THE OPTIMAL SOLUTION OF GROUNDWATER MANAGEMENT APPLYING GENETIC ALGORITHMS IN WADI EL-FARIGH AREA, WESTERN DELTA, EGYPT

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ABSTRACT

Groundwater in the western desert especially in Wadi El-Farigh area is considered a strategic water reserve because of its scarcity as the unique source of fresh water in this area. The exceeding rates of exploitation the agricultural development beside new reclamation projects has been threatened the groundwater potentiality which subjected to high rate of depletion; therefore sustainable management strategies should be developed by decision makers to optimally utilize groundwater resources in this promising area.

In order to optimize and conserve the use of groundwater in the study area, some strategies should be considered, such as managing the supply and the demand, improving the efficiency of groundwater use, reducing the waste water and ensuring sustainability. The aim of this research is to apply a Single Objective Genetic Algorithms namely (SOGA), which based on the combination of the groundwater flow model (MODFLOW) and the Genetic Algorithms technique to find the optimal solution of pumping rates of discharge and related optimal drawdown moreover the predicted changes in the piezometric heads from the Miocene aquifer in Wadi El-Farigh (MAIWF) under existing policy and three proposed scenarios.

The results of applying SOGA indicate that the optimal pumping rates are higher than the pumping rates in the management scenarios, and consequently the drawdown values. This may be attributed to the maximum and minimum discharge values as well as the permissible drawdown which assumed to be one third of the saturated thickness at each well. As the constraints of the objective function of increasing pumping rates.

Keywords: Groundwater Management, Miocene aquifer, Single Objective Genetic Algorithms, Wadi El-Farigh, Egypt.

1 INTRODUCTION

Management of available water resources is more complicated than commonly recognized; such management involves complicated social, organizational, legal and economical issues in addition to the undoubtedly importance technical matters and environmental aspects.

In many areas of limited freshwater resources, the productive potential of surface water such as rivers or lakes is not sufficient to cover the increasing demands for fresh water. Therefore, exploitation of groundwater resources has greatly increased on a worldwide scale during the second half of the 20th century. Where available in appropriate quantity and quality, groundwater aquifers are a convenient freshwater storage. Due to over-abstraction, groundwater levels have regionally declined in different areas of the world. This phenomenon is an indication of non-sustainable resource utilization. It characterizes situations of resource mining where mean recharge to the resource is inferior to what is being abstracted over a prolonged period of time. The quantity of groundwater resources continues to decrease. Therefore, sustainable management strategies should be developed by decision makers to optimally utilize the groundwater resources.

Optimization methods were used in the field of hydrogeology with the development of study on the optimization control and management of groundwater system. The GA (genetic algorithm) was widely used to modify the parameters of groundwater flow models (Yan et al. 2003; Yao et al. 2003) and to solve the management models of groundwater resources (Mckinney and Lin 1994; Liu et al. 2002; Zhu et al. 2003) .One of the most challenging problems associated with the simulation optimization approach to groundwater quantity management, especially when confronted with a problem encompassing multiple conflicting objectives, is how to incorporate these objectives with flow modeling into the optimal decision-making process. Aquifer management models that combine simulation with optimization help in understanding how social and economic forces interact with the water resource allocation. A simulation model is a tool to understand the physical behavior of an aquifer system, a management model can be thought of as a tool, which provides insight into the economic and social consequences of institutional changes.

Genetic Algorithms have been used to solve many problems in the field of water resources management. From this point of view, its application has led to a growing realization that through good management, use of groundwater can be more productive and sustainable. This study is provided through groundwater resources management model in which the solution is performed through a combined simulation-optimization model. The proposed optimization model is based on the combination of MODFLOW code as a simulation model with FORTRAN code as optimization model based on genetic algorithms GA. Generally, the performance of the proposed GA based management model is tested for three separate groundwater management problems which are; (i) maximization of total pumping from an aquifer (steady-state and transient); (ii) minimization of the total pumping cost to satisfy the given demand (steady-state and transient); and (iii) minimization of the pumping cost to satisfy the given demand for multiple management periods (steady-state and transient). For solving each of the above mentioned groundwater management problems, the principles of the GA method have to be applied.

Solving the first groundwater management problem, which is maximizing the total pumping from the MAIWF, is the aim of this study which is developing a groundwater resources management model that combines the MODFLOW and genetic algorithms. The proposed management model is applied on the El-Moghra Aquifer In Wadi El-Farigh (MAIWF) to develop the optimal (maximum) pumping rate under the different proposed scenarios and the corresponding drawdown. Also, the prediction of the future changes in the hydraulic head of (MAIWF) was made.

1.1 Location and climate of the study area

The study area lies in the western fringes of the Nile Delta, Egypt, between longitudes 30º 00' and 30º 50' E and latitudes 30º 00' and 30º 33' N (Figure 1). It extends from km 62 (Cairo-Alex. Desert Highway) in the south to El-Alamin Desert Road at km 126 to the north, covering an area of 800,000 Fadden. It encompasses Wadi El-Farigh, Wadi El-Natrun and adjacent areas. The climate is characterized by a long hot summer and a short warm winter, low rainfall and high evaporation.

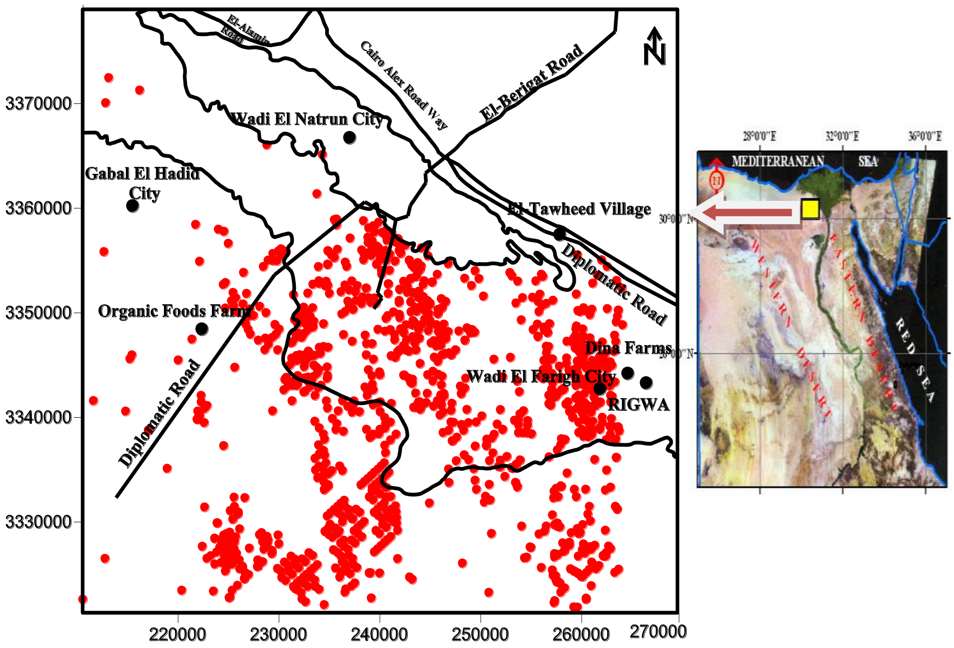

Figure 1. Location map of the study area and operating wells(2006).

1.2 Geomorphological and geological setting

Shata, et al., (1962), Said, (1962), Omara and Sanad, (1962), El-Fayoumy (1964), Shata, (1970), Sanad, (1973), El-Ghazawi, (1982), and Abdel-Baki, (1983) studied the geomorphology and geology of the study area. They concluded that the study area comprises three geomorphological units. The Alluvial plains (young and old alluvial plains) which are characterized by an average gradient of 0.l m/km. The elevation varies from +12 m to +14 m for the young alluvial plains, and between 60 m and 20 m for the old alluvial plains. The lowest point in Wadi El-Natrun and Wadi El-Farigh depressions are -23m and -4m respectively. The Structural plains (depressions, folded ridges and structural plateaux) which have an elevation ranges between 110 m at Gebal Hamza and 200 m at Abu Roash (the ridges bounding Wadi El-Farigh). The Tablelands which are differentiated into Maryut tableland and marginal tableland. The sedimentary succession in the study area ranges in age from Late Tertiary which is differentiated into Oligocene at 400 m, Miocene at 200 m and Pliocene at 150 m to Quaternary at 300m. The study area also is affected by a number of faults having NW-SE and NE-SW trends ,Figure 2.

1.3 Groundwater hydrology

There are three main aquifers in the study area, namely; The Nilotic sand and gravel (Pleistocene aquifer), Wadi El-Natrun sand and clay (Pliocene aquifer) and El-Moghra quartizitic sand (El-Sheikh, 2000 and Ibrahim 2005). The present study will concentrate on the MAIWF, according to its high transmisivity and water quality.

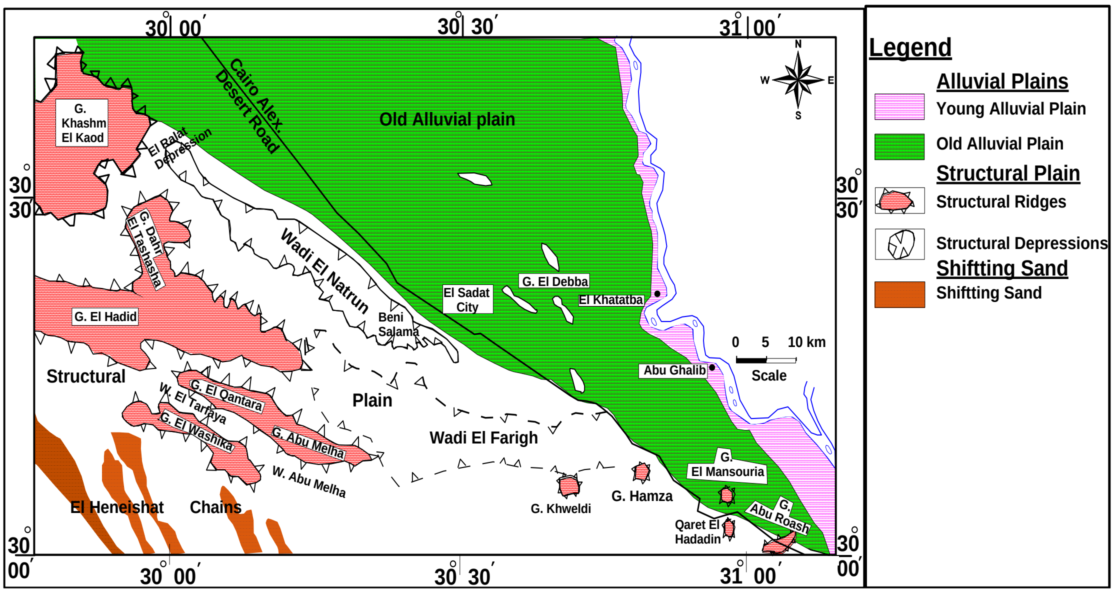

Figure 2. The different geomorphologic units in the study area (compiled after different authors)

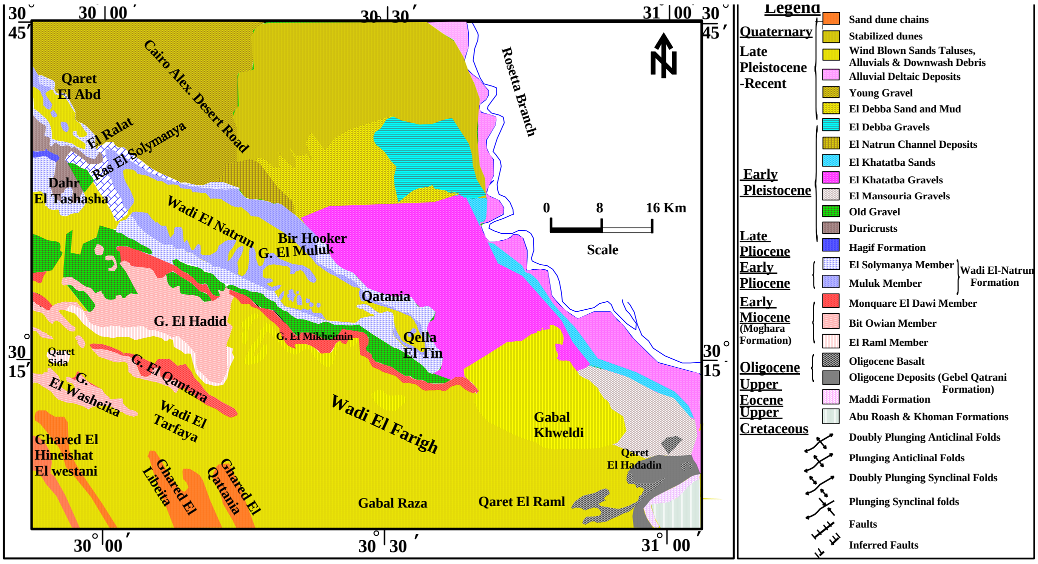

Figure 3. Geological map of the study area (compiled after different authors)

The lateral and vertical distributions of the encountered aquifers as well as their inter-relationships are well illustrated through two cross sections as shown in Figure 3. Regarding this Figure and figure 4, the Pleistocene aquifer exists at the northeast part of the study area to the east of Wadi El-Natrun with thickness range of 65 m to 75 m. The Pliocene aquifer exists at Wadi El-Natrun depression with thickness of 50 m to 70 m. The MAIWF exists at Wadi El-Farigh depression to the south and west of Wadi El_Natrun having a thickness of about 100m. The basaltic sheets were detected along the southeastern part of the study area and is considered as the base of the MAIWF and as a marker bed separating the overlying Miocene aquifer and the underlying Oligocene aquifer. The faults play an important role in the connections between the different aquifers as well as the direct effect on the saturated zones. The depth to water ranges between zero at the ground surface at Wadi El-Natrun lakes to 180 m from the ground surface to the west of Wadi El-Natrun. Generally, the depth to water increases from Wadi El-Natrun to the other directions. The general trends of the groundwater movement are from east to west, from northeast to southwest, from south to north and from southwest to northwest. The contour lines make a closer around Wadi El-Natrun and reach its minimum level -

22 m. This means Wadi El-Natrun depression is recharged from the surrounding aquifers, in other words it acts as a drain for these aquifers.

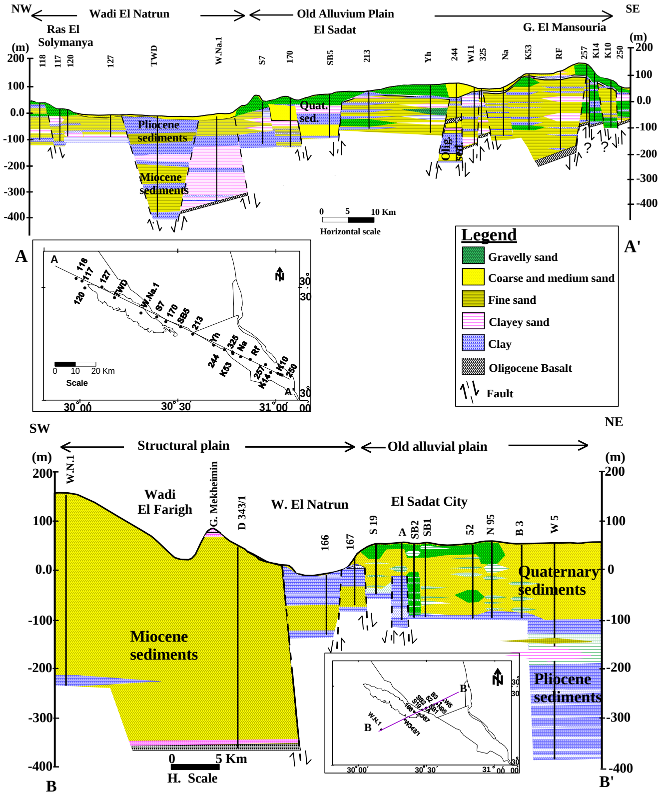

Figure 4: Hydrogeological cross sections in the E-W and NW-SE directions of the study area (Diab et al 2002)

2 METHODOLOGY

The methodology of this research based on the simulation of the MAIWF using MODFLOW, then applying a SOGA to develop the optimal pumping rate under three proposed scenarios. The model used named (SOGA) which is created and verified by (S. Khalaf, 2012)

2.1 Conceptual model of MAIWF

To enable studying groundwater potentiality in Wadi El-Farigh area, the conceptual model of the MAIWF has been constructed. It based on the geology and the petro physics of the Moghra Formation. Its thickness is about 75 m in the northern portion, 150 m in some localities at Wadi El Farigh, 250 m in Wadi El Natrun and gradually increases northwestward with a maximum thickness of about 900 m at El Qattara Depression (Omara and Sanad, 1973). The basaltic sheets are separating the overlying MAIWF and the Daba’a shale Formation, it has variable thickness ranging between 20 to 30 meters and located at different vertical levels.(Figure 5)

The hydrogeologic system was concerned unconfined and confined of one layer type. The variations of the hydraulic conductivity are resulting from the variation in the saturated thickness through the flow section as well as the variation in the transmisivity resulting from the change in the Potentiometric level.

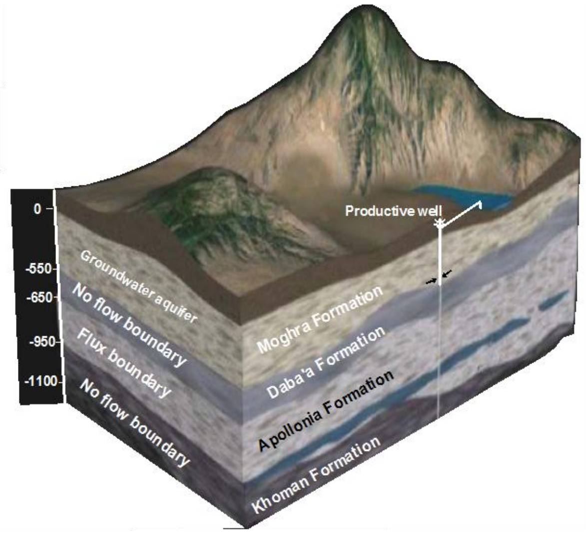

Figure 5. Conceptual model of the MAIWF

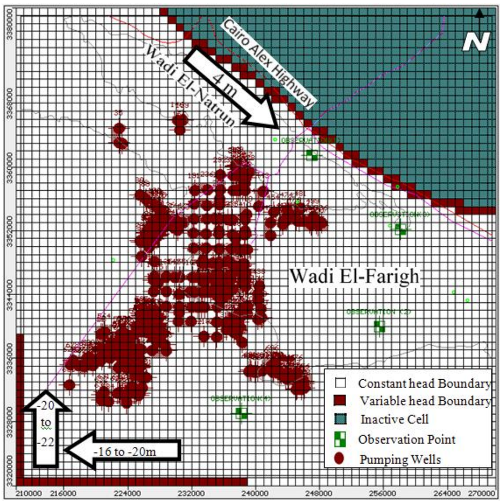

Figure 6. the model domain grid and the boundary conditions of the MAIWF

2.2 Model domain and boundary conditions

The simulation procedure was started by dividing the MAIWF domain into a suitable grid pattern on which all the input items are performed via input menus. The total surface area of the model domain reaches 3600 km^2 (60 km in length and 60 km in width). The computational grid for the aquifer domain in the study area is divided into 3600 cells (60 columns and 60 rows). The dimension of the cell nodes reaches 1000m for the cultivated and reclaimed areas (Figure6).

The boundary conditions are represented by the outer boundaries which are chosen to be natural boundaries to the system taking into account that the boundaries should be taken remote enough from the effect of wells field. These constant head boundaries were assigned in the NE direction with constant value of 8 m asl, in the east direction with variable values ranged between 8 to 2 m asl, in the south western direction with variable values ranged between 16 to 20 m usl and finally in the south west direction with values ranged between 20 to 22 m usl (Figure 6).

2.3 Aquifer characteristics

The input parameters for the MAIWF simulation include aquifer hydraulic parameters (permeability and storage coefficients), aquifer geometry (vertical and areal extent of the aquifer) and aquifer stresses (recharge and discharge). The hydraulic parameters of the MAIWF are given in Table 1.

The United States Geological Survey (USGS) has converted the topographic maps of Egypt into digital elevation model (DEM) files. These files represent the land surface as a matrix (grid) of elevation values at a given space (resolution) apart. The 1:250,000 map series has been converted into 3 arc-second (approximately 90 m) resolution DEMs. DEM data is used in WMS to automatically delineate topography and ground elevation of the model domain (Figure 6). The depth to impermeable bed (bottom of the aquifer) is used to estimate the aquifer thickness of every cell in the modeled area .

Table 1.The hydraulic parameters of the MAIWF

Aquifer	Author	Location	Hydraulic parameters			
			T (m^2/day)	K (m/day)	S (---)	T/S (m^2/day)
Pleistocene	Pavlov (1962)	East Wadi El-Natrun	---	15.38	---	---
	Saad (1962)	East Wadi El-Natrun	1291.7	52.98	3.95x10^{-3}	327012.7
	Shata (1970)	NE Wadi El-Natrun	---	11	---	---
	Desert Institute (1974)	NE Wadi El-Natrun	---	31.96	---	---
	El-Shazly et al(1975)	NE Wadi El-Natrun	2600	77.76	---	---
	General Petroleum Company (1977)	East Wadi El-Natrun	---	26	3.9x10^{-3}	---
	Ahmed (1999)	East Wadi El-Natrun	1925	---	---	---
	Ibrahim (2000)	El-Khatatba	3033.96	---	---	---
Pliocene	Saad (1964)	East Wadi El-Natrun	695.5	38.9	1.35x10^{-3}	515185.2
	Saad (1964)	Northern part of Wadi El-Natrun	1180.8	---	2.65x10^{-3}	445584.9
	Saad (1964)	Eastern part of Wadi El-Natrun	95.04	---	7.5x10^{-3}	12672
	RIGW (1990)	Wadi El-Natrun area	500	9.8	1.7x10^{-3}	294117.6
	Mostafa (1993)	East Wadi El-Natrun	943	47	7x10^{-3}	134714.3
	Ahmed (1999)	North Wadi El-Natrun	1043.9	---	---	---
	Ahmed (1999)	south Wadi El-Natrun	---	---	---	---
	Ahmed (1999)	Near El-Hamra Lake	794.9	---	---	---
Miocene	Mostafa (1993)	Wadi El-Farigh	1951.3	---	1.2x10^{-4}	16260833

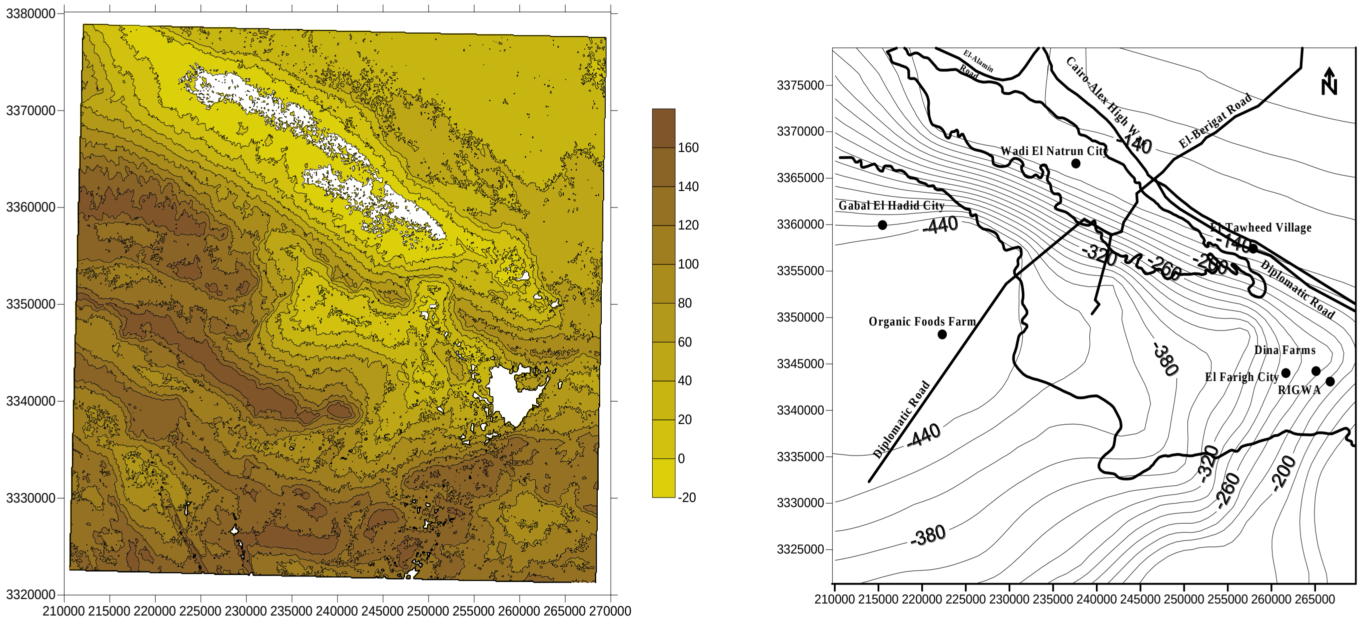

Figure 8.The topographic contour map of the model domain extracted from Digital Elevation Model (left map) and the depth to aquifer bottom map in amsl (right map)

2.4 Aquifer stresses

The recharge to the modeled aquifer system may be from the Nile Delta area in the East and the Tahrir Province in the north as well as rainfall. The annual estimated rainfall in this arid area can be neglected. The discharge from the aquifer may be from natural discharge represented in the evapotranspiration from Wadi El-Natrun depression and it is neglected. Artificial discharge is mainly through water extraction for the development projects and this is the source of discharge in the model domain. The total annual losses due pumping reaches 303.7 Million m^3/year, from number of wells reached 443 well.

2.5 Initial hydraulic head distribution

The water level measurements through the bore hole piezometers in the model domain during November, 1991 were used to construct a contour map for the initial hydraulic head distribution (Figure 7).

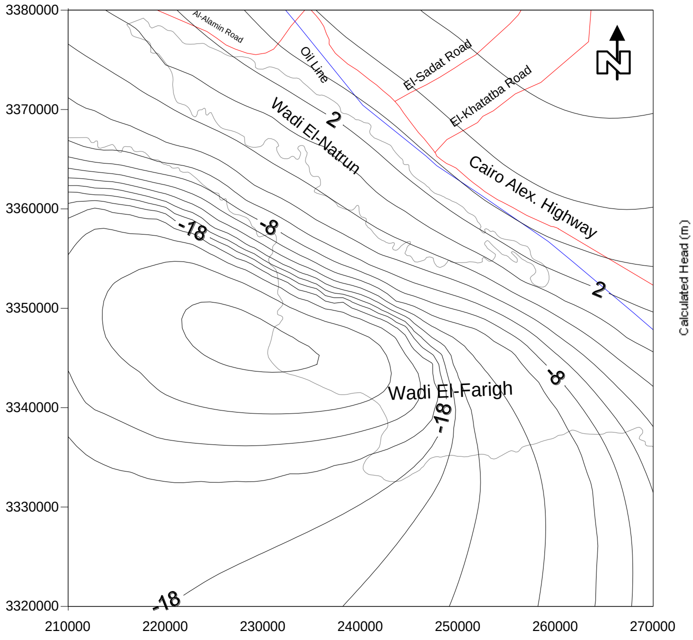

Figure 9. Observed piezometric head contour map of the MAIWF (after Mostafa 1993)

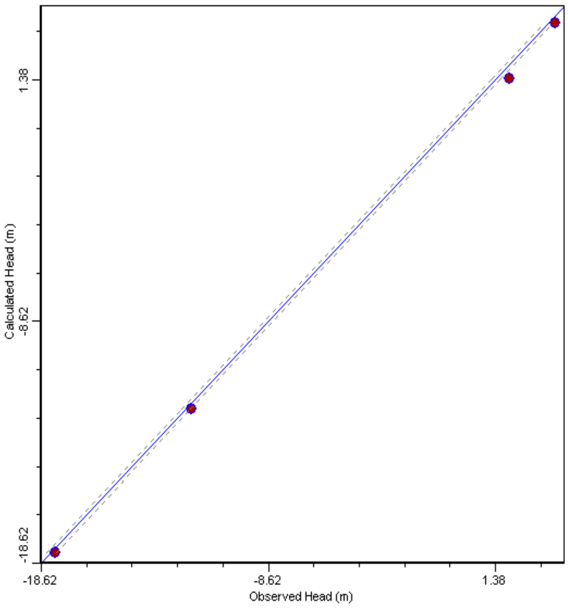

Figure 10.The calculated head vs the observed head for the steady calibration in

2.6 Calibration and verification of the model

The initial data of the hydraulic parameters such as hydraulic conductivity (K) and specific yield (S) have been entered to the model with initial values based on data collected after different authors in the study area. These data have very wide different ranges all over the modeled area. Every once these data entered to the constructed model, is allowed to run. If there is a convergence between the observed heads and calculated heads, an input data error is present which should be repaired time after time until running process goes successfully. This means that the model successes for computing the heads of the aquifer at every cell. As a result, a water level contour map namely calibrated head map is constructed by using these calculated heads. It differs from the map plotted from the actual field head measurements namely observed head map. The relation between the calculated and the observed heads is checked every run from the calculated- observed head curve. The calibration process is very important to minimize the variance to a lower possible value. After many times of changing the K values, the variance between the observed and the calculated heads was minimized to 1.623% (Figure 9).

After completing the stage of calibration, the output of the first round was used to replace the initial condition with the condition of implementing the exploitation policies. The testing scenarios included three proposed water exploitation policies. The first proposed water exploitation policy (existing Policy) was the initial proposed strategy of total pumping rate of 569020 m^3/day from 443 productive wells with an operating time of 10 hours, and study the expected change in groundwater level during time of simulation (44 years) in five arbitrary observation wells covering the model domain.

First Scenario represents the existing policy in the study area at 2006, with total pumping rate 569020 m^3/day from 443 productive well, assuming that the operating time per day is 10 hours. The groundwater model is invoked to simulate this scenario to predict the hydraulic head and drawdown during time of simulation from the year 2006 to the year 2050.

Second Scenario tests an increase of the pumping rate by 17%. This increase either achieves by increasing the operating time per day from the same number of wells or by increasing the number of the productive wells in order to satisfy the increase in cultivated areas till the year 2050.

Third Scenario detects the effect of decreasing the pumping rate from the operative wells by 5% assuming that this percentage represents the decrease in groundwater exploitation rates that may happen due to deterioration of the groundwater quality in the shallow wells till the year 2050.

Table 2. Scenario descriptions based on the different extraction

Scenario description	Extraction (m^3/day)		
	Scenario 1	Scenario 2	Scenario 3
Total pumping rate from model domain	**-569020**	**0**	**0**
Increasing pumping rate by 17%	**0**	**-665781**	**0**
Groundwater depletion or deterioration (Decrease pumping rate by 5%)	**0**	**0**	**-540756**
Total	**-569020**	**-665781**	**-540756**

2.7 Application of SOGA on MAIWF

In this study, a groundwater resources management model is proposed the solution performed through a linked simulation-optimization model. MODFLOW-96 FORTRAN code was used as the simulation of groundwater flow this code is linked with genetic algorithm optimization. Figure 11 shows the flow chart for simulation-optimization model where FORTRAN power station program used to link between the simulation code and genetic algorithm code.

2.8 Objective Function

The function objective in this case is to maximize the pumping rate (Q_j)

$$\text{Max } Z = \sum_{j=1}^{N_w} Q_j - P_j$$

Where: N_W is the total number of pumping wells (443) and P_j is penalty.

2.9 The optimization process subjected to the following constrainnts

Pumping constraint, the pumping rates at potential pumping wells in the water demand were constrained to values between some minimum (Q_j^{min} =1000m^3/day) and maximum (Q_j^{max}= 5000m^3/day) permissible pumping rates as the following:

$Q_j^{min} \leq Q_j \leq Q_j^{max}$ j = 1,2,…….., Nw

Drawdown constraint, this constraint normally meant to protect the ecosystem by avoiding excessive drawdown. In this work, the drawdown constraints were formulated to avoid mining and formulated as follows:

$$\sum_{j=1}^{N_w} r_j \leq d_i$$

Where: r_j is the drawdown at control point *i* caused by a pumping rate from pumping well *j*, d_i is the permissible drawdown at control point *i*.

Water demand constraint, the aquifer was considered as the sole source of water. This, therefore, means that the designed optimal pumping strategy must supply at least the minimum water demand for each scenario. It was formulated as follows:

$$\sum_{j=1}^{N_w} Q_j \geq Q_D$$

Where: Q_D is the water demand for specified scenario.

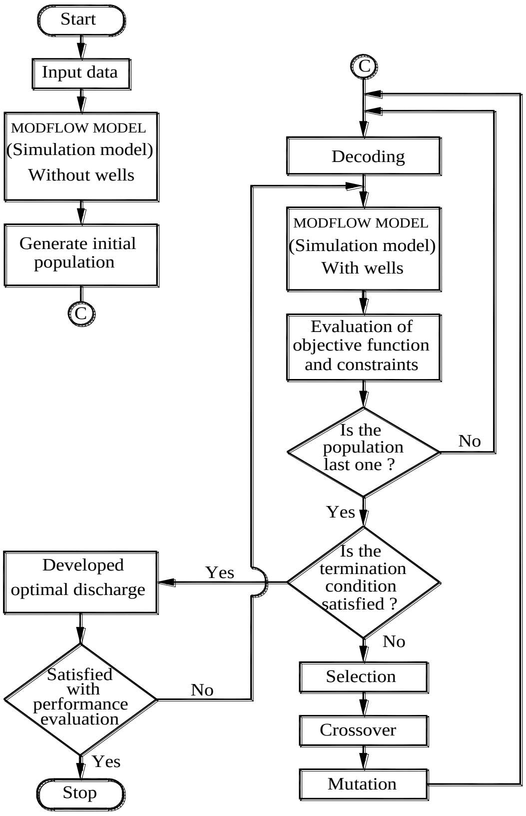

Figure 11. Flow chart of SOGA code

3 RESULTS AND DISCUTIONS

3.1 Output of first scenario (Existing policy):

This application investigates optimal pumping rate from the current 443 productive wells penetrating the MAIWF. The model developed is run for time periods (2015, 2020, 2025, 2030, 2040 and 2050). Table (3) presented the comparison between current pumping rate demand and optimal pumping rate during simulation periods and related drawdown is tabulated in. The current pumping rate demand reaches 569020 m^3/day, and its drawdown ranges from 11.32m to 16.85m. For optimal solution, the optimal pumping rate and the corresponding drawdown ranges from 573891.9 m^3/day to 540586.9 m^3/day and 14.94m to 21.13m respectively. Predicted head distribution maps of the MAIWF for optimal pumping rate for the above mentioned years shown in Figure 13.

Table 3 Comparison between the simulated and optimized results for the1st scenario

Year	2015	2020	2025	2030	2040	2050
Q_C (m^3/d)	569020	569020	569020	569020	569020	569020
r_c (m)	11.32	12.26	13.1	13.9	15.42	16.85
Q_{opt} (m^3/d)	619551	614102	611767	611456	611300	611145
r_{opt}(m)	14.94	15.99	16.93	17.83	19.53	21.13

Where: Q_C, is the current discharge under existing policy (1st scenario), r_C, is maximum drawdown corresponding to current discharge, $Q_{opt,}$ is the total optimal pumping rate from all wells, and r_{opt}, is the maximum drawdown corresponding to the optimal pumping rate of discharge.

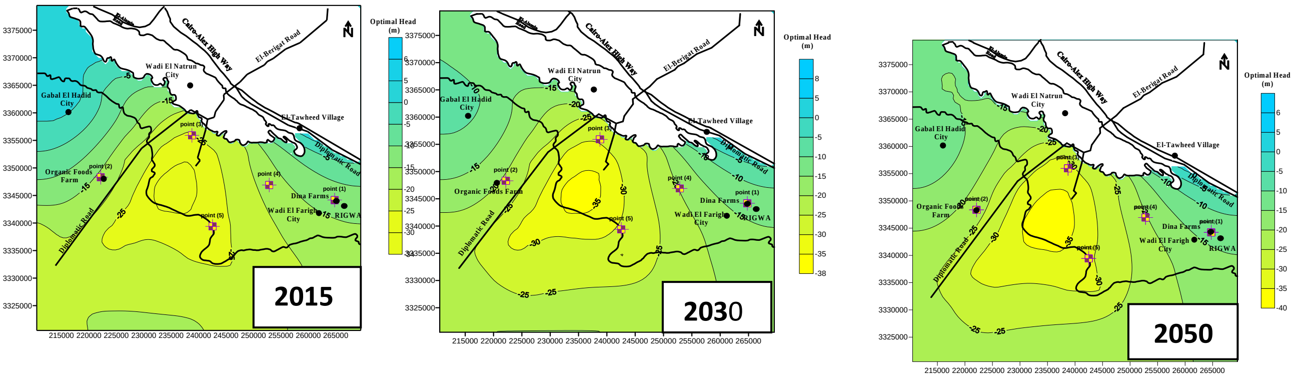

Figure 13. Predicted head distribution map of the MAIWF based on the optimal pumping rate applying SOGA model (1 st scenario)

3.2 Output of second scenario

The second scenario tests an increase of the operating time or increasing the pumping rates from the productive wells by 17%. In this scenario, the total irrigation water demand reaches 665781m3/day and the drawdown ranges from 12.86 to 20 m. For optimal solution, the optimal pumping rate and drawdown range from 723384.3m3/day to 681403.7m^3/day and from 16.17m to 23.23 m respectively. As indicated in Table (4), the predicted head distribution map of the MAIWF for optimal pumping rate for years 2015, 2020 ,2025, 2030, 2040 and 2050 are shown in (Figure 14) respectively.

Table 4. Comparison between the simulated and optimized results for the 2nd scenario

Year	2015	2020	2025	2030	2040	2050
Q_C (m^3/d)	**665781**	**665781**	**665781**	**665781**	**665781**	**665781**
r_c (m)	**12.86**	**14.15**	**15.28**	**16.32**	**18.24**	**20**
Q_{opt} (m^3/d)	**690424**	**684353**	**681751**	**681404**	**681230**	**681057**
r_{opt} (m)	**16.17**	**18.11**	**19.37**	**20.54**	**22.7**	**23.23**

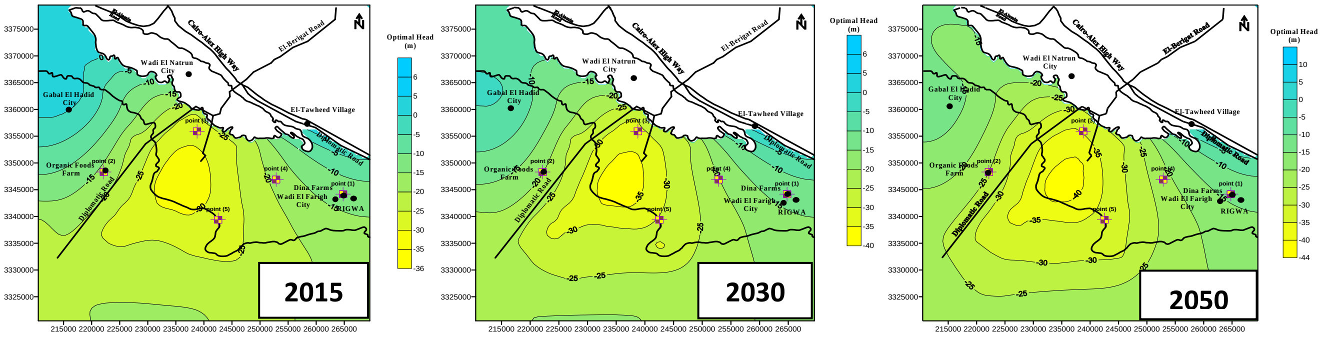

Figure 14. Predicted head distribution map of the MAIWF based on the optimal pumping rate applying SOGA model (2 nd scenario)

3.3 Output of third scenario

The third scenario detects the effects of decreasing the pumping rates from the operative wells by 5%, assuming that this percentage represents the decrease in groundwater exploitation rates that may happen due to deterioration of the groundwater quality in the shallow wells. In this scenario water demand is 540756 m^3/day and drawdown ranged is from 10.2m to 15.35m. Comparison between water demand and optimal pumping rate during simulation periods was presented. For optimal solution, the optimal pumping rate and drawdown ranged from 573891.9 m3/day to 540586.9 m^3/day and from 13.68m to 19.43m respectively, as indicated in Table (5). the predicted head distribution map of the MAIWF for optimal pumping rate for years 2015, 2020 2025, 2030, 2040 and 2050are shown in (Figure 15) respectively.

Table 5. Comparison between the simulated and optimized results for the 3rd scenario

Year	2015	2020	2025	2030	2040	2050
Q_C (m^3/d)	540756	540756	540756	540756	540756	540756
r_c (m)	10.2	11.06	11.83	12.57	13.98	15.35
Q_{opt} (m^3/d)	594578	589350	587109	586810	586661	586511
r_{opt}(m)	13.68	14.64	15.51	16.34	17.91	19.43

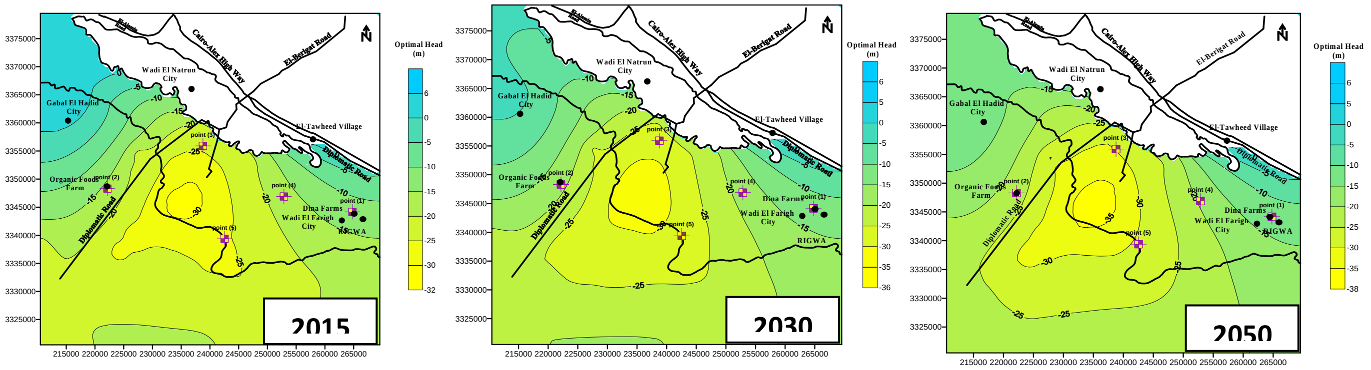

Figure 15. Predicted head distribution map of the MAIWF based on the optimal pumping rate applying SOGA model (3 rd scenario at 2050)

3.4 Performance evaluation optimization criteria

Performance of the groundwater management model is evaluated on the basis of some GA criteria. These criteria are mutation ratio, crossover type and crossover ratio. Uniform crossover probability is 0.60; tolerance for the convergence of iterations is 0.001, a population size of 200 and number of generations reaches 100generations. Regarding the previous mentioned criteria, mutation ratio is the most criteria affected the model evaluation as shown in Figure 17.

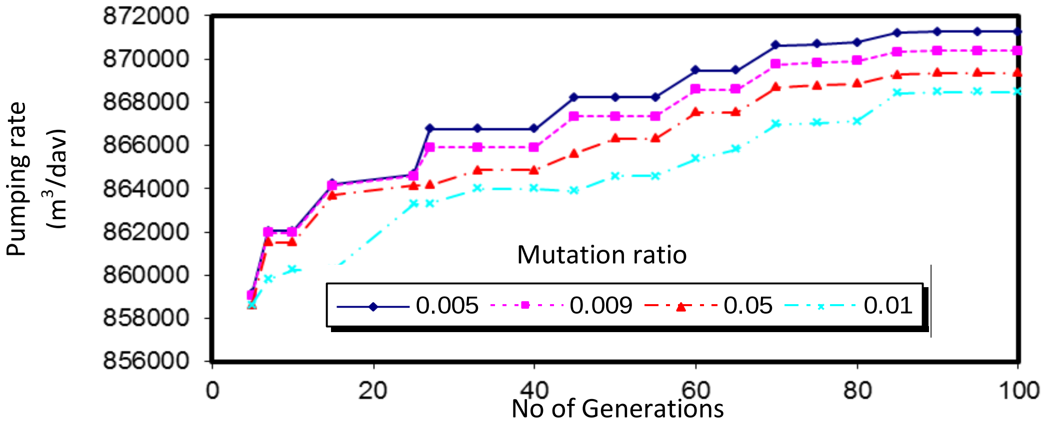

Figure 17. Optimal pumping rate versus number of generations applying first scenario

It demonstrates the effect of the mutation ratio on convergence rate to optimal solution (total pumping rate). The Figure indicates a slow convergence of the GA for mutation ratio of 0.005.

4 CONCLUSION AND RECOMMENDATIONS

From the results obtained from this study it can be concluded that:-

- ✓ Generally the increasing of the agriculture development depending on the groundwater resources will lead the Miocene aquifer in the study area to be depleted.
- ✓ The results of applying SOGA indicate that the optimal pumping rates are higher than the pumping rates in the management scenarios, and consequently the drawdown values. This may be attributed to the maximum and minimum discharge values as well as the permissible drawdown which assumed to be one third of the saturated thickness at each well. As the constraints of the objective function of increasing pumping rates. Although that The results obtained from the study validate that the GA technique represented in SOGA model has the consistency to solve groundwater management problems for three dimensions complex aquifer, complicated boundary conditions, steady and transit state.

To conserve the storage of the Miocene aquifer for sustainable development from the ground water Resources in the study area, it is recommended that:-

- ✓ Any decision of drilling new wells should satisfy the sustainability of the groundwater resources plan in the study area within great restricted rules to avoid the depletion of this important source of water.
- ✓ Reduce the initial and running time (not more than 12 hours),
- ✓ The government of Egypt should implement the project of west Delta development which was proposing a surface canal to decrease the stress on the groundwater in the area, but after studying the effect of different types of lining materials in order to maximize the recharge process from the canal to the aquifer.
- ✓ Applying discrete irrigation system and achieving the objective of implementing the development policy with the groundwater recharge from the proposed new canal.

- ✓ It is highly recommended to construct of monitoring network to assure the recharge from the proposed new proposed canal after construction and to assess the impacts of the development periodically and update the model results.
- ✓ A detailed study can be implemented on the study area after dividing it into small local areas in order to determine their individual effect on the aquifer to detect the critical localities that must be controlled.
- ✓ Study the vulnerability of the Miocene aquifer of the study area.
- ✓ Study the effect of uncertainty and sensitivity analysis in aquifer hydraulic parameters estimate for groundwater quality management
- ✓ Applying a Multi objectives Genetic Algorithm model in order to take into consideration the cost and the new drilled wells locations.

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