Groundwater resources in Egypt: potentials and limitations

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ABSTRACT This paper reviews the history of groundwater exploration and utilization in Egypt which dates back to some centuries before Christ. The extraction of groundwater in the Western Desert turned the El-Kharga oasis into a vast cultivable land. The Roman wells and galleries along the coast of the Mediterranean Sea still function at present. As time went by, the dominance of the surface water resources did not provide a fair chance for a real development of the groundwater resources. At present the Nile water within Egypt is under control, but the development of the yield of the Nile basin is not the responsibility of Egypt alone. The time has certainly come to develop more of the groundwater resources in an attempt to cover some of the needs of the ever-increasing population. With the exception of the Eastern Desert and the Sinai Peninsula the surface of Egypt can be divided into five zones. The groundwater potentials and limitations in each zone are discussed in this paper.

Les ressources en eau souterraine en Egypte: potentiels et limitations

INTRODUCTION AND PROBLEM PRESENTATION

The continuous growth of the population of Egypt and the tendency to increase the share of water per inhabitant, makes the supply of an ever-increasing quantity of water each year a pressing demand. Egypt's principal source of water is the River Nile. The regulation of the flow in modern Egypt started more than a century ago. Upon the construction of the High Aswan Dam, almost two decades ago, river regulation within the country almost reached completion.

Figure 1(a) shows the growth of population from 1820 to 1980, and Egypt's share of Nile water. The area of the cultivated land in

![Figure 1(a) and 1(b)](attachment:image.png)

FIG. 1 (a) The increase in the population of Egypt and her share in the Nile water from 1800 to 1980. (b) The change with time in the cultivated area, cropped area and the share per capita of each of them.
Egypt did not seem to increase with time during the past few decades: on the contrary, it seemed to decrease. It is true that the land is cultivated more frequently than before causing the total cropped area to increase. Nevertheless, the area per capita of both cultivated and cropped land is diminishing gradually with time (Fig.1(b)).

As a consequence of the increase in the number of land holders, the average size of holding is diminishing with time. Additionally, more than 80% of the available water is used for land irrigation, and the methods of irrigation in common use are the traditional ones. The result is that the overall irrigation efficiency is deteriorating with time, and the losses associated with irrigation have certainly reached alarming figures.

The water balance calculations presented by Whittington & Guariso (1983) show clearly that at least 2 mm day\(^{-1}\) are lost in the soil underlying the 2.5 million ha comprising Egypt's agricultural land. Some of this recharges the aquifers and causes a steady rise in the groundwater table. In many places this rise has reached to within 1.0 m of the surface. Since the development of the available water supply lags behind the demand, the decline below self-sufficiency in food production is getting bigger with time. Any plan aiming at maintaining the present production, not to think of improving it, includes the provision of additional water supplies for irrigating a larger acreage of land at a much higher efficiency.

Increasing the average river flow in Egypt calls for the implementation of a number of water conservation schemes in the Upper Nile. So far, the matter is in dispute but its solution needs time, not to mention the difficulties associated with the financing of such projects. This situation has prompted the Ministry of Irrigation to plan future water policy on re-using drainage water and withdrawing an extra amount of 2.7 \(\times 10^9\) m\(^3\) year\(^{-1}\) by the year 2000 from the aquifers underlying the Nile Valley and the Delta. The exploitation of these groundwater resources is what interests us here.

GROUNDWATER EXPLOITATION ZONES

During the course of time, the exploitation of the groundwater resources in the five geographical zones (Fig.2) has taken place. These zones are: the coastal plain of the Western Desert along the Mediterranean, the oases (mainly El-Khargah and Dakhlah) in the Western Desert, the desert area between the Nile Delta and the Suez Canal, the Nile Delta area and the Nile Valley.

HISTORICAL BACKGROUND

Probably one of the earliest groundwater works in Egypt is the well situated near Cairo and known as Joseph's well, dating back to 1700 BC. Biswas (1972) mentioned that it is about 100 m in depth.

Shortly after 512 BC Admiral Scyloxx was sent by King Darius I to the Kharga Oasis in Egypt. Butler (1933) mentioned that Scyloxx introduced the Persian method of irrigation by means of underground conduits fed by water from the strata of sandstone where it
collected in faults. A longitudinal profile and a cross section of an unlined kanát (gallery) is shown in Fig.3.

The development of irrigation in the Kharga oasis went fairly well during the Ptolemaic period (332-30 BC). The artesian water was fully exploited during the Roman Empire (30 BC-AD 395) to meet with the requirements of cultivation. According to Thompson & Gardner (1932), large scale mining became aggravated during the Byzantine period (AD 395-638) with the establishment of the Christian settlements. In subsequent periods those remarkable works were left to deteriorate.

Beadnell (1908) adopted the hypothesis established earlier that the precipitation on the Darfur region in the northern Sudan is the origin of water in the Western Desert of Egypt. Ball (1927) drew an approximate map showing the equipotential lines of groundwater in the Egyptian Western Desert. That map was later improved by Hellström (1940) and much later by El-Ayouty & Ezzat (1961). They all emphasized that the groundwater stored in the desert is fossil
and that its source lies at the Tibesti mountains in Chad.

In the Libyan Desert, along the coastal plain from Alexandria to Sallum, the fresh water in the Nubian Sandstones is too deep to be tapped by just ordinary wells. Along that coast the annual rainfall, averaging from 140 to 200 mm, supplies fresh water to the upper strata near the surface. The fresh water body floats on a much deeper salt water zone. Shallow wells along the coast may tap that fresh water. During World War II, perched basins of fresh water were detected near Fuka and Matruh.

The country which lies between Cairo and the Suez Canal, in addition to being a home for some of the natives, was the site of a number of military establishments. Though the consumption from the sweet water canal was heavy, the supply of groundwater was desirable. A number of boreholes were sunk for water and hydrological and geological data were gathered. The area is still subject to investigation with the hope of using groundwater in the recent reclamation and rehabilitation operations.

Nothing much was known about groundwater in the Nile Delta and Valley before the French invasion of Egypt. Some of the French and British professionals, who came to Egypt in the last century, were fascinated by the possible relation between groundwater and the Nile water. The different data presented by Balls (1953) added to more recent data, are plotted as shown in Fig.4. This figure indicates that the water table near Cairo had risen by about 2.3 m in less than a century.

**GROUNDWATER EXTRACTION: POTENTIALS AND DIFFICULTIES**

**The Coastal Plain in the Western Desert**

The extraction of the groundwater in this area was accelerated by the campaigns during World War II. The area which is reviewed here runs from the northwest end of the Nile Delta to the longitude of Tobruk (24°E).

Geologically, the area is made up of Miocene rocks, which have generally a slight dip to the north. Departures from this rule result in small basin structures in which perched water may be found. The rocks are usually limestones, fine-textured and compact. Interbedded with these and of less importance are clay bands.
Beneath this series lie Miocene sands and sandstones, again with subordinate clays. Borehole drilling was mainly in limestone. The data about salinity and yield of boreholes at Sidi-Barrani (see Fig.2) and at other locations were given by Shotton (1946). The change in salinity with time during a pumping test is shown in Fig.5.

The general conclusion was that water with salinity of 1500 ppm (considered good for drinking purposes) had been at about 5.0 m below the water table, with the exception of one borehole. Later investigation concluded that the area has some fresh water pockets of different depths, aerial extents and yields. Even under the condition of extracting low yields, the salinity is expected to approach the general basin salinity of the water table, and so...
become undrinkable unless regenerated by new rain.

In addition to the boreholes, one of the important perched-water basins discovered during World War II is the Fuka basin (Fig. 2). It consists of a thin covering layer of desert sand not exceeding 5 m in thickness followed by an upper and lower clay layer sandwiching a limestone aquifer of variable thickness. It is the water in that limestone aquifer that is drinkable. Figure 6 shows the observed changes in water table level and quality with time, caused by withdrawing about 45 000 t of water during 195 days in 1941 and 1942. The capacity of the basin calculated on the basis of aquifer porosity of 7.5% is about 210 000 t.

Investigation of groundwater extraction along the coastal strip has pointed to the possibility of permanent exploitation on a scale not yet properly determined, for a supply which would not be subject to those fluctuations of salinity which characterize the coastal collecting galleries. In Matruh basin, like many others, new boreholes must be sunk and maintained, and old native wells be cleaned and deepened. Boreholes 0.25 m in diameter and 30 m deep with water depth of 10 to 12 m can each easily supply 60 m³/day of good water.

The Kharga and Dakhla oases in the Western Desert

In 1950 the cultivated area in the Kharga oasis was about 24 km² out of a total of 4000 km². Recent geological investigations have shown that the entire Western Desert in Egypt and much of North Africa are underlain by thick water-bearing sandstone beds known as Nubian sandstone, that contain in storage and can transmit considerable quantities of fresh water.
Seven deep boreholes were drilled between 1938 and 1952, with a depth varying between 342.5 and 509.3 m, all of the seven wells except one encountered artesian flow. The yields of those wells decreased after a few years of operation by not less than 40% of their initial values.

Paver & Pretorius (1954) used the available taxation records and converted them approximately to the number and yield of shallow wells in the Kharga oasis as follows:

<table>
<thead>
<tr>
<th>Year</th>
<th>No. of wells</th>
<th>Yield (m$^3$day$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1900</td>
<td>577</td>
<td>109.600</td>
</tr>
<tr>
<td>1925</td>
<td>872</td>
<td>22.480</td>
</tr>
<tr>
<td>1931</td>
<td>949</td>
<td>229.280</td>
</tr>
<tr>
<td>1953</td>
<td>805</td>
<td>253.500</td>
</tr>
</tbody>
</table>

The same investigators included in their report some hydrological estimates (Table 1).

<table>
<thead>
<tr>
<th>Item</th>
<th>Kharga</th>
<th>Dakhla</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total yield of deep wells (10$^6$ m$^3$year$^{-1}$)</td>
<td>3.8</td>
<td>16.8</td>
</tr>
<tr>
<td>Total yield of shallow wells (10$^6$ m$^3$year$^{-1}$)</td>
<td>38.7</td>
<td>92.7</td>
</tr>
<tr>
<td>Total annual withdrawal (10$^6$ m$^3$year$^{-1}$)</td>
<td>42.5</td>
<td>109.5</td>
</tr>
<tr>
<td>Total annual inflow (10$^6$ m$^3$year$^{-1}$)</td>
<td>240.0</td>
<td>150.0</td>
</tr>
<tr>
<td>Inflow-withdrawal (10$^6$ m$^3$year$^{-1}$)</td>
<td>197.5</td>
<td>40.5</td>
</tr>
<tr>
<td>Average yield of deep well (10$^6$ m$^3$year$^{-1}$)</td>
<td>0.640</td>
<td>2.4</td>
</tr>
<tr>
<td>Permissible number of new wells</td>
<td>308</td>
<td>17</td>
</tr>
</tbody>
</table>

The above studies and many more were urgently needed in the mid 1950s as the basis of the New Valley project, aiming at expanding the cultivated area in the Kharga and Dakhla oases. In the planning of that project, the regional transmissivity was assumed to vary from 1000 to 1800 m$^2$day$^{-1}$, and the storativity from 2 x 10$^{-4}$ to 4 x 10$^{-4}$. An extensive system of deep production wells has been dug in both oases, and the shallow wells have been flowing as described in Table 1. In 1963 the combined discharge of the wells in El-Kharga reached about 117 x 10$^6$ m$^3$ and by the end of 1967 had dropped to 80 x 10$^6$ m$^3$. The system of deep wells in Dakhla oasis was completed by 1966 and the combined yield of the shallow and deep systems rose to 190 x 10$^6$ m$^3$. By the end of 1969 it was not more than 159 x 10$^6$ m$^3$. Hammad (1969) used those data for estimating the future discharges of the wells, assuming that the flow in one time to be free and in another time to be pumped. Shahin et al. (1970) reported that the artesian head in the various aquifer zones underlying the Dakhla oasis was declining with time. As the rate of replenishment was not known accurately, it became difficult to estimate the amount that can be withdrawn safely each year.

The response of the head of water to the growing withdrawals from the deep wells in Kharga and Dakhla oases appears in a FAO/UNDP report (1977). The changes in exploitation and in water head from 1956 to 1975 are shown in Fig.7. The Egyptian authorities are planning to augment the extraction till it reaches 2.4 x 10$^3$ m$^3$year$^{-1}$
Groundwater resources in Egypt

by the year 2000. The extraction of such a volume will lead to further decline in the head of water to the extent that artesian water will not flow.

FIG. 7 Changes in the water level and volume extracted from the El-Kharga and Dakhla oases from 1956 to 1975.

The area between Cairo and the Suez Canal east of the Damietta Branch

The country between Cairo and the Suez Canal east of the Damietta Branch is traversed by a number of large drains and canals, of which the Ismailia Canal is a vital feature.

The geology of this area was explored, and boreholes as early as 1917, during World War I, sunk to supply the military establishments there with fresh water. Additional boreholes were drilled to supply fresh water to a few scattered villages. Exploitation of groundwater went on a larger scale during World War II. The data presented by Shotton (1946) show that the continuous operation (1941-1943) of some of the wells caused a significant rise in the salinity of the extracted water. Until 1973 a further increase in extraction was not possible because of the wars with Israel, and because of the fear of increasing the seepage from the Ismailia canal.

Shahin (1983) classified the zone in question into three distinct divisions: A, B and C (Fig. 8). The main geohydrological parameters are as included in Table 2. It has been recommended not to increase the extraction before the permeable reaches of the canal are lined. The withdrawal from B is for the time being under experimentation, and extraction from C is not advisable due to the poor quality of the groundwater.
The Nile Delta area

The groundwater reservoir underlying the Nile Delta area is extensive in size, about 12,000 km². The investigations up to 1962 were summarized by Solait (1964). The principal findings at that time were: the clay cap is about 20 m thick in the central part and decreases east and west until it disappears at the desert fringes; the aquifer in the central part is about 500 m thick decreasing east and west to say 350 m; the salinity above Kafr El-Sheikh (Fig. 8) is rather low, and the total salinity of 1000 ppm can be found at levels deeper than 200 m in the west and at shallower depths in the east. The flow across the line I-I, (Fig. 8), was computed for the hydrological conditions in 1960 and the results were: gain to Damietta Branch = 67.5 x 10⁶ m³ year⁻¹, flow to the Mediterranean 190 x 10⁶ m³ year⁻¹ and the gain to Rosetta Branch 229 x 10⁶ m³ year⁻¹.

Since then further investigations have been carried out and many more are underway. The aquifer recharge was estimated by El-Kashef (1983) at 6.4 x 10⁹ m³ year⁻¹ and by Shahin (1983) at 3.8 x 10⁹ m³ year⁻¹. If we reduce the average of these two figures by 1.6 x 10⁹ m³ year⁻¹, which is already extracted, the extra amount that can be withdrawn is 3.5 x 10⁹ m³ year⁻¹. The different types of the aquifers, and their geohydrological characteristics are given in Fig. 8 and Table 2 respectively.

The length of the intruded salt-water wedge was estimated by El-Kashef (1983) at a distance of 45 to 95 km from the coast. The recent waste in irrigation water, however, acts as a huge source of recharge to the aquifer, reducing the extent of salt-water intrusion. Farid (1985) applied the so-called MANAGEMENT model to develop an
TABLE 2  Geohydrological parameters* of the Nile Delta aquifers including the zone between Cairo and Suez Canal east of Damietta Branch

<table>
<thead>
<tr>
<th>Division</th>
<th>Type of aquifer</th>
<th>$k$ (m day$^{-1}$)</th>
<th>$D_f$ (m)</th>
<th>$T = k.D_f$ $(10^3$ m$^2$day$^{-1}$)</th>
<th>$S$</th>
<th>$k_y$ $(10^{-3}$ m day$^{-1}$)</th>
<th>$d$ (m)</th>
<th>$C$ $(10^3$ day$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Phreatic</td>
<td>50-80</td>
<td>50-150</td>
<td>(2.5-15)</td>
<td>0.15-0.25</td>
<td>none</td>
<td>none</td>
<td>none</td>
</tr>
<tr>
<td>B</td>
<td>Semi-confined</td>
<td>25-100</td>
<td>100-250</td>
<td>(2.5-25)</td>
<td>(1-10)$10^{-4}$</td>
<td>(1-3)</td>
<td>8-20</td>
<td>(3-20)</td>
</tr>
<tr>
<td>C</td>
<td>Confined</td>
<td>unknown</td>
<td>unknown</td>
<td>unknown</td>
<td>unknown</td>
<td>&gt;1</td>
<td>20-50</td>
<td>&lt;20</td>
</tr>
</tbody>
</table>

TABLE 3  Geohydrological parameters* of the aquifer underlying Upper Egypt

<table>
<thead>
<tr>
<th>Division</th>
<th>Type of aquifer</th>
<th>$k$ (m day$^{-1}$)</th>
<th>$D_f$ (m)</th>
<th>$T = k.D_f$ $(10^3$ m$^2$day$^{-1}$)</th>
<th>$S$</th>
<th>$k_y$ $(10^{-3}$ m day$^{-1}$)</th>
<th>$d$ (m)</th>
<th>$C$ $(10^3$ day$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>Phreatic</td>
<td>40-80</td>
<td>25-60</td>
<td>(2-5)</td>
<td>0.10-0.20</td>
<td>none</td>
<td>none</td>
<td>none</td>
</tr>
<tr>
<td>E</td>
<td>Semi-confined</td>
<td>40-120</td>
<td>40-240</td>
<td>(1.5-30)</td>
<td>(5-50)$10^{-4}$</td>
<td>(1-3)</td>
<td>3-20</td>
<td>(1-20)</td>
</tr>
</tbody>
</table>

* $k$ = coefficient of permeability,
$D_f$ = depth of fresh-water layer,
$T$ = coefficient of transmissivity,
$S$ = storativity,
$k_y$ = vertical hydraulic conductivity,
$d$ = thickness of clay cap, and
$C$ = resistance of clay cap.
efficient groundwater allocation policy for the Nile Delta aquifer. It was found that the groundwater can be utilized, on the principle of safe yield operation, to satisfy one or more of the following demands:

(a) a domestic supply of $0.9 \times 10^9 \text{ m}^3\text{year}^{-1}$ by the year 2000;
(b) saving about $0.5 \times 10^9 \text{ m}^3\text{year}^{-1}$ from the western part of the Delta to irrigate about 40 000 ha of land;
(c) saving about $1.1 \times 10^9 \text{ m}^3\text{year}^{-1}$ from the eastern part of the Delta to help irrigate about 80 000 ha of land; or
(d) saving about $1.5 \times 10^9 \text{ m}^3\text{year}^{-1}$ from the central part of the Delta to help irrigate say 120 000 ha of land.

In the above study the critical rate of pumping was set at $3 \times 10^9 \text{ m}^3\text{year}^{-1}$. The possible consequences on the quality of water or the position of the salt-fresh water interface were not considered.

Upper Egypt

The surface area under cultivation in Upper Egypt is about 11 000 km². In the past there were a few wells dug to supply additional water to the basins irrigated from the Nile, whenever and wherever that was necessary. The types of aquifer and their properties were analysed and reported by Solait (1964), Attia (1974, 1985) and Shahin (1983). A summary of the aquifer properties is included in Table 3, and Fig.9 shows the types of aquifer in Upper Egypt.

Similar to the Nile Delta area, the groundwater level in Upper Egypt has risen due to the introduction of perennial irrigation. The head has risen further with the construction of the High Aswan Dam. The rise has reached 2 m or more in some places with the obvious consequence of waterlogging and salinity problems in several parts of Upper Egypt. Extraction of groundwater can supply the irrigation needs for cultivating the highly elevated lands. Moreover, the lowering of the piezometric head in the aquifer might help the topsoil drain its high water table.

The water balance has shown that the aquifer recharge is about $1.34 \times 10^9 \text{ m}^3\text{year}^{-1}$, and that the gain in the river reach between Aswan and Cairo amounts to $2.0-2.5 \times 10^9 \text{ m}^3\text{year}^{-1}$. Attia (1985) applied the simulation model AQUIFEM-1 together with the flow quality/model WTSHEd-7 for forecasting the aquifer response to some management policies. It was concluded that the extraction wells should be located farther than 4.5 km from the river. Continuous pumping at high rates is unavoidable to effectively drain the clay cap.

CONCLUSIONS

From the above discussion one can arrive at the following conclusions:

(a) The Egyptians, during the course of centuries, have undertaken to varying extents, the exploitation of groundwater.
(b) Other than the Eastern Desert and Sinai there are five contributing zones: coastal plain in the Western Desert (zone 1),
oases in the Western Desert (zone 2), country between Cairo and the Suez Canal east of the Nile Delta (zone 3), the Nile Delta area (zone 4), and the Valley in Upper Egypt (zone 5).

(c) The groundwater in zone 1 is renewed by rain water, in zone 2 it is fossil and in zone 3 it is replenished by seepage water. Zones 4 and 5 are replenished through over-irrigation and seepage from canals.

(d) The estimated extractions from the five zones are respectively: 0.25, 2.0, 0.5, 3.0 and 1.25 $\text{m}^3\text{year}^{-1}$.

(e) The extractions mentioned in (d) will cause a lowering of the piezometric head. This might improve the drainage of the clay cap covering zones 4 and 5. Instead of flowing freely, groundwater has to be pumped from the deep wells in the oases. This is going to affect the economy of the project aimed at expanding the agriculture there.

(f) The salt water may intrude further inland in the Delta area as a result of continuous pumping. Since the fresh-water layer overlying the saline water body in the western coastal strip is thin, care should be exercised while locating the depth at which extraction of groundwater takes place as well as the rate of extraction.
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