# PREDICTION OF GROUND WATER QUANTITIES IN SIWA OASIS

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## ABSTRACT

Siwa is one of the most important oases in Egypt. The Nubian Sand Stone ,which is considered the main aquifer, is feeding the oasis with fresh water.The water is extracted ,using deep wells of high piezometric head, for purposes of irrigation and people needs.In the present time Siwa oasis has six deep wells; El-Dakrour, EL- Kaf, Army, El-Gara, Abo-Shroof, and Koreshet which are fed from the Nubian Sand Stone Aquifer. The goal of this paper is to study the oasis hydrology for a period up to year 2020. A mathematical model "Mod Flow" is used to evaluate and predict the piezometric head maps for the oasis. The model accounts for all operated wells. A three arbitrary wells are suggested at different positions to study their effect separately or as a group on the piezometric head map of the oasis. The results are presented in the form of contour maps and charts.

*Keywords: Siwa oasis, Aquifer, Ground water, Water budget, Deep wells.*

## INTRODUCTION

Siwa oasis is located at the farthest western edge of the western desert, and forms a closed basin. It is located about 65 km east of Libyan border, and 300 km south of the Mediterranean Sea. The total area of Siwa oasis is approximately 1000 $km^2$. Most of the central part levels of the oasis lies below the sea level, as shown in Figure (1).

The total annual average rainfall is of 9.9 mm for the period of 1921 to 1985. The mean annual evaporation per day is 10.3 mm for the same period. The prevailing wind direction is from west and northwest side of the oasis depression. The relative humidity ranges between 39 to 66%. The maximum air temperature reaches to 29.8 °C and the minimum equals 13.8°C for the period of 1931 to 1985, El Ramly[1].

The ground water elevations and piezometric head contours through the oasis are studied in many publications[3]. Figure(2) shows the piezometric head map, which has been performed by Bieser Consulting Firm & Regwa Co.[2] in 1987, for the saturated fresh water part of the Nubian sand stone aquifer.

The geological section in Siwa is completely known after analyzing data of about 15 wells drilled in the vicinity and surrounding for oil purposes. Some of these wells penetrated the whole section through the Nubian sand stone such as El-Dakrour, Army, El-Kaf, El-Gara, Abo-Shroof and Koreshet, Figure (1), and others are partially penetrated. Table (1) shows the existing six deep wells including date of construction, the initial piezometric heads which is measured from the main sea water level, and the discharge of wells, as given by El Ramly[1] and from Regwa[5 through 9].

In the present study a mathematical model (Mod. Flow)[4] is used to predict the piezometric head maps of Siwa oasis up to year 2020. The behavior of the existing six deep wells are also investigated for the studied period. The water budget of the Nubian Sand stone in the Oasis is also evaluated using the same mathematical model.

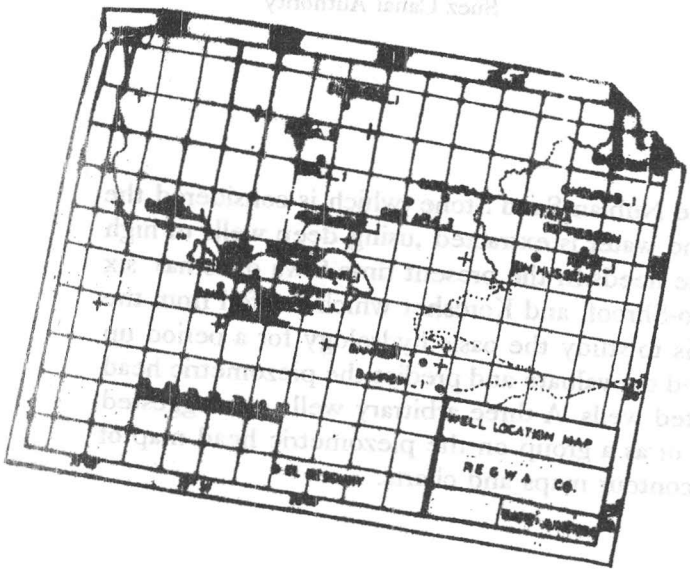


Figure 1. Positions of deep wells in Siwa oasis.

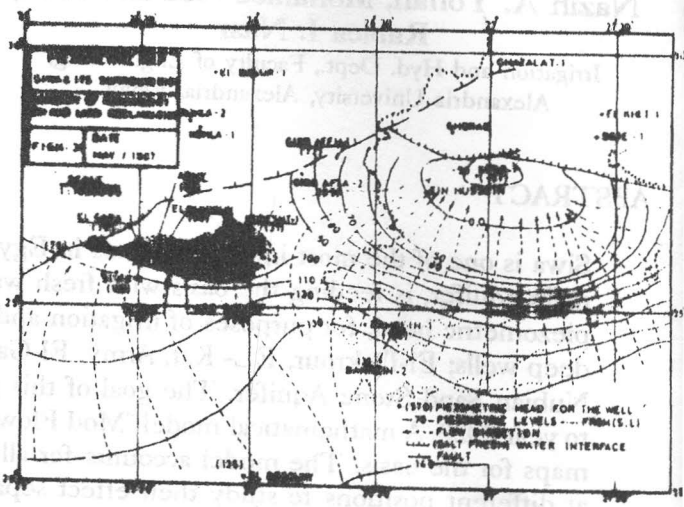

Figure 2. Piezometric head map of siwa oasis and its surrounding, 1987, Ref. [2].

Table 1.

| Well name | Date of construction | Initial piezometric head | Well discharge $m^3$/hr. |
|---|---|---|---|
| El-Dakrour | 1989 | 26.17 | 500 |
| Army | 1990 | 56.98 | 600 |
| El-Kaf | 1991 | 54.52 | 550 |
| El-Gara | 1992 | 72.98 | 500 |
| Abo Shroof | 1993 | 15.75 | 600 |
| Koreshet | 1994 | 28.10 | 500 |

## MATHEMATICAL MODEL

The prediction of piezometric heads of the Nubian sand stone in Siwa oasis ,for the studied period, is carried out using a three dimensional finite difference ground water model (Mod. Flow)[4]. The model was designed by the U.S. Geological Survey. The model computation packages is a multi phase for many purposes of ground water investigation. Five suitable packages of the model, Basic package; Well package; Block centered flow package(BCF); General head boundary package(GHB) and Strongly implicit procedure package(SIP), are used. The model is verified using the available field data.

## RESULTS AND ANALYSIS

### 1- *Piezometric head maps*

The distribution of the actual piezometric head map ,which was obtained according to the field measurements by Regwa [2] in 1987 for Siwa oasis, is shown in Figure (3).The map was prepared before construction of any deep well therefore, the map is considered as the initial piezometric head map and the year 1987 is the basic year for all calculations in the mathematical model. Figure (3) shows that the

piezometric head in Siwa oasis ranges between 100 m along the boundary and 10 m in the middle zone.

Figures (4 and 5) show the predicted piezometric head maps ,for the required stress period at the end of years 1990 and 1994. The figures indicate that there is no noticeable effect or change on the initial piezometric head map of 1987.This explains that the inflow water to the oasis is high compared to the total outflow discharge of the six deep wells.

Figures (6 and 7) show the predicted piezometric head maps at the end of years 2000 and 2020, respectively, considering the existing six deep wells discharges for the studied period. These figures also indicate that there is no appreciable change in the piezometric head contours. Three additional arbitrary wells are suggested to study their effect on both of piezometric head maps and the total budget of Siwa oasis. Figure (8) shows the piezometric head map for the oasis considering the suggested arbitrary well II, which lies at the middle zone of the oasis, for year 2000. Figure (9) shows the predicted piezometric head map, for the case of three arbitrary wells working as a group at the same time, for year 2020. The figures indicate that the head contours are highly influenced by the case of wells in groups rather than in individuals. Figure (9) shows that the high head contours are moved to the oasis center therefore, the expected inflow is bigger than the outflow and new wells can be constructed.

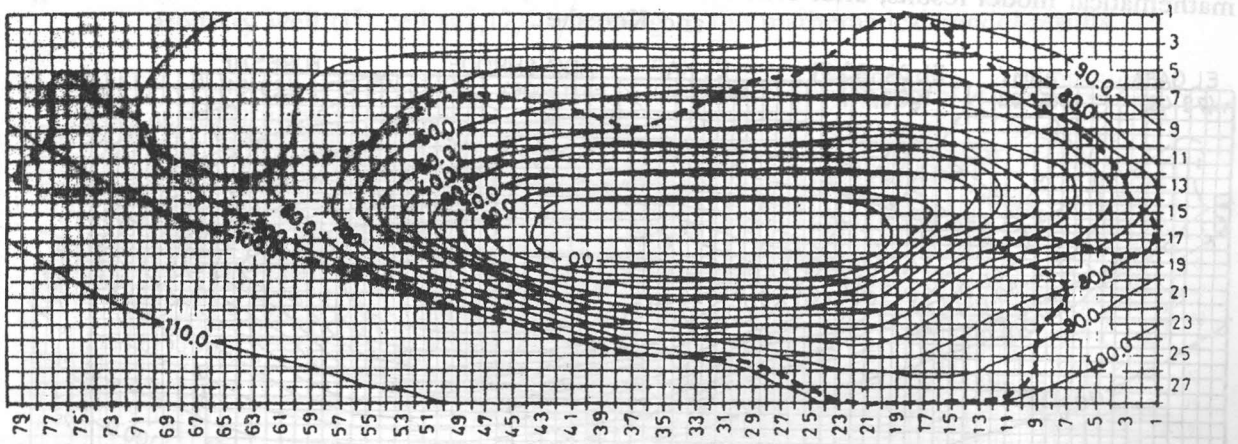


Figure 3. Distribution of the actual piezometric head at the end of the basic year, 1987 Regwa.

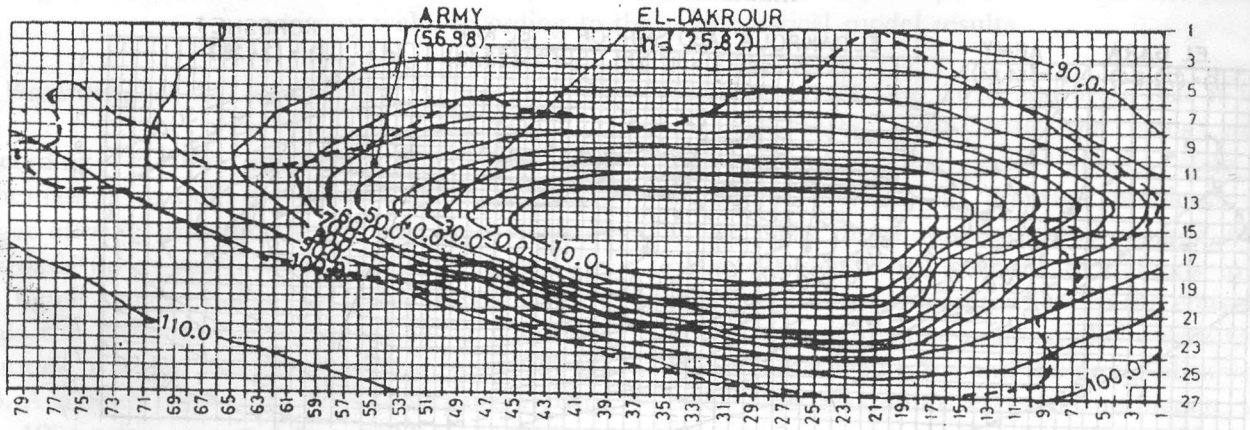


Figure 4. Distribution of the Predicted piezometric head at the end of year, 1990 according to the mathematical model results, after construction of El-Dakrour Army.

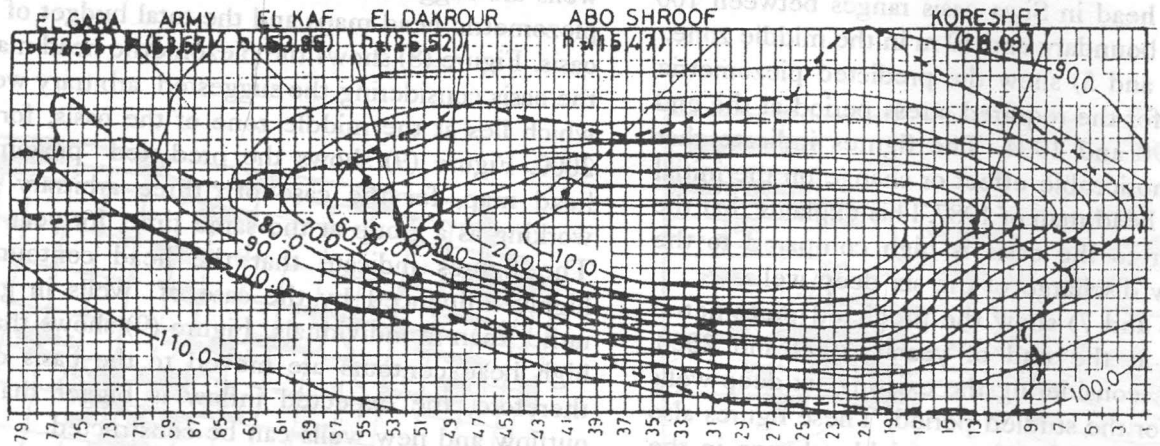


Figure 5. Distribution of the Predicted piezometric head at the end of year, 1994 according to the mathematical model results, after construction of El-Dakrour Army, El-Kaf, El Gara, Abo Shroof and Koreshet.

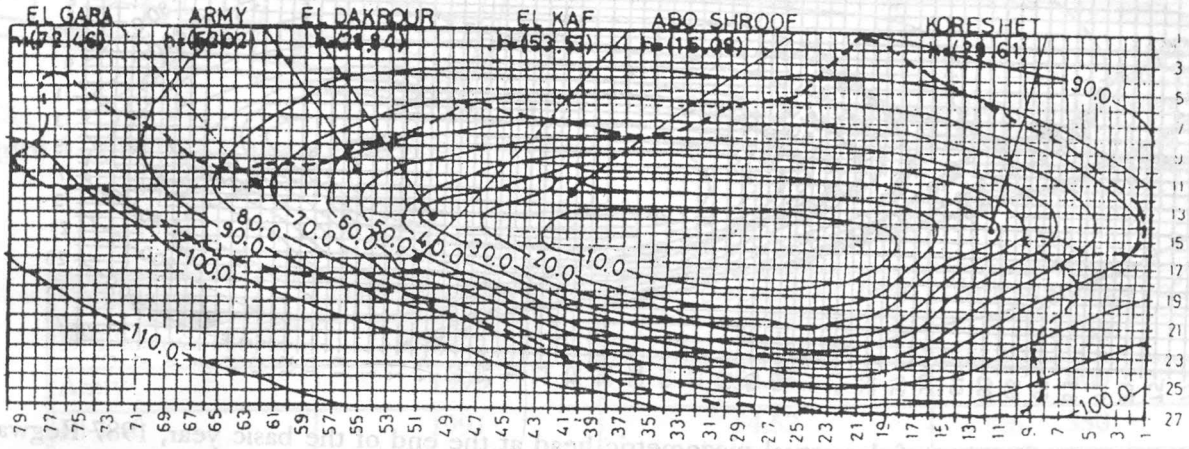


Figure 6. Distribution of the Predicted piezometric head at the end of year, 2000 according to the mathematical model results.

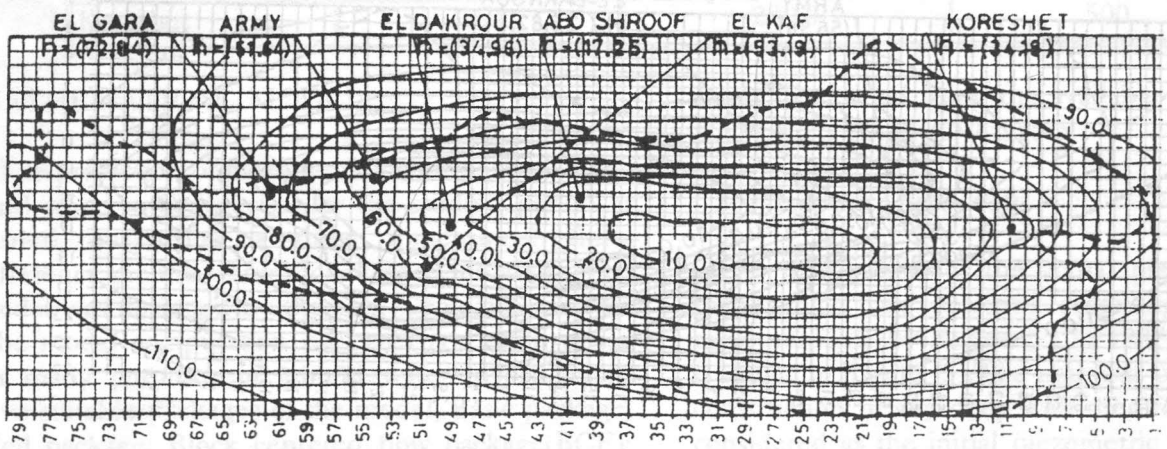


Figure 7. Distribution of the Predicted piezometric head at the end of year, 2020 according to the mathematical model results.

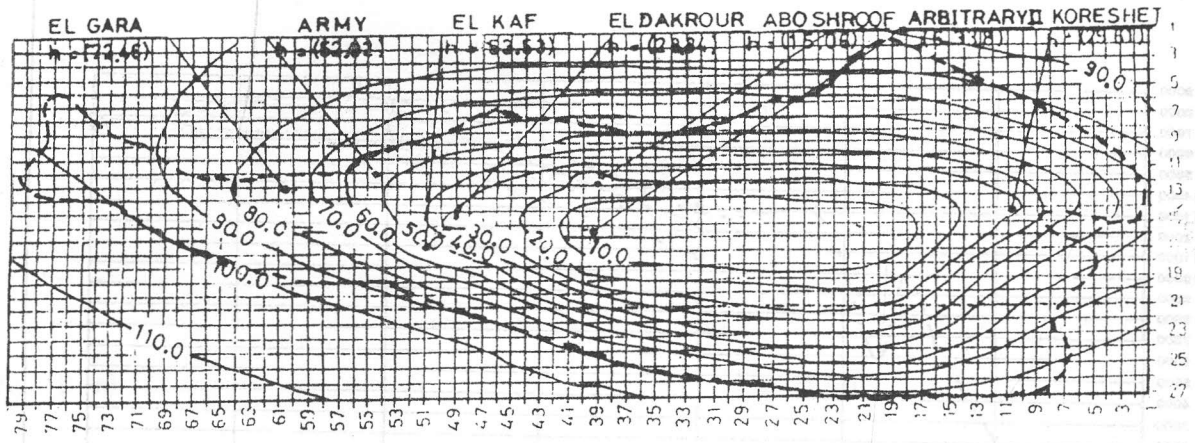


Figure 8. Distribution of the Predicted piezometric head at the end of year, 2000 "with additional arbitrary well (II) cell (41,17)" according to the mathematical model results.

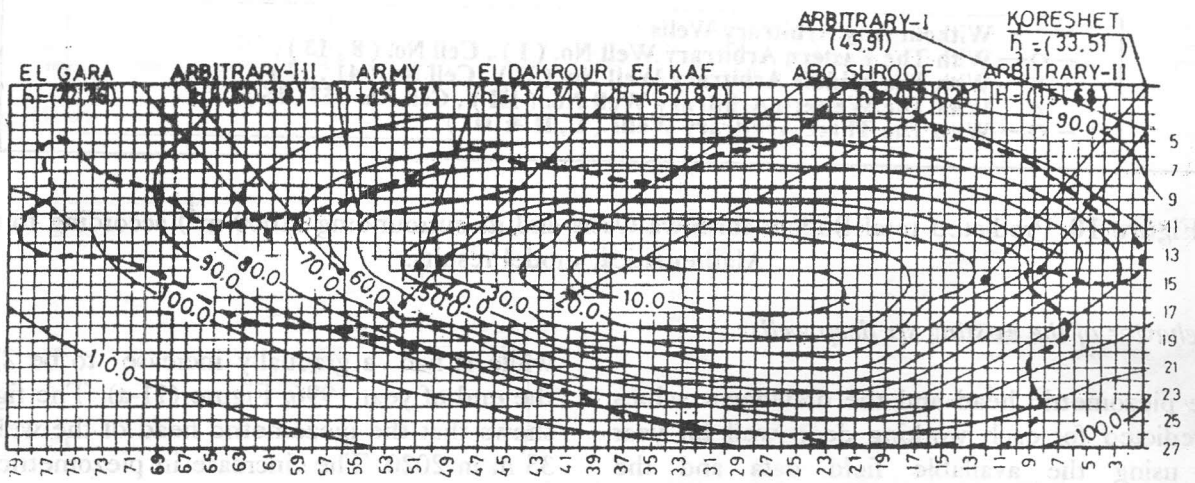


Figure 9. Distribution of the Predicted piezometric head at the end of year, 2020 "with the three arbitrary wells according to the mathematical model results.

## 2- *Water balance and total budget*

According to the available field data and mathematical model, the prediction of the total budget of water through the Nubian sand stone in Siwa oasis up to year 2020 is given in Figure (10). The figure indicates that the water storage, which equals the difference between inflow and outflow quantities of water, was increased from year 1989 till 1993. A sudden drop in the storage was occurred in year 1994 after construction of Koreshet deep well.The figure also indicates that the storage will be reincreased till year 2010 and after that it will be constant. After year 2010 the oasis will be, approximately, ideal case (steady state flow) therefore, there is no drainage problems in the future. The maximum expected storage in Siwe oasis, till year 2010, is about 18 millions $m^3$. The total budget is also affected due to the construction of the suggested three arbitrary deep wells for both of individual well cases and the group of three wells case. The maximum expected reduction in the storage, for group case, is about two millions $m^3$ in year 2010.

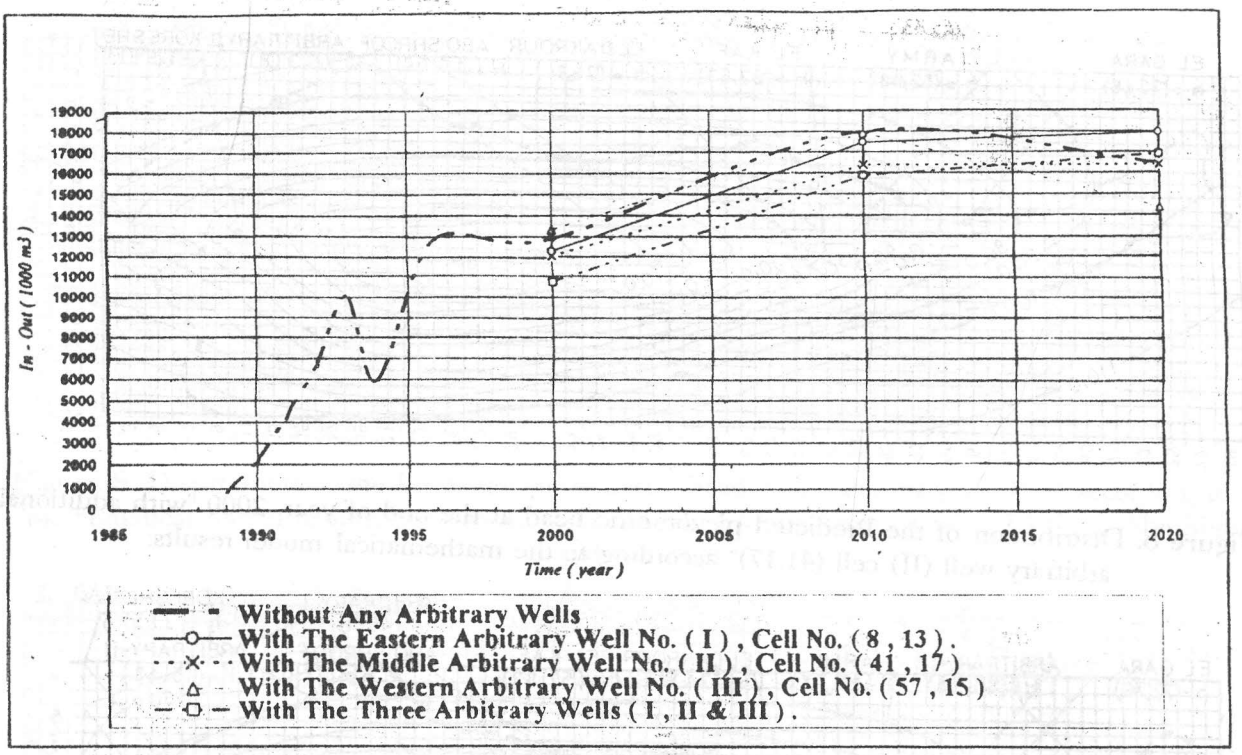


Figure 10. Predicted total Budget for Siwa Oasis and its surrounding (1000 $m^3$) according to the Mathematical model results.

3- *Behavior of the existing six deep wells*

The piezometric head and the drawdown values are predicted for each working deep well till year 2020, using the available field data and the mathematical model. The results of all deep wells are given in Figure (11) and the development of the drawdown values of each well can be also determined from the figure.The positions of the six deep wells are shown in Figure (1). The analysis of the results for each deep well are explained as follows:

***El Dakrour*** well was dug in 1989 and its safe discharge, which was given by Regwa[5], is 500 $m^3$/hr. The initial piezometric head at the well position was 26.17 m as recorded in 1987 in the initial piezometric map, Figure (3). After construction of the well the head had a slight decreases and it was 25.8 m at the end of year 1991, while it had a gradually increase to be 27.4 m at the end of year 1996, Figure (11-a). The figure also shows that the piezometric head of the well will be 35 m in 2020. The increase in piezometric head is related to the high budget of the inflow water to the Oasis, consequently the future recommendation is to increase the well discharge more than the given value by Regwa. The figure also indicates that the well does not affected due to the construction of the suggested three arbitrary wells.

***Army well*** was dug in 1990 and its safe discharge, which was given by Regwa[6], is 600 $m^3$/hr. The initial piezometric head of the well was 56.98 m as recorded in year 1990. For the constant discharge of the well, the head decreases till year 2010 to be 51.6m and almost still constant till year 2020, Figure (11-b).

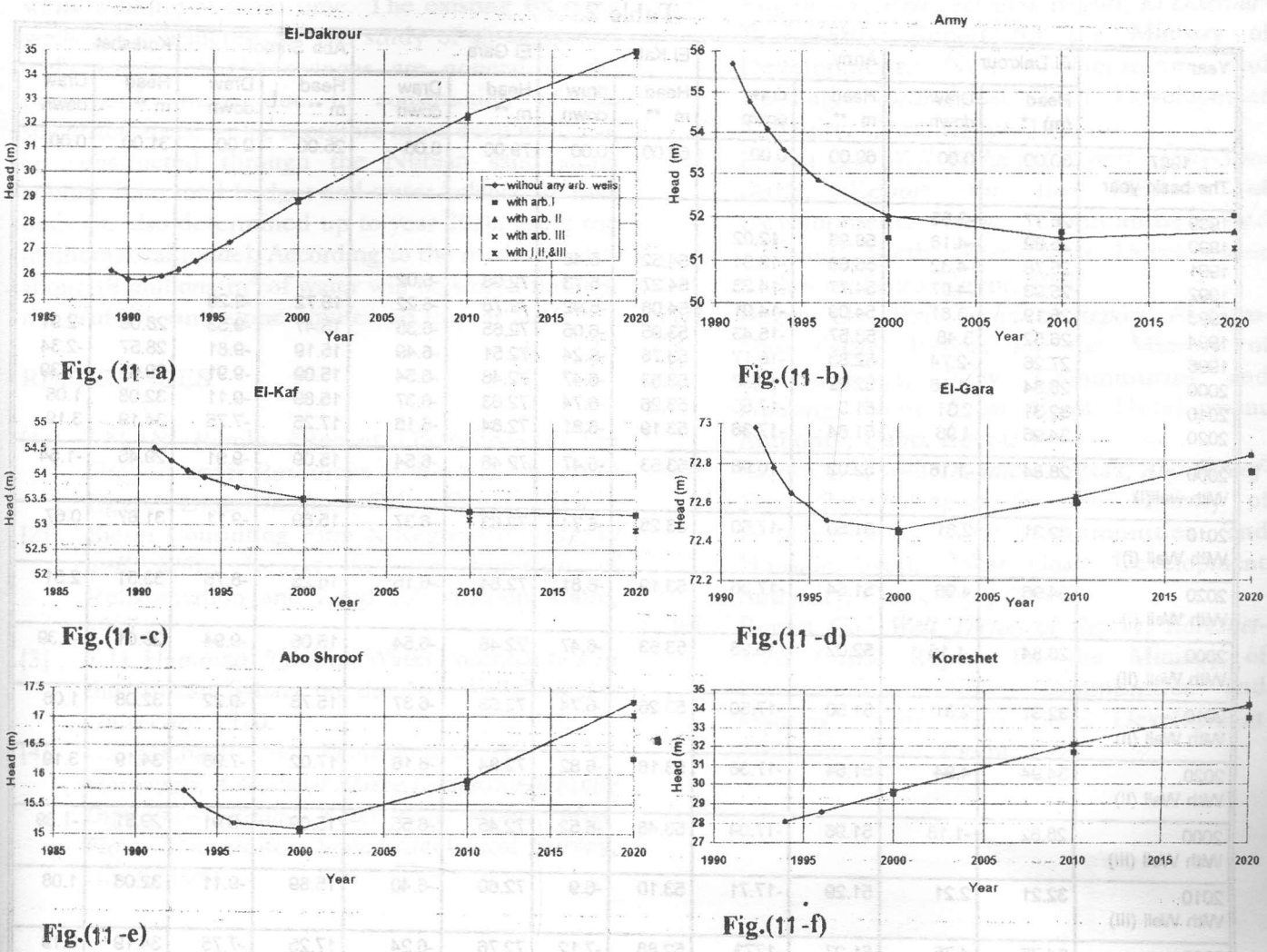


Fig. (11 -a)

Fig.(11 -b)

Fig.(11 -c)

Fig.(11 -d)

Fig.(11 -e)

Fig.(11 -f)

Figure 11. Predicted head for the existing deep wells in Siwa Oasis.

EL Kaf ***well*** was dug in 1991 and its safe discharge, which was given by Regwa, Ref.[1], is 550 $m^3$/hr. The initial piezometric head of the well in 1991 was 54.52 m and decreases with time as shown in Figure (11-c) to become 53.2 m in 2020.

***EL Gara well*** was dug in 1992 and its safe discharge, which was given by Regwa[7], is 500 $m^3$/hr. The initial piezometric head of the well was 73 m in 1992, as shown in Figure (11-d). The head of the well decreases with time till year 2000 to become 72.45 m, and after that the head increases to be 72.84 in year 2020

***Abo Shroof well*** was dug in 1993 and its safe discharge is 600 $m^3$/hr as given by Regwa[8]. The initial piezometric head of the well was 15.72 m in 1993. The head decreases with time and will be 15.09 m in year 2000, and it will increase to be 17.25 m in year 2020 as shown in Figure (11-e).

***Koreshet well*** was dug in 1994, and its safe discharge is 500 $m^3$/hr as recorded by Regwa[9]. The initial piezometric head of the well was 28.09 m in 1994 and increases with time to reach 34.19 m in 2020, Figure (11-f).

All predicted data about head and drawdown of the above six deep wells is summarized in Table(2)

Table 2.

| Year | El Dakrour | | Army | | El Kaf | | El Gara | | Abo Shroof | | Koreshet | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Head (m) ** | Draw down | Head m ** | draw down | Head m ** | draw down | Head m ** | Draw down | Head m ** | Draw down | Head m ** | Draw down |
| 1987 The basic year | 30.00 | 0.00 | 69.00 | 0.00 | 60.00 | 0.00 | 79.00 | 0.00 | 25.00 | 0.00 | 31.00 | 0.00 |
| 1989 | 26.17 | -3.83 | | | | | | | | | | |
| 1990 | 25.82 | -4.18 | 56.98 | -12.02 | | | | | | | | |
| 1991 | 25.78 | -4.32 | 55.69 | -13.31 | 54.52 | -5.48 | | | | | | |
| 1992 | 25.93 | -4.07 | 54.77 | -14.23 | 54.27 | -5.73 | 72.98 | -6.02 | | | | |
| 1993 | 26.19 | -3.81 | 54.09 | -14.91 | 54.08 | -5.92 | 72.78 | -6.22 | 15.72 | -9.28 | | |
| 1994 | 26.52 | 3.48 | 53.57 | -15.43 | 53.95 | -6.05 | 72.65 | -6.35 | 15.47 | -9.53 | 28.09 | -2.91 |
| 1996 | 27.26 | -2.74 | 52.83 | -16.17 | 53.76 | -6.24 | 72.51 | -6.49 | 15.19 | -9.81 | 28.57 | -2.34 |
| 2000 | 28.84 | -1.16 | 52.02 | -16.98 | 53.53 | -6.47 | 72.46 | -6.54 | 15.09 | -9.91 | 29.61 | -1.39 |
| 2010 | 32.31 | 2.31 | 51.5 | -17.50 | 53.26 | -6.74 | 72.63 | -6.37 | 15.89 | -9.11 | 32.08 | 1.08 |
| 2020 | 34.96 | 4.96 | 51.64 | -17.36 | 53.19 | -6.81 | 72.84 | -6.16 | 17.25 | -7.75 | 34.19 | 3.19 |
| 2000 With well(I) | 28.84 | -1.16 | 52.02 | -16.98 | 53.53 | -6.47 | 72.46 | -6.54 | 15.09 | -9.91 | 29.46 | -1.54 |
| 2010 With Well (I) | 32.31 | 2.31 | 51.50 | -17.50 | 53.26 | -6.74 | 72.63 | -6.37 | 15.89 | -9.11 | 31.67 | 0.67 |
| 2020 With Well (I) | 34.96 | 4.96 | 51.64 | -17.36 | 53.19 | -6.81 | 72.84 | -6.16 | 16.25 | -8.75 | 33.51 | 2.51 |
| 2000 With Well (II) | 28.84 | -1.16 | 52.02 | -16.98 | 53.53 | -6.47 | 72.46 | -6.54 | 15.06 | -9.94 | 29.61 | -1.39 |
| 2010 With Well (II) | 32.31 | 2.31 | 51.50 | -17.50 | 53.26 | -6.74 | 72.63 | -6.37 | 15.78 | -9.22 | 32.08 | 1.08 |
| 2020 With Well (II) | 34.94 | 4.94 | 51.64 | -17.36 | 53.18 | -6.82 | 72.84 | -6.16 | 17.02 | -7.98 | 34.19 | 3.19 |
| 2000 With Well (III) | 28.82 | -1.18 | 51.96 | -17.04 | 53.48 | -6.52 | 72.45 | -6.55 | 15.09 | -9.91 | 29.61 | -1.39 |
| 2010 With Well (III) | 32.21 | 2.21 | 51.29 | -17.71 | 53.10 | -6.9 | 72.60 | -6.40 | 15.89 | -9.11 | 32.08 | 1.08 |
| 2020 With Well (III) | 34.75 | 4.75 | 51.27 | -1773 | 52.88 | -7.12 | 72.76 | -6.24 | 17.25 | -7.75 | 34.19 | 3.19 |
| 2000 With (I, II, III) | 28.87 | -1.13 | 51.94 | -17.06 | 53.48 | -6.52 | 72.45 | -6.55 | 15.06 | -9.94 | 29.49 | -1.51 |
| 2010 With (I, II, III) | 32.21 | 2.21 | 51.29 | -17.71 | 53.10 | -6.90 | 72.60 | -6.40 | 15.78 | -9.22 | 31.67 | 0.67 |
| 2020 With (I, II, III) | 34.74 | 4.74 | 51.27 | -17.73 | 52.87 | -7.13 | 72.76 | -6.24 | 17.02 | -7.98 | 33.51 | 2.51 |

** all heads are measured from the main sea water level

## CONCLUSIONS

The ground water hydrology of Siwa oasis is studied for a period up to year 2020. Piezometric head maps of the Nubian sand stone in the oasis are predicted based on the available field data and the mathematical model.The maps are prepared considering the existing working deep wells, El-Dakrour; Army; El-Kaf; El-Gara; Abo-Shroof and Koreshet. A comparison between the predicted head maps and the initial piezometric head map(1987) shows that there is no considerable change in piezometric head contours. Three arbitrary wells are suggested in different positions through the oasis and piezometric head maps are also predicted for the cases of individual wells and for the case of a group

wells working at same time. The existing six deep wells are considered for the study of all suggested wells cases. Slight changes are noticed in the piezometric maps due to construction of the suggested three wells, therefore more deep wells can be constructed through the Nubian sand stone aquifer. The total budget and water balance in Siwa oasis are also determined up to year 2020, using the mathematical model. According to the model results, about 18 millions $m^3$ of water will be stored through the Nubian sand stone aquifer up to year 2010.

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