Simulation of Flow Regime of Dibdibba Dandy Aquifer in Safwan-Zubair Area, South of Iraq

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Abstract

A two-dimensional model is constructed to simulate the flow regime of the upper part of Dibdibba sandy aquifer in Safwan-Zubair area, south of Iraq. Although the Dibdibba Formation is a multi-layer system in the surveyed area, the suggested conceptual model which is advocated to simulate the flow regime of aquifer is fixed for one layer, i.e., the activity of the deeper aquifer is negligible. The model is calibrated using trial and error procedure in two stages: steady state followed by transient state. The outcome of the calibration process demonstrated considerable spatial variations in transmissivities and storativites of the aquifer system. A very good similarity between the observed and simulated groundwater levels in the steady state calibration is observed. A reasonable representation of the hydraulic gradient over the mode area which consistent with relative magnitude of hydraulic conductivies is obtained during this calibration stage. Transient calibration is undertaken to calibrate the aquifer storage parameter after the steady state calibration is achieved. The transient calibration results are evaluated by comparing water levels at eight observation wells. Good matches are observed for all cases. The reliabilities of calibrated parameters are checked through sensitivity analysis. Verification test is also added to ensure that the calibrated model could be an adequate counterpart of the actual groundwater system and to verify the reliability of the model results. The model is verified against the measured heads during June 2000. The verified model is utilized to predict behaviour of the aquifer over a planning horizon of 10 years (2000-2010) under two developments scenarios. The management plans are undertaken with continuity of existing trend of growth of pumping wells, i.e., 200 wells per year and without growth and still the situation is similar to that in year 2000. The first run indicates that the decline of groundwater heads of about one meter in the central part of the area and of about 0.5 meter in the northern and western parts is expected. The outcome of the second run demonstrates that no significant changes from 2000 status have occured. The calibrated model can be used, if necessary data is available, to establish the responses of the aquifer to artificial recharge which is suggested to enhance the water availability and rebalance the aquifer in other context.

الخلاصة

استخدم نموذج رياضي لتمثيل نظام الجريان للجزء الاعلى من مكمن الدبدبة الرملي في منطقة سفوان– الزبير، جنوب العراق. تمت معايرة النموذج باستخدام طريقة المحاولة والخطأ لحالتي الجريان المستقر وغير المستقر. اوضحت نتائج تمثيل الحالة المستقرة تطابقاً جيداً مع القياسات الحقلية للمناسيب ولوحظ بان النموذج في هذه الحالة يتحسس بشكل كبير للتغيرات في قيم معامل الناقلية. ولقد كان سلوك المناسيب المحسوبة باستخدام النموذج في حالة الجريان غير المستقر مشابهاً لسلوك القياسات الحقلية مع الاخذ بنظر الاعتبار الاختلاف في درجة التطابق بين بئر واخرى اعتماداً على توزيع معدلات الضخ وتوزيع الخصائص الهيدروليكية

للمكمن المائي. بينت اختبار تحليل الحساسية لهذه الحالة من الجريان تاثرالنموذج بشكل كبير للتغيرات في قيم معامل الخزن. وللتثبت من نتائج النموذج شغل الاخير وقورنت المناسيب المحسوبة مع تلك المقاسة للمنطقة للعام 2000. استخدم النموذج المعاير للتنبؤء بسلوك المكمن المائي خلال عشر سنوات (2000−2010) تحت خطتي تطوير مفترضتين. تضمنت الاولى وجود نفس الاتجاه لزيادة عدد الابار في المنطقة اي 200 بئر في السنة والخطة الثانية تضمنت عدم وجود مثل هذه الزيادة وبقاء الحال على ما هو عليه في العام 2000. اوضحت نتائج التنبؤء وفق الخطة الاولى بان المنطقة ستعاني من انخفاض ملحوظ في مناسيبها قد يصل الى اكثر من (0.5 م) في الجزئين الشمالي والغربي من المنطقة. اما نتائج التنبؤء وفق الخطة الثانية فقد اوضحت بقاء الحال على ما هو عليه بدون حدوث تغيرات كبيرة في المناسيب. ان النموذج الرياضي المعاير يمكن ان يستخدم فيما اذا توفرت المعلومات الضرورية لتقييم استجابة المكمن المائي لعملية الشحن الصناعي المقترحة في دراسات سابقة لتلافي تدهور المكمن.

Introduction

Safwan-Zubair area is located at south of Iraq. It represents the southern sector of Iraqi Desert which is an arid region with scare and finite water resource Fig.1. The average annual rate of rainfall is 148 mm or less, while the evaporation rates are very high (reach to 3534 mm) **[1]** due to dominance of desertic climatic condition. Because no perennial river exists, groundwater is a major natural resource within the interested area. The upper part of Dibdibba formation, a clastic sandy unconfined aquifer, is the only aquifer that contains natural relatively brackish water resource available in the area. The groundwater is being overused for agricultural usages. Mismanagement of this resource over the last five decades has moved groundwater system into the period of instability, and without adequate policy, it is also at risk of contamination. The reduction of groundwater storage of the usable aquifer and the drop in its hydraulic heads during the last three decades has led to the marked deterioration of groundwater quality. The upward seepage of the saline water of the deeper aquifers below the interested one has become one of the sources of groundwater deterioration. To deal with this situation, it is vital that we become more acknowledgeable in the way in which we protect groundwater in the area of question to ensure sustainability of developments. Numerical modeling is considered the most powerful means to identify the state of groundwater and provide a relevant and useful scientific tool for predicting impacts and developing management plans. The purpose of this paper is to present a numerical model of the upper part of Dibdibba stratified aquifer because there is a growing need to carry such a study that will provide a relevant evaluation and management of the resource in concern.

Geological Setting

Geomorphological Features:

The area of concern is involved within the Dibdibba plain which is considered as a part of Iraqi Western Desert Fig.2. The topography is relatively flat with a gentle overall slope toward the Euphrates River to its north, and the Shatt Al-Arab River to its east and southeast. Natural ground surface elevations range from (17 to 23 m) above sea level. Some intermittent wadies poorly dissect the landscape of the area. These surface drainages may carry high volumes of runoff after heavily rainstorms especially during winter and spring seasons. These wadies originate from the south and southwest and form a parallel pattern with respect to each other. Sand dunes represent other land forms within the area. They are located in the southern and western part of the region. A singular significant relief within the area is Jabal Sanam, a rounded hill which rises about (150 m) above sea level. There is a significant depression with a depth of about (3 to 4 m) located to the east and northeast of Jabal Sanam. This depression is linked with the formation of Jabal Sanam **[2]**. Tidal flat is also distributed throughout the area at Khor Al-Zubair region.

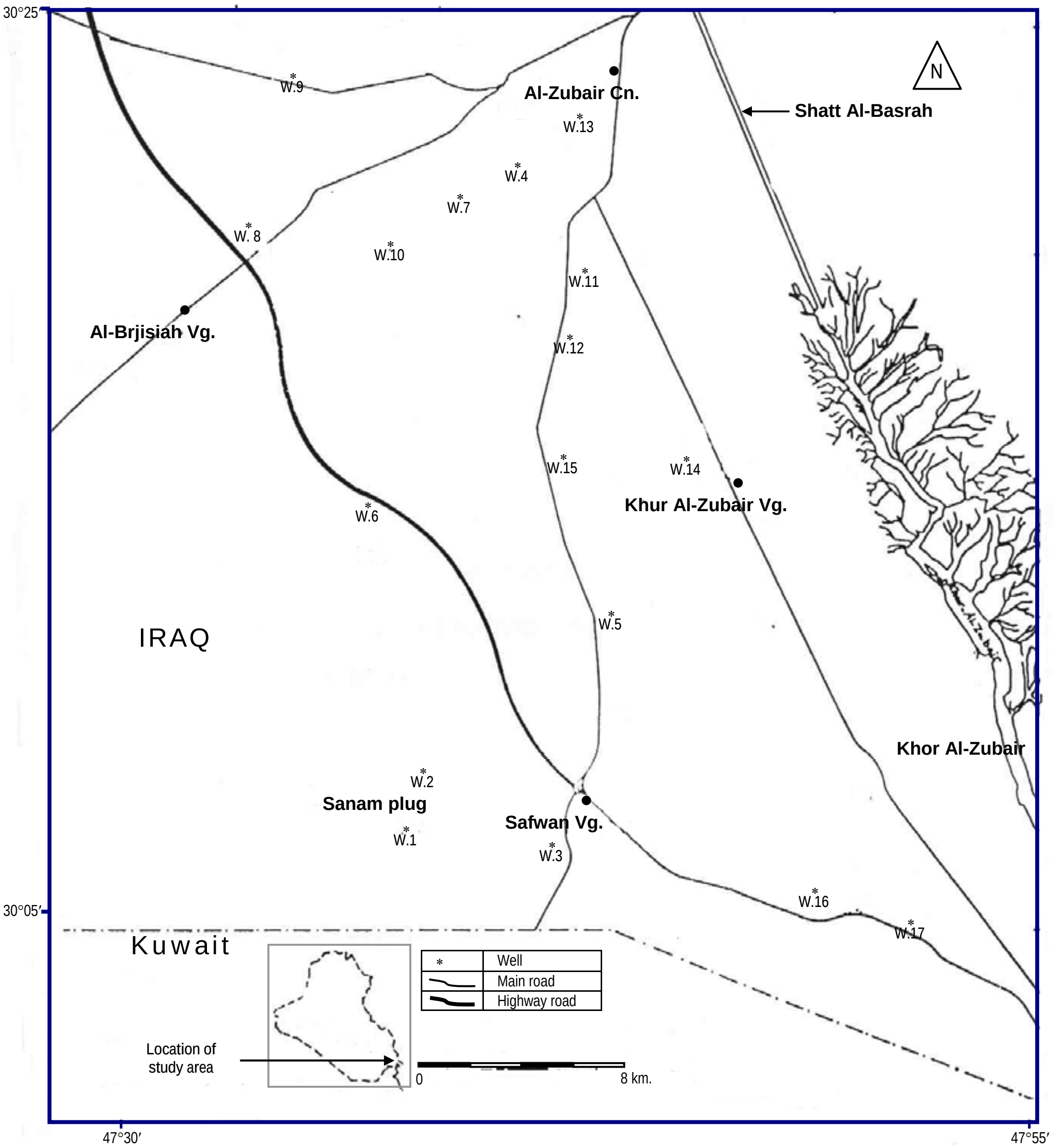


Figure (1): Location map of study area

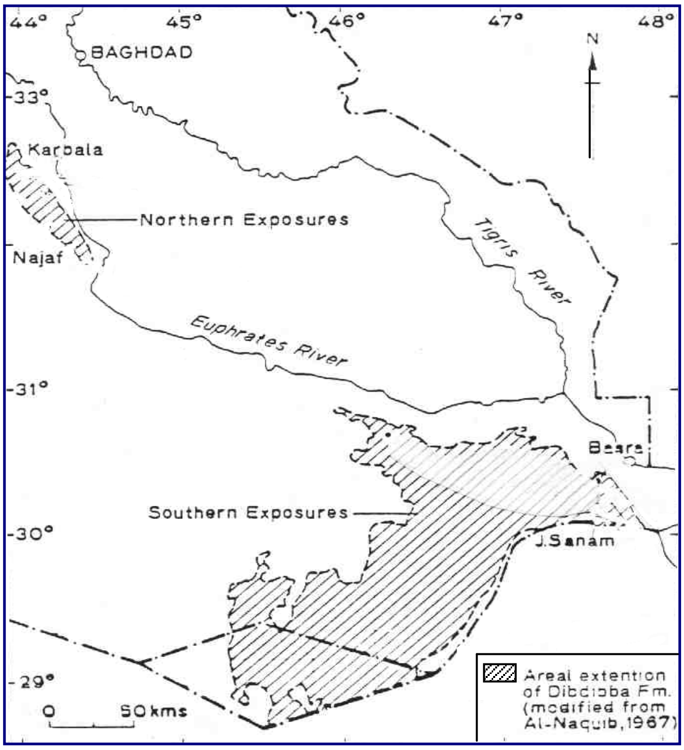


Figure (2): Arial extension of Dibdibba Formation (After Al-Dabbas [3])

Stratigraphical Setting

Dibdibba Formation (Pliocene-Upper Miocene) has a large extension over large areas in the southern part of Iraq, beside some parts in the middle of country Fig.2. The Dibdibba Formation is normally gently dipping and it consists of sand and gravels with some cementing material such as silt and clay. It also contains lenticles of sandstone and silty marl with fibrous gypsum veins Fig.3. Dibdibba Formation sediments are generally known as being changed gradually from marine sediments into river sediments which are crumbs increased [in quantity and the size of granules changed from oldness into moderness, which does not have any index fossils] **[4]**. The maximum thickness of Dibdibba Formation is variable, but there is an evidence that it reaches (350 m) in the northern wells of Zubair oil field. Thickness of the formation decreases gradually toward the south and the west of Iraq. Dibdibba deposits are mainly composed of some minerals such as quartz, feldspar, gypsum and calcite. Dibdibba Formation is underlain by the Fatha Formation (Middle Miocene) which is composed of anhydrite, gypsum, marls and shallow water limestone as shown in Fig.3. Fatha Formation is underlain by the Ghar Formation (M/L Miocene) which is composed of sandstone with subordinate gravels and occasional clay, and is about (150 m) thick. Ghar Formation lies unconformably on the Dammam Limestone Formation (Middle Miocene) which is composed of recrystallized limestone of nummultic facies up to (325m) thick **[5]**.

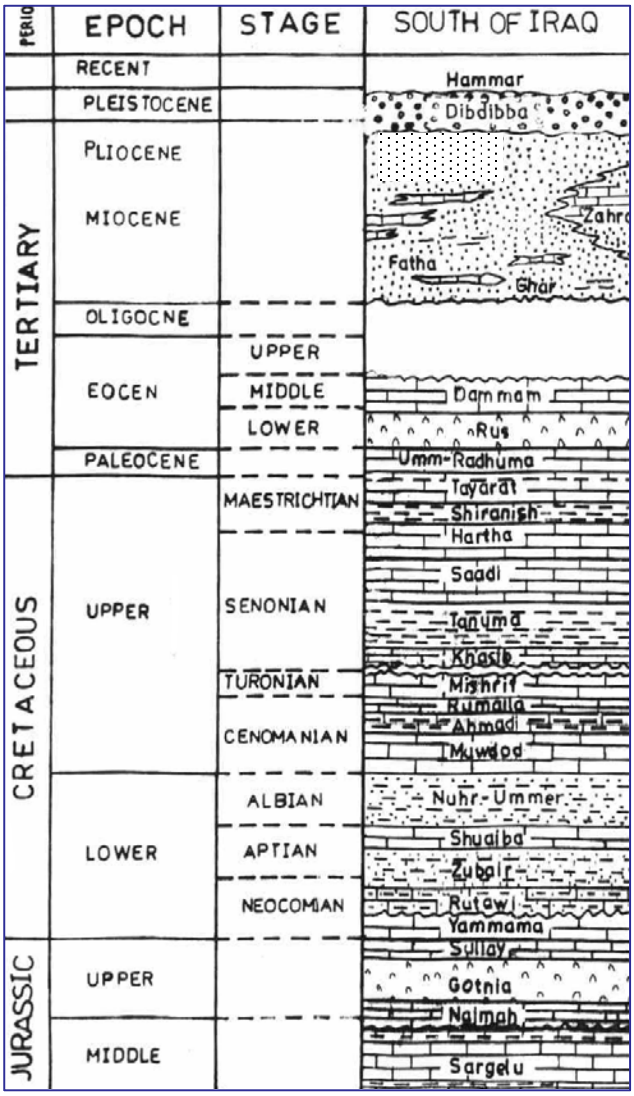


Figure (3): Generalized composite stratigraphic columnar subsurface section, Basrah area (after Al-Naqib [2])

Tectonic Setting

From the tectonic point of view, the area in concern is recognized at Shibica subzone which belongs to the stable shelf. According to the transverse tectonic subdivision of Iraq, the area in question is specified at Basrah zone. Basrah zone includes many faults extending from the northeast to southeast, which discretize Basrah zone into three subzones Fig.4 **[6]**. Due to the fact that these faults are deep, it is advocated that the aquifer system under consideration is not affected.

Figure (4): Tectonic map of the Basrah block (after Al-Kubaisi [13])

Hydrological Setting

As stated by earlier studies **[5]** **[7]** and **[8]**, a multilayer system exists within the Dibdibba Formation. The intervening layers are clayey hard beds with low hydraulic conductivities. The hydraulic continuity between two adjacent aquifers is possible under existing vertical gradients. Due to the fact that a major portion of the pumping wells in the study area ranges in depth between (10-25 m), much of the focus has been on the upper part of aquifer system. This part also represents the only part containing relatively brackish water suitable for agricultural purposes. Over the last three decades, a great number of studies and investigations have been implemented, resulting in a better understanding of the flow regime and hydrochemistry of this part of the aquifer system. It is considered as an unconfined one. The saturated part of it is found to have a maximum thickness of (20 m). The groundwater depths range between (5 to 25 m). Generally, clayey lenses are often disposed throughout the body of the aquifer in its saturated and unsaturated parts Fig.(5,I). Some lenses of the unsaturated part may be formed traps for percolating water and hence, limited extent perched aquifers may be found due to this phenomenon. The base of the aquifer is a varying thickness hard clayey bed with relatively regional extent. Thickness of this bed ranges between (1 to 3 m). The hydraulic conductivity of this lenticular clayey bed is variable, but it reaches (0.38 m/d) **[8]**. The base of the aquifer separates the usable part of the Dibdibba aquifer system from the confined to semi-confined more saline aquifer below. The hydraulic continuity between the two water bodies results in transfer of water between them under the existing hydraulic gradients. Change in the vertical flow rates between the two aquifers would be induced by the head changes in the aquifer system due to the change in the pumping activities. The transmissivity of the aquifer is generally greater than (300 m^2/d), while the specific yield ranges between (0.035-0.40). The flow direction is generally from northeast to southwest with an average of hydraulic gradient of about 0.0018 **[9]**.

Conceptual Model

The proper definition of the nature of a given hydrologic system is the corner stone in the selection of the applicable mathematical model. Lack of sufficient data is another critical reason affecting such selection. Figure (5,II) shows the suggested conceptual model of the upper part of the Dibdibba sandy aquifer in Safwan-Zubair area. The suggested model which is advocated to simulate the flow regime of the aquifer is fixed for one layer. It is assumed that the base of the aquifer is an impermeable boundary, i.e., the activity of the deeper aquifer is negligible. Lacking of sufficient data on the static level of the deeper aquifer which requires more costly piezometric system is the main reason affecting such choice, in addition to the detailed limitations by **[5]**. The comparison between the area prototype and conceptual model is given in Fig.5.

Selection of Numerical code

A graphical interface (GUI) computer program namely Processing Modflow for Windows (PMWIN v.5) is selected to simulate the aquifer behaviour being studied. MODFLOW code

(originally developed by United State of Geological Survey **[10]** is generally accepted as an industry-leading public domain numerical flow model because of the following reasons: (1) its code has been verified against a range of analytical solutions (2) it has been used to successfully simulate a wide range of aquifer systems across the world (3) its code was developed with a modular structure which is considered as the great strength of code **[11]**. Modflow is a computer program that simulates three dimensional groundwater flows through a porous medium by using a finite difference method. In Modflow an aquifer system is replaced by a discretized domain consisting of an array of nodes and associated finite difference blocks (cell). The nodal grid forms the framework of the numerical model. The locations of cells are described in terms of column, rows, and layers. PMWIN offers a totally integrated simulation system for modeling groundwater flow and transport process with MODFLOW-88, MODFLOW-69, PMPATH, MT3D, MT3DMS, MOC3D, PEST and UCODE **[12]**.

Model grid and boundary conditions

The area of interest was discretized into a non-unifrom grid, consisting of 42 columns and 74 rows. The spatial discretization of grid is fine in the middle of area domain where a great number of wells existing, but it becomes coarse away from this sector of area because it is a good practice to use a smaller grid in areas where the hydraulic gradient is expected to be large (areas around the operating wells). Thus, the area of cell in the middle of the region is equal to (500 × 500 m) and begins to increase toward the edges of the model area. In the present model, the northern, southern west and southern edges of the area almost parallel with the flow lines Fig.7, Therefore, these boundaries are represented as no flow boundaries Fig.6. The eastern edge of the model area is considered as a constant head boundary because the canal of Shatt Al-Basrah River lies along this edge. The data concerning the canal stage was obtained from the General Faculty for the Operation of Estuaries River for the period (1999-2001). The data for the period (1988-1989) is not available and accordingly this period was discarded. The western boundary is modeled as head-dependent boundary to allow inflow to the modeled region at a rate proportional to the dead difference between the aquifer outside the simulated area and the model boundary. The top of the model was represented as unconfined aquifer. The water table elevation changes as part of the model solution. The bottom of the model was represented as a no-flow condition. The vertical location of this boundary was selected to correspond with the base of the aquifer (the hard clay layer).

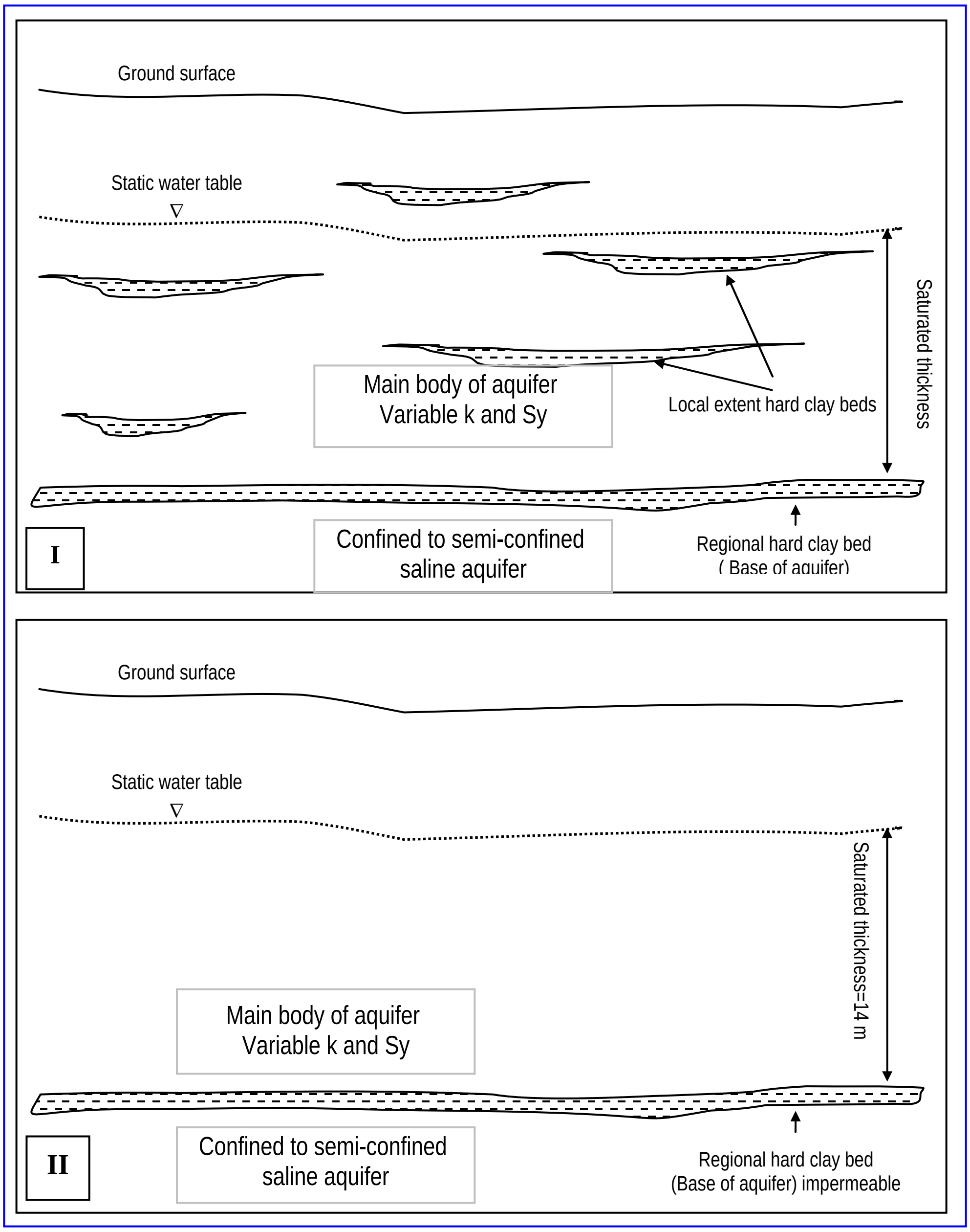


Fig. (5): (I) the area prototype diagram (II) the area model diagram

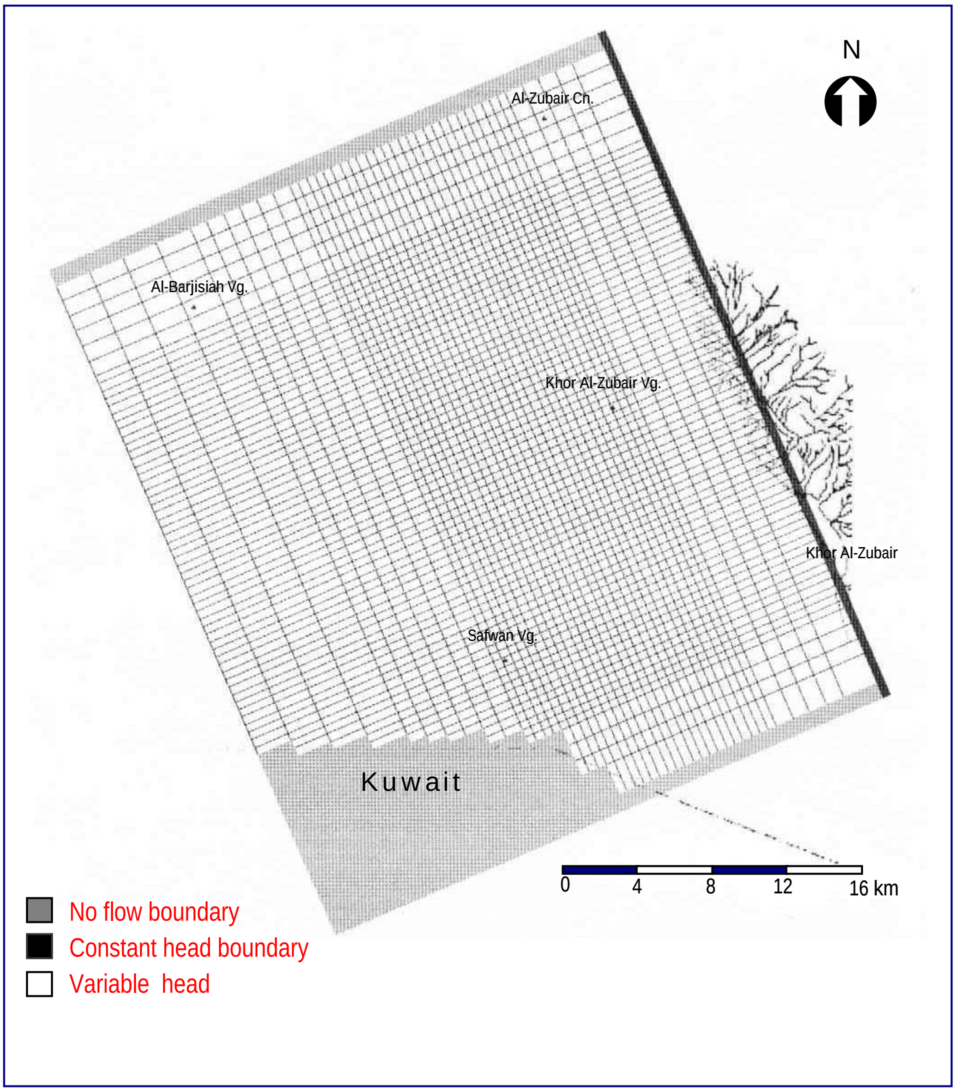


Fig.(6): Configuration of modal network and boundary conditions

Input data

Initial Phreatic surface distribution

Although groundwater resource in the area in question has been exploited during the last 50 years, there is no data available about the start of the groundwater usages. However, it is known that heavily groundwater exploitation started about 30 years ago, when diesel pumps were introduced. Scientific Research Council (SRC) provided data on the spatial and temporal distribution of measured water levels for the period (January, 1988 to September, 1989). Map of the pseudo-steady state phreatic surface of the upper part of Dibdibba Formation was developed depending upon this data Fig.7. Examination of this map shows a general flow pattern from west and southwest to east and northeast, towards the Khor Al-Zubair and Euphrates River respectively. Generally, the hydraulic gradient is low over the whole area and the pattern of equipotential lines reflects the homogeneity of aquifer.

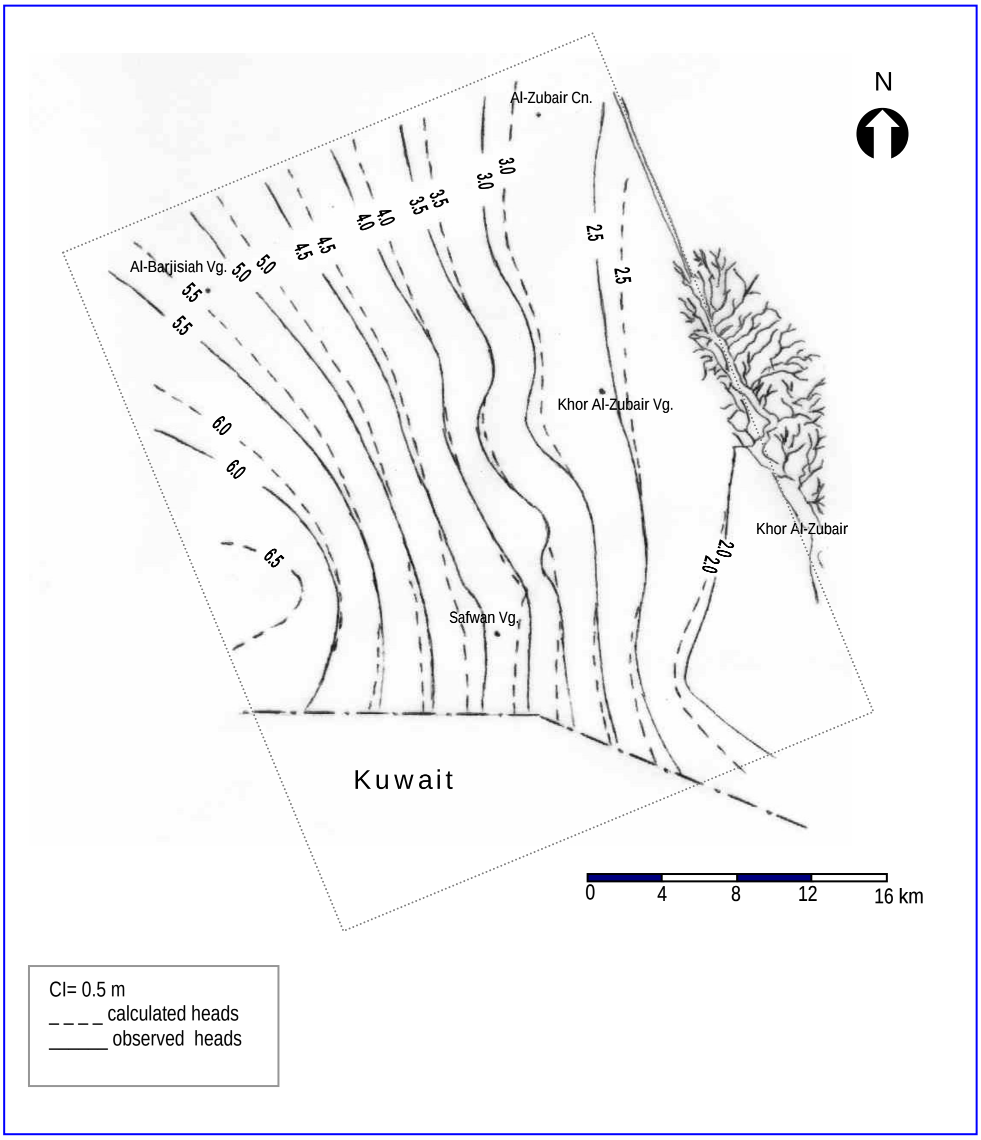


Fig. (7): Distribution of simulated and observed static hydraulic heads

Initial Assessment of hydraulic characteristics

Several filed tests have been conducted to assist the hydraulic characteristics of Dibdibba Formation in Safwan-Zubair area in both shallow upper and lower levels **[5] [7] [7] [8] and [13]**. The spatial distribution of hydraulic characteristics over the model area is concluded depending on the numerical solution technique results which recently applied by **Atiaa [9]**.

Extracting rates and distribution of pumped wells

Most irrigation wells of Safwan-Zubair area penetrate the quadral sediments and then Dibdibba Formation. Large diameter hand dug wells are commonly used for abstract groundwater compared with tube wells due to **(1)** shallow depths of water table **(2)** high well capacity **(3)** and the seepage area they are provided. Hand dug wells are conducted randomly with non-unifrom shapes. Operating wells are located at various spaces from each other, ranging from (500 to less 100 m). Therefore, interfering among adjacent wells is possible under the existing pumping activities. Pumping rates of wells are variable and may range from (5 to 8 L/s). The average of pumping rate is taken as (7 L/s). No data concerning the exact number of wells is available, but there is only an approximated gathered data in some water years Table.1. It is worth noting that it was not possible to distribute the wells over the area in 1988. Examination of the second editions of the area map which is produced by the Iraqi

Military Forces in 1999 reveals that one can find out how wells were distributed during this year. Figure 8 shows the advocated wells distribution based on the map mentioned above. The number of pumping hours is determined in the light of agricultural season. The pumping period is nearly most of the day hours, which extended to (12 h/d) in the period from November to May and (20 h/d) in August, September and October. The maximum total period of total stress of irrigation reaches to 198 days **[14]**. Duration of total stress is divided into three time periods of pumping (Table 2). Because the soil does not possess water except for a very short time, percentage of irrigation water that returns to the groundwater system is estimated to be (84%)**[1]**. Propagation of the trickle irrigation system usage decreases this quantity because this system leads water to be evapotranspired instead of percolated into the groundwater system. The uses of this irrigation method increased considerably with time because it is easily constructed and economical in irrigation water amounts. In the present study, the percentage used to represent the percolated quantities of water that return back to groundwater from irrigation water is assumed equal to 70% and only 30% of water is consumed.

Table (1): Numbers of well in study area during some water years

well No.	Date	Reference
3000	**1988-1989**	**Al-Jawad et al. (1989)**
4000	**1995-1996**	**Al-Kubaisi (1996)**
5000	**1999-2000**	**Atiaa (2000)**

Table (2): The stress periods of pumping during one water year (After Al-Abidi [14])

stress period	pumping hour per the day	percentage of pumping time
Relaxation period	**00.00**	**0.00**
concentration pumping period	**20.00**	**80%**
Normal pumping period	**12.00**	**50%**

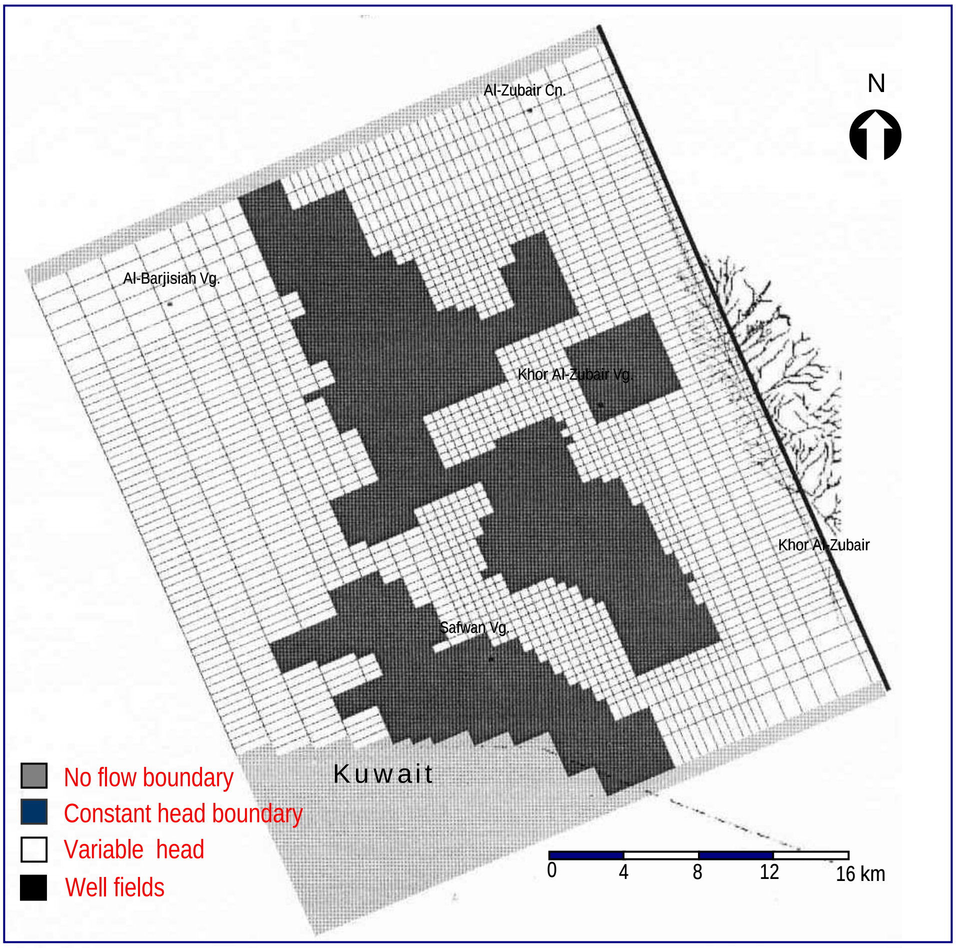


Fig. (8): Advocated distribution of pumping well fields over the study area

Direct recharge

The previous studies that deal with recharge arrived at different results and conclusions with reference to the percentage of rainfall which percolate to the groundwater. Haddad and Hawa **[1]** and Al-Rawi et al. **[12]** hypothesized that the percentage of recharge lies between (17-26%) and (3.3-14.3%) respectively. Hydrogeological conditions permit 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 are no significant valleys that collect water in the study area with the exception of Al-Battin valley. These valleys are small and short, that is why one can accept that the surface runoff may be of little amount. (3) Owing to the nature of the soil under study, it is believed that such soil does not remain wet for a long period, as water either percolates to the groundwater or evaporates to the atmosphere. For this reason, the saturation factor is neglected when calculating the components of water budget. From what has been mentioned above, it is assumed that the percentage of the percolation water from rainfall is equal to (20%).

Calibration of the model

Processing MODFLOW for windows (PMWIN) supports two methods to calibrate a given model: trial-and-error and automated calibration. Recently, there is a trend way from trial-and-error to automated calibration because the first method is recognized to be labour intensive (therefore expensive), frustrating (therefore often left incomplete) and subjective (therefore biased and leading to results the quality of which is difficult to estimate **[16]**. Calibration of the model was accomplished by manual trail-and-error procedure. This is partly because of difficulties inherent in inverse modeling technology, which is related to the mathematics used to represent the process, the complexity of the simulated systems, and the sparsity of data in most situations; and partly due to a lack of effective, versatile inverse models**[17]**. In addition, an automatic calibration does not necessarily lead to a success **[12]**. In the trial-and error calibration process, the independent variables (Parameters and fluxes) of a model are adjusted manually, in successive model runs, to produce the reasonable match between the simulated and measured data. Calibration of the model was carried out in two sequential stages, a steady state calibration followed by transient calibration. The model was calibrated according to the fifty measured hydraulic head for the steady state condition and depending on the historical groundwater elevations at eight observation wells for the transient condition as shown in Fig.1.

Steady state calibration: steady state simulation is used to model equilibrium conditions where aquifer storage changes are not significant. Thus, dynamic stress and storage effects are excluded from the steady state calibration process. The aim of this calibration stage is to obtain a reasonable representation of the hydraulic gradient over the model area which is consistent with the relative magnitudes of hydraulic conductivities. Comparison between the observed and calculated heads for this calibration is shown in Fig.7. As shown in the figure, there is a great similarity between the observed and simulated groundwater heads. This naturally depends on the extension of the area and sensitivity of hydraulic parameters such as hydraulic conductivity. The final calibration distribution of hydraulic conductivity over the model area is shown in Fig.9.

Transient Calibration: After the steady state calibration was achieved, transient calibration was undertaken to calibrate the aquifer storage (specific yield) parameter. The results of steady state calibration were introduced as initial conditions for the transient calibration. The transient calibration results were evaluated by comparing the temporal variations in simulated heads with those of observed water levels at eight target locations (observation wells). Generally, good matches were observed for all cases Fig.10. The spatial calibrated distribution of specific yield is shown in Fig.11. Table (4) shows the unweighted groundwater levels calibration statistic (m).

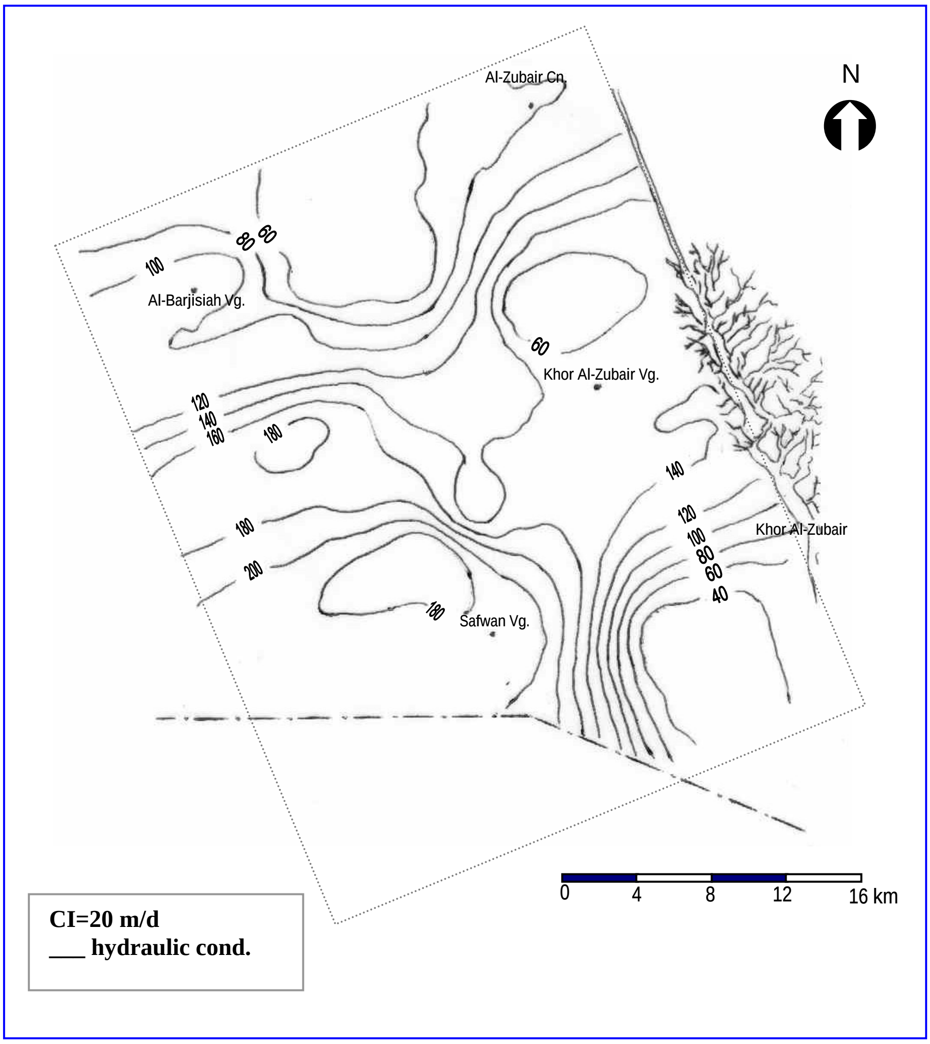


Fig. (9): Distribution of calibrated hydraulic conductivity values over the study area.

Sensitivity Analysis

In the simulation of the aerial aquifer system, modelers are often faced with uncertainty as the exact values assigned to the physical parameters of the system. Therefore, one must conduct a sensitivity analysis to identify the limits within which the values of the parameters of physical system may vary without appreciably affecting the models. Its purpose is to identify those parameters which are most important in determining the aquifer behaviour. Sensitivity analysis of the model being studied was carried out in two stages:

Sensitivity analysis of steady state condition: It became clear that changes in the values of hydraulic conductivity lead to great improvements in hydraulic heads. On the other hand, it seems that there is some direct effect of the change in the values of hydraulic conductivity imposes on the values of hydraulic heads; this leads to a significant matching between the observed and calculated heads. In steady state, the storage term in equation of groundwater flow is set to zero. Therefore, this parameter is not included in sensitivity analysis table (5).

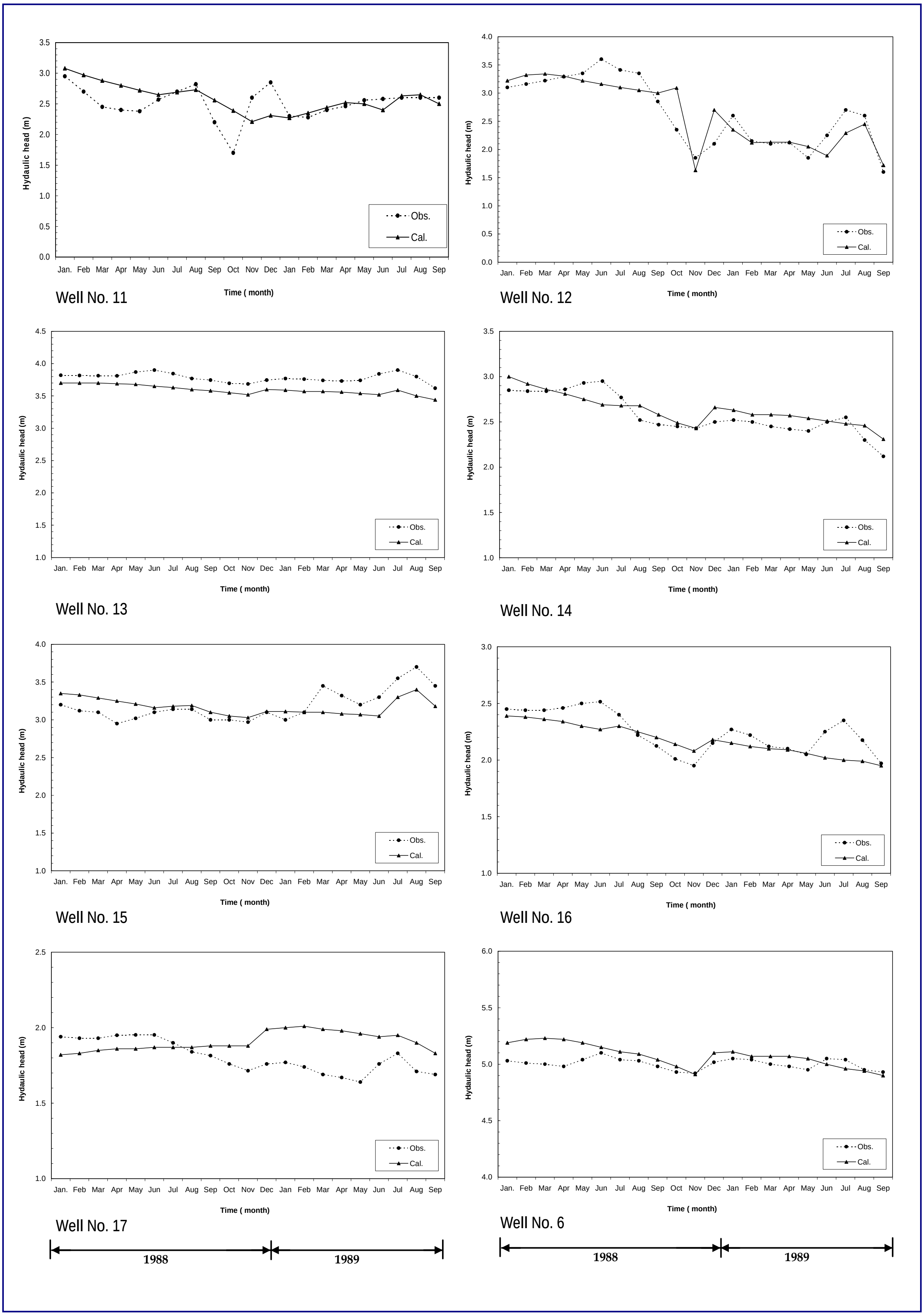


Fig. (10): Comparison between observed and simulated heads at observation wells.

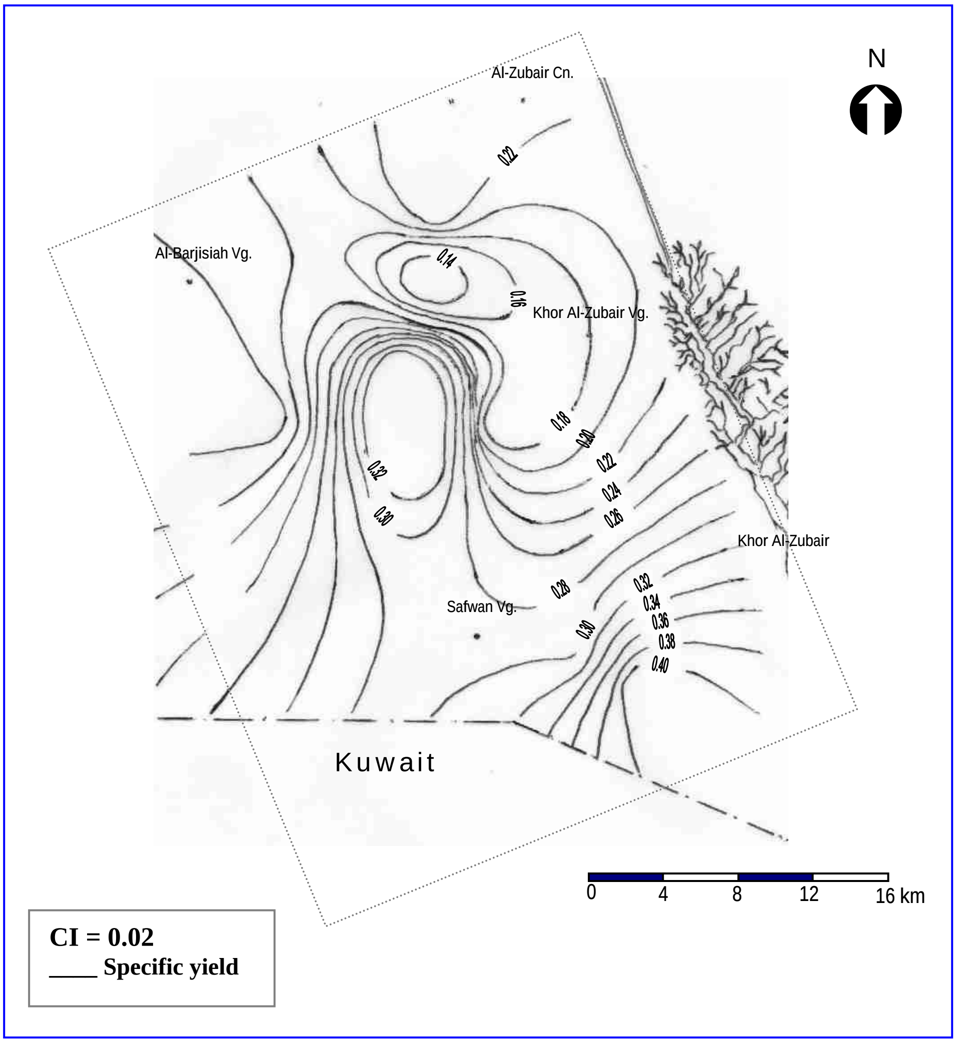


Fig. (11): Distribution of calibrated specific yield values over the study area.

Table (4): Unweighted groundwater levels calibration statistics

Well No.	Calibration statistics*	
	Mean absolute error	Root mean squared error
11	0.250	0.353
12	0.291	0.363
13	0.250	0.282
14	0.123	0.146
15	0.175	0.239
16	0.181	0.299
17	0.132	0.168
06	0.111	0.125

*** are calculated using the following formulas (Domenico and Schartz [18])**

Mean absolute error: $\frac{1}{n}\sum_{i=1}^{n}\left|(h_m - h_s)_i\right|$, **Root mean squared error:** $\left[\frac{1}{n}\sum_{i=1}^{n}(h_m - h_s)_i^2\right]^{0.5}$

Where: n: number of observation, h_m: measured head and h_s: simulated head

Table (5): Sensitivity analysis of steady state

Well No.	Simulated head (m)	Variation of horizontal hydraulic conductivity K_h	
		25%	50%
11	2.95	3.00	3.20
12	3.10	3.45	3.80
13	3.82	3.95	4.30
14	2.85	3.20	3.45
15	3.20	3.45	3.82
16	2.45	2.80	3.10
17	1.94	2.00	2.35
6	5.03	5.30	5.56

Sensitivity analysis of transient condition:

In transient 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 values of this parameter has effected the matching between simulated and measured heads. On the other hand, it has not been proved that there is any sensitivity concerning the changes in the values of hydraulic conductivity. As for the effect of boundary conditions on the sensitivities analyses leads to specific changes in the northern and southern boundaries. The change stems from state of no-flow boundaries into variation heads, no change in the values of hydraulic heads has been noticed.

Table (5): Sensitivity analysis of transient condition

Well No.	Simulated head (m)	Variation of Specific yield Sy	
		25%	50%
11	2.70	2.78	2.93
12	2.00	2.10	2.24
13	3.50	3.60	3.71
14	2.48	2.52	3.65
15	3.25	3.30	3.45
16	1.92	1.98	2.00
17	1.82	1.88	2.00
6	5.01	2.08	2.01

Verification of the model

Verification is a test of whether the model can be used as a predictive tool, by demonstrating that the calibrated model is an adequate representation of the physical system **[11]**. To verify the applicability of the model prepared for the area under investigation, a comparison was made between the calculated heads and those measured during June, 2000 by Al-Abadi (2002) **[15]** as shown in Fig.13. Extraction rates of wells and their numbers during the verification test were concluded according to the assumption that there is a systematic growth of well number at a rate of about 200 wells per year. Direct recharge was also derived from values of rainfall which are taken from the Basrah meteorological station. Based on Fig.13, it is noticed that there is some difference between the observed and simulated heads at end of the verified period but it is within acceptable range. Figure (13) shows the scattergram of measured versus modeled head with unweighted matching statistics.

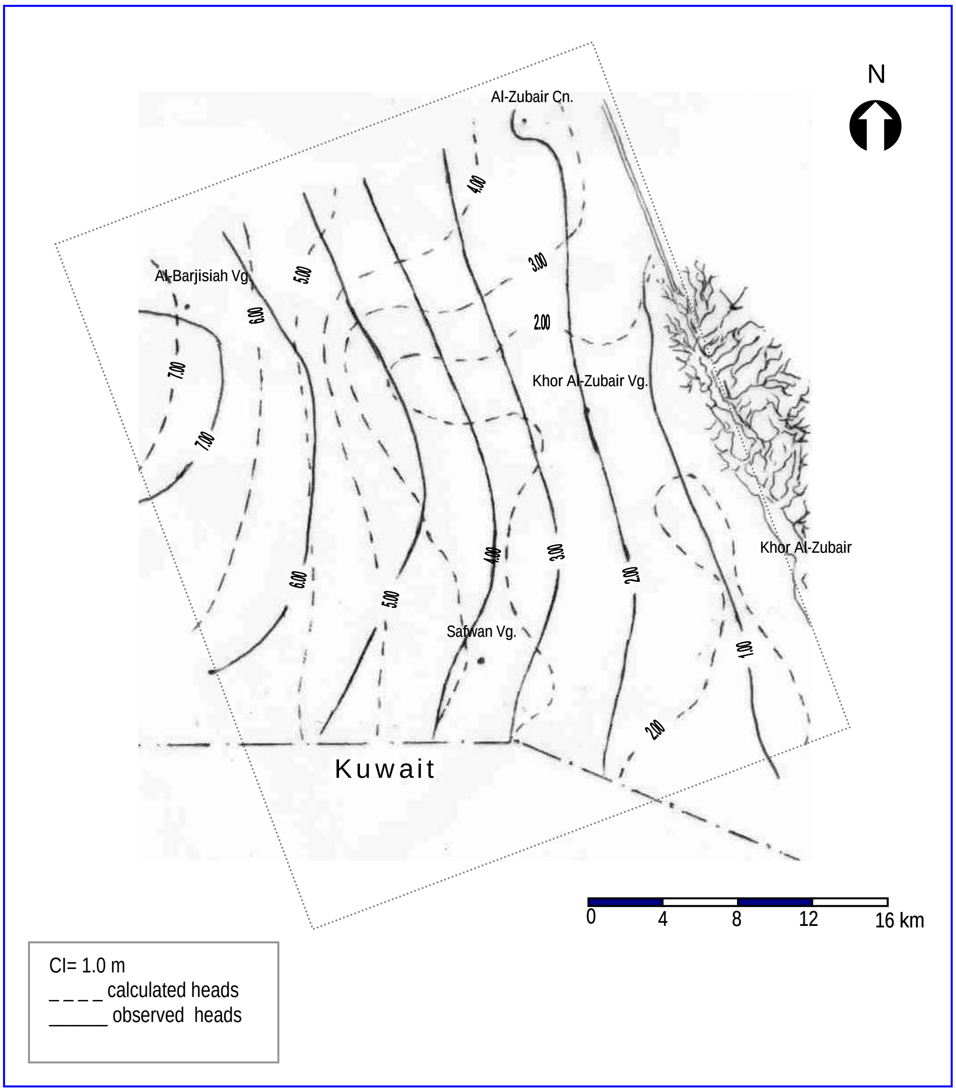


Fig. (12): Comparison between observed and simulated heads for the year 2000

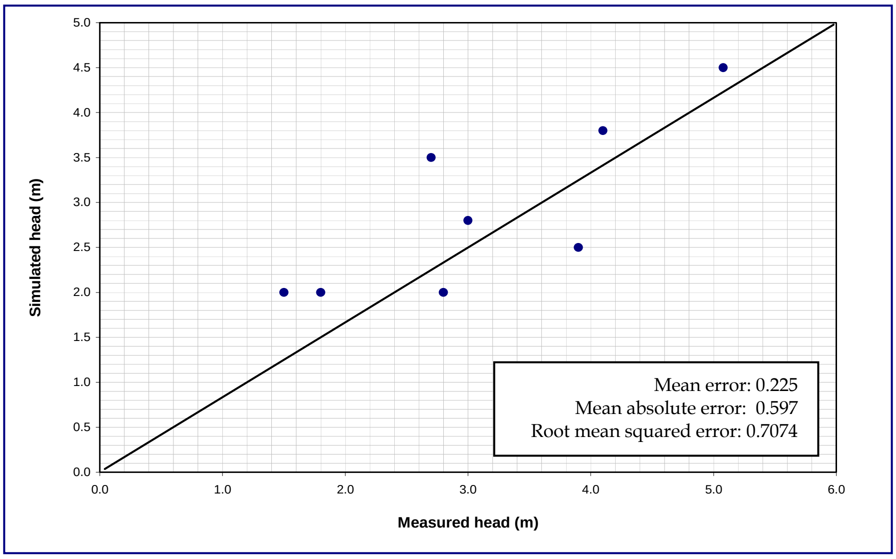


Fig. (13): The scattergram of measured versus modeled heads for year 2000.

Prediction Runs

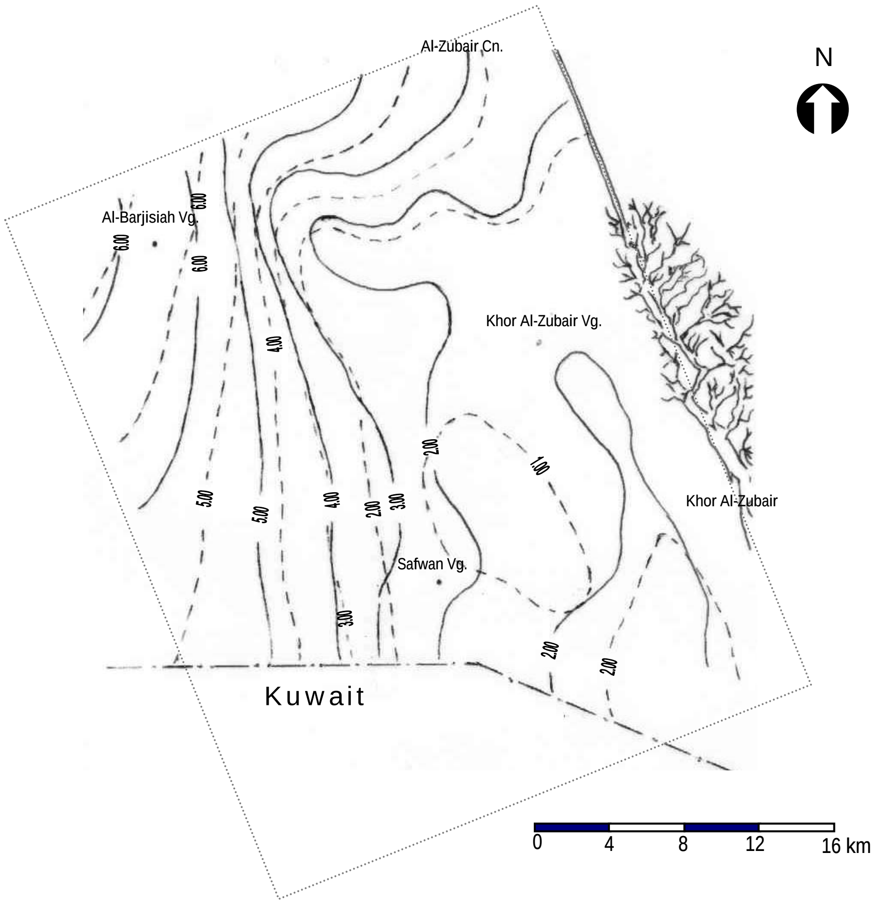
Once a model has been calibrated, and preferably verified, to historical conditions, it would be considered suitable for use as a predictive tool **[11]**. The main purpose of groundwater flow modeling is to carry out resource management predications for specified future periods. Two management scenarios were undertaken by running the model with the adopted (calibrated) parameters. A planning horizon of 10 years was selected for these management plans:

Management Scenario I: Existing trends continue

The first management development plan is based on that the existing trend of growth of operating wells is continuous, i. e., 200 wells per year without any modifications. Figure (14) shows a comparison between the groundwater levels in the year 2000 and that in the year 2010. It can be noticed that the phreatic levels drop to (1 m) in the central part of the area under investigation. This drop in head is expected to occur due to the fact that a large number of operating wells will exist then, in this sector of area. On the other hand, the drop in phreatic levels is about (0.5 m) in the western and northern parts of the area of concern. The result of this run further indicates that water levels will not be stabilized by the year 2000, and that they will continue to decline uniformly beyond that time. Such drop in head, if occurs, is not acceptable in the area of question because most of the hand dug wells will become completely dry. Similar results were indicated throughout the detailed study of water budged of the aquifer **[19]**.

Development Scenario II: No growth

The utilization of groundwater for agricultural needs has remained constant during the planning period. The result of this management plan shows no significant changes from 2000 status.



CI= 1.0 m
_ _ _ _ calculated heads for the year 2000
______ calculated heads for the year 2010

Well No.	Simulated heads (m)		
	2000	2010	difference
11	3.5	2.5	1.0
12	2.8	1.8	1.0
13	3.8	2.8	1.0
14	2.0	1.8	0.2
15	2.5	1.9	0.6
16	2.0	1.7	0.3
17	2.0	1.8	0.2
06	4.5	3.2	1.3
mean			0.7

Fig. (14): Comparison between calculated heads for the year 2000 and that in year 2010.

Conclusions:

A numerical two – dimensional groundwater flow model is constructed for the upper part of Dibdibba sandy aquifer system in Safwan-Zubair area, south of Iraq, to evaluate two development scenarios. Calibration of the model is carried out in two sequential stages: a steady state calibration followed by transient calibration. The reliabilities of the calibrated parameters are checked by sensitivity analysis. The model is verified against the measured heads during June 2000. The calibrated and verified model is utilized to predict the responses of the aquifer over a planning horizon of 10 years (2000-2010) under two management plans. The first management plan is based on that the trend of growth of pumping wells is continuous while the second is based on that the growth ceases and the status of 2000 will remain without any modification. The first run 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 responses of the aquifer to artificial recharge which is suggested to enhance the water availability and rebalance the aquifer in other contexts.

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