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Using Modflow as a Mangment tool for the Groundwater System in the Area Northeastern Cairo, Egypt.

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Abstract: *The northeastern part of Greater Cairo is a target for development and anthropogenic activities that stress both the quantitative and qualitative aspects of the groundwater resources. On the other hand, it is a critical area, being adjacent to the Second Egyptian Research Reactor.An annual increase in groundwater levels (0.206 m/year) was estimated by earlier work of Al Gamal, 2011. This represents a crucial problem in the study area where it may influence the environmental and population safety due to the nuclear installation under the effects of potential radiological release. The main aim of this research is to provide an additional insight into the behavior of the groundwater flow system in the study area, and to provide valuable information for the decision-maker to the exploration of alternative management approaches.The main aim of this research is to provide an additional insight into the behavior of the groundwater flow system in the study area. and to provide valuable information for the decision-maker to the exploration of alternative management approaches.The groundwater model MODFLOW has been used as a simulator for groundwater flow both in steady and unsteady state to provide a solution for the problem of expected groundwater increment . The simulated groundwater flow system has been calibrated and production scenarios have been proposed and tested as a solution of the expected groundwater storage increase. One of these scenarios gave accepted results, by using eight production wells withdrawing this water to face such rise of the groundwater level, and using of this water in reclamation of the desert area around the nuclear facility.*

Keywords: *Northeastern Cairo, Groundwater flow model, waterlogging, Exploration scenarios.*

I. Introduction

Groundwater systems are affected by natural processes and human activities. They require targeted and ongoing management to maintain the quantitative and qualitative aspects of groundwater within acceptable limits, while providing the desired economic and social benefits. Groundwater management and policy decisions must be based on knowledge of the past and present behavior of the groundwater system, the likely response to future changes and the accountancy of the uncertainty. The northeastern part of greater Cairo, where the study area is located, is a target for various development activities (i.e. agriculture, industry and urbanization). On the other hand, this area is adjacent to the Second Egyptian Research Reactor. These activities stress both the quantitative and qualitative aspects of the ground water resources and adversely affect the sustainability. It is also of high concern to indicate that the characteristics of the groundwater system in the study area and vicinities may influence the environmental and population safety due to the nuclear installation under the effects of potential radiological releases**,** (nternational Atomic Energy Authority, 2003).

Numerical modeling of groundwater helps to simulate its flow characteristics in the simple or complex system. Demonstration of the models to reproduce past behavior of the groundwater system, helps to predict its response in the future and can support decision-making and selecting alternative management approaches (Reilly, 2001). Among these models, visual MODFLOW is the most commonly used simulator for groundwater flow and solute transport in subsurface systems, (Brooks and Mason (2005). An annual increase in the groundwater volume of Miocene aquifer in the study area has been referenced in the work of Al Gamal et al, 2011; it was estimated to be in the range of 67980 m^3 with an average rise of 0.206 m/year. The increase in groundwater level in the study area is a crucial problem where it may influence the safety of the nuclear installation, or may influence the potential radiological impacts.

Physical sitting

The study area, Figure (1), is divided into two zones separated by Ismailia Canal. The first zone (old cultivated lands) is located to the west and northwest of Ismailia Canal, while the other zone (the desert area) is located to the east and southeast of the canal. Inshas area which is the subject of the current study belongs to the eastern zone.

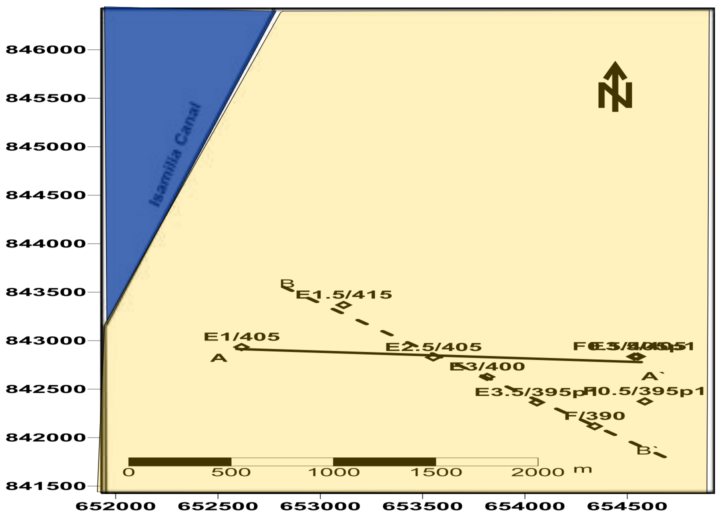

Figure (1): Location map of the study area.

The desert area is characterized by a mild to moderate topography (El Sayed, 2005). Digital Elevation Model (3DEM) declear that its land surface slopes to the north and west and is dissected by a network of dry wadies that terminate downslope, (Fig. 2). The area is covered by different types of soils; some are of sandy clay nature (near the old cultivated land).

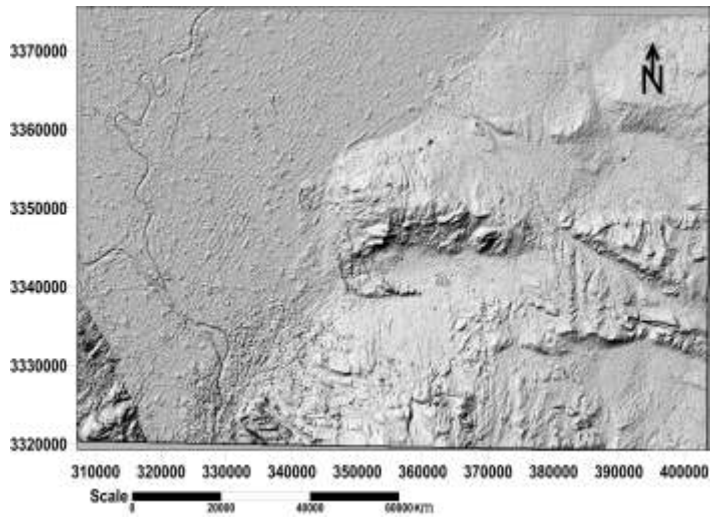

Figure (2): Topography of the study area using Digital Elevation Model (3DEM)

The studied area is characterized by an arid to semi-arid climatic conditions where summer is hot and winter is mild rainy.

Geological and Hydrogeological Setting

The major lithostratigraphic units encountered in the study area are related to Quaternary and Tertiary, (Fig. 3), The Quaternary deposits are represented by a section of Nile sediments appearing on the surface and extending in subsurface for about 60 m maximum thickness (EGSMA, 1997). It mainly consists of loose quartz sand and gravel interbeds occasionally with thin streaks of silty clay. The Quaternary sediments are underlain by a thin bed of yellowish brown clay of one meter thickness. The latter is underlain by basalt sheets appearing at different depths from 7m to 59m below surface, (Desert Research Centre, 1993). The Tertiary sediments are represented by Miocene strata which occupy the northeastern and southern parts of the area and exhibit a variation in thickness up to 98m. These sediments consist of dark grey clayey silt and calcareous marl interbeds with gravel and sand bands.

The surface of the two lithostratigraphic units is strongly dissected by a complex system of faults striking, mostly through aganion haydrulic E-W. The Miocene and Quaternary aquifers face each other in the study area where connection occurs along the NW/SE fault plane (Desert Research Centre, 1993), (Fig. 4a and 4b). A detailed cross section showing the different geologic units and the lateral and vertical changes in lithostratigraphy and structural features is given in the work of (Al Gamal et al, 2011).

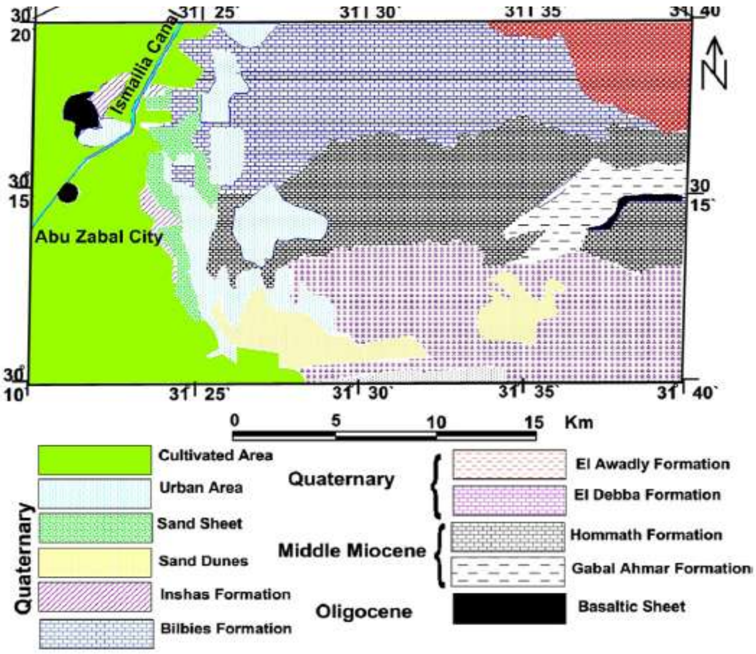

Figure (3): Geologic map of the study area (Sultan ,etal 2012).

Groundwater occurs in two main water bearing formations; Quaternary and Miocene aquifers. According to Desert Research Centre (1993), the Quaternary aquifer occupies the western sector of Inshas region (to the west of the NW fault). It is mainly composed of loose sand, rounded to subrounded very coarse to fine well sorted. The thickness of this aquifer varies from 7 m to the NE up to 48m in SW of the site, and the aquifer is underlain by a thin bed of clay followed downwards by basalt sheet. The Quaternary aquifer within the area of study is found under semi-confined conditions depending on the presence or absence of clay intercalation. The depth to water ranges from 21 m (NE) to 91 m (SW).

The Miocene aquifer is exposed to the east of the NW fault in Inshas area (facing the Quaternary to the west). It is composed of dark grey clayey silt and calcareous marl interbeded with gravel and sand bands at the top. This aquifer is enclosed between two impervious clayey beds which create a piezometric head and turns the aquifer confined. Its thickness reaches 98m, (Al-Gamal et al, 2011) and the depth to water varies from 14 m to 36 m. The recharge of the Miocene aquifer mainly takes place from precipitation during the past wet periods. It also takes place due to irrigation return and inflow from Pleistocene aquifer in some areas. The discharge takes place through production wells and pumping for different purposes.The permeability coefficients of the study aquifers, based on pumping test, range from 4.9×10^{-3} to 8.1×10^{-3} cm/sec and the transmissibility ranges from 56.7 to 100 m^3/day/m (El Sayed, 2005).

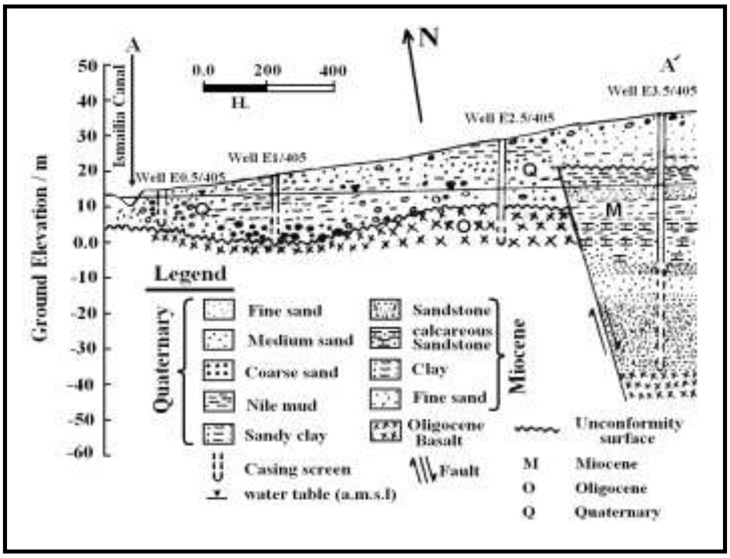

Figure (4a): Geological Cross section `, EAEA site Inshas area, (Al Gamal et al, 2011).

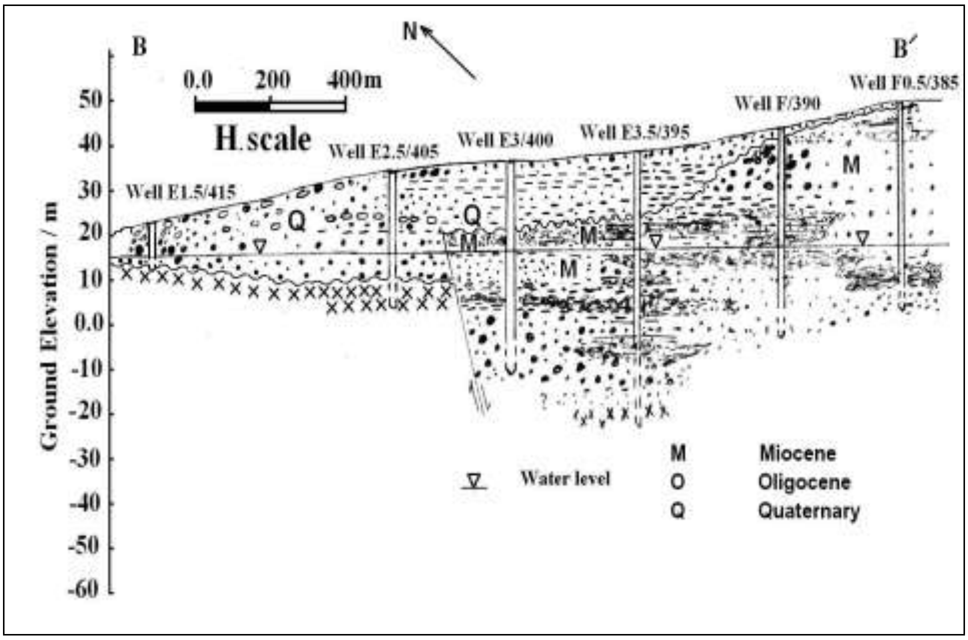

Figure (4b): Geological Cross Section, BB`, EAEA site Inshas area, (Al Gamal et al, 2011).

II. Material and Methods

The data that describe the hydrodynamic properties, lithostratigraphic characteristics, dimensions and geometry of the water bearing formations and bounding units have been inventoried from the work of (DRC, 1993 and El Sayed, 2005). The data also include the parameters of groundwater flow (head, gradient, direction, interconnections…. Etc.) and well design at the points of sampling.The mathematical modeling technique has been applied by using the visual MODFLOW computer program (Mc Donald and Harbaugh, 1988). The model is capable for simulating the time-dependent flow as well as mass and heat transport. The time-dependent data which are included into the Finite Difference Model (FDM) has to be stored outside in database or GIS systems. The governing equations are derived through combination between the water balance equation and Darcy's law (Anderson and Woessner, 1992). The model describes groundwater flow of constant density under non-equilibrium conditions in a heterogeneous and anisotropic medium according to the following equation (Bear, 1979), which was solved using the finite difference technique:

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)-W=S_s\frac{\partial h}{\partial t}$$

Where K_{XX}, K_{yy} and K_{zz} are the hydraulic conductivity along the x, y, and z coordinate axes, (Lt^{-l}); h is the potentiometric head (L); W is a volumetric flux per unit volume and represents sources and/or sinks of water (t); Ss, is the specific storage of the porous material (L^{-l}); and t is time (t). In general, S_s, K_{xx}, K_{yy}, and K_{zz} may be functions of space (S_s = Ss(x,y,z), K_{xx} = K_{xx}(x,y,z), etc.) and W may be a function of space and time (W = W(x,y,z,t)).

Processing and results of the model

To achieve the objective of the current study; (i.e. to simulate the groundwater flow system and to determine its response against changes of relevant attributes (head and discharge) & also, to review the specific data, parameters and information which characterize the hydrogeological regime in the study area) ,the following procedure has been followed:

Conceptual model

A hydrogeological conceptual model has been developed by taking into account the available geological and hydrogeological data and information, including aquifer parameters and groundwater level observations (Varni and Usunoff, 1999). The groundwater system under study has been conceptualized as a one hydrogeological layer of approximately 98m thickness, representing the two main aquifers (Quaternary and Miocene). The hydraulic conductivity values vary in a narrow range from 0.005 to 0.034 m/min and from 0.177 m/min to 0.163 m/min in the two aquifers, respectively, (DRC, 1993). A faulting system (NW-SE) strikes the local area and upraises the Miocene aquifer to face the Quaternary one up to 73m (DRC, 1993 and El Sayed, 2005). The two aquifers are hydraulically connected through the fault plane and show the same hydraulic conditions in the local study area, (Attia, 2009). Groundwater levels range from 13.5 to 16 m.a.s.l. in the modeled area for both aquifers (Fig. 5). A fluctuation of groundwater levels in the range of 50-100 cm has been recorded in the period from 1997 to 2005 (Al-Gamal et al, 2011). Groundwater flow in the aquifer is governed by the conditions at the boundary of the regional system.

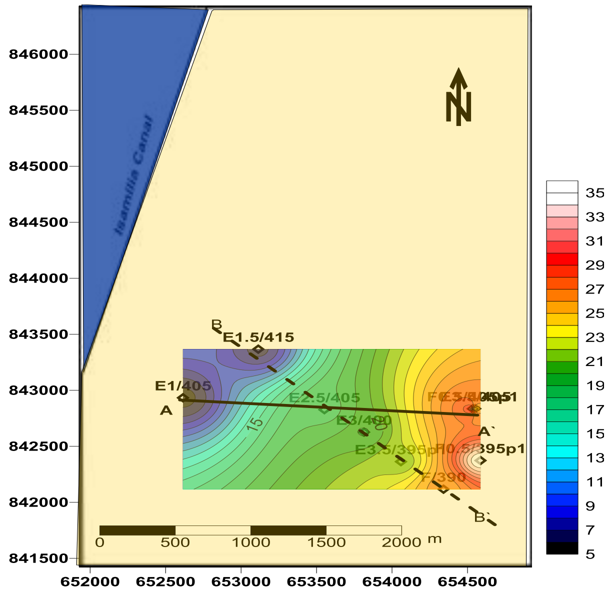

Figure (5): Water table map of the study area (2005), (Al-Gamal etal, 2011).

Steady State Simulation

Based on the availabe data and hydrogeological conditions in the study area, the two aquifers in a 1200 feddan area were divided into 100 columns and 100 rows for simulating groundwater flow. The layers modeled, their dimensions, their hydrogeological parameters, the chosen boundaries and all the characteristics of the system are fed to the modeling design, for accountancy in the output calculations. Proper representation of model boundary conditions is very important for proper simulation of groundwater flow. These should correspond to the actual hydrologic boundaries of the system, as they constrain and control the results of simulation. Ismailia Canal has been considered as a constant head boundary to the Northwest of the study area and a general flow boundary has been assigned to the northern, southeastern parts (Fig. 6).

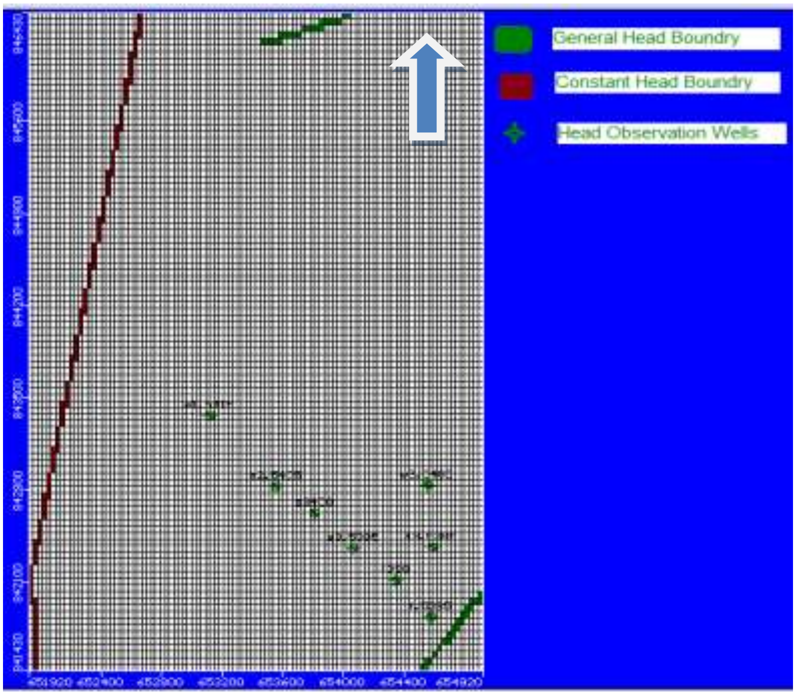

Figure (6): Grid and boundaries of the modeled area.

The evaporation rate exceeds the total annual rainfall rate in the study area. The main groundwater recharge at the zone of interconnection, comes from irrigation return, (Mohamed, 2002)flow and from Ismailia Canal at specific locations. The groundwater levels of the year 2005 have been used to model the groundwater flow for steady state conditions in the area under study. The availability of relatively complete historical records of hydraulic head at a number of observation wells in the period 1995 - 2005, (El Sayed, 2005 and Al-Gamal et al, 2011) helped to conduct the model calibration (Fig. 7) so the hydraulic conductivity and transmissivity are changed by trial and error method (Doherty, J. 1990) until the contours of the calculated heads match the observed heads of the year 2005. The efficiency of the simulation process and the compliance between calculated and observed head values was 0.994, with a residual mean of 0.718 m, (Fig. 8). This indicates an acceptable comparison and satisfactory calibrated results and renders the adjustment of hydraulic conductivity, not necessary.

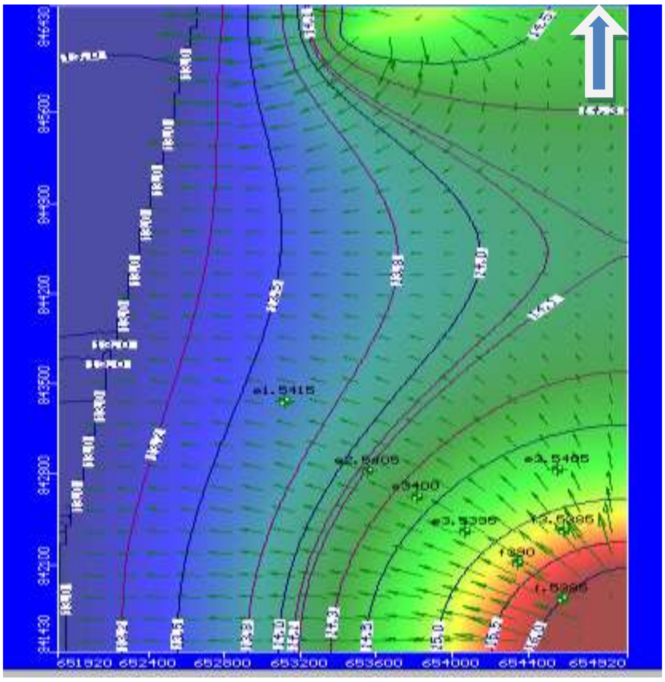

Figure (7): Water level contour map of the steady state during year 2005.

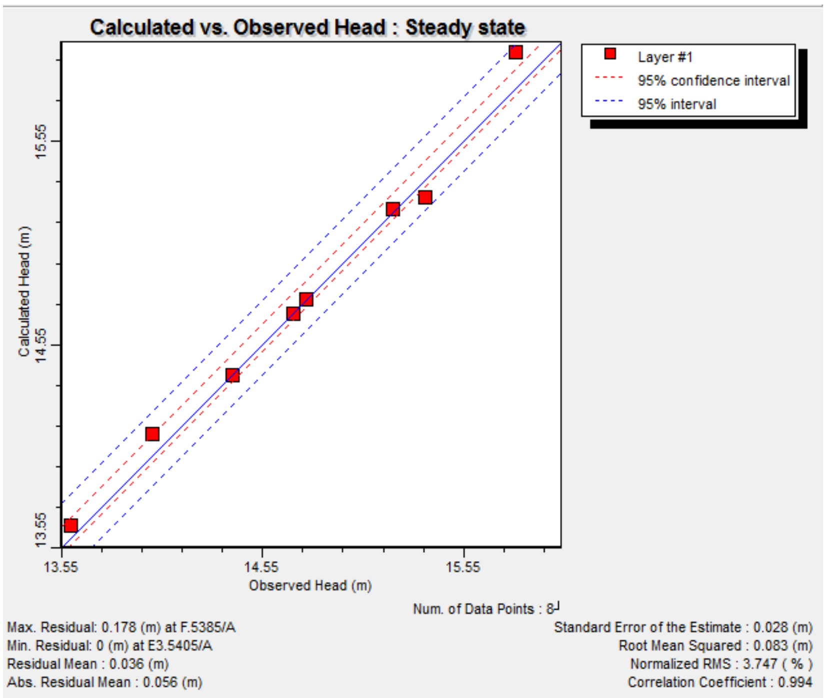

Figure (8): Relation between the observed and the calculated head, steady state calibration

Unsteady State Simulation

After completing the steady state simulation, the output of the first round was used for simulating the unsteady state condition of the system. This have been done by using the simulated hydraulic head of the year 2005 under the same boundary conditions and applying the available reference period of piezometric head records (2005 to 2015). The storage coefficient values introduced to the model were deduced from previous studies (El Sayed, 2005). The simulated head in the unsteady state (Fig. 9), showing that the groundwater movement in the sector under study , is generally from southeast to north and west directions (i.e. from the Miocene aquifer to the Quaternary aquifer), ending as base flow in Ismailia Canal. The calibration of the unsteady state simulation shows a good correlation (0.97) between the observed hydraulic head and the calculated head, (Fig. 10).

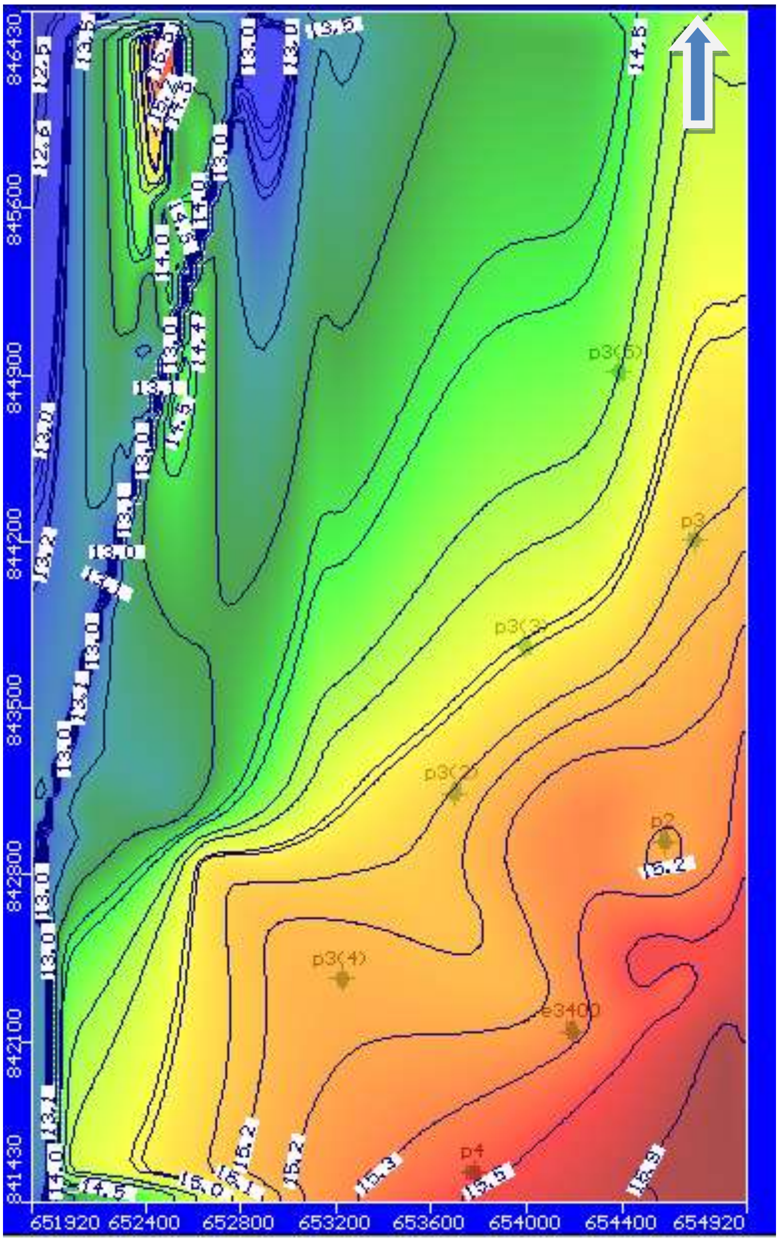

Figure (9): Water level contour map of the unsteady state during year 2005.

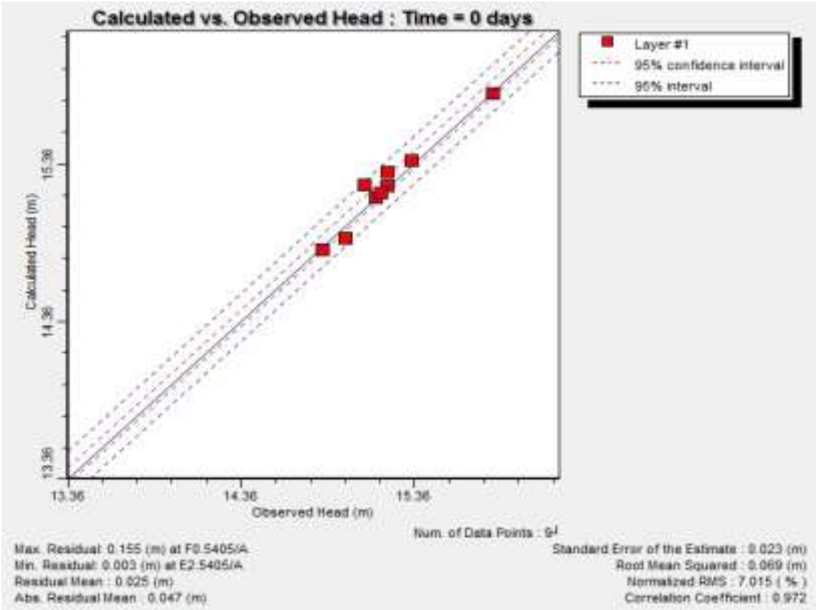

Figure (10): Relation between the observed and the calculated head, unsteady state calibration.

The current situation till year 2040

The output of simulated heads in 2015 has been used as initial values for predication of the change in head in the year 2040. The results of prediction is illustrated in (Fig.11), where the drawdown was estimated to be 2.52m through the next 25 years (i.e. the yearly drawdown is nearly equal to 0.101m). These values of the predicated head with the assumption that the rise in the water table is 0.206m/year (Al Gamal et al, 2011) uprising a problem that threaten the design structure of the nuclear facility in the study area.

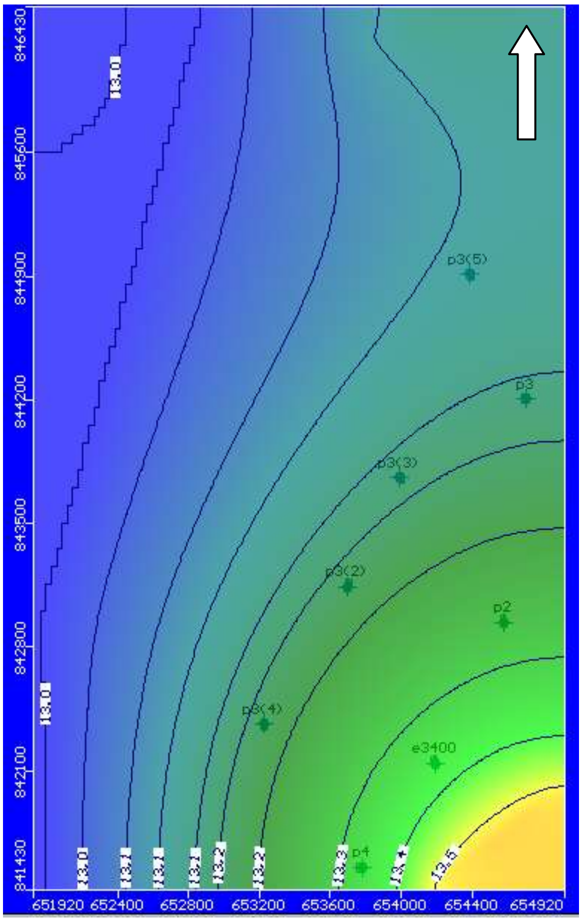

Figure (11): Water level contour map of the unsteady state during year 2040.

Proposed scenarios for the existing problem
First Scenario

A first scenario has been proposed to face the increment of groundwater level by designing four exploitation wells , covering the Miocene aquifer in the model domain with an operating time of 10 hours with rate 40 m^3/day. This resulted to decrement of nearly only 0.098 m/ year which is not sufficient to cope with the expected increment, (Fig. 12).

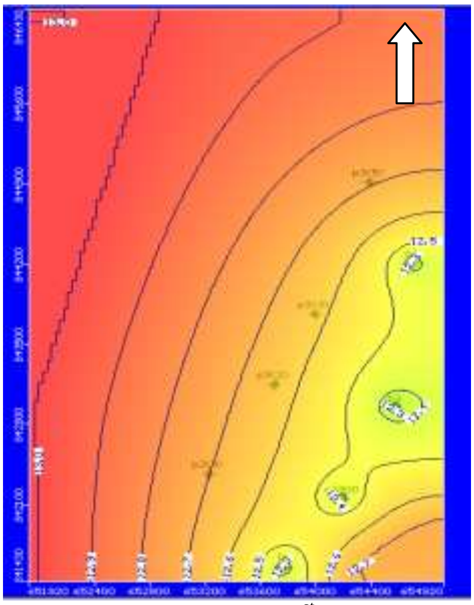

Figure (12): The predicted head from 1st scenario in the year 2040.

Second Scenario

A second scenario has been proposed by increasing the productive wells to eight wells with an operating time of 10 hours with rate 40m^3/day covering both the Miocene and the Quaternary aquifer in model domain. The predicted head due to the 2nd scenario of production was illustrated in (Fig. 13), revealing that the decrement will reaches about 0.151 m/ year, which is still not sufficient for the increment.

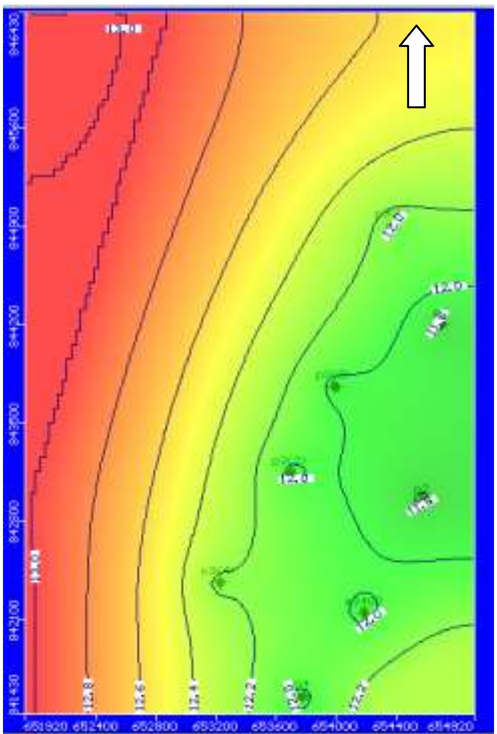

Figure (13): The predicted head from 2nd scenario in the year 2040.

Third scenario (solution problem scenario)

A third scenario has been proposed to withdraw the expected future increment in groundwater level and to use the withdrawn water from cultivation of the desert area around Inshas site. It was proposed to design eight productive wells with an operating time of 10 hours with rate 80 m^3/day covering both the Miocene and Quaternary aquifer. Figure (14) illustrates the predicated head under the effect of the proposing scenario, resulting in decrement of the groundwater level of about 0.206 m/ year which is satisfactory to cope with solving the problem of groundwater level increase.

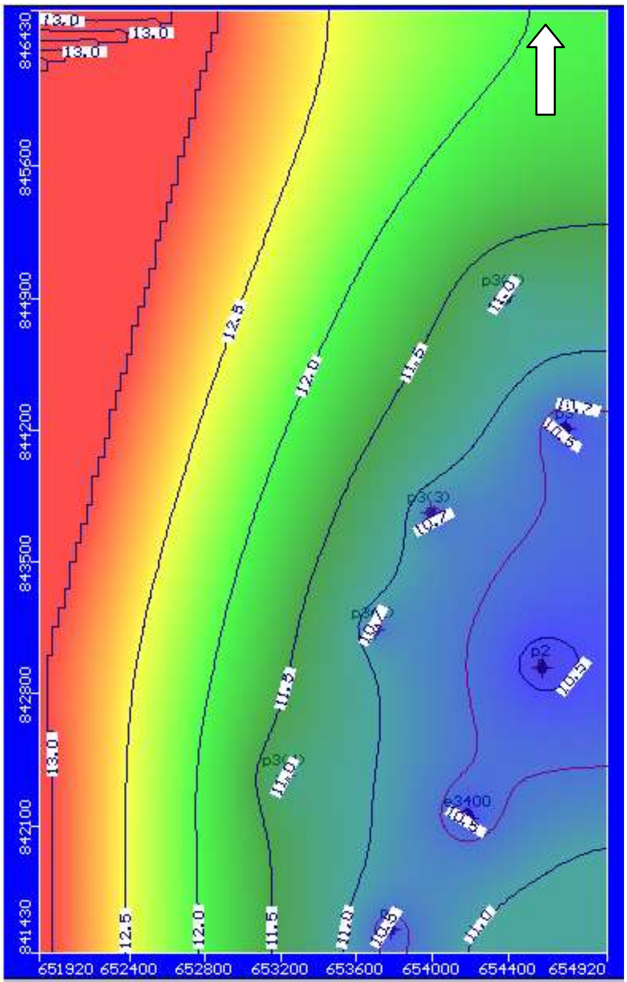

Figure (14): The predicted head from 3rd scenario in the year 2040.

The water produced from the proposed productive wells would be used for the cultivation of 1200 feddan in the area and can be used for any type of crops as their salinities are low ((EC~ 0.95 mmhos/cm) (Ahmed, 2002 and El Sayed, 2005), they can be used for field crops (such as, Bean cowpea), some vegetables (Beans, lettuce, onion, and radish) as well as some fruits (Avocado, strawberry) (Ayers and Westcot, 1976; and NWQMS, 2000).

III. Conclusion

The groundwater flow system in the area of northeast Cairo has been successfully simulated and modeled under steady and unsteady conditions using the visual MODFLOW model. The result of prediction in the current situation scenario estimated to be 2.52 m through the next 25years (i.e. the annual drawdown is nearly equal to 0 .101m). These values of the predicted head with the assumption that the rise in the water table is 0.206 m/year uprising a serious problem that threaten the design structure of the nuclear facility in the area. The calibrated model has been used to introduce another scenario to face the annual increase in groundwater storage of the Miocene aquifer that threatens the facility in Inshas area, by proposing eight wells resulting in decrement of the groundwater level of about 0.206 m/year which is satisfactory to cope with solving the problem of groundwater level increase. In this scenario, the withdrawn water from the system can be used in the cultivation of the surrounding desert area.

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