6	20.0	3.7	0.00	0.00	0.00	0.00	9.2	13.4	27.9