



EGYPT

Area: 1,001,000 km²

Population: 44.53 million (United Nations estimate, 1983)

I. BACKGROUND

Physiography

In addition to the Nile Valley and its Delta, where the majority of the arable land and population are concentrated, Egypt has three geographical areas: the Western Desert, the Eastern Desert and the Sinai Peninsula; these areas are themselves subdivided into distinct physiographic units.

i) The Western Desert, where the New Valley region is located, with the oases of El Kharga, El Dakhla, El Farafra, El Bahariya and Siwa, includes the following units:

- The vast limestone plateau west of the Nile Valley, with a cliff some 150 m high dominating the low sandstone plateaus which form the base of the topographical depressions of El Dakhla and El Kharga. This vast and undulating plateau is 200-500 m high and has an irregular surface dissected by the beds of wadis. The hydrographic system is mainly of the arborescent type. Part of the plateau is covered with dunes running north-south or north-west/south-east. The northern part of the plateau includes the areas of El Bahariya and El Faiyum. This is a desert of the "serir" type, while the southern part, including El Farafra, El Dakhla and El Kharga, is of the "hammada" type, with vast horizontal stony tablelands.

- The great sea of sand, with 150,000 km² of sand dunes extending as far as the country's western borders, west of El Bahariya and El Farafra.

- The oasis depressions, distinctive features of the Western Desert, are found at the foot of the plateau (100-200 m), at altitudes of 1 to 150 m above sea level. Their beds are covered with alluvial and lacustrine deposits, with gravel, cobbles and shifting sands.

ii) The Eastern Desert also has characteristic features with the following units:

- The limestone plateau in the north along the south-east edge of the Nile Delta, the Nile's lower course, the Gulf of Suez, and the El Mellaha mountains in the east.

- The sandstone plateau (Nubian sandstone) of typical morphology extends from the Red Sea and the Nile Valley as far as the southern border with Sudan. It is marked by the deep narrow valleys of the wadis which flow into the Nile. Secondary wadis can sometimes develop in arborescent systems, but

their direction is clearly determined in most cases by the fractures - and the joints of the Nubian sandstone formation. South of Wadi El Allaqi the Nubian sandstone is much more deeply eroded, producing a complex system of mesas and flat-topped alignments.

- The Red Sea Mountains rise to 1,500 m. They have a contrasted, deeply eroded topography. Most of the wadis draining the South-Eastern Desert come from this area, which forms the region's main hydrographic basin. A similar landscape is found in the region between the eastern mountains and the Nubian sandstones. Vast granodiotitic systems underlie the great sand plains interrupted by the trachyte ridges typical of this region. Parallel arrangements of low peaks and valleys along the lines of dykes are also found. The coastal zone forms a narrow strip of land between the basement rock and the shore of the Red Sea. It is covered by sediments of Middle Cenozoic and Quaternary age, with the exception of Wadi Araba and the plateau of North Galala, where Paleozoic and Upper Mesozoic sediments predominate. The coastline is low between Suez and El Zaafarana and it widens from that point as far as Safaga and again from the vicinity of Ras Benas as far as the Sudanese border in the south. Copious deposits of gravel are found along a gently sloping terrace ending abruptly at the sea which has been eroded by the wadis draining the mountain region beyond the plain.

III) The Sinai Peninsula includes:

- The triangular massifs in the south, constituting the most mountainous part of the peninsula. Mt. Musa and Mt. Catherine are the highest peaks, at 600 m above sea level.

- The central limestone plateau of central Sinai, 1,000 m above sea level, composed mainly of Mesozoic and Tertiary sediments. It is deeply eroded by valleys bounded by abrupt escarpments. The beds of these valleys fall sharply, producing cascades during flood crests.

- The Randon Hills, running north-east/south-west and bounded by the sand-dune plain in the north and the plateaus of El Tih and Egmä in the south. They have steep to moderate slopes.

- The sand-dune plain, which extends from the Suez Canal in the west as far as Rafah in the east, and from the Mediterranean in the north to the Randon Hills in the south. These wind-formed dunes rapidly change their shape and position.

- Aqaba - the coastal plains are wider along the Mediterranean and narrower along the Gulf of Suez and Gulf of Aqaba, except for the El Gaa plain whose maximum width is 20 km.

The depressions are of considerable importance in the desert areas, for ground water is often found in them at moderate depths; they are moreover protected from the wind and therefore from evaporation. These are the most suitable areas for human settlements and agriculture. Egypt's main depressions are, from south to north:

Wadi El Natrun	(-20 m)
Qattara	(-134 m)
Siwa oasis	(-18 m)
El Faiyum	(-60 m)
El Bahariya oasis	(+100 m)
El Farafra oasis	(+100 m)
El Dakhla oasis	(+100 m)
El Kharga oasis	(+50 m)

Climate

With the exception of the Valley and a few oases, 93 per cent of the country is desert. It rains in Egypt only from October to May, the summer months (June to September) being "dry". It has rained on occasion in June or September, but there are hardly any valid data on any light rain that may have fallen in July or August.

The heaviest rainfall, although still moderate (about 200 mm/year), is found in the coastal zone where it rains on 40 days a year, mainly from December to February - an effect of the "Cyprus low-pressure areas".

The rainfall generally shows a marked and rapid decline from the coasts towards the interior. In the middle of the Delta it is only 80 mm/year, falling on 20 days. Rain is even rarer in Upper Egypt. At Assiout, 350 km south of Cairo, the annual average is only 7 mm and the maximum recorded in a season is 25 mm, falling in a single storm.

The rainfall is not only meagre, it is also very irregular from year to year. At Alexandria, for example, the season's maximum can vary from 50 to 400 mm from one year to the next. At Marsa Matrouh in the Western Desert the annual average is 160 mm. The rain can be torrential, with one storm bringing 100 mm in a single day.

In the Eastern Desert and the Sinai torrential runoffs can occur in the wadis after a storm, usually in October-December. Such storms may be rare but they can be very violent at times. At Quseir on the Red Sea coast, for example, the average annual rainfall is only 4 mm, but more than 30 mm has been recorded in a single storm.

The maximum rainfall and river crests in the Sinai and the Eastern Desert occur about every 20 and 11 years respectively, and every seven years in the coastal zone of the Western Desert.

The following evapotranspiration occurs:

Western Desert: from 770 mm (Matrouh) to 2,600 mm (Dakhla oasis)
Eastern Desert: 1,540 mm (Quseir)
Sinai: 1,440 mm (El Tor)

Geology

Egypt is part of the foreland structure on the northern edge of the Arabo-Nubian Shield. In southern and south-eastern Egypt Precambrian and Lower Cambrian basement rocks outcrop or suboutcrop (southern Sinai, anticlinal of the Red Sea, Aswan and El Uweinat). These are igneous and metamorphic rocks offering good prospects for mining.

The basement rock is overlain by a mainly sandstone formation produced by epicontinental sedimentation, the thickness of which increases from the south (500 m) to the north where, at the sites of a number of boreholes, it attains 2,500 m and marine facies are found in places. This formation is of Paleozoic or Lower Mesozoic age. The main aquifers in Egypt are associated with this system, generally known as "Nubian sandstone".

Towards the north-west, after the Paleozoic-Mesozoic sandstones, lies a formation of carbonate rocks interbedded with clay about 2,500 m thick. This formation, which dates from the Upper Mesozoic (Jurassic and Cretaceous) and Lower Cenozoic (Paleocene) periods, offers typical examples of karstic hydrology and occupies a large part of the plateau zone.

Egypt's geological landscape acquired most of its present characteristics in the era following the Paleocene. The main geological events in that era were as follows:

- Widespread lifting of the continental surface, retreat of the sea, continental deposits, with volcanic and hydrothermal activity during the Oligocene and Lower Miocene periods;
- Formation of the Red Sea graben;
- Local north-south intrusions of the sea during the Oligocene, Miocene and Pliocene eras (caused by oscillations in the level of the Mediterranean);
- Formation of the Nile basin, first in the form of a marine gulf in the Pliocene era, then as a body of fresh water flowing from south to north during the Pleistocene;
- Successive climate changes producing desertification, the present features being the accumulation of sand dunes, degradation of the soil and vegetation over most of the zone, increasing salination, and lack of rainfall.

II. AQUIFER SYSTEMS: BACKGROUND

Egypt has three main aquifer complexes corresponding to the sedimentary systems which overlie the Precambrian crystalline basement rock.

i) The lower detrital formation or "Nubian sandstone", consisting mainly of sandstone in thicknesses ranging from 100 to 2,500 m. This aquifer is artesian. Within Egypt's borders the piezometric level declines from an altitude of 500 m in the south-west to approximately sea level in the north.

These Nubian sandstones also extend into Libya, Chad and Sudan to form the artesian basin of north-eastern Africa. The chemistry of the ground water of this vast system varies from place to place, with a dry residue generally below 500 ppm.

Carbon-14 dating and other radio-isotope techniques indicate that most of the water infiltrated to deep levels during one or several rainy periods. This fossil water is between 20,000 and 40,000 years old. Hydrogeologists generally agree that the aquifer might be recharging at present from small recharge zones outside Egyptian territory by infiltration of equatorial rainfall and the waters of the Nile in northern Sudan.

The underground runoff is towards several natural or artificial outlets in the vast area west of the Nile, in particular towards the depressions of Qattara and Siwa, the oases of El Kharga and El Dakhla, and the oases of El Farafra and El Bahariya.

ii) The formation of "middle limestones" of Cenomanian to Upper Eocene age, composed of fissured limestone which is well karstified in many cases and common throughout Egypt. Mention may be made here of several rich sources of water fed from these limestones, which so far have received hardly any study.

- West of the Nile, almost all the natural springs of El Farafra, El Kharga, Sitra, Arag, El Bahrein, Garra, Siwa, Wadi Rayan, etc., and almost all the wells in the limestone plateau north of the Qattara depression;
- East of the Nile, including the Sinai, the many natural springs lying along the Red Sea anticlinal, at Helouan and in adjacent areas as far as the east of Cairo (heavily mineralized water), in the fault region of western Sinai (sulphur springs of Hamman Faraun; hot salt springs), and bordering the calcareous plateau of eastern Sinai.

iii) Lastly, the formation of Upper Oligocene to recent age, which is mainly detrital but does have some organic limestones such as the Mediterranean calcarenites of the coastal plain which form undulating terrain. These deposits of marine or continental origin form an aquifer along the whole length of the one thousand kilometres of coastline at an altitude close to sea

level. This aquifer, in which the salinity is about 1,000 ppm, rests on a mass of salt water produced by sea-water intrusion. However, subartesian conditions are found in a few places, as are perched aquifers, attributed both to the change of facies and to the geological structure of the terrain. Recharge is by direct infiltration of local rainfall.

One of Egypt's very important aquifers is found in the sand and gravel formations deposited in the depression of the Nile and the Delta - the Nilotic deposits of the Pleistocene era. This aquifer is about 350 m thick and rests on Pliocene clays which can be considered an aquiclude. It is practically saturated with water of about 500 ppm salinity and is recharged from the waters of the Nile and the network of irrigation channels. In this part of Egypt the ground-water aquifer is continuous and sinks gradually from south to north. After the construction of the Aswan Dam the ground water in the Nilotic deposits began to rise, apparently as a result of the marked difference of head between the water in the dammed lake (+178 m) and the surface of the water in the river to the north (maximum level of about +90 m). As the lithology of the deposits in the Nile Valley is not homogeneous, isolated lenticular formations of clay are found - explaining the subartesian conditions which occur at certain points. The volume of renewable water stored in this aquifer is probably about 600 million m³ and its discharge zone includes the following outlets:

- Wadi El Natrun (-20 m) and perhaps the Qattara depression (-134 m) in the west as well;
- Wadi Tumeilat, the Bitter Lakes and the Suez Canal in the east;
- The lagoons along the Mediterranean coast in the north;
- The many wells in the coastal strips.

At the northern edge of the Delta there are heavy intrusions of sea water, caused perhaps by the excessive pumping of ground water.

Recent hydrogeological studies tend to indicate that these aquifer systems are in contact with each other at many points.

III. GROUND WATER IN THE WESTERN DESERT

Nubian sandstone

South of the 29° 30' parallel N the Nubian sandstones stored great amounts of infiltration water during the rainy periods at the end of the Quaternary epoch and they have retained this water since then. In ancient times this water was exploited in the oasis depressions of El Kharga, El Dakhla and El Bahariya. These same regions have been exploited by 400 boreholes of various depths for about thirty years. The table below gives data for the El Uweinat area east of the Gifl Kebir plateau in the south of the Western Desert.

Aquifers in El Uweinat

Type of well (by yield)	Type 1	Type 3	Type 4	Type 5
Yield (m ³ /h)	6	40	18	25
Transmissivity (m ² /day)	1,688	2,437	1,987	44
Permeability (m/day)	28	50	40	0.60
Storage	17.5 x 10 ⁻²	5.3 x 10 ⁻³	11.7 x 10 ⁻²	5.3 x 10 ⁻⁴
Drawdown (m) (Q = 50 m ³ /h)	1.36	1.36	1.18	56
Salinity (ppm)	810	1,260	1,280	1,230

The depth of the piezometric level varies from a few to almost 50 metres.

It should be noted that the average permeability at the El Bahariya oasis is 6.2 m a day and the transmissivity 8,000 m² a day.

It has been established by the radio-isotope method that the Paleozoic-Lower Mesozoic aquifer system varies according to its geographical location, as shown by the following table.

	<u>El Kharga</u>	<u>El Dakhla</u>	<u>El Farafra</u>	<u>El Bahariya</u>	<u>Nile waters</u>
Deuterium H ₂ * (percentages)	-83.4	-83.9	-79.1	-79.7	+25
O ₁₈ * (percentages)	-10.9	-11.0	-10.5	-10.4	+ 3

* Standard Mean Ocean Water.

These results tend to indicate that there is a separation between the oasis water of the north and south and the Nile, which thus does not feed the Nubian sandstones.

It has been estimated that the daily recharge by rainfall of the Nubian sandstones, which are more than 3,000 m thick west of the El Farafra oasis, is in excess of four million cubic metres, exclusively between the 29° 30' parallel N and the Egyptian-Sudanese border. During the period 1963-1970 the

annual drawoff was about 80 million m³, increasing between 1970 and 1981 to 300 million and 450 million respectively, and to an estimated one billion cubic metres in 1985-1990.

The drawoffs of ground water at the four oases in the southern part of the New Valley have been calculated by mathematical model as follows:

Ground-water drawoffs - New valley

(Southern oases)

(millions of m³/year)

	<u>Wells</u>	<u>Evapotranspiration</u>	<u>Total</u>
El Kharga	50	55	105
El Dakhla	115	35	150
El Farafra	1	6	7
El Bahariya	25	30	55

In the vicinity of the High Dam Lake the thickness of the Nubian sandstone varies from 200 to 600 m and the depth of the aquifer from 20 to 60 m over a strip of land 10-kilometres wide around the shores of the lake. Beyond 10 kilometres the depth of the water varies from 150 to 200 m. The recharge of the Nubian sandstone by the waters of the Nile amounted to 5 million m³ a year before the construction of the High Dam. The lake began to form in August 1964, and the recharge of the Nubian sandstone from the lake has increased to 1.5 billion m³ a year, with roughly equivalent distribution for the eastern and western parts. In this vicinity the salinity of the ground water in the Nubian sandstone is about 200 ppm.

It has been determined by means of deep boreholes that in the Siwa oasis, to the south of the El Qattara depression, the fresh water overlies deep salt water, while in the north of the Western Desert only salt water is found.

Depressions have been dug in the aquifer by the drawoff of surface water in the oases over more than a thousand years, and vertical hydraulic gradients have been created, drawing deep water up towards the surface. Where deep aquifers have been exploited, the gradient is reversed and water is drawn down from the higher levels.

It is clear that the Qattara depression and the El Kharga oasis are the main outlets and that El Dakhla and the El Bahariya oasis make only small contributions. Before 1960 there was a rough equilibrium between the recharge from the south and the discharge through the natural springs and traditional wells of the oases and the flow towards the Qattara depression. With the exploitation of deep wells since 1960 this balance has been upset, and the

water table at the oases has been observed to decline, particularly at El Kharga. Modelling of the water balance in the New Valley and the Qattara depression has indicated ground-water flow and escape (discharges of the springs and wells and evapotranspiration losses) as follows:

	<u>Millions of m³/year</u>
El Farafra area	1
El Bahariya area	100
El Bahrein area (south of Qattara)	50
South of Siwa	140
Qattara depression	<u>90</u>
Total	381

The effects of various pumping schedules on the water levels have been simulated for a period of 100 years for an aquifer lying 1,000 m below the soil.

The discharge safety levels, up to which pumping does not threaten the water resources, are as follows:

	<u>Millions of m³/year</u>
El Farafra (Nubian sandstone)	365
El Bahariya "	182
Siwa (Middle Miocene)	<u>140</u>
Total	686

Source: General Petroleum Co., 1981.

Aquifers of the Upper Mesozoic to Quaternary periods

These aquifers are fed from the underlying Nubian sandstones through faults and grabens. Moreover, there are no impermeable strata blocking the upward migration of the water. The Upper Mesozoic-Lower Cenozoic formations, which consist mainly of carbonate rocks, have not been extensively explored along the northern edge of the Western Desert, except for the

fractured chalk of the El Farafra oasis and the fractured limestone of Middle Eocene age along the natural lake zones south of the Qattara depression.

Minor aquifer systems of small extent and potential can still be of considerable economic and social importance in areas where there is no other source of water.

The Oligocene aquifers consist of sands, clays, gypsums and calcarenites. They are found in the eastern part of the Western Desert north of the 28th parallel N. They extend as far as the banks of Wadi El Natrun in the east and the El Moghra oasis (north-east of the Qattara depression) in the west. These aquifers are recharged by direct infiltration of rainfall and surface runoff.

Miocene-Pliocene and Quaternary aquifers are found in interbeds of argillaceous calcarenites and limestones with some sandy strata. The water has an acceptable salt content in the Siwa oasis (Middle Miocene), at Moghra (Oligocene-Miocene), in the Qara oasis (Miocene) and in the area of Wadi El Natrun (Quaternary Pliocene). The aquifer is recharged exclusively by direct infiltration of rainwater and transfers from the Oligocene aquifer in the north-east of the Western Desert (from El Moghra to Wadi El Natrun). In the case of Wadi El Natrun and the El Rallat depression to the north, the flow towards the Miocene-Quaternary aquifer is mainly from the western part of the Nile Delta. The annual recharge from Rayah El Beheiri and the Nubariya canal can attain 9 million m³. About 18.5 million m³ a year can be taken from Wadi El Natrun to irrigate 5,000 feddans (2,000 ha), while according to the mathematical model the total drawdown after 100 years will be 28 m. The salinity of the water varies from 200 to 5,000 ppm from east to west of Wadi El Natrun and it can attain 20,000 ppm in the north-west in the areas west of the Nubariya canal along the northern part of the El Rallat depression.

Oligocene-Miocene to Quaternary basalts outcrop west of the High Dam lake, at the El Bahariya oasis, north of the El Faiyum depression (at Begel Qatram), west of the area of the Gizeh pyramid, and in the vicinity of Abu Roash. Boreholes drilled in the basalts of the El Bahariya oasis have revealed a considerable volume of good-quality ground water.

Pleistocene and Holocene sediments outcrop along the Mediterranean coast in the form of oolitic calcareous sandstones (in isolated hills), sand in layers and dunes, and alluviums of sabkhas and wadis. The hills, coastal dunes and wadi deposits constitute the main aquifers of the coastal region. The ground water is exploited by wells equipped with pumps, windmills and infiltration galleries. At Fuka, for example, the wells draw off 50,000 m³ a year and the windmills 24,000 m³; at Baggush the galleries produce 200 m³ a day; at Hekma the windmills pump 400 m³ a day. At Negila 100,000 m³ is drawn off per year, with 100,000 m³ a year at Wadi Maguid. At El Qasr the pumps and windmills draw off 75,000 m³ a year and the galleries - with a total length of 11 km - 360,000 m³ a year.

IV. GROUND WATER IN THE EASTERN DESERT

Ground-water research in the Nubian sandstones began only recently and was to conclude in 1986. It has been carried out in conjunction with mining operations. Ground water is present in the fractures of the crystalline basement rock, including metavolcanic rocks, gneiss, schists, and granitic and serpentinite intrusions. The presence of veins assists the flow of ground water along the main wadis. The fracturation of these rocks depends on the tectonic conditions, while the deep alteration is determined by age and paleo-climate.

In Wadi Lahmi, west of Ras Benas, the aquifer is 26 m deep. The wells yield 100 m³/day. At Wadi Karim (east of Quseir), the depth is 30 m and the yield 10 m³/day. At Wadi Basha south-west of Hurghada the aquifer is at 16 m and the drawoff is 60 m³/day. The water has a fairly high salt content: from 2,000 to 3,000 ppm.

The storage of the ground water in the fractured rocks is poor, as is the recharge. By contrast, the alteration zones which have a good storage co-efficient are not very permeable. The best location for wells is in places where the fractures are overlain by water-saturated altered rocks (wadi alluviums). The ancient volcanic rocks are very moderate aquifers except in fault zones. On the other hand, the more recent volcanic rocks give good yields in areas with sufficient rainfall.

The Nubian sandstones of the Eastern Desert satisfy local requirements, particularly in the main wadis of the central section of the Desert and near the eastern shore of the High Dam lake and the shore of the Red Sea. This aquifer system extends from the northern part of the Gelala plateau as far as Egypt's southern borders and into Sudan. It has hardly been explored at all, except at El Laqita (drilling depth: 450 m) and near the shores of the High Dam lake (drilling depth: 600 m). Promising aquifers have been found along Wadi Araba west of the Gulf of Suez. The salinity at El Laqita is up to 400 ppm, with heavy concentrations of iron and hydrogen sulphide. The recharge is estimated at 300 million m³ a year.

In the Ras Gharib plain (at Shagar for example) the Nubian sandstone has been reached at a depth of 900 m. The wells at Shagar yield 3,000 m³ of drinking water a day. The salt content is as high as 2,500-3,500 ppm at Wadi Araba and in the mining boreholes at Quseir - an indication of very poor recharge by rainfall.

The consumption of water in future years (m³/day) in the three zones of the Eastern Desert is estimated as follows:

	<u>1985</u>	<u>1990</u>	<u>1995</u>	<u>2000</u>	<u>2010</u>
Zaafarana-Gemsa Bay (south of Gulf of Suez)	10,500	19,000	25,000	28,000	34,000
Ghardaka-Safaza-Quseir (central part)	28,000	45,000	90,000	132,000	144,000
Mersa-Alam-Berenia (southern part)	<u>200</u>	<u>3,500</u>	<u>7,000</u>	<u>11,000</u>	<u>15,000</u>
Total	38,700	67,000	122,000	171,000	193,000

Six wells have been drilled in the Shagar area. The aquifer was reached at 70 m. The drawoff is 5,000 m³/day. Four other wells have been drilled south of Shagar (Ras Shukein) with a capacity of 4,500 m³/day. The salinity of the water ranges between 2,600 and 3,400 ppm.

Water has also been drawn from the phosphate mines between Shagar and Quseir: 500 to 1,000 m³/day from the Hamzawein mine, with a salt content of 2,400 to 2,800 ppm.

There are good wells along the old Qena-Safaga railway line; the two wells at Bir Merkh yield 115 m³/day, with salinity between 400 and 800 ppm.

Most of the now abandoned mines in the Red Sea Hills have deep wells in hard rocks yielding up to 40 m³/day of water of varying salinity.

The production cost of the ground water varies from LE 0.07 1/ per cubic metre for the wells in the Nubian sandstone to the west of the Western Desert mountains and the shallow wells in the coastal zone to LE 0.12 per cubic metre for the deep wells in the coastal zone (Shagar).

It has not yet been possible to evaluate the ground-water resources of the limestone plateau in northern Galala owing to its uneven permeability, which depends on the local fracture conditions. The southern piedmont of the Galala plateau (the area of the St. Paul monastery) warrants exploration, for here the Nubian sandstone is not very deep. Between the two Galala plateaus the plain of Wadi Araba, overlying a thick aquifer of Nubian sandstone, constitutes a very substantial reservoir of slightly brackish water.

V. GROUND WATER IN THE SINAI PENINSULA

Ground water accounts for more than 90 per cent of the peninsula's consumption. The volume of water stored in the aquifer system (Nubian sandstone - Quaternary) is estimated at about 75 billion m³. Moreover, the Nubian sandstone receives a recharge of 100 million m³ a year, i.e. 67 per cent of the total recharge of the aquifer systems. The aquifers include

1/ LE: Egyptian pound.

interbedded sandstones and clays and some layers of sandy limestone. The salinity of the water varies from 1,000 to 2,000 ppm. The fractured limestones have hardly been explored or studied at all; their water has varying concentrations of minerals (800 to 10,000 ppm). There are other smaller aquifers (fractured crystalline basement rock, fractured volcanic rocks, Quaternary deposits) which can be of local importance when there are no other sources of exploitable water. Quaternary aquifers are found only in the coastal zone or in the wadi beds. The water quality varies from good to brackish (700 to 3,000 ppm). The water requirements in the Sinai are estimated at the following amounts (hm³/year):

<u>Year</u>	<u>Domestic</u>	<u>Tourism</u>	<u>Industry</u>	<u>Agriculture</u>
1985	10	-	-	35
2000	100	2	80	100

At present, almost 50,000 m³/day is taken from the Quaternary aquifers of the Sinai and about 2,000 m³/day from all the other aquifers together.

VI. GROUND WATER IN THE NILE VALLEY AND DELTA

The Nile Valley and Delta constitute one of the world's biggest ground-water reservoirs, with a capacity of 400 billion m³: 120 million in Upper Egypt and 280 in the Delta. The annual recharge is estimated at 8.6 billion m³: 5.6 billion in the Delta and 3 billion in Upper Egypt.

In Upper Egypt there are three characteristic levels in the alluviums of the Valley. The upper level consists of clays, silts and fine sands and is 4-20 m thick; it overlies the main aquifer, which includes sands, gravels and cobbles, with shallow argillaceous lenses. The thick level of 15 to 250 m is of Pleistocene age. It overlies layers of clay and neogenic limestone. The transmissivity is in the order of 8,000 m²/day; the permeability is 100 m/day. The storage co-efficient ranges from 7×10^{-6} to 8×10^{-3} . The vertical permeability has been estimated at 0.04 m/day.

The thickness of the ground-water reservoir in the Delta zone increases towards the north, from Cairo (100 m) to the Mediterranean coast (900 m). The transmissivity is around 100 m²/day, the storage co-efficient from 10^{-4} to 10^{-3} , the permeability from 0.02 to 0.05 m/day. The drawoffs from the aquifer for domestic, agricultural and other needs, and the losses, have been estimated as follows:

<u>Nile Delta</u>		<u>hm³</u>
- Drainage towards the branches of the Nile		212
- Vertical drainage through clay strata		97
- Flow towards the El Natrun aquifer		50
- Yield of the pumping stations (irrigation and domestic uses)		<u>1,600</u> (1980)
TOTAL		approx. 2 billion m ³

<u>Upper Egypt Valley</u>		
- Drainage towards the river		3,500
- Pumping		<u>1,300</u>
TOTAL		almost 5 billion m ³

It is estimated that the following additional amounts could be drawn off without risk:

2.5 billion m³ in the Delta

1.5 billion m³ in Upper Egypt

In the Delta the quality of the ground water varies considerably from year to year. In Tahrir province the salinity ranges from 480 to 1,920 ppm and it can reach 16,000 ppm in the north of the province. West of the Cairo-Alexandria road the salinity varies from 7,500 to 16,000 ppm. In other parts of the Delta it ranges from 500 to 4,000 ppm and even higher.

In general, the water quality in Upper Egypt is satisfactory for all uses (120 to 1,200 ppm). Since the completion of the High Dam the water quality of the aquifer has been deteriorating owing to the rise of the piezometric level and the exposure of the ground water to increased evaporation, with a consequent increase in its salinity.

Owing to the development of irrigation in the Nile Valley and Delta following the construction of the High Dam, the piezometric level has risen by an average of two metres in Upper Egypt and by one and a half metres in the Delta. In some areas bordering the western part of the Delta the water table has risen by 28 m in the north and 20 m in the south, with an increase of 50 million m³/year in the volume of water stored in the aquifer.

VII. CONCLUSION

It is necessary to stress the considerable importance of ground water in Egypt, its close connection with the waters of the Nile, and the very pronounced changes brought about in the ground-water system by the building of the High Dam.

Egypt's Desert Institute is responsible for the study, evaluation and exploitation of ground-water resources. Detailed studies of the various aquifers are being carried out under the Institute's auspices at present; both traditional methods and modern techniques are used: various analogical and mathematical models, radio-isotopes and remote sensing. All this activity will eventually result in an evaluation of the potential of these aquifers, the possibilities for exploitation of which are of interest to many public bodies.