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MODELLING OF GROUNDWATER FLOW OF KHANAQIN AREA, NORTHEAST IRAQ

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ABSTRACT

Prediction of aquifer drawdown is important for the management of groundwater system especially in arid and semi-arid regions in which groundwater is a major source for agricultural and domestic requirements. Khanaqin area, northeastern Iraq, is under water stress due to increasing demand of groundwater for different purposes. The use of mathematical model is an important tool to predict the status of the aquifer drawdown. In this study we have used the MODFLOW model to simulate the aquifer in both steady and transient states. Good agreement of the simulated steady state heads with the observed ones is noticed. For transient simulation, the model was run for one year starting from January, 2013 to December, 2013, and the results were compared with the observed head of the three monitoring wells (w4, w8 and w28). The calibrated model is used to predict the drawdown of the groundwater for 4 years under three scenarios: **1)** present discharge conditions maintained, **2)** discharge increase at rate of the irrigation need in the future, i.e from 5L/ sec to 10 L/sec, **3)** increasing well drilling for the next 4 years at specific locations. These scenarios and the resulted head distribution urge for integrated management program for the conjunctive use of both surface and groundwater recourses of the study area.

موديل حركة المياه الجوفية لمنطقة خانقين، شمال شرق العراق

سوسن مجيد علي و علياء شاكرعليوي

المستخلص

يعد التنبأ بأنخفاض مناسيب المياه الجوفية عنصرا مهما لإدارتها خصوصا في المناطق الجافة وشبه الجافة حيث تشكل هذه المياه المصدر الأساسي للاستخدامات الزراعية والمنزلية. تعد منطقة خانقين الواقعة في شمال شرق العراق من المناطق المتاثرة بوضوح بسحب المياه الجوفية لذلك تم استخدام نمودج رياضي لمحاكاة الخزان المائي بحالتيه المستقرة وغير المستقرة. تم الحصول على تطابق جيد بين القيم الحقلية للمناسيب وتلك المحسوبة من الموديل للجريان المستقر كما تم تشغيل الموديل ومعايرته لمدة سنة واحدة لحالة الجريان غير المستقر باستخدام ثلاثة آبار للمراقبة. واستخدم موديل المعاير للتنبأ بمقدار انخفاض المناسيب لفترة أربعة سنوات لاحقة وبثلاث سيناريوهات: الأول باستخدام نفس التصاريف والثاني بمضاعفة هذه التصاريف الى 10 لتر/ثا لكل نقطة سحب والثالث باقتراح حفر آبار جديدة لمواقع محددة في المنطقة. السيناريوهات المختلفه وطبيعة توزيع المناسيب الناتجة تحتم ضرورة استخدام برنامج متكامل لإدارة متقارنة للموارد المائية الجوفية والسطحية في منطقة الدراسة.

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INTRODUCTION

Groundwater plays important roles as main source of water especially in arid and semi-arid regions. Management of groundwater recourses requires understanding of aquifer performance under current conditions, and predicting the impact of recharge and increasing discharge on that aquifer. In order to predict the effect of recharge, discharge and different hydrologic and hydrogeologic impacts on the water table, the aquifer can be simulated using numerical flow modeling (Asghari *et al*., 2005).One of the most popular mathematical model that simulate aquifer behavior is the MODFLOW model (McDonald and Harbough, 1988). MODFLOW is a three dimensional model that simulate flow in heterogeneous and anisotropic saturated and unsteady porous environments. It can be described by the partial differential equation based on Darcy's law and the conservation of mass (Kinzelbach, 1986) as follows:

$$\frac{\partial}{\partial x}\left[K_{xx}\frac{\partial h}{\partial x}\right]\frac{\partial}{\partial y}\left[K_{yy}\frac{\partial h}{\partial y}\right]+\frac{\partial}{\partial z}\left[K_{zz}\frac{\partial h}{\partial z}\right]-w=Sc\frac{dh}{dt} \quad \text{.................. 1}$$

Where: Kxx, Kyy, Kzz are hydraulic conductivities along x, y and z coordinate axes (L/t), h: is the potentiometric head (L), w: volumetric flow rates per unit volume of (sink and/or source) (L3t-1), Sc: specific storage of the porous media (L-1), and t: time (T).

Several studies in the area have been achieved dealing only with the hydrogeological and hydrochemical aspects, such as that of the General Commission of Ground Water (1982), Al-Tamimi (2007) and Al-Jiburi, (2009). This study is the first to deal with groundwater flow simulation; therefore, the aims of the present work are to study the groundwater flow system in Khanaqin area using steady and unsteady state numerical groundwater flow models and to predict the effects of further groundwater exploitation on the groundwater levels.

The studied area lies in the northeastern part of Iraq between the southern part of Sulimaniya and northeastern part of Diyala provinces. It is bounded by the Iranian borders on the east and from the west by Diyala River. It is restricted to latitudes (34°18' 30" – 34°22' 00") N and longitudes (45 °13' 33" – 45°31' 00") E, with an area of about 600 Km^2 (Fig.1).

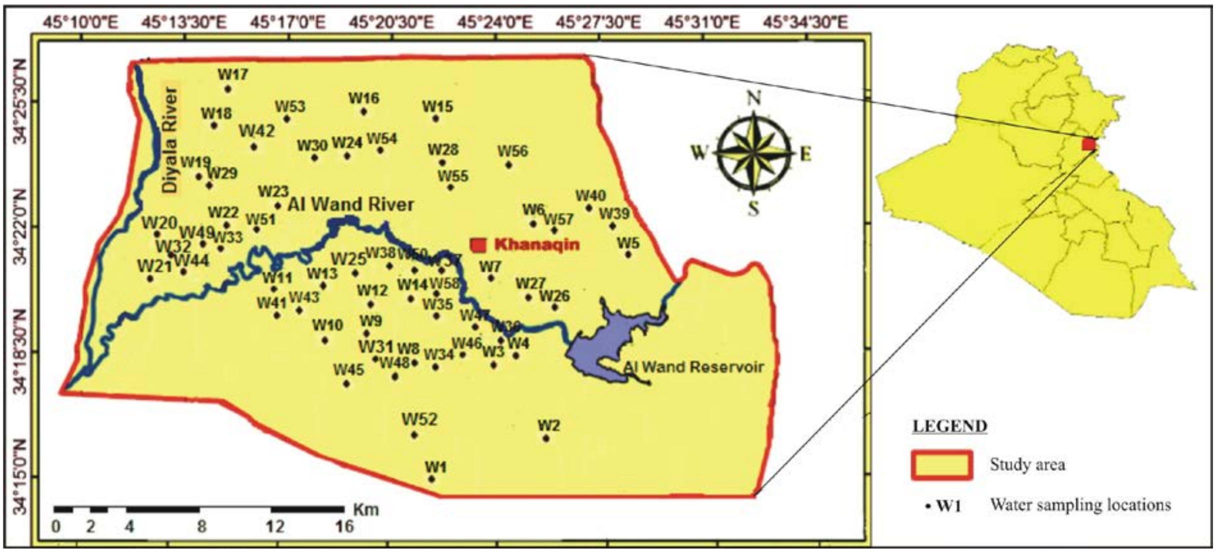

Fig.1: Location map of the study area

Al-Wand River, a branch of Diyala River, originates from Iran and passes through Khanaqin from the northeast where Al-Wand reservoir occurs.

CLIMATIC AND GEOLOGY CONDITIONS

The climate of the studied area is arid to semi-arid, characterized by a cold winter and long, hot and dry summer. Precipitation begins in October and ends in May, where the mean monthly precipitation for the period (1990 – 2013) of Khanaqin station, ranges from 5.69 (May) to 58.0 mm (January) whereas, the mean accumulated annual rainfall calculated for the same period is 273.3 mm. The mean monthly class A pan evaporation values have a range of 58.17 mm (January) to 543.8 mm (July) whereas the mean monthly temperature ranges from 10.0 °C (January) to 36.5 °C (July). The mean monthly relative humidity and wind speed range from 25.81% (July) to 76.51% (January) and from 1.0 m/s (December) to 1.8 m/s (May), respectively, (Iraqi Meteorological Agency, 2013).

The topography of the area is a flat plain that rises gradually from the southwest to northeast. The plain generally slopes from northeast where the elevation reaches (310 m) above sea level towards the southwest with an elevation of less than (130 m). The land surface is covered by sand, silt and clay, some time with gravel especially near the banks of Al-Wand River with small amount of gypsum (Jassim and Goff, 2006). The outcropping formations are, from the oldest to the youngest: Al-Mukdadiyah Formation (Pliocene) and the Quaternary deposits (Pleistocene – Holocene) represented by the river terraces, aeolian deposits and sediment filling the valleys in the region as shown in Fig. (2). Al-Mukdadiyah Formation consists of alternation of sandstone, silstone and claystone. This formation is conformably overlain by Bai-Hassan Formation which consists of conglomerate alternations interbedded with sandstone, claystone, and scattered siltstone (Barwary and Selwa, 1995).

Structurally the study area lies within the Unstable Shelf of the Arabian Plate, and is divided into two parts; the northeastern part is located within the High Folded Zone and the Foot Hill Zone which covers most parts of the studied area, (Buday and Jassim, 1987).

HYDROLOGICAL AND HYDROGEOLOGICAL SETTING

Al-Wand River originates from the Iranian territories and flow to the southwest to confluence with the Diyala River. The total area of Al-Wand Basin is (3340) Km^2, 80% of which is located in Iran, while 20% lies in Iraq. The total length of Al Wand River is (152) Km; 89 Km of it occurs inside Iran and 63 Km occurs in Iraq. The width of the river differs from one place to another (Esmail, 2012) .The river deposits consist of sand, silt and clay.

Discharges and water levels of Al-Wand River for the studied year, (January 2013 to December 2013) show that the highest water level and discharge are 177.9 m a.s.l (January) and 31.7 m^3/sec (November), while the lowest level and discharge are 177.0 m a.s.l (May – September) and 1.35 m^3/sec (May – September). Al-Wind River may dry out especially at the low rainfall periods. Diyala River, one of the River Tigris tributaries in Iraq, represents the northwestern boundary of the study area and confluence with Al-Wand River in the southwest of the area, the highest and lowest discharges are 97.2 m^3/sec (July) and 34.79 m^3\sec (April), while the water level is 115 – 116 m a.s.l. (National Center for Water Management, 2013), (Table 1).

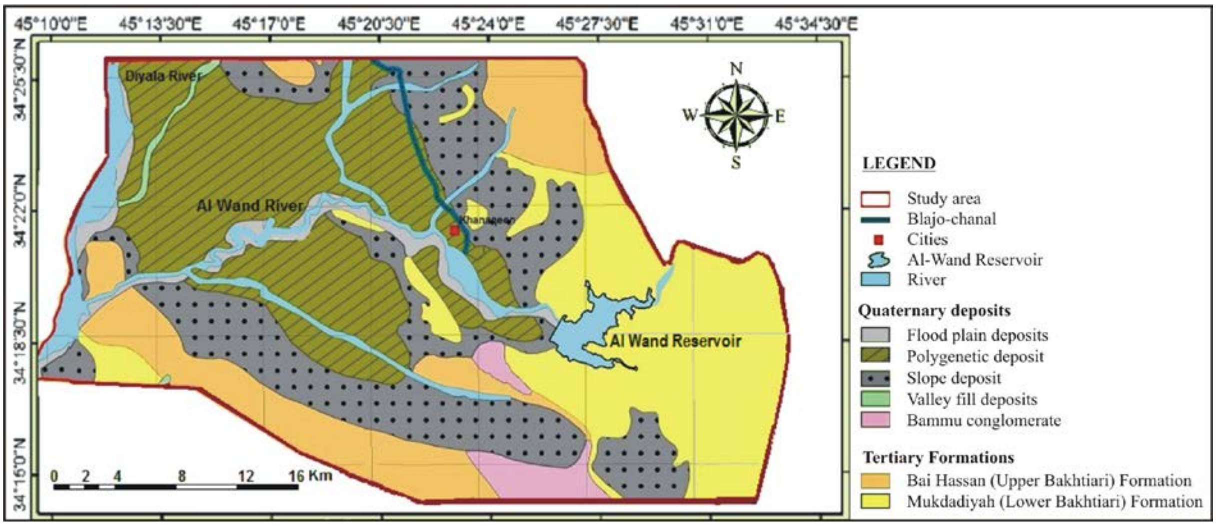

Fig.2: Geological map of the study area (after Barwary and Selwa, 1995)

Table 1: Discharge and water level of Diyala and Al-Wand Rivers

Months	Al-Wand River		Diyala River	
	Discharge (m^3/sec)	Water level (m.a.s.l.)	Discharge (m^3/sec)	Water level (m.a.s.l.)
January	11	177.9	78.77	115.9
February	24	177.15		
March	3	177.03		
April	1.65	177.01	34.79	115
May	1.35	177	87.12	115.6
June	1.35	177	93.5	115.9
July	1.35	177	97.2	116
August	1.35	177		
September	1.35	177		
October	1.9	177.02		
November	31.7	177.2		
December	24.42	177.15	71.47	115.6

According to the General Commission of Groundwater survey, Quaternary aquifer represents the main aquifer through the entire part of the study area, while, Bai Hassan – Quaternary sediment aquifer occurs in a minor part of the area. The depth of groundwater in the wells tapping these deposits ranges from 9 to 96 meter below ground surface; the value of permeability ranges between 0.4 and 47.3 m/day, while the transmissibility ranges between 14 and 539 m^2/day (Al-Jiburi, 2009). These values are explained by the wide variation in the lithology within the area. The value of Storage Coefficient is 0.001, which is a typical value of unconfined to semi-confined aquifer (Ahmed *et al*., 2005). The flow regime is mainly from the northeastern parts towards the southwestern parts, i.e towards Diyala River. The flow line and the equipotential lines explain the homogeneity of the study area which is typical for clastic aquifers where the hydraulic gradients seem to be uniform through the study area with a value of 0.0036 (Fig.3).

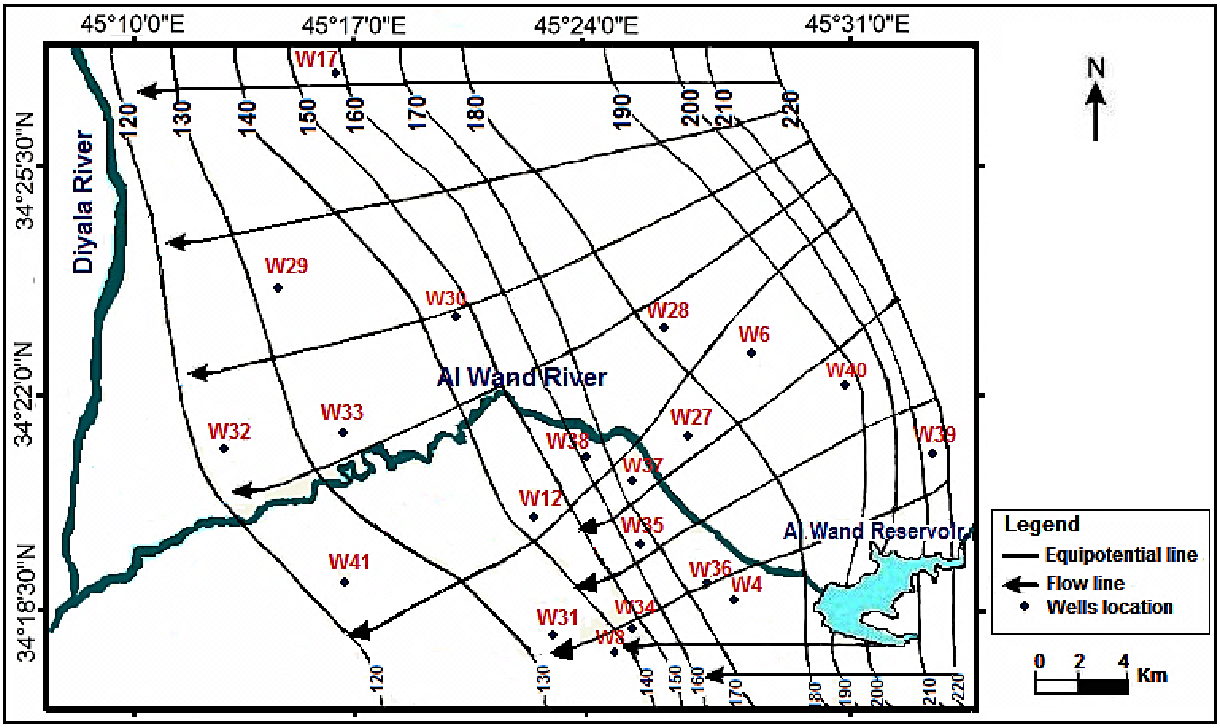

Fig.3: Groundwater flow map of the study area

GROUNDWATER FLOW MODELING

For the purpose of the present study, PMWIN, a program, developed by Chiang (2005), is used. This software simulate the three-dimensional flow problems under different hydrgeologic conditions using the original MODFLOW code developed by (McDonald and Harbough, 1988).

- **Model design and boundary conditions**

The first step in modeling is to discretize the system by superimposing a mesh of finite difference grid over the map of the area. The size of the mesh or, in other words, the number of rows and columns that are to be adopted depends on the required accuracy (Prickett and lonngquist, 1971). In the current study, uniform grid of spacing of 2 Km for each cell is selected in x, y directions, where the model consists of 13 rows and 17 columns; the total active cells are 200 where the cell area ranges from 26000 m^2 to 34000 m^2, (Fig.4). Boundary conditions can be regarded as a very important input parameter. For the steady state, all model boundary cells and both Diyala River and Al-Wand cells are regarded as constant head cells, For unsteady state simulation, the upper and lower boundaries of the study area are regarded as no flow boundaries. The eastern boundaries are regarded variable head cells, while the Diyala River and Al-Wand reservoir boundaries are regarded as constant head since there is no significant changes during the year of study in their levels.

- **Input data files**

Field measurements of the head at 20 wells are used as initial head for steady state simulation. Hydraulic conductivity, specific yield and specific storage of the model grid are taken from previous studies. Water levels of Diyala River and Al-Wand reservoir as well as the monthly measurements of groundwater level at the wells 4, 8 and 28 for the year 2013 are used for the model calibration.

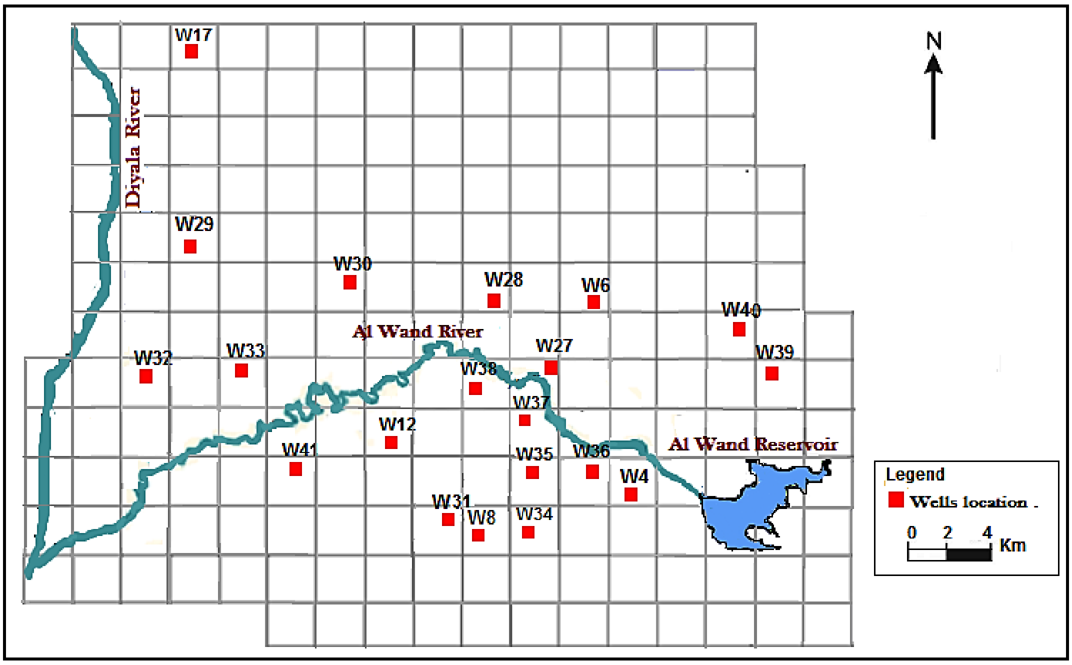

Fig.4: Grid design of the study area

- **Model calibration**

The steady state is a condition that exists in the aquifer before any variation takes place. By trial and error the hydraulic conductivity is adjusted during the model application until good matching between the observed and calculated heads are obtained, (Fig.5). Good agreement of the simulated steady state head with the observed ones is noticed. Table (2) shows the values of the above two head values, where the difference between them varies from (0.1) m to (0.80) m which seems to be a reasonable difference.

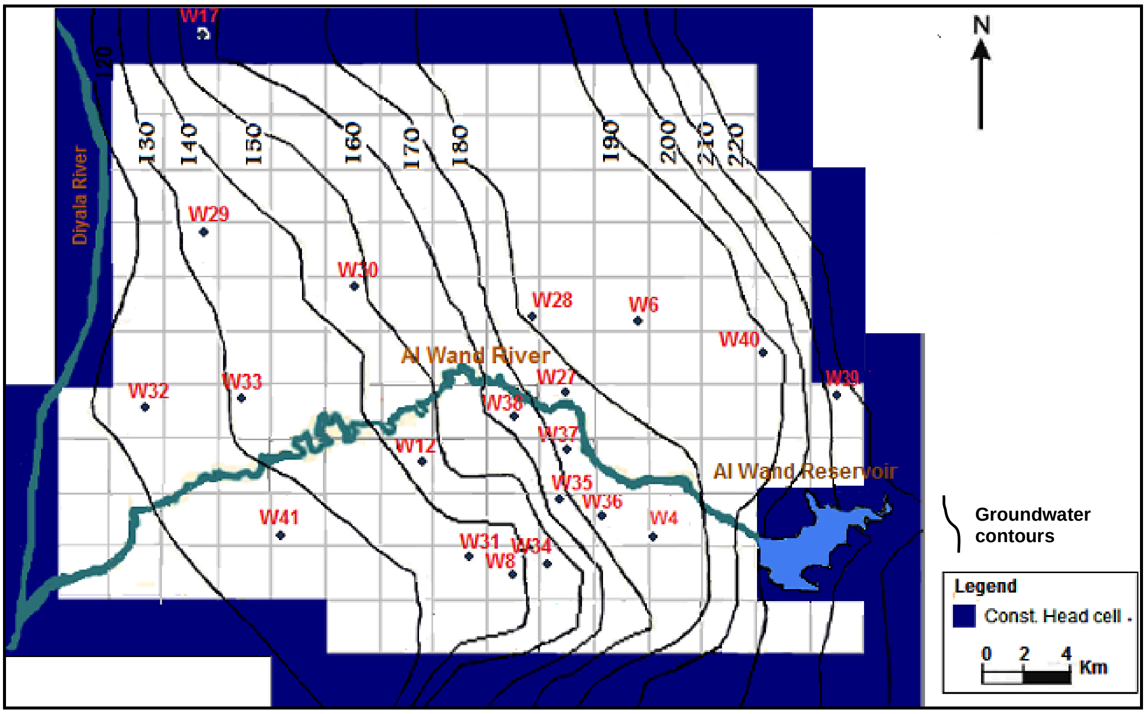

Fig.5: Calculated steady state of the heads for the study area

Table 2: Calculated steady state and observed heads (m) of the selected wells in the study area

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.
W4	173	173.20	W32	124	124.1
W6	185.7	186.1	W33	132	132
W8	138.4	138.65	W34	143	143
W12	140.7	140.0	W35	169	168.8
W17	159	159	W36	171	171.6
W27	175	175.5	W37	172	172.5
W28	180.4	180.1	W38	165	165.7
W29	133	132.6	W39	212	212
W30	148.5	147.9	W40	188	188.4
W31	135	134.2	W41	123	123.1

The final simulated steady state is used as initial input for transient simulation. Selection of the simulation time steps is a critical step in transient model design because the value of the space and time discretization strongly influences the numerical results (Anderson and Woessner, 1992). The present model is run for one year starting from January, 2013 to December, 2013, a period that is divided into twelve time intervals and the result are compared with the observed head of the three monitoring wells (w4, w8 and w28).

The value of pumping rate of 5 l/sec for 58 were assigned for model cells containing the wells and a value of specific storage of (0.001) as obtained from a previous study (Ahmed *et al*., 2005) was assigned for the entire model domain. Figs. (6 and 7) show the head distribution of model operation for 1 and 12 month periods. These figures give similar patterns to that of the steady state, but with gradual general decrease in the head values as shown in Fig. (8). The figure shows a rise in the head for well 4 during the time periods, while there is a decline in the head of wells 8 and 28. This rise in the head value is due to the fact that some of the grid cells (Al-Wand reservoir and Diyala River) are regarded as constant head cells, which means continuous recharge sources. According to the above results, and after the model is calibrated, it can be used for head prediction under different pumping schemes scenarios.

- **Sensitivity analysis**

A sensitivity analysis is the process whereby the model input parameters are varied over a reasonable range and observing the relative change in model response (Rushtoon, 2003). It is a measure of the uncertainty in the calibrated model caused by uncertainty in the aquifer parameters and boundary conditions (Holzbecher and Sorek, 2005). The main objective of the sensitivity analysis is to understand the influence of various model parameters and hydrogeological stresses on the aquifer system and to identify the most sensitive parameter which will need a special attention in the future (Anderson and Wessner, 1992). The present steady state model shows sensitivity to hydraulic conductivity, while the unsteady state model is sensitive to the increase and decrease of the specific storage values.

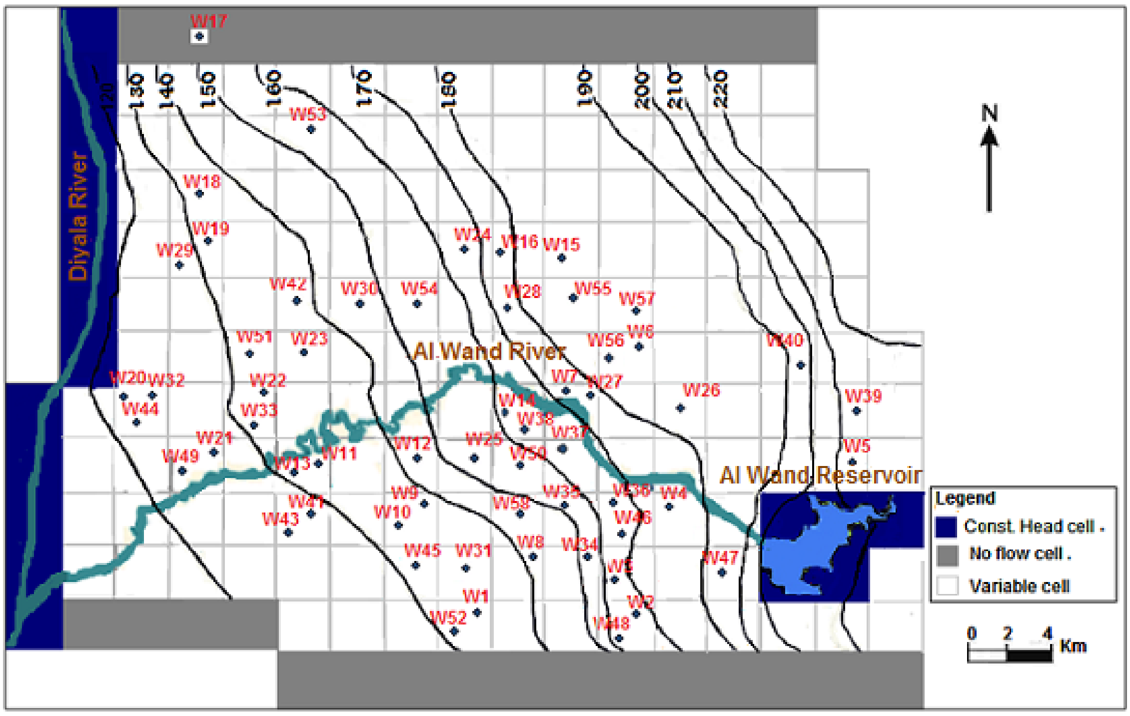

Fig.6: Calculated unsteady state of the model for one month pumping

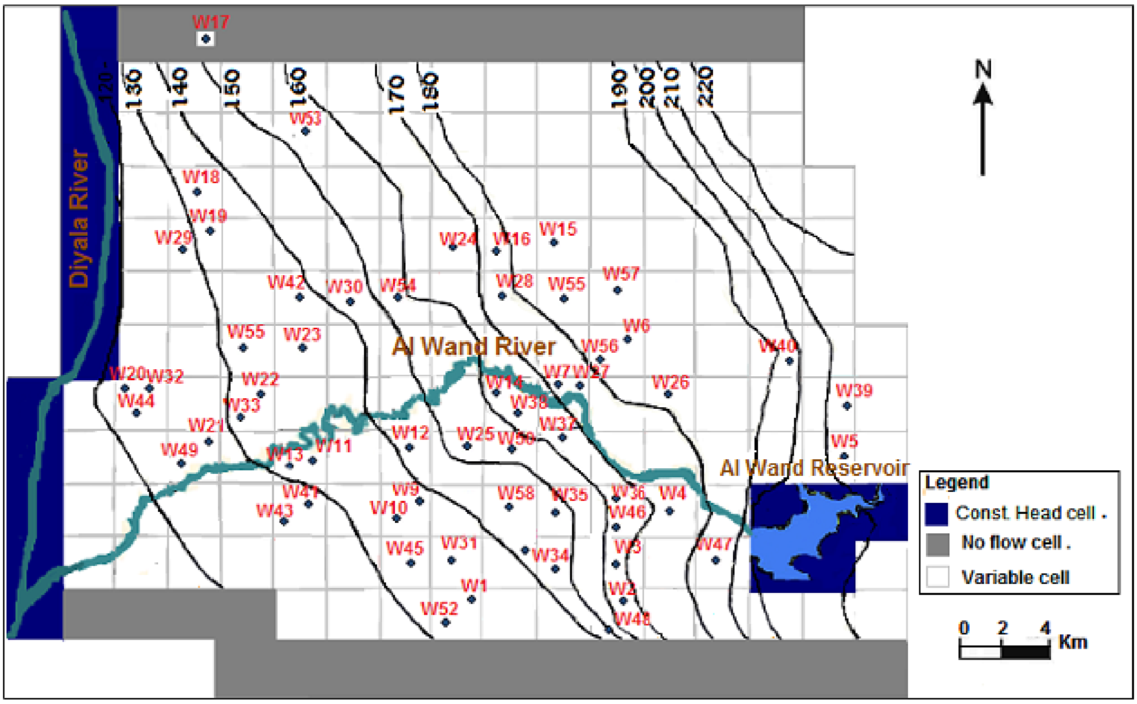

Fig.7: Calculated unsteady state of the model for twelve months pumping

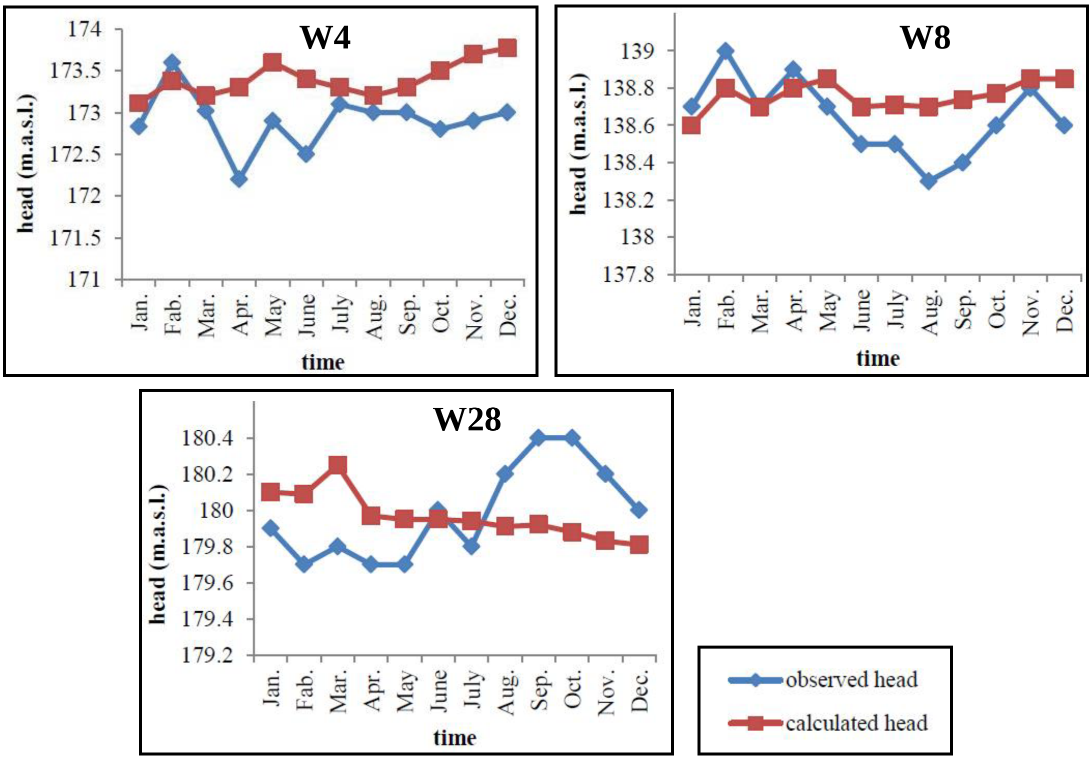

Fig.8: Calculated and observed heads of the wells 4, 8 and 28
for the study area

- **Model prediction**

A model may be used to predict some future groundwater flow condition; the model that has passed the calibration stage would be suitable for future prediction of the aquifer state. The calibrated model over one year period (2013) is used to display the impacts of the aquifer of the study area for 4 additional year under different scenarios as follows:

— **Scenario one:** In this scenario, present discharge condition is maintained and the prediction is carried out for the next 4 years, starting from 2014 to 2017. Fig. (9) shows the calculated head values after 4 years pumping; this figure gives similar patterns to that of the steady state but with general gradual decrease in the head values. Table (3) shows the hydraulic heads for the selected wells during different simulation periods. Simulated head values indicate that present groundwater level increases about 0.87 in cells (13, 10) and decreases about 1.59 m, 0.35 m, 0.35 m, 0.65 and 0.71 m in the other cells. The increase in the cell (13, 10) is due to the closeness of Al-wind Lake which is still steady state cells. This is an encouraged head distribution and can be regarded suitable for future developments.

— **Scenario two:** In this scenario, discharge is increased at a rate of the irrigation needed in the future, i.e from 5 L/sec to 10 L/sec for the next 4 years later (Fig.10). Simulated head values indicate that groundwater level increases about 0.67 in cells (13, 10) and decreases about 1.75 m, 0.57 m, 0.75 m, 0.84, and 0.89 in the other cells respectively (Table 3). As shown from the two scenarios, the difference between the two hydraulic heads of the study area is very small.

— **Scenario three:** An increase of the drilled wells at specific locations is suggested in this scenario (Fig.11). It is noted that the increase in the number of wells have no significant effects on the head distribution and the situation doesn't differ from the present state. It should be mentioned that the prediction is done by assuming a constant level of both Diyala River and Al-Wand reservoir during the simulation period.

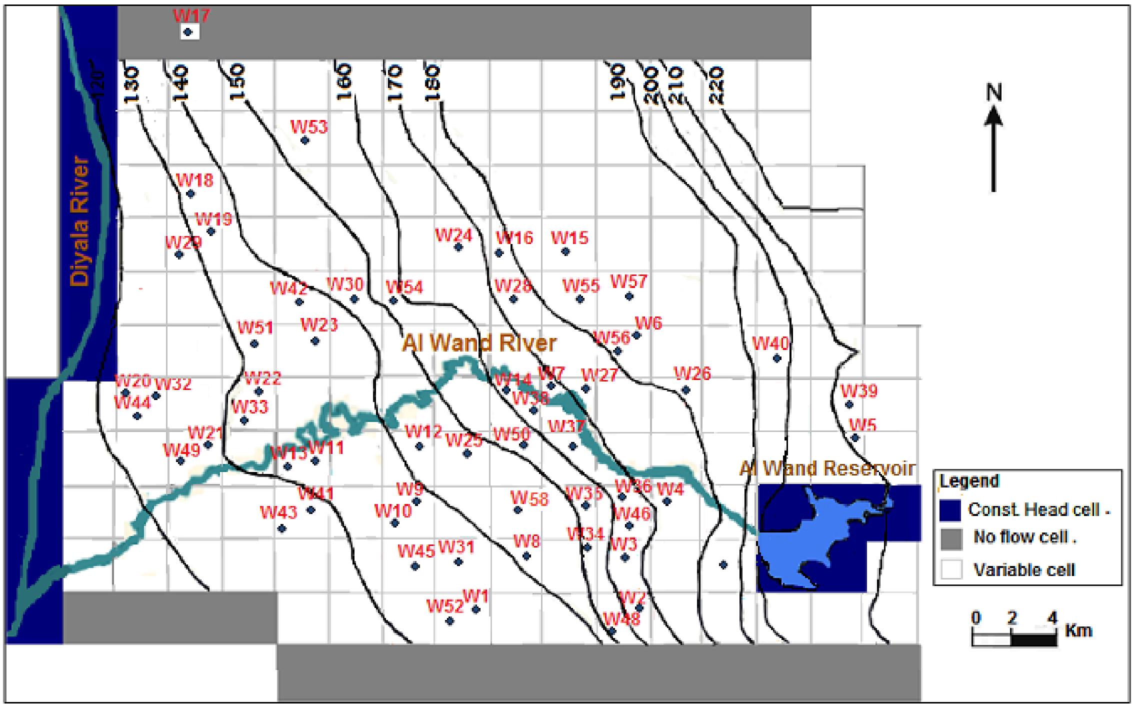

Fig.9: Predicted head distribution for 4 years model operation (scenario one)

Table 3: Aquifer head for selected cells during different simulation periods

Cell no. Colum-row	Observed head (m) a.s.l.	Calculated head (m) a.s.l.	Unsteady state (m) a.s.l.	Prediction head of wells (m) a.s.l. with present discharge and number of wells			
				1 year	**2 year**	**3 year**	**4 year**
10 – 6	180.40	180.10	179.81	179.55	179.29	179.05	178.81
10 – 11	138.40	138.60	138.90	138.67	138.45	138.20	138.05
13 – 10	173	173.20	173.77	173.80	173.82	173.85	173.87
3 – 8	124.0	124.0	123.93	123.85	123.77	123.70	123.65
16 – 8	212.0	212.0	211.83	211.70	211.50	211.40	211.35
4 – 5	133.0	132.60	132.45	132.37	132.35	132.31	132.29
Prediction head of wells (m) a.s.l. with increasing discharge 10 L/sec							
10 – 6	180.40	180.10	179.81	179.49	179.20	178.90	178.65
10 – 11	138.40	138.60	138.90	138.40	138.23	138.02	137.83
13 – 10	173.0	173.20	173.77	173.79	173.77	173.77	173.67
3 – 8	124.0	124.0	123.93	123.69	123.50	123.36	123.25
16 – 8	212.0	212.0	211.83	211.66	211.49	211.32	211.16
4 – 5	133.0	132.45	132.45	132.25	132.20	132.14	132.10
Prediction head of wells (m) a.s.l. with increasing number of wells drilling							
10 – 6	180.40	180.10	179.81	179.55	179.28	179.05	178.81
10 – 11	138.40	138.60	138.90	138.65	138.44	138.20	138.05
13 – 10	173.0	173.20	173.77	173.79	173.82	173.84	173.87
3 – 8	124.0	124.0	123.93	123.83	123.76	123.70	123.65
16 – 8	212.0	212.o	211.83	211.68	211.50	211.39	211.35
4 – 5	133.0	132.45	132.45	132.35	132.34	132.31	132.29

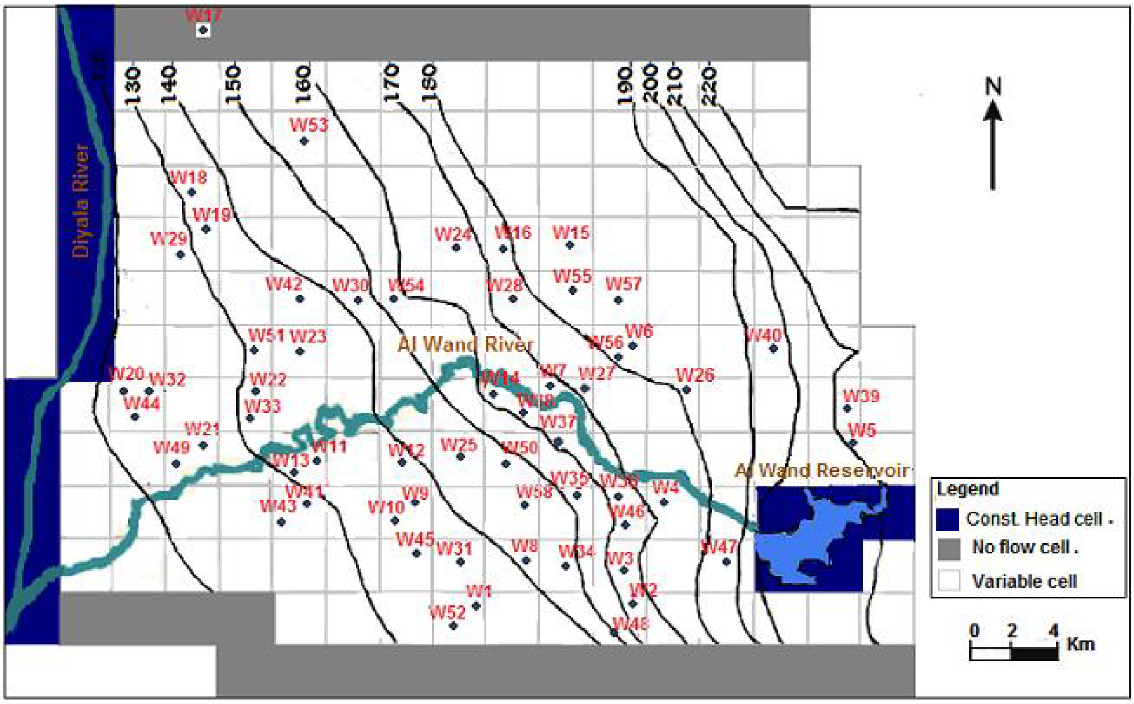

Fig.10: Predicted head distribution for 4 years model operation (scenario two)

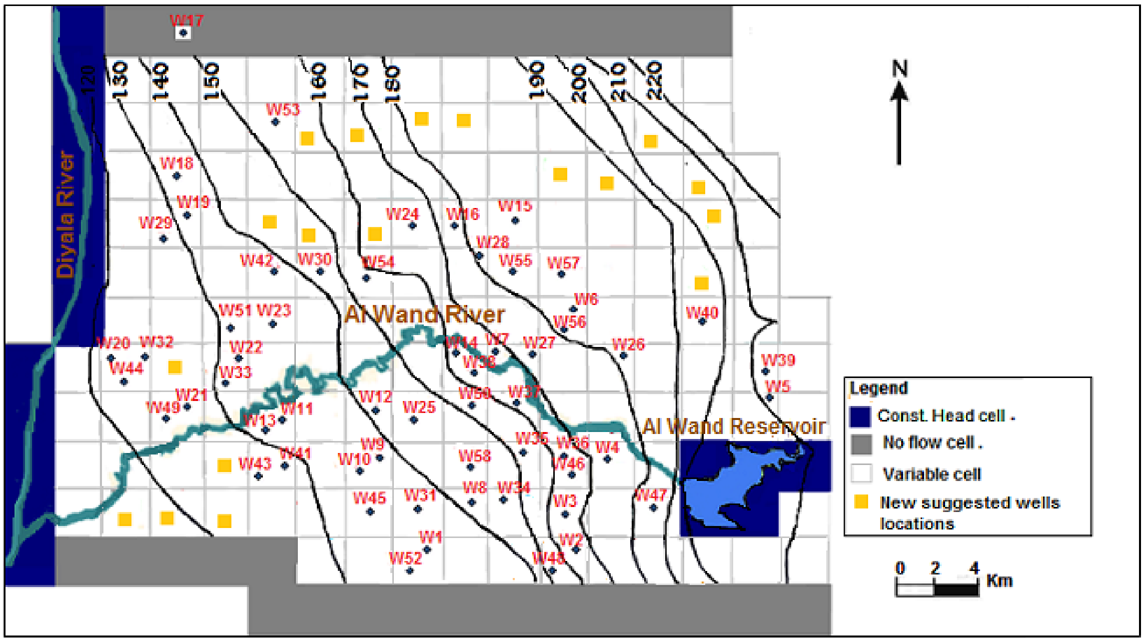

Fig.11: Predicted head distribution for 4 years model operation (scenario three)

CONCLUSIONS

- The study area is characterized by the presence of wide variation of geologic formations which in turn lead to presence of different hydrogeologic units where the unconfined Quaternary aquifer is the main aquifer for the different uses.
- Hydraulic properties show significant variation through the study area due to the lithological variations.

- Steady state flow model of the area shows good agreement between the calculated and the observed head distribution. Hydraulic conductivity is shown to be the most sensitive parameter for the steady state simulation.
- Unsteady state runs reveal an acceptable matching between these run outputs with the observed head in these observation points (wells).
- Low groundwater decline makes the area promisable for further groundwater exploitation via doubling the pumping rates from the already drilled wells or by increasing well drilling at specific locations in the area.
- The different groundwater exploitation scenarios urge the need for integrated management program for the water resources in the area by the conjunctive use of both the Quaternary aquifer and the Al-wind River and reservoir.

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