Management of Groundwater Using Mathematical Model at Bahariya Oasis, Egypt

Himida, I.H .[1] Holial, H.M.[2], Shaaban, M.N.[2], El-Fiky, A.A.[3], Abd El-Latif, R.M.[1]

ABSTRACT

The Bahariya Oasis is located in the central part of the Western Desert. The Nubian Sandstone Aquifer is the most important source of groundwater in the Western Desert, particularly in the Bahariya Oasis. The E-W and SW-NE cross sections in the study area were constructed and revealed that the Nubian Sandstone Aquifer system can be classified into six zones depending on the lithologic facies variation and behaves as one hydrogeologic system. The transmissivity values range between 3660 m^2/day in the southwestern part to 315 m^2/day in the northeastern part of the Bahariya oasis. Unfortunately, the increased reliance on groundwater resources, without any scientific pre-plans, has caused some negative hydrogeological implications such as rapid decline in groundwater potentiometric levels with time and possible salinization of groundwater. During the course of this model, different scenarios will be discussed in order to show the high efficient output, as indicated by all possible prediction periods and safe conditions for economic uses of ground water. The sustainable management of the groundwater of the Nubian Sandstone Aquifer will hopefully influence

The future policies and strategies of the groundwater exploitation in the Bahariya Oasis depend on the sustainable management of the groundwater of the Nubian Sandstone Aquifer put the Bahariya Oasis on the track of the development plans in Egypt in the near future.`

Keywords: Nubian Sandstone. Groundwater resources management Bahariya Oasis.

INTRODUCTION

The Bahariya Oasis is a natural depression approximately located in the heart of the Western Desert of Egypt (Fig. I). It is located between latitudes 27°4¯W and 28°30¯N and longitudes 28°35¯ and 29°10¯E, about 370 km southwest of Cairo and around 190 km west of Samalut town at the Nile Valley. There is an argue for groundwater management in the area of study in order to avoid a crisis due to the continuous decline of groundwater potentiometric heads and possible salinization of groundwater. Mismanagement and overexploitation of this resource can lead to these adverse effects. Formulation of the management of the groundwater resources in the Bahariya Oasis requires a major shift from the classical paradigm used in water resource planning and management to a new innovative paradigm. At present time, it is recognized that mathematical modeling is the proper tool to be used for groundwater management in the Bahariya Oasis. The aims of this study were to manage the groundwater resources in the Bahariya Oasis and to simulate the response of the groundwater system to different development scenarios using the Finite element flow model.

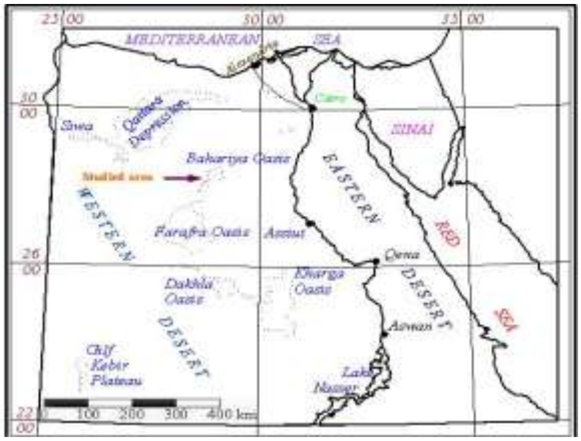

Fig. 1.Location map of the study area

MATERIALS AND METHODS

A) Geological Setting

The regional geology of the Bahariya Oasis was first described in the extensive work carried out by Ball and Beadnell (1903), Hume (1909), Stromer (1914), Lebling (1919), Leroy (1953), Faris et al. (1956), Zaatout (1958), El-Shazly (1962), Said (1962), El-Akkad and Issawi (1963), Said and Issawi (1964), Basta and Amer (1969a and 1969b), El-Bassyouny (1978), Franks (1982), El-Mansy (1983), Holail (1987). Abdel Ati (1995 and 2002), Moustafa et a!. (2003), and Abd El-Latif, 2007.

The Bahariya Oasis is located along the hinge line between the stable- unstable shelves (Said, 1962). Thus, the lithologic features of both the stable and unstable shelves are represented. The oldest outcropping rock unit in the study area is the Bahariya Formation of Early Cenomanian age, which is represented by sandstone, sandy clay and shale intercalations. The Bahariya Formation is exposed at the isolated hills in the Bahariya

[1]Dept of Hydrology, Desert Research Center, Egypt
[2]Dept of Geology, Faculty of Science, Alexandria University, Egypt
[3]Dept of Environmental, Faculty of Science, Alexandria University, Egypt
Received December 08, 2011, Accepted December31, 2011.

Oasis. The upper part of the Bahariya Formation unconformably underlies E1-Heiz Formation whereas its basal part is unexposed(Said, 1962). Structurally, the Bahariya Oasis resembles a bracky anticline, formed of two separated major anticlines with a NE-SW trend. The first lies at the northern part of the oasis and represented by Ghorabi and El-Gedida-El-Harra anticlines and the other at the southern part of the depression where it is represented by El-Heiz anticline. Moreover, a group of hills which is located between the northern and southern anticlines is believed to lie on the same axis. The Bahariya Formation is exposed at the floor of the depression, as well as, at the cores of Ghorabi and El-Gedida-El-Harra anticlines. The Bahariya Formation is considered to be a part of the Nubian Sandstone Aquifer system that underlies the Western Desert of Egypt (Parsons, 1962). The General Company for Research and Groundwater (REGWA) has drilled many water wells in the Bahariya Oasis. The collected data from REGWA drilling program includes 10 logs of water wells and 16 ditch samples from the water-bearing rocks (from Am Yousef Well (20/12/2003) and El Gazareen Well (25/12/2002).

The classification of sediments in the study area into distinct aquifers is a problematic task (Abd El-Latif, 2007). This might be due to the absence of marked key horizon within the undifferentiated sandstone and shale intercalations of the water-bearing formation and the great sediment facies variations due to different environmental and tectonic effects However, as shown in the E-W (Fig.2) and SW-NE (Fig.3) cross sections in the study area were constructed. The results obtained from Figs3&4 revealed that the Nubian Sandstone Aquifer system can be classified into six zones depending on the lithologic facies variation i.e. shale content, as follows (Table 1):

It is evident, however, that rock fabrics (both primary and secondary and structural frameworks) have affected the hydraulics of groundwater in the Nubian Sandstone Aquifer System.

The groundwater flow through the water-bearing formation depends on two different types of void. The first is the original pores of the sediments which are affected by the original fabric components and the second type of voids is attributed to secondary and diagenetic processes. The proposed faults in the cross sections (Figs.4 and 5) act as pathways or channels for the upward groundwater movement. Since the thickness of the sandstone beds is greater than that of the clay and shale beds, thus along the fault displacement, clay and shale beds cannot act as barrier for the vertical groundwater flow. In the Bahariya Oasis, four major ENE-oriented structural belts (i.e. Gebel Ghorabi, Gebel Radwan-Gebel El-Hefhuf-El-Harra, Sandstone Hills and Northern Farafra) overlie deep-seated faults. Fracturing is associated mainly with rock deformation by faults and/or folds.

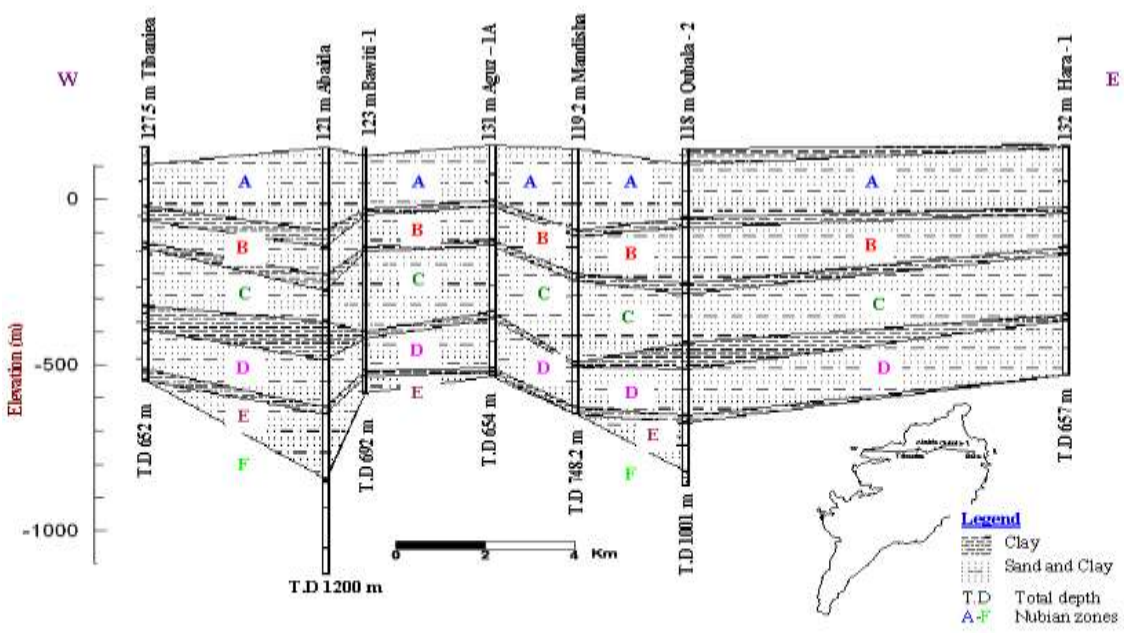

Fig.2.E-W correlation chart showing Nubian Sandstone zones in the Bahariya Oasis

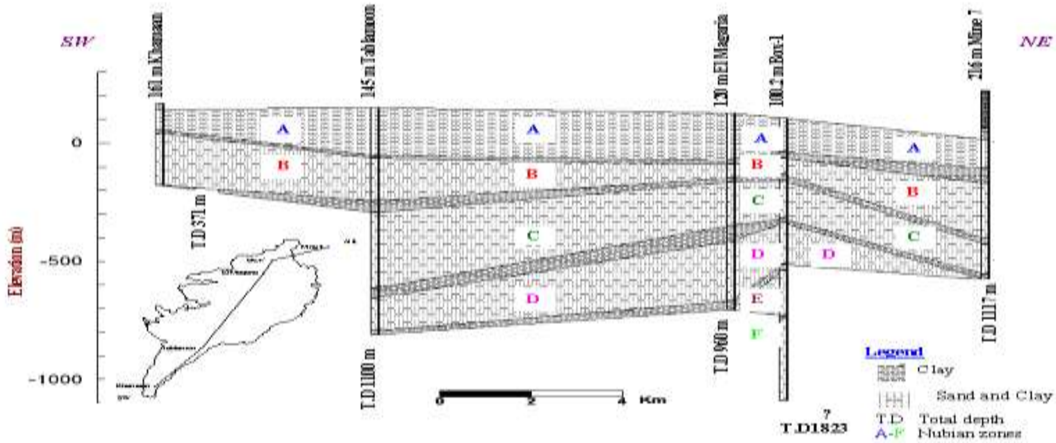

Fig.3. SW-NE correlation chart showing Nubian Sandstone zones in the Bahariya Oasis

Table 1. Classification of the Nubian Sandstone zones based on shale content

Zones	Depth
A	Upper most zone extends from 0-225 m
B	225-400 m (175 m thick)
C	400-600 m (200 m thick)
D	600-750 m (150 m thick)
E	750-1000 m (250 m thick)
F	> 1000 m

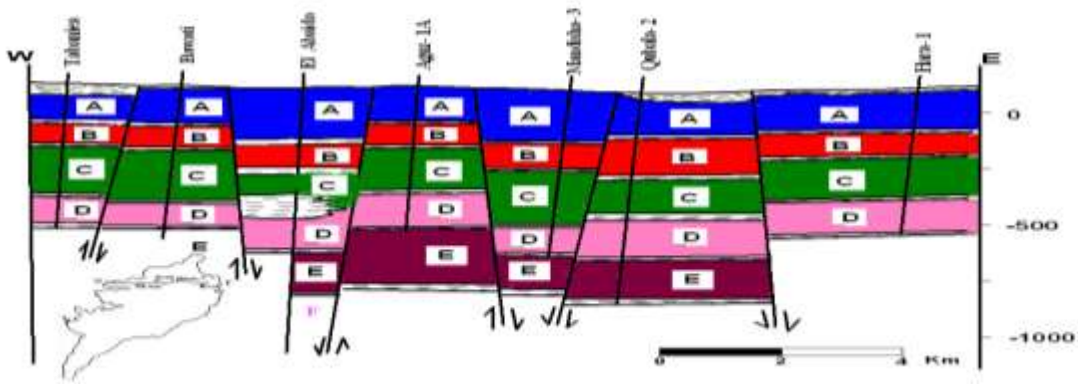

Fig.4. E-W geological cross section of the Bahariya Oasis illustrating the proposed faulting structure (after Abd El-Latif, 2007)

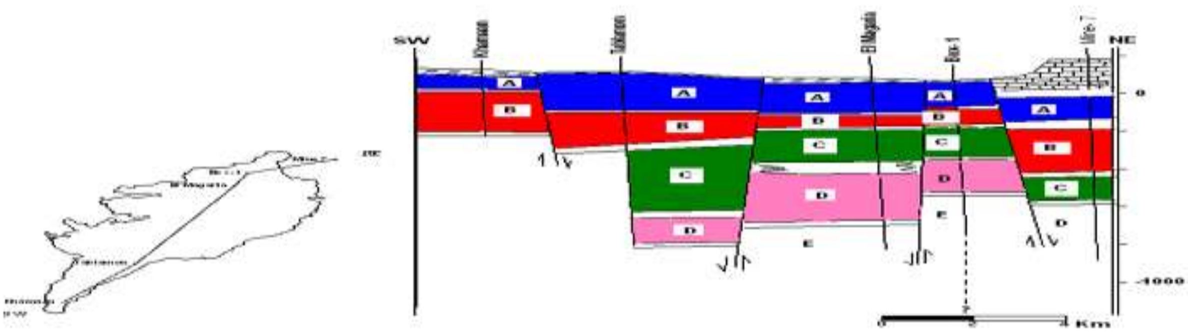

Fig.5.SW-NE geological cross section of the Bahariya Oasis illustrating the proposed faulting structure (after Abd El-Latif, 2007)

B) Hydrogeology of Bahariya Oasis

The groundwater-bearing horizons in the investigated area follow two aquifer systems. These are, from top to bottom: a) The Post-Nubian Sandstone Aquifer System, which occurs to the north of latitude 26° in the Western Desert of Egypt (CEDARE, 2001). It is composed of marine sediments; mainly consist of clay, marl and limestone, overlain by continental clastic sediments, which exhibit noticeable facies variation in the northern parts of Egypt to pass laterally into carbonate facies. This sequence ranges in age from Late Cenomanian to Recent. b) The Nubian Sandstone Aquifer System, which represents the main water-bearing horizon in the study area. It consists of continental elastic sediments, mainly sandstone alternating with shale and clays. Based on the stratigraphic setting of the study area and the paleogeographic events, which took place since the Post Turonian (Late Cretaceous), the Nubian-Post Nubian contact displays local discordance which is represented by local open windows between the two sequences either due to the non-deposition, or erosion. This accounted for the reduction of the thickness of the Upper Cretaceous-Lower Tertiary deposits, and consequently for the establishment of direct connection. This phenomenon is pronounced at the Bahariya Depression (CEDARE, 2001). Accordingly, the Nubian and Post-Nubian aquifers are hydraulically-connected through a good pathways or channels that permit upward leakage (Abd El-Latif, 2007). Thus, the confined Nubian Sandstone Aquifer in the Bahariya Oasis is a multilayered artesian aquifer that behaves as one hydrogeologic system. The groundwater in the study area has the same general flow pattern (SW-NE) that reported for the groundwater of the great Nubian Sandstone Aquifer in the Western Desert of Egypt (Ezzat, 1959b; Ayouty and Ezzat, 1961; Himida, 1964 and Shata, 1982)

C) Conceptual model of the groundwater system

Schematization of the aquifer system

A local mathematical model using FEFLOW 5.2 was developed in the Bahariya Oasis to analyze the behavior of the Nubian Sandstone Aquifer System (Abd El-Latif, 2007). This will help in proposing different development scenarios and predicting the aquifer response to water abstraction. The construction of the model includes several stages: geometrical, physical, mode of calculation and results display. When using the Finite Element Method (FEM), many data are needed because all cells need to be filled. With the help of modern GIS-based pre-processors, this problem can be solved easily. In each model, the study of the natural system is represented by a conceptual model. Conceptualization made in the present study of the Bahariya Oasis is as follows (Abd El-Latif, 2007): 1. Creation of the model for saturated zone (confined aquifer) as a flow-only problem with unsteady flow conditions using a horizontal projection of the area. 2. Groundwater pumpage in the Bahariya Oasis is mainly from one hydrogeological unit, namely the Nubian Sandstone Aquifer System which is considered as a multilayer artesian aquifer that behaves as one hydrogeologic unit subjected to high rates of groundwater extractions. This assumption is based on the fact that there is a direct connection among all the Nubian aquifer zones within the modeled area. 3. The modeled area was designed to represent a closed system. The model area was extended beyond the depression boundary to avoid the impact of the artificial imposed boundary. 4. Two-dimensional Finite Element Model using FEFLOW v.5.2 was chosen for the simulation of the Nubian Sandstone Aquifer of the Bahariya Oasis where the modeled area is about 1800 Km^2. In addition, the designing of a 3D visualization projection for the modeled area was done using FEFLOW v.5.2. 5. The finite element mesh was designed to minimize numerical dispersion by ensuring that the major flow paths associated with discharging wells are where mesh sizes are smallest and gradually diminish towards the model boundaries. 6. The aquifer is heterogeneous and anisotropic. Darcy's law is applicable and hydraulic head gradients are the only significant driving mechanisms for groundwater flow. 7. The magnitude and spatial distribution of the aquifer characteristics (transmissivity and storativity) are obtained from the analysis of the available pumping test data of the drilled water wells during the period (1960-2000). 8. Since the hydrodynamic impact of the present groundwater extraction on the potentiometry of the Nubian Sandstone Aquifer shows groundwater depletion and nearly absence of shallow wells and springs (artesian flow character) which had been dominated in the past periods of exploitations, that leads up to most of wells in the study area are mechanically pumped. Thus groundwater can be considered as a weakly renewable resource under unsteady-state conditions.

D) Boundary Conditions

Depending on the demonstration of FEFLOW v.5.2 software, the boundary conditions for the suggested model area are as follows (Abd El-Latif, 2007):

1) **Fixed head boundary (1st kind, Dirichlet' condition):**

At this boundary, the head in the aquifer is known and doesn't change with time (i.e. fixed potential at a node), the head in the corresponding node is maintained at a specific value throughout the simulation. Constant fixed head boundaries have been assigned for the northern and southern parts of the study area. The northern boundary in the model is set first, and from the potentiometric head map a reasonable hydraulic head is assumed along its border.

Consequently, the value set for the northern fixed head boundary is about 100 m. On the other hand, the value of the southern constant hydraulic head was set at about 160 m.

2) No-flow boundary (2nd kind, Neumann' condition):

It was assigned to the eastern and western parts of the Bahariya Oasis and represented by the flow lines which are perpendicular to the contour lines in any places in the potentiometric head map. It defines the no-flow boundary at which the transmissivity is equal to zero at a given node, so no-flow (i.e. no flow in or out of this line) can occur across the boundary of that cell.

3) Well (4th type):

It describes the withdrawal of water at a single node.

E) Model Calibration

Model calibration is the process used to solve this inverse problem. That is, model calibration is the process of tuning the model to identify the independent input parameters by fitting the model results to field or experimental data, which usually represent the dependent system parameters (Hassan, 2004).

The period 1970-1999 was chosen as the calibration period in the study area due to the following reasons (Abd El-Latif, 2007):

- Groundwater development in the Bahariya Oasis as a part of the New Valley began in 1970 and the initial values of the hydraulic heads of 11 wells are known.
- The availability of relatively complete historical records of water levels in this period (1970-1999), especially the year 1999 (57 wells).
- Large changes in water levels have occurred during this period.

Traditionally, model calibration in groundwater relied on manual trial-and-error adjustment of the model independent parameters (e.g., hydraulic conductivity, recharge, boundary conditions) until a good match between modeled and observed heads occurred (Hassan, 2004).

To establish a model of the Nubian Sandstone Aquifer of the Bahariya Oasis with a given information, two stages of unsteady state model calibration were performed:

1) The model calibration for the period 1970-1999 (Fig. 6 & 7).

2) The model calibration for the year 1999 (Fig. 8 & 9).As a result, several discrepancies between the computed and the field measurements of groundwater heads (Table 2&3). These required several adjustments (trial-and- error method) of the values of the coefficient of transmissivity (T) in order to attain better coincidence (i.e. less than 5% error) of the groundwater heads.

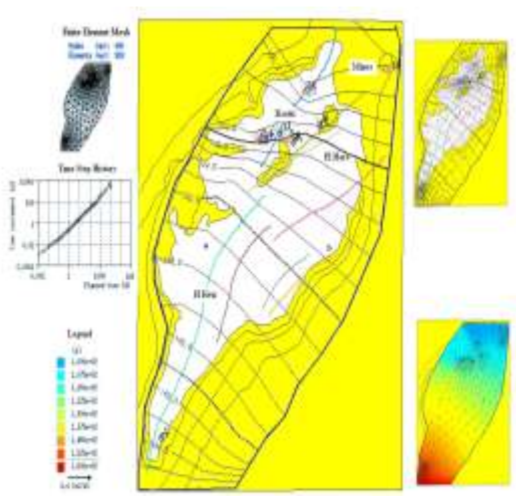

Fig.6. Simulated hydraulic head (m a.s.l.)for the Nubian Aquifer System for the year 1999 in the Bahariya Oasis, using the actual extraction rates starting from 1970

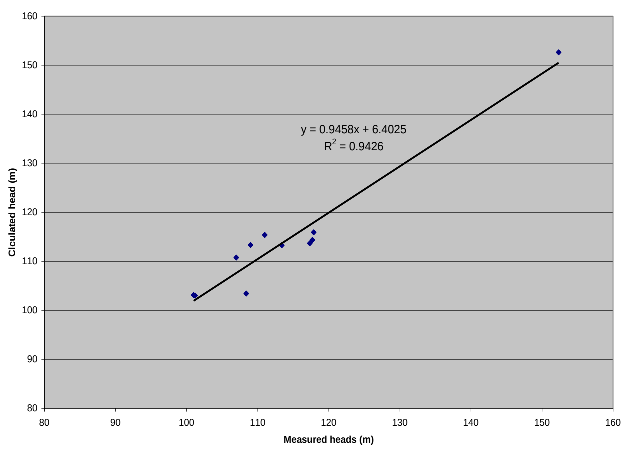

Fig.7.Scatter plot and linear regression Analysis of the calculated heads (m) against measured heads (m) for the period (1970-1999)

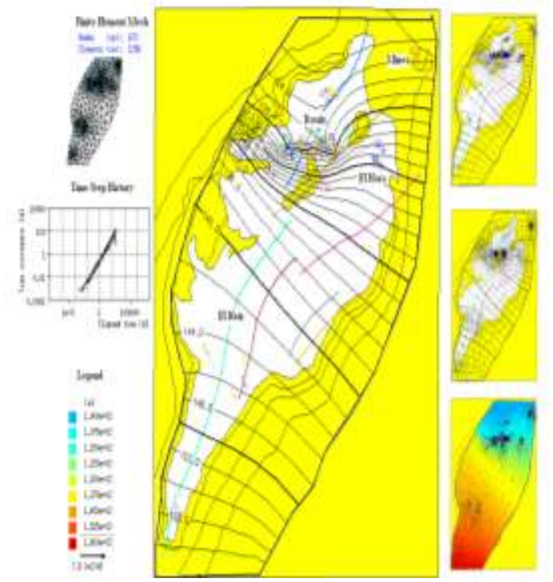

Fig.8. Simulated hydraulic head (m a.s.l.) for the Nubian Aquifer System for the year 1999 in the Bahariya Oasis

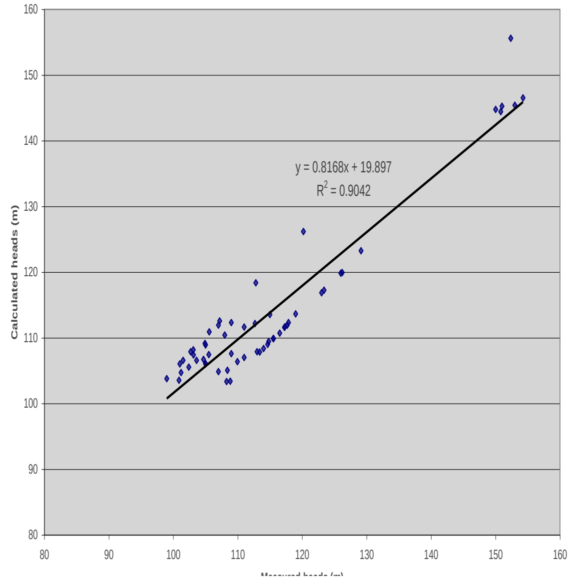

Fig.9. Scatter plot and linear regression analysis of calculated heads (m) against measured heads (m) for the year 1999

Table 2. Discrepancies between measured and calibrated values of water head of the Bahariya Oasis after 29 years, started in 1970. (Abd El-Latif, 2007)

No.	Name	Measured Head (m) 1970	Measured Head (m) 1999	Model calculated Head (m) (1970-1999)	Discrepancies %
1	Khamaan	153.35	152.35	152.6	0.2
2	Tibaniea	132.5	109.00	113.31	4.0
3	El Ayoun	137	117.33	113.65	3.1
4	Waled	143.21	117.70	114.33	2.9
5	Aguz-3 West	125.8	111.00	115.35	3.9
6	Aguz East	140.9	117.89	115.9	1.7
7	Qassa-2	115.32	101.00	103.08	2.1
8	Qassa-3	119.3	101.20	102.99	1.8
9	Qassa-4	121	107.00	110.74	3.5
10	M-2	129	108.40	103.41	4.6
11	Bawiti drink	137.1	113.40	113.27	0.1

The attained good match between the observed and calculated parameters in the short period simulation (1970-1999) was considered as a verification of the model. Thus, it was used to predict the Nubian Aquifer response to the future groundwater development plans in the next hundred years (1999-2 100).

The following remarks can be concluded from (Table 4) as follows: a) The decrease of the calibrated transmissivity values from south at El-Heiz area to north at Bawiti area (i.e. present discharge area) coincides with the increase of clay contents in the northern part of the study area. b) Comparison between the present calibrated transmissivity values of the Nubian Sandstone Aquifer either in the northern or southern parts of the study area and the regional transmissivity values stated by Allam et al., 2002 (5000 to 10000 m^2/d) Diab et al., 1978 (9400 to 13160 m^2/d) and GARPAD, 1981 (17100 m^2/d) that the showed calibrated transmissivity values are more or less reasonable.

The budget analysis parameters in case of the previously mentioned two stages of calibrations (i.e. the period (1970-1999) and the year 1999) show that the difference between the fluxes In (+) / fluxes Out (-) is in the order of 0.05 and 0.15 (less than unity), respectively. The attained good match between the observed and calculated parameters in the short period simulation

Table 3. Discrepancies between measured and calibrated values of water head of the Bahariya Oasis after one year, January 1999. (Abd El-Latif, 2007)

NO	Well name	Measured Head (m) 1999	Model calculated head (m) 1999	Discrepancies %
1	**Sidi Ahmed**	150.80	144.44	4.2
2	**Mehebes**	154.27	146.54	5.0
3	**Tablamoon**	153.00	145.43	4.9
4	**Khamaan**	152.35	155.61	2.1
5	**Ain Qara**	150.00	144.76	3.5
6	**Ain el Ezza**	151.00	145.28	3.8
7	**Barakat**	112.80	118.38	5.0
8	**Tibaniea**	109.00	112.36	3.1
9	**Meftela**	109.00	107.62	1.3
10	**El Dolab west**	115.00	113.58	1.2
11	**Mady**	120.20	126.18	5.1
12	**Ain Embash**	115.57	109.92	4.9
13	**El Ayon**	117.33	111.72	4.8
14	**El Shroey**	116.51	110.71	5.0
15	**Dedela**	113.00	107.88	4.5
16	**Ain Shawer**	112.68	112.17	0.4
17	**Waled**	117.70	111.96	4.9
18	**El Matar**	99.00	103.80	4.9
19	**El Abaida**	115.51	109.92	4.8
20	**El Qeles**	114.80	109.47	4.6
21	**Bawiti drink**	113.40	107.86	4.9
22	**Gevara**	129.13	123.25	4.6
23	**Wadi el Mazarea**	104.91	109.18	4.1
24	**El Amrecan**	103.60	106.56	2.9
25	**Dehqema**	103.10	108.21	5.0
26	**Beshmo**	114.63	109.01	4.9
27	**Ain Halfa**	117.23	111.59	4.8
28	**Aguz-3 West**	111.00	111.64	0.6
29	**Aguz East**	117.89	112.32	4.7
30	**El Gazaier**	111.00	107.03	3.6
31	**El Ghaba el Qeblia**	107.00	104.87	2.0
32	**El Kebier**	102.40	105.58	3.1
33	**Tobela**	104.70	106.71	1.9
34	**Ain Hamra**	101.53	106.57	5.0
35	**Qubala West**	105.00	108.91	3.7
36	**Qubala-2 East**	107.20	112.59	5.0
37	**Segam**	105.59	110.92	5.0
38	**Maesera**	102.70	107.89	5.1
39	**Kom Shoron**	119.00	113.64	4.5
40	**Abu Singo**	108.00	110.42	2.2
41	**Kom Shada**	105.50	107.48	1.9
42	**Mehibes**	103.14	107.41	4.1
43	**El Habasy**	105.00	106.08	1.0
44	**Ain Ghard**	114.00	108.41	4.9
45	**El Magaria**	105.00	106.06	1.0
46	**Qassa-2**	101.00	106.06	5.0
47	**Qassa-1&2Rep.**	100.90	103.57	2.6
48	**Qassa-3**	101.20	104.72	3.5
49	**Qassa-4**	107.00	111.97	4.6
50	**Ain Gedid**	123.40	117.29	5.0
51	**Ain Hadad**	125.98	119.86	4.9
52	**Ain El Bahariya**	123.00	116.86	5.0
53	**Ain El Wadi**	126.21	119.96	5.0
54	**M-1**	109.95	106.41	3.2
55	**M-2**	108.40	105.07	3.1
56	**M-7**	108.85	103.41	5.0
57	**M-8**	108.28	103.37	4.5

Table 4. Results of the calibrated transmissivity values of the Nubian Aquifer of the Bahariya Oasis. (Abd El-Latif, 2007)

Region	Calibrated transmissivity values	
	Minimum (m^2/d)	Maximum (m^2/d)
A) Northern modeled area		
El-Qasr area	518	800
Bawiti area	189	2074
Aguz area	691	1901
Mandisha area	259	2592
El-Zabu area	688	2074
El-Qassa area	658	673
El-Harra	2160	2333
Mine area	5098	
B) Southern modeled area		
El Heiz area	11362	

(1970-1999) was considered as a verification of the model. Thus, it was used to predict the Nubian Aquifer response to the future groundwater development plans in the next hundred years (1999-2100).

RERSULTS AND DISCUSSION

Future groundwater development plans

The main objective of this study is to develop a comprehensive plan for the efficient and orderly allocation of the groundwater resources to meet the present and projected socio-economic development plans of the Bahariya Oasis. The study was initiated with an inventory of the natural and human resources and socio-economic activities. The calibrated model was used to test three different possible future exploitation/development management scenarios for a period of 100 years (1999-2100) in terms of exploring the hydrologic feasibility of these scenarios. It is also used to determine the safe yield of the Nubian Sandstone Aquifer System of the Bahariya Oasis, these scenarios are as follows (Abd El-Latif, 2007):

•**Ordinary Scenario**, the first possible exploitation plan assumes that the present groundwater exploitation rates (i.e. discharge rate = 95409 m^3/day) = 34.8x10^6 m^3/year) in the study area are constant for the next one hundred years. When applying this scenario, the model shows that there is no change in the potentiometric heads of the Nubian Sandstone Aquifer of the Bahariya Oasis. Accordingly, the first exploitation plan is to assume that the present exploitation rate is doubled (i.e. discharge rate = 190618 m^3/day = 69 x10^6 m^3/year) during the next 100 years (1st scenario).

• **Promising Scenario**, involves the planned increase in groundwater exploitation depending on soil potentialities and consumptive demands by drilling new wells in the study area, that followed by gradual increase in the groundwater withdrawal rate from 10% to 100% of the proposed promising scenario.

•**Maximum Possible Economic Scenario(Q_{safe})**, assuming an increase in the groundwater extraction until reaching the maximum possible economic level (drawdown 100 m.). These scenarios were tabulated as follows:

Proposal scenario	Duration	Discharge m^3/d	Area (Feddan)
1st scenario	**1999-2100**	**Q = 190618**	**11914**
2nd scenario	1999-2100	Q1 = actual discharge + total water demand = 169565	10598
	1999-2100	Q2 = Q1 + 10% Q1 = 186522	11658
	1999-2100	Q3 = Q1 + 25% Q1 = 211957	13247
	1999-2100	Q4 = Q1 + 50% Q1 = 254348	15897
	1999-2100	Q5 = Q1 + 75% Q1 = 296740	18546
	1999-2100	Q6 = Q1 + 100% Q1 = 339130	21196
Q_{safe}	1999-2100	Q_{safe} = 837357	52335

Feddan: The traditional area unit for land in Egypt, which is 4200 m^2 (i.e. equivalent to 1.04 acre)

Scenario	Discharge m^3/d	Stability of the simulated drawdown after: (Year)
1st scenario	(Q)	≈ 9
2nd Scenario	(Q1)	≈ 4
	(Q1+10% Q1)	≈ 7
	(Q1+25% Q1)	≈ 6
	(Q1+50% Q1)	≈ 24
	(Q1+75% Q1)	≈ 20
	(100% Q1)	≈ 16
Maximum possible economic scenario (Q_{safe})	(Q_{safe})	≈ 7

Model simulation results of the proposed scenarios

It is worth to mention that, in all the proposed scenarios, the change in the hydraulic head values during the Finite Element Model simulation occurs in the first 25 years and then the simulated head values became nearly constant during the next 75 years of simulation, as follows (Abd El-Latif, 2007):

1st scenario

The first exploitation plan assumes that the current exploitation rates (95409 m^3/day= 34.8×10^6 m^3/year) will be doubled during the next 100 years. Results of the flow model for this scenario are illustrated in Fig.(10) and Table (5). The contour map of the simulated hydraulic head for this development plan indicates that the trend of groundwater flow remains generally from southwest to northeast. The maximum drawdown attained in the modeled area due to applying the proposed discharge rate Q =190618 m^3/working day (i.e. 69.6×10^6 m^3/year) to irrigate 11914 feddans is 25.7 m recorded at Bawiti and El-Zabu towns in the northern part of the Bahariya Oasis, whereas the minimum drawdown values are 1.4 m and 1.8 m recorded at El-Heiz town in the south and Qassa area in the north, respectively (Fig.17). This indicates that the proposed exploitation rate in this scenario can afford water requirements for the next 100 years to the Bahariya Oasis without adverse effect on water levels.

2nd scenario

Several management plans were proposed using different discharge rates to cope with the increasing demand for water used for development of the study area. According to the 2nd development plan, the discharge rate will be Q1 = 169565 m^3/working day (i.e. 62.6×10^6 m^3/year), representing the current discharge in the modeled area (in 1999) and the discharge from the proposed 42 new wells in the southern sector of the study area depending on the soil classification priority (Class III) to irrigate 4600 feddans, and for domestic and livestock demands. The maximum drawdown attained in the area due to water extraction is 12 m recorded at El-Heiz area in the south while the minimum recorded drawdown is 0.27 m at Mandisha area in the north (Fig.11 and Table 5), which is very safe and economic.

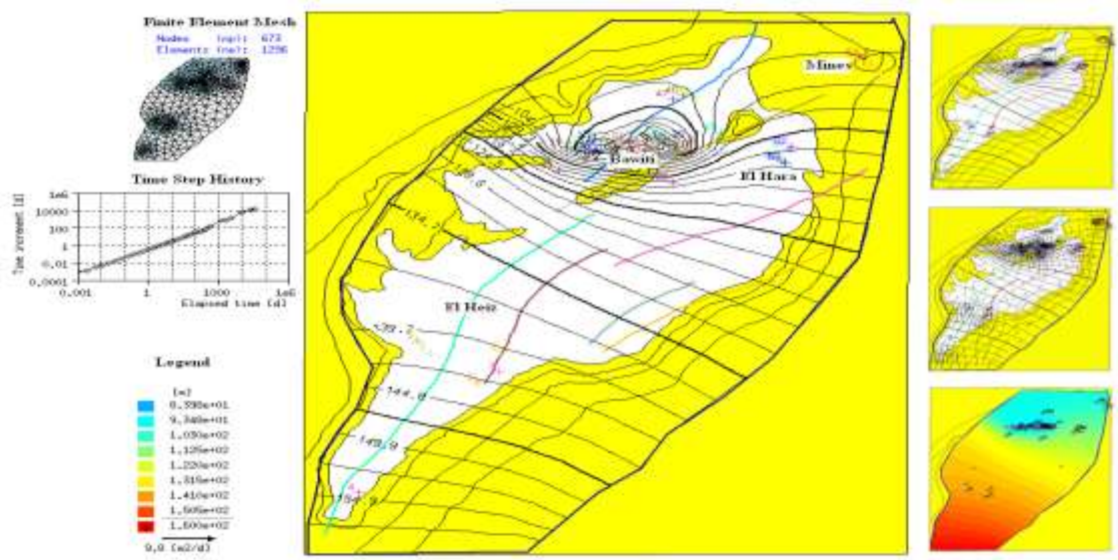

Fig.10. Simulated hydraulic head (m a.s.l.) for the Nubian Aquifer System of the Bahariya Oasis for the period 1999-2100 with extraction rate Q

The promising scenario (2nd scenario) was proposed in order to expand horizontally adjacent to the already reclaimed land in the northern sector of the Bahariya Oasis and the new one especially in El-Heiz area (southern sector), which in turn leads to increase the vertical expansion, taking into consideration the increase of water requirements for inhabitants and livestock. Consequently, in order to determine an optimum pumpage policy, the following discharge rates (i.e. Q2 to Q6) were proposed. Accordingly, by applying the Finite Element Model (FEFLOW 5.2) with the percentage gradual increase in the groundwater withdrawal of the 2nd development plan, the groundwater levels of the Nubian Sandstone Aquifer in the study area will decline as compared to their initial conditions, as follows:

1) **Discharge rate Q2**: accounts for an increase in the groundwater extraction to Q1+10%Q1 (i.e. 186522 m^3/working day = 68.6×10^6 m^3/year). The maximum drawdown attained in the area due to this water exploitation to irrigate 11658 feddans is 13 m recorded at El-Heiz area in the south while the minimum drawdown is 0.03 m recorded in Aguz area in the north (Fig.17 and Table 5).
2) **Discharge rate Q3**: in this scenario in groundwater extraction increased to Q1+25%Q1 (i.e. 211957 m^3/working day = 77×10^6 m^3/year). The maximum drawdown attained in the area due to water exploitation for irrigating 13247 feddans is 14 m recorded at El-Heiz area in the south while the minimum drawdown is 0.16 m recorded at Qassa area in the north (Fig.17 and Table 5).

Discharge rate Q4: accounts for an increase of the groundwater extraction to Q1+50%Q1 (i.e. 254348 m^3/working day = 93×10^6 m^3/year). The maximum drawdown observed in the area due to water exploitation for irrigating 15897 feddans is 20 m recorded at Bawiti area in the north while the minimum drawdown is 0.4 m recorded at El-Heiz area in the south (Fig.17 and Table 5).

3) **Discharge rate Q5**: aims to increase the groundwater extraction to Q1+75%Q1 (i.e. 296740 m^3/working day= 108×10^6 m^3/year). The maximum drawdown attained in the area due to water exploitation for irrigating 18546 feddans is 25 m recorded at Bawiti area in the north while the minimum drawdown is 1.3 m recorded in El-Heiz area in the south (Fig.17 and Table 5).
4) **Discharge rate Q6**: the groundwater extraction increased to its full capacity or 2Q1 (i.e. 339130 m^3/working day = 124×10^6 m^3/year). The maximum drawdown attained in the area due to water exploitation for irrigating 21196 feddans is 31 m recorded at Bawiti area in the north while the minimum drawdown is 2.1 m recorded at El-Heiz area in the south (Fig.17 and Table 5).

From the above results the following remarks could be taken into consideration: a) In the 2nd scenario and its complementary discharge rates (i.e. Q2 to Q6), the groundwater flow direction remains generally from southwest to northeast. b) Drilling of new wells in the southern sector (El-Heiz) of the study area gives the advantage of minimizing decline of groundwater levels when pumping from the whole study area rather than pumping only from the northern sector of the Bahariya Oasis (i.e. increasing the distance between wells and decrease well interference). This is obvious from the average groundwater level decline when applying 1st scenario (i.e. discharge rate= 190618 m^3/day = 69.6×10^6 m^3/year) which is 15 m while the average groundwater level decline when applying Q2 scenario (i.e. discharge rate= 186522 m^3/day= 68.6×10^6 m^3/year), with approximately the same value of discharge, is 6 m (Fig.18). c) Generally, the maximum permissible economic lifting depth is approximately 100 m from the ground surface. Since the maximum drawdown attained in the modeled area when applying the 2nd scenario and its complementary scenarios (i.e. Q2 to Q6) is 31 m (i.e. less than the economic lifting depth value). Accordingly, the current exploitation rate scenarios are suitable, very safe and economic in use for the next 100 years in the Bahariya Oasis (Abd El-Latif, 2007). d) It is not recommended to increase the existing extraction by drilling new production wells in the northern part of the study area, especially in the Bawiti town owing to the adverse effect of well interference.

Maximum possible economic scenario (Q_{safe})

The safe yield approach was defined as the amount of naturally occurring groundwater that can be withdrawn from an aquifer, economically and legally, without impairing the native groundwater quality or creating undesirable effect such as environmental damage. Recently, synonymous for safe yield is the sustainable yield which is defined as the quantity of groundwater that can be pumped in the long term by considering the future generations and all components of the hydrologic system. Moreover, Howard (2002), Alley and Leake (2004) and Maimone (2004) concluded that sustainability must be defined as "a system that maintains acceptable risk over an indefinite time horizon".

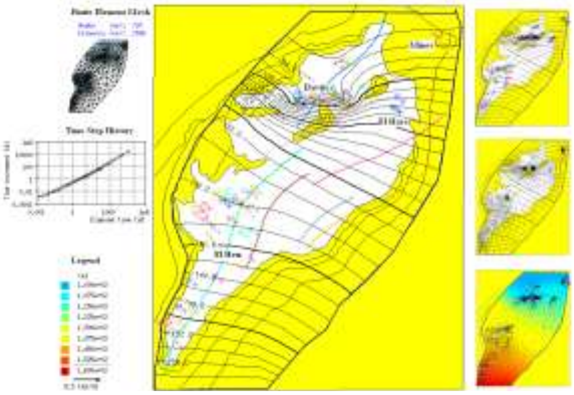

Fig.11.Simulated hydraulic head (m a.s.l.) for the Nubian Aquifer of the Bahariya Oasis for the period 1999-2100, applying the second scenario with extraction rate Q1

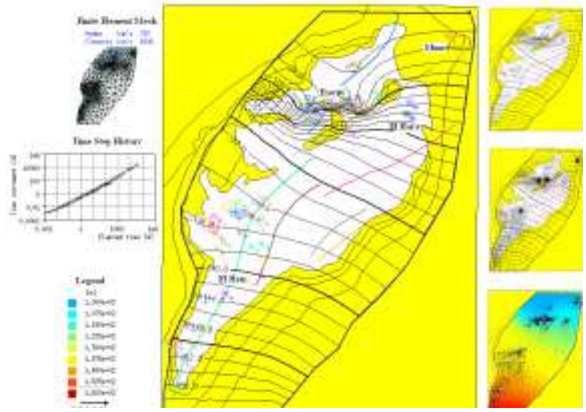

Fig.12. Simulated hydraulic head (m a.s.l.) for the Nubian Aquifer of the Bahariya Oasis for the period 1999-2100, applying the 2nd scenario with extraction rate Q2.

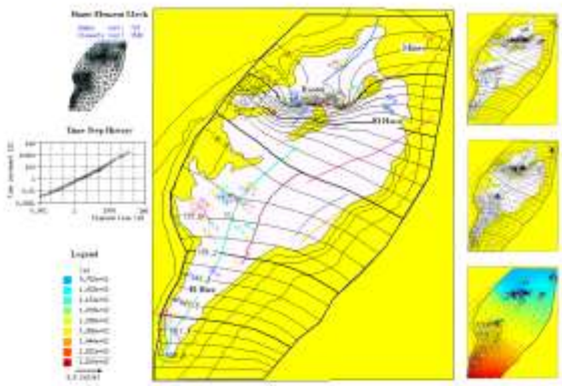

Fig.13. Simulated hydraulic head (m a.s.l.) for the Nubian Aquifer of the Bahariya Oasis for the period 1999-2100, applying the 2nd scenario with extraction

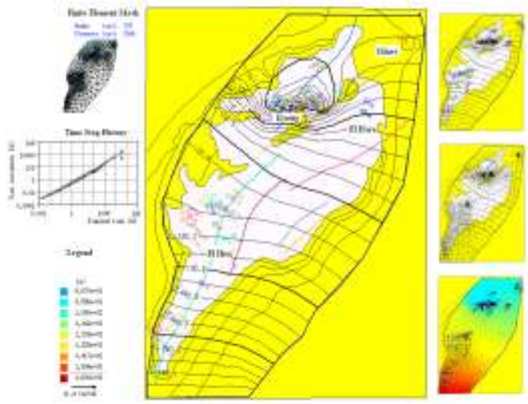

Fig.14. Simulated hydraulic head (m a.s.l.) for the Nubian Aquifer of the Bahariya Oasis for the period 1999-2100, applying the 2nd scenario with extraction rate Q4.

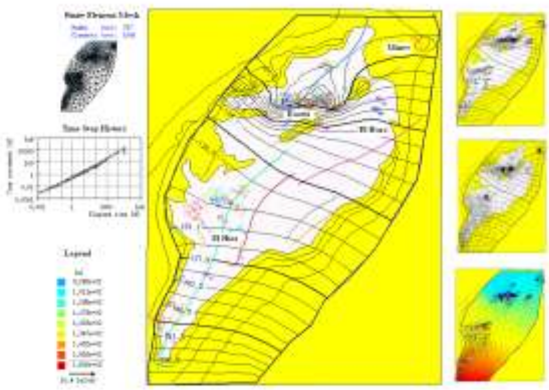

Fig.15. Simulated hydraulic head (m a.s.l.) for the Nubian Aquifer of the Bahariya Oasis for the period 1999-2100, applying the 2nd scenario with extraction rate Q5.

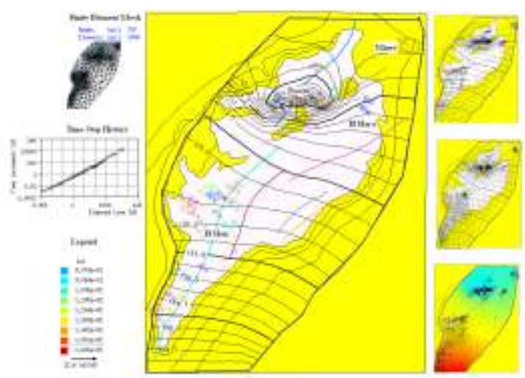

Fig.16. Simulated hydraulic head (m a.s.l.) for the Nubian Aquifer of the Bahariya Oasis for the period 1999-2100, applying the 2nd scenario with extraction rate Q6.

The risk is a function of uncertainty in both supply and demand. Therefore, water resources should be managed in an integrated manner that are compatible with maintaining them for the future generations (Sakiyan and Yazicigil, 2004). The maximum permissible lifting depth is approximately 100 m from the ground surface which is considered to be economic for irrigation (DRC, 2000 and Ebraheem, et al., 2003). The results obtained from the maximum possible economic scenario indicate that a major cone of depression will be located in the center of the northern sector of the Bahariya Oasis (Fig.19), with maximum decline (≈100 m) recorded at Mandisha, Bawiti and El-Zabu areas in the north whereas the minimum drawdown values are 12 m and 15 m recorded at El-Heiz in the south and Mines area in the north, respectively. Therefore, the present extraction rate of the Bahariya Oasis is 95409 m^3/day (i.e. 34.8×10^6 m^3/year) that can be increased to 837357 m^3/day (i.e. 305.6×10^6 m^3/year) safely for the next 100 years (1999-2100). The value of extraction rate when applying the maximum possible economic scenario in the study area (i.e. 270.8×10^6 m^3/year) is greater than the values introduced by Himida (1964) and CEDARE (1994) (173×10^6 m^3/year) and by Brinkmann, et al. (1987) (143×10^6 m^3/year). This can be attributed to the accuracy of the flow model used (Finite Element Model) and the availability of data including number of wells, discharge rates, pumping and recovery test data for the Nubian Sandstone Aquifer of the study area. The simulation results of this scenario and the calculated drawdown (Table 5) indicate that the simulated extraction rate (837357 m^3/day) is feasible for irrigating 52335 feddans (i.e. 54428 acre) in the next 100 years (1999-2100). Depending upon the result of the maximum possible economic scenario, three priorities for land reclamation are proposed to use in the next 100 years, as follows (Abd El-Latif, 2007):

a) The *first priority* of using this future extraction involves reclaiming all the soil classes capabilities (Class III, IV, VI and VII) which are distinguished using USDA system (1973) and represented by 48470 feddans in the southern sector (El-Heiz) of the Bahariya Oasis.

b) The *second priority* of using this scenario in the development of other localities such as Mines and Hara areas in the north (Fig.17).

c) Since all the drawdown values within the limit of the maximum permissible lifting depth (100 m), the *third priority* can be proposed for using this maximum possible economic scenario in Qassa, El-Qasr, Bawiti, Aguz and Mandisha (Fig.17) (Abd El-Latif, 2007). The results of the various scenario runs demonstrate that the groundwater potentiality in the Bahariya Oasis is high. Therefore, the agricultural development is highly recommended, if within the framework of the sustainable development of the precious groundwater resource, as suggested by the maximum possible economic scenario (Q_{safe}). These results should be taken into account in the preparation of a long-term management plan for the optimum use of the groundwater resource of the Nubian Sandstone Aquifer in the promising lands of the Bahariya Oasis.

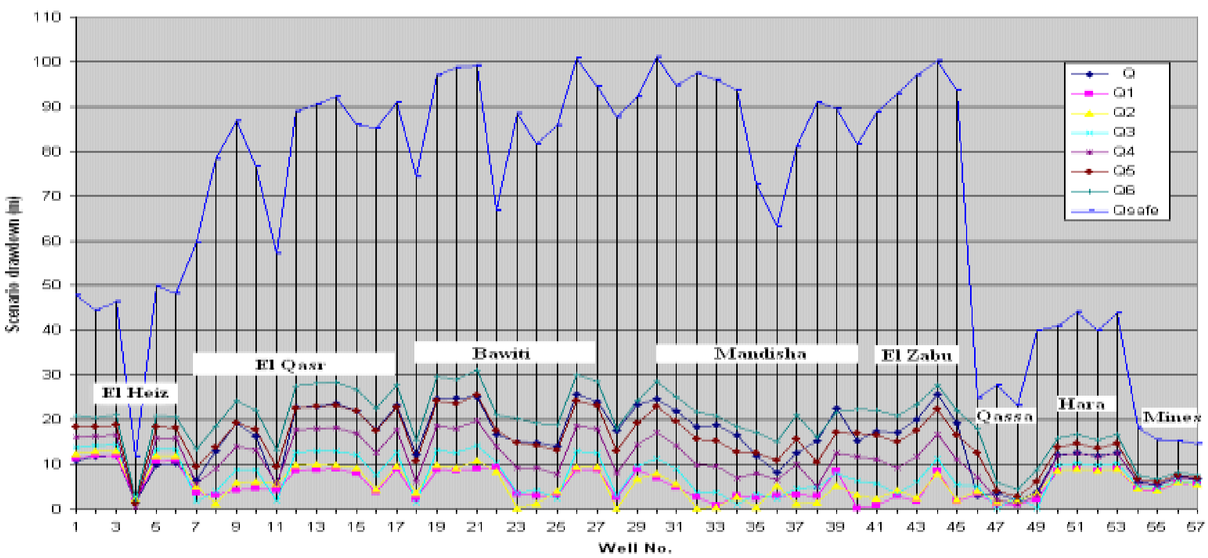

Fig. 17. Simulated drawdown of the different scenarios at different areas of the Bahariya Oasis for the period 1999-2100

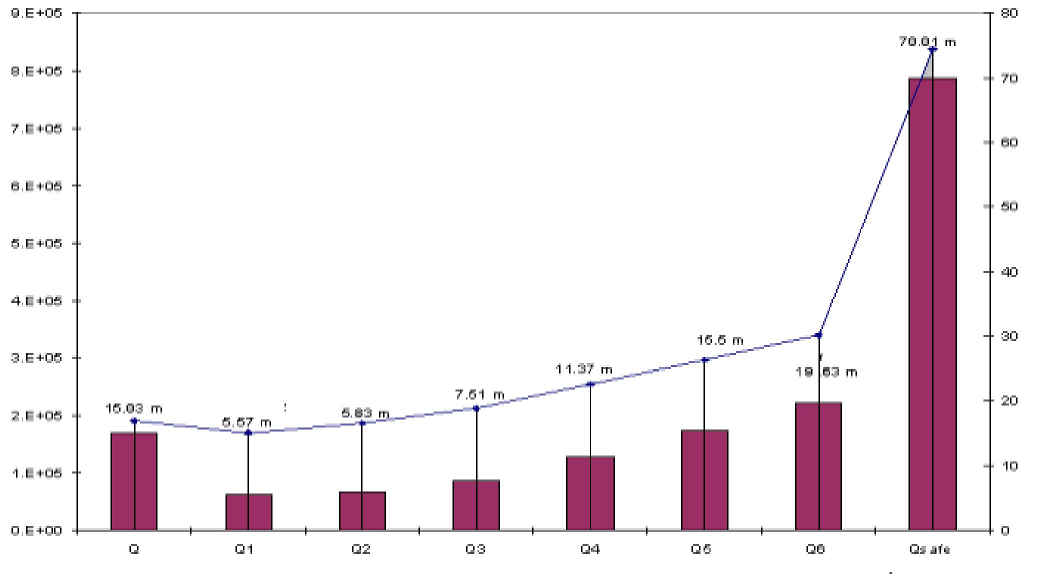

Fig.18. Relation between average groundwater level decline (m) and discharge (m^3/d) for different scenarios during the period 1999-2100

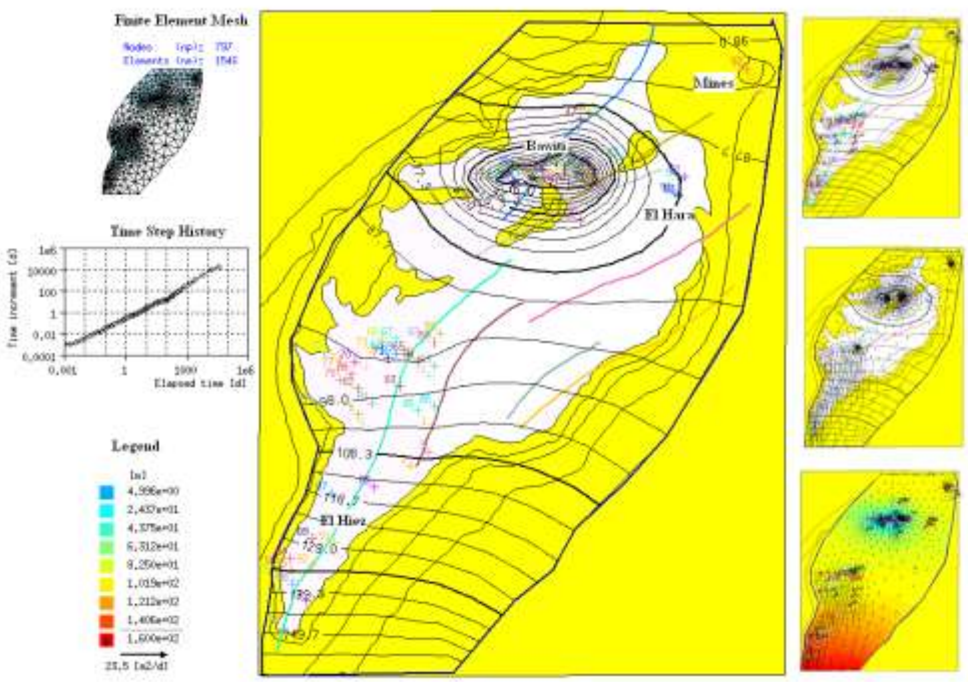

Fig. 19. Simulated hydraulic head (m a.s.l.) for the Nubian Aquifer of the Bahariya Oasis for the period 1999-2100, applying the maximum possible economic scenario with extraction rate Q_{safe}.

Table 5. Predicted maximum drawdown (m) in the Bahariya Oasis due to different discharge rates after 100 years. (Abd El-Latif, 2007)

	Ordinary (1st)	Promising Scenario (2nd)						Max. Possible Economic Scenario
	Q =190618	Q1 =169565	Q2 =186522	Q3 =211957	Q4 =254348	Q5 =296740	Q6 =339130	Qsafe =837357
	Drawdown	Drawdown	Drawdown	Drawdown	Drawdown	Drawdown	Drawdown	Drawdown
1	10.86	11.18	12.34	13.75	16.11	18.47	20.82	47.73
2	11.71	12.00	12.98	14.24	16.32	18.41	20.50	44.42
3	11.90	11.98	13.03	14.36	16.57	18.78	20.99	46.36
4	1.39	1.94	2.31	2.82	0.40	1.25	2.09	11.75
5	9.79	10.68	11.81	13.32	15.83	18.34	20.85	49.82
6	10.13	10.83	11.94	13.38	15.78	18.18	20.57	48.16
7	6.41	3.54	5.03	1.75	5.60	9.45	13.29	59.76
8	13.04	3.17	1.16	4.06	8.89	13.73	18.57	78.33
9	19.27	4.17	5.75	8.84	13.99	19.14	24.28	86.86
10	16.24	4.62	6.11	8.78	13.23	17.68	22.13	76.66
11	4.58	4.19	5.71	1.87	5.60	9.33	13.06	57.14
12	22.74	8.60	9.74	12.71	17.67	22.63	27.59	88.90
13	22.86	8.77	9.97	12.99	18.02	23.06	28.09	90.53
14	23.56	8.90	9.83	12.93	18.09	23.24	28.40	92.32
15	21.85	7.87	9.27	12.17	17.01	21.85	26.68	85.93
16	17.68	3.70	4.49	7.50	12.51	17.52	22.53	85.18
17	23.07	8.92	9.62	12.65	17.69	22.73	27.78	90.92
18	12.05	2.38	3.53	1.48	6.08	10.67	15.26	74.37
19	24.59	8.80	9.87	13.17	18.66	24.15	29.64	97.09
20	24.76	8.54	9.13	12.46	18.00	23.55	29.09	98.68
21	25.04	9.01	10.91	14.26	19.85	25.44	31.02	99.17
22	16.80	9.43	8.26	10.39	13.93	17.47	21.01	66.81
23	15.01	3.43	0.26	3.60	9.17	14.74	20.31	88.59
24	14.81	2.84	1.25	4.25	9.24	14.23	19.22	81.71
25	13.88	3.17	4.04	2.24	7.74	13.25	18.75	85.78
26	25.70	8.70	9.47	12.89	18.60	24.30	30.01	100.76
27	23.97	8.78	9.31	12.52	17.87	23.22	28.57	94.49
28	17.58	2.58	0.03	3.01	7.97	12.93	17.89	87.66
29	23.40	8.73	6.59	9.52	14.41	19.30	24.18	92.31
30	24.72	6.80	7.92	11.37	17.13	22.88	28.64	101.00
31	21.97	4.71	5.67	8.89	14.26	19.63	24.99	94.70
32	18.42	2.81	0.21	3.79	9.75	15.70	21.66	97.40
33	18.86	0.89	0.38	3.81	9.52	15.24	20.95	96.08
34	16.50	2.89	2.71	1.14	6.91	12.67	18.44	93.80
35	12.00	2.59	0.49	3.25	7.84	12.44	17.03	72.65
36	8.21	2.88	5.13	2.29	6.54	10.79	15.04	63.23
37	12.52	3.07	1.15	4.49	10.05	15.61	21.17	81.08

Table 5. Cont.

No.	Ordinary (1st)	Promising Scenario (2nd)						Max. Possible Economic Scenario
	2Q = 190618	Q1 = 169565	Q2 = 186522	Q3 = 211957	Q4 = 254348	Q5 = 296740	Q6 = 339130	Qsafe = 837357
	Drawdown	Drawdown	Drawdown	Drawdown	Drawdown	Drawdown	Drawdown	Drawdown
38	15.20	2.99	1.42	4.72	5.04	10.54	16.04	91.02
39	22.45	8.56	5.22	7.97	12.55	17.13	21.71	89.50
40	15.20	0.27	3.12	6.32	11.65	16.98	22.30	81.52
41	17.29	0.76	2.30	5.59	11.07	16.56	22.04	88.63
42	17.07	2.90	4.16	3.38	9.19	14.99	20.80	92.97
43	20.12	1.71	2.49	5.95	11.74	17.52	23.30	97.08
44	25.70	8.54	7.98	11.29	16.80	22.30	27.81	100.26
45	19.29	1.71	2.17	5.48	11.00	16.51	22.02	93.82
46	2.85	3.28	3.94	4.99	7.00	12.51	18.02	24.81
47	3.65	1.03	1.68	0.16	2.07	3.98	5.89	27.75
48	1.84	0.99	1.78	2.81	1.01	2.74	4.46	23.12
49	3.77	2.06	3.54	0.29	3.14	6.00	8.86	39.88
50	12.01	8.52	8.63	9.83	11.83	13.83	15.82	40.83
51	12.43	8.90	8.99	10.29	12.45	14.61	16.77	44.01
52	11.85	8.49	8.57	9.73	11.67	13.61	15.55	39.78
53	12.51	8.93	8.99	10.28	12.43	14.59	16.74	43.87
54	6.08	4.39	4.57	5.07	5.90	6.73	7.56	18.06
55	5.50	4.01	4.15	4.57	5.28	5.98	6.68	15.53
56	7.27	5.90	6.00	6.34	6.91	7.48	8.05	15.18
57	6.74	5.37	5.47	5.81	6.37	6.94	7.50	14.58

Note: Q (m^3/day) and drawdown (m)

REFERENCES

Abd El-Latif, R.M., 2007. Study of groundwater resources management in Bahariya Oasis. Ph.D. Thesis, Fac. Sci., Alexandria University, 248 pp.

Abdel Ati, A.A., 1995. Groundwater conditions in El Bahariya Oasis and future development. M.Sc. Thesis, Fac. Sci., Cairo Univ., 172pp.

Abdel Ati, A.A., 2002. Hydrogeological studies on the Nubian Sandstone Aquifer in Bahariya and Farafra depressions, Western Desert, Egypt. Ph.D. Thesis, Fac. Sci., Ain Shams Univ., 164 pp.

Allam, A.R., Saaf, E.J. and Dawoud, M.A., 2002. Desalination of brackish groundwater in Egypt. Elsevier, Desalination, V.152, p.19-26.

Alley, W.M. and Leake, S.A., 2004. The journey from safe yield to sustainability. Ground Water, V.42, No.1, p.12-16.

Ayouty, M.K. and Ezzat, M.A., 1961. Hydrogeological observations in the search for underground water in the Western Desert of Egypt. U.A.R Inter. Assoc. of Sci. Hydrology, Gentbrugge, Belgique, No.56, p.114-118.

Ball, J. and Beadnell, J.H.L., 1903. Bahariya Oasis: its topography and geology. Survey Department, Ministry of Public Works, Egypt, 84pp.

Basta, E.Z. and Amer, H.I., 1969a. Geological and petrographic studies on El-Gedida area, Bahariya Oasis, U.A.R. Bull. Fac. Sci., Cairo Univ., No.43, p.189-208.

Basta, E.Z. and Amer, H.I., 1969b. Mineralogical investigations on the iron ore deposits of El-Gedida area, Bahariya Oasis, U.A.R. Bull. Fac. Sci., Cairo, Univ., No.43, p.237-269.

Brinkmann, P.J., Heinl, M., Hollander, R. and Reich, G., 1987. Retrospective simulation of groundwater flow and transport in the Nubian Aquifer System. Berliner Geowiss. Abh.(A), V.V.75.2, p.465-516.

CEDARE, 1994. Regional program for the development and utilization of the Nubian Sandstone Aquifer. National Status Report. Center For Environment and Development Arab Region and Europe (CEDARE), Cairo.

CEDARE, 2001. Regional strategy for the utilization of the Nubian Sandstone Aquifer System. Center For Environment and Development Arab Region and Europe (CEDARE), Cairo, V.I, II and III.

Diab, M.SH., Zeidan, S. and Himida, I.H., 1978. Recent study of the hydrogeology of Bahariya Oasis, Western Desert Egypt. 10th Arab Petrol. Cong., Tripoli, Libya, Paper No. 140(B-3), 14pp.

DRC, 2000. Strategy of using groundwater and surface water in the development of south Egypt. Ministry of Agriculture and Land Reclamation. Desert Research Center, 2nd Report, 213pp. (In Arabic)

Ebraheem, A.M., Garamoon, H.K., Riad, S., Wycisk, P. and Seif El-Nasr, A.M., 2003. Numerical modeling of ground-water resource management options in east Oweinat area, SW Egypt. Environmental Geology, V.44, p.433-447.

El-Akkad, S. and Issawi, B., 1963. Geology and iron ore deposits of the Bahariya Oasis. Geol. Surv. and Min. Res. Dept., Cairo, paper 18, 301pp.

El-Bassyouny, A.A., 1978. Structure of the northeastern plateau of the Bahariya Oasis, Western Desert, Egypt. Geologie en Mijnbouw, V. 57, p.77-86.

El-Mansy, I.M.I., 1983. Sedimentological and mineralogical studies of some Upper Cretaceous surface sections from Bahariya Oasis, Western Desert, Egypt. Ph.D. Thesis, Fac. Sci., Ain Shams Univ., Cairo, Egypt, 218pp.

El-Shazly, E.M., 1962. The results of drilling in the iron ore deposit of Gebel Ghorabi, Bahariya Oasis, Western Desert, and report on the mineralogy of the low grade iron ore of El-Heiz area, Bahariya Oasis, Western Desert. Geol. Surv. and Min. Res. Dept., Government Press, Cairo, 28pp.

Ezzat, M.A., 1959b. Origin of the underground water in Libya Desert and preliminary evaluation of its amount. Report of G.D.D.O., Cairo.

Faris, M.I., Farag, I.A.M. and Gheith, M., 1956. Contribution to the geology of Bahariya Oasis. Abs. Proc. Geol. Soc., Egypt. Vol.2, p.36-38.

Franks, G.D., 1982. Stratigraphical modeling of Upper Cretaceous sediments of Bahariya Oasis. Proceedings of the 6th Egyptian General Petroleum Corporation Exploration Seminar, V.I, p.93-105.

GARPAD, 1981. Groundwater data book. V.1- Regional development of the New Valley Region. Report submitted to Ministry of Development.

Hassan, A.E., 2004. Validation of numerical ground water models used to guide decision making. Ground Water, V.42, No.2, p.277-290.

Himida, I.H., 1964. Artesian water of the oases of Libyan Desert in U.A.R. Ph.D. Thesis, M.G.R.U., Moscow (Russian Language).

Himida, I.H., 1970. The Nubian Artesian Basin, its regional hydrogeological aspects, paleohydrogeological reconstruction. Journal of Hydrology, Neozeland, V.9, No.2, p.89-116.

Holail, H.M., 1987. Stable isotopic composition and its relation to origin and diagenesis of some Upper Cretaceous dolomites and dolomitic limestones from Egypt. Ph.D. Thesis Fac. of Purdue University, 283pp.

Howard, C.D.D., 2002. Sustainable development – risk and uncertainty. Journal of Water Resources Planning and Management, V.128, No.5, p.309-311.

Hume, W.F., 1909. The distribution of iron ores in Egypt. Geol. Surv., Cairo, paper 20, 16pp.

Lebling, C., 1919. Ergebnisse der Forschungreisen Prof. E. Stromers in den Wusten Agyptens, Forschungen in der Baharije Oase und anderen Gegenden Agyptens. Abh. Bayer. Akad. Wiss., Math. Phys., Munchen K1., 29, 1, 44 S.

Leroy, L.W., 1953. Biostratigraphy of the Maqfi section, Egypt. Geol. Soc. Am. Mem. No 54, p.1-73.

Maimone, M., 2004. Defining and managing sustainable yield. Ground Water, V.42, No.6, p.809-814.

Moustafa, A.R., Saudi, A., Moubasher, A., Mohamed, I., Molokhia, H. and Schwartz, B., 2003. Structural setting and tectonic evolution of the Bahariya Depression, Western Desert, Egypt. GeoArabia, Gulf Petrolink, Bahrain, V.8, No.1, p.91-124.

Parsons, R.M., 1962. Bahariya and Farafra areas, New Valley project, Western Desert of Egypt. Final Report, Egyptian Desert Development Organization, Cairo.

Said, R., 1962. Geology of Egypt. Elsevier Publishing Co., Amsterdam, New York, 377pp.

Said, R. and Issawi, B., 1964. Geology of the northern plateau, Bahariya Oasis, Egypt. Geological Survey of Egypt, No.29, 41pp.

Sakiyan, J. and Yazicigil, H., 2004. Sustainable development and management of an aquifer system in western Turkey. Hydrogeology Journal V.12, No.1, p.66-80.

Shata, A.A., 1982. Hydrogeology of the great Nubian Sandstone Basin, Egypt. Quaternary Journal of Engineering Geol., London, V.15, p.127-133.

Stromer, E., 1914. Ergebnisse der Forschungreisen Prof. E. Stromers in den Wusten Agyptens. Topographie und Geologie der Strecke Gharaq-Baharije nebst Ausfuhrungen uber die geologische Geschichte Agyptens. Abh. Bayer. Akad. Wiss., Math.-Phys. K1., 26, 11, 77 S., Munchen.

USDA Soil Conservation Service, 1973. Land capability classification. U.S. Dept. of Agri. (USDA) Handbook No.210.

Zaatout, M.A., 1958. The iron ore deposits of Bahariya Oasis. (unpublished report) Geol. Surv. Egypt, 370pp. (In Arabic

الملخص العربي

ادارة المياه الجوفية باستخدام النمذجة الرياضية فى الواحات البحرية بمصر

ابراهيم حسن حميدة، حنفى محمود هليل، محمد ناصر شعبان، انور عبد العزيز الفقى و رمضان محمد عبد اللطيف

تقع الواحات البحرية في الجزء الأوسط من الصحراء الغربية ويعتبر خزان الحجر الرملي النوبي من مصادر المياه الجوفية في الصحراء الغربية، ولا سيما في الواحات البحرية. من خلال القطاعات الهيدروجيولوجية تبين ان خزان الحجر الرملي النوبى مكون من 6 طبقات معظمها من الرمل والطين ومتصلة هيدروليكياً. قيم الناقلية transmissivity تتراوح ما بين 3660 م^2/يوم فى الجنوب الغربى الى 315 م^2/يوم فى الشمال الشرقى من الواحة. لذا فمن الضروري حُسن إدارة الخزان الجوفى في هذه المنطقة الحيوية من مصر لتجنب حدوث بعض الظواهر الهيدروجيولوجية السلبية مثل هبوط بعض مناسيب المياه مع الزمن أو جفاف بعض العيون نتيجة للسحب الجائر في مناطق مجاورة مما يهدد باضمحلال المورد المائي في الطبقات الضحلة منه. ومن ثم فان وضع نموذج هيدروجيولوجى على أسس رياضية يعتبر عمل ضروري وعلى درجة عالية من الأهمية لإدارة هذا المورد المائي الهام والذي يتميز بظاهرتين هامتين وهما عذوبة المياه و كبر حجم الخزان الجوفى (الطبقات الحاملة للمياه).

وبذلك نحقق الهدف المرجو في كيفية التوفيق بين الاستهلاك المائي الحالي وبين الزيادة في الاستهلاك نتيجة للزيادة السكانية والتوسع في التنمية الزراعية والسياحية مستقبلاً. وتتطلب خطط التنمية الجديدة سحب المزيد من المياه. والتساؤل هنا هل الخزان الجوفي بمنطقة الدراسة سيستجيب لتدعيم هذه الزيادة مع الاحتفاظ بجودة وعمق المياه في منسوب اقتصادي. لذا تم استخدام النموذج الرياضي Finite Element Model, FEFLOW v.5.2 بحيث يحاكى الظروف الهيدروجيولوجية للخزان الجوفى كي يعطى تنبؤا لما قد يطرأ مستقبلا على عمق المياه نتيجة زيادة السحب منه على مدى طويل يكافئ 100 سنة. وهذا يضع الواحات البحرية على مسار خطط التنمية في مصر في المستقبل القريب.