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Groundwater Management of Eocene Limestone Aquifer in the Area between Beni Mazar and Mallawi West El Minia, Egypt

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Abstract: The hydrogeological inventory in the area between Beni Mazar and Mallawi west El Minia governorate in Egypt, there are three groundwater aquifers namely; Oligocene, Eocene, and Nubian Sandstone. Oligocene and Eocene aquifers are hydraulically connected through faults. The saturated thickness of the Oligocene sandstone aquifer attains 80.4 m and increases towards the west. The Eocene limestone aquifer is the main aquifer in the area and is represented by Samalut Formation. It is an unconfined condition with water level ranges from - 30 m below ground surface to + 90 m above sea level. The saturated thickness ranges from 45.5 m and 394.7 m and groundwater salinity vary greatly from 400 ppm to 2050 ppm. Application of processing 3 dimensions MODFLOW model delineates a realistic view during the development process and protects the area from groundwater decline. Under the transient conditions, three management scenarios are applied to mitigate the water level depletion of the Eocene and Oligocene aquifers. It was found that the Eocene and Oligocene aquifers have good potentiality under different stresses. The decline in water levels in the third scenario shall not exceed 10 m through the next 50-years till the year 2068. This scenario could be applied for starters to reclamation in the area.

keywords: West El Minia, Beni Mazar, Mallawi, groundwater, Oligocene and Eocene aquifers, MODFLOW model, management scenarios.

1.Introduction

Groundwater is considered as one of the most important sources of water for different uses. In the last decades, the development of the desert areas by building up new communities attracted the attention of the decision makers and the investors. This natural expansion for agricultural, industrial and civil activities in the desert areas needs more exploration activities for groundwater resources. The aforementioned activities may lead to decline of groundwater level. Monitoring of the groundwater resources was essential to evaluate the impact of the reclamation.

Because of shortage in groundwater in the present area a detailed hydrogeological study needs to be done. The main object of this study is to estimate groundwater potentials of different aquifers for future development. El Minia Governorate occupied area of about 245 Km south of Cairo on both the Western and Eastern banks of the River Nile. It is bounded by Latitudes 27.8 and 28.6 and Longitudes 29.4 and 31.8 (Fig. 1).

The desert area west El Minia is subjected greatly to reclamation in the past twenty years depending mainly on the groundwater extraction through drilled wells. The main irrigation canals (El Ibrahimaya and Bahr Yousef) and the main drain (El Moheet drain) run generally from south to north parallel to the Nile. It characterized by a wide variation in topography from depressions to hills. The elevated plateau and isolated hills constitute the most scenic land features in the study area. These act as the principal watershed areas and have a direct impact on the groundwater replenishment. The area is subdivided into the following geomorphic features (Figs. 2): Tableland, isolated hills, flood plains, sand dunes belt and drainage network.

Geologically, the sedimentary successions of the area between Beni Mazar and Mallawi to

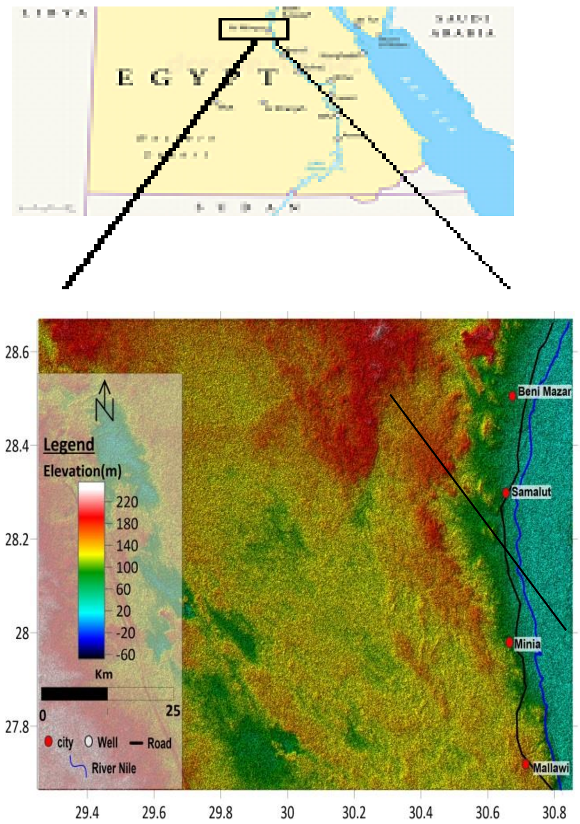

Fig. 1 Location map of the study area.

the west ranges in age from Lower Eocene to Quaternary. The interest of the area is due to the well exposed of Eocene which can be considered the main water bearing rocks. The stratigraphic succession of the investigated area was previously studied by many authors (1,2,3,4,5). The stratigraphic concepts of the water bearing formations were employed with the structural setting and sedimentologic studies to discuss and compare the impacts of the geologic conditions on the occurrence of the groundwater in the area of study .

Methodology

In this part, the processing MODFLOW code program is used to simulate the hydrogeological conditions of the Eocene aquifer in the area between Beni Mazar and Mallawi to the west. This model is designed for aquifers in which saturated flow conditions exist, the density of groundwater is constant and the principal directions of horizontal hydraulic conductivity or transmissivity do not vary with time. Building and developing of the model are based on the following steps:

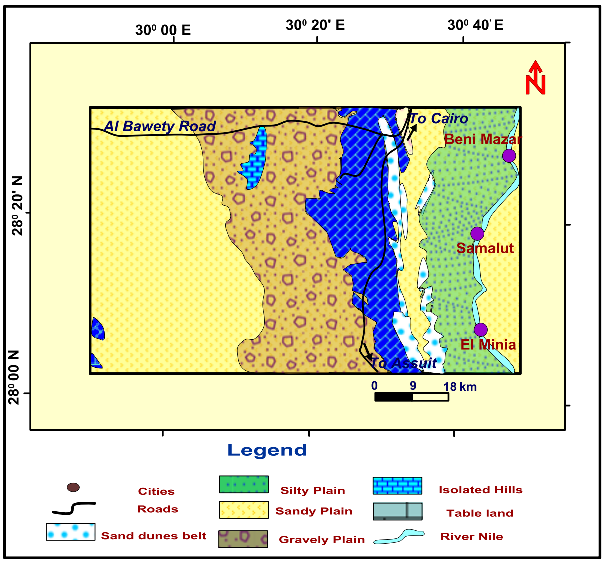

Fig. 2 Geomorphologic units in the area between Beni Mazar and Mallawi to the west (6).

Conceptual model

Conceptual model of water flow system is constructed for the Eocene aquifer based on number of assumptions verified as following:

The unconfined nature of the aquifer system in the area.

The aquifer rests on the Cretaceous age rocks.

The groundwater movement is generally from the west to the east.

The spatial variations in directional transmissivity and hydraulic conductivity due to variation in saturated thickness of the flow section.

The temporal variation in the transmissivity resulting from potentiometric level changes.

The realistic outer boundaries are preferably to be natural boundaries and accurately defined in location.

Model grid structure

A grid of 200 cells (20 columns and 10 rows) is constructed to cover the area between Beni Mazar and Mallawi to the west (Fig. 3). The active cells represent the area covered by the Eocene and Oligocene aquifers. Refinement of the cells occurred in columns and rows to the area of heavy data as the path of the Nile River and the area of heavy wells.

Assigning of the field data to this grid is very important since the data should be compatible to the model grid scale. The processing MODFLOW code receives data in a spreadsheet. The different parameters *(hydraulic conductivity, transmissivity, groundwater levels …….etc.)* were prepared by using the grid tool of the SURFER package applying the kriging statistical method (7).

Boundary conditions

Accurate defining of the aquifer boundaries should be handled with great care. Thus, referring to the present hydrological studies the natural boundaries of the Eocene and Oligocene aquifers could be defied as follows:

a- Nile River is considered as recharge or discharge boundary according the characteristics of the Nile like its width, elevation of its bottom and conductance.

b- The northern and the southern boundaries are represented by open boundary.

c- The western boundaries are represented by General Head boundary which is used to simulate head dependent flow boundaries. Its value depends on the head value and hydraulic conductance value.

d- The main recharge is from surface water (El Ibraheimia and Bahr Yousef Canals), upward leakage from Nubian Sandstone and contact with Quaternary aquifer in the eastern part.

Model geometry

Model geometry examines the top and bottom of the aquifer to calculate the aquifer thickness for each cell node. The calculated thickness should have positive value; otherwise, the model can't continue the iteration process (convergence state). The data is simulated by using the program data editor

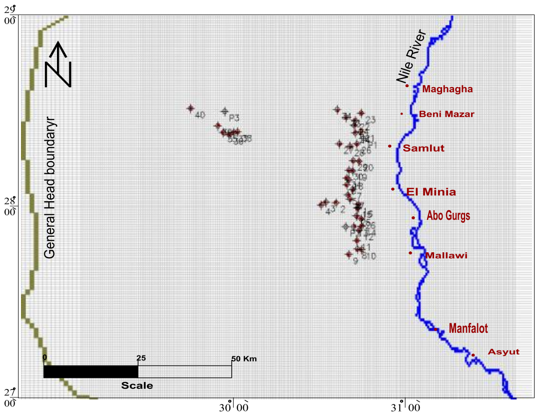

Fig. 3 Grid design, boundaries and wells location in the area

Building the groundwater system

Based on the hydraulic parameters of the Quaternary aquifer of the study area, the groundwater system is built up by assigning the horizontal hydraulic conductivity and transmissivity distribution values to the model grid.

Initial hydraulic head includes:

a- General Head value of + 40 is assigned to the active cell.

b- Head value of + 65 to + 70 (average level of Nile River, year 2017) is given as active cells.

Running of the model

The model is allowed to run after completing enters of the required data. If there is a convergence, an input data error appears, it should be repaired as many times until the running process goes successfully. This means that the model succeeded in computing the heads of the aquifer at every cell. As a result, a water level contour map is constructed by using these calculated heads. The relation between the calculated and observed heads is also checked from the calculated - observed head curve. If the variance has large value, then it indicates great difference between the heads calculated by the model and the actually measured heads so the calibration process is very highly required to minimize this variance to a lower accepted value.

Model calibration

Calibration is an essential step in the

modeling process. It is very important to give some assurance in the constructed model. It is done by finding a set of parameters, boundary conditions and stresses that make the simulated heads; match the actual measurement values with an acceptable range of error. It can be performed either by hand- operated trial - and - error method or by inverse model codes such as PEST and UCODE (8). Trial and error method is chosen in calibrating the Oligocene and Eocene aquifer model. Three observation wells (P_1, P_2 and P_3 are used to check the relation between the calculated and the observed heads after many times of changing the hydraulic conductivity and transmissivity values.

Unsteady state calibration

The model becomes ready to run under transient conditions (time dependent conditions). The heads resulting from the steady state simulation are used as starting heads to the transient analysis. Other parameters such as storage coefficient, specific yield and discharging rate of wells are assigned to the model grid. Time parameter is converted into transient and a simulation period of 360 day (1 year) is applied. This simulation time is subdivided into 4-time step. The head is checked after one year (2018) where a number of observation wells (3 wells) are measured by the author. The relation between the observed heads and calibrated heads are checked. The storage coefficient and well discharging rates are modified until the observed and calibrated heads became comparable. The variance between the observed and calculated heads was minimized to 0.000398 and the calculated water level map is very closely related to the field - measured water level map (Fig. 4). At this moment the model is considered suitable for future management of the groundwater regime of the Quaternary aquifer.

2.Results and Discussion:

The water bearing sediments have a very widely geographical distribution in the Nile Valley and also in the adjacent desert wadies. They are mainly composed of gravels, sands and clay, which relate to the Pliocene clay overlying the fissured carbonates form the base of the Quaternary aquifer in the area.

Hydrogeological aspects

The hydrogeological properties of different aquifers of the area between Beni Mazar and Mallawi to the west are defined from top to base as follow:

1. Oligocene sandstone aquifer
2. Samalut limestone aquifer
3. Nubian sandstone aquifer

3.1.1. Oligocene sandstone aquifer

The Oligocene sandstone aquifer which occupying the western portion of the area between Beni Mazar and Mallawi to the west is represented by Qatrani Formation. Oligocene sandstone aquifer is composed mainly of calcareous sandstone with clay intercalation

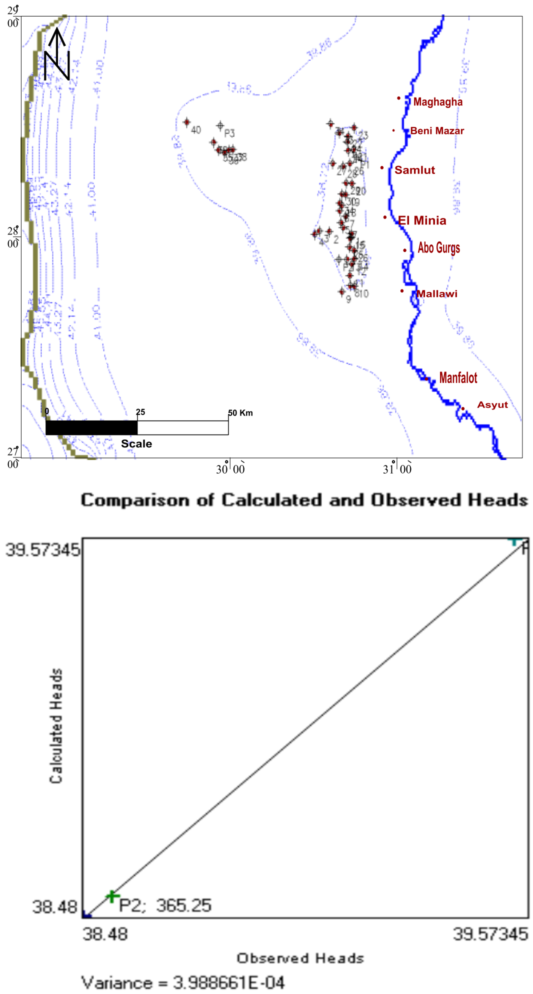

Fig. 4 Calibrated water level in unsteady state and the variance between calibrated and observed heads

It is represented by two wells No. 38 and No. 39 and depth to water reaches to 98.66 m (well No. 38), (Fig. 5). The partially saturated thickness of the Oligocene sandstone aquifer attains 80.43 m and its thickness increases towards the west of the area (9). The groundwater level attains +49.34 m (well No. 38). The Qatrani Formation is assigned to Oligocene age (10).

The groundwater of the Qatrani sandstone aquifer occurs under unconfined condition. Oligocene sandstone aquifer is hydralically connected with the underlying Samalut fracture limestone aquifer (Fig. 6). The aquifers Oligocene and Samalut fracture come in contact with each other as result of faulting displacement or through the connection along faults plains (Fig. 6).

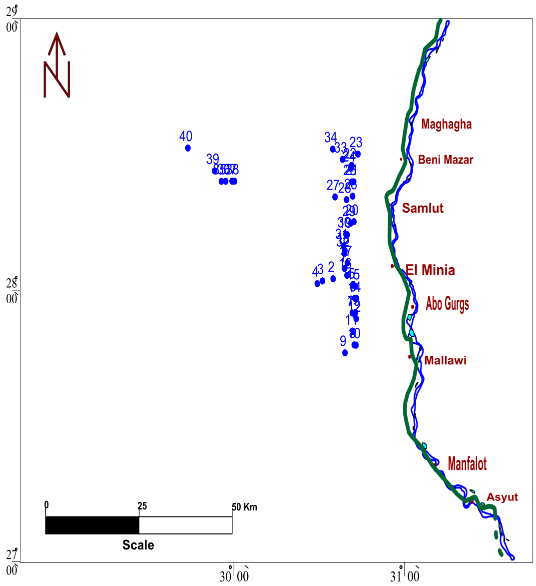

Fig. 5 Well locations map in the area between Beni Mazar and Mallawi to the west.

Samalut limestone aquifer

The Eocene rocks have a distribution all the most parts of surface rocks in the studied area especially the eastern portions (tableland). The Eocene rocks are mainly composed of carbonate intercalations with shale and marl. The Eocene limestone aquifer is the main aquifer in the area represented by Samalut Formation and is characterized by unconfined condition, the depth to water ranges from 12.5 m below ground surface (well No. 20) to 215 m (well No. 8).

The partially saturated thickness is ranged from 45.5 m to 394.66. According to the stable isotope values of (11), they are ranging between (-17.1 and 22.9 δD) and (-3.31, 2.70 $\delta^{18}O$) showing that samples have the isotopic signature of the modern Nile water with slightly contribution of paleo-water of the Nubian sandstone. It is worthy mention that the Eocene limestone aquifer (Samalut Formation) receiving a highly contribution, through upward leakage from the paleo-water of the Nubian sandstone aquifer in the northeastern portion of the area and Nile river with direction southeast to northwest.

The above mentioned criteria is confirmed by the highly depleted values of stable isotope (-37.7 δ D -5.46 $\delta^{18}O$), (-63.6 δ D -8.32 $\delta^{18}O$) of the groundwater in the northeastern part of the study area (11)

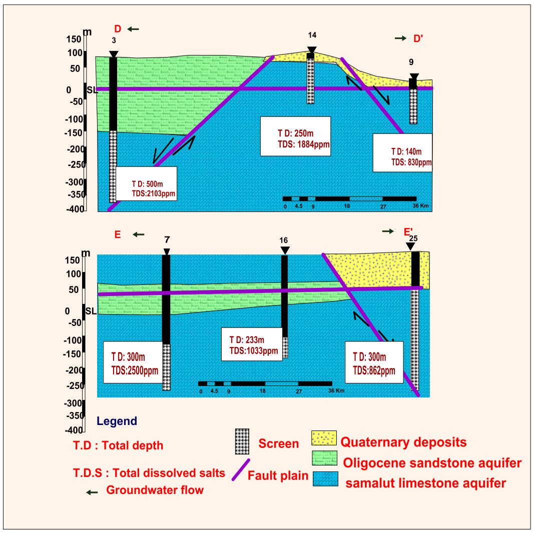

Fig. 6 Hydrogeological cross section D - D- (West - East) and E- - E (North - South) (after 9).

Samalut Formation is assigned to Middle Eocene age. The investigated aquifer is directly rest on the Minia Formation. Samalut limestone aquifer is highly cavernous and rich with *Nummulits gizahensis* which dissolved in subsurface increasing caves and fracture. Accordingly; Samalut limestone aquifer has highly fractures and caves so this aquifer has high potential aquifer.

Nubian sandstone aquifer (Baharyia Formation)

Nubian sandstone aquifer is encountered in subsurface in one productive well in the area. This rock unit is recorded at depth +1490m under the surface. The great depth is attributed to big thickness of Eocene sedimentary succession. The Baharyia sandstone aquifer underlies the Khoman chalk Formation. It belongs to the Lower Cenomanian age (1). The groundwater in the investigated aquifer occurs under confined condition. The well tapping Baharyia aquifer and is characterized by flowing condition.

Groundwater management

The model becomes ready to run under transient conditions (time dependent conditions). Other parameters such as storage coefficient, specific yield and discharging rate of wells are assigned to the model grid. Time parameter is converted into transient and a simulation period of 360 day (1 year) is applied. This simulation time is subdivided into 4-time step. The head is checked after one year

(2018) where a number of observation wells (3 wells) are measured by the author. The relation between the observed heads and calibrated heads are checked. The storage coefficient and well discharging rates are modified until the observed and calibrated heads became comparable. The variance between the observed and calculated heads was minimized to 0.000398 and the calculated water level map is very closely related to the field - measured water level map (Fig. 7). At this moment the model is considered suitable for future management of the groundwater regime of the Quaternary aquifer.

According to the measured water level of the study area, Three management scenarios are applied to mitigate the water level depletion of the Eocene and Oligocene aquifers as follow

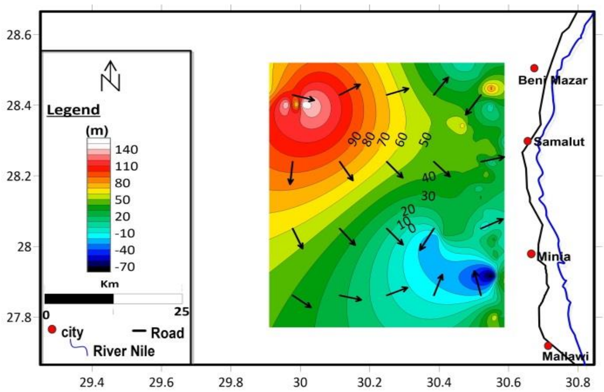

Fig. 7 Water level contour map and flow direction.

The first scenario

This scenario investigates changes in groundwater head in response to pumping of 40 area wells in the study area. The discharge rate is 120 m^3 for 12 hour per day equal to 1440 m^3/day for each well. The discharge rate in this scenario is equal to 57600 m^3/day for all wells and is equal to 20736000 m^3 /year as well as the effect of Nile River on the aquifer as a source for recharge or discharge, recharge from limestone plateau and upward leakage from Nubian sandstone aquifer.

The model runs under these stresses. Accordingly, predicted hydraulic head distribution maps after 50 years (till year, 2068) is constructed as shown in Fig.7. This figure indicates the following:

i- There are remarkable changes in heads or flow directions. The initial appearance of minor declined areas indicated by concentric and/or curved contour lines around coning area west Beni Mazar and Mallawi.

ii- Also a change in head is noticed in the other parts at west of the area as the wells the water level decreased and shifted to the east see contour line 41 become east of well No. 41.

iii- A remarkable depletion in heads is predicted in all pumped wells and the surrounding wells reaches to 3.0 m (0.06 m/year) especially in eastern side which mean that the aquifer has good potentiality.

iv- The area beneath Nile River is affected by small decreasing in head and the contour of heads take the another directions of the unsteady state calibration.

v- The depletion in head in the well is smoothing (not acute) in the eastern side and increase or not changed in the western side according to the recharge from the Eocene plateau and upward leakage from the Nubian sandstone aquifer (Fig. 8).

The second scenario

This scenario was simulated to investigate the impact of pumping of wells when we suppose that the number of wells area is duplicated for reclamation requirement (reach to 80 wells). The new wells area are concentrated around the road between Beni Mazar and El Bawiti, spread in the area by a safe distance from each other and cover all reclamation area. The discharge rate is the same rate in the first scenario, about 120 m^3 for 12 hour per day equal to 1440 m^3/day for each well. The discharge rate in this scenario equals 115200 m^3/day for all wells about 41472000 m^3 /year as well as the effect of Nile River on the aquifer as a source for recharge or discharge, recharge from limestone plateau and upward leakage from Nubian sandstone aquifer. The model runs under these stresses.

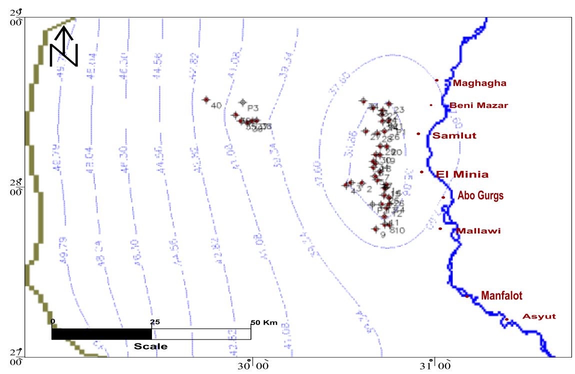

Fig. 8 Predicted head distribution map of the first scenario (year 2068).

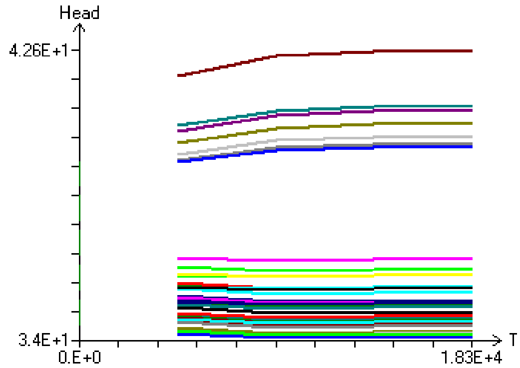

Fig. 9 Drawdown through simulation time of the first scenario.

Accordingly, a predicted hydraulic head distribution map after 50 years (till year, 2068) is constructed as shown in Fig.9. The resulting head distribution map shows the following points:

i- There are remarkable changes in heads or flow directions. The initial appearance of major declined areas indicated by concentric and / or curved contour lines around coning area west Beni Mazar and Mallawi.

ii- Also a change in head is noticed in the other parts at west as the wells make a shift in head contour line from west to east see contour line 42 changed by contour line 37 beside well No.40 in the western side.

iii- A remarkable depletion in heads is predicted in all pumped wells compared to first scenario and reaches to 8.21 m (0.16 m/year) especially in the eastern side.

iv- The area beneath Nile River is still affected by small decreasing in head and the contour of heads take the another directions of the unsteady state calibration and the first scenario.

v- The depletion in head in the well in the second scenario also is smoothing (not acute) as in first scenario according to the recharge from the Eocene plateau and upward leakage from the Nubian sandstone aquifer as in the first scenario but depletion occurs in all the wells (Fig.10).

vi- Moreover, the groundwater flow is still going in the same directions as discussed in the first scenario except in the southeastern part of the area, the head line is shifting to the north direction in the direction of the coning and its value is decreased.

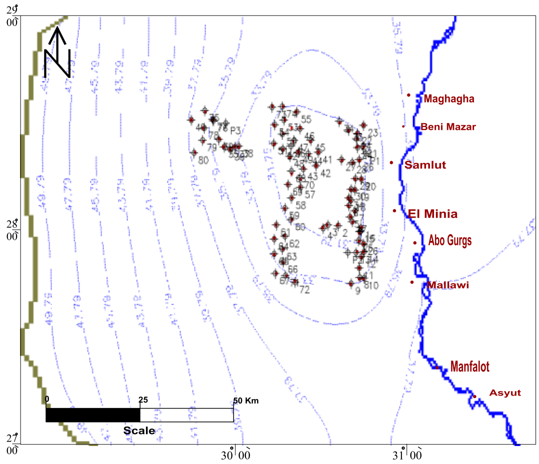

Fig. 10 Predicted head distribution map of the second scenario (year 2068).

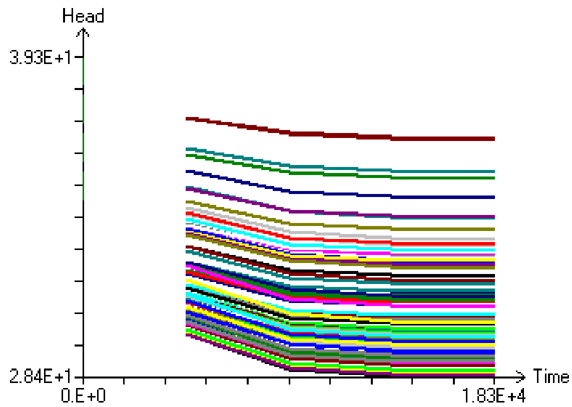

Fig. 11 Drawdown through simulation time of the second scenario

Third scenario (suggested scenario for future prospect)

This scenario was designed to investigate the impact of pumping of the existing wells area in the second scenario in addition to increase the number of wells area by forty wells to reach (120 wells) by the end of the year 2068. The new wells area are concentrated around the road between Beni Mazar and El Bawiti, spread in the area by a safe distance from each other and cover all reclamation area. The discharge rate is still 120 m^3 for 12 hour per day. The discharge rate in this scenario is equal 172800 m^3/day for all wells about 62208000 m^3 /year as well as the effect of Nile River on the aquifer as a source for recharge or discharge, recharge from limestone plateau and upward leakage from Nubian sandstone aquifer. The model runs under these stresses. Accordingly, predicted hydraulic head distribution maps after 50 years (till year, 2068) is constructed as shown in Fig. 11.

From this map the following results can be concluded:

i-There are remarkable changes in heads or flow directions. The initial appearance of major declined areas is indicated by concentric and / or curved contour lines around coning area between Beni Mazar and Mallawi to the west.

ii-Also a change in head is noticed in the other parts at west in the direction of El Bawiti as the wells make a shift in head contour line from west to northeast direction.

iii-A remarkable depletion in heads is predicted in all pumped wells less than second

scenario reaches to 10 m (0.2 m/year) especially in the west direction.

iv-The area beneath Nile River is still affected by small decreasing in head and the contour of heads take the another directions of the second scenario.

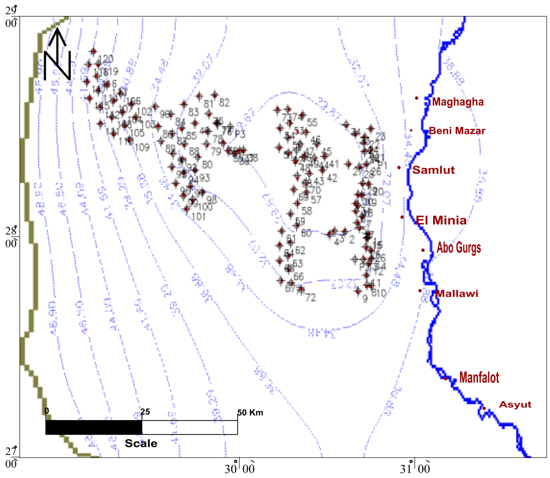

Fig. 12 Predicted head distribution map of the third scenario (year 2068).

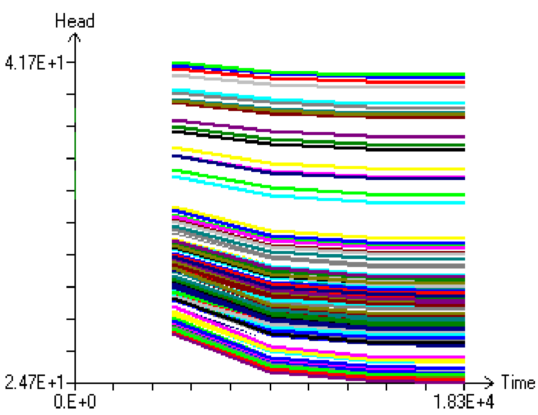

Fig. 13 Drawdown through simulation time of the third scenario

v- The depletion in head in the well in the third scenario also is smoothing (not acute) according to the recharge from the Eocene plateau and upward leakage from the Nubian sandstone aquifer but depletion occurs in all the wells as in the second scenario (Fig.12).

vi- Moreover, the groundwater flow is still going in the same directions as discussed in the second scenario and the head line is shifting to the west direction in the direction of the coning and its value is decreased(see contour line 34 which replaced contour line 37 in second scenario).

vii- The conning in east direction is increased in its value than in the second

scenario and have more effect on head contour its value and its direction.

From the fore mentioned results, the Eocene and Oligocene aquifer between Beni Mazar and Mallawi to the west have good potentiality under different stresses. The decline in water levels in the third scenario shall not exceed 10 m through the next 50-years till the year 2068. This scenario could be applied for a starter to reclamation in the area between Beni Mazar and Mallawi to the west and to extend the area to the north and south around the road between Beni Mazar and El Bawiti on the short and long terms

Conclusions:

The management of groundwater in the study area was discussed carefully by using the mathematical processing MODFLOW model to predict the future drawdown in groundwater levels by applying three scenarios, after 50 years till the year 2068, indicating the high potentiality of Eocene aquifer. Thus West of El Minia governorate is considered a promising area depending on the groundwater resources for future development.

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