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Groundwater potential for irrigation in the East Oweinat area, Western Desert, Egypt

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Abstract The Nubia Sandstone aquifer system is one of the most extensive groundwater systems in North Africa, covering an area of about 2,000,000 km^2, including parts of Egypt, Libya, Sudan, and Chad. In the Western Desert of Egypt, the Nubian formation has a thermal gradient of 1.1–5°C 100 m^{-1} with the exception of the East Oweinat area, located in the southern part of the Western Desert. This is the only part of this huge system where groundwater occurs under unconfined conditions in an area where the Nubian sandstone crops out and is underlain by shallow basement rocks; in this area groundwater has no thermal characteristics. The aquifer system in the East Oweinat area attains a relatively high hydraulic conductivity. The direction of groundwater flow is generally northeastwards but is distorted at faults and fracture zones. Chemical analyses of groundwater in the area indicate a low salt content and suitability for irrigation purposes. As the estimated recharge to the area is low compared with the foreseen irrigation water requirement, the development of groundwater in the East Oweinat should be based on groundwater mining. Although the evaluation of the groundwater resources in East Oweinat has indicated that groundwater can be extracted at a rate of 4.7×10^6 m^3 d^{-1}, the long-term economics of extraction that can sustain large-scale development projects has to be assessed.

Key words Groundwater · irrigation · Egypt

Introduction

To overcome the problem of overpopulation around the Nile Valley and Delta areas, where the balance between the land and man is distorted, the Ministry of Agriculture and Land Reclamation has decided to extend its land reclamation activity into the vast desert areas, based on the utilization of the available groundwater resources.

During the period 1978–1985, a comprehensive and systematic hydrogeological investigation in the East Oweinat Area was carried out by the petroleum sector (G.P.C. 1984) to assess the availability of groundwater for irrigated agriculture projects.

Based upon the results of groundwater resource evaluation in the East Oweinat area, and to justify the assumptions about the aquifer response to required extraction, a land reclamation project of 15,000 feddan (1 feddan = 0.4 ha) is planned during the current five-year plan. As the groundwater extraction from the Nubia Sandstone aquifer is known to be under mining conditions, the groundwater extraction should be economical, rational, and sustainable to assume prosperity for generations to come. Therefore, the technoeconomical feasibility of the groundwater exploitation for irrigated agriculture in the East Oweinat area should be studied.

In this paper, the results of the groundwater resources evaluation study and the on-going and the 1992–1997 plans for groundwater development in the East Oweinat area are presented. The technoeconomical feasibility study envisaged to assess the long-term economical groundwater extraction is discussed.

Physical setting

Location and climate

The East Oweinat area is located in the southwestern part of the Western Desert, 880 km from Cairo and 400 km to the southwest of Kharga Oasis. It is bounded by longitudes 27°45′–29°30′E and latitudes 22°00′–23°20′N (Fig. 1).

The East Oweinat is connected to the Kharga and Dakhla Oases by asphalt roads. The East Oweinat area

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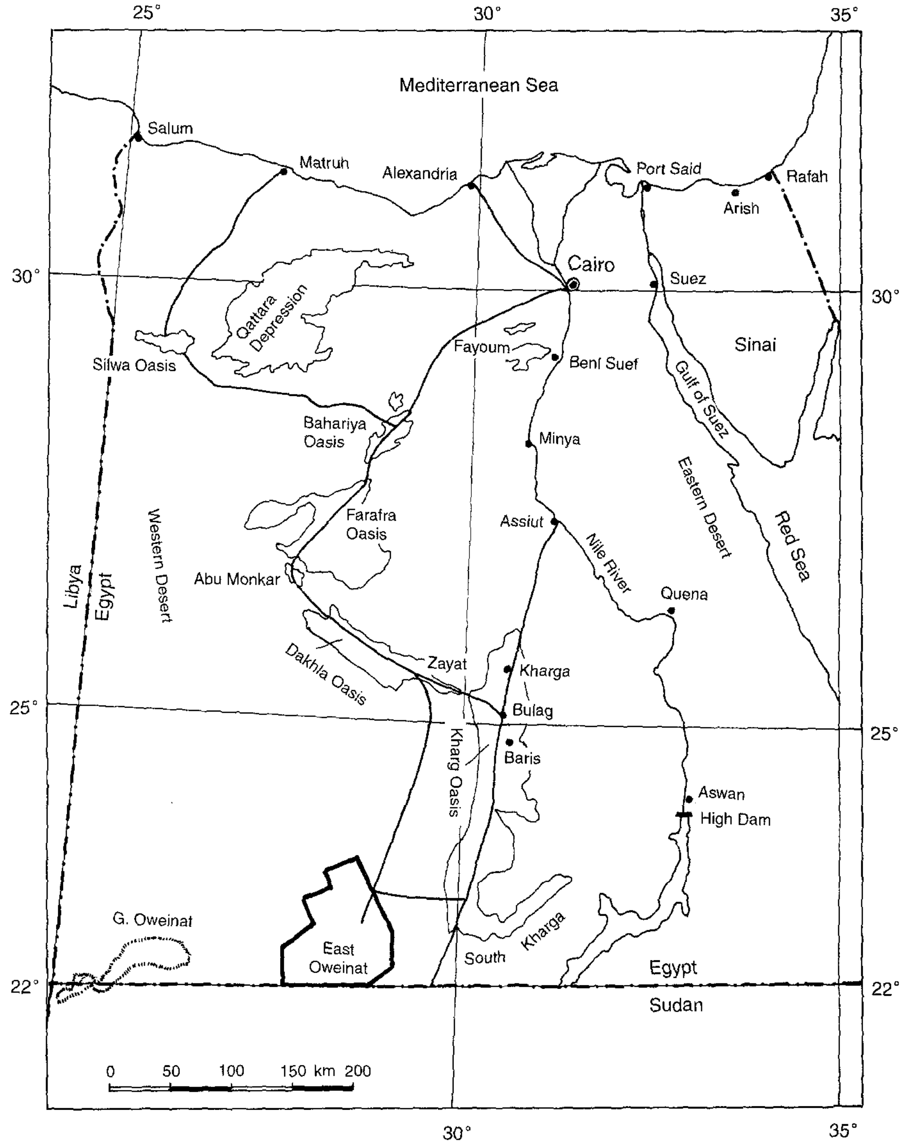

Fig. 1 Location of study area

lies within the arid belt dominating north Africa and is warm in winter and rather hot in summer with minimal precipitation.

Maximum temperature during summer often exceeds 40°C, whereas minimum temperature during winter may decline close to freezing. Natural evaporation rate ranges between 10 mm d^{-1} during January to 31 mm d^{-1} during July, with an average of 22.2 mm d^{-1}. The relative humidity ranges between 11% in May and 41% in December.

The mean monthly minimum wind velocity is 21 km h^{-1} in December and January while the mean maximum is 32 km h^{-1} in September. The prevailing wind direction is generally northwest to northeast.

Topography

The East Oweinat Area forms a flat sandy terrain, with its ground surface sloping from west to east and from south to north. The ground surface elevations range between 350 m in the southwest to 250 m at the northeast, with a northeasterly surface slope of 0.6 m km^{-1}.

Geological setting (Fig. 2)

The surface of the East Oweinat area is underlain by Mesozoic sediments attributed, in most of the area, to the lowermost part of the Nubia Sandstone sequences, which dip northwards. However, these sediments are extensively covered by dunes or by sarir surfaces, with the exception of its massive surface exposures in the areas to the northeast of Qaret El Mayet basement outcrop. East of longitude 29°5′E, the Nubia sequence is covered by younger sediments of the Upper Cretaceous–Lower Tertiary age. At the northern limit of the area (latitude 24°N), the formation is capped by late to early Cretaceous sediments. The basement rocks crop out at several places in

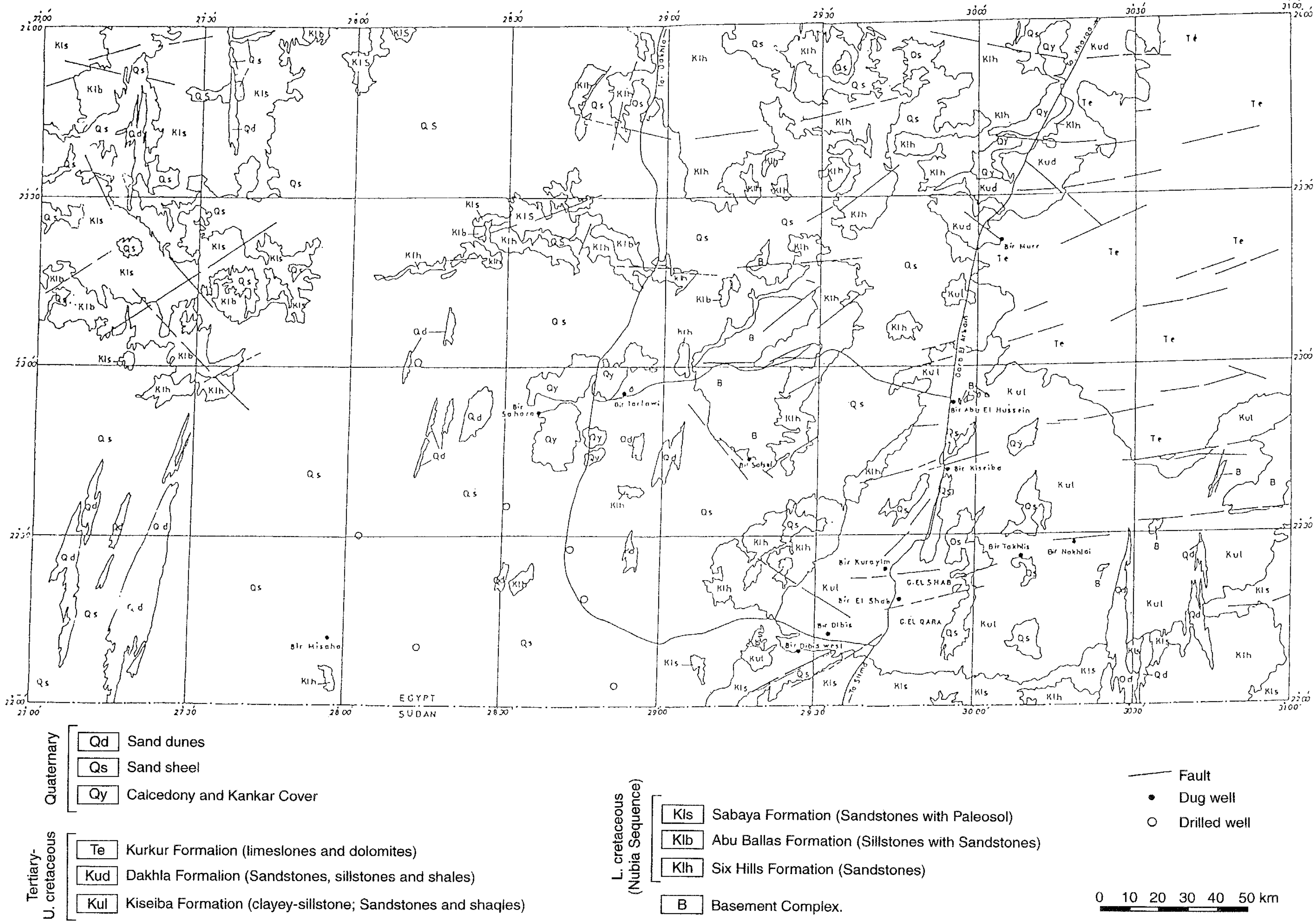

Fig. 2 Geological interpretation map

the East Oweinat Area: Gebel kamel, Qaret El Mayet and Nusab El Balgum (Issawi 1971).

Lithostratigraphy

The basement complex

The basement rocks exposed in the area are of the Aswan-type granites, magmatic gneisses, and granodiorites. The basement relief map (Fig. 3) shows an area of shallow basement with elevations ranging between −100 m and +200 m, extending between G. Kamel and Qaret El Mayet–Nusab El Balgum basement outcrops, and further eastwards to G. El Asr. This shallow zone is interrupted by a deep graben structure between G. Kamel and Bir Misaha, where the elevation of the basement was −400 m (Klitzsch and others 1983).

The Misaha structural trough extends northwards to the southern reach of Dakhla Oasis and southwards to latitude 21°30′N. The basement surface generally dips northwards from G. Kamel–Tarfawi basement high towards the north and northeast, where it attains an elevation of −500 to −800 m. Elsewhere in the area, the basement surface is controlled by the ENE–WSW striking fault system with a vertical displacement of 10–100 m.

The Nubia sequence

Overlies unconformably the basemen and is covered in most of the study area by Quaternary and Recent deposits. In the eastern part, the sequence is overlain by the Upper Cretaceous and Lower Tertiary rock complex.

Lithologically, the Nubia sequence consists of a succession of sandstone beds with minor intercalation of siltstones, koalinite, and koalinitic sandstone in the area between Bir Sahara and Bir Tarfawi and southwards to latitude 22°N. Outwards from this area, the clayey materials are predominant. The sandstones near the fault zones appear to be intensively furroginated and/or silicified forming hard, compact, low permeability zones.

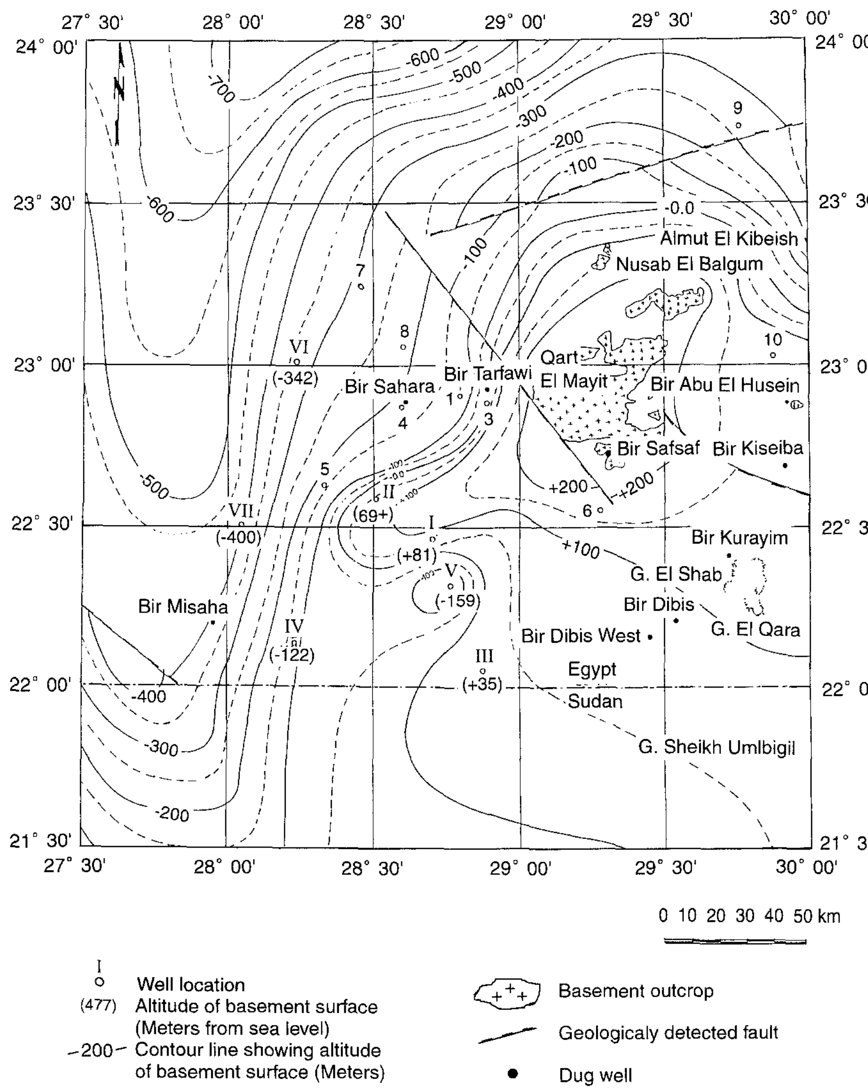

Fig. 3 Structure contour map of basement complex surface

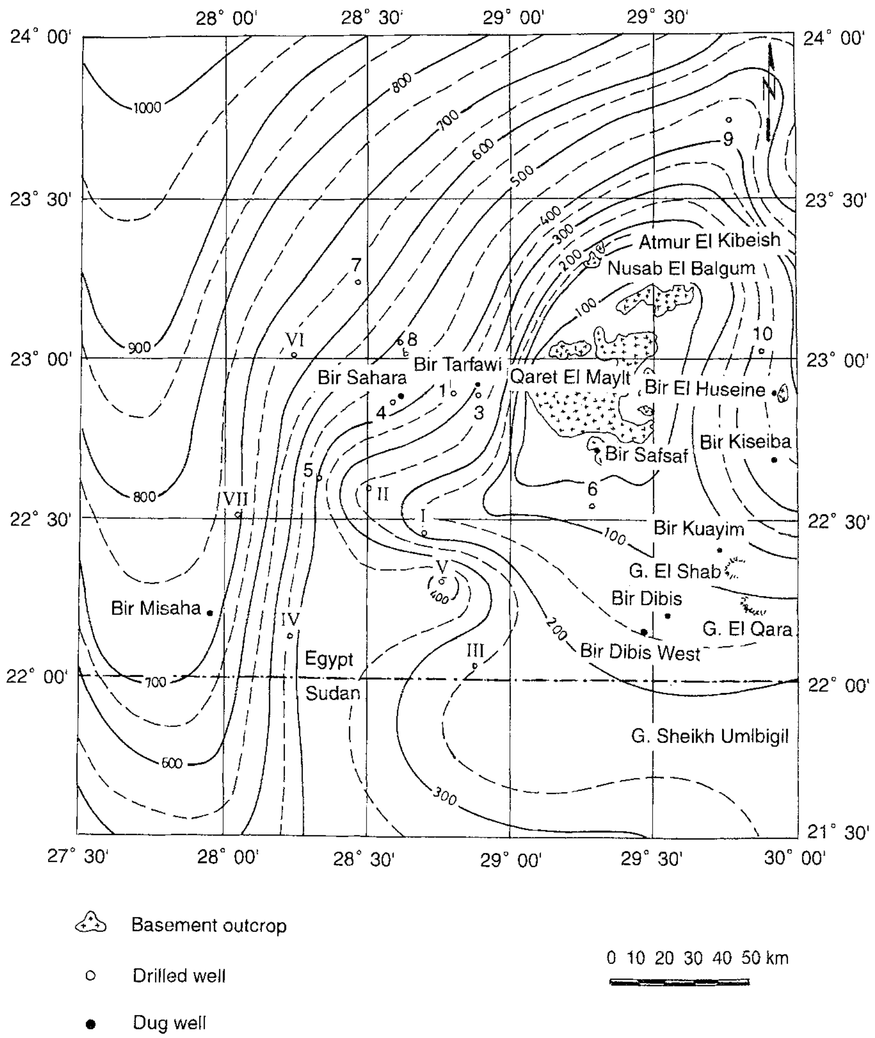

Fig. 4 Isopach map of Nubia sandstone aquifer

The thickness of the Nubia Sandstones ranges between 100 and 400 m in the area of shallow basement between Bir Misaha, Bir Sahara, Tarfawi, and Bir Dibis and from 500 to 700 m in the Misaha trough, and increases northwards to about 1000 m at the southern portion of Dakhla Oasis (Fig. 4).

Quaternary deposits

It covers most of the study area, overlying the Nubia sequences, and consists of aeolian sands, sand dunes, salt crust, and lake deposits of Pleistocene to Holocene age.

Hydrogeology

The Nubia Sandstone sequence in the East Oweinat area forms a small part of the immense Nubia Sandstone aquifer system that underlies much of northeast Africa.

Geometry and hydraulic parameters

In the area between Bir Misaha and Tarfawi, the aquifer is unconfined, while elsewhere it is under semiconfined conditions as a result of the occurrence of clayey intercalations within the aquifer section. The basement rock forms the base of the aquifer. The upper boundary of the aquifer system is the potentiometric surface. The saturated thickness of the aquifer (Fig. 5) ranges from 100 to 350 m within the Misaha–Tarfawi area and from 500 to 650 m within the Misaha trough. The hydraulic conductivity ranges from 10 to 20 m d^{-1}, the transmissivity ranges between 1000 and 2700 m^2 d^{-1}. The aquifer specific yield in its unconfined part is 0.16–0.23 while its storativity is 10^{-3} in the semiconfined part of the system.

Groundwater flow

Figure 6 shows the potentiometric surface of the aquifer in the East Oweinat area. The map indicates that the poten-

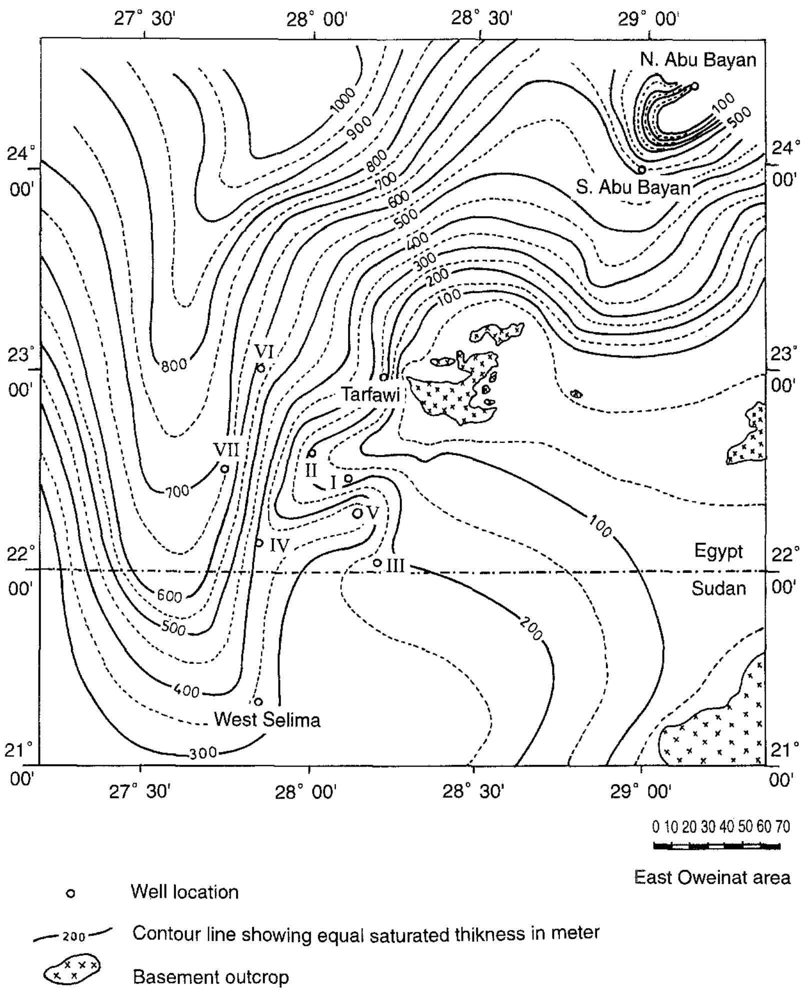

Fig. 5 Aquifer saturated thickness map

tiometric surface level slopes from 260 m in the southwest to 140 m in the northeast with a gentle groundwater gradient of 0.0001, which can be attributed to the high hydraulic conductivity. To the east of Darb El Arbain road, a rather steep gradient is shown due to the aquifer's low hydraulic conductivity. The potentiometric surface map indicates a general direction to the northeast of groundwater flow, a change eastwards near the ENE–WSW trending faults, which act as very low permeability barriers.

Recharge–discharge pattern

Using the aquifer potentiometric surface map and applying the net flow analysis, the annual rate of groundwater inflow to the East Oweinat area was estimated to be about 120×10^6 m^3, of which 50% reaches the part of the area planned for agricultural development.

Although present groundwater extraction for irrigation is limited to about 15,000 m^3 d^{-1}, the extraction planned to irrigate the reclamation projects in the East Oweinat area by the hear 1997 is 450,000 m^3 d^{-1}. The groundwater losses in the area where the water table is near the ground surface have not been estimated.

Groundwater quality

The quality of the groundwater in the East Oweinat area is fresh, with a TDS ranging between 200 and 700 ppm. The SAR value ranges between 0.5 and 1.7, while the RSC ranges between 0.69 and 2.45 epm, thus the suitability of East Oweinat groundwater for irrigation purpose is classified as excellent.

Groundwater resources evaluation

A groundwater finite element model of the Nubia Sandstone aquifer in the East Oweinat was developed (Fig. 7). The model was used to provide forecasts of the long-term aquifer response to groundwater extraction required to support the irrigation of the areas of highest land capability of 1.2×10^6 feddans (DRTPC 1984). The result of model simulations indicated that groundwater could be extracted at the rate of 4.7×10^6 m^3 d^{-1} over a period of 100 years without any adverse effects (Figs. 8–10). Based upon long-term groundwater availability, the depth to water and the expected pumping level, groundwater priority areas could be delineated (Fig. 11).

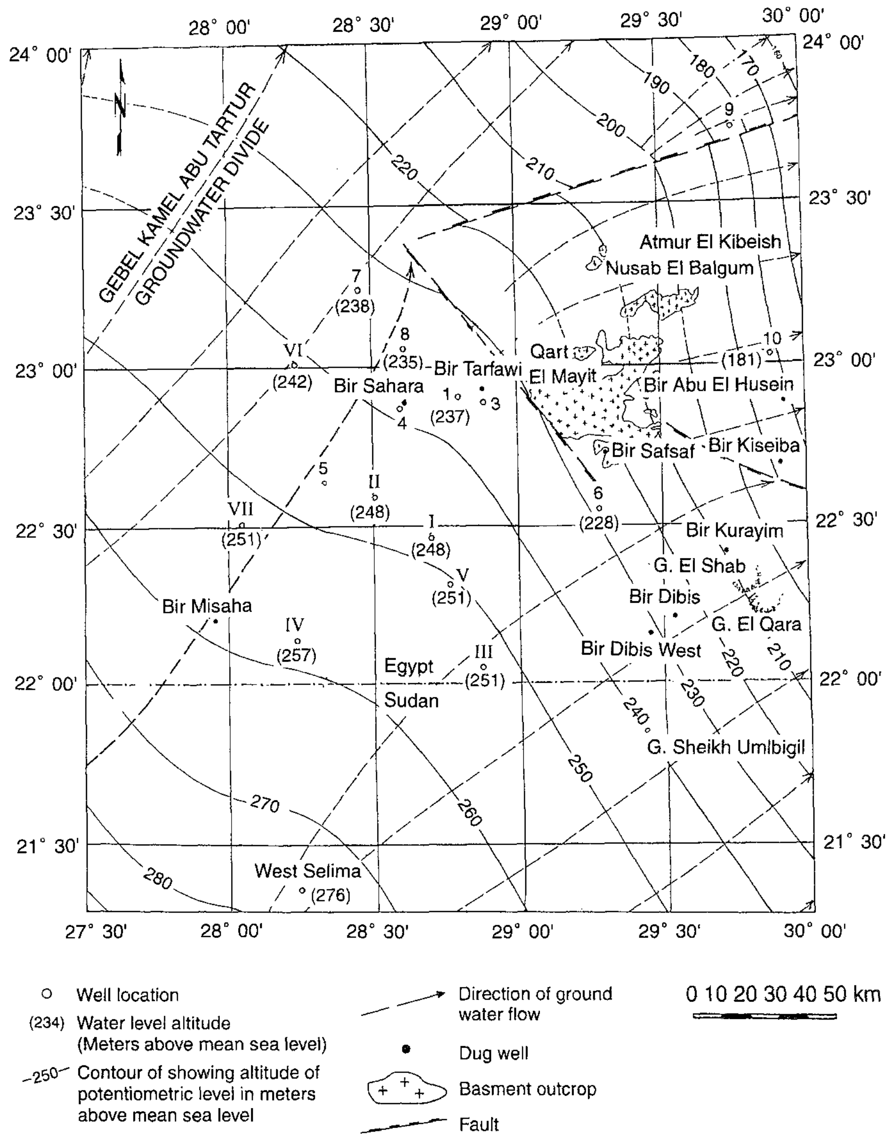

Fig. 6 Potentiometric surface map

Groundwater development plans

Criteria for groundwater development

Since the natural annual recharge to the Nubia aquifer system in the East Oweinat area is too low to support large-scale irrigated agricultural development, the plan for groundwater development should be based upon an aquifer depletion concept, i.e., the major part of groundwater withdrawal will be from aquifer storage.

Present groundwater development

During the period 1988–1992, a reclamation pilot project in an area of 3000 feddans was established in the first priority groundwater development area. Thirty-one wells were drilled to supply the required irrigation water. During the current five-year plan, an additional area of 12,000 feddans will be reclaimed. The foreseen irrigation water requirements by the end of the year 1997 are about 450,000 m^3 d^{-1}. This reclamation plan will allow placing the aquifer under actual exploitation conditions while monitoring the anticipated time-dependent change in water level.

Recommended technoeconomical feasibility study

Objectives

Although the previous groundwater resources evaluation study indicated the availability of long-term groundwater extraction of 4.7×10^6 m^3 d^{-1}, the economic feasibility of its utilization in an irrigated agricultural project is not yet assessed. The importance of such an economic study should be considered for the following reasons: (1) As the

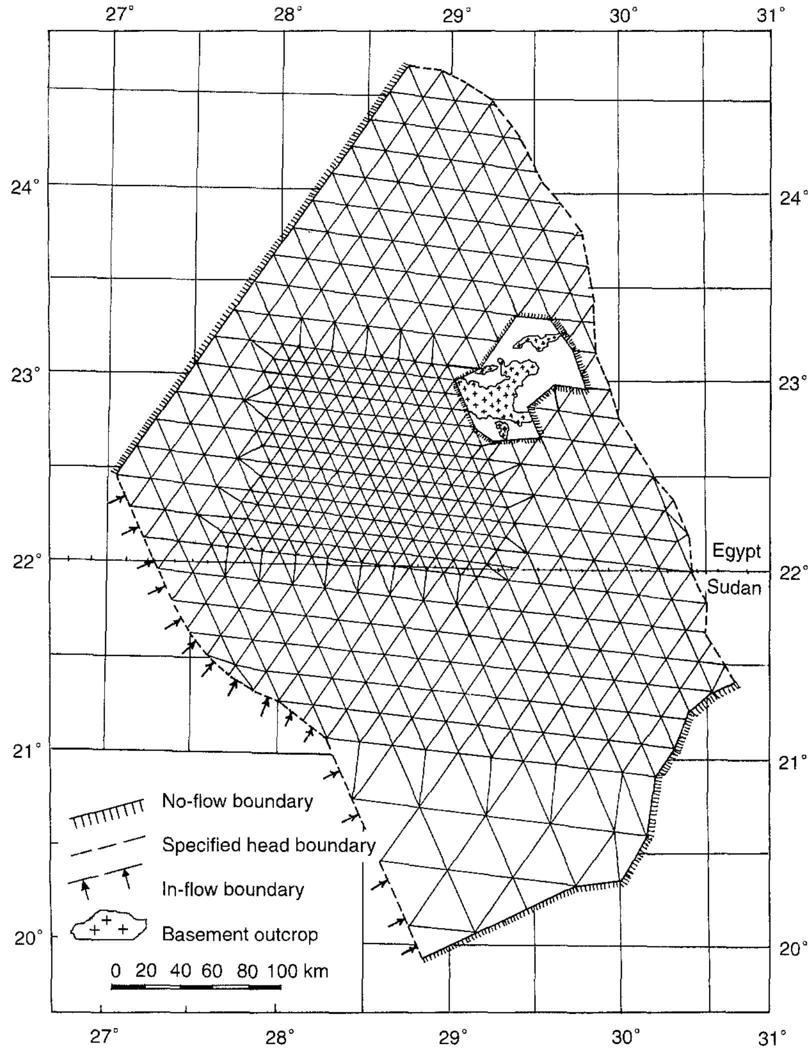

Fig. 7 Groundwater model, East Oweinat area

aquifer in the East Oweinat Area is part of the Western Desert nonrenewable aquifer system, the major part of the groundwater withdrawal will be from storage, with a subsequent continuous decline in the potentiometric level with time until a state of equilibrium is reached. (2) The marginal economical pumping level is considered to be the controlling factor that determines the maximum groundwater extraction rate and the area that can be feasibility reclaimed. (3) It is obvious that, in the absence of determining the maximum economic ground extraction, the possibility that the depth of water lift will exceed the economic pumping level at any time during the project life and will result in a decline of agricultural development activity and, in turn, the reclaimed areas.

The long-term impacts of groundwater extraction in the East Oweinat area on development in the northern Kharga and Dakhla Oases will be studied, as well as the proposed extraction plans in the South Kharga Plain area. This will be carried out by updating and extending the present model (Fig. 12).

The best locations will be determined for water well fields within the East Oweinat area to provide the required economic groundwater rate for the areas to be reclaimed. The well fields and well designs will be optimized to ensure high operating efficiency and minimum cost. The results of optimization should address well pumping rate, number of wells required per field, well spacing, well depth, and detailed well design.

Figure 13 shows a flow chart for a suggested planning procedure for the development of the groundwater resources in the East Oweinat area.

Conclusions and recommendations

The outcrop of the lowermost part of the Nubia Sandstone sequence forms the aquifer in the East Oweinat area. The base of the aquifer is the basement complex that occurs at shallow depth (100–400 m) with the exception of the down-faulted trough to the west of Bir Isaha, where the recorded depth ranges between 500 and 750 m.

The saturated thickness of the aquifer ranges between 100 and 350 m in the shallow basement zone and is 450–700 m within the Misaha structural trough area.

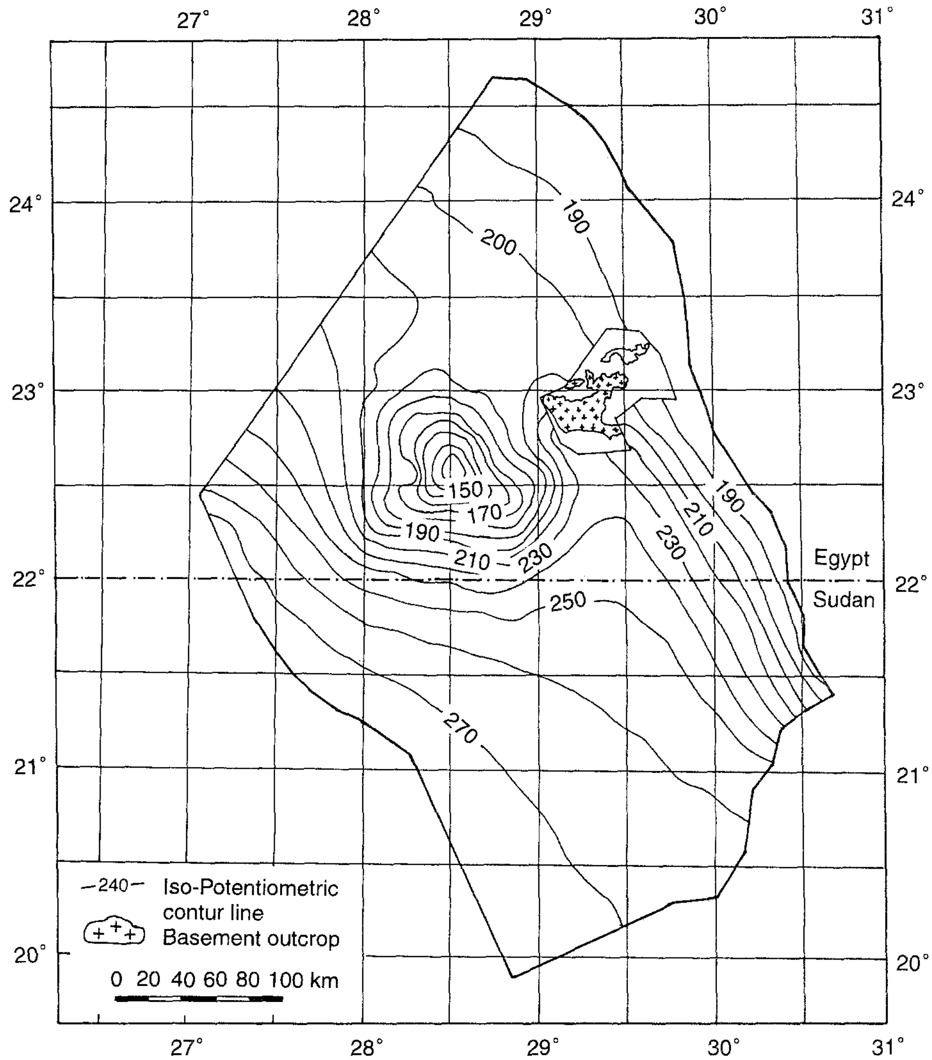

Fig. 8 Simulated potentiometric surface after 100 years (extraction: 4.7×10^6 m^3 d^{-1}) (after Development Research and Technological Planning Center 1984)

The aquifer has a hydraulic conductivity of 10–12 m d^{-1}, and transmissivity ranging between 1000 and 2700 m^2 d^{-1}. The upper aquifer is unconfined to semi-confined.

The aquifer potentiometric surface indicates a regional groundwater flow from the southwest to the northeast, but is diverted eastwards near faulted areas where low-permeability zones occur. The annual groundwater inflow to the East Oweinat area is estimated to be 120×10^6 m^3.

The groundwater salinity ranges between 200 and 700 ppm and is classified as excellent water for irrigation.

The groundwater model study indicated the possibility of groundwater extraction at a rate of 4.7×10^6 m^3 d^{-1} with a maximum anticipated water level decline of 100 m over an exploitation period of 100 years.

Due to the slow movement of groundwater in the Nubia Sandstone aquifer, the major part of groundwater extraction will be derived from aquifer storage. Therefore, the criteria of groundwater development in the East Oweinat Area should be based on mining.

A reclamation project of 15,000 feddans is to be implemented in the East Oweinat groundwater development priority areas during the current five-year plan, with a total groundwater extraction of 450000 m^3 d^{-1} by the year 1997.

It is highly recommended that the long-term groundwater extraction that can sustain the foreseen large-scale agricultural development in the East Oweinat area be determined. A technoeconomical feasibility study should therefore be carried out.

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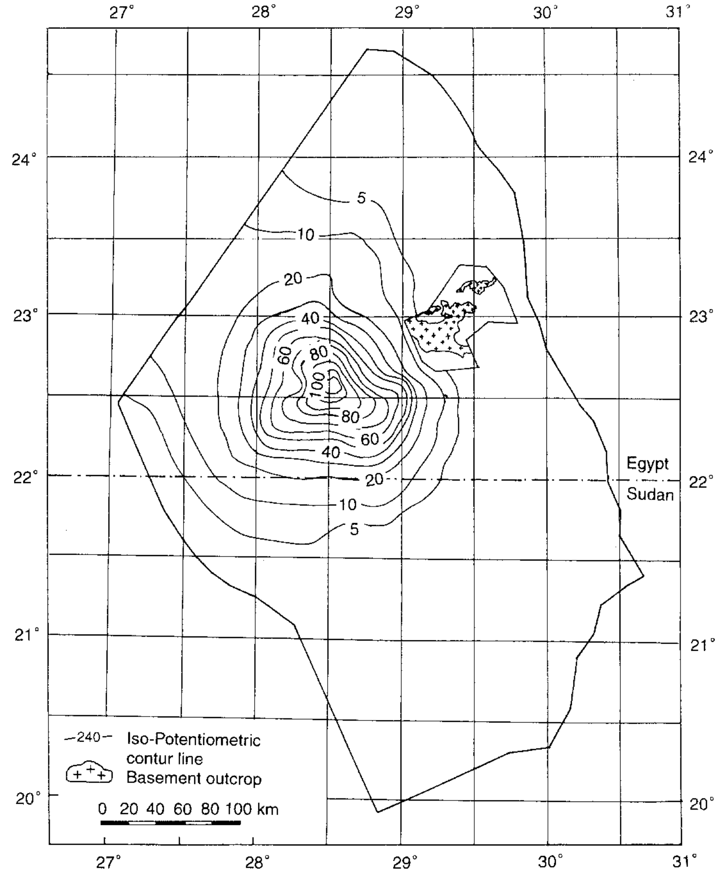

Fig. 9 Potentiometric surface decline after 100 years (extraction: 4.7×10^6 m^3 d^{-1}) (after Development Research and Technological Planning Center 1984)

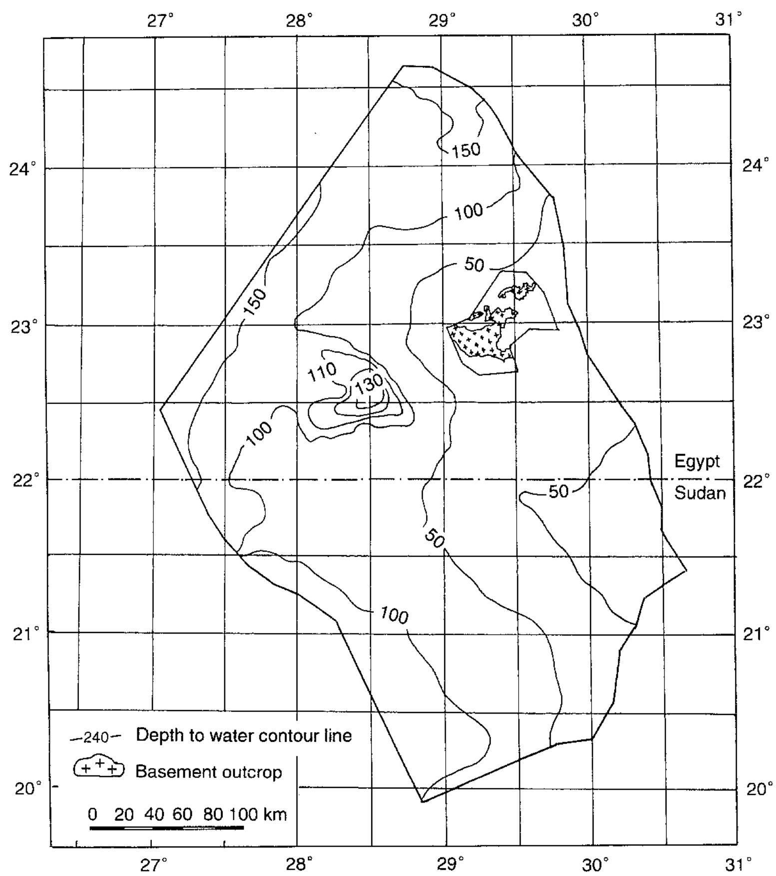

Fig. 10 Depth to water table after 100 years (extraction: 4.7×10^6 m^3 d^{-1}) (after Development Research and Technological Planning Center 1984)

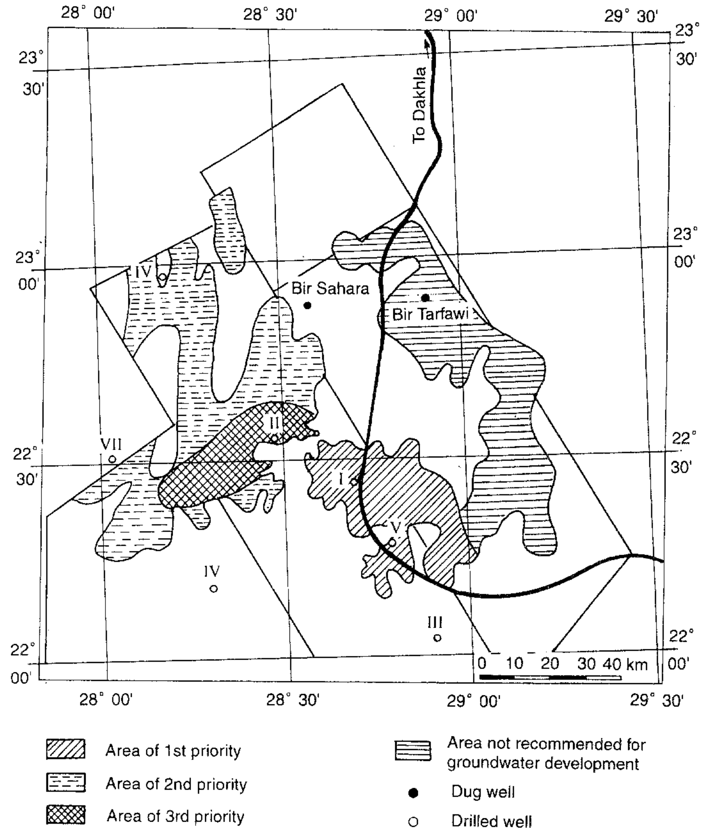

Fig. 11 Priority areas for groundwater development

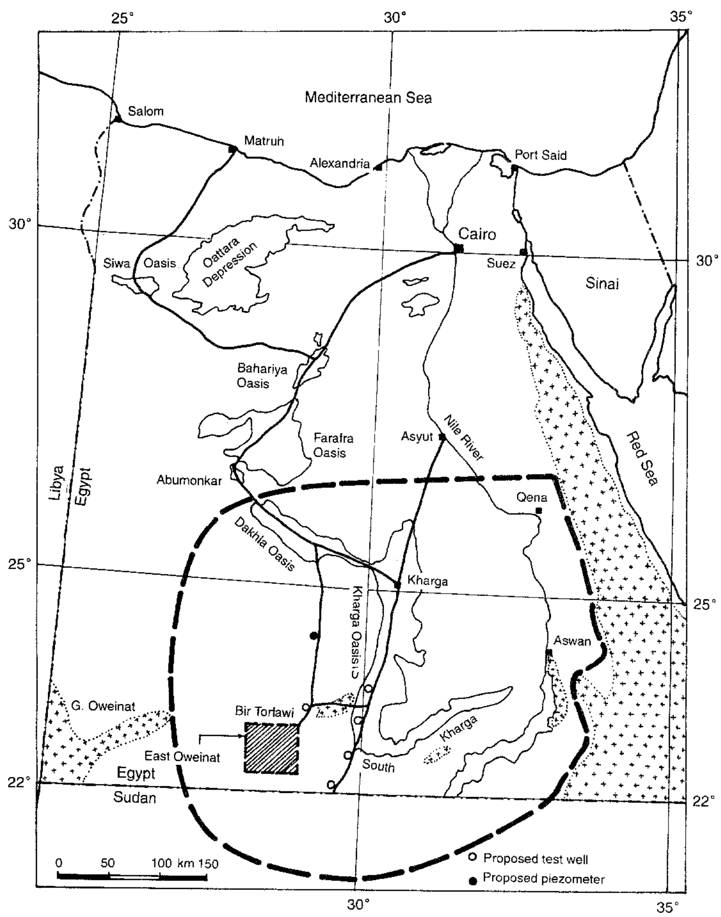

Fig. 12 Location map of the proposed model study area

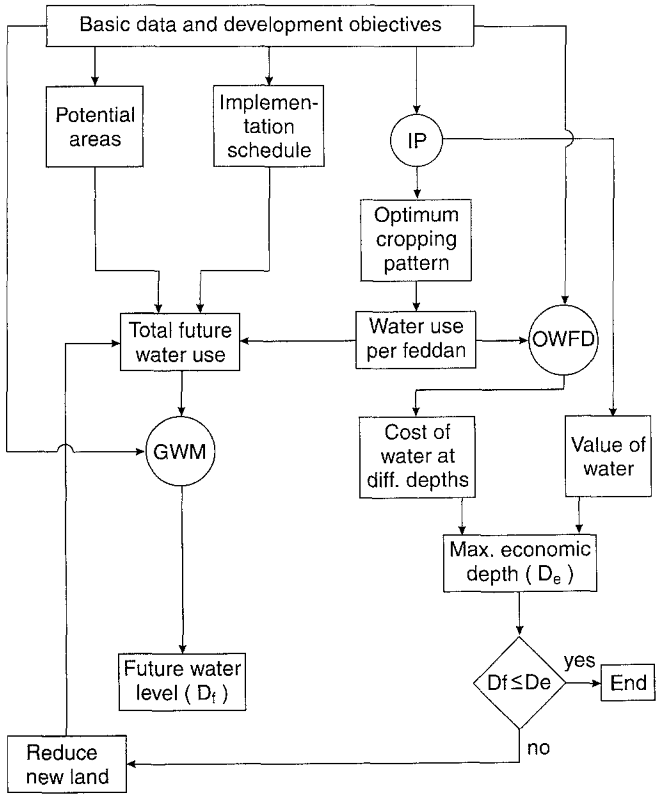

Fig. 13 Planning procedure for development of groundwater resources