Journal of Scientific Research & Reports
6(4): 243-254, 2015; Article no.JSRR.2015.150
ISSN: 2320-0227

SCIENCEDOMAIN *international*
www.sciencedomain.org

Groundwater Flow Modeling in a Nubian Sandstone Aquifer, South Western Desert, Egypt

Ahmed Hassan[1], Gamal Elsaeed[2*], Mohamed Nagaty[3] and Eman Abdelghani[3]

[1]Department of Civil Engineering, Faculty of Engineering, Ain Shams University, Cairo, Egypt.
[2]Department of Civil Engineering, Faculty of Engineering, Shobra, Benha University, Cairo, Egypt.
[3]Department of Irrigation and Hydraulics, General Authority for Rehabilitation Projects and Agricultural Development (GARPAD), Egypt.

Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JSRR/2015/15736
Editor(s):
(1) Shahid Naseem, Department of Geology, University of Karachi. Pakistan.
Reviewers:
(1) Anonymous, Nigeria.
(2) Anonymous, Jordan.
(3) K.Arumugam, Department of Civil Engineering, Kongu Engineering College, Anna University, India.
Complete Peer review History: http://www.sciencedomain.org/review-history.php?iid=965&id=22&aid=8330

Original Research Article

Received 15th December 2014
Accepted 12th February 2015
Published 3rd March 2015

ABSTRACT

This paper presents a methodology for management and evaluation of groundwater aquifer in the Middle Part of Darb El-Arbaein Area. Three dimensional lithologic modeling techniques have been used for detailed characterization and groundwater flow modeling of the aquifer system in the middle part of Darb El-Arbaein area. Well log data was used for setting the lithologic model using Rock Works software V. 15. A groundwater flow model, facilitated by MODFLOW 2011, was built using results of the lithologic model. The model is used for simulation of the groundwater heads and quality changes for next 10, 25 or 50 years under four different scenarios as follows :- (i) The first scenario with the present extraction rate which is 97360 m^3/day to irrigate 2430 feddans, (ii) The second scenario is to increase the new cultivated lands in the studied area, the rate of groundwater extraction is 133360 m^3/day to irrigate 3240 feddans, (iii) The third scenario is to change the discharge and working hours of productive wells, groundwater extraction rate reaches 48600 m^3/day to irrigate 2430 feddans, (iv) The fourth scenario is to use the third scenario and increase new cultivated lands, the total rate of groundwater extraction is 64800 m^3/day to irrigate 3240 feddans. The simulation results for the first and the second scenarios show that, the groundwater table started to decline due to the over pumping from the productive wells but the third

**Corresponding author: Prof. Gamal Elsaeed - Email: gelsaeed@feng.bu.edu.eg;*

and the fourth scenarios control and safe groundwater extraction. The non-reactive transport model MT3DMS has been applied along the flow model. It was found that TDS of the groundwater in the studied area increased throughout 10 years, but after 25 years there would not be a significant change of expected groundwater salinity and it became constant.

Keywords: Darb el-arbaein; lithologic modeling; MODFLOW; nubian sandstone aquifer.

1. INTRODUCTION

The reclamation process was accelerated during the eighties and up till now. The total groundwater abstraction was 870 million, m^3/year by the year 2000 and increased to more than one billion m^3/year in 2007 [1]. The groundwater table started to decline due to the unplanned groundwater abstraction, and over pumping from productive wells while the aquifers receive little or no replenishment particularly during the last decades because of the scarcity in the rainfalls [2].

Darb El-Arbaein is one of new developing areas which have been planned. The middle part of Darb El-Arbaein is started to be developed based on groundwater, since 2000. Due to rapid and continuous development, some side effects emerged such as: continuous drawdown in water levels (increasing the discharge versus recharge) with noticeable increase in the salinity. This, in turn, causes a local depletion in some of such locations towards the future development. Monitoring such development is needed to minimize the undesirable side effects.

1.1 Objective

The main objective of this research is to present an integrated study on management and evaluation scheme of groundwater aquifer in the middle part of Darb El-Arbeain area, which is considered the sole resource of water to be used for different purposes such as domestic use and irrigation in such an arid area. Also it's to predict the short and long-term impacts on a groundwater aquifer (quantity and quality) to avoid aquifer depletion and to ensure that the water with a compatible quality with national and international standards for irrigation requirements.

1.2 The Studied Area

The selected area is located between 30º 15$^/$ E and 30º 25$^/$ E longitude and 23º 55$^/$ N and 24º 05$^/$ N latitude. It is accessible through asphaltic road starting from Baris -Kharga Oasis and lasting southerly for about 185 km.

The geology of Darb El-Arbaein area is covered mainly by Upper Cretaceous to lower Tertiary sediments which is unconformable underlie the Quaternary deposits with exposures of basement igneous and metamorphic rocks belonging to Late Precambrian to Early Paleozoic age [3] (Fig. 1).

The ground elevation in the studied area ranges between 130 m (msl) at the eastern and southeastern parts and 160 m (msl) at the western and southwestern parts. The ground surface slopes gently from NW to SE which is characterized by low gradient, which amounts to 5.0 m / km as shown in Fig. 2. From the climatic view point, the area is located in an arid region, where the absolute maximum air temperature is 48.6ºC in May and the absolute minimum is –2.1ºC occurs in February. The annual rainfall does not exceed 1.1 mm, with a maximum total monthly rain fall 0.3 mm occurs from December to February. The annual evaporation is about 17.2 mm, with a maximum monthly evaporation rate about 21.32 mm occurs in June [4].

The studied area is mainly depending on the groundwater in its industrial, agricultural and domestic activities. The aquifer characterization will be the starting point for groundwater management and decision making.

1.3 Hydrogeological Conditions

The generalized hydrogeological section indicates that the area is dissected by 26 normally-exposed faults and concealed faults [5]. The central area is bordered by Gabal Abu Rayan El-Bahari from the north and the Kiseiba anticline from the south. The natural recharge of the aquifer system in the Western Desert is thought to be about 1.5 billion m^3/year [6], while groundwater which flows from Libya to Egypt is about 3.782 mcm/d [7].

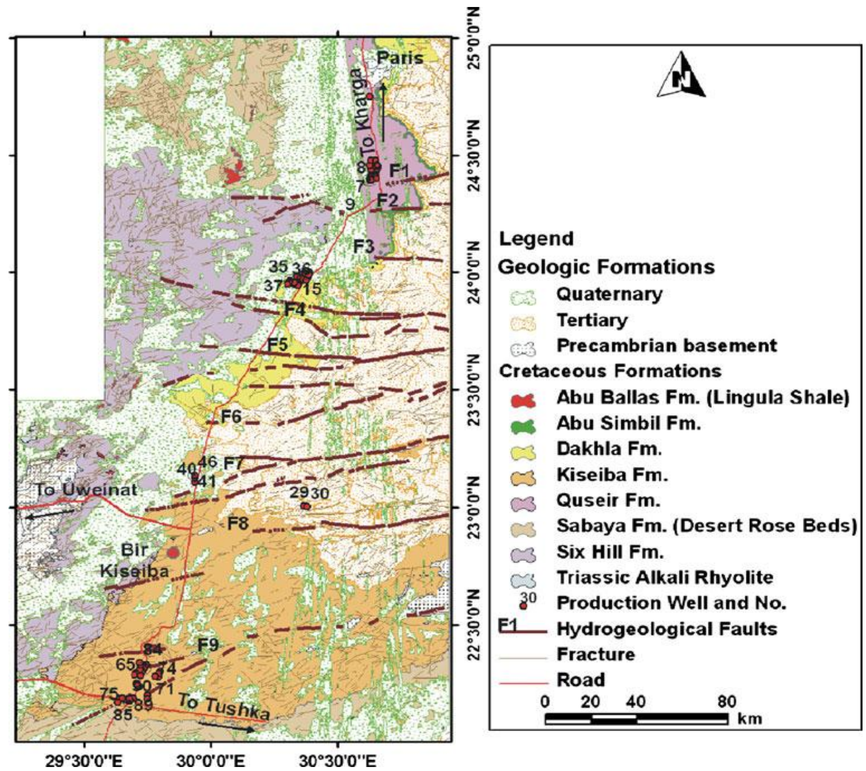

Fig. 1. Geological and structural map of Darb El-Arbaein area (based on CONOCO 1987, NG36SW-luxor sheet and landsat satellite ETM+ image mosaics taken in 2000)

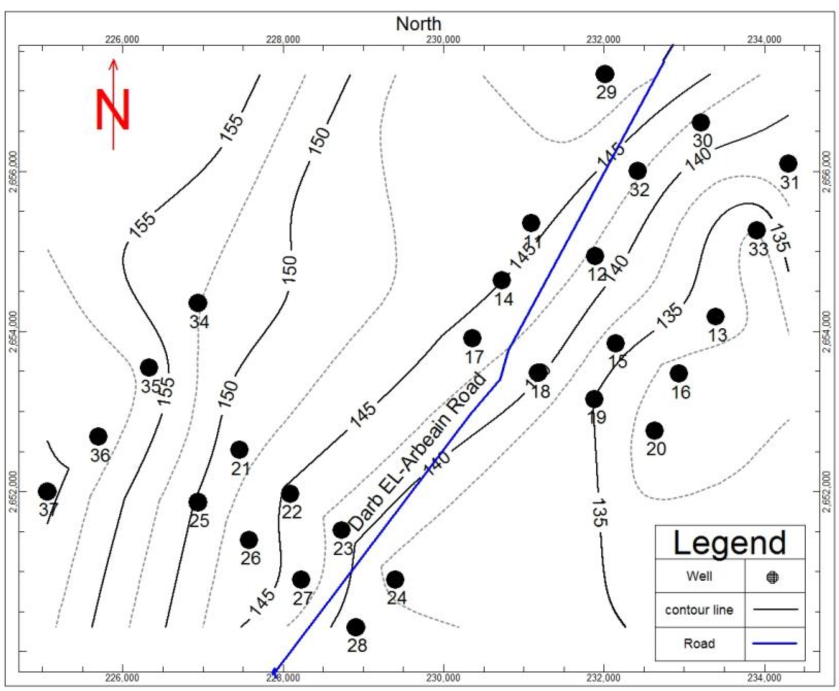

Fig. 2. Topographic contour map and wells in the studied area

The groundwater is believed to have accumulated and preserved in the Nubian sandstone aquifer since 10000 year BC or even earlier as revealed by C^{14} and H_3 iso- topes [8]. The stored water in Nubian sandstone is mainly fossilized water and ranges from 20000 to 40000 year [9, 10].

At the middle part of Darb El-Arbaein, the groundwater flows from west to east, in the opposite direction of increasing the depth of groundwater. The hydraulic gradient has changed in the studied area and reached 0.0067 m/km, attributed to structural patterns and lithological changes.

The effective porosity of sand layers ranges from 21% to 30%, transmissivity ranges from 240 m^2/day to 547 m^2/day, and storativity ranges from 0.78 x 10^{-4} to 2.65 x 10^{-4}. The aquifer is represented by the Paleozoic- Mesozoic sandstone layers, and Upper Taref formations and Kiseiba formations as shown in Fig. 3 [11]. The basement rocks form the base of the aquifer, while the Dakhla formation acts as an impermeable layer. The thickness of this aquifer ranges between 174 m and 237 m.

2. LITHOLOGIC MODELING OF AQUIFER SYSTEM

The present study used the lithologic modeling techniques based on the solid modeling in which a true three-dimensional gridding process was used. A box was created of regularly spaced nodes from irregularly spaced data by interpolating measured values of lithology types as shown in Fig. 4. The obtained lithologic model analyzed the well log data and revealed a complex sedimentary system, which is composed of three stratigraphic rock units Kiseiba formation, Taref formation and Paleozoic – Mesozoic sandstone layer. They overlay directly the basement rocks and are capped by the Dakhla formation.

The thickness of the Kiseiba Formation ranges between 76 m and 116 m as shown in Table (1).This unit is saturated by groundwater from the underlying Taref sandstone aquifer through fault planes. The Taref formation ranges between 73 m and 112 m. The thickness of the Paleozoic-Mesozoic sandstone layer ranges between 7 m and 64 m [4].

The sedimentary sequence encountered in the studied area revealed the complexity of the sedimentary basin and heterogeneity of the aquifer system.

3. GROUNDWATER MODEL

The results of the lithological model of the studied area were used to build the groundwater flow model. Other necessary input data were used from different sources such as hydraulic properties, recharge, pumping rates, boundary, and initial conditions such as groundwater levels and concentrations of pollution.

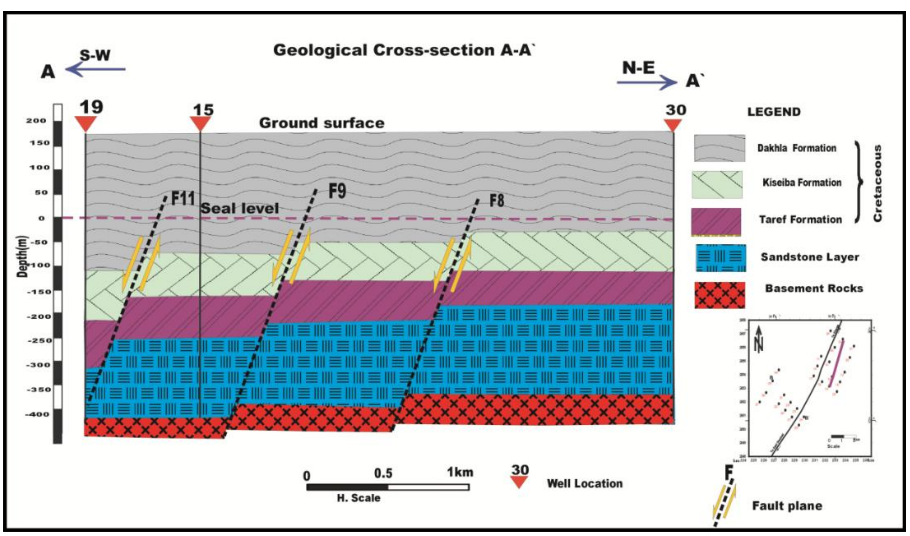

Fig. 3. Subsurface geologic cross section of the middle part of Darb El-Arbaein

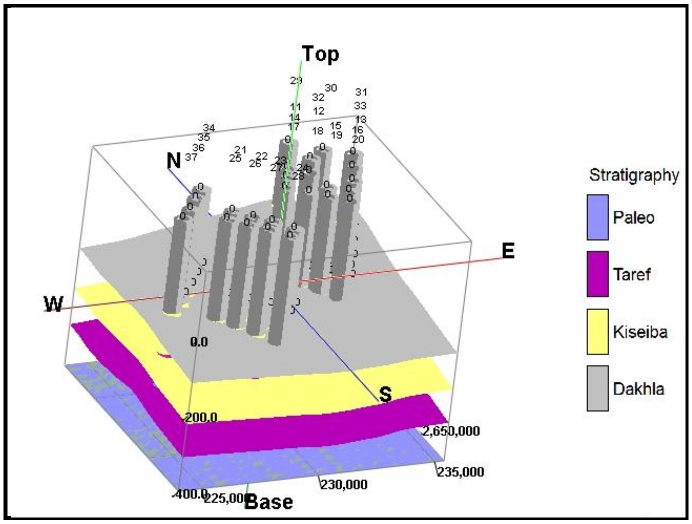

Fig. 4. The three-dimensional lithology model

Table 1. Lithostratigraphic sequence in the middle part of darb El-Arbaein [12]

Age	Location: the middle part of darb el arbaein	Formation	Max. thickness (average), m
Upper cretaceous	Maestrichtian – early paleocene	Dakhla	161 – 285
	Campanian- maestrichtian	Kiseiba	76 – 116
	Turonian-Santonian	Taref	73 – 112
Paleozoic- mesozoic sandstone layer			7 – 64
Pre-cambrian	Ash basement		Base is not reached

Groundwater models describe groundwater flow, fate and transport processes using mathematical equations that are based on certain simplifying assumptions. These assumptions typically involve the direction of flow, geometry of the aquifer, the heterogeneity or anisotropy of the sediments or bedrock within the aquifer and the contaminant transport mechanisms. The equations that describe the groundwater flow and transport processes can be discussed in the following paragraphs.

3.1 Governing Equation on Groundwater Modeling

3.1.1 Flow equation

The partial-differential equation of groundwater flow used in MODFIOW is [13]

$$\frac{\partial}{\partial x}(K_x \frac{\partial h}{\partial x}) + \frac{\partial}{\partial y}(K_y \frac{\partial h}{\partial y}) + \frac{\partial}{\partial z}(K_z \frac{\partial h}{\partial z}) \pm Q = S_s \frac{\partial h}{\partial t} \quad (1)$$

as where,

K_x, K_y, K_z = Hydraulic conductivity along x, y, z axis, m/sec [L/T]
h = Piezometric head, m[L]
Q = Volumetric flux per unit volume representing source / sink terms [L^3/T]
Ss = Specific storage coefficient defined as the volume of water released from storage per unit change in head per unit volume of porous material, [1/L]
t = Time, (s) [T]

3.1.2 Solute transport equation

The equation governing the one-dimensional migration of a contaminant in a groundwater system is extended to the three- dimensional transport regime. The second-order partial differential equation describing contaminant transport is as follows [14]:

$$\partial C/\partial t + (1-n)/n\rho_s\, \partial Ca/\partial t = -vi\, \partial C/\partial xi + D_L \partial 2C/\partial x2 - \lambda C \quad (2)$$

as where,

λ = Decay constant [T^{-1}]
ρ_s = Density of dry matrix material [M/L^3]
C_a = Adsorbed concentration = mass of contaminant/ mass of dry matrix material [-]
n = Total porosity [-]
D_L = Longitudinal coefficient of hydrodynamic dispersion [L^2/T]
α_L = Longitudinal dispersion coefficient [L]
D_d = Molecular diffusion coefficient [L^2/T]
D = Dispersion coefficient [L^2/T]
v = Transport velocity [L/T]
α = Soil dispersivity [L]
t = Time, (s) [T]

3.2 Visual Modflow

Visual MODFLOW is an integrated modeling environment for MODFLOW, MODPATH, and MT3D. It provides professional 3D groundwater flow and contaminant transport modeling using MODFLOW, MODPATH, MT3DMS and RT3D. It allows the graphical design of the model grid, properties and boundary conditions, visualizing the model input parameters in two or three dimensions, running the groundwater flow, path line and contaminant transport simulations, automatically calibrating the model using Win PEST or manual methods and displaying and interpreting the modeling results in three-dimensional space [15].

4. METHODOLOGY

Visual MODFIOW 2011 is used to simulate and calibrate groundwater flow and solute transport model. The water heads have been calculated to study the expected drawdowns of groundwater levels. The water quality parameter (TDS) was studied by a non-reactive transport model MT3DMS.

4.1 Input Parameters

4.1.1 Pumping wells

Twenty-seven wells were drilled with depths that range between 365 m and 535 m. They are fully penetrating the Nubia sandstone successions which overlie directly the Pre-Cambrian basement rocks. The pumping tests were performed for all wells.

Pumping wells were located in the grid and the pumping rates were assigned. Therefore head observation wells were located in the grid. The calibration package of the Visual MODFLOW saves the calculated heads at the locations of specified observation wells. This allows the modular to compare simulated heads with observed heads, production calibration statistics, and production hydrographs at observation wells. Concentration observations well are monitoring the groundwater quality in various locations of the studied area.

4.1.2 Aquifer characteristics

The studied area covers about 120 km^2. It is divided into 100 rows and 100 columns with cell size amounts 110 m * 110 m. With the available literature and the study reports, the aquifer properties are assigned in the model. Due to lack of certain hydraulic values for the different parameters, all hydraulic parameters were calibrated and based on the minimum and maximum values as constraints. The calibration of parameters was done using the automated techniques described in groundwater vistas (Environmental Simulations Inc. 1996) as shown in Table (2):-

1. Horizontal hydraulic conductivities, K_h, including K_x, K_y for all lithologic types in the model;
2. Vertical hydraulic conductivities, K_z, for all lithologic types;
3. Specific storage, S_s, for all lithologic types;

Table 2. Input parameters for the numerical model

The model grid:	• No. of aquifers = 1 divided into 4 layers • X*Y= 11000 m * 11000 m • No. of Columns = 100 • No. of Rows = 100
The aquifer characteristics:	•Hydraulic conductivity : $K_x = K_y$ = 2.1 m/d K_z = 0.1 Kx •Specific storativity = $1E^{-4}$ m^{-1} •Effective porosity = 0.15 •Total porosity = 0.3

4.1.3 Model boundary conditions

The middle part of Darb El-Arbaein area is too far from the natural actual regional boundaries of the Nubian aquifer system and due to the lack of hydrogeological information in between, the following outer boundaries of the Nubian Aquifer in the studied area have been assumed. These boundaries reflect the following (Fig. 5):

1. The western boundary consist of 2 segments (line segment C-D and D-E) representing constant head = 139 m and 146 m;
2. The southern boundary (line segment H-I) representing by a no-flow boundary;
3. The eastern boundary (line segment F-G) representing a constant head = 120 m;
4. The northeastern boundary (line segment A-B) representing by a constant head = 159.5 m

4.1.4 Non-reactive transport using MT3DMS

The initial concentration assigned in the model is based upon the salinity contour map from previous studies [16]. In the model, the total dissolve solids (TDS) are in the range of 1000 – 1900 mg/L as shown in Fig. 6.

4.1.5 MT3DMS limitations

The TDS was studied by a non-reactive transport engine model MT3DMS, linear isotherm (equilibrium controlled) with no kinetic reactions was assumed. The average values of the soil parameters which affect the flow transport, consequently the water quality results are, longitudinal dispersivity (αx) =11 m, molecular diffusion (D) = 0, $S_s = 1e^{-4}\ m^{-1}$, n = 0.30.

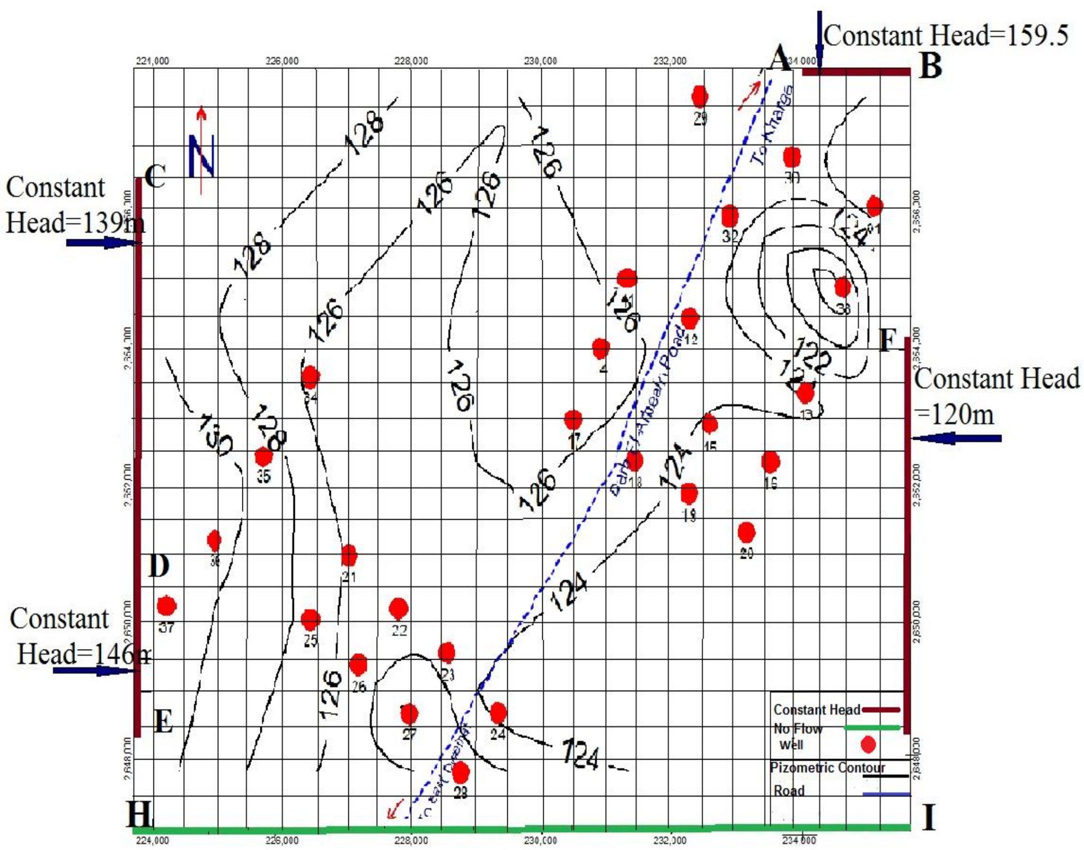

Fig. 5. The regional area of the study by MODFLOW 2011 and the boundary conditions

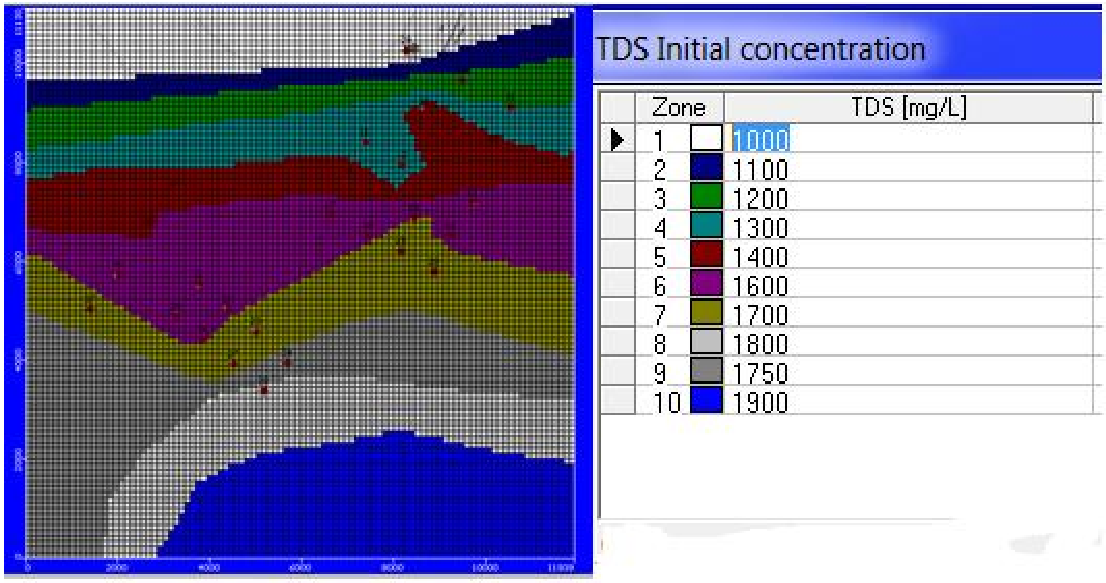

Fig. 6. Distribution of the initial concentration zones

5. GROUNDWATER FLOW MODEL CALIBRATION

The MODFLOW and MT3D models were run for steady state, and then groundwater flow model was calibrated on a regional model by using a groundwater piezometic map in 2002, using a combination of manual and automated parameter estimation techniques. Initial hydraulic parameters were used from the available literature. Due to scarcity of information about hydraulic parameters of lithologic type in the studied area, each unit was assumed to be of unique hydraulic value throughout the model domain. The hydraulic parameters were then manually adjusted in an iterative process until good agreement was obtained between modeled and observed heads at 27observation targets. Then MT3DMS started studying the influences on the water quality changes (total dissolved solids, TDS).

The concentration levels observed for the year 2003 was taken as initial condition. The initial values of the parameters such as porosity, hydraulic conductivity, longitudinal and transverse dispersitivities were used for simulation. The MODFLOW and MT3D models were run for steady state. Calibration of the model is done by adjusting the input parameters to match the simulated results with measured field results with 95 % confidence level as shown in Fig. 7.

6. STUDIED MODELS

After carrying out a calibration successfully on a regional model the calibrated model is used to run the MODFLOW and MT3D in the transient conditions in order to provide forecast of the response of the Nubian Aquifer System to different groundwater extraction scenarios for the next 10, 25 and 50 years.

7. THE EXTRACTION SCENARIOS

The Visual MODFLOW output screen gives the concentration versus time (in days) and also gives drawdown throw wells verses time graphs.

Scenario (1): This scenario with the present extraction rate which is 97360 m^3/day to irrigate 2430 feddans.

Scenario (2): Presumes to use the first scenario and increase the new cultivated lands in the studied area. The expected amount of groundwater extractions rate is 133360 m^3/day used to irrigate 3240 feddans. The proposed new wells are 9 wells with discharge rate of 250 m^3/h and the working hours are 16 hour daily to irrigate 90 feddans for each well.

Scenario (3): The third scenario is to change the discharge and working hours of productive wells, (Promising scenario). The discharge rate is 150 m^3/h and the working hours are 12 hour daily for each well to irrigate 90 feddans. These wells achieve the proposed scenario by changing the crop patterns. The most optimum and safe groundwater extraction rate reaches 48600 m^3/day used to irrigate 2430 feddans.

Scenario(4): The fourth scenario is to use the third scenario and increase new cultivated lands, the total rate of groundwater extraction is 64800 m^3/day to irrigate 3240 feddans. The proposed new wells are 9 wells with discharge rate of 150 m^3/ h and the working hours are 12 hour daily for each well to irrigate 90 feddans.

8. ANALYSIS OF RESULTS

The model is allowed to run under the previous conditions. Consequently, the predicted drawdowns of groundwater distribution levels and groundwater salinity of the Nubian sandstone aquifer in the studied area for time intervals of 10, 25 and 50 years are constructed using the presentation tools of MODFLOW model. The results of these scenarios will be discussed in details in the following paragraphs:

8.1 After 10 Years

The predicted drawdown in groundwater levels in all wells versus time are plotted (Fig. 8). For the first scenario there is a large drawdown in groundwater levels in all wells. The drawdown in groundwater level reaches 15.0 m as a maximum value for wells numbers (15, 18 and 19).While for the third scenario, there is a little drawdown in groundwater levels in all wells. The drawdown in groundwater level reaches 5.0 m as a maximum value for the same wells number.

Also the predicted TDS values in groundwater in all wells versus time are plotted (Fig. 9), and reflects increases in groundwater salinity in all wells for both first and third scenarios.

This increase of salinity is attributed to the increase of sulfates and chloride salts due to leaching and dissolution processes of evaporates minerals that deposited in shale and layers within the Nubian sandstone rock units in the studied area.

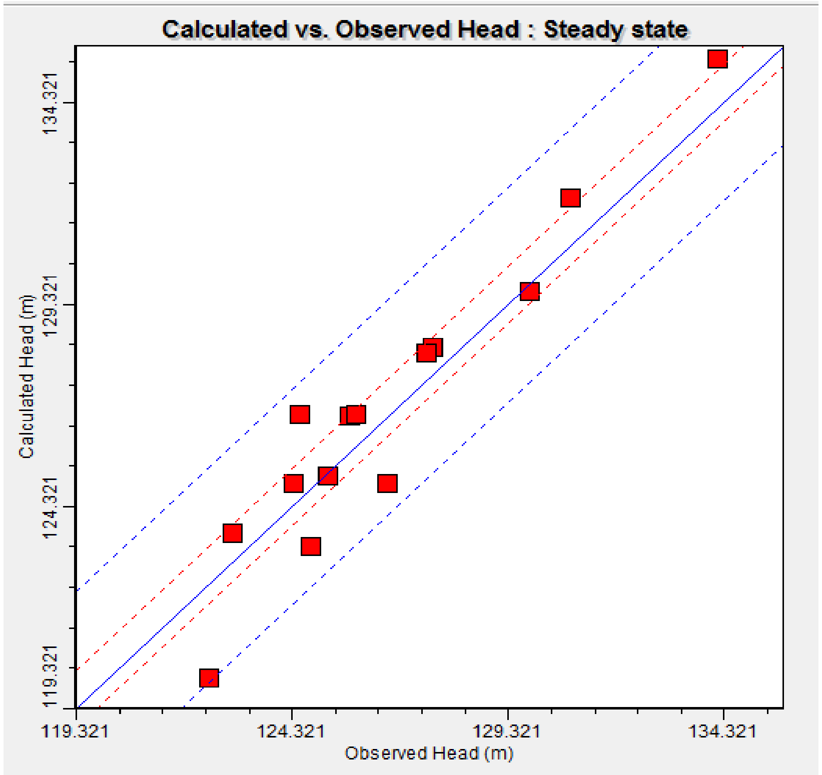

Fig. 7. Calculated vs. observed piezometic levels results

8.2 After 25 Years

For the first scenario there is a continuous decline in groundwater levels in all the wells. The drawdown in groundwater level reaches 19.5 m as a maximum value for wells numbers (15, 18 and 19).While for the third scenario there is little drawdown in groundwater levels where the drawdown in groundwater level reaches 6.5 m as a maximum value for the same wells numbers.

The predicted TDS values in groundwater in all wells versus time for both first and third scenarios indicate that there won't be a significant change of expected groundwater salinity and it becomes constant, this may be due to reach saturated zone.

8.3 After 50 Years

For the first scenario, there is a considerable improvement in the expected groundwater quantity; the drawdown in groundwater level reaches 18.5 m as a maximum value for wells numbers (15, 18 and 19). But for the second scenario there is a sharp decline of groundwater levels in the development areas. The drawdown in groundwater level reaches 28.5 m as a maximum value for wells numbers (15, 18 and 19). For the third scenario there is a considerable improvement in the expected groundwater quantity; the drawdown in groundwater level reaches 4.5 m as a maximum value for wells numbers (15, 18 and 19). Finally for the fourth scenario there is a little drawdown in groundwater levels in all the wells as, a response to the increase of new cultivated lands in the studied area the drawdown in groundwater level reaches 7.5 m as a maximum value for the same wells numbers (15, 18 and 19).

The predicted TDS values in groundwater in all wells versus time for first, second and third scenarios indicate that there is a considerable improvement in the expected groundwater quality. We have to note that there is a little decreasing in groundwater salinity in wells numbers (29 and 32).

Table (3) shows a comparison between the predicting results of the different scenarios after 50 years (the water extraction rates and the maximum expected drawdown values).

Table 3. The water extraction values for different scenarios

After 50 years	Number of wells	Cultivated lands (fed)	Water extractions (m^3/day)	Drawdown (m)
First scenario	27	2430	97360	18.5
Second scenario	36	3240	133360	28.5
Third scenario	27	2430	48600	4.5
Fourth scenario	36	3240	64800	7.5

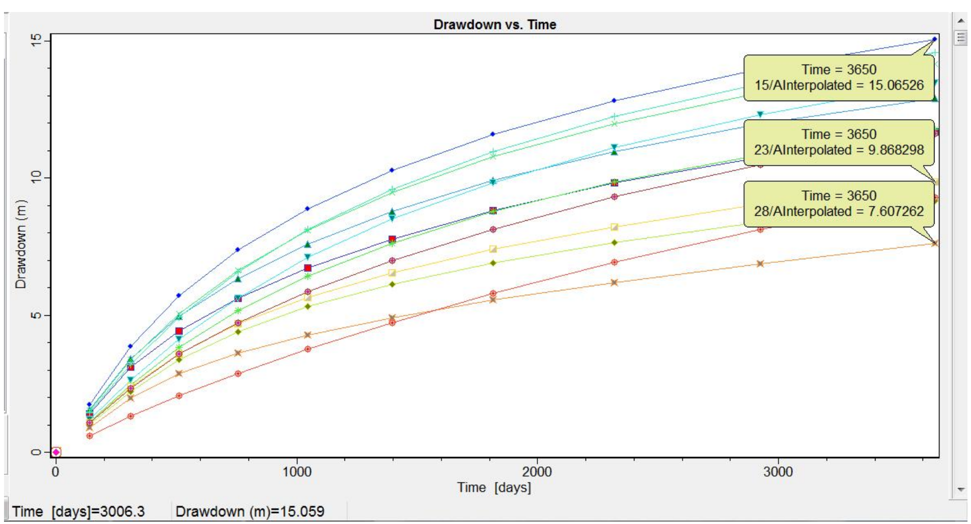

Fig. 8. The expected drawdown in wells versus time

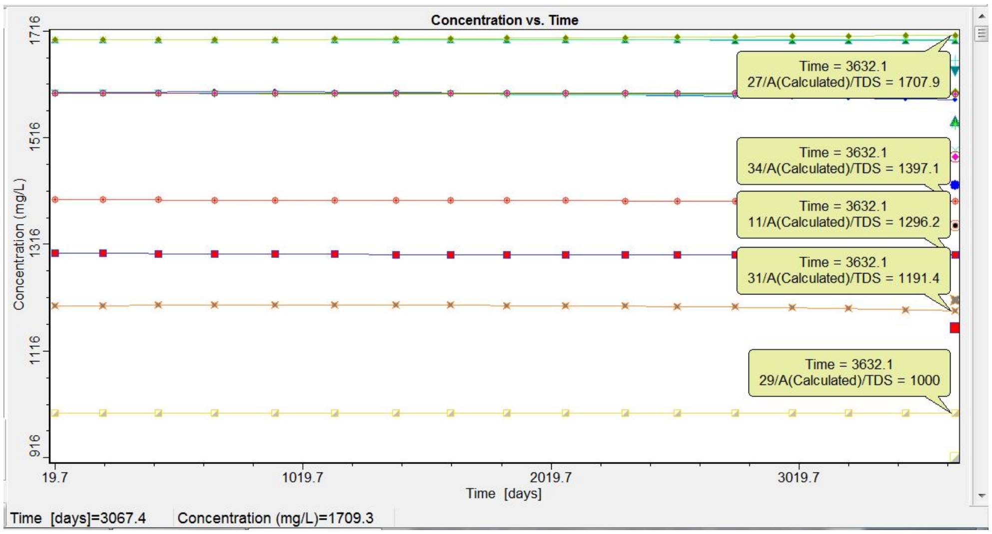

Fig. 9. The expected TDS values in wells versus time

9. CONCLUSION

1. Results of the three dimensional lithologic modeling techniques have been used for clarifying the features of groundwater flow modeling of the aquifer system in the three dimensional groundwater flow model.
2. The numerical groundwater flow and quality model have been implemented referring to the quantification of potential impact on the existing water policy and the expected environmental impacts on the groundwater potential as integrated information. In addition, it describes the expected status of the groundwater under the end time of the proposed project.
3. Under the proposed second scenario and the present extraction rate, it is noticed that the reclamation of 3240 feddans is technically not feasible, within a period of 50 years where the water level dropped by about 28.5 m because of high pumping, increasing the number of wells and low recharge rate. This can affect the economic visibility of the development projects in the future.
4. As a result of lowering the pumping rate and working hours, there is an improvement in the expected groundwater potential in its quantity and increasing in the aquifer's storage.
5. Under the proposed third scenario, the optimum safe yield for all wells in the studied area is 150 m^3/ h; 12 operating hours per day because there is no significant change in the outputs of such case in long term, such as water levels and salinity where the aquifer reaches the steady state condition.
6. The groundwater extraction is accompanied by an increase in groundwater salinity for 10 years, but after 25 years there won't be a significant change of expected groundwater salinity and it became constant, this may be due to reaching saturated zone.
7. Under the proposed forth scenario, there is a limited change in groundwater potential factors (depth of water and salinity). The present groundwater developments in the middle part of Darb EL-Arbeain should be extended, as the present groundwater extraction will cause 7.5 meters drawdown by the end of the next 50 years.
8. The space (interval distance) between each two successive new wells should not be less than 1 km in order to minimize the interference drawdown between them.
9. This paper gives a method and an algorithm for management and evaluation of groundwater aquifer which can be used for analyzing and studying any other area according to its available data.

CONSENT

All authors declare that 'written informed consent was obtained from the patient (or other approved parties) for publication of this study.

ETHICAL APPROVAL

All authors hereby declare that all experiments have been examined and approved by the appropriate ethics committee and have therefore been performed in accordance with the Ethical standards laid down in the 1964 declaration of Helsinki.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. The World Bank. West Delta Water Conservation and Irrigation Rehabilitation Project. 32393- EG; 2007.
2. Ghaly SS. Environmental Impact of artificial recharge on groundwater in Bustan extension area. Master Thesis. Faculty of Engineering- Ain Shams University, Egypt; 2001.
3. CONOCO, Continental Oil Company. Geologic Map of Egypt; 1987.
4. Korany EA, Fathy RG, Nagate M. Contributions to the hydrogeology of nubia sandstone aquifer in the middle part of Darb El- Arbeain, South Western Desert, Egypt. The Sediment Logical Society of Egypt. 2002;1110(10):119-143.
5. Fathy RG. Atef AA, El-Gammal NM, Nagate MEL editor. Contributions to the hydrogeological and hydrochemical characteristics of nubia sandstone aquifer in Darb Al-Arbeain, South Western Desert, Egypt. Al-Azhar Bull. Sci. 2002;13(2):69-100.
6. Ambroggi RP. Water under the Sahara. Scientific American .1966;214(5).
7. Ezzat M A, Abul- Atta. Exploration of groundwater in EL-Wadi EL-Gedid project area hydrogeological conditions, Dakhla-Kharga Area. Ministry of Agriculture and Land Reclamation, Cairo; 1974.
8. German Water Group. Hydrogeological study of groundwater resources in the Kufra Area. German Water Engineering. 1977;(5).
9. Shata A, Knetsch G, El Shazly M. The geology, origin and age of the groundwater supplies in some desert Areas of U.A.R.", Bull. Inst. Desert, EL-Mataria, Cairo. 1962; 12(2):61-124.
10. Shata A. Hydrogeology of the great nubian sandstone Basin, Egypt. Engineering London. 1982;(15):127-133.
11. Abd Elghani E editor. Management and evaluation of groundwater aquifer in the middle part of Darb El-Arbaein Area, South Western Desert, Egypt. Ph.D. Thesis. Faculty of Engineering, Shoubra, Benha University, Egypt; 2015.
12. GARPAD. General Authority for Rehabilitation Projects and Agricultural Development. Lithologic Logs and Geophysical Logs of Water Wells, Darb El-Arbaein Area, South Western Desert, Egypt; 2001.
13. McDonald MG, Harbaugh AW. A modular three dimensional finite difference groundwater flow model. USGS Scientific Software Group. Washington D.C., USA. ; 1988.
14. Spitz K, Moreno j. A practical guide to groundwater and solute transport modeling. John Wiley and Sons. New York; 1996.
15. Rajamanickam R, Nagan S. groundwater quality modeling of Amaravathi river basin of Karur district, Tamil Nadu, Using Visual MODFIOW. Environmental Sciences. 2010;1(1).
16. Nagate M, El A, editor. Hydrogeological studies of nubian sandstone aquifer in the middle part of Darb El-Arbaein Area, South Western Desert, Egypt. Ph.D. Thesis, Geology Dept., Fac. of Sci., Ain Shams Unvi. 2003;160.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history.php?iid=965&id=22&aid=8330