

Numerical modelling of groundwater resource management options in the East Oweinat area, southwest Egypt

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Abstract Southwest Egypt is an arid area with no surface water, but reasonable resources of useable groundwater in the well-known Nubian Sandstone Aquifer System. Currently, these groundwater reserves are being heavily exploited. A calibrated regional numerical model with grids refined on the major pumping centres has been used to investigate the hydrodynamic impacts of different groundwater management options on the potentiometry of the aquifers. The results indicate that there is a real threat of either dewatering the shallow aquifer in some areas (e.g. Kharga Oasis), or lowering of the water level to uneconomic lifting depths. It also indicates that although the planned extraction rates in Dakhla, Farafra, and Bahariya oases are feasible for at least the coming hundred years, the present extraction rate at Kharga Oasis, and the planned rate for the East Oweinat area have to be reduced substantially.

Key words groundwater management; Nubian Sandstone Aquifer; Oweinat area; southwest Egypt

INTRODUCTION

The area under discussion is bounded by latitudes 22°00'N and 23°00'N and longitudes 28°00'E and 29°00'E. The occurrence of useable groundwater is restricted to the Nubian Sandstone Aquifer. Several recent studies (e.g. Heinl & Thorweihe, 1993; Nour, 1996; Ebraheem *et al.*, 2002) indicate that natural annual recharge to the Nubian Aquifer System in this area is too low to support large-scale irrigated agricultural development. Therefore, plans for groundwater development should be based upon an aquifer management concept.

During the period 1988–1992, a pilot reclamation project was established in an area of 3000 feddans (1 feddan = 0.4 ha). Since then, the reclaimed area has continuously expanded with the goal to add an additional 30 000 feddans every five years as part of a plan of reclaiming a total of 190 000 feddans by the year 2022). The foreseen irrigation water requirements by the end of this year will be approximately 450 000 m³ day⁻¹ when the target area will be totally reclaimed. There are, at present, a number of critical management problems in this area with respect to meeting water needs, and avoiding groundwater depletion. The objective of the present research is therefore, to create a groundwater resources management model and apply this model to study the technological and economic feasibility of groundwater exploitation for irrigated agriculture in this area and its impact on the groundwater potential of other areas including Dakhla, Kharga, Farafra, and Bahariya oases (Fig. 1).

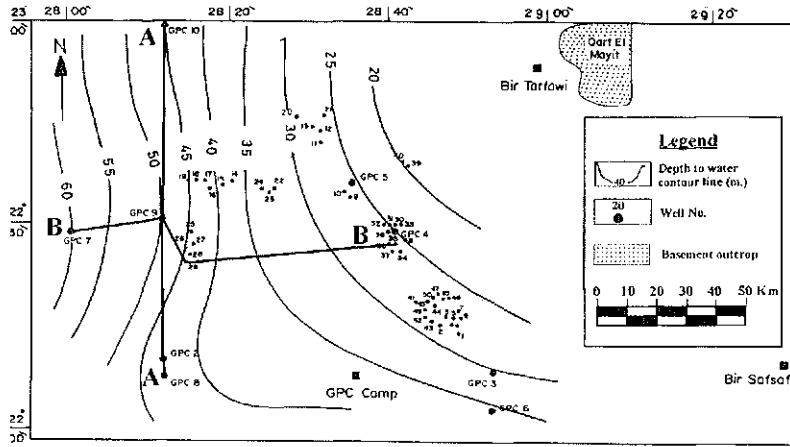


Fig. 2 Location map of the drilled water wells in East Oweinat area. Contours of the observed water depth of year 2000 are also shown (after El Sayed *et al.*, 2002).

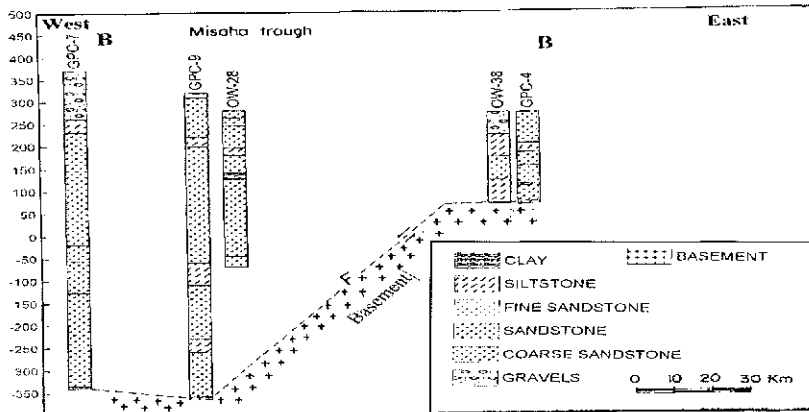


Fig. 3 Lithological logs of some of the drilled water wells in the study area (after El Sayed *et al.*, 2002).

Tarfawi and southwest of latitude 22°N. It attains a thickness of 200 m, interfingering toward the north with mudstone and sandstone beds, originating from a shallow marine environment. The basement top shows a vertical displacement of about 200 m and thus the thickness of the aquifer increases to its maximum value near Well GPC7 (Fig. 3). The basement rocks form the lower boundary whereas the potentiometric surface forms the upper boundary of the aquifer.

Water depth ranges between 20 m below the ground surface in the eastern part of the study area to more than 60 m in the western part. The occurrence of a few places with near-surface groundwater area is caused by the crustal basement of the Oweinat-Safsaf uplift system which dams up the southwest–northeast regional groundwater flow.

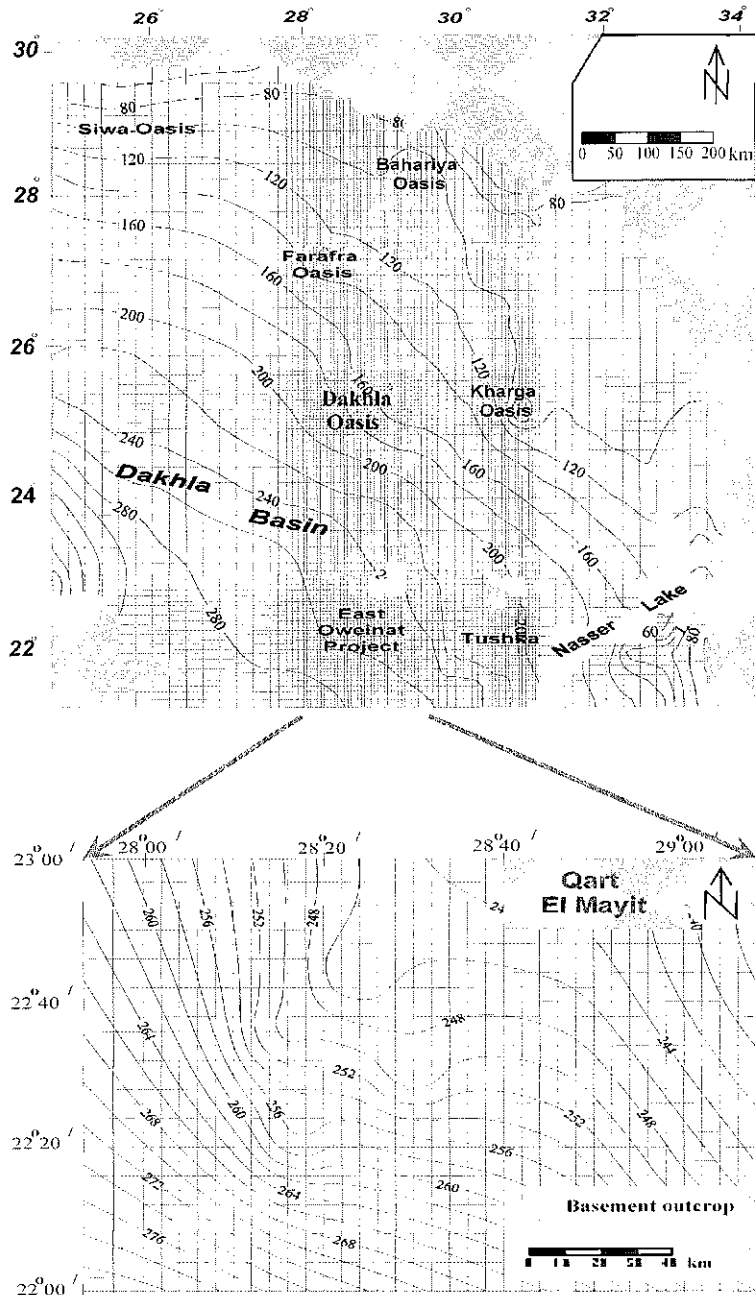


Fig. 4 Simulated hydraulic head by year 2000: Scenario 1.

LOCAL-SCALE GROUNDWATER FLOW MODEL

The Nubian Sandstone Aquifer in the East Oweinat area is only a small part of the whole Nubian Sandstone Aquifer System of Egypt. Groundwater flow in the main

aquifer layers is governed by conditions at the boundaries of the regional system. These conditions are not well defined for the East Oweinat area. Therefore, in order to model groundwater flow in the Nubian Sandstone Aquifer in this area, a regional calibrated model for the whole Nubian Sandstone Aquifer of Egypt (Ebraheem *et al.*, 2002) was used to develop the local-scale model of this area.

Its grid was refined into 34 columns and 23 rows in the regional model with a grid spacing of 5000 m in both directions (Fig. 4). The regional model was used to calculate the flow fluxes across the boundary cells of the area of the local-scale model (Leake & Claar, 1999).

CONSTRAINTS FOR GROUNDWATER DEVELOPMENT

At present, a pumping head of more than 100 m is considered to be uneconomic for irrigation. The calculated lifting depth in this area is approximately equal 100 m from the ground surface. However, in other areas (e.g. Kharga Oasis), the economic water lifting depth is only 38 m from the ground surface (Ebraheem, 2002). The possible management scenarios for groundwater resource in this area were simulated using the developed model.

ASSESSMENT AND EVALUATION OF PLANNED GROUNDWATER DEVELOPMENT

The Ministry of Public Work and Water Resources (MPWWR) plans to increase groundwater production by developing new well fields in the study area. The simulation model was used to evaluate five different possible future exploitation/development plans for the aquifer system under consideration in order to explore the hydrological feasibility of these plans. The simulation extended from year 2000 to the year 2100. The groundwater extraction rate of each of the scenarios is presented in Table 1. The permissible and economic lifting depth for the different development areas are shown in Table 2. The computed declines in the water levels and potentiometric heads for the Nubian Sandstone Aquifer in Egypt in general, and in the East Oweinat area in particular, under the five scenarios are briefly discussed below.

Scenario 1 (year 2000 extraction rates): the results obtained indicate that the major cones of depression, are centred in the Kharga, and Dakhla oases (Fig. 4) with maximum declines of 80, 50, and 20 m by the year 2100 for Kharga, Dakhla, and East Oweinat areas respectively. The calculated water depth in the East Oweinat area, Dakhla, Bahariya, and Farafra oases (Fig. 5, Table 3) indicates that the simulated rates in this scenario for these areas are lower than the permissible/potential rates for the coming 100 years except at Kharga oasis where the rate needs to be decreased substantially.

Scenario 2: The extraction rate has risen to its full capacity in Bahariya, Farafra, and Dakhla Oases. Also it was increased to 300 million $\text{m}^3 \text{year}^{-1}$ in East Oweinat and decreased to 124 million $\text{m}^3 \text{year}^{-1}$ in Kharga. The resulting declines in the potentiometric surface and increase in water depth are shown in Figs 6 and 7, respectively.

Table 1 The five possible future groundwater exploitation scenarios.

Area	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Bahariya	34	177	177	177	177
Farafra	283	471	471	471	471
Dakhla	439	625	625	500	625
Kharga	203	124	93	93	93
East Oweinat	164	300	600	900	1200

Table 2 Permissible and present groundwater exploitation rates and their associated water depths for the major development areas.

Area	Permissible discharge ($10^6 \text{ m}^3 \text{ year}^{-1}$)	Economic lifting depth (m below ground surface)	Present discharge rate ($10^6 \text{ m}^3 \text{ year}^{-1}$)	Average water depth in 100 years
Bahariya	177	124	34	3
Farafra	471	115	283	-18 (still flowing)
Dakhla	500	63	439	37
Kharga	124	38	203	53 (uneconomic)
East Oweinat	900	100	164	23
Total	2172		1013	

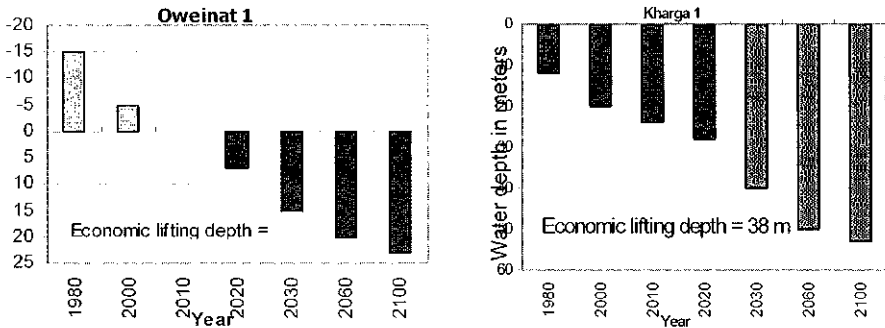


Fig. 5 Average simulated water depth: Scenario 1.

Scenario 3: groundwater extraction rates are the same as Scenario 2, except that the rate at Kharga Oasis was reduced to 93 million $\text{m}^3 \text{ year}^{-1}$ and at East Oweinat was increased to 600 million $\text{m}^3 \text{ year}^{-1}$. The resulted declines in the water levels and potentiometric surface are similar to those of Scenario 2, though the declines are greater for East Oweinat area

Scenario 4: groundwater extraction rates are the same as Scenario 3, except that the rate of Dakhla Oasis was lowered to 500 million $\text{m}^3 \text{ year}^{-1}$ and of East Oweinat was increased to 900 million $\text{m}^3 \text{ year}^{-1}$. The simulation results of this scenario and the calculated water depths (Fig. 8 and Table 3) indicate that the simulated extraction rates in all the development areas are feasible for the coming hundred years with no exception.

Table 3 The simulated water depths under the five possible future groundwater exploitation scenarios.

Year		1980	2000	2010	2020	2030	2060	2100
Bahariya	Scenario 1	-10	-7	-6	-5.5	-5	0	3
	Scenario 2	-7	-5	-3	0	2	7	10
Farafra	Scenario 1	-60	-40	-35	-30	-25	-22	-18
	Scenario 2	-23	-15	-11	-6	0	1	3
Dakhla	Scenario 1	-25	-5	-2	2	5	18	37
	Scenario 2	-18	-1	12	25	39	45	57
Mawhoub West	Scenario 1	-80	-60	-53	-47	-40	-30	-20
	Scenario 2	-60	-40	-35	-30	-25	-15	-5
Kharga	Scenario 1	12	20	24	28	<u>40</u>	<u>50</u>	<u>53</u>
	Scenario 2	-5	5	10	15	20	30	<u>40</u>
	Scenario 3	-7	4	8	13	17	26	36
East Oweinat	Scenario 1	-15	-5	0	7	15	20	23
	Scenario 2	16	20	22	24	25	30	34
	Scenario 3	26	30	32	35	37	45	58
	Scenario 4	27	35	39	44	53	64	95
	Scenario 5	10	40	55	70	80	95	<u>145</u>

Underlined values indicate deeper than economic lift depth.

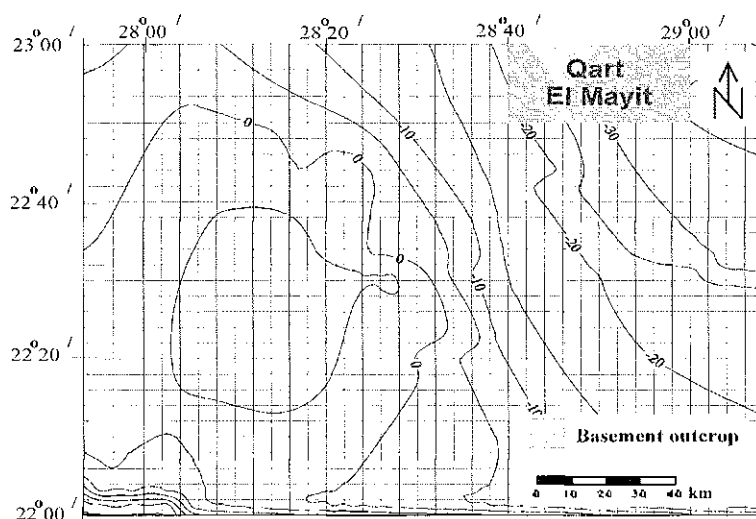


Fig. 6 Simulated decline in hydraulic heads in East Oweinat area by year 2030, Scenario 2.

Scenario 5: our intention in this scenario was to investigate the consequences of expanding the groundwater extraction rates in East Oweinat and Dakhla Oasis to their planned rate (1200 and 625 million m^3 year $^{-1}$, respectively). The resulted declines in the water levels (Fig. 9) indicate that the core of the cone of depression will cover the entire planned reclaimed area. Water depth in this area will be greater than 140 m below the ground surface (Fig. 8 and Table 3).

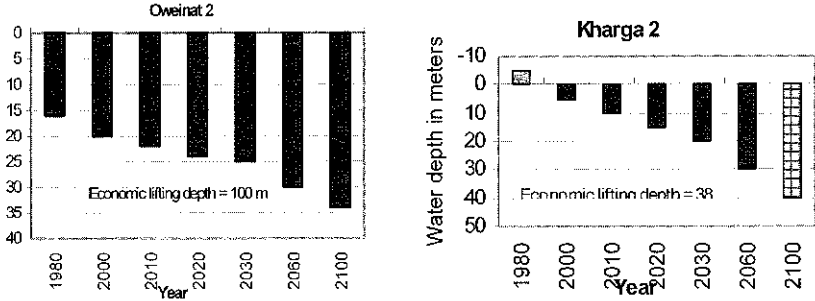


Fig. 7 Average simulated water depth: Scenario 2.

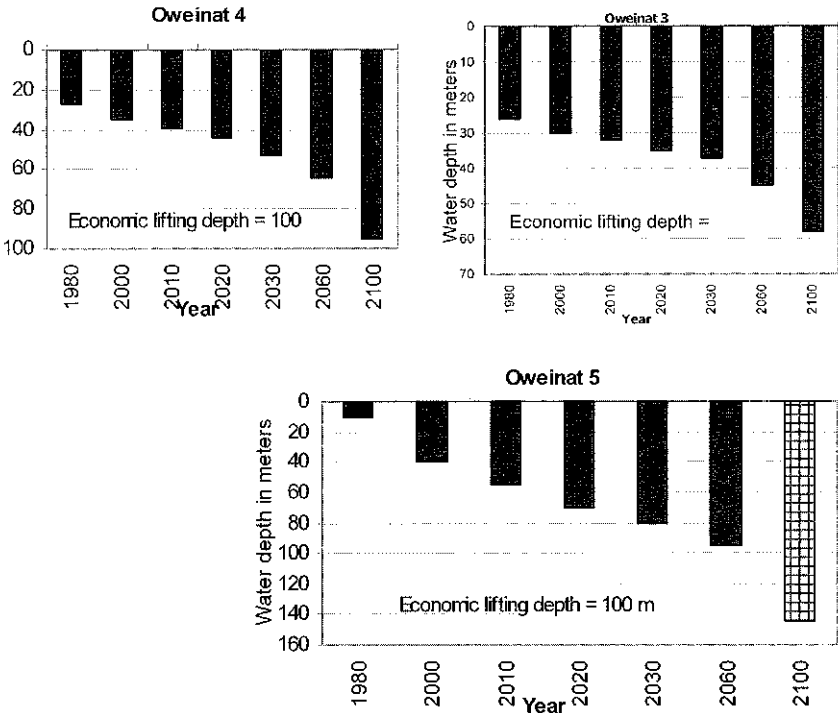


Fig. 8 Average simulated water depth in East Oweinat area: Scenarios 3, 4, and 5.

CONCLUSION

Expanding the presently established well field to its full capacity by year 2020, will result in the water levels continuously declining until the year 2100 (the end of the simulation period) and beyond. To avoid groundwater depletion in the shallow aquifer and to ensure sustainable development of this precious natural resource in Kharga Oasis, the present extraction rate in this oasis needs to be lowered to only 93 million $m^3 \text{ year}^{-1}$ (present value 203 million $m^3 \text{ year}^{-1}$).

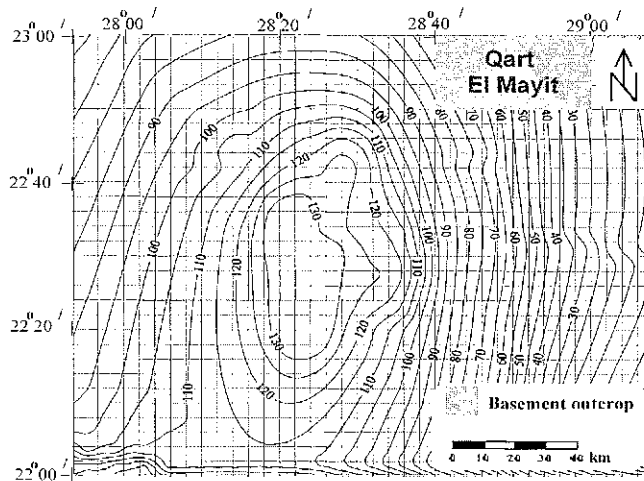


Fig. 9 Simulated decline in hydraulic heads by year 2100: Scenario 5.

The planned extraction rate of 1200 million $\text{m}^3 \text{year}^{-1}$ in the East Oweinat area is not feasible for the coming hundred years and will have a negative impact on water levels not only in East Oweinat area but also in several areas within the Dakhla basin. However, the Dakhla, Bahariya and Farafra Oases, as well as the East Oweinat area, are good areas for groundwater development if the framework for the sustainable development of this precious resource as suggested by Scenario 4 is followed.

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