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Hydrogeology of Deep Aquifers in the Western Desert and Sinai

Prepared By
Water Policy Reform Program
International Resources Group
Winrock International
Nile Consultants

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HYDROGEOLOGY OF DEEP AQUIFERS IN THE WESTERN DESERT AND SINAI

Report No. 10

August 1998

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LIST OF ABBREVIATIONS

DRTPC	Development Research and Technological Planning Center, Cairo Univ
EEC	European Economic Community
EGSMA	Egyptian Geological Survey and Mining Authority
F A O	Food and Agriculture Organization
GARPAD	General Authority for Rehabilitation Projects and Agricultural Development
GOE	Government Of Egypt
IWACO	Consultants for Water and Environment
JICA	Japanese International Cooperation Agency
MALR	Ministry of Agricultural and Land Reclamation
MPWWR	Ministry of Public Works and Water Resources
NVDA	New Valley Development Authority
NVID	New Valley Irrigation Department
REGWA	General Company for Research and Groundwater
RIGW	Research Institute for Groundwater
WRRI	Water Resources Research Institute

EXECUTIVE SUMMARY

This study report was prepared within the framework of the Water Policy Reform Project Implementation Plan under the Water Supply Augmentation Activity-Deep Groundwater component to address the hydrogeological setting of the deep aquifer systems in the Western Desert and Sinai, their groundwater resources potential, the historical and current practices of deep groundwater development, exploitation and utilization as well as their availability for future development plans This assessment provides the basic foundation for developing a national strategy for achieving the optimal use of deep groundwater, over time The report also includes the plans for additional hydrogeologic investigations required to better describe the deep aquifer systems and to support the evaluation of sustainable and economic deep groundwater resources potential in the Western Desert and Sinai

1 The Western Desert

The hydrogeological framework of the Western Desert encompasses three principal deep aquifer systems the lower Miocene Moghra sandy aquifer, the Tertiary / Upper Cretaceous fissured carbonate aquifer, and the Mesozoic / Paleozoic Nubia Sandstone aquifer

The deep groundwater in these aquifer systems is considered a non-renewable resource except the part of the Moghra aquifer at the Desert fringes of the Delta region which receives recharge from the adjacent Nile Delta aquifer

The Nubia Sandstone aquifer in the Western Desert is considered to have the greatest resource development potential It contains large volumes of fresh groundwater (<1000 ppm) in storage (200 000 bcm) The aquifer development plans should be considered as a mining process with continuous lowering of the aquifer potentiometric levels

The Nubia Sandstone sequence is outcropping in the southwestern part of the Western Desert, where it behaves as an unconfined aquifer, while northwards, it disappears under a thick low permeability cover and functions as a confined to semi-confined aquifer The Nubia Sandstone aquifer transmissivity ranges between 240 m^2/d in Toshka basin area and 17000 m^2/d in El-Bahariya Oasis

The potentiometry of the Nubia Sandstone aquifer indicates a regional NE-N groundwater flow towards the aquifer base level at the Qattara-Siwa-Giaghboub depression area where groundwater at a rate of 90 mcm/year is naturally lost

The groundwater of Nubia Sandstone aquifer is fresh (< 1000 ppm) in the southern and central parts of the Western Desert, while to the north of 29^0 N latitude saline to hyper-saline groundwater saturates the lower most part of the aquifer which increases in thickness northward to be completely saline water bearing at the fresh/salt water interface

Groundwater isotope measurements indicate that the groundwater in the Nubia Sandstone aquifer was formed during several successive humid periods which prevailed over the desert, the last of which was 8,000 years ago Therefore, the groundwater in the Nubia aquifer is considered to be a non-renewable resource

The results of the Nubia groundwater resource evaluation in the Western Desert indicate the availability of sustainable and economic groundwater for 100 years in the New Valley Oases of El-Kharga, El-Dakhla, El-Farafra, and El-Baharıya at an extraction rate of 1 045 bcm/year

In the East Oweinat and Siwa Oasis, groundwater model studies showed that groundwater can be exploited from the Nubia Sandstone aquifer at an annual rate of 1 2 bcm and 0 14 bcm respectively, over 100 years, although the economic evaluation of the groundwater use in these two areas has not yet been assessed

The total groundwater extraction in the Western Desert in 1997 was 0 679 bcm from the Nubia Sandstone aquifer and 0 272 bcm from the Upper Cretaceous/Tertiary carbonate aquifer systems in El-Farafra and Siwa Oasis It is estimated that 92 percent of this total groundwater extraction is used for agriculture The present total reclaimed area under irrigation using the Nubian groundwater is 105,000 feddan, while that on the Post-Nubia aquifers is about 10 000 feddan

Based on the groundwater resources potential of the Nubia Sandstone aquifer, the available additional groundwater for future developments in the Western Desert priority areas are 220 mcm/year in El-Farafra Oasis 83 mcm/year in El-Dakhla Oasis, 58 mcm/year in El-Baharıya (Figure 2)

In the areas of Dakhla, Farafra and Siwa Oases, naturally flowing groundwater conditions occur Because of problems with collapsing wells due to high back pressures during rapid closure, wells are not shut-off daily This results in uncontrolled and continuous flowing wells causing water wastage, water logging and soil salinization

The GOE has identified a number of groundwater development plans for irrigated agriculture projects in the South Valley region (East Oweinat, Darb El-Arbain, Aswan-Abu Simbel road area) as well as proposed reclamation plans in Ain El-Dalla and Wadi El-Qubaniya areas Groundwater conditions at these locations should be investigated and evaluated, before the start of their implementation

To better understand the regional hydrogeology of the Nubia Sandstone aquifer deep test wells should be drilled at Gilf El-Kebir, north East Oweinat, El-Kharga-Armant road, Ain El-Dalla (El-Farafra Oasis), Baharıya-Siwa road, Wadi El-Qubaniya The present groundwater monitoring program in the Western Desert Oases needs to be strengthened Measures should be put in place to ensure proper and regular well monitoring is carried out

Detailed hydrogeologic studies are recommended for the Moghra aquifer, the fractured carbonate aquifer in El-Diffa plateaux, the Nubia Sandstone aquifer in the South Valley region, to assess and evaluate the economic and sustainable groundwater resources potential for the planned irrigated agriculture in these areas The recommended studies include detailed geological and geophysical surveys, drilling of test wells, pumping tests and groundwater modeling

The costs of well replacement maintenance and operation in the old reclaimed areas in El-Kharga, El-Dakhla, El-Farafra and El-Baharıya Oases are still the responsibility of the MPWWR, while the GOE has recently allocated new areas for horizontal expansion projects

2

using deep groundwater to the private sector which will be fully responsible for project infrastructure

As the Nubia aquifer system groundwater is a non-renewable resource, its development plans should be based on a gradual process and its extraction and utilization should be rational, economic and sustainable Moreover, it should be realised that the initial free-flowing groundwater condition in the Western Desert is temporary and pumping will eventually be required as the groundwater pressures and discharges decrease over time

Techno-economic evaluation studies should be carried out for the two groundwater development options of collective large scale groundwater extraction and widely spaced, small-scale groundwater extraction centers

Corrective measures should be immediately taken for efficient utilization and proper management of free-flowing groundwater in the Western Desert areas of El-Dakhla, El-Farafra and Siwa Oases to minimize the environmental adverse effects (water wastage, water logging, soil salinization) currently occurring in these areas

For proper development of the deep groundwater resources in the Western Desert and to prolong the Nubia sandstone aquifer utilization period, it is recommended that groundwater extraction be distributed among the different aquifer horizons

It is recommended to promote the establishment of groundwater user associations in the Western Desert reclaimed areas These organizations would be responsible for groundwater development, operation, maintenance, with full technical coordination and support from the MPWWR

2 Sinai

Six deep aquifer systems have been identified in Sinai the Miocene sands, the Eocene limestones, the Upper Cretaceous carbonates, the lower Cretaceous sandstones, the Jurassic sedimentary rocks and the Paleozoic sandstones

The Lower Cretaceous is considered to be the aquifer with the greatest development potential among the other aquifer systems in Sinai due to their limited extent, poor productivity and/or water quality

The lower Cretaceous Sandstones formation (El-Malhah formation) extends from its southern outcrops along El-Egma and El-Hazim plateau and northwards to the north of Gebels El-Maghara – El-Halal and to the east to the Dead Sea-Gulf of Aqaba Rift Valley in southern Israel, and westward to the Gulf of Suez Rift Valley

The Lower Cretaceous aquifer is unconfined north of its southern outcrops, and confined in central and north Sinai where it is covered by a thick limestone/shale cover The aquifer transmissivity ranges between 11 m^2/d and 400 m^2/d However it attains minimum values of <1 m^2/d in the strongly folded areas

The groundwater in the lower Cretaceous aquifer flows from its southern and eastern outcrops towards the El-Thamad-Nakhl Zone, into central Sinai where it diverts east towards the Dead Sea-Wadi Arava in south Israel and west toward Ayun Musa area on the Gulf of Suez, with these two areas representing the aquifer natural discharge zones

The lower Cretaceous aquifer groundwater salinity ranges between 500 ppm-1500 ppm in southern Sinai plateau areas, to 1600 ppm-3000 ppm in central Sinai In the northern foreshore zone and western coastal zone of Sinai the salinity sharply increases to reach 227,000 ppm except in the area of Ayun Musa where it ranges between 2500-3000 ppm

The Lower Cretaceous aquifer storage capacity is estimated to be 1100 bcm, while that with groundwater salinity of ≤2000 ppm is 980 bcm The aquifer water balance estimation indicates that the total annual subsurface inflow in the aquifer toward central Sinai is 21 4 mcm, and the aquifer annual outflows toward the Dead Sea-Wadi Arava in South Israel is 15 mcm, and to Ayun Musa area is 6 mcm The sustainable and economic groundwater extraction plans from the Lower Cretaceous aquifer in Sinai for different use sectors has not yet been evaluated

At present, the total annual groundwater extraction from the different deep aquifer systems in Sinai is 3 199 mcm of which 1 89 mcm is used for agriculture and 1 309 mcm for domestic use Additional groundwater of 1 36 mcm/year can be utilized when putting the existing unused wells into operation These wells were drilled and equipped with pumping equipment, but their use not allocated to the various sectors

Based on the aquifer productivity, depth to water, and water quality, first priority areas for the development of the Lower Cretaceous groundwater in Sinai were identified to be at the down streams of Wadi Feiran and Wadi Gharandal in Western Sinai followed by the area between El-Minsherah, Nakhl and El-Bruk in central Sinai, and Wadi Watir in south Sinai

At present, the drilling of wells, supply of well pumping equipment, water storage reservoirs, well operation and maintenance are the responsibility of the MPWWR, while the water users are only responsible for the supply and maintenance of the drip irrigation systems

The results of the recently drilled deep test wells in the southern plateau areas of Sinai to test the lower Cretaceous aquifer, together with the available aquifer hydrogeologic data in the rest of Sinai, can adequately establish the data-base required for the recommended simulation model of the lower Cretaceous sandstone aquifer in Sinai The simulations model would be used to evaluate and assess the economic and sustainable groundwater potential of the Lower Cretaceous Sandstone aquifer for different use sectors, over time

It is recommended to allocate the deep well use sector before the implementing stage, to get the full use of it

The absence of groundwater monitoring system necessitates the establishment of monitoring well network in the areas of existing and future well fields to observe the deep aquifer response to groundwater extraction (water level and quality) A telemetry system is recommended centrally to receive continuous and regular well monitoring records from remote wells networks

Encouragement and incentives for greater private sector participation in well operation and maintenance in Sinai is recommended

1 INTRODUCTION

1 1 Overview

Egypt's Nile River water resources is under increasing stress due to increasing competition for available water Irrigation needs are expanding, as are domestic and industrial water needs due to population and industrial growth An increasing load of pollutants is threatening Egypt's water quality, environment and the health of its citizens The Ministry of Public Works and Water Resources (MPWWR) is the primary Egyptian governmental agency charged with the management of water resources Keenly aware of the need to improve the utilization efficiency, productivity, and protection of water resources in Egypt, the MPWWR and the US Agency fpr Internaitonal Development (USAID) in 1996-97 developed a "water resources results package' based upon years of earlier joint experience in water resources management projects

The package had four major results 1) improved irrigation policy assessment and planning process, 2) improved irrigation system management, 3) improved private sector participation in policy change, and 4) improved capacity to manage the policy process The MPWWR and USAID designed the water resources results package aimed at policy analyses and adjuctments leading to improved water use efficiency and productivity Specific objectives are

1 To increase MPWWR knowledge and capabilities to analyze and formulate strategies, policies and plans related to integrated water supply augmentation, conservation and utilization, and to the protection of the Nile water quality
2 To improve water allocation and distribution management policies for conservation of water while maintaining farm income
3 To recover the capital cost of mesqa improvement, and to establish a policy for the recovery of operation and maintenance costs of the main system
4 To increase users' involvement in system operation and management
5 To introduce a decentralized planning and decision making process at the irrigation district level

In early 1997, the water reources results package was folded into the USAID Mission's Agricultural Policy Reoform Program (APRP) APRP is a broad-based policy reform program ınvolvıng five Egyptıan Mınıstrıes (Mınıstry of Agrıculture and Land Reclamatıon (MALR), MPWWR, Mınıstry of Trade and Supply (MOTS), Mınstry of Publıc Enterprıse (MPE) and Mınıstry of Internatıonal Cooperatıon) APRP has the goal of developıng and ımplementıng polıcy reform recommendatıons ın support of prıvate enterprıse ın agrıculture and agrıbusıness

USAID supports the MPWWR ın five progam actıvıtıes under APRP These five actıvıtıes are 1) water polıcy analyses, 2) water polıcy advısory unıt, 3) water educatıon and communıcatıon, 4) maın systems management, and 5) Nıle Rıver monıtorıng, forecastıng and sımulatıon USAID supports the Mınıstry's efforts through cash transfers (tranches) based on performance ın achıevıng ıdentıfied and agreed upon polıcy reform benchmarks and technıcal assıstance

Technıcal assıstance for the water polıcy analysıs actıvıty ıs provıded through a task order (Contract PCE-I-00-96-00002-00, Task Order 807) under the umbrella of the Envıronmental Polıcy and Instıtutıonal Strengthenıng Indefinıte Quantıty Contract (EPIQ) between USAID and a consortıum headed by the Internatıonal Resources Group (IRG) and Wınrock Internatıonal Local Technıcal Assıstance and admınıstratıve support ıs provıded through a subcontract wıth Nıle Consultants

Thıs report ıs concerned wıth the hydrogeologıc settıng and the potentıal resources of the deep aquıfer systems ın the Western Desert and Sınaı, wıth specıal emphasıs on the Nubıa Sandstone aquıfer ın the Western Desert and Cretaceous aquıfers ın Sınaı

1 2 Objectıves of the Study

The specıfic objectıves of thıs study can be summarızed as follows

1 Revıew prevıous ınvestıgatıons to assess the hydrogeologıc characterıstıcs of the deep groundwater aquıfers ın the Western Desert and Sınaı, ıncludıng aquıfers lıthostratıgraphıc unıts, geometry, hydrogeologıc boundarıes, aquıfer hydraulıc parameters, potentıometery, regıonal groundwater flow, groundwater qualıty and the sustaınable and economıc deep groundwater resources whıch can be best utılızed for agrıculture and other use sectors

2 Identify priority areas for deep groundwater development and uses based on aquifer characteristics and potential

Identify areas with inadequate hydrogeologic information of deep groundwater aquifers in the Western Desert and Sinai in order to design a plan which will provide the information necessary to assess potential resources

1 3 Approach and Methodology

This assessment is based on information obtained from the following sources

(i) Review of documents, reports, and previous studies

(ii) Hydrogeologic data of the deep oil exploration wells and deep water test wells previously drilled in the Western Desert and Sinai (Unfortunately, the results of recent deep test drilling in north and south Sinai were not made available)

(iii) Data collected from the Irrigation Directorates during team field visits to several deep groundwater development sites in the Western Desert Oases and Sinai

1 4 Description of the Report

This report is a status report made up of six chapters Chapter 1 is an introduction highlighting the background and objectives of the study Chapter 2 describes the hydrogeologic characteristics of the deep aquifer systems in the Western Desert with special emphasis on the Nubia Sandstone aquifer system The evaluation of deep groundwater resources is presented and development priority areas are identified The hydrogeology of the deep aquifer systems in Sinai is presented in Chapter 3, focusing on the Cretaceous aquifers and their resource potential as well as the identification of areas of highest priority for deep groundwater development and exploitation Chapter 4 addresses the areas with inadequate hydrogeologic information in the Western Desert and Sinai and states plans for additional investigations to evaluate the regional setting of the deep aquifer systems and their groundwater resources Conclusions and recommendations are summarized in Chapter 5 and Chapter 6 contains a list of the references that have been used in the preparation of this report

2 -HYDROGEOLOGY OF DEEP AQUIFER SYSTEMS IN THE WESTERN DESERT

2 1 Previous Investigations

The groundwater resources of the deep aquifer systems in the Western Desert of Egypt have attracted the attention of investigators since the late 1920's Many authors have discussed the regional hydrogeologic conditions of the Western Desert and the areas of El-Kharga, El-Dakhla, El-Farafra, El-Baharıya, Siwa, East Oweinat and South Kharga-Toshka basin

Important contributions to the understanding of the regional hydrogeologic conditions in the Western Desert were made in investigations by Ball (1927), Hellestrom (1940), Shata (1953), Ezzat (1959) Burdon and Pavlov (1959), Parsons (1963), Ezzat et al (1962), Jacob (1964), Hemida (1968) Borelli and Karanjac (1968), Ezzat and Abu El-Atta (1974), Nour et al (1979), Joint-venture Qattara (1979) General Petroleum Company (1985) Thorwei (1987), Nour (1987), Talkhan (1988) and Shousha et al (1995), and the controlled hydrogeologic data from deep oil exploration wells, mainly located to the north of lat 28°N and about 400 deep groundwater wells drilled in the Western Desert development areas of El-Kharga, El-Dakhla, El-Farafra, El-Baharıya, Siwa, East Oweinat, South Kharga, and Toshka basin with depths ranging from 500 m to 1200 m

2 2 Physiographic Provinces of the Western Desert

The Western Desert is a plateau area (680,000 km^2) of rolling surfaces and rugged upland surfaces, cut by dry wadis The plateau is interrupted by natural depressions formed by erosion, weathering, faulting and folding Some parts are covered by rock rubble, or by bed rocks that crop out Great swaths of S-SE trending sand dunes also make up some of the plateau surface The regional slope of the plateau is eastward and its general altitude ranges from 200 to 400 meters above mean sea level (m a m s l)

The Western Desert may be divided into three principal physiographic provinces, as follows (Figure 2)

The Southern Plateau

The southern plateau extends over an area of 284,000 km^2, from the Nile Valley in the east to the Tebesti and Ennedi highlands (Chad) in the west, and from the highlands of Kordfan (Sudan) in the south to the Eocene-Cretaceous escarpment in the north The surface of this plateau is covered mainly by the known Nubia Sandstone sequences and islands of basement rocks developed mostly in the south Moving northward, the ground surface falls steadily from Gilf El-Kebir (average elevation 500 m a m s l) to the Kharga-Dakhla Oases (average elevation < 200 m a m s l) and towards the Nile Valley until it dips under the Eocene-Cretaceous escarpment

The areas of south Kharga-Toshka, East Oweinat, El-Kharga and El-Dakhla Oases are located within the southern plateau

The Central Plateau

The central plateau covers an area of 253,000 km^2 west of the Nile, and consist mainly of compact Eocene and Cretaceous limestones underlain by the softer clastics of the Mesozoic-Paleozoic age (Nubia Sandstones) In the south, it is well defined by the bold escarpment overlooking the sandstone low lands that form the floor of El-Dakhla and El-Kharga Oases In the east, it is interrupted by the Nile Valley where it forms towering cliffs The northern boundary is the steep scarp on the north side of Siwa and Qattara depressions and on the west, it is overlain by the Great Sand Sea

The plateau is broad and attains a maximum height in the extreme south of over 500 m a m s l From there it slopes gently northward, where it is interrupted by the large natural depressions of Siwa, Qattara, El-Natrun, El-Fareigh, El-Fayum, El-Rayan, El-Bahariya and El-Farafra and prominent siefs in the south, as the Abu Muharriq dune belt

The Northern Plateau

The northern plateau extends from the bold escarpment at Siwa and the Qattara Depressions northward to the Mediterranean, and from the Nile Delta westward to the Libyan border, covering an area of 122,000 km^2 The underlying rocks of this plateau are limestones and sandstones of Miocene age

2 3 Regional Geological Setting

2 3 1 Stratigraphy

Based on the results of surface geological mapping and deep test drilling in the Western Desert, the regional geological succession could be identified

A schematic geological map showing the distribution of the lithostratigraphic units is shown in Figure (3), while Figures (4) and (5) represent the stratigraphic type sections in the northern and southern parts of the Western Desert, respectively Descriptions of the different lithostratigraphic units in the Western Desert, which are of hydrogeologic importance are hereinafter given from older to younger

2 3 1 1 The Basement Complex

The basement complex is exposed prominently to the southwest in the Gebel El-Oweinat area, while small exposures occur in the areas between Oweinat and Aswan near Bir Tarfawi, Bir Nakhlai, Bir Dungul, Aswan and in the vicinity of Abu Bayan to the south of Kharga Oasis The basement is overlain by the Nubia Sandstone sequences and their contact surfaces are marked either by unconformity or by faults

The basement rocks consist mainly of granites and granodiorites Figure (6) is a basement relief map which was compiled based on the results of geophysical surveys with depth control from oil exploratory and water test wells The map indicates that the basement surface elevations range from +100 m near its outcropping areas in the southern part of the Western Desert to – 4500 m south of Siwa Oasis The map also shows several structural trends which may affect groundwater flow, as shown in Figure (7)

- Bir Dessouki-South Qattara Depression low
- Farafra – Baharıya – Abu Roash high
- North Gilf El-Kebir-Dakhla-Assiout low

- Bır Tarfawı-Abu Bayan hıgh
- Bır Kerım-Sın El-Kaddab low
- Bır Nakhlaı-Aswan hıgh

2 3 1 2 The Nubıa Sandstone Sequences

The Nubıa Sandstone sequence rests unconformably on the rugged surface of the basement complex, and comprıses all clastıc sedıments from the top of the Lower Cenomanıan (Upper Cretaceous) to the Pre-Cambrıan Basement The general geologıcal map (Fıgure 3), shows the area dıstrıbutıon of these deposıts on the surface The deposıts cover the floors of El-Kharga, El-Dakhla El-Baharıya Oases and extend outcroppıng ın western and southern dırectıons towards the El-Gılf El-Kebır- Nasser Lake basın area, whıle dısappearıng under a thıck blanket of clays and carbonates north of lat 25°N The Nubıa sandstones consıst of alternatıng beds of sandstone, shale and clay The average sand/shale ratıo ıs about 70 percent The shale and clay beds are laterally dıscontınuous and of varyıng thıckness wıth mınor lateral extent ın the southern part of the Western Desert and an ıncrease northward and westward

The Nubıa Sandstone ıncreases ın thıckness from 200 m to 700 m ın East Oweınat area, 300 m to 900 m ın El-Kharga Oasıs, 1 500 m ın El-Dakhla Oasıs, 2 200 m ın El-Farafra Oasıs, 1,800 m ın El-Baharıva Oasıs and 3,500 m west of El-Farafra Oasıs

In the vıcınıtıes of the basement outcrops, the thıckness of the Nubıa Sandstone ıs reduced to less than 50 m

2 3 1 3 Upper Cretaceous

From El-Kharga and El-Dakhla Oases northward, shale and carbonate rocks of the Upper Cretaceous age overlıe the Nubıa Sandstone sequence, formıng an ımpervıous cap

Wıthın El-Kharga and El-Dakhla Oases areas, the varıegated shales and the overlyıng Dakhla shales, of the Campanıon and Maestrıchtıan ages respectıvely, form the confınıng formatıon to the Nubıa Sandstone The thıckness of the varıegated shales varıes between 126 m ın El-Dakhla and 265 m ın El-Kharga Northward, the varıegated shales change ınto more sandy facies The Dakhla shales increase gradually from 130 m in south Kharga to 300 m in the southern part of El-Farafra, where it passes laterally northward into chalk forming an impervious floor in El-Farafra

South of El-Kharga, and El-Dakhla Oases, the Upper Cretaceous complex is missing and the Nubia Sandstone is exposed on the surface

2 3 1 4 Tertiary Deposits

The plateau area surrounding the depressions of south-Kharga, El-Kharga, El-Dakhla, El-Farafra, El-Bahariya, Siwa and Qattara is covered by Tertiary carbonate rocks of Eocene age Their thicknesses range between 500 m and 600 m around El-Dakhla-El-Kharga scarp and 150 m around El-Farafra Oasis

The Dabaa shale formation of Eocene-Oligocene age occurs underlying the Qattara Depression and extends northward to the northwestern coast and eastward to the Nile Delta, while pinching out to the west and the south of the depression The thickness of the Dabaa shales ranges between 150 m and 200 m

Basalt intrusions of the Oligocene age occur in several localities in El-Bahariya Oasis, Gebel Qatarani north of Fayoum and in the south Kharga area north of Gebel El-Asr

The lower Miocene Moghra formation is composed of sand and sandstone with clay and siltstone intercalations It overlies the Dabaa shales and extends from the western fringes of the Nile Delta to the Qattara Depression and southward to El-Fayoum It is facially changed into limestones and shales to the west of the Qattara Depression

The entire northern scarp of Siwa Oasis and the plateau north of the Qattara Depression is covered by the Middle Miocene Marmarica limestone formation (or Giaghboub formation) with a reported thickness of 80 m at Siwa Oasis

2 3 1 5 Quaternary – Recent Deposits

Lacustrine deposits are known to exist in El-Kharga Oasis, while sabkhas and salt marshes exist in the small depressions located at the western and southwestern edges of the Qattara Depressions (Qara and Tibaghbagh) and its floor

Sand sheets and sand dunes cover the surface at several locations, most conspicuously at the Great Sand Sea along the Western border between Siwa Oasis and El-Gilf El-Kebir, and Ghard Abu Muharriq between west El-Bahariya and El-Kharga Oases

2 3 2 Structural Framework

Based on the available geophysical data supported by geological evidence, the Western Desert has been subjected to several tectonic movements which resulted in the development of the following major structural blocks, shown in Figure (8), (Geofizika, 1966-Borelli, 1968 and Ezzat, 1974)

2 3 2 1 The Northern Up-Thrown Block

The east-west oriented Siwa Oasis is located in this block which is separated from the rest of the Western Desert blocks by the east-west fault running south of the Siwa Oasis and extending into Libya

2 3 2 2 The Middle Down-Thrown Block

The Ain El-Dalla Oasis, situated west of El-Farafra Oasis, is located within the Ain El-Dalla basin, oriented in a NE-SW direction The Kufra basin in southeast Libya is oriented in the same direction The Ain El-Dalla basin is situated along the axis of maximum development of the Nubia-type sandstones in the Western Desert

The El-Farafra – El-Bahariya uplift forms the eastern boundary of the middle down-thrown block, while its western boundary is formed by the jabal Dalma (Libya)-Bahariya-Abu Roash uplift

2 3 2 3 The Southern Up-Thrown Block

The southern up-thrown block occupies most of the area of the Western Desert, and contains the depressions of El-Baharıya, El-Farafra, El-Dakhla, El-Kharga, south Kharga and East Oweinat It is bounded in the northwest by the middle down-thrown block and in the southeast by the Nakhlai-Aswan swell The following northeast structural elements were identified within this block

- Farafra-Baharıya Uplift

  This uplifted zone is believed to be situated in a high permeability zone due to successive uplifting since it began during the Devonian structural stage

- Abu Tartur Uplift

  Located between El-Kharga and El-Dakhla depressions, this zone was formed during the Paleocene and rejuvenated during lower the Eocene time It is a northeast uplift, in a high permeability zone in El-Zayat area, midway between El-Kharga and El-Dakhla Oases

- Tarfawi – Abu Bayan Uplift

  This is a northeast oriented uplift, extending between Bir Tarfawi and Abu Bayan basement outcrop forming the eastern boundary of El-Kharga-El-Dakhla Oasis

- Nakhlai – Aswan Uplift

  This structural uplift extends between the basement outcrops in Bir Nakhlai – Barq El-Sahab - Aswan This is a northeast uplift and forms the southeastern boundary separating the Dakhla basin from the Nasser Lake basin

- North El-Gilf – Dakhla – Assiout Basin

  This basin lies in the middle part of the southern block, between north El-Gilf El-Kebir and Assiout, passing by El-Dakhla Oasis

- Pottery Hill Basin

  Pottery Hill basin is located between Abu Tartur and Tarfawi – Abu Bayan uplifts

- Kurayim Basin

  This is a small basin bounded to the west by Tarfawi – Abu Bayan uplift and to the east by the Nakhlai – Aswan uplift and includes the Darb El-Arbain area

- Nasser Lake Basin

  Nasser Lake basin is located to the west of Nasser Lake and bounded on the west by the Nakhlai – Aswan uplift The surface is occupied by the Nubia Sandstone sequences with some basement and basaltic outcrops The basin is dissected by E-W and N-S fault systems

2 4 Deep Aquifer Systems in the Western Desert

The lithology of the different stratigraphical units, their regional extent and general tectonic setting led to the development of several aquifer systems in the Western Desert These are as follows from younger to older (Figure 9)

2 4 1 The Moghra Aquifer System

The Moghra aquifer covers a wide tract of the Western Desert between the Nile Depression in the west, the Mediterranean coast in the north and the Baharya-Abu Roash uplift in the south (50,000 km^2) The Moghra formation is composed of sand, sandstone with clay and siltstone intercalations The base of the aquifer is formed by the Oligocene Dabaa shales/ basalt, and the top is the water table surface

The Moghra formation thickness varies between 200 m in the east (Wadi El-Fareigh) and 800 m in Abu Gharadiq basin east of the Qattara Depression, which gradually decreases to the north and west until it interfingers with the Miocene Marmarica carbonates and the Western Plateau carbonate/shale complex respectively Southward it disappears at the northern flank of El-Baharya-Abu Roash uplift The aquifer saturated thickness ranges from 75 m in the east to 700 m in the west (RIGW, 1990)

The Moghra aquifer exists under phreatic conditions south of lat 30^{0}N but is confined by Pliocene deposits in the north The groundwater table ranges between 10 m b m s l at contact with the Nile Delta aquifer in the east to about 50 m b m s l at the Qattara

Depression in the west and 48 m b m s l at Miswag well to the south of Qattara (Joint-Venture Qattara, 1979)

The results of pumping tests indicates that the average hydraulic conductivity of the Moghra aquifer ranges between 0 1-0 3 m/day in the Qattara surroundings and 10-25 m/day in the Wadi El-Fareigh (located at the desert fringes of the West Delta area), while the transmissivity ranges between 500 and 5,000 m^2/day

The salinity of groundwater in the Moghra aquifer changes from < 500 ppm in the area close to the West Delta region (Wadi El-Fareigh) and increases westwards to reach 10,000 ppm at El-Moghra Oasis in the eastern rim of the Qattara Depression

The aquifer groundwater is a mixture of paleo and renewable water It is reported that the lateral groundwater flow from the Nile Delta aquifer passes the Moghra aquifer with a low gradient of 10^{-4}- $2x10^{-4}$ of which part is intercepted at Wadi El-Natrun depression where it is lost bv evaporation The annual lateral seepage from the Nile Delta aquifer to the Moghra aquifer is estimated to range between 50-100 x 10^6 m^3 (RIGW – IWACO, 1992)

The Moghra groundwater resources evaluation was only assessed in the Wadi El-Fareigh project area, where a groundwater model study indicates the possibility of long term groundwater extraction at a rate of 120 mcm/year to irrigate an area of about 35,000 feddan At present, the groundwater extraction in Wadi El-Fareigh is 57 2 mcm/year to irrigate 12,700 feddan

2 4 2 The Fissured Carbonate Aquifer Complex System

Regionallv, this aquifer system comprises the calcareous water-bearing formations of Upper Cretaceous to Eocene deposits (UCE), in the central and northern parts of the Western Desert and the Lower to Middle Miocene in the western part of the northern plateau area (El-Diffa Plateau) It consists of limestones, dolomites, marls, chalk and shales

The surface outcrop area of the UCE aquifer is bordered to the south by Nubia Sandstone along the Oases of El-Dakhla and El-Kharga, and separated from the underlying Nubia Sandstones by the Upper Cenomanian – Lower Senonian low premeability shale-limestone

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complex In the northeastern part of the Western Desert, the aquifer is topped by the Oligocene Dabaa shales and plunges northward to more than 500 m b m s l The Miocene calcareous aquifer known as Jahgboub formation occurs outcropping in the northwestern part of the Western Desert overlying the UCE aquifer system The thickness of the UCE ranges from 150-200 m in El-Farafra Oasis to 500-10,000 m in the Siwa – Qattara area The Miocene aquifer attains a thickness of 100-400 m in El-Diffa plateau

Few wells have tapped the UCE aquifer in the central part of the Western Desert, where water levels are only known to be 80 m a m s l in El-Farafra Oasis, 62 m a m s l at Gebel Augilla and 48 m a m s l at Diyur well (Joint –Venture Qattara, 1979) The potentiometric levels of the Miocene Carbonate aquifer range between 1-10 m b m s l in Siwa Oasis and 60-180 m a m s l in El-Diffa Plateau (RIGW, 1997)

It was reported that the upward leakage of groundwater from the underlying Nubia Sandstone aquifer through faults, fissures and deep fractures obviously is the source of recharge to the UCE aquifer, (El-Ramly 1967, il Nouvo-Castoro-1985), while the Miocene aquifer is believed to be recharged by the groundwater inflow from Gebel Al-Akhdar in Libya

The UCE aquifer productivity is low reaching 120 m^3/day, while wells tapping the Miocene aquifer in Siwa Oasis are discharging water at a rate ranging from 120 m^3/day to 7,200 m^3/day (RIGW,1997)

Groundwater quality of the UCE aquifer has a very wide range In El-Farafra Oasis it is relatively fresh, with salinity less than 1,000 ppm, while in the southern part of the northern plateau salinity ranges between 2,000-5,000 ppm, and in the northeastern part of the Western Desert where the aquifer is capped by the thick Dabaa shales, the salinity rises up to 10,000 ppm (Joint Venture Qattara, 1979) The groundwater salinity of the Miocene aquifer ranges between 1,600 to 5,000 ppm in Siwa Oasis and from 3,000 ppm to 5,000 ppm in the southern part of El-Diffa Plateau and increases northward to reach 10,000 ppm

RIGW has recently completed a reconnaissance study on the "Regional Prospective of the Fissured Carbonate Aquifer System in Egypt" A preliminary attempt for estimating the carbonate aquifer potential was made using a numerical model based on the double porosity approach, but due to lack of data, the model did not succeed in estimating the long-term groundwater potential of the carbonate aquifer system (RIGW, 1997) The final report of the study (RIGW,1997) delineated areas with potential for groundwater resources development in the carbonate aquifer system which have to be investigated to better describe the aquifer hydrogeologic characteristics and to support the evaluation of these resources Of these areas, El-Diffa plateau area is recommended for future detailed hydrogeologic investigations to assess the groundwater resources of the carbonate aquifer which can be best used in development sectors, over time

2 4 3 The Nubia Sandstone Aquifer System

The hydrogeological setting of the Moghra and the Carbonate aquifers in the Western Desert described above, indicates that these aquifers are of comparatively limited extension and have not yet been adequatelv investigated for their groundwater potentials On the other hand, the Nubia Sandstone aquifer, although it is a non-renewable aquifer, holds large volumes of freshwater in storage, estimated to be of $2x10^{14}$ m^3 (Ezzat, 1974), which can provide groundwater resources for sustainable development in the Western Desert Therefore, in the following text, detailed hydrogeologic characteristics of the Nubia Sandstone aquifer in the Western Desert will be reviewed

2 5 Hydrogeologic Characteristics of the Nubia Sandstone Aquifer System

The Nubia Sandstones form a huge groundwater basin which covers the Western Desert and extends into southeast Libya, northwest Sudan and northeast Chad, and occupies an area of about 2,000,000 km^2 (Figure 10) In Egypt, the Nubia sandstones cover an area of 850,000 km^2, representing 43 percent of the total basin area

The Nubia Sandstone aquifer system has been subjected to numerous geological, geophysical and hydrogeological surveys, while detailed survey and test drillings were conducted in the depression areas of El-Bahariya, El-Farafra, El-Dakhla, El-Kharga, South Kharga-Toshka (designated as the New Valley) The results of these investigations together with the intensive oil exploration works in the northern part of the Western Desert made it possible to assess to a great extent the regional hydrogeologic setting of the Nubia Sandstone aquifer system

2 5 1 Definition of the Aquifer System

The Nubia Sandstone aquifer consists of the thick clastic sediment of sandstone, sandy clay intercalated with shale and clay beds, ranging from Cambrian to Upper Cretaceous in age

The Nubia Sandstone basin is tectonically affected by regional faulted structures (see Section 2 3) and is separated into different sub-basins or hydrogeologic blocks of which the Dakhla basin in the Western Desert has hydraulic continuity with the Kurfa basin in Libya and Sudan

The Nubia aquifer system behaves locally as a multi-layered artesian aquifer (designated as horizons A, B, C and D by Ezzat, 1974) but regionally it behaves as one aquifer system

2 5 2 Aquifer Geometry and Boundaries

The eastern, southern and western boundaries of the Nubia sandstone aquifer lie outside the Western Desert The eastern boundary is the natural boundary formed by the impervious Pre-Cambrian basement complex of the Red Sea mountain ranges The aquifer stretches far south into Sudan to the high lands of Kordfan, east into southeast Libya and to the Tebesti-Ennedi mountains in Chad Thus the Western Desert comprises only the northeastern corner of the huge Nubia Sandstone basin

Oil exploration drilling revealed that the Nubia fresh water aquifer north of El-Bahariya Oasis (lat 29^0 N) is underlain by saline water which sharply increases in thickness northward to the fresh/salt water interface, which follows a fault line located north of Siwa Oasis, crosses the Qattara Depression and then swings in a southeast direction south of Wadi El-Rayan The fresh/salt water interface represents the northern boundary of the Nubia fresh water aquifer system (Figure 10)

Although the Nubia Sandstone aquifer system is bottomed by impervious basement rocks, the base of the freshwater aquifer is formed in the Western Desert by two layers of a completely different nature

the surface of the basement complex in the southern and central parts of the Western Desert, and the interface surface between the fresh and salty groundwater within the Nubia Sandstone aquifer in the northern section of the Western Desert (north of lat 29^0 N)

Figure (11) shows the elevations of the fresh water aquifer base

The upper boundary of the Nubia Sandstone aquifer is exposed at the ground surface south of the southern plateau, where the aquifer is unconfined To the north, it disappears under a thick cover of the Upper Cretaceous-Eocene complex of shale-carbonate rocks, where the aquifer is confined Figure (12) is a contour map representing the top of the Nubia aquifer, indicating that it ranges between 200 to 1,000 m a m s l in the area of East Oweinat - El-Gilf El-Kebir To the north and west of El-Dakhla – El-Kharga Oases, the depth to top of the Nubia aquifer increases forming a basin of more than 1,000 m deep It comes close to sea level on a ridge running along El-Farafra - Bahariya and then it dips again to the north and east of Baharıya Oasis reaching a depth of more than 700 m b m s l

Figure (13) shows the isopacheous map of the Nubia Sandstone fresh water aquifer which varies between 100 to 600 m in Nasser Lake - South Kharga - East Oweinat area, 200-800 m in El-Kharga Oasis, 1 300 m in El-Dakhla Oasis, 2,200 m in El-Farafra Oasis, 1,800 m in El-Baharıya Oasis and reaches its maximum thickness of 3,000 m in Desouky basin south of Siwa Oasis The aquifer fresh water thickness decreases sharply north of lat 29^0 N until it pinches out at the fresh/salt water interface

2 5 3 Aquifer Hydraulic Parameters

To assess the hydraulic parameters of the Nubia Sandstone aquifer in the Western Desert, pumping tests have been conducted during thee period 1960-1995 by different agencies which include 64 tests in Kharga Oasis, 32 tests in Dakhla Oasis, 20 tests in Farafra Oasis, 10 tests in Baharıya Oasis, 5 tests in Siwa Oasis, 64 tests in East Oweinat, and 6 tests in Aswan – Nasser Lake areas Table 1 shows the local transmissivities of the aquifer zones being tested in the different Western Desert areas

Table (1) – Local Transmissivity of the Nubia Sandstone Aquifer, Western Desert

Area	Transmissivity (m^2/d)		
	Minimum	Maximum	Average
Kharga Oasis	60	3050	1380
Dakhla Oasis	380	3753	2437
Farafra Oasis	1080	2830	2200
Bahariya Oasis	238	3840	1600
Siwa Oasis	3300	4000	3500
East Oweinat	975	2750	2110
Aswan	120	520	316

The hydraulic conductivity of the Nubia Sandstone aquifer has only been determined from pumping and recovery tests on deep wells Borelli et al (1968), Ezzat (1974), and FAO (1976) collected and assessed the hydraulic conductivity of the Nubia Sandstone aquifer in El-Kharga and El-Dakhla Oases Gad et al (1971) determined the hydraulic conductivity values on the basis of the results of recovery tests carried out on 10 deep wells in El-Bahariya Oasis In El-Farafra, it was estimated from the analyses of aquifer tests (il Nouvo Castoro, 1985, GARPAD, 1994) The hydraulic conductivity of the aquifer has been determined by the analyses of long duration pumping tests conducted by the General Petroleum Company (1985) in the East Oweinat area Table (2) indicates the aquifer hydraulic conductivity in the tested areas in the Western Desert

Table (2) Hydraulic Conductivity of the Nubia Sandstone Aquifer, Western Desert

Area	Hydraulic Conductivity (m/day)		
	Minimum	Maximum	Average
Kharga Oasis	0 38	14 1	2 5
Dakhla Oasis	2 5	30 8	5 8
Farafra Oasis	2 3	10 5	6 5
Bahariya Oasis	2 8	32	9 5
Siwa Oasis	10	20	12
East Oweinat	10 8	20	12
Aswan	1 1	2 5	1 2

Because the transmissivity of an aquifer is the product of its thickness times its hydraulic conductivity and because of the multi-layered nature of shales and sandstones of the Nubia aquifer system in the Western Desert, it is necessary to distinguish between the tapped aquifer zone transmissivity as determined from well tests and the transmissivity of the whole Nubia Sandstone succession, i.e. the regional aquifer transmissivity which, in turn, is the product of the average hydraulic conductivity of the aquifer times its aggregate thickness as given in Table (3)

<u>Table (3) - Regional Transmissivity of the Nubia Sandstone Aquifer, Western Desert</u>

Area	Average Hydraulic Conductivity (m/d)	Average Aquifer Thickness (m)	Regional Transmissivity (m^2/d)
Kharga	2.5	600	1500
Dakhla	5.8	1200	6960
Farafra	6.5	2000	13000
Bahariya	9.5	1800	17100
Siwa	12	500	6000
East Oweinat	12	300	3600
Aswan	1.2	200	240

Source GARPAD (1981)

In the southern part of the Western Desert where the Nubia Sandstone formation is exposed at the ground surface and unconfined aquifer conditions prevail with aquifer specific yield values range between 0.1 to 0.2 North of lat 25^0 N, where the Nubia aquifer is under confined condition by the overlying blanket of shales - limestone cap rocks, the aquifer storativity ranges from $3x10^{-4}$ to 0.05 (Ezzat, 1974 and Nour 1983) The aquifer regional storativity was estimated from the specific storage (calculated from pumping tests as the storativity per unit thickness of tested aquifer), as follows

Aquifer regional storativity = specific storage (m^{-1}) x aquifer thickness (m)

Using the aquifer storativity value determined from pumping tests and calculating the specific storage values in the different tested areas of the Western Desert, a specific storativity map was prepared as shown in Figure (14) (Euroconsult/Pacer Consultants, 1983), and used to derive the aquifer regional storativity in terms of its total thickness

Pumping of groundwater from the multi-layered Nubia Sandstone aquifer system will create vertical hydraulic gradients and will result in vertical flow In this case, the water levels in the shallow and deep aquifer zones will change when water is extracted from one or both of them Therefore, the vertical permeability of the aquifer system must also be considered for proper simulation of the groundwater condition It should be made clear that the vertical permeability of Nubia sandstone must be low due to the frequent occurrence of shale intercalation within the sandstone beds

The vertical permeability of the Nubia sandstone aquifer, or its reciprocal, the vertical resistance, in the Kharga-Dakhla area, was 400,000 days, determined for the aquifer of 1,000 m depth (FAO 1979) For the Bahariya Oasis, the value of the vertical resistance of the aquifer was estimated to be 130,000 days due to more intensive fracturing, folding, and other tectonic movements (Euroconsult/ Pacer Consultants 1983)

2 5 4 Aquifer Potentiometry and Groundwater Flow Pattern

The potentiometric map of the Nubia Sandstone aquifer system constructed by Ball in 1927 has been modified by several investigators using improved aquifer data records and information Based on the measured potentiometric levels in the monitoring wells in the Western Desert (Figure 15), a modified potentiometric surface map was prepared by Ezzat (Figure 16) The aquifer piezometric levels in remote areas were interpolated with the potentiometric levels in Libya The map indicates that the groundwater elevations are 260 m in El-Gilf El-Kebir, 250 m in East Oweinat, 145 m in El-Dakhla Oasis, 80 m in El-Kharga Oasis, 130 m in El-Bahariya Oasis, 100 m in Siwa Oasis and – 50 m in the Qattara Depression The regional groundwater gradient is about 0 0007 with a groundwater flow pattern moving generally N-NE towards the major discharge areas at the Western Desert Oasis and the Qattara Depression, although the flow direction is distorted near the fault structures and diverted parallel to the fault plane due to the existence of very low permeability zone resulting from the silicification and/or the ferrugination of the Nubia

Sandstone formation along the fault zones The Giaghboub Oasis (Libya)-Siwa Oasis – the Qattara Depression, topographically low land, is considered the final base level of Nubia groundwater where natural lakes, sabkhas, and salt marshes exist The map also indicates obvious groundwater depressions forming closed sinks at El-Kharga Oasis, El-Dakhla Oasis, and the Qattara Depression due to long-term groundwater outflow

Ezzat, through flow-net analysis (1974) estimated the total annual recharge to the Western Desert Nubia Sandstone aquifer system to be about 3 36x10^6 m^3/day, of which 1 82x10^6 m^3/day inflows through the western front from Libya, 0 52x10^6 m^3/day inflows through the Gilf El-Kebir uplift and 1 02x10^6 m^3/day inflows through the southern front with Sudan

Although observation wells are scattered in and around the Western Desert oases, no regular groundwater monitoring data was found available since 1980 This is probably due to the remoteness of the monitoring wells and inadequate technical staff Table (4) shows the observed piezometric levels of the well monitoring network in the Western Desert Oases, which indicates that the rate of decline in the piezometric head ranges between 0 2 m/year and 2 2 m/year

2 5 5 Origin of Nubia Groundwater

The origin of the groundwater resources in the Nubia Sandstone aquifer, has been the subject of many hydrogeologic studies These studies have resulted in the following concepts

- The Allochtonous Concept This concept postulates a regional continuous groundwater recharge from the southwestern recharge areas (Tebesti and Ennedi in Chad) to the north and northeastern discharge areas in Kufra Oasis (Libya) and the Western Desert depressions which indicates that the groundwater is considered a renewable resource This concept is based on the observed groundwater gradient from the southwest to northeast

Table (4) Change in Piezometric Levels of the Observation Wells in the Western Desert

Monitored Area	Well Average Piezometric head(m a m s l) & Year of Observation	Change in Head During Observation Period (m/year)
Kharga Oasis		
Umm El-Qusur	77 4 (1967) * 55 5 (1997)	0 73
El-Malaa	64 5 (1962) * -11 51 (1997)	2 20
East Bulaq	40 1 (1968) * 26 5 (1997)	0 47
Baris -20	80 5 (1966) * 76 4 (1997)	0 13
Zayat -1	145 8 (1961) * 144 3 (1980)	0 08
Dakhla Oasis		
Mut-3	154 6 (1962) * 142 8 (1968)	1 97
Mut airport	130 9 (1965) * 123 6 (1997)	0 20
Mawhub west-2	140 9 (1964) * 138 3 (1968)	0 65
Mawhub west-15	150 0 (1969) * 148 0 (1978)	0 20
Balat - 8	146 4 (1962) * 133 8 (1968)	2 10
Farafra Oasis		
Qasr EL-Farafra	150 6 (1966) * 145 6 (1978)	0 42
El-Farafra - 1	151 8 (1965) * 147 0 (1978)	0 37
West Farafra - 7	157 8 (1967) * 154 8 (1983)	0 19
West Farafra - 11	152 (1967) * 149 7 (1983)	0 14
Bahariya Oasis		
EL-Maisra -1	127 8 (1963) * 120 (1970)	1 10
EL-Qasaa - 3	127 6 (1963) * 119 3 (1970)	1 20

Source

GARPAD (1981)
IL Nouvo Castoro (1985)
NVID (1997)

- The Authochtonous Concept This concept infers that the bulk of the groundwater was formed locally in the surroundings of the present discharge areas during one or more intervals of a more humid climate which prevailed over the desert, the last of which was 8,000 years ago This is based mainly on the interpretation of groundwater isotope measurements, which resulted in groundwater age dating ranging between 10,000 and 30,000 years B P Because no age gradient along groundwater flow lines has been observed, the groundwater of the Nubia aquifer is considered a non-renewable resource

2 5 6 Groundwater Quality

The Nubia Sandstones were deposited under shallow marine conditions and consequently were filled with salt water When the Nubia Sandstone was brought to its present continental position, fresh water recharge during the successive pluvial times flushed out the salt water to the maximum down dip northward to its present fresh – salt water contact This coincides with the trace of a fault plane forming a permeability barrier to the north of Siwa Oasis and crossing the Qattara Depression to the north of Ghazalat well, then swinging in a southern direction to lie south of Wadi El-Rayan depression This permeability barrier prevented any further flushing of the salt water northward, where the Nubia aquifer is still fully saturated with its saline formation water

The salinity of the Nubia Sandstone aquifer groundwater changes vertically and laterally To the south of lat 29^0 N the groundwater salinity ranges between 100 ppm and 500 ppm (Figure 17)

In general, the recorded salinity decreases, with depth in El-Kharga and El-Dakhla Oasis, from 1,000 ppm in the upper horizons to 200 ppm in the lower ones No change in groundwater salinity was observed during the last 30 years in the New Valley Oasis At Siwa – Qattara area, near the fresh–saltwater interface, the upper part of the Nubia aquifer is saturated with 200-400 ppm of fresh water and underlain by hypersaline water with chloride salinity up to 100,000 ppm The demarcation of the depth – water salinity profile, its density and piezometric heads is required to assess the sustainable potential of the fresh groundwater, which can be safely exploited in the development area of Siwa Oasis without causing quality deterioration

Although Nubia groundwater is fresh, it has been found to be highly corrosive This is due to the presence of free CO_2 and H_2S and the relatively low p^H and redox potential (Clark, 1962) which causes corrosion of well casings, screens and pumps

2 5 7 Groundwater Resources Evaluation

Assessment of the groundwater resources potential of the Nubia Sandstone aquifer system in the Western Desert was carried out using groundwater simulation modeling techniques which included analogue and numerical models A number of models have been used to simulate part or all of the Nubia Sandstone aquifer The regional models were used to perform a sensitivity analysis on the most important aquifer parameters, which will be considered for further detailed field investigations Figure (18) shows the boundaries of these regional models The results of the calibration for the initial aquifer condition are given in Table (5), which indicates different values due to the difference in model boundaries and aquifer parameters

The following presentation is a summary of the results of the numerical groundwater models which were developed to simulate existing and future groundwater extraction plans for different use sectors and their long-term consequences The current groundwater development plans in the Western Desert have been designed based on the outcomes of these models

2 5 7 1 Groundwater Model of the New Valley Region

This model was developed within the framework of the New Valley Regional Development Plan Study Project carried out by Euroconsult/Pacer Consultants (1983) The model study area covered the four oases El-Baharıya, El-Farafra, El-Dakhla and El-Kharga (Figure 19) It was developed to simulate different groundwater extraction plans, to predict the aquifer response over 100 years of exploitation and the economic return of its use in irrigated agriculture The model was calibrated for steady state conditions using pre-1960 data and for transient conditions for the period 1960-1980

The calibrated model was then used to test the economy of various groundwater development scenarios for irrigated agriculture Table (6) presents the final results of the prediction runs

Table (5) - Summary of Regional Models Calibration Results for Initial Condition of the Nubia Sandstone Aquifer in the Western Desert

Auther / Date	Model Type	Calibration Objective	Model Calibration Results										Inflow through boundaries (MCM/Y)
			Kharga Oasis	Dakhla Oasis	Farafra Oasis	Bahariya Oasis	Siwa Oasis	Nasser Lake area	Gilf el-Kebir	South Qattara Losses	Outflow through boundaries	Total Outflow	
Borelli et al (1968)	R C Analogue Model	(1)	400 1500	3000 4200	4500	6000		200					
Ezzat (1975)	Leap Analogue Model	(2)	67 16	115 72	0 73	189 8				28 72		662 11	Eastern Desert 18 98 Sudan front 193 815 Gilf el Kebir 449 315 662 11
Amer et al (1980)	Finite element Model	(2) (3)	105 92 2 5	150 93 5 7	6 61 4 2	54 91 7 6	69 03 4 8	 2	 8	87 03 4 8	Western boundary 114 92 Southern boundary 32 96	622 43	Western boundary 489 23 Southern boundary 133 19 622 42
Heinel & Brinkman (1987)	Finite element Model	(1)	500 1000	3000 4000	4000	2000	2000	500	3000	500			

(1) Aquifer calibrated regional transmissivity (m^2/day)

(2) Aquifer system water balance with outflow in the Oases including well discharges and natural losses and only natural losses in Qattara depression (mcm/year)

(3) Aquifer calibrated hydraulic conductivity (m/day)

Figure (20) shows the Nubia Sandstone aquifer long-term response to economic groundwater extractions

2 5 7 2 East Oweinat Model

A finite element, one layer model was developed by the Development Research & Technological Planning Center of Cairo University (DRTPC 1984) for the Nubia Sandstone aquifer system in the East Oweinat area (Figure 21) The model's objective was to forecast the long-term aquifer response to various groundwater development scenarios for irrigated agriculture

After being calibrated for the aquifer's initial condition, the model was used to test different groundwater extraction scenarios to assess the long-term safe pumping schedule The following constraints over an exploitation period of 100 years were used

- Decline in aquifer potentiometric level should not exceed half of its initial saturated thickness
- The maximum allowed decline in water level should not exceed 100 m

The results of the various simulated extraction scenarios indicated that groundwater pumping at a rate of 4 74 mcm/day could be safely implemented over a period of 100 years Predicted drawdown would range from 35 m to 100 m and the depth to water would be between 58 and 115 m b g l by the end of the 100 year period (Figure 22)

The groundwater development priorities in the East Oweinat area were ranked by the land development areas according to the decline of the aquifer water level and the depth to pumping level with a proposed extraction plan of 4 74 mcm/day for 100 years

Table (6) - Results of Forecast System Response to Groundwater Economic Extraction Plan in the New Valley, Western Desert

Development Area	Economic Groundwater Extraction (mcm/year)	Economic Pumping Level (m b g l)	Predicted Depth to Water After 100 Years (m b g l)	Total Possible Area to be Irrigated (feddan)
El-Kharga Oasis	110*	38	52	10,000
El-Zayat Area	14	62	64	2,500
Abu-Tartur Phosphate	22	---------	200	---------
El-Dakhla Oasis and Mawhub West	374	63	62	56,000
El-Farafra Oasis and Abu Minqar	410	115	65	65,000
El-Bahariya Oasis	115	96	75	20 500
Total	**1,045**			**154,000**

* Groundwater extraction in 1980

Source Euroconsult/Pacer Consultants (1983)

Figure (23) shows East Oweinat groundwater development priority areas where future groundwater utilization should be located Table (7) indicates the possible hydroagricultural potentials in each of the three priority areas

Table (7) – Groundwater Development Priority Areas, East Oweinat

Priority Rank	Total Area* (feddan)	Groundwater Availability (mcm/day)	Possible Area to be Irrigated (feddan)
1st priority	180,000	1 65	66,000
2nd priority	574,000	2 31	92,400
3rd priority	71,000	0 78	30,400
Total	**825,000**	**4 74**	**188,800**

* Area where groundwater extraction well-fields should be evenly distributed (3465Km^2)

Source DRTPC (1984)

The simulation model did not take into consideration the groundwater losses by evaporation in those parts of the modeled area where the water is near the ground surface Also, the economic aspects of long-term groundwater extraction in the East Oweinat area for irrigated agriculture have not been determined, which will have a serious impact in deciding the maximum economic and sustainable groundwater potential use in the area

2 5 7 3 South Qattara Model

Ezzat, et al (1977) developed a one-layer model to cover the areas of Siwa, El-Bahariya and El-Farafra Oasis (Figure 24) to verify the hydrodynamic parameters of the aquifer and to determine its response to future groundwater development

The analogue model was developed using the Electronic Circuit Analyses Program (ECAP) The model was run for steady and unsteady state conditions with development scenarios for El-Farafra, El-Bahariya and Siwa, using storativity values of 10^{-4} and 10^{-2} The results are presented in Table (8)

Table (8)-Predicted Drawdowns Against Groundwater Development in South Qattara Area

Development Area	Groundwater Extraction (mcm/year)	Initial Water Level (m)	S = 0 0001		S = 0 01	
			(1)	(2)	(1)	(2)
El-Farafra Oasis	364	164	351	361	141	142
El-Baharıya Oasis	182	132	335	345	118	130
Siwa Oasis	140	- 8	194	204	0 9	3 7

(1) Drawdown over 50 years (m)

(2) Drawdown over 100 years (m)

Source Ezzat et al (1977)

The South Qattara model did not take into account the lateral and vertical changes in groundwater salinity in the Western Desert north of lat 28^0 N This might have adverse impacts on the model results with regard to sustainable fresh groundwater extractions, especially in the Siwa Oasis Also, the economic groundwater potential in the three Oases for irrigated agriculture has not been evaluated

2 5 7 4 Nubia Basin Model

Soliman (1987), developed a two-dimensional finite element model which covers the Nubia basin on both sides of Nasser Lake (Figure 25) The objective of the model was to estimate the yield of the Nubia Sandstone aquifer at periods of low floods when the level of the lake is the lowest and the recharge to the aquifer is minimal

The results of the model indicated that the potential groundwater extraction from the aquifer, at the different locations selected for irrigated agriculture (Wadi Allaqi, Afia, Toshka, Abu

Simbel) amounts to 257 mcm /year with anticipated drawdowns ranging between 60 m and 70 m

2 5 7 5 Nubia Sandstone Aquifer Regional Model

Heinel and Brinkman (1987) developed a regional finite element model to simulate the Nubia Sandstone basin with its sharing countries This included Egypt's deserts, southeast Libya, northeast Chad and northwest Sudan The model covered an area of two million km^2 (Figure 26), and was constructed to test different concepts of groundwater origin, aquifer recharge and the long-term aquifer response to future groundwater extraction plans in the different aquifer sharing countries

The model was calibrated for both long-term simulation (since the last pluvial period of 8,000 years B P to the year 1960) and short-term simulation during the period 1960-1980 The results indicate that most of the groundwater in the Nubia Sandstone aquifer in Egypt and Libya is locally recharged during humid and semi-arid climatic periods Although there is some regional inflow, it is not sufficient to maintain equilibrium conditions under the present climate Therefore, the groundwater resource in the Nubia Sandstone aquifer system should be considered a non-renewable resource

The calibrated model was used to predict the aquifer long-term response to proposed future additional extraction in Egypt and Libya (Figure 27) The base period is 1980 with a planning horizon of 80 years The results of these extraction simulations showed the development of extraction cones in the different pumping centers as well as the interference between these centers A huge cone of depression was focused around the New Valley Oases The predicted drawdowns at the end of 100 years of extraction in the Western Desert groundwater development areas are shown in Figure (28)

2 5 8 Sustainable Groundwater Potentials

A number of model studies have been conducted by different consultants to simulate the Nubia Sandstone aquifer system in the different parts of the Western Desert, where irrigated agriculture development projects are expected to be initiated or expanded The numerical model developed for the Nubia aquifer in the Oases of the New Valley (Euroconsult/Pacer

Consultants, 1983) estimates the sustainable and economic groundwater extraction rates for irrigated agriculture and mining sectors at 1,045 mcm/year (see Table 6) The East Oweinat, South Qattara (Siwa Oasis) and Nasser Lake area models should be updated with available new hydrogeologic data, address the environmental consequences of the long-term groundwater extraction and estimate the economic feasibility of its utilization in different use sectors Table (9) and Figure (29) present a summary of the groundwater potential in the Western Desert

2 6 Present Status of Groundwater Development in the Western Desert

2 6 1 Basic Criteria

Within the context of the national development goals, the objectives of the regional development of the Western Desert are

Settling population away from overcrowded areas in the Nile Valley and Delta

Getting the maximum use of the existing natural resources in the isolated vast desert areas

Connecting these areas to the rest of the country

Creating new job opportunities for unemployed youths

The development activities in the Western Desert depend on the groundwater resources in the Nubia Sandstone aquifer As previously indicated, the natural recharge to the aquifer is presently limited It is essentially a non-renewable resource The planning of its exploitation and utilization should be based on a mining process that results in a continuous lowering of aquifer potentiometric levels over time For proper development and optimal utilization of such non-renewable resources, the following criteria should be satisfied

- Extraction of groundwater resources should be economic and rational
- The exploitation must be sustainable to assume prosperity for the coming generations

It should be noted that the results of groundwater monitoring in the Western Desert Oases areas indicate that exploitation of groundwater from the Nubia Sandstone aquifer usually starts with free-flowing conditions Over time as groundwater extraction rates increase, well artesian pressures decrease, resulting in the need for pumping

Table (9) - Available Groundwater and Present Extraction from the Nubia Aquifer System at Different Development Areas, Western Desert

Development Area	Present Extraction (1997) (mcm/year)	Total Available Economic Extraction (mcm/year)	Average Pumping Depth after 100 Years (m)	Economic Pumping Depth (m)
New Valley				
Kharga	118	110	52	38
El-Zayat	3	14	66	62
Abu Tartur Phosphate	7	22	200	
Dakhla & Mawhub West	291	374	63	63
Farafra & Abu Minqar	160	410	66	110
Bahariya	57	115	75	96
Total New Valley	636	1045		
East Owemat	31	1200* (Safe Yield)	<100	not yet defined
Siwa Oasis	20	140**	<100	not yet defined
Grand Total	687	2385		

* Groundwater resources should be reevaluated to asses the economic extraction rate

** Groundwater resurces should be reevaluated to asses the sustainable and economic extraction rate which can be safely utilized without quality deterioration

Source Euroconsult / Pacer Consultants, 1983

GARPAD, (1996)

El Mudallal, (1990)

2 6 2 Design of Well and Well-Field

During the early stage of the large-scale groundwater development scheme in the New Valley Oases (1960-1966), the groundwater development plans for irrigated agriculture were based on the followings concepts

1 The wells should continue to discharge naturally over time
2 The minimum spacing between wells should not be less than 2 km
3 The wells should be constructed to extract water from the deeper horizons of the Nubia Sandstone aquifer This would avoid over-exploitation of the shallow horizon from which the existing springs and native wells derive their water for irrigation
4 The deep irrigation wells were drilled based on the following design criteria
   - Depth 400-800 m
   - Production casing API, carbon steel 8 5/8″ or 9 5/8″casings
   - Screen of 6 5/8″ or 7″ diameter, made of carbon steel
   - The wells spaced 2 km apart without interlinkage
   - The area reclaimed per well based on 75 percent of the initial flowing discharge

The application of such well and well-field design resulted in the following problems specifically in El-Kharga Oasis

- The size of the production casing expected to be used during the pumping stage as pump house casing was too small for the well pump needed to produce the required water for irrigation
- The groundwater of the Nubia Sandstone aquifer is proved to be highly corrosive to normal steel pipes, pumps, and equipment used in well construction, which resulted in the collapse of the wells in a shorter period than expected

- The irrigated areas were small, sparse, and widely spaced Because the wells were not interlinked (minimum spacing of 2 km), in case of well or pump failure, it was not possible to transfer water from one well to another to provide irrigation water for the cultivated crops

Because of the above-mentioned problems, the design of the wells in the Western Desert development areas was reconsidered and modified to ensure maximum operating hydraulic efficiency, and to satisfy free flow and pumping stage criteria over their economic lifetime The following concepts were introduced

- Well production rate is the rate which can be efficiently produced from the well during its lifetime (20-25 years), based on the characteristics of the aquifer horizon tapped by the well, the critical economic pumping level in the area of the well-field and the maximum well operating hydraulic efficiency This rate should be set by considering the effects over the life of the well on free-flow and pumping stage regardless of the initial well discharge rate

- The expected pumping level throughout the well life-time

- The use of API standard steel well pump house casing and production casing which will be of suitable sizes and lengths to accommodate the required pump future pumping levels and minimize well losses Corrosion-resistant materials for the well screens and screen casings to ensure long life of the well should also be used

Details of present practices of well and well-field design for different development areas in the Western Desert will be presented later when discussing the present status of groundwater exploitation in these areas

2 6 3 Groundwater Exploitation Practices in the Western Desert

2 6 3 1 Historical Background

Even in ancient times, water from natural springs in the Western Desert Oasis originating from the Nubia Sandstone aquifer system was used Prior to 1960, a more systematic exploitation of groundwater resources was developed by the construction of shallow wells with depths from 50-70 m The upper most horizon of the aquifer was tapped by applying the cable tool drilling technique and using wooden log lining made from the dome trees

After 1960 deep wells, extracting water from the deep aquifer horizons with depths ranging between 300 m and 1,200 m, were drilled to provide water supplies for proposed large scale irrigated agriculture and new settlements in the New Valley Oases region at El-Kharga, El-Dakhla, El-Farafra and El-Baharıya

The groundwater extractions during the period 1960 to 1997 from the Nubia Sandstone aquifer system are presented by area in Table (10) The data given in this table were based on the observed discharges of the individual wells, which were measured every three months Well observations were carried out by the General Authority for Rehabilitation Projects and Agriculture Development (GARPAD) and the New Valley Development Authority (NVDA) until mid-1995 after which the New Valley Irrigation Department (NVID) of the MPWWR took over this responsibility

Table (10) and Figure (30) indicate that the total groundwater extraction from the shallow and deep wells tapping the Nubia Sandstone aquifer was 203 mcm/year in 1960 (from 1,043 shallow wells and 27 deep wells) and increased to 678 7 mcm/year in 1997 (from 904 shallow wells and 692 deep wells) Presently 271 7 mcm/year are extracted from 1,516 shallow wells and springs from the post-Nubia fractured carbonate aquifers in El-Farafra and Siwa Oases

2 6 3 2 Groundwater Conditions and Utilization in the Western Desert Development Areas

As previously stated, the Western Desert is a large plateau area with its surface in the central and northern parts consisting of limestone rocks The plateau is interrupted by a series of north-south oriented topographic depressions These are the south Kharga, El-Kharga, El-Dakhla, El-Farafra, El-Baharıya and Siwa Oases as well as the East Oweinat area (located in the southern sandstone plateau) where vast tracts of arable lands suitable for agricultural development exist

In the following sections the description of the present groundwater conditions and utilization in the different development areas of the Western Desert will be discussed

Table (10) - Groundwater Historical Extraction from the Nubia Sandstone Aquifer in the Western Desert during the Period 1960 1997(MCM/Year)

Area	Well Type*	1960		1965		1970		1975		1980		1985		1990		1995		1997		Total *** extraction
Kharga Oasis	S	279**	36 90	231	23 80	180	19 90	150	14 90	120	14 90	47	6 00	27	3 90	23	2 90	16	2 2	541 2
(including	D	12	15 80	96	64 20	102	61 90	125	65 70	141	78 60	178	107 90	175	121 30	162	126 1	192	119 1	3240 7
Zayat area)[1]	Total		52 70		88 00		81 80		80 60		93 50		113 90		125 20		129		121 30	3781 9
Dakhla Oasis	S	632	79 70	564	69 10	517	59 60	510	62 50	630	65 40	499	60 60	599	67 90	550	65 30	505	60 20	2460 2
(including Mawhub	D	15	37 90	95	152 90	106	150 80	114	146 20	151	187 53	194	212 10	228	207 10	252	201 00	305	230 70	6189 8
West area)[2]	Total		117 60		222 00		210 40		208 70		252 93		272 70		275 00		266 30		290 90	8650 0
Farafra Oasis	S****	23	0 85	23	0 85	23	0 85	23	0 85	23	0 85	22	0 80	23	0 73	16	0 68	16	0 67	76 8
(including Abu	D					1	1 10	1	1 10	1	1 10	20	46 30	40	83 30	97	159 36	97	159 36	1457 3
Minqar Area)	Total		0 85		0 85		1 95		1 95		1 95		47 10		84 03		160 04		160 03	1534 1
Bahariya Oasis	S	332	32 40	332	28 90	300	25 30	250	21 80	188	18 20	300	20 10	387	31 60	390	31 40	383	25 60	970 2
	D			9	10 40	12	10 10	15	10 50	25	15 20	39	20 10	42	22 80	40	25 10	59	31 00	940 6
	Total		32 40		39 30		35 40		32 30		33 40		40 20		54 40		56 50		56 60	1910 8
Siwa Oasis	S*****	200	69 4	200	69 4	200	69 4	200	69 4	200	69 4	700	155	1350	235	1500	271	1500	271	4939 8
	D															5	20	5	20	60 0
	Total		69 4		69 4		69 4		69 4		69 4		155		235		291		291	4999 8
East Oweinat	S														-					-
	D													10	10 5	10	10 5	34	30 5	113 5
	Total														10 5		10 5		30 5	113 5
Grand Total			272 95		419 55		398 95		392 95		451 18		628 9		784 13		913 34		950 33	**20990 1**

(1) Number of operating wells in Zayat area 7 wells pumped at a rate of 3 4 MCM/Year (1997)
(2) Number of operating wells in West Mawhub area 26 wells discharging at a rate of 60 85 MCM/Year (1997)

* S = Shallow wells , D = Deep wells
** Number of wells
*** Total Groundwater extraction during 1960 1997 (MCM / Year)
**** Shallow wells tapping Upper Cretaceous chalky limestone aquifer (Post Nubia Sandstone formation)in Farafra Oasis
***** Shallow wells tapping Middle Miocene Limestones aquifer in Siwa Oasis

Sources

GARPAD (1981) NVDA (1994)
El Mudallal, (1990) NVID (1997)

2 6 3 2 1 El-Kharga Oasis Prior to 1938, groundwater extraction in the Kharga Oasis was only confined to the uppermost horizon of the Nubia Sandstone aquifer through the natural springs and shallow wells (50 m to 70 m deep) Exploitation of deep aquifer horizons in the Oasis began during the period 1938-1952 when seven deep wells (300-500 m deep) were drilled as test-productive wells In the year 1960, when large-scale land reclamation started in the New Valley, development of groundwater from the deep horizons with free-flowing conditions was started to supply irrigation water, and to avoid over-exploitation of the shallow aquifer horizon, previously the only source of water

The groundwater conditions in El-Kharga Oasis can be summarized as follows

(a) Aquifer Hydrogeologic Setting

The detailed hydrogeologic studies of the Nubia Sandstone aquifer system in El-Kharga Oasis indicate that it is composed of four horizons of sandstone with shale and silt intercalations and separated by semi-pervious, discontinuous clay and shale beds as shown in Figure (31) The main hydrogeologic characteristics of the four aquifer horizons are given in Table (11)

Table (11) - Hydrogeologic Characteristics of the Nubia Sandstone Aquifer Horizons in El-Kharga Oasis

Aquifer Horizon	**Depth (m) From-To**	**Average Geologic Parameters**		**Average Hydraulic Parameters**		
		Total Thickness (m)	**Net Sand Thickness (m)**	**T (m^2 / d)**	**S (x 10^{-4})**	**Q (m^3 / hr)**
A	7-170	99	71	250	8	190
B	200-440	240	165	565	3	430
C	450-600	150	90	230	2	310
D	650-750	84	52	242	3	125

T Transmissivity S Storativity Q Expected well yield

Source Ezzat, (1974)

The shallow wells and springs in the Kharga Oasis take their water from horizon A, while the deep wells are tapping horizons B, C and D, with the majority from horizons B and C

Groundwater salinity in El-Kharga Oasis ranges between 200 ppm and 800 ppm, with no significant changes during the last 35 years of exploitation

(b) Groundwater Exploitation

Table (10) indicates that 279 shallow wells and springs and 12 deep wells were in use in El-Kharga Oasis in 1960, yielding a total discharge of 52 7 mcm/year, to irrigate an area of 5,800 feddan During the period 1960-1997, the number of deep wells increased to 185 to irrigate the new reclaimed lands and the old native lands and to substitute the shallow wells or springs that were abandoned

The present groundwater extraction in El-Kharga Oasis is 118 3 mcm/year (total economic extraction 110 mcm/year) of which 92 7 mcm/year is used to irrigate 17,000 feddan while the rest is allocated for domestic water supply (Table 12) Figure (32) shows the change in the number of active shallow and deep wells and their total discharges in El-Kharga Oasis during the period 1960-1997 It also indicates that the average daily discharge of the free-flowing deep wells has decreased from 3,598 m^3/day in 1960 to 1,400 m^3/day at present The rate of decline has been 61 1 percent during this period Out of 185 deep wells in El-Kharga Oasis, 180 wells are currently pump-operated and only 16 shallow wells are still free-flowing

The results of groundwater monitoring in El-Kharga Oasis during the last 35 years shows that a rate of decline in groundwater elevations ranged between 0 13 and 2 2 m/year

Table (12) - Deep Groundwater Exploitation in the New Valley Development Areas (1997)

Development Area and Water Use Sector	Present groundwater extraction						Total Number of Wells & Extraction rate (m3/day)		Present Cultivated Area (feddan)
	Flowing Wells		Pumped Wells		Springs & native wells				
	Number	*Total Discharge* (m3/day)	Number	*Total Pumpage (m3/day)*	*Number*	*Total Discharge (m3/day)*			
(1) Kharga Oasis									
* Agriculture	5	7000	158	274000	16	6000	179	287000	17000
* Domestic			22	37000			22	37000	
Total	5	7000	180	311000	16	6000	201	324000	
(2) El Zayat									
* Agriculture			7	8400			7	8400	700
Total			7	8400			7	8400	
(3) Dakhla Oasis									
* Agriculture	239	357000	27	57000	505	165000	771	579000	30500
* Domestic	39	48000					39	48000	
Total	278	405000	27	57000	505	165000	810	627000	
(4) West Mawhub									
* Agriculture	26	170000					26	170000	7000
Total	26	170000					26	170000	
(5) Bahariya Oasis									
* Agriculture	15	18000	29	51000	383	70000	427	139000	12500
* Domestic	15	16000					15	16000	
Total	30	34000	29	51000	383	70000	442	155000	
(6) Farafra Oasis & Abu Minqar									
* Agriculture	94	421700	-	-	16	1863	110	423563	14000
* Domestic	3	14900					3	14900	
Total	97	436600			16	1863	113	438463	
Grand Total	436	1052600	243	427400	920	242863	1599	1722863	81000

Source New Valley Irrigation Dept (NVID, 1997)
GARPAD (1997)

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The only groundwater development activity in El-Kharga Oasis currently is the replacement of old wells, with new ones The replacement wells in El-Kharga Oasis are being drilled according to the designs shown in (Table 13)

Table (13) – Current Well Designs in El-Kharga Oasis

Design Parameters	Shallow Wells	Deep Wells
Total depth	250m	650m
Aquifer horizon	A & B	B & C
Casings		
20″ conductor casing locally manufactured	30m	50m
API pump house casing	16″ (150m)	13 3/8″ (150m)
API production casing	---------	9 5/8″ (300m)
Screen & Screen casing	± 100m	± 200m
6 5/8″ stainless steel, grade 304		

Source Ezzat (1974)

2 6 3 2 2 El-Dakhla Oasis The results of previous detailed hydrogeologic investigations and well monitoring indicate that the groundwater conditions in El-Dakhla Oasis (including Mawhub West Area) are as follows

(a) Aquifer Hydrogeologic Setting

El-Dakhla Oasis can be geologically described as alternating synclines and anticlines with their axes plunging in a northeast direction Figure (33) shows an east-west hydrogeologic section along El-Dakhla Oasis It indicates that the four aquiferous zones A, B, C, and D of El-Kharga Oasis can be traced and correlated to continue in El-Dakhla Oasis, even though the deepest horizon was only partially penetrated as none of the deep wells reached its base The hydrogeologic properties of the Nubia Sandstone aquifer horizons in El-Dakhla Oasis are presented in Table (14)

The groundwater salinity in El-Dakhla Oasis ranges from 200-500 ppm in the upper horizon (A) while it varies from 150-800 ppm in the deep horizons No pronounced change in salinity has occurred during the past 35 years

Table (14) – Hydrogeologic Characteristics of the Nubia Sandstone Aquifer Horizons in El-Dakhla Oasis

Aquifer Horizon	Depth (m) From–To	Average Geologic Parameters		Average Hydraulic Parameters		
		Total Thickness (m)	Net Sand Thickness (m)	T (m^2/d)	S ($x10^{-4}$)	Q (m^3/hr)
A	80-180	127	97	825	7 6	65
B	190-490	280	252	1900	11	210
C	520-700	137	114	940	11	145
D*	>710					

* Not fully penetrated and tested

T Transmissivity S Storativity Q Expected well yield

Source Ezzat (1974)

(b) Groundwater Exploitation

By the time the intensive horizontal expansion activity was initiated in 1960, the total groundwater extraction in El-Dakhla Oasis was 117 6 mcm/year, discharged from 632 shallow wells and springs, and 15 deep wells to irrigate about 10 000 feddan (Table 10) At present a total of 505 shallow wells and 305 deep wells are being utilized with a total extraction rate of 290 9 mcm/year of which 273 4 mcm/year is used to irrigate 37,500 feddan, and 17 5 mcm/year is used for domestic purposes in El-Dakhla and Mawhub West area (Tables 10 and 12)

Figure (34) shows the development of groundwater exploitation in El-Dakhla Oasis and Mawhub West area during the period 1960-1997 It also shows that the average daily discharge of the free-flowing wells decreased from 6,923 m^3/day in 1960 to 1,891 m^3/day in 1997 This is a decline of 72 7 percent In the high topographic areas in the eastern part of El-Dakhla Oasis (Teneida and Balat areas), pumping of groundwater from 27 deep wells is already practiced

Periodic monitoring of groundwater levels in El-Dakhla Oasis indicates that the rate of decline in the aquifer piezometric pressures ranges between 1 2 m/year and 2 0 m/year

Since 1970, the well design shown in Table (15) has been used in El-Dakhla Oasis to satisfy both free-flowing and pumping conditions and to ensure economic well life

Table (15) – Current Well Designs in El-Dakhla Oasis

Design Parameter	Shallow Wells	Deep Wells	
Total depth	± 300m	± 500m	± 1000m
Aquifer horizon	A, B	B	C & D
Casings			
20″ conductor casing	± 50m	± 50m	± 50m
Pump house casing 13 3/8″ API	± 150m	± 120m	± 120m
9 5/8″ API production casing		From ±140m to ± 300 m	From ±140 m to ± 800 m
Screen & Screen casings 6 5/8″ Stainless steel grade 304	± 150m	± 200m	± 200m

Source Ezzat, (1974)

The main current groundwater activity in El-Dakhla Oasis – Mawhub West area is the rehabilitation of presently cultivated areas This includes replacement of the old wells which have exceeded their economic life and those shallow or deep wells which have ceased flowing or have severely decreased their free-flow discharge The current practice is to replace old wells (average depth 800m) by drilling new wells to tap the deeper horizon (1,000-1,200 m deep) at a cost of about 1 000,000 L E / well This is neither rational nor economic where the old wells are still structurally fit and can be equipped with a pump to increase the well water production, as the free-flowing discharges of the new wells do not exceed 2 000 m^3/day which result in the increase in the cost of extracting a unit of water

Due to the uncontrolled flowing groundwater conditions in El-Dakhla Oasis, Mawhub West area, serious water wastage and drainage problems exists It was noticed during a recent field visit to the area (November 1997) that the agriculture drainage lake near Mut, the capital of the Oasis, is used as a dump site for the area s untreated sewage water This prevents drainage water reuse for agriculture or aquiculture and causes adverse environmental effects Recently, in El-Dakhla Oasis, arable lands were allocated to be reclaimed by private investors, where a total of 27 wells have been drilled

2 6 3 2 3 El-Farafra Oasis

(a) Aquifer Hydrogeologic Setting

Several geological and hydrogeological studies of El-Farafra Oasis have been carried out either for the oasis itself or within the New Valley region

The hydrogeological studies conducted by Euroconsult/Pacer Consultants (1983) and il Nuovo Castoro (1986), as well as the results of deep test drilling have outlined the hydrogeological conditions of El-Farafra Oasis These studies indicate that the Nubia Sandstone section, which has been penetrated to a depth of 1 200 m, includes three main water-bearing horizons separated by shale aquitards (Figure 35) The hydrogeological characteristics of the three-aquifer horizons are presented in table (16)

The potential development of the first aquifer horizon is poor compared to that of the second and third horizons Therefore, for economic reasons, all of the deep wells in El-Farafra Oasis were completed in the second aquifer horizon

Although the salinity of the Nubia groundwater in El-Farafra Oasis is rather low and very suitable for all uses, it contains a high concentration of iron (2-20 ppm) which causes problems for use in drip irrigation, as it precipitates and clogs the drippers when it changes from ferrous into ferric ions immediately after being exposed to the atmosphere

Table (16) - Hydrogeologic Characteristics of the Nubia Sandstone Aquifer Horizons in El-Farafra Oasis

Aquifer Horizon	Average Geological Parameters		Average Hydraulic Parameters			
		Net Sand (m)	H(1)	Q(2)	T(3)	T D S(4)
Covering bed (Shale + Chalky Limestone)	0-200	-------	------	--------	--------	240-990
1st horizon	200-350	90-110	78	150	66-200	450-550
2nd horizon	450-750	235-280	149	450	2200-3370	150-250
3rd horizon*	950->1200	95->250	150	540	1815-2506	150-250

* Partially penetrated

(1) Piezometric head (m a m s l)

(2) Maximum possible well discharges (m^3/hr)

(3) Aquifer transmissivity (m^2/day)

(4) Groundwater salinity (ppm)

Source GARPAD, (1994)

(b) Groundwater Exploitation

Before 1965, the source of water supply in El-Farafra Oasis was confined to 23 springs originating from the upward flow of groundwater from the Nubia Sandstone along fault planes, fractures and joint systems and through the shales or chalky limestone of Maestrichtian age The total annual discharge was 0 85 mcm At present, the number of active springs has decreased to 16 with a total annual discharge of 0 68 mcm

During the period 1965-1967, 15 deep wells were drilled as test-production wells in El-Farafra-Abu Minqar area, to investigate the hydrogeological setting of the Nubia aquifer system The wells had a total initial combined discharge of 32 5 mcm/year These completed wells were left unused except for one well (Qasr El-Farafra) which was allocated for domestic use In 1982 when land reclamation activity began in El-Farafra (El-Nahda area) and Abu Minqar, an additional 8 production wells were drilled These wells naturally discharged groundwater at a rate of 25 4 mcm/year

During the period 1985-1995, a large-scale land reclamation scheme was implemented in El-Farafra and Abu Minqar areas A total of 73 wells were drilled in El-Farafra (Sheikh Marzouk and West Qasr El-Farafra projects) and 5 wells in Abu Minqar At present, 97 wells are in use in El-Farafra-Abu Minqar area, yielding naturally flowing groundwater at an annual rate of 160 mcm, of which 154 6 mcm/year is allocated to irrigate 14,000 feddan and about 5 4 mcm/year for domestic uses (Tables 10,12 and Figure 36)

The total reclaimed area in El-Farafra-Abu Minqar is 31,000 feddan, which will be irrigated by groundwater at a rate of 190 mcm/year

The groundwater monitoring data in El-Farafra Oasis was available only for the period 1965-1983 This data indicated a decline in the piezometric level of 0 14-0 42 m/year (see table 4)

At present the wells and well-fields in El-Farafra Oasis are constructed with the following design features (GARPAD, 1994)

Well design discharge 450 m3/hr

Well spacing 1 25-1 5 km

(for irrigated agriculture the wells are placed in a line along the main irrigation canal)

Well depth ± 800 m

Producing aquifer horizon Second horizon (± 500m to ± 800 m)

Casings

- 20" conductor casing to ± 50 m depth
- 16" API pump house casing to ± 200 m depth
- 11 3/4' API production casing (from ± 190 m to ± 550 m)

Screen and screen casing 6 5/8" made of stainless steel, grade 304 (± 250 m)

The present practice of groundwater use by the landowners in El-Farafra Oasis is to let the wells flow freely during the day This is because of the problem encountered with daily well shut-off as the well structure is too weak to withstand the effect of water hammer, no technical staff is available to gradually close the well to control its flow rate, and there are no night storage reservoirs which could be used to save the water wasted during the night to drains Comparing the rate of water allocated for the agriculture sector with the present cultivated area in winter (about 14,000 feddan out of 31,000 feddan of reclaimed area) one can conclude that the applied consumptive use appears to be rather high (11,040 m^3/feddan/year) compared to the normal applied water requirement/feddan in the area (7,500 m^3/year), which indicates a water wastage of about 50 mcm/year

2 6 3 2 4 El-Bahariya Oasis

(a) Aquifer Hydrogeologic Setting

The result of the detailed hydrogeologic studies of the Nubia Sandstone aquifer in El-Bahariya Oasis (Parsons, 1963, Ezzat, 1974, and Euroconsult/Pacer Consultant, 1983) revealed that the aquifer is exposed at the surface and attains a total thickness of 1,800 m It consists of four water-bearing horizons A, B, C and D separated by semi-pervious, regionally discontinuous clay and shale layers (Figure 37) Table (17) shows the hydrogeologic characteristics of the four aquifer horizons of the Nubia Sandstone in El-Bahariya Oasis

Table (17) – Hydrogeologic Characteristics of the Nubia Sandstone Aquifer Horizons in El-Bahariya Oasis

Aquifer Horizon	Depth (m)		Average Geologic Parameters		Average Hydraulic Parameters		
	From	To	Total Thickness (m)	Net Sand Thickness (m)	T (m^2/d)	S	K (m/d)
A	Surface	275	275	180	1450-3800	10^{-3}	17
B	290	440	150	80	600-650	10^{-4}	6
C	440	520	80	42	250-440 (C and D)	0 8 x 10^{-4}	4
D*	540	>650	> 110	> 45			

* Partially penetrated

T = Transmissivity , S = Storativity , K = Hydraulic Conductivity

Source GARPAD, (1981)

The groundwater salinity in El-Bahariya Oasis ranges between 200 to 700 ppm in the upper most horizon (A) and from 100 to 300 ppm in the deeper horizons

(b) Groundwater Exploitation

Before 1963, the existing shallow wells and natural springs were the only source of water for agriculture and domestic use in El-Bahariya Oasis Deep well drilling was initiated in 1963 as a part of a land reclamation plan Table (10) and Figure (38) show the development in groundwater extraction in El-Bahariya Oasis during the period (1963-1997) A total of 332 shallow wells and springs were in use in 1960 producing free-flowing water at a rate of 32 4 mcm/year, to irrigate an area of about 400 feddan

During the period 1963-1997, the number of deep wells has increased from 7 to 59, of which 29 are presently pump-operated Groundwater of the Nubia Sandstone aquifer is currently extracted at a rate of 56 6 mcm/year of which 50 7 mcm/year is used to irrigate an area of 12,500 feddan while the remaining 5 9 mcm/year is allocated for domestic purposes (Table 12)

The aquifer piezometric head in El-Bahariya Oasis has not been regularly monitored since 1970 and records are only available for the period 1963-1970 Table (4) indicates that the rate of annual decline in the piezometric level during this period was approximately 1 2 m The current implemented well designs in El-Bahariya Oasis are the same as those of El-Dakhla Oasis

2 6 3 2 5 *Siwa Oasis* The Siwa Oasis is considered a part of the Qattara Depression – Giaghboub Oasis (Libya) topographically low area, with its lowest ground surface elevation is about 10 to 18 m b m s l The Oasis is characterized by four main lakes along its lowest parts These are the Zeitun, Aghormi, Siwa and Maraki Lakes

At present the Oasis is facing serious water-logging and drainage problems which prevent the implementation of the required development plans This is due to the absence of any control on water-well drilling, the increase in groundwater extraction, the lack of proper development plans and the improper management of groundwater resources in the Oasis

(a) Hydrogeologic Setting

According to the results of the oil exploration wells and the deep test-production water wells which were drilled in Siwa Oasis and the surrounding areas, four major aquifer systems have been identified (Figure 39)

(1) The Quaternary-Recent Deposits Aquifer

This aquifer consists of alluvial deposits of sands, gravel, and calcareous rock fragments, sometimes with fractured limestone The thickness of this aquifer ranges from 10 to 20 m, while the depth to water ranges from 1 to 5 m below ground surface The reported water salinity is up to 5 000 ppm in the southern part of the Oasis and increases to 40,000 ppm in the area extending between Siwa and Zeitun Lakes The aquifer is recharged by seepage of irrigation water, the continuous flow of uncontrolled and poorly designed wells and from the upward flow from the underlying carbonate aquifers through faults and deep fractures

(2) The Middle Miocene Limestone Aquifer

This aquifer occurs under confined conditions, and is composed of two water-bearing zones

- The Upper Zone has thickness of 30 m, at a depth of 20 to 40 m It consists of hard limestone with shale intercalations Wells tapping this zone yield 10-30 m3/hr with a piezometric head of 1 to 5 m above ground surface The water salinity ranges between 2,500 and 2 800 ppm although it reaches 8,000 ppm in the areas near the sabkhas and salt marshes
- The Lower Zone has a thickness of 80 m, and is separated from the upper zone by 40 m of impervious shales and marls This zone exists at a depth of 70-150 m and consists of an upper part of hard limestone interbedded with thin layers of shales and marls, and a lower part of highly fractured dolomitic limestone bottomed by 30 m of shales and marls forming an impervious base The wells tapping this zone (depth 70 to 130 m) discharge water at an average rate of 35 m^3/hr, with a piezometric head of 5 to 10 m above the well head and a salinity range between 1,600 and 1,800 ppm

The recharge of the Middle Miocene aquifer is still questionable, although it was reported that it is recharged from the rainfall area at Jebel Akhdar in Libya (El-Mudallal, 1990)

(3) The Eocene Limestone Aquifer

This aquifer attains a thickness of 350-400 m, and consists of highly fractured limestone with thin marl and shale layers The limestone beds are very rich in gypsum, which is soluble in water causing large cavities and creating a karst zone at the interval from 290 m to 440 m, which was penetrated during deep test drilling in the Oasis The aquifer is underlain by the carbonate-shale complex of the late Upper Cretaceous (120 m thick) Although none of the drilled deep wells in the Oasis tapped this aquifer, quantitative analysis of well geophysical logs indicated that the average water salinity in the Eocene aquifer ranges from 6,000 to 7,500 ppm

(4) The Nubia Sandstone Aquifer

This aquifer is considered to have the highest potential for fresh groundwater in Siwa Oasis due to its vast extension in the Western Desert and its high water quality The Nubia aquifer system consists of the sandy sequences and shale intercalations occurring between the lower Cenomanian and the Pre-Cambrian basement complex

The results of deep test drilling in Siwa Oasis and the surrounding areas indicate that the thickness of the Mesozoic-Paleozoic clastics is up to 2,700 m The upper part belongs to the Lower Cenomanian at a depth ranging from 600 to 700 m below ground surface and has a thickness of 300 to 500 m It has good hydrogeologic characteristics and groundwater quality The drilling and testing of the deep wells in Siwa Oasis (El-Dakruri, Quaraishet, Bahai El-Din and Abu Shuruf wells) have been to a depth of 1,000 m The results indicate free-flowing discharges of 300 to 600 m^3/hr and a pressure head of 80 to 120 m above ground surface, with the following aquifer characteristics

- Average transmissivity 3300-4000 m^2/d
- Average hydraulic conductivity 15-20 m/d
- Total salinity 200-400 ppm

The drill-stem tests, which were conducted in the different lithostratigraphic units at the oil exploration well Siwa-1 (Joint Venture Qattara 1979), indicate that the groundwater salinity increases with depth as follows (see Figure 39)

Tested Interval (m)	Era	Geologic Age	Salinity (ppm)
797-810	Mesozoic	Cenomanian	465
1,122-1 125		Lower Cretaceous	1,500
1,865-1 870	Paleozoic	Carboniferous	14,000
2,000-2,500		Devonian	24,500

Previous hydrochemical studies of the Nubia Sandstone aquifer system to assess its freshwater saturated zone have indicated that the thickness of the freshwater aquifer progressively decreases to the north of the Qattara Depression-Siwa Oasis zone until latitude 29^0 30' N where the entire aquifer is saturated with saline or hyper-saline water

(b) Groundwater Exploitation

Before 1980, the only source of water in Siwa Oasis was the water discharged from 200 natural springs, flowing on the ground surface at an estimated rate of about 70 mcm/year, with salinity ranging between 1,800-8,000 ppm to irrigate about 2,000 feddan Much of the water was left to flow into the depression ponds, which form the present Oasis lakes These springs are recharged from the upper zone of the Middle Miocene limestone aquifer, although previous studies have indicated that the three large springs of Abu-Suruf, Quraishet and Mashandit springs (97,200 m^3/day) are recharged from the deep Eocene highly fractured limestone aquifer, through major fault systems

The time-dependent data regarding the discharges and water levels of the springs in Siwa Oasis showed a drop in the flowing discharge of 25 percent and 2 to 3 m in the water level during the period 1962-1990 (Arar, 1991)

Because of the decrease in the spring discharges (60 mcm/year in 1990), and to compensate for the water shortage, the local people started to construct hand-dug wells of 20-40 m deep Over 1,000 hand-dug wells were completed in the upper zone of the Middle Miocene limestone aquifer during the period 1981-1992, yielding a total discharge of 105 mcm/year In addition another 200 wells were drilled to tap the lower zone of the Middle Miocene limestone aquifer (70-130 m deep) These wells are yielding flowing water of 70 mcm/year

The total extraction from the carbonate aquifers in Siwa Oasis in 1990 was about 235 mcm/year which was mainly utilized in agriculture The current total cultivated area in Siwa Oasis is 10,000 feddan and the total extraction from the native shallow wells and spring is 271 mcm/year This indicates a rather high consumptive use of 27 100 m^3/year/feddan which together with the poor distribution of wells (concentrated in the low topographic area along the center of the Oasis) and improper well design (uncased or uncemented cased wells causing seepage of ascending water into the top soil profile) have resulted in wasted water at a rate of 196 mcm/year causing water logging, drainage and soil salinization problems in the Oasis

During the period 1990 to 1996, five deep wells were drilled and completed in the Nubia Sandstone aquifer to a depth ranging between 850 m (Army Well) and 1,000 m (Bahai El-Din Well) and are discharging freely at a rate of 20 mcm/year with a pressure head of 80-120 m above well head and a water salinity of 200-400 ppm

Table (10) and Figure (40) show the historical groundwater extraction from both shallow and deep wells in Siwa Oasis during the period 1960-1997, which indicate that the present groundwater extraction in the Oasis is about 291 mcm/year, of which 271 mcm/year is utilized in irrigated agriculture and the remaining 20 mcm/year is allocated for domestic use and the bottled water industry

The implemented well design at present in Siwa Oasis is shown in Table (18)

A comprehensive hydrogeologic investigation program is being conducted at present in Siwa Oasis by the Research Institute for Groundwater (RIGW) of the National Water Research Center (NWRC) The purpose is to assess the sustainable groundwater potential in the oasis, which can be economically utilized for irrigated agriculture and other uses The investigation is also intended to develop the necessary measures for proper management and conservation of the groundwater resources and to avoid environmental hazards such as water wastage, water logging and drainage problems

Table (18) – Well Design Practices in Siwa Oasis

Design Parameter	Shallow Well	Deep Well
Target aquifer	Miocene Limestone	Nubia Sandstone
Total depth	± 150 m	± 1000 m
Casings		
20″ locally made conductor casing	± 20 m	± 50 m
13 3/8″ API pump house casing	---------	± 200 m
9 5/8″ API production casing	---------	From ± 190 m to ± 800 m
12″ locally made casing	Surface to ± 80 m	---------
Screens		
12″ locally made, bridge slotted screen with gravel Pack	From ± 80 to ± 150 m	---------
6 5/8″ stainless steel, screen, grade 304	---------	From ± 800 to ± 1000 m

Source El-Mudallal, (1990)

2 6 3 2 6 East Oweinat Area The East Oweinat area is located in the southwestern part of the Western Desert, covering an area of 16,000 km^2 The area is designated to become one of the major areas for agricultural development in the South Valley region Groundwater and land resources are available to sustain irrigated agricultural projects in about 190,000 feddan to be implemented by private investors

During the period 1978 to 1985, comprehensive groundwater and land resource evaluation studies were conducted in the East Oweinat area by General Petroleum Company The results of these studies exhibited a high potential to support integrated development plans using the area's renewable solar and wind energy resources.

(a) Aquifer Hydrogeologic Setting

Geologically, the East Oweinat area is located in the Dakhla basin (Klitzsch, 1987), situated in the Oweinat-Aswan structural high. It is interrupted by a north-south oriented structural trough west of Bir Misaha as well as basement rock exposures at Qaret El-Mayet, Nusab El-Balgum, Bir Abu El-Hussein and Bir Nakhlai.

Groundwater occurs in the East Oweinat area in the Nubia Sandstone sequences, which unconformably overlies the basement complex forming an unconfined aquifer, except in those areas where frequent clay intercalations occur. Here it functions as a semi-confined aquifer. The depth to water ranges between 20 m and 60 m below ground surface, and the aquifer saturated thickness varies between 100 and 400 m in the uplifted shallow basement area and 500 to 700 m to the west of Bir Misaha and northward (Figure 41). The aquifer potentiometric levels range between 260 m.a.m.s.l. in the southwest and 230 m.a.m.s.l. in the northeast with a groundwater hydraulic gradient of $2.5x10^{-4}$ regionally oriented in a northeastern direction. The results of pumping tests indicate the following aquifer hydraulic characteristics:

- Transmissivity: 975-2750 m^2/day
- Hydraulic conductivity: 10-20 m/day
- Storativity: 0.16-0.23 for unconfined aquifer
  $2-8x10^{-4}$ for semi-confined aquifer

The groundwater salinity in the East Oweinat area ranges between 200 to 700 ppm. The groundwater resource evaluation study in the East Oweinat area estimate (DRTPC, 1984) the possibility of a safe groundwater extraction rate of 4.74 mcm/day over 100 years with a decline in the potentiometric levels of 35 to 100 m (see Figure 22).

(b) Groundwater Exploitation

During the period 1988 to 1995, MALR initiated a land reclamation pilot project in the East Oweinat area to irrigate about 6,800 feddan using drip and sprinkler irrigation. A total of 59 wells were drilled to a depth of 350 m (with 13 3/8″ pump-house casing to a depth of between

150 m and 200 m and a length of 200 m of 6 $^{5}/_{8}''$ screen) to provide the required irrigation water at the rate of 60 5 mcm/year when put into full production At present, only 32 wells are being pumped at an annual rate of 28 5 mcm (Figure 42) which is mostly used to irrigate an area of 3,000 feddan and only 0 6 mcm/year is used for domestic water In addition, an experimental farm of 200 feddan was initiated in the area in 1988 where irrigation water was supplied from two wells pumped at a rate of 1 4 mcm/year using solar energy Center pivot irrigation system was recently constructed by a private company to irrigate an area of 1,500 feddan within the previously reclaimed 6,800 feddan

In 1979, the GOE decided to implement a 200,000 feddan land reclamation plan in the East Oweinat area to be allocated to 20 private investors to establish irrigated agriculture schemes of 10,000 feddan each Nine monitoring wells have been drilled in the East Oweinat area, but no regular records of time-dependent groundwater levels, extraction rates and water quality data are available Regular groundwater monitoring will be of vital importance when the large-scale groundwater development begins

During a recent visit to the area (April, 1998), it was noticed that the ongoing groundwater development activities in the East Oweinat area are being carried out without the necessary control and follow-up by the New Valley Irrigation Directorate (NVID)

2 6 3 2 7 West Nasser Lake Area

(a) Aquifer Hydrogeologic Setting

In the Western fringes of Nasser Lake, the Nubia Sandstone aquifer consists of two main aquifer zones separated by shale and sandy shale The upper zone is unconfined with a maximum thickness of 200 m

The Lower zone is confined and reaches a maximum thickness of 300 m The aquifer hydraulic conductivity ranges between 1 to 1 2 m/day The groundwater quality in the area west of Nasser Lake ranges between 400 to 1000 ppm in the Upper zone and 2000 to 7000 in the Lower zone

Groundwater level observations in the area west of Nasser Lake indicate that the upper zone in hydraulic connection with the water of the lake and receives considerable recharge by seepage, while the Lower zone is hydraulically separated from the lake, except in the northern part of the area (Kalabsha) where monitoring wells showed groundwater response to the lake water fluctuations (Hefny, 1996)

Previous groundwater resource evaluation in the Nasser lake basin area (see Section 2 5 7 4) indicates the potential groundwater extraction from the Nubia Sandstone aquifer for irrigated agriculture development at Abu Simbel, Toshka, Afia may reach 200 mcm/year (Soliman, 1987, Hefny, 1991)

(b) Groundwater Exploitation

A number of deep wells (14) are under constuction along the main canal of Toshka project to provide water for the construction and to provide water for planned demonstration farms In addition (6) wells are being drilled by the Nasser Lake Development Authority for afforestation around Nasser Lake environmental protection zone The expected total annual groundwater extraction from these (20) is about 10 mcm

2 7 Long-term Deep Groundwater Development Plans in the Western Desert

2 7 1 Status of Groundwater Development

The development strategies in the arid areas of the Western Desert should focus primarily, on a rational allocation and exploitation of water, the scarcest resource In allocating the groundwater to various economic sectors (e g , agriculture, mining, tourism, industries, services) priorities have to be set for the exploitation of unique location-bound activities, such as mining and tourism The remainder of water resources can best be used for the rehabilitation and reclamation of potentially suitable soils

Since the allocated groundwater to the mining sector is fixed (24 5 mcm/year for Abu Tartur phosphate mine and El-Baharrya iron mine out of 679 mcm/year being extracted in the Western Desert at present), and since the allocation for the tourism sector is insignificant, the planning of the optimal use of groundwater resources has to be centered on the allocations to the agriculture and domestic use sectors

Before 1996, national large-scale land reclamation projects in the Western Desert were carried out by the Government, which usually included the development of basic infrastructures such as irrigator wells, irrigation and drainage networks, settlements and roads The reclaimed lands were then tenured to small farmers, investors, cooperative societies and graduates Since 1997, the GOE began to encourage the private sector participation in land reclamation activities in the Western Desert where about 235,000 feddan were allocated to be reclaimed by private investors in the East Oweinat and El-Farafra areas

Evaluation of the Nubia groundwater resources in the different development areas of the Western Desert indicates the viability of long-term groundwater exploitation for agriculture and other sectors over 100 years as follows

New Valley Oases	1045 mcm/year (see table 9)
East Oweinat	1200 mcm/year
Siwa Oasis	140 mcm/year

Total	**2385 mcm/year**

It should be made clear that long-term economic groundwater extraction was evaluated for the New Valley development areas of El-Kharga, El-Dakhla, El-Farafra and El-Baharnya Oasis, while it has not been estimated for future development in Siwa and East Oweinat areas Also, the Nubia Sandstone aquifer potential in the South Valley area, which extends between East Oweinat-Darb El-Arbain- Nasser Lake area has not been evaluated for sustainable and economic groundwater utilization

Previous soil surveys in the Western Desert have indicated vast areas of suitable land for irrigated agriculture, although only part of it can be developed on groundwater Table (19) indicates that the area of the highest land capability which can be readily reclaimed on Nubia groundwater is about 365,500 feddan of which 105,000 feddan had already been reclaimed by 1997

2 7 2 Future Groundwater Development Plans

According to the results of deep groundwater resources evaluation in the Western Desert, the present extraction rates for different use sectors (e g , agriculture, mining, domestic) as shown in Tables 9 and 12, and the GOE current plans to implement large-scale horizontal expansion projects in the South Valley region, the future deep groundwater development in the different parts of the Western Desert are summarized as follows

2 7 2 1 El-Kharga Oasis

No additional groundwater extraction is foreseen in this area as the present extraction (118 mcm/year) exceeds the maximum economic extraction rate (110 mcm/year)

2 7 2 2 El-Zayat – Abu Tartur Area

The total available groundwater extraction in El-Zayat – Abu Tartur areas is 36 mcm/year The present extraction in the two areas is 10 mcm/year of which 3 mcm/year is used in El-Zayat to irrigate 700 feddan (out of the 1,200 feddan already reclaimed) and 7 mcm/year in Abu Tartur for phosphate ore benefaction and domestic water supplies Thus, an additional groundwater extraction of 26 mcm/year can be pumped in both areas

2 7 2 3 El-Dakhla Oasis – West Mawhub Area

While the total available groundwater extraction in the area is estimated to be 374 mcm/year, the present extraction for agriculture and domestic use is 291 mcm/year Therefore, an additional groundwater rate of 83 mcm/year can be feasibly extracted from 57 new wells (1 44 x 10^6 m^3/year/well) It should be expected that the shallow wells and springs will cease flowing over the time, and a plan should be developed to drill the required number of properly designed replacement wells

2 7 2 4 El-Farafra Oasis – Abu Minqar Area

The total estimated annual economic groundwater extraction from the Nubia Sandstone aquifer system in El-Farafra Oasis – Abu Minqar area is 410 mcm The present extraction rate of 160 mcm/year is used for agriculture and domestic water supply, which is expected to be increased to 190 mcm/year when the existing wells are put into full operation

Table (19 Possible Future Land Reclamation Plan Utilizing Nubia Groundwater in the Western Desert (feddan)

Development Area	Total Priority Area for Reclamation	Present Reclaimed Area	Area Feasible for Future Reclamation on Groundwater	Remarks
El-Kharga Oasis & Zayat Area	48000	17000		No future expansion as present groundwater withdrawal exceeds the economic extraction rate
Dakhla Oasis & Mawhub West	56000	37500	18500	
El-Farafra Oasis & Abu Minqar	66000	31000	35000	
El Bahariya Oasis	20500	12500	8000	
East Oweinat	189000	7000	182000	Economic evaluation of groundwater utilization in irrigated agriculture is not yet assessed
Siwa Oasis	17000	-	17000	Present cultivated areas irrigated by groundwater from carbonate aquifer is 10,000 fed
South New Valley(Darb el-Arbain)	130000	-	?	Potential and economic groundwater extraction is not yet assessed
Ein Dalla (Farafra Oasis)	20000		?	
Total	546500	105000	260 000	

Source

GARPAD (1981)
Euroconsult / Pacer Consultants (1983)
NVID (1997)

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Recently, the GOE has allocated an additional 35,000 feddan to be reclaimed by the private sector in eastern Farafra (Karawin plain) where irrigation groundwater of 220 mcm/year can be feasibly exploited from 85 new deep wells that are going to be drilled by the investors (2 59 x 10^6 m^3/year/well)

The soil survey previously conducted in El-Farafra Oasis indicates an additional area of 20 000 feddan of high land capability recommended to be reclaimed in Ein Dalla – Wadi El-Obeid area to the north of El-Farafra Oasis, if the required groundwater is proved to be feasibly available (GARPAD, 1981)

2 7 2 5 El-Bahariya Oasis

A total economic groundwater extraction rate of 115 mcm/year can be feasibly utilized in El-Bahariya Oasis for multi-disciplinary development uses The present annual extraction of 57 mcm is used in agriculture (12,500 feddan) and domestic water supply, thus, future groundwater development at an annual rate of 58 mcm is envisaged, which can be obtained by drilling 40 new wells (1 44 x 10^6 m^3/year/ well)

2 7 2 6 Siwa Oasis

Previous Nubia groundwater resources evaluation has indicated the possibility of reclaiming 17,000 feddan in Siwa Oasis, using 140 mcm/year

Future groundwater development in Siwa Oasis is constrained by the existing serious water logging and drainage problems in the Oasis caused by the uncontrolled flowing wells and excessive groundwater outflow from the carbonate aquifer system It is necessary to re-evaluate the Nubia groundwater resources by using updated results of the detailed hydrogeological investigations currently carried out by the Research Institute for Groundwater (RIGW) to assess the maximum sustainable fresh groundwater extraction rate from the Nubia Sandstone aquifer in Siwa Oasis without causing water quality deterioration

2 7 2 7 South Valley Area

The South Valley area is located in the southern part of the Western Desert and extends between the East Oweinat area in the west, the Darb El-Arbain road in the middle and Nasser Lake in the east (Figure 43) This area was recently allocated by the GOE for national large scale horizontal expansion projects, based on the Nile water (Toshka Project) and the Nubia aquifer groundwater (East Oweinat, Darb El-Arbain road, and Aswan-Abu Simbel road irrigated agriculture projects)

2 7 2 7 1 The East Oweinat Area Although the result of the groundwater resource evaluation in the East Oweinat area indicated the possibility of a sustainable exploitation of the Nubia Sandstone aquifer at a rate of 1200 mcm/year over a period of 100 years the economic feasibility of groundwater utilization in irrigated agriculture in the area has not yet been assessed This will definitely determine the economic groundwater extraction rate and consequently the final scale of horizontal expansion in the area

The present groundwater extraction rate in the East Oweinat is 30 5 mcm/year, primarily used to irrigate an area of 3 200 feddan of the previously reclaimed area of 6,800 feddan

Recently, the GOE allocated 200,000 feddan to be reclaimed by twenty private investors, which were only concentrated in the second and third groundwater development priority areas (Figure 44), instead of being distributed over the whole planned aquifer development areas (see Table 7) This could result in a rapid and serious decline of aquifer potentiometric levels exceeding the marginal economic pumping level in a short period which will have serious impact on the sustainability of development in the area It is recommended that the areas allocated for future large-scale horizontal agricultural expansion as shown in Figure 44, be reconsidered regarding proper distribution of groundwater extraction patterns and rates based on the groundwater development priority areas, which should ensure sustainable and economic development in the East Oweinat area

2 7 2 7 2 Darb El-Arbain Road Area In the framework of the National South Valley Development Project, the GOE planned to establish agricultural community centers along the strategic road of Darb El-Arbain, which extends between Assiout on the Nile Valley in the north to the Sudanese border in the south and then continues into Sudan

Based on the results of previous geological, geophysical surveys and a few test wells in the South Kharga depression area, nine agricultural communities, spaced 20 km apart are being established at present along the Darb El-Arbain road, with a total area of 10,300 feddan The irrigation water will be supplied from 85 wells at a rate of 100 mcm/year It was estimated that such a groundwater extraction rate will result in a decline in the water level ranging between 35 m and 90 m over a period of 25 years (REGWA Co , 1997) The interaction between the two foreseen large-scale groundwater extraction centers at Darb El-Arbain and the East Oweinat has not been studied

2 7 2 7 3 *Aswan – Abu Simbel Road Area* This area is located within the eastern part of Toshka basin which is bounded in the west by Nakhlai-Aswan uplift and in the east by Nasser Lake western shore line

At present, 20 wells are planned to be drilled in the Toshka project area, of which (14) are under construction along the bank of main canal to provide water for construction and to be used later for demonstration farms The wells are being drilled to a depth of 300 m yielding 100 m^3/hr of salinity 400 – 700 ppm to irrigate 100 fed each The other 6 wells will be drilled for afforestation around Nasser Lake environmental protection zone The total expected groundwater extraction is about 10 mcm/year As the ongoing South Valley irrigated agriculture project of 540,000 feddan will depend on Nile water, the evaluation of the groundwater potential in the Nasser Lake basin has to be updated The updating should include the results of the new drillings in the area, the expected changes in the aquifer water balance due to future recharge by the infiltration of surface irrigation water The aquifer response to the GOE groundwater extraction plan to irrigate 145,000 feddan along the Aswan – Abu Simbel road should also be evaluated

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3 HYDROGEOLOGY OF DEEP AQUIFER SYSTEMS IN SINAI

The interest in water resources in Sinai dates back to ancient times, as evidenced by the well-known story of the prophet Moses He left Egypt with his people and wandered in Sinai for many years looking for a settlement, until he found the twelve springs (Moses's Springs) along the eastern coast of the Gulf of Suez

During the last two decades, interest in getting the maximum use of available water resources in Sinai, including the deep groundwater, has been considered by the MPWWR as part of their national development program

The Sinai Peninsula covers an area of approximately 61,000 km^2 It is triangular in shape with its apex formed by the junction of the Gulf of Aqaba and the Gulf of Suez in the south and its base by the Mediterranean Sea coastline between Port said in the west and Rafah in the east (Figure 45)

3 1 Previous Investigations

Many water resource studies have been undertaken in the Sinai Peninsula by various individuals and agencies during the last four decades

- Shata (1956) discussed the structural development of the Sinai Peninsula based on the geological studies done by petroleum companies He indicated that the Sinai Peninsula is divided into seven parts the Mediterranean foreshore, the mobile platform (including the major strongly-folded areas of Gebel El-Maghara, Gebel Yallaq and Gebel El-Halal), the northern stable platform (hing belt), the central Sinai slightly folded area, the central Sinai stable foreland, the southern Sinai Shield area, and the west and east Sinai rift areas (Suez rift valley and Aqaba rift valley)

- Geofizika Co (1963), carried out geological, geophysical, hydrological and hydrogeological and soil investigations in the northern, central and southwestern parts of Sinai, to assess the basic data and information of water and soil resources for future

agricultural development plans In this study, the geomorphological features and the geological succession were described
Both Wadi El-Karm and Wadi El-Letheili were found to be of high potential for surface and groundwater storage

The groundwater occurrences in the deep tertiary aquifers in El-Hemma basin and in the Lower Cretaceous Sandstones in the central part of Sinai were discussed with special emphasis to their recharge mechanism and salinity variations The groundwater resources in the southwestern part of the Peninsula were reported to be of low potential in the closed geologic structures due to high salinity Further detailed resource investigations should be limited to areas of open geologic structures, and should include the establishment of a number of rain gauges, a detailed geoelectrical sounding survey and the drilling of test wells

- Issar et al (1972) discussed the hydrogeologic characteristics of the Nubia Sandstone aquifer of the Lower Cretaceous to Upper Jurassic underlying central Sinai and the Negev (Israel) He estimated the aquifer storage capacity to be several hundred billion cubic meters, although only a small fraction of this water can be pumped A large part of the water in this aquifer is fossil, and its dating using ^{14}C, indicates an age range from 13,000 to more than 30,000 years

- Dames and Moore (1985) carried out a comprehensive study of the water resources of the Sinai Peninsula as a part of the Sinai Development Study Project Based on the existing stratigraphic data from 69 wells and 57 columnar sections and hydrogeologic data from 716 water points, Sinai was divided into seven groundwater provinces bounded by the occurring regional geologic structures Seven different lithostratigraphic groundwater-bearing units were identified, namely the Quaternary deposits, the Miocene sandstone, the Eocene limestone, the Upper Cretaceous carbonates, Lower Cretaceous sandstone, sedimentary rocks of Cambrian to Jurassic, and the fractured basements

  The study showed that the regional groundwater flow in the Lower Cretaceous sandstone aquifer tends to be strongly influenced by large-scale folds and faults In this aquifer, regional flow occurs generally northward and N-NE towards the Arava Valley – Dead Sea Rift in Israel, but another component of flow occurs towards the Gulf of Suez The study concluded that the southern mountains in Sinai generally have the best quality groundwater and the Suez Rift province has the worst among all the geologic units considered

Rate of recharge to the different deep aquifer systems in Sinai was estimated to be 90 000 m^3/day to the Lower Cretaceous Sandstones, 190,000 m^3/day to Middle Cretaceous Carbonates

The study indicated that groundwater extraction from the deep aquifers in Sinai is 2,000 m^3/day drawn from the Miocene, Eocene and Cretaceous aquifers

- The WRRI in cooperation with EEC, conducted a water resource study project in Sinai One of its aims was to assess the deep groundwater resources in Sinai, which included geological, geophysical and test drilling works The study summarized the hydrogeologic characteristics of the deep Upper and Lower Cretaceous aquifers and estimated the storage capacity of the Lower Cretaceous freshwater aquifer in Sinai (salinity < 2000 ppm) to be 980 bcm of which a total of 117 bcm can be extracted (Nour et al , 1993)

  A numerical model of the Cretaceous aquifers was prepared, but it was reported that the model calibration for aquifer initial condition did not succeed due to the lack of controlled aquifer hydrogeologic data in Negev area in Israel and inadequate information of the aquifer boundary conditions in northern and western Sinai

- During the period 1988 – 1992, JICA executed a groundwater resources study in North Sinai Nineteen test wells were drilled and seven were completed into the Lower Cretaceous Sandstone aquifer

  The study concluded that the Lower Cretaceous aquifer was recharged in the South Sinai area approximately 20,000 years ago, and that the groundwater quality in South Sinai is better and has more potential than that in north Sinai The study's final report included a series of hydrogeological maps for north Sinai and recommended expanding the study to south Sinai for better evaluation of the aquifer groundwater resources in the whole Sinai Peninsula

- The water resources in the area of Wadi Watir, southeast Sinai was the subject of the study project "South Sinai Water Resources Development' conducted in 1995 by the WRRI, and financed by a grant from the Italian Government through the local Italian Commodity Fund The project included geological, geophysical and hydrogeological studies as well as the analysis of hydrogeological data of wells drilled in the Wadi Watir area

  The study indicated that the Lower Cretaceous Sandstone aquifer is the most promising aquifer in the study area in terms of its potential and water quality The storage capacity of the aquifer is estimated to be 320 bcm, while the annual groundwater inflow is estimated at 50 mcm To satisfy the water demands estimated at 10,500 m^3/day by the year 2030 in the Wadi Watir area, a groundwater development plan was proposed to include drilling of five deep wells and two shallow wells beside five existing wells

3 2 Physiographic Features of Sinai Peninsula

The southern portion of Sinai consists of an intricate complex of rugged mountains formed by the Pre-Cambrian igneous and metamorphic rocks A major part of the peninsula comprises a massively developed limestone plateau One of the largest drainage systems is formed by the Wadi El-Arish with its many tributaries The eastern and western edges are dissected by deep gorge drainage into the Gulf of Aqaba and the Gulf of Suez respectively In the northern portion, the regional dip slope is broken up into many large hills followed northward by a belt of low lands, with high sand dunes along the Mediterranean coast The main geomorphologic units in the Sinai can be described as follows (Figure 46)

- The eastern rift basin is situated along the eastern coast of the peninsula consisting of a strip of low land between the Gulf of Aqaba and the basement ridges

- The western rift basin is situated along the west coast of the peninsula, and is a part of the Gulf of Suez down-faulted rift valley

- The basement ndges are composed of the ıgneous core of the Sınaı sıtuated ın the south of the Penınsula The hıghest peak of these ndges ıs Mount St Catherıne, whıch attaıns an altıtude of 2,630 m a m s l

- The structural plateau occupıes 40 percent of the penınsula and ıs represented by El-Tıh Plateau (500-1,000 m a m s l) and El-Egma plateau (500-1,500 m a m s l), sıtuated ın the central part of Sınaı The surface of these plateaux are underlaın by Cretaceous and Eocene lımestone beds, and are strongly dıssected by compıled draınage lınes, whıch debouch northward (Wadı El-Arısh) or eastward towards the Gulf of Aqaba or westward towards the Gulf of Suez

- The mobıle plateau ıs formed by several domes, at Gabals El-Maghara, El- Halal, Rısan Aneıza, El-Geddı, Yallag, and forms a zone that coıncıdes wıth the mobıle shelf of Sınaı

- The north coastal plaın belongs to the Medıterranean foreshore and ıs tılted seaward

- The deltaıc plaın ıs represented by the alluvıal and floodplaıns and ıs found ın a small part of the western Sınaı near Lake Tımsah

3 3 Regıonal Geologıcal Settıng

3 3 1 Stratıgraphy

Fıgure (47) shows a schematıc geologıc map of the Sınaı Penınsula (EGSMA, 1981), whıch ındıcates the dıstrıbutıon of the dıfferent formatıon unıts Based on the results of deep test wells (Fıgure 48), the lıthostratıgraphıc rock unıts of the northern and southern parts of Sınaı could be ıdentıfıed and presented as shown ın Fıgure (49), and as descrıbed ın the followıng from older to younger

3 3 1 1 Pre-Cambrian Basement Complex

Pre-Cambrian crystalline rocks make up the bulk of the southern mountains, and are mainly composed of igneous and metamorphic rocks with joints, fractures, and fault zones

3 3 1 2 Paleozoic Rock Units

The undifferentiated Paleozoic rock units were described from their surface exposures at Umm Bogma in west Sinai and from subsurface sections penetrated in central and southern Sinai, (Wells Nakhl-1, Shaira-1, Feiran-1, and Wadi Gharandal-1, 3) Lithologically the undifferentiated Paleozoic sequences consist mainly of sand and sandstone with thin shale interbeds There are also marine dolomitic beds (Umm Bogma formation of Carboniferous age) making up part of the section (Said, 1962) The total thickness is about 350 m in the central parts of Sinai and increase northward to reach 714 m at well Abu Hamth in Nakhl area

3 3 1 3 Mesozoic Rock Units

3 3 1 3 1 *Triassic Rock Unit* The Triassic Areif El-Naga formation is exposed at Gebel Arief El-Naga in central east Sinai, attaining a thickness of about 400 m Similar sections are encountered in the subsurface at Nakhl area Lithologically, the formation is made up of limestone with shale and sandstone intercalations Southward the section becomes more continental, mostly of sandstone facies

3 3 1 3 2 *Jurassic Rock Unit* Jurassic rocks cover the cores of the domal structural areas at Gebel El-Maghara, Risan Eneiza, El-Minshera and others (EGSMA, 1981) The maximum reported thickness of this unit reaches 2,200 m at Gebel El-Maghara The section consists of about 45 percent limestone and dolomite, 25 percent shale and 30 percent sandstone (Al Far, 1966)

Results of deep drilling at Wadi Feiran, Wadi Gharandal and south Nakhl indicate that the percentage of sandstone increases in south Sinai A gradual thickening was found to be associated with the increase of marine sediments northward The Upper Jurassic Massajid formation is one of the main groundwater-bearing formations in El-Maghara area

3 3 1 3 3 *Cretaceous Rock Units* These rock units were deposited over the uneven, highly corrugated surface of the Pre-Cretaceous rocks The Cretaceous units are divided into Lower and Upper Cretaceous

a) The Lower Cretaceous unit known as the "Malhah formation" (corresponds to Nubia sequences in the Western Desert and Kurnub formation in Israel) is reported to be the deep groundwater aquifer in Sinai with the most potential for development as a water resource The formation was the main focus in a deep groundwater investigation in Sinai, and several deep wells were drilled to assess the Malhah formation hydrogeologic characteristics It consists of sandstone and sand with shale intercalations in the central and southern parts of Sinai, while it facially changes into limestone and shale to the north of the Gebel Maghara and Gebel El-Halal strongly-folded zone (where it is known as the Rizan Aneiza formation) (Figure 50) The Lower Cretaceous formation attains a thickness of 200 m at Nakhl, 550 m at El-Maghara, 700 m at the core of Gebel El-Halal and 975 m to the site of El-Khabra oil exploration well and thins out south of Nakhl and El-Thamad zone until it reaches 150 m near its southern outcrops (Figure 51) The depth at the top of the Malhah formation ranges from 100 to 500 m in south Sinai, 600 to 900 m around Nakhl and 1,000 to 1,200 m in the area between El-Hasana and El-Gifgafa area The formation was penetrated at shallow depth of 122 m at Ayun Musa (well no 45), 90 m at El-Hamra (well no 46), 44 m in the vicinity of El-Minsherah domal structure (well no 34) and at ground surface at Gebel Falig (well no 27) Figure 52 shows the iso-depth contour map to the Lower Cretaceous Malhah formation from the ground surface The map indicates that the depth is getting deeper in the central part of the area between Nakhl and El-Hasana, and in the northern part between Gifgafa, Baghdad and Wadi El-Amro

b) The Upper Cretaceous unit represents a marine section, which includes Cenomanian, Turonian, and Senonian rock units It consists mainly of limestone, dolomite, shale mark and thin sandstone beds The Upper Cretaceous can be described under the following formations from older to younger
    - The Raha (Galala) formation is of Cenomanian age and consists of limestone, marl, shale and sandstone beds which are exposed on the scarp face of Raha

plateau ın West Sınaı, overlyıng the Turonıan – Santonıan beds and underlyıng the Lower Cretaceous Malhah formatıon and attaıns a thıckness rangıng from 170 to 200 m

- The Wata Formatıon ıs of Turonıan age, exposed at Wadı Wata and Raha plateau ın west central Sınaı It consısts of about 55 m sılıceous, partly dolomıtıc lımestone ınter-bedded wıth thın marl and shale bands It has a wıde dıstrıbutıon at El-Tıh plateau, to the west and east of Sınaı and around the northern domal structures, e g Gebel Mahgara, El-Halal, Yallaq and others

- The Matalla Formatıon ıs of Santonıan age It conformably follows the Turonıan rock unıt, and ıs exposed along the walls of the Egma Plateau, on the surface ın the downthrown sıde of the major east–west Ragabat El-Naam fault whıch extends west from Wadı Raha, north of Taba ın the east and covers the low lands between the hıghly-folded areas ın north Sınaı (El-Maghara, El-Halal and Um Hoseıra), Gebel Yallaq, Arıf El-Naga and El-Kherım ın central Sınaı The formatıon has a thıckness of 170 m consıstıng of sand, shale, marl and brown lımestone beds

- The Sudr Formatıon ıs of Upper Campanıan – Maestrıchtıan, lıthologıcally consısts of about 100 m of snow whıte, chalky lımestone and marl, but ın places ıts thıckness reaches up to 220 m, as ın Sudr area, west Sınaı

<u>3 3 1 4 Tertıary Rock Unıts</u>

3 3 1 4 1 *Paleocene Rock Unıts* Represented by Esna shale, whıch consısts of greenısh gray shales ınterbedded wıth chalk and marly lımestone, the Paleocene rock unıt occurs as a thın well mapable rock unıt exposed and located along the scarp face of El-Tıh and Egma plateau areas The thıckness of the unıt reaches 70 m

3 3 1 4 2 *Eocene Rock Unıts* The Eocene rock unıts occur over a wıde area ın the central and northern parts of Sınaı, and unconformably overlıe the Cretaceous formatıons The Eocene rock unıts can be classıfıed ınto

- The Lower Eocene (Thebes Formation) which consists of limestone, marl at base, with a thickness reaching 40 m

- The Middle Eocene (Mokattam Formation) consists of about 200 m of highly fossiliferous massive limestones

- The Upper Eocene (Maadi Formation) has a limited distribution in West Sinai (Gabal Hammam Faraun) where it consists of grits, marl and sandstone with thin conglomerate beds The thickness reaches 16 m

3 3 1 4 3 *Oligocene Rock Unit* The Oligocene rock unit has a limited extension and unconformably overlies the Eocene formation It consists of about 45 m of brown tuff and basalt overlying a black sandstone, breccia and conglomerate At the coastal area of Sinai, the Oligocene section becomes marine represented by about 700 m of shales, siltstones and sandstones

During the Oligocene, the area was affected by a series of volcanic activities Parallel dolorites and basalt dikes and sills cut across the Cretaceous and Eocene rock units in Wadi Gharandal-Gebel Somar area

3 3 1 4 4 *Miocene Rock Units* The Miocene sediments, with relatively greater thickness, have been reported in the coastal area of northern Sinai and to the west of Sinai, ranging between 1 000 m and 1,350 m as encountered in well Sneh –1(well no 3) Thin Miocene sands were drilled south of El-Arish at well El-Misri–1 (well no 2) attaining a thickness of 118 m Miocene fractured basalt was penetrated in El-Hemma – El-Hasana area At well Habashi-1, west of the Great Bitter Lakes, the Miocene sands were encountered at the depth interval of 480 – 533 m

3 3 1 4 5 *Pliocene Rock Units* The Pliocene rock unit consists of shale, siltstone, sandstone and limestone interbeds, with an increasing thickness northward reaching 250 m in well Sneh-1 A Pliocene lacustrine facies is recorded at El-Kuntilla at Wadi Gerafi area The Pliocene shale and clay form the base of the Quaternary deposits in the coastal zone between Romana and Rafah

3 3 1 5 Quaternary Rock Units

These units consist of calcareous sandstone (Kurkar) at the northeastern coastal area, with alluvium sand and gravel cover They also consist of old beach deposits of 20-60 m thick along the coastal zone between Sheikh Zuwayid and Rafah and the sand dunes extensively distributed in the coastal plain which range between 20 m and 30 m thick, as well as the alluvial deposits forming the Wadis beds

3 3 2 Major Structural Elements

Figure (53) shows the major structural features in Sinai The area is characterized by the presence of folds, domal structures, faulting and unconformities These structural elements have been recognized both above and below surface

From the structural point of view, Sinai is subdivided into seven major parts (Shata 1956) These subdivisions are the southern Sinai shield area, the central Sinai stable foreland, the central Sinai slightly folded area, the north Sinai hing belt, the north Sinai strongly-folded area, the Mediterranean foreshore area, and the west and east Sinai rift areas (the Gulf of Suez and the Gulf of Aqaba – Dead Sea Rift valleys)

The major tectonic features in Sinai which have direct impact on the groundwater conditions in terms of replenishment flow and potentiality, can be pointed out in the following

a- The fractures and joint systems in the carbonates favor the development of important aquifers in the Upper Cretaceous rock units

b- The basalt–dolorite dikes trending NW-SE and NE-SW act as local geologic boundaries to groundwater flow in Western Sinai, e g the SSW-NNE dike extending from Wadi Gharandal to Gebel Somar area

c- The pronounced folded structures at Gebels El-Maghara, Yelleq, El-Halal and Gebel Minsherah, Abu Kandu, Kherim, Arif El-Naga, and with the abrupt changes in the elevations of the different groundwater bearing formations causing possible diversion in its flow directions

d- The major east–west Ragabat El-Naam fault which extends westward from slightly north of Taba towards El-Themed, to the Nakhl area, and finally to Gebel Raha in West Sinai The throw of this fault is about 400 m to 500 m in the area between Taba and El-Themed and decreases westward, with minor vertical dislocation around Nakhl (40 m), but a considerable displacement is observed further west

The ENE-WSW trending fault, north of the Syrian Arc folded zone of Gebels Maghara, Risan Aneiza and El-Halal, with its northward downthrown side has caused the Cretaceous intergranular formation to be blocked by the low permeability Upper Cretaceous / Tertiary formations carbonate shale complex

The two major faults along the rifts of the Gulfs of Suez and Aqaba, caused a pronounced differential block faulting which brought the Cretaceous formation against the Pre-Cambrian rocks along the Gulf of Aqaba and the Tertiary evaporites along the Gulf of Suez

3 4 Deep Aquifer Systems in Sinai

The existing deep aquifer systems in Sinai derive their characteristics from past geological events of sedimentation and structural movements on the peninsula, and from regional and local recharge conditions occurring over the past centuries

The results of deep test drilling for oil and groundwater investigation in the different parts of Sinai (see Figure 48) show that seven deep lithostrategic units serve as the primary deep aquifers in Sinai

In the following, the hydrogeologic setting of these hydrostratigraphic units will be described A special emphasis is given to the Cretaceous aquifer systems because they offer the most potential aquifers in Sinai both in quantity and quality Figure (54) shows the location of four regional hydrogeologic sections in Sinai which are represented in figures (55), (56), (57) and (58) Table (20) indicates the technical and hydrogeologic data of the drilled wells tapping deep aquifers in Sinai

Table (20) - Sinai Deep Aquifer Technical and Hydrogeologic Well Data

Map Well No	Well Name	Well Depth (m)		Aquifer Tapped		Depth to Water (m b g l)	Yield (m3/hr)	Salinity (p p m)	Well Type	Well Use
		Drilled	Completed	Lithostratigraphic Unit *	Depth (m b g l)					
1	El-Arish - 1	1667	-	L Cr Lst	375-1250	-	-	-	Oil exploration well	Abandoned
2	El-Arish - 1	260	260	Miocene Sands	141-259	27	-	10450	Oil exploration well	Abandoned
3	Sneh - 1	2990	-	L Cr Lst	2050-2850	-	-	19000**	Oil exploration well	Abandoned
4	El Khabra - 1	3134	-	L Cr Lst & Sdst	730-1704	-	-	14000**	Oil exploration well	Abandoned
5	El Magdaba Unicef well	978	-	U Cr Lst	-	67	-	10870	Production	Abandoned
6	Wadi El Amro Unicef well - 1	980	980	U Cr Lst	504-974	73	30	4000	Production	Not in use
7	Um Shihan Unicef well - 1	1003	902	L Cr Lst	387-1003	113	35	3900	Production	Irrigation 48 fed & domestic
8	Um Shihan MPWWR well - 2	N/A***	N/A	L Cr Lst	N/A	113	60	3900	Production	Not yet in use
9	El Fath - 1	N/A	N/A	Upper Jurassic Lst	N/A	40	3 5	800	Production	Domestic
10	El Fath - 2	N/A	N/A	Upper Jurassic Lst	N/A	140	9	2100	Production	Domestic
11	El Maghara MPWWR well No 1	N/A	N/A	Upper Jurassic Lst	N/A	110	28	2500	Production	Agriculture
12	El Maghara MPWWR well No 2	N/A	N/A	Upper Jurassic Lst	N/A	-	5	1800	Production	Agriculture
13	El Maghara MPWWR well No 5	N/A	N/A	Upper Jurassic Lst	N/A	135	70	1800	Production	Agriculture
14	El Maghara MPWWR well No 12	N/A	N/A	Upper Jurassic Lst	N/A	110	20	2500	Production	Agriculture

* L Cr Lower Cretaceous, U Cr Upper Cretaceous, Lst Limestone, Sdst Sandstone

** Salinity determined from well logs

*** N/A Data not available

Table (20) Cont - Sinai Deep Aquifer Technical and Hydrogeologic Well Data

Map Well No	Well Name	Well Depth (m)		Aquifer Tapped		Depth to Water (m b g l	Yield (m3/hr)	Salinity (p p m)	Well Type	Well Use
		Drilled	Completed	Lithostratigraphic Unit	Depth (m b g l)					
15	El Halal well - 2	No Data Available				140	35	2000	Production	Agriculture
16	El Halal well - 1	No Data Available				160	10	2500	Production	Agriculture
17	Gebel Libni WRRI well No 36C	300	240	U Cr Lst	63 - 300	220	11	3700	Production	Agriculture
18	Baghdad Unicef well	927	-	U Cr Lst	861 - 927	-	-	-	Dry	
19	El Monbateh Unicef well	1003	972	U Cr Lst	352 - 1003	120	20	3500	Production	Agriculture
20	El Mowaleh WRRI well - 1	170	64	Eocene Lst	0 - 64	23	-	19000	Test well	Abandoned
21	El Halal Israeli well	900	640	L Cr Sdst	360 - 640	250	70	3500	Production	Irrigation of 40 fed (65 in future)
22	El Hasana WRRI well No 49	210	N/A	U Cr Lst	0 - 210	-	-	-	Dry	
23	El Melarz Army well	1321	1321	U & L Cret Lst & Sdst	1008-1321	219	-	2480	Production	Domestic
24	El Gifgafa Unicef well	860	850	U Cr Lst	400 - 850	219	35	3500	Production	Domestic
25	Habashi well - 1	2500		Lower Miocene Sdst	480 - 533	44	-	1020**	Oil exploration	Abandoned
26	Talaat El Badan Unicef well	657	502	U Cr Lst	50 - 316	163	-	4690	Test productive	Abandoned
27	Gebel Falig Jica well No J - 13	402	302	L Cr Sdst	0 - 331	288	-	-	Dry	
28	El Hasana Unicef well	1038	959	U Cr Lst	330 - 1038	172	50	4120	Production	Desalinated for domestic use

Table (20) Cont - Sinai Deep Aquifer Technical and Hydrogeologic Well Data

Map Well No	Well Name	Well Depth (m)		Aquifer Tapped		Depth to Water (m b g l)	Yield (m3/hr)	Salinity (p p m)	Well Type	Well Use
		Drilled	Completed	Lithostratigraphic Unit	Depth (m b g l)					
29	El Hasana MPWWR well - 1	N/A								
30	El Hasana WRRI well No 5	298	200	U Cr Lst	181 - 295	180	-	7000	Production	Not in use
31	El Hasana MPWWR well No 2	N/A								
32	El Minshareh WRRI well No 57 A	502	462	U Cr Lst	307 - 502	162	-	2740	Piezometer	Not in use
33	El Minsherah Army well	1060	1060	L Cr Sdst	747 - 1060	158	-	1500	Production	Abandoned
34	El Minsherah Jica well No J-12	300	270	L Cr Sdst	44 - 286	182	30	2970	Production	Not in use
35	Wadi El Meraiz WRRI well No 70	293	293	U Cr Lst	0 - 293	97	20	8480	Production	Abandoned
36	El Tamada - 1	1300	1300	L Cr Sdst	800 - 1300	225	-	2630	Production	Abandoned
37	Arif El Naga MPWWR No 1	N/A		L Cr Sdst	-	271	15	3500	Production	Irrigation & dom uses
38	Arif El Naga MPWWR No 2	N/A		U Cr Lst		92	40	2300	Production	Irrigation & dom uses
39	Arif El Naga MPWWR No 3	N/A		L Cr Sdst		110	18	3500	Production	Irrigation & dom uses

Table (20) Cont - Sinai Deep Aquifer Technical and Hydrogeologic Well Data

Map Well No	Well Name	Well Depth (m)		Aquifer Tapped		Depth to Water	Yield	Salinity	Well Type	Well Use
		Drilled	Completed	Lithostratigraphic Unit	Depth (m b g l)	(m b g l	(m3/hr)	(p p m)		
40	Arif Al Naga MPWWR well No 4	No Data Available		L Cr Sdst		-	30	3200	Production	Irrigation & Dom uses
41	Arif Al Naga Jica well No J-1	902	902	L Cr Sdst	556 - 720	300	40	3008	Production	Irrigation & Dom uses
42	El Bruk Jica well No J-17	189	189	U Cr Lst	128 - 189	132	20	5628	Production	Not yet in use
43	El Bruk Jica well No J-16	799	799	L Cr Sdst	487 - 715	152	30	2318	Production	Not yet in use
44	Ayun Musa - 1	1661	152	L Cr Sdst	65 - 167	+11	flowing	2536	Oil exploration	Abandoned
45	Ayun Musa - 2	1770	268	L Cr Sdst	122 - 271	+14	flowing	3186	Oil exploration	Abandoned
46	El Hamra - 1	1460	-	L Cr Sdst	91 - 435	-	-	10000**	Oil exploration	Abandoned
47	Sudr El Heitan WRRI well -1	1040	996	L Cr Sdst	775 - 992	270	50	2000	Production	Not yet in use
48	Nakhl MPWWR well No 1(Bir Shash)	1020	1020	L Cr Sdst	826 - 1020	254	40	1650	Production	Domestic
49	Nakhl MPWWR well No 2 (Bir Youssef)	1095	1082	L Cr Sdst	826 - 1095	233	50	1630	Production	Not in use*
50	Abu Hams - 1	2714	-	L Cr Sdst	769 - 1006	-	-	<2500	Oil exploration	Abandoned
51	Nakhl MPWWR well No 4	N/A		L Cr Sdst	N/A		50	1535	Production	Not yet in use
52	Nakhl - 1	1696	1118	L Cr Sdst	871 - 1118	181	-	1635	Oil exploration	Abandoned
53	Nakhl Unicef well	1083	1083	L Cr Sdst	870 - 1083	210	60	1200	Production	Not in use
54	Nakhl MPWWR well No 5	1192	N/A	L Cr Sdst	N/A	198	50	1614	Production	Irrigation of 10 fed ([illegible] up to 40 f d)

* The well is ready for use in agriculture, but the nearest suitable land is 4 5 km from the well site

Table (20) Cont - Sinai Deep Aquifer Technical and Hydrogeologic Well Data

Map Well No	Well Name	Well Depth (m)		Aquifer Tapped		Depth to Water	Yield	Salinity	Well Type	Well Use
		Drilled	Completed	Lithostratigraphic Unit	Depth (m b g l)	(m b g l)	(m3/hr)	(p p m)		
55	Nakhl MPWWR well No 6	N/A		L Cr Sdst	N/A				Production	Not yet in use
56	Nakhl MPWWR well No 7	N/A		L Cr Sdst	N/A					Not yet in use
57	Darag well	844	844	L Cr Sdst	810 - 844	183	-	1490	Oil exploration	Abandoned
58	El Kuntilla WRRI well No 1	652	-	-	554 - 750	Failed to be completed due to frequent complete loss of mud circulation				
59	El Kuntilla WRRI well No 2	No Data Available		L Cr Sdst			50	1728	Production	Not in use
60	El Thamad Unicef well	760	730	U Cr Lst L Cr Sdst	245 - 554 554 - >760	380	?	3500	Production	Not in use
61	El Thamad MPWWR well No 2	805	789	L Cr Sdst	408 ->789	382	30	1768	Production	Not in use
62	Ras Sudr - 15	1930	-	L Cr Sdst	1860-1930	-	-	227450	Oil exploration	Abandoned
63	Jica test well No 1	N/A	N/A	L Cr Sdst	N/A				Test-production	Not in use
64	Jica test well No 2	N/A	N/A	L Cr Sdst	N/A				Test-production	Not in use
65	Jica test well No 3	N/A	N/A	L Cr Sdst	N/A				Test-production	Not in use
66	Jica test well No 4	N/A	N/A	L Cr Sdst	N/A				Test-production	Not in use
67	Jica test well No 5	N/A	N/A	L Cr Sdst	N/A				Test-production	Not in use
68	Taba Heights Co well No 2	742	742	L Cr Sdst	545 - 730	358	75	1556	Production	Not yet in use but water will be piped to the Gulf Coast for domestic use in touristic centers
69	Taba Heights Co well No 1	852	826	L Cr Sdst	695 - 822	355	75	1387	Production	

Table (20) Cont - Sinai Deep Aquifer Technical and Hydrogeologic Well Data

Map Well No	Well Name	Well Depth (m)		Aquifer Tapped		Depth to Water	Yield	Salinity	Well Type	Well Use
		Drilled	Completed	Lithostratigraphic Unit	Depth (m b g l)	(m b g l	(m3/hr)	(p p m)		
70	Naqab test well No J-15	400	-	L Cret Sdst	295 - 400		Dry			
71	Shaira WRRI well No 1 (Km 83)	815	804	L Cret Sdst	564 - 807	355	23	1680	Production	Used in irrigating an experimental farm of 20 fed
72	Shaira WRRI well No 2 (Km 83)	328	325	U Cret Lst	175 - >325	85	5	1024	Production	
73	Shaira MPWWR well No 3 (Km 83)	830	828	L Cret Sdst	565 - 815	350	30	1200	Production	Not yet in use
74	Shaira MPWWR well No 4 (Km 82)	735	714	L Cret Sdst	483 - 731	347	30	1236	Production	Not yet in use
75	El Hithi MPWWR well No 2 (Km 70 5)	408	400	U Cret Lst L Cret Sdst	0 - 330 330 ->403	93	26	1050	Production	Not yet in use
76	El Hithi MPWWR well No 1 (Km 72 5)	352	352	U Cret Lst L Cret Sdst	0 - 160 160 - >352	289	10	1269	Production	Not yet in use
77	Wadi Watir MPWWR well No 1 (Km 52 5)	920	860	L Cret Sdst	625 - >960	141	60	768	Production	Not yet in use
78	Wadi Watir MPWWR well No 2 (Km 53)	860	860	L Cret Sdst	615 - >860	148	46	887	Production	Not in use
79	Wadi Gharandal WRRI well No 1	230	228	U Cret Lst	0 - 230	21	5	8680	Production	Abandoned
80	Wadi Gharandal WRRI well No 2	550	515	L Cret Sdst	420 - 510	78	50	1300	Production	Domestic

Table (20) Cont - Sinai Deep Aquifer Technical and Hydrogeologic Well Data

Map Well No	Well Name	Well Depth (m)		Aquifer Tapped		Depth to Water (m b g l)	Yield (m3/hr)	Salinity (p p m)	Well Type	Well Use
		Drilled	Completed	Lithostratigraphic Unit	Depth (m b g l)					
81	Wadi Gharandal WRRI well No 3	930	777	Upper Paleozoic Sdst	657 - 770	96	57	2500	Production	Domestic
82	Jica test well No 6			L Cret Sdst	No Data Available			(500)?	Test production	Not in use
83	Petropel Co well-fiel (four wells)	N/A		Miocene Sands			350	4600		House hold & industrial use
84	Wadi Feiran WRRI well No 2	676	623	L Cret Sdst	390 - 623	57	60	864	Production	Not yet in use
85	Wadi Feiran WRRI well No 1	776	450	L Cret Sdst	185 - 450	37	50	850	Production	Not yet in use
86	Wadi Feiran WRRI well No 3	366	250	L Cret Sdst	150 - 270	39	70	850	Production	Domestic
87	Wadi Feiran WRRI well No 4	600	560	L Cret Sdst		67	65	1150	Production	Not yet in use
88	Wadi Feiran MPWWR well No 5	550	472	L Cret Sdst		37			Production	Not yet in use
89	Wadi Feiran MPWWR well No 6	N/A		L Cret Sdst	N/A				Production	Not yet in use
90	Wadi Feiran MPWWR well No 7	N/A		L Cret Sdst	N/A				Production	Not yet in use

3 4 1 The Miocene Aquifer System

The Miocene units serving as aquifers are sandstone, belonging to the Lower Miocene Gharandal Group, and sandstone and grits forming a thin basal Miocene unit These units occur on the west side, along the Gulf of Suez, in the Bitter Lake area, Wadi Feiran and the coastal foreshore area (south of Rafah and El-Magdaba)

The Miocene aquifer system has only been tested in a few wells in western and northern Sinai At the Habashi oil exploration well (well no 25), east of Bitter Lakes, a Miocene sandstone unit produced water with a salinity of 1,020 ppm South at Ras Misalla, wells tapping basal Miocene yielded water with a total salinity ranging from 2,600 ppm to 5,000 ppm Further south, the aquifer groundwater salinity progressively increases to reach 380,000 ppm at well Lagia–2 Downstream of Wadi Feiran, at the Petropel Co well-field, wells tapping Miocene sandstone unit (well no 83) yield water with salinity ranging from 3,900 ppm to 5 300 ppm The results of testing the Miocene sandstone in the northern coastal foreshore area at well Misri – 1 (well no 2) showed that its groundwater is of poor quality, (10,000 ppm)

3 4 2 Eocene Aquifer System

The Eocene fractured carbonate aquifer is represented by limestone and marl It extends outcropping from El-Tih and El-Egma plateau in central Sinai to cover vast areas northward to the line between Risan Aneiza and Gebel Maghara and attains a thickness of 200 to 360 m

The Eocene aquifer was only tapped in a few wells in north and west Sinai, (Table 20), but none of them have been tested for the aquifer hydraulic parameters Based on the available data regarding the groundwater quality, the Eocene limestone aquifer appears to yield water of usable quality at only a few locations in central and northeastern Sinai A characteristic of this aquifer, developed in the limestone, is the shortage of groundwater at the basal part of the limestone underlain by the impervious Paleocene Esna shales This is clearly demonstrated at Ain El-Gudeirate and Ain Qedees in El-Quseima area which issue from the Eocene limestone and discharge water at daily rates of 1,500 m^3 and 480 m^3 with a total salinity of 1,440 ppm and 1,200 ppm respectively Also, an abandoned oil exploration well located northeast of Ras Sudr (well Abu Qiteifa 1), yielded water from the Eocene rocks with a salinity of 1,990 ppm, which increases progressively to reach 310,000 ppm at Lagia area south of Ras Sudr All other wells tapping the Eocene aquifer north of the zone between Gifgafa and El-Quseima yielded water with a total salinity ranging from 8,500 ppm to reach 19,000 ppm at El-Mowaleh well (well no 20)

The Eocene carbonate aquifer in Sinai is mainly recharged by the percolation of rainfall through its highly fractured and fissured outcrops

Based on the limited hydrogeologic information, the favorable areas for groundwater development from the Eocene aquifer include the area between El-Hasana and El-Quseima and the area north of Nakhl and El-Thamad, where the aquifer hydrogeologic setting is similar to that prevails in northeastern Sinai at Ain El-Gudeirate and Ain Qedees

3 4 3 The Upper Cretaceous Aquifer System

The Upper Cretaceous carbonate aquifer system is composed of three hydrostratigraphic units, e g , the Senonian Matalla unit, the Turonian Wata unit and the Cenomania Galala unit However, due to the scarcity of hydrogeologic data for the first two water-bearing formations, the three units will be dealt with, in this report, as one aquifer system designated as the Upper Cretaceous aquifer system

3 4 3 1 Occurrence and Extent

The upper Cretaceous aquifer system consists mainly of chalky limestones and shales in the upper part (Senonian Matalla Formation) and limestones, dolomites, dolomitic limestones and marls in the lower part (Turonian Wata Formation and Cenomanian Galala Formation)

The aquifer occupies vast tracks in Sinai, with its southern boundaries located north of the southern slopes of El-Tih and El-Egma plateau, where the aquifer is elevated above its regional potentiometric surface

The aquifer extends north until it is dammed by the down-faulted block of Teriary formations north of Gebels Maghara, Risan Aneiza and El-Halal zone forming its northern boundary To the east, the aquifer extends to the Aqaba - Dead Sea Rift Valley, while to the west, it is bounded by the down-faulted Tertiary and Recent low permeability sequence and the basalt and diorite dikes between Gebel Somar and Wadi Gharandal (see Figure 47)

The aquifer thickness ranges from 400 m to 700 m in the central and northern parts of Sinai, while it gradually decreases southward reaching 150 to 200 m in the vicinity of its outcropping area along the El-Tih and El-Egma plateau slopes

3 4 3 2 Aquifer Potentiometry

Data obtained from test wells tapping the Upper Cretaceous carbonate aquifer in Sinai (Table 20) indicate that the depth to water ranges from 85 m at well Shaira – 2 (well no 72) and 180 m at El-Hasana well (well no 30) to 40-90 m at Wadi El-Amro / El-Magdaba areas in north Sinai (Nour 1993)

Figure (59), shows the potentiometric surface map of the Upper Cretaceous aquifer The map indicates a general SE - NW groundwater gradient of 0 0035 The map also shows a groundwater divide near the eastern borderline with a groundwater flow eastward to the aquifer discharge area at the Dead Sea region in Israel, where a potentiometric level of 250 m b m s l at well Admon – 1 was reported (Dames and Moore, 1985)

3 4 3 3 Aquifer Hydraulic Parameters

The results of the aquifer tests conducted at seven well sites in Sinai indicate that the transmissivity of the Upper Cretaceous Turonian aquifer was determined to be as low as 0 94 m^2/day at Shaira shallow well (well no 72) in southeast Sinai and 6m^2/day at Wadi Gharandal (well no 79) in southwest Sinai The highest aquifer transmissivity values were recorded at those wells tapping the Cenomanian limestone at El-Hasana (well no 28) and El-Bruk (well no 42) areas, being of 102 and 660 m^2/day, respectively The specific capacity of the wells producing from the Upper Cretaceous aquifer ranges from 0 05 m^3/hr/m at Wadi Gharandal and 4 5 m^3/hr/m at Wadi El-Bruk The Upper Cretaceous aquifer system is confined in the major part of central and northeastern Sinai while elsewhere, the system is unconfined

3 4 3 4 Aquifer Recharge

The recharge of the Upper Cretaceous aquifer occurs through the direct infiltration of rainfall or from surface flow on its exposed areas The estimated rate of recharge to the Upper Cretaceous aquifer is estimated to be 190,000 m^3/day (Dames & Moore, 1985)

3 4 3 5 Groundwater Quality

Figure (60) represents the iso-salinity contour map of the Upper Cretaceous aquifer system It indicates a general trend of salinity increase towards the north, with the lowest values of 1,100 and 1,500 ppm observed at Shaira well (well no 72) and Yerqa Spring (located in the western part of Gebel El-Tih) respectively The highest salinity of 5,628 ppm was observed at El-Bruk well (well no 42) and 10,870 ppm at El-Magdaba well (well no 5)

Although, the map indicates that the Upper Cretaceous aquifer contains relatively low salinity groundwater in El-Tih and El-Egma Plateau area, the observed salinity at Wadi Gharandal well tapping the same aquifer (well no 79) was reported to be about 5,000 ppm, which may be attributed to the fact that the Cretaceous aquifer in Wadi Gharandal is hydraulically separated from the other part of the aquifer in El-Tih / El-Egma plateau

3 4 4 The Lower Cretaceous Aquifer System

3 4 4 1 Occurrence and Extent

The Lower Cretaceous Malhah water-bearing formation, consists mainly of alternating beds of sandstones and shales in the central and southern parts of Sinai, while to the north of Gebel Maghara- Gebel El-Halal folded zone, the formation is facially changed into carbonates and shales complex The aquifer thickness ranges, in general, between 150 m and 300 m, although it reaches 600 m at Gebel El-Halal

The aquifer extends between the areas of the Dead Sea - Wadi Arava Rift in southern Israel in the east and Ayun Musa on the Gulf of Suez in the west Its northern boundary is located north of Gebels Maghara, Risan Aneiza and El-Halal zone, while its southern and southeastern boundaries are defined by the line where the regional water table intercepts the aquifer base approximately at 10 to 20km to the north of its outcrops along the face of El-Tih, El-Egma and El-Hazim plateaux (see Figure 57) The aquifer is bounded to the west by the major NW-SE fault where it is blocked when the uplifted Tertiary evaporates with only narrow western continuity into Ayun Musa area The Gebel Somar basaltic dike forms an internal boundary to the aquifer

The aquifer is topped by the Cenomanian dolomitic, marly limestones and shales The top surface of the Malhah formation slopes broadly from the south to north, with its depth ranging between 100 m at the northern vicinity of its southern outcrop, 500 m at Shaira (well no 71), 800 to 900 m at Nakhl area and increases northward to reach 1,000 to 1,200 m in the Hasana – Gifgafa area, (see Figure 52)

The base of the Lower Cretaceous aquifer has been reached in very few wells, where it is represented by the top surface of the Upper Jurassic formation

The Malhah aquifer system is believed to function as an unconfined aquifer only at a limited zone (1 to 2 km) near its southern outcrops, and is confined elsewhere, being capped by the overlying Tertiary – Upper Cretaceous complex (see Figure 57)

3 4 4 2 Aquifer Potentiometry

Figure (61) shows the depth to water from the groundwater surface in the Lower Cretaceous aquifers It indicates that north of Ragabat El-Naam fault the depth to water is about 200 m b g l around the Nakhl – El-Hasana road and gets deeper eastward and westward to reach 300 to 400 m b g l South of the fault, the depth to water in the Lower Cretaceous aquifer in El-Tih – El-Egma plateau area ranges between 300 m b g l in the northern part and increase to 400 m b g l near the southern outcrops of the Malhah formation

Figure (62) shows the Lower Cretaceous aquifer potentiometric surface map The map indicates that the highest observed potentiometric level of 420 m a m s l was observed at the well Shaira-1 (well no 71), while the lowest level of 24 m a m s l was observed at the Halal Israeli well (well no 21) A regional flow direction is distorted by the existence of the E-W Ragabat El-Naam sector type fault which seems to interrupt the aquifer hydraulic continuity at its eastern and western terminus, and the northern folded structures at Gebel Yallaq, Minsherah, Maghara, and El-Halal which cause partial hindrance to groundwater flow

The map also shows that the groundwater in the Lower Cretaceous aquifer system flows from its southern recharge (outcrop) area along El-Tih, El-Egma and El-Hazim plateaux to the north and northwest to the vicinities of the Ragabat El-Naam fault It then diverts its direction toward the Nakhl area where the fault displacement is minor, and through which the flow crosses the fault northward to central Sinai

The existence of the NE folded structures in central Sinai and the aquifer northern low permeability boundary north of Gebel Maghara, Risan Aneiza and Gebel El-Halal zone, causes the diversion of the groundwater flow direction to the E-NE and the W-SW towards the system s major discharge areas at the Dead Sea-Wadi Arava rift in southern Israel and Ayun Musa area on the Gulf of Suez rift, where the potentiometric surface map shows two potentiometric depressions of –250 m and +40 m, respectively There is no evidence of any flow in the Lower Cretaceous aquifer to the north of Gebel Maghara, as the predominant Carbonate shale facies present is of low permeability, and the pronounced differential block faulting causes the diversion of groundwater flow eastward to the Dead Sea region

3 4 4 3 Aquifer Hydraulic Parameters

Based on the interpretations of both long-duration and step-drawdown tests conducted for 11 wells tapping the Lower Cretaceous aquifer Nour (1993), reported that the aquifer transmissivity ranges between 11 to 54 m^2/day for wells located near or at the domal structures at El-Halal, El-Minsherah, and El-Bruk, while higher transmissivity values ranging between 100 to 400 m^2 / day were observed at the wells of Sudr El-Heitan, Nakhl, Arif El-Naga, and Shaira wells where no significant structural disturbance occurred

The aquifer hydraulic conductivity exhibits its lowest values (0 17 to 0 7 m/day) in the folded zone at El-Minsherah, El-Bruk and El-Halal, while the aquifer attains its highest values (2 to 4 m/day) in the areas between El-Hassana, Talaat El-Badan, Arif El-Naga, Nakhl, and Sudr El-Heitan, as well as in the areas of Shaira, Wadi Gharandal, and Wadi Feiran

The storativity of the Lower Cretaceous was found to vary between 10^{3} at Arif El-Naga well (well no 41) and 10^{5} at Wadi Gharandal well (well no 81) The specific capacity of the wells yielding water from the Lower Cretaceous aquifer indicates ranges between 2 and 9 m^3/hr/m with the exception of El-Bruk and El-Halal Israeli deep wells (wells no 34 and 22) which indicate rather low specific capacities (0 5-0 9 m^3/hr/m)

3 4 4 4 Groundwater Quality

Figure (63) represents the iso-salinity contour map of the Lower Cretaceous aquifer It shows a general increase of groundwater salinity towards the west and the north, with four salinity zones recognized as follows

Zone I Groundwater salinity is <1,500 ppm It occupies the area of the aquifer located south of the main road joining Sudr El-Heitan, Nakhl, and Ras El-Naqb Within this zone, the recorded aquifer salinities of the Sudr El-Heitan, Nakhl, Wadi Feiran, Shaira and Gharandal wells are 1,246, 1,600, 800, 1 500 and 1,330 ppm, respectively Recent test drilling in the Lower Cretaceous aquifer in the southwestern part of El-Egma plateau at Jica well no 6 (well no 83) indicated a salinity of 500 ppm (El-Behairy 1998, Personal Communication)

Zone II occurs to the east of the line joining Sudr El-Heitan- Nakhl – El-Bruk – El-Menashereh – El-Hassana – El-Quseima, where the aquifer salinity ranges between 1,500 and 2 000 ppm Within this zone and in the vicinity of the folded structures at El-Bruk, G El-Minsherah and G Arif El-Naga, the salinity appears to be high due to the possible groundwater stagnancy around these highly elevated structures allowing for more dissolution of salts This occurs at El-Minsherah well no 34 (2,973 ppm) and Arif El-Naga well no 41 (3,008 ppm)

Zone III is characterized by salinities ranging between 2,000 ppm and 5,000 ppm It occupies a narrow zone surrounding Zone I and extends to Ayun Musa area in the west and Gifgafa north of G El-Halal in the north

Zone IV occurs to the north of Zone III and has salinities in the Lower Cretaceous aquifer ranging between 5 000 and 10,000 ppm

Zone V occupies the northern and western parts of Sinai where the Lower Cretaceous aquifer has been deeply buried by faulting The rather high salinity values in this zone (14,000 ppm at well no 4, 19,000 ppm at well No 3) may be due to the ineffective flushing of the formation's saline water by the recharging meteoric water due to the interruption of the groundwater flow paths by block faulting

Along the eastern coast of the Gulf of Suez, the salinity of the Lower Cretaceous aquifer is high (227,000 ppm at well Ras Sudr 15 well no 62) because it is deeply down-faulted and the formation water has not been diluted or flushed by groundwater inflow from the east The exception to this is the aquifer discharging area at Ayun Musa where the groundwater salinity of 2,536 to 3,180 ppm was observed at wells no 44 and 45, This could be attributed to the fact that the aquifer occurs at a shallow uplifted block and it is possible that hydraulic continuity occurs with the aquifer in the east

Recent age dating studies of the Lower Cretaceous groundwater indicate the presence of age gradient from south to north Sinai, which can be explained by recent rainfall recharge to the aquifer through its outcrops in the south

3 4 4 5 Aquifer Storage Capacity and Groundwater Inflow - Outflow Pattern

3 4 4 5 1 Aquifer Storage Capacity Nour (1993), estimated the storage capacity of the Lower Cretaceous sandstone aquifer system in Sinai to be approximately 1,100 bcm, while in the part of the aquifer containing groundwater with salinity less than 2,000 ppm in central and southern Sinai, the amount of stored water is about 980 bcm, of which 117 bcm could be recovered

3 4 4 5 2 Aquifer Inflow – Outflow The recharge to the Lower Cretaceous aquifer in Sinai is by infiltration of rain through its outcrops along the face of El-Egma – El-Hazim plateaux in south Sinai and its exposed surface in the cores of the northern mountains in North Sinai Dames and Moore (1985) estimate the recharge to the Lower Cretaceous aquifer system to be about 90,000 m^3/day

The Lower Cretaceous aquifer outflow is represented by the groundwater abstraction by wells, and by natural losses in the topographically low areas located along the two rift valleys i e , the Dead Sea – Wadi Arava in southern Israel, and the Ayun Musa area in the eastern coast of the Gulf of Suez, which represent the base level of the aquifer where groundwater is most probably exploited or lost by evaporation

Based on the groundwater flow pattern in the Lower Cretaceous aquifer (Figure 59) and its hydraulic parameters, Nour (1993) estimates the annual aquifer system water balance using the Darcian approach, to be as follows

- Annual inflow from the southern recharge area = 21 4 mcm
- Outflow
  - Annual outflow through the eastern border to Wadi Arava (Israel) 10 mcm
  - Annual outflow through the northeastern border to the Dead Sea 5 mcm
  - Annual outflow to Ayun Musa area at the Gulf of Suez 6 mcm
  - Total annual outflow from the aquifer 21 mcm

3 4 5 The Pre-Lower Cretaceous Aquifer Systems

The hydrogeology of the Pre-Lower Cretaceous section in Sinai has been inadequately studied It consists of the following aquifer systems (Jica, 1992)

- *The Jurrasic aquifer* has been identified in Gebel El-Maghara area in north Sinai and in Ayun Musa area in west Sinai The aquifer system occurs in the Upper Jurassic limestones (Massajid formation) and the Middle Jurassic sandstones (Safa formation) and shales

- *The Upper Jurassic Massajid aquifer* is reported to contain a limited amount of groundwater, owing to their lithologies and limited outcrops at Gebel El-Maghara area Recent local recharge from runoff on the Gebel slopes provides groundwater to shallow wells (30 m to 110 m deep), which yield 120 to 840 m^3/day with a salinity ranging between 800 ppm and 2,500 ppm

- *The Middle and Lower Jurassic sandstone aquifer* developed in the dome of Gebel EL-Maghara, at a shallow depth ranging between 150 m and 275 m Wells tapping this aquifer yield groundwater with a salinity ranging between 4 100 ppm and 7,500 ppm
  The Jurassic aquifer in the area of Ayun Musa, near the Gulf of Suez rift, yields groundwater with chloride concentrations ranging between 4,000 and 8,000 ppm

- *The Paleozoic sandstone aquifer* occurs overlying the Pre-Cambrian basement rocks with its catchment area in south Sinai along the face of the southern plateau and the igneous-sedimentary belt along both the Gulf of Suez and the Gulf of Aqaba (see Figure 47)

The hydrogeologic characteristics of the Paleozoic aquifer in Sinai are poorly identified due to lack of adequate studies Only in Wadi Gharandal, has the Upper Paleozoic sandstone aquifer been tapped and tested in well Gharandal-3 (well no 81), which yields 57 m^3/hr with a salinity of 3 700 ppm The results of the aquifer test conducted at the well site indicate an aquifer transmissivity of 173 m^2/day and a hydraulic conductivity of 1 3 m/day

3 5 Deep Groundwater Resources Evaluation

A review of available assessments of the deep groundwater resources in Sinai indicate a lack of proper evaluation of the resource potential for different use sectors, and the long term hydrodynamic response of the deep aquifers to groundwater extraction plans This was essentially due to inadequate hydrogeologic information of the deep aquifers

As previously mentioned in 3 1, the deep groundwater potential of the Cretaceous aquifer systems were only estimated by Dames and Moore (1985) and Nour (1993) applying the water balance and Darcian approaches The results of the south Sinai groundwater resources study project recently conducted by JICA will make it possible to complete the hydrogeologic data base required to develop a simulation model for the Lower Cretaceous aquifer system in order to assess its optimum exploitation, over time

3 6 Deep Groundwater Development in Sinai

3 6 1 Background

The drilling of deep wells in Sinai was started in the mid–fifties by the oil companies for oil exploration purposes Later, the Army Corp of Engineers and the Unicef drilled a number of deep wells to produce water from the Cretaceous aquifer systems in central Sinai to provide drinking water supplies for local settlements

In 1992, the MPWWR implemented a deep well drilling plan The plan includes the drilling of 52 deep production wells to tap the Cretaceous aquifer system at different selected locations in central and south Sinai

The drilling of deep production wells, the supply and installation of pumps their maintenance and operation works and the construction of a water storage reservoir is the responsibility of the MPWWR while the water users are responsible for the supply, maintenance and operation of the drip irrigation systems

The Sinai Water Resources Development Department based the use of the groundwater from deep wells in Sinai on the ratio 80 percent for agriculture and 20 percent for domestic uses

Although all of these wells are equipped with pumps, most of the wells are not yet in use This is probably due to the absence of targets and lack of allocating the well use among different sectors at the planning stage

3 6 2 Existing Groundwater Extraction and Utilization

The utilization of deep groundwater in Sinai is very recent, as most groundwater use was focused on the Quaternary aquifer systems in northeastern Sinai (El-Arish – Rafaa coastal zone) and the El-Qaa plain on the eastern coast of the Gulf of Suez in south Sinai Current groundwater abstraction from the deep aquifer systems at different parts of Sinai can be summarized as follows

- The Miocene Sandstone Aquifer

A total of 1,400 m^3/day (0 511 mcm/year) is reported to be withdrawn from the Miocene sandstone aquifer in Wadi Feiran (at the junction with El-Tor road) in south Sinai by the Petropel Oil Co for use in the oil fields The Hammam Saidna Musa at El-Tor city discharges Miocene water at a rate of 430 m^3/day

- The Eocene Limestone Aquifer

Groundwater discharging from the Eocene aquifer at El-Gudeirate and Qedees springs in northeast Sinai (El-Quseima area) is estimated to be at the rate of about 2 000 m^3/day (0 73 mcm/year) mostly used in irrigating 200 feddan of olive trees The Hammam Faraun Spring, located 40 km south of Ras Sudr, discharges thermal water (70° C) from the Eocene formation at a rate of 2,000 m^3/day

- The Upper Cretaceous Carbonate Aquifer

The total annual groundwater extraction rate from the Upper Cretaceous Carbonate aquifer in north and south Sinai is 0 426 mcm (from 7 deep wells), of which 0 261 mcm/year is used in irrigation while the rest is allocated for domestic purposes

- The Lower Cretaceous Sandstone Aquifer

Thirty-one deep wells tapping the Lower Cretaceous Sandstone (Malhah formation) aquifer were drilled and equipped with pumping facilities and ready for operation at an annual rate of 4 56 mcm At present only 12 of these wells are in use, yielding about 0 99 mcm/year of which 0 54 mcm/year is utilized in agriculture and 0 45 mcm/year is allocated for domestic purposes

- The Jurassic Aquifer System

Confined only to El-Maghara area, 6 wells are producing water from the Massajid formation at an annual rate of 0 396 mcm of which 0 037 mcm/year is used for domestic purposes and the rest of is utilized in the irrigation of about 120 feddan in Gebel El-Maghara Rural Developments Project

- The Paleozoic Sandstone and Aquifer

Only one well tapping the Paleozoic sandstone aquifer at Wadi Gharandal in south Sinai is producing water that is totally used for domestic purposes at a rate of 400 m^3/day (0 146 mcm/year)

The current total deep groundwater extraction from the different aquifer systems in Sinai peninsula is 3 199 mcm/year of which 1 89 mcm/year is used in agriculture and the rest is used for domestic and industrial uses This does not include the free groundwater discharges from the thermal springs located along the rift valley of the Gulf of Suez such as Ayun Musa, Hammam Saidna Musa at El-Tor (34°C) and Hammam Faraun (70°C) which outflow from Miocene and Lower Cretaceous units, and Ain Um Ahmed at Wadi Zelega and Ain El-Hadra at Wadı Lıthı El-Kebır along the rıft valley of the Gulf of Aqaba, whıch derıve theır water from the Paleozoıc aquıfer

3 6 3 Deep Groundwater Development Prıorıty Areas ın Sınaı

Because of ıts wıde extensıon, consıderable storage and faırly good water qualıty, the Cretaceous aquıfers are consıdered to be of hıgh potentıal Prıorıty areas for deep groundwater development from these aquıfers can be ıdentıfied based on the hydrogeologıc characterıstıcs of the Cretaceous aquıfers, whıch are

Groundwater salınıty levels and ıts suıtabılıty for dıfferent uses, *Depth to water* determınes the cost of lıftıng a water unıt to the ground surface for dıfferent uses, and the possıbılıty of completıng an efficıent productıon well, *Depth to aquıfer* determınes the cost of well constructıon, and *Aquıfer productıvıty* whıch controls the well optımum productıon rate and the cost of producıng one unıt of groundwater

3 6 3 1 The Upper Cretaceous Carbonate Aquıfer

The salınıty of groundwater ın thıs type of aquıfer ıs rather hıgh ın most of Sınaı (3,200 to 10 870 ppm) wıth the exceptıon of ıts central part along G El-Tıh El-Egma, and Shaıra zone, where the reported groundwater salınıty of the Upper Cretaceous ranges between 1,100 ppm and 1,500 ppm In thıs zone, although the recorded depth to water ıs relatıvely shallow (85 m b g l at well Shaıra –1), the aquıfer productıvıty proved to be very poor (well specıfic capacıty 0 08 m^3/hr/m) Consequently, ıt ıs not recommended to rely on exploıtıng thıs aquıfer for future development projects ın Sınaı

3 6 3 2 The Lower Cretaceous Sandstone Aquıfer

Wıth reference to Fıgures (52), (61) and (65), the prıorıty areas for the development and utılızatıon of groundwater of the Lower Cretaceous aquıfer are presented ın Table (21) and shown ın (Fıgure 64)

Table (21)- Priority Areas for Lower Cretaceous Groundwater Development in Sinai

Priority Class	Location	Aquifer Characteristics			
		Salinity (ppm)	Depth to Water (m b g l)	Depth to Aquifer (m b g l)	Well Productivity (m³/hr)
(A)	(A1) • Western Sinai Downstream of Wadi Feiran and Wadi Gharandal	800-1500	37 - 78	190 – 350	50 – 80
	• Central and South Sinai El-Minshera Nakhl, El-Bruk, Wadi Watir	800-2000	100 - 200	500 – 800	30 – 60
	(A2) El-Quseima Arif El-Naga El-Kuntilla, El-Thamad, Sudr El-Heitan	1500-3000	200-300	500-700	20 – 40
(B)	(B1) El-Tih plateau, South of Sudr El-Heitan, El-Thamad road, Shaira	≤ 1500	300-400	500-900	50-75
	(B2) Ayun Mosa, Gifgafa, El-Hasana, Talat El Badan, El-Halal, Um Shihan, Wadi El Amro, El-Kherim	3000-5000	150-250	800-1000	30-60

Source Nour, (1993)

The areas located north of Gebel El-Maghara, Gebel El-Halal and El-Ouga, and along the eastern coastal zone of the Gulf of Suez between Ras Sudr and Ras Mohamed, where groundwater salinity ranges from 5,000 ppm to more than 200,000 ppm, are not recommended for the development of the Lower Cretaceous groundwater

The identified deep groundwater development priority areas, should be considered in the evaluation of their sustainable potentials, applying groundwater modeling and in the assessment of the economics of their use for different sectors

3 6 4 Water Well Design

For deep groundwater development in Sinai until 1993, the following deep production well design was used

- Well total depth 325 – 1200 m
- Design well yield 50 m^3/hr

  Production Casing $9\,^{5}/_{8}\,''$ API Carbon Steel casing
- Screen $6\,^{5}/_{8}\,''$ stainless steel screen grade 304 hanged in the $9\,^{5}/_{8}\,''$ casing

To maximize the well productivity to more than 50 m^3/hr, the following deep production well design has been modified to include

- Pump house casing $13\,^{3}/_{8}\,''$ API carbon steel casing

  Production casing $9\,^{5}/_{8}\,''$ API carbon steel casing with 10 m overlap in the $13\,^{3}/_{8}\,''$ casing
- Screen $6\,^{5}/_{8}\,''$ stainless steel screen, grade 304 hanged in the $9\,^{5}/_{8}\,''$ casing

4 ADDITIONAL HYDROGEOLOGIC INVESTIGATIONS PLANS IN THE WESTERN DESERT AND SINAI

Review of the previous investigations of the deep aquifer systems in the Western Desert and Sinai and the evaluation of their resources indicate the need to carry out additional investigations in those areas lacking adequate hydrogeologic information Further investigations are also needed for the evaluation of groundwater resources which are currently under development (the Nubia sandstone, the Malhah sandstone, and the Moghra aquifer systems) and those which are planned for future development (the Carbonate aquifer systems)

Recommended plans for the required additional investigations to be carried out for the potential deep aquifers in the Western Desert and Sinai, are presented in the following sections

4 1 The Western Desert

4 1 1 The Moghra Aquifer System

Figure (9) shows the location and extent of the Moghra aquifer system As previously stated, the aquifer was only subjected to a detailed hydrogeologic study in Wadi El-Fareigh located in the desert fringes of the West Delta area, where a large scale irrigated agriculture project based on El-Moghra fresh groundwater has been developed (planned 35,000 feddan of which 12 700 feddan is cultivated at present) Only a few wells have been drilled into the Moghra aquifer These provide domestic water for the oil fields of Abu Sinan, Abu El-Gharadiq and Qarun, located between the West Delta desert fringes and Qattara – Bahariya Depressions

4 1 1 1 Objectives of the Additional Investigation

Additional hydrogeologic investigation are needed to

- Define aquifer geometry, hydrogeologic boundaries and hydraulic parameters
- Determine the aquifer groundwater salinity in space and time

- Forecast the aquifer long-term response to the present and future groundwater extraction and to asses its optimum potential over time for different use sectors (including domestic water supply and afforestation in the existing oil fields), with a special emphasis on the possibility of groundwater quality deterioration over time in areas where intensive extraction is practiced at present (Wadi El-Fareigh)

4 1 1 2 Investigation Work Plan

The following work plan is proposed

- Collection, review and analysis of all available hydrogeologic information and well data pertinent to the aquifer geometry, hydraulic parameters, hydrogeologic boundaries and groundwater quality
- Based on the results of the analysis of available information, and in the areas which lack data on aquifer hydrogeologic characteristics, 260 vertical electrical soundings should be conducted along 4 N-S geoelectric sounding profiles and 2 E-W profiles with special emphasis on the area along El-Giza-Bahariya Oasis road and the area between Wadi El-Fareigh and Qattara Depression The results of these geoelectric soundings will help determine the aquifer aggregate and saturated thickness, the depth of the aquifer base and the related geological structures, water quality, and the proposed locations for test drilling
- Drilling of test wells (5 wells) to a depth of ± 500 m each with satellite piezometer to obtain controlled data regarding the formation thickness, depth to water, aquifer hydraulic parameters, well-specific capacity and water salinity One proposed test-drilling site will be 50 km west of Wadi El-Fareigh (near Zebeida oil exploration well) and the other two will be along Giza – El-Bahariya road and Giza - Fayoum road
- Establishment of a hydrogeologic data base for the Moghra aquifer system which will include the geological and structural setting of the Moghra formation, its extent, lateral and vertical boundaries, potentiometric surface, aquifer hydraulic parameters (transmissivity, hydraulic conductivity and storativity), water salinity, present and future groundwater extraction plans
- Development of an appropriate groundwater model for the Moghra aquifer to simulate the present and proposed future groundwater extractions and to predict the aquifer response to the different extraction scenarios and probable changes in groundwater quality over the

foreseen period of exploitation, to assess the optimum, economic and sustainable groundwater extraction plan

- For proper control and management of El-Moghra aquifer groundwater currently utilized for irrigated agriculture in Wadi El-Fareigh project (at present 12,700 feddan to be expanded to 35,000 feddan in future), the existing monitoring well network should be supported by an additional 2 wells to be located in the western and northwestern vicinities of the project area to monitor probable movement of the Moghra brackish groundwater towards the project fresh water well-field

4 1 2 The Eocene – Miocene Carbonate Aquifer System

This system is bordered in the south by the Nubia Sandstone Complex along El-Dakhla – El-Kharga – South Kharga depressions, and in the north by the northern plateau overwhelming the northwestern coastal zone (Figure 65)

The area of El-Diffa plateau located to the north of Siwa Oasis – Qattara Depression in the south and the Salum – Matruh coastal zone in the north and crossed by the Siwa – Matruh road in the West and El-Almein – Qattara rim road in the east, is considered a target area for future nomad settlements, animal grazing and for water supply and afforestation purposes, in the existing oil-fields

The Nubia Sandstone aquifer in this part of the Western Desert is highly saline (chloride salinity of 10 000-120,000 ppm), while the overlying Upper Cretaceous – Middle Miocene Carbonates jointly described as the Western Plateau aquifer complex attains a thickness of 500 to 600 m and salinity of 2,000 ppm in the south which increases to 10 000 ppm in the northern part of the plateau

Based on geomorphological and morphostructural analyses which provide a comprehensive 2D view of possibly karstified terrains and the salinity of the carbonate groundwater, the area of the northwestern plateau (El-Diffa Plateau) was identified by RIGW (1997) as one of the promising basins for groundwater development in the carbonate aquifer system and is proposed for detailed hydrogeologic investigation to assess its groundwater potential

The following is the proposed plan for detailed hydrogeologic investigation required to evaluate the carbonate aquifer groundwater resources

4 1 2 1 Investigation Objectives

The objectives of the investigation program of the Carbonate aquifer in the northwestern plateau area of the Western Desert are

- To delineate areas of possibly karstified or fractured limestone terrains
- To determine regional tectonic lines and fault zones and the intensive karstification which can be associated therewith
- To evaluate the aquifer hydraulic parameters (hydraulic conductivity and storativity) as well as its hydrodynamic behavior
- To determine the aquifer water balance (inflow – outflow pattern)
- To determine groundwater genesis and origin and its relation to current or paleo recharge
- To evaluate the groundwater resources potential in the carbonate aquifers and their optimal utilization, over time

4 1 2 2 Investigation Work Plan

The following work plan is proposed

- Review and analyze all previous studies, information pertinent to geology, geophysics, hydrogeology, hydrochemistry and well data of the Carbonate aquifer systems, with a special emphasis on the results of geophysical surveys and the test wells previously carried out by the oil companies
- Analyze available lineaments and geologic structure maps to assess geomorphological and morphostructural features of the study area to identify the structure of the formations, surface infiltration zones as well as the tectonic evaluation of the area which will reveal possible karstified or fractured limestone terrains
- Conduct geophysical surveys applying the microgravimetric and micro-resistivity method, along a number of N-S profiles in areas which have proved to be intensively karstified or fractured
- Based on the results achieved from the geomorphological, geological and geophysical surveys, test wells (5 wells of ±500 m depth each) will be located, drilled and tested to

determine the subsurface hydrogeologic setting of the aquifer and its hydraulic parameters of fractures transmissivities, storage coefficient and the porous media storage coefficient and leakage factors between the two continual media Satellite piezometers shall be constructed to monitor the test well during pump testing The hydrochemical characteristics of the groundwater and its suitability for different use sectors will be assessed

- Prepare a potentiometric surface map and determine of the main direction of groundwater flow in the Carbonate aquifer system
- Evaluate of the aquifer system hydrodynamics by applying the water balance approach to determine the aquifer inflow-outflow components
- Based on the results of the geomorphological, geological, geophysical surveys and test drilling a hydrogeologic data base of the carbonate aquifer system in the study area will be prepared to include aquifer geometry, (extent, lateral and vertical boundaries, thickness) hydrogeologic boundary conditions (location and type), hydraulic parameters (fracture and porous transmissivities and storage coefficients), aquifer potentiometry and recharge - discharge pattern

The model will be calibrated to verify the present aquifer potentiometric levels and will then be used as a tool to forecast the aquifer response to groundwater extraction plans over time, and to select the most optimum, economic extraction plan which will ensure its sustainability without water quality deterioration

4 1 3 The Nubia Sandstone Aquifer System

The additional regional and detailed hydrogeologic investigations proposed for better describing the regional hydrogeologic setting of the Nubia Sandstone aquifer system and to cover the hydrogeologic information gap areas in the Western Desert to support the evaluation of its groundwater resources in the planned development areas

Regular and continuous groundwater monitoring (levels, extraction and quality) is essentially required

4 1 3 1 Regional Hydrogeologic Investigations

The proposed additional regional hydrogeologic investigation of the Nubia Sandstone aquifer system in the Western Desert include

4 1 3 1 1 Test Wells Drilling of seven deep test wells (with associated satellite piezometers) to fully penetrate the Nubia Sandstone formation is proposed The wells will be lithostratigraphically described, geophysically logged and pump-tested with the objectives of determining the tops of the penetrated hydrolithostratigraphic units and their thickness, depth to water, hydraulic parameters (transmissivity, hydraulic conductivity, storativity, leakage factors, well-specific capacity) and water quality Open-hole aquifer tests in the post-Nubia Sandstone carbonate aquifers should also be conducted The results can be used to better control the hydrogeologic database of the Nubia Sandstone aquifer system in the Western Desert This will significantly help better describing the hydrogeology of the system and will provide more controlled data for the development of regional and local simulation models for groundwater resource evaluation

The proposed sites for the recommended 7 deep test wells are (Figure 66)

- El-Gilf El-Kebir to the northwest of Gebel Kamel, with expected total depth of ±1 000 m
- NorthEast Oweinat Proposed location is midway between East Oweinat project area and El-Dakhla Oasis The expected drilling depth is ± 1 000 m
- El-Kharga – Armant Road Crossing the Nile Valley western plateau, the recommended test-drilling site is midway between El-Kharga and Armant The proposed test well is expected to penetrate Eocene – Upper Cretaceous Carbonate and the Nubia Sandstone formations with an expected total depth to the aquifer base (the Pre-Cambrian Basement) at ± 1,500 m
- Wadi El-Qubaniya located to the northwest of Aswan where potential land resources for irrigated agriculture are targeted for future development The test well will be drilled in the Nubia Sandstone formation to a final depth of ±500 m
- Ain Dalla Depression situated in the known Kufra – Ain Dalla structural basin to the northwest of El-Farafra Oasis The area is considered one of the potential areas for horizontal expansion in the Western Desert The expected total depth of the proposed two test wells is ± 2,000 m each

- El-Baharıya Oasıs – Sıwa Oasıs Road The proposed sıte for test drıllıng ıs located along the El-Baharıya – Sıwa road and south of El-Bahreın depressıon (south perıphery of Qattara Depressıon) The expected well total depth ıs ± 2,500 m

4 1 3 1 2 Groundwater Monıtorıng Because the exıstıng observatıon wells networks ın the Western Desert Oases (see Fıgure 15) used to monıtorıng groundwater levels are located at 50 to 100 km apart, renderıng regular on-sıte observatıon to be dıfficult (see Sectıon 2 5 4) It would be more effectıve to establısh a monıtorıng well network usıng a telemetry system to transmıt perıodıc water level records to a central control statıons ın El-Kharga, El-Dakhla, and El-Farafra Oases

4 1 3 2 Detaıled Groundwater Evaluatıon Studıes

Detaıled groundwater resources evaluatıon studıes are recommended ın those areas ın the Western Desert where groundwater ıs expected to be exploıted for ırrıgated agrıculture Prıorıty should be gıven to the areas of Sıwa Oasıs, Aın Dalla and the southern part of the Western Desert desıgnated as the "South Valley Development Project", where the GOE has recently ınıtıated a natıonal horızontal expansıon project that ıncludes East Oweınat, Darb El-Arbaın and Aswan – Abu Sımbel road areas, usıng the Nubıa Sandstone aquıfer groundwater (see Fıgure 43)

4 1 3 2 1 Sıwa Oasıs The deep Nubıa aquıfer fresh groundwater resource ın Sıwa Oasıs ıs currently beıng ınvestıgated by the RIGW wıthın the framework of the study of the draınage problems ın the Oasıs It ıs expected that the results of the present hydrogeologıc ınvestıgatıon wıll address the sustaınable and economıc groundwater extractıon rate, whıch can be utılızed wıthout causıng any envıronmental adverse ımpacts It ıs recommended that a deep test well of ± 2,000 m depth be drılled to fully penetrate the Nubıa Sandstone formatıon from the top of Lower Cenomanıan (Baharıya formatıon) to the base of the Carbonıferous The dıfferent hydrolıthostratıgraphıc unıts (the Terıary carbonates, the Mesozoıc and Paleozoıc clastıcs) should be tested for groundwater pıezometrıc and salınıty levels Thıs ınformatıon can be used to develop the approprıate model to sımulate possıble groundwater qualıty changes, over tıme, agaınst groundwater extractıon from the fresh water aquıfer

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caused by upward flow of the salıne groundwater ın the lower Paleozoıc aquıfers or by lateral movement of the northern saltwater / fresh water ınterface towards the Oasıs

4 1 3 2 2 Aın Dalla Area The Aın Dalla depressıon area located ın the northwestern vıcınıty of El-Farafra Oasıs, has been targeted wıth potentıal land resource development of about 20,000 feddan Two test wells should be drılled ın thıs area Data from these wells and avaılable hydrogeologıc data for the Nubıa Sandstone aquıfer ın El-Farafra wıll form suffıcıent hydrogeologıc database to evaluate the Nubıa groundwater water potentıal ın the Aın Dalla area A detaıled groundwater model should be developed for the El-Farafra Oasıs ıncludıng the Aın Dalla area to assess the economıc and sustaınable groundwater resources for land reclamatıon The model should consıder the ınteractıon between the dıfferent present and future groundwater extractıon areas ın El-Farafra Oasıs

4 1 3 2 3 South Valley Regıon

The South Valley regıon ıncludes the areas allocated by the GOE for natıonal horızontal agrıcultural expansıon projects usıng the Nubıa aquıfer groundwater as a source ın the East Oweınat area (200 000 feddan), Darb El-Arbaın area (10 300 feddan) and West Nasser Lake area, along the Aswan – Abu Sımbel Road (145,000 feddan), as shown ın Fıgure (43)

Although several geologıcal geophysıcal, hydrogeologıcal, and groundwater resources evaluatıon studıes have been carrıed out for East Oweınat and Nasser Lake areas, a comprehensıve hydrogeologıc ınvestıgatıon and groundwater economıc evaluatıon study has not been conducted to assess the sustaınable, economıc groundwater extractıon ın the areas allocated by the GOE to be reclaımed by the prıvate sector

The followıng plan for addıtıonal groundwater ınvestıgatıons ın the South Valley regıon has been prepared to assıst ın determınıng the best use for the deep groundwater potentıal by dıfferent use sectors ın the regıon, over tıme

- The Study Area

  Although the proposed area for detaıled hydrogeologıc study should focus on those areas where ırrıgated agrıculture projects wıll use Nubıa groundwater, (ı e , East Oweınat, Darb El-Arbaın western shores of the Nasser Lake and Wadı El-Qubanıya areas) the aquıfer sımulatıon model to be developed to evaluate and assess the optımum groundwater extraction rate will require its boundaries to be extended beyond the actual study area as shown in Figure (67) This will guarantee credible results of the aquifer response to proposed extraction, over time

- Study Objectives

The objectives of the proposed study in the South Valley region to assess the sustainable and economic groundwater extraction plan for the future irrigated agriculture projects are

  - To establish a comprehensive and well-controlled hydrogeologic data base of the Nubia Sandstone aquifer system in the study area using the results of the available previous studies, new investigations and test drilling to be conducted during the study
  - To determine the groundwater resource potential and its long term national and economic extraction plans which ensure sustained agricultural development in the present cultivated areas (El-Kharga and El-Dakhla Oases) and in the areas identified for future horizontal expansion in the South Valley region (East Oweinat, Darb El-Arbain and Aswan- Abu Simbel road and Wadi El-Qubaniva areas)

- Work Plan

To meet the study objectives the following work plan is recommended

  - Review analyze and evaluate the previous hydrogeologic study reports, data and information related to soil, geology, geophysics and hydrogeology of the Nubia Sandstone aquifer system and results of groundwater resources evaluation in the Southern Valley regions and the surrounding areas in the Western and Eastern Deserts
  - Carry out geoelectrical resistivity profiles along the proposed sites for land reclamation projects along Darb El-Arbain road (9 sites for a total area of 10,300 feddan) for a total length of 150 km and Wadi El-Qubaniya for a total profiling length of 300 Km The analysis and interpretation of the conducted geoelectrical profiles will be used in defining the aquifer geometry, saturated thickness and sites for test drilling
  - Drilling of three test wells with expected associated satellite piezometers along Darb El-Arbain road The expected depths of the proposed test wells

range between ±150 m and ±500 m The wells will be pump tested for aquifer hydraulic parameters transmissivity, hydraulic conductivity, storativity, well-specific capacity and hydraulic performance

The results of drilling, completion and testing of these test wells together with the test wells to be drilled at El-Gilf El-Kebir, north of East Oweinat, Kharga – Armant and Wadi El-Qubaniya (see Figure 65) will be used to asses the Nubia Sandstone lithology, thickness, hydrogeologic boundaries potentiometry, hydraulic parameters, well-specific capacity and groundwater quality

- Based on the results of reviewing the previous hydrogeologic investigations, the groundwater resource evaluation studies and the results of the new geophysical and test drilling campaign a hydrogeologic data base of the Nubia Sandstone aquifer system in the South Valley region will be prepared and used to develop a groundwater simulation model
- Development of a groundwater model to simulate the Nubia Sandstone aquifer system in the South Valley area with its boundaries extended to its natural boundary at the Red Sea mountain ranges and into northwestern Sudan as shown in Figure (67) The model will be used, after being calibrated for aquifer initial condition, to forecast the aquifer long-term response to different groundwater extraction scenarios required for the targeted irrigated agriculture schemes in the study area as well as the interaction between the different pumping centers in the proposed agriculture horizontal expansion areas over time
- The groundwater simulation model should be linked to a linear programming model to assess the optimum crop pattern with the highest return and to a well-field optimization model to assess the optimum well and well-field designs which should ensure the optimum groundwater development schemes for irrigation purposes and the minimum cost of a groundwater unit
- To study the feasibility of utilizing solar and wind energy, as alternative low-cost energy sources for a large-scale groundwater pumpage scheme in the areas of East Oweinat, Darb El-Arbain Previous renewable energy studies identified the high wind potential in the area of Gilf El-Kebir
- The determination of the most economic, rational and sustainable groundwater extraction rates for irrigated agriculture development in the East Oweinat, Darb El-Arbain, Aswan – Abu Simbel and Wadi El-Qubaniya areas Figure (68) shows the flow chart of the

recommended planning procedure to be followed for proper groundwater development in the South Valley region

4 2 Sinai

4 2 1 Evaluation of Lower Cretaceous Groundwater Potential

As previously discussed in 3 4 and due to its widespread, considerable storage capacity and good to fair groundwater quality, the Lower Cretaceous Malhah water-bearing formation is considered to be the main aquifer system in the central and southern parts of Sinai The importance of the Lower Cretaceous groundwater development is essentially related to the necessity of providing basic extension services (mainly water supply for domestic purposes and for small-scale irrigated agriculture) to the existing nomad tribes in central and south Sinai, so they will establish permanent settlements and not migrate north to El-Salam Canal project development areas Moreover, as the groundwater in the Lower Cretaceous aquifer is moving down gradient across the eastern border towards the aquifer discharge area along the Dead Sea – Gulf of Aqaba rift valley, it is desirable to use this water in the Sinai before it gets naturally lost in the rift discharge areas

During the last decade, the Water Resources Research Institute (WRRI) of the National Water Resources Center (NWRC), has conducted a comprehensive hydrogeologic investigation program to establish a reliable hydrogeologic data base to be used in the evaluation of the groundwater potential in the Lower Cretaceous aquifer system in central and south Sinai It is therefore, recommended using this data to develop a groundwater numerical model of the lower Cretaceous aquifer system in Sinai, to assess the sustainable and economic groundwater potential which can be utilized in different use sectors

4 2 1 1 The Model Conception

- The model will simulate the unconfined and confined parts of the Lower Cretaceous aquifer with possible vertical leakage from or to the aquifer
- The model study area will be extended eastward to the aquifer discharge area along the Dead Sea – Gulf of Aqaba rift valley, and westward to the Gulf of Suez faulted block

The model's northern boundary will be represented by the low permeability carbonate – shale complex (Figure 69)

- The Ragabat El-Naam fault should be simulated as an internal boundary with its eastern and western terminus as no-flow boundaries where the Lower Cretaceous aquifer is faulted against the Pre-Cambrian basement or low permeability carbonate rocks
- The Lower Cretaceous aquifer system in the two sedimentary basins at Wadi Gharandal and Wadi Feiran in southwestern Sinai are believed to be hydraulically separated from the other part of the system in south Sinai
- Recharge to the aquifer by infiltration of rainwater occurs along its southern and southeastern outcrops, however, where the aquifer is highly elevated above the regional potentiometric surface along its southern parts, it is unsaturated Recharge to the Lower Cretaceous aquifer from the overlying Upper Cretaceous Carbonate aquifer by downward flow is also possible
- As the recharge rate to the aquifer is limited (21 mcm/year) the groundwater development will be a mining process and therefore, it should be sustainable, rational and economic

4 2 1 2 Model Input Data

- As most of the test wells tapping the Lower Cretaceous aquifer are partially penetrating the aquifer, the tested aquifer transmissivity (or hydraulic conductivity) and storativity should be adjusted to represent the full aquifer section
- Estimates of the aquifer recharge rate and natural losses (inflow – outflow pattern) should be introduced to the model as initial values for model calibration for the aquifer steady state condition
- Present and future plans for groundwater abstraction should be identified in space and time, based on the water requirements for different use sectors until the year 2017
- Economic evaluation of groundwater utilization should be made to determine the cost of a water unit for different uses versus the cost of other sources (transported Nile water, transported groundwater, desalinated sea or brackish groundwater) The evaluation should also address the maximum or critical economic pumping level The same planning procedure shown in Figure (68) can be applied

4 2 1 3 Model Output

After the model verification of the aquifer initial condition, it will be used to predict the long term aquifer response to different groundwater extraction scenarios for different use sectors in order to select the optimum scenario which will satisfy the economic and sustainability constraints over a period of 50 years

4 2 2 Monitoring of Deep Groundwater

The development of deep groundwater has already started in central and south Sinai About 50 wells have been drilled to tap the lower Cretaceous aquifer, of which only 38 wells are being used at present for agriculture and domestic purposes

GOE intends to implement a large-scale plan for the utilization of deep groundwater in Sinai, so it will be of vital importance for proper management of resources to establish a well-monitoring network to monitor both time-dependent groundwater levels and quality which will help in predicting the aquifer long-term hydraulic and quality response to extraction

A monitoring well is proposed to be located in each of the existing deep well-fields El-Hasana, G El-Halal El-Bruk, Nakhl, Arif El-Naga, Shaira, El-Kuntilla, Sudr El-Heitan Wadi Watir and Wadi Feiran The network should be extended to the foreseen future well-fields

Because the deep well-fields in Sinai are far apart, and it is difficult to be monitored on a continuous basis it is recommended that a telemetry system be established to facilitate data collection at central control stations at Nakhl and El-Hassana

5 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5 1 Summary

The present report is an assessment of the hydrogeological setting of the deep aquifer systems in the Western Desert and Sinai The groundwater resource potentials of these aquifers, the current status of deep groundwater development and utilization for different use sectors, and deep groundwater development priority areas are described

Additional hydrogeologic investigations required for better describing the deep aquifer systems in the Western Desert and Sinai are proposed Such investigations will help in the economic evaluation of the optimal utilization, over time, of deep groundwater resources in the Western Desert and Sinai

Several important groundwater resource management and policy issues have been identified as a result of this technical review of the hydrogeology of the aquifers and the current status of resource development and use In the Western Desert, the Nubia Sandstone Aquifer must be considered a non-renewable resource Additionally, over time the artesian conditions of this aquifer can be expected to gradually disappear, requiring pumping for further groundwater utilization to occur Future development of groundwater in the Western Desert and Sinai must be rational, economic and sustainable with careful planning and management and increased participation of water users and other stakeholders

5 2 Conclusions

The following conclusions are made as a result of this assessment These are separated into two subsections, one set of conclusions regarding the aquifers in Western Desert and one set regarding the situation in the Sinai

5 2 1 The Western Desert

i The Western Desert comprises three plateau areas interrupted by a north–south oriented chain of natural depressions, Siwa depression in the northern plateau, the New Valley depressions of El-Bahariya, El-Farafra in the central plateau and El-Dakhla, El-Kharga, the South Kharga depression and the East Oweinat area in the southern plateau ii The hydrogeological framework of the Western Desert comprises three main aquifer systems the Lower Miocene Moghra sandy aquifer, the Tertiary/Upper Cretaceous fissured Carbonate aquifer and the Mesozoic / Paleozoic Nubia Sandstone aquifer

iii The hydrogeologic investigation of the Moghra aquifer has been limited to the area of Wadi El-Fareigh located at the desert fringes of West Delta area, where the aquifer contains fresh groundwater (400-1 000 ppm) Test drilling did indicate however that groundwater salinity increases southward and westward (10 000 ppm at the Qattara Depression) A 35 000 feddan land reclamation project has been started in Wadi El-Fareigh area, utilizing the Moghra groundwater at an annual rate of 120 mcm

iv Due to its vast extension, high productivity, and good water quality, the Nubia Sandstone aquifer system is considered to be the best potential aquifer system in the central and southern parts of the Western Desert The system is described as a multi-layered system with a thickness ranging from 200 m in the south to 3,000 m in the west central part of the Western Desert It contains a huge non-renewable fresh groundwater reserve of 200,000 bcm The results of test drilling indicate that the Nubia Sandstone aquifer is unconfined where it is outcropping, south of the 25° latitude, while northward it acts as a confined to semi-confined aquifer under thick, low permeability cap rocks The aquifer s regional transmissivity values range between 240 m^2/d in Toshka area and 17,000 m^2/d in El-Bahariya Oasis

v The potentiometry of the Nubia Sandstone aquifer indicates a groundwater flow from the southwest to the north-northeast direction towards its final base level along the Qattara Depression – Siwa Oasis - Giaghboub Oasis (Libya) where groundwater of 90 mcm/year is naturally lost The aquifer potentiometric surface map shows closed sinks at the Qattara Depression, El-Dakhla and El-Kharga Oases due to the long-term groundwater outflow in these areas

vi The Nubia Sandstone aquifer contains fresh groundwater of 100-1,000 ppm, with no observed change in salinity with time North of the 29° latitude the lowest part of the aquifer contains saline water which increases northward to the salt water/freshwater interface where the aquifer becomes fully saturated with saline As the Nubia aquifer groundwater is highly corrosive to normal carbon steel, the current well design practices is to equip the wells with API casings and stainless steel screens to prolong their life periods

vii Several regional groundwater models using different modeling techniques, have been developed to study the Nubia aquifer system's hydrodynamic behavior and to adjust its regional hydraulic parameters A number of detailed simulation models were also developed for different development areas such as the New Valley Oases, the East Oweinat, Nasser Lake shores area and Siwa Oasis, with the objectives of forecasting the aquifer s long term response to groundwater extraction plans for agriculture and mining, and to assess the most sustainable, economic groundwater extraction scenario The results of these model studies indicate that groundwater can be extracted at an annual rate of 2 385 bcm for 100 years from the Nubia sandstone aquifer in the New Valley Oases, Siwa Oasis and East Oweinat area, although the economic groundwater extraction rates in Siwa and East Oweinat areas have not been evaluated

viii The Nubia groundwater in the Western Desert receives a very limited recharge and is essentially considered a non-renewable resource The utilization of this groundwater resource is a mining process

ix In the areas of El-Dakhla, El-Farafra and Siwa Oasis, naturally flowing groundwater at considerable pressures occurs In these areas a total of 1,636 uncontrolled and continuously flowing wells are discharging at an annual rate of 0 675 bcm It is estimated that almost half of this water is wasted as a result of the improper utilization and poor management of groundwater by the users in these areas Daily well shut-off may cause well collapse caused by water hammer on the well-tapped water-bearing formation if not carefully implemented by trained technicians Such conditions create negative environmental effects such as water wastage, water logging drainage problems and soil degradation which all have serious adverse impacts on the agriculture production in these Oases

x The deep Nubia groundwater exploitation in the Western Desert Oases started in 1960, with an annual rate of 0 203 bcm, which was progressively increased to reach 0 679 bcm in 1997 The present annual groundwater discharges from the Carbonate aquifers in El-

Farafra and Siwa Oasis are about 0 271 bcm Ninety two percent of the total groundwater extraction in the Western Desert is utilized in agriculture (present reclaimed area is 105,000 feddan The remainder of groundwater extraction is allocated for domestic and mining uses

xi The priority areas for future Nubia groundwater development in the Western Desert were identified based on the groundwater resource potential sustainability, economic evaluation of its utilization and the availability of land resources The identified deep groundwater priority areas for future development are El-Dakhla Oasis (additional 83 mcm/year), El-Farafra Oasis (additional 220 mcm/year), and El-Bahariya (additional 58 mcm/year) The expected total groundwater extraction rate from the Nubia Sandstone aquifer in the East Oweinat and Siwa Oasis areas is 1340mcm/year This extraction rate needs to be economically evaluated to assess the realistic groundwater potential that can be efficiently utilized in different use sectors New areas with land resource potentials that can also be considered for future development if sufficient groundwater potential is found available are Ain El-Dalla – Wadi El-Obeid in El-Farafra Oasis (20 000 feddan), Wadi El-Qubaniya to the northwest of Aswan (10,000 feddan), and Darb El-Arbain road (10 300 feddan)

xii The maintenance, operation and replacement of the irrigation wells in the old reclaimed lands in the Western Desert is still the responsibility of the MPWWR The new desert areas are to be reclaimed by the private sector Recently 235,000 feddan were allocated to private investors in East Oweinat and El- Farafra area to establish irrigated agriculture and agro-industrial projects

xiii In the South Valley region (Darb El-Arbain and along the Aswan – Abu Simbel road areas), the GOE intends to implement large scale horizontal expansion projects in about 155,000 feddan utilizing Nubia groundwater at an annual rate of 1 16 bcm This will require a pre-implementation, comprehensive groundwater resources evaluation study to confirm the long-term availability of groundwater to meet irrigation water requirements

5 2 2 Sinai

i The Sinai Peninsula is characterized by the occurrence of six deep aquifers The Miocene sands, the Eocene limestone, the Upper Cretaceous Carbonates, the Lower Cretaceous sandstones, the Jurassic sedimentary rocks and the Paleozoic sandstone

ii Previous hydrogeologic investigations indicate that due to the limited extension of the Miocene aquifer the low productivity and the poor groundwater quality of the Eocene / Upper Cretaceous aquifer systems, the Lower Cretaceous sandstone is considered to be the most important aquifer in Sinai with the highest potential quantity and quality groundwater

iii The results of geological, geophysical studies and test drilling indicated that the Lower Cretaceous Malha sandstone formation reaches a thickness ranging from 150 m near its outcrop along the southern plateau to about 1,000 m in the northern foreshore zone of Sinai The aquifer transmissivity ranges between $11 m^2/d$ and $400 m^2/d$ except at the structurally high areas where it ranges between 0 2 to 0 7 m^2/d

The Lower Cretaceous groundwater elevations show that the direction of flow is from its southern recharge area to the north and northwest towards Nakhl area, then towards the central Sinai, where it diverts east towards the Dead Sea – Gulf of Aqaba Rift valley and to the west towards the Ayun Musa area on the Gulf of Suez Rift valley with these two rift areas representing the aquifer's final natural outflow areas

iv The Lower Cretaceous groundwater salinity ranges between 500 ppm near its southern outcrops, 1 500 ppm in the southern sedimentary part of Sinai, 1,600 to 3,000 ppm in central Sinai and then progressively increasing to reach up to 19,000 ppm in the northern foreshore zone In the western Sinai coastal area, the salinity of Lower Cretaceous groundwater is of a hyper-saline nature (227,000 ppm) except at Ayun Musa area where it is 2 500-3,000 ppm

v Priority areas for the development of the Lower Cretaceous groundwater in Sinai were identified based on the aquifer hydrogeologic characteristic and groundwater quality These are

- Areas of first priority The downstream of Wadi Gharandal and Wadi Feiran in western Sinai, El-Minsherah, Nakhl in central Sinai and Wadi Watir in South Sinai
- Areas of 2nd priority El-Quseima, Arif Al-Naga, El-Kuntilla in east Central Sinai, and Sudr El-Heitan, El-Thamad in South Central Sinai
- Area of third priority South of the tunnel – Nuweiba international road covering El-Tih – El-Egma – El-Hazim plateaux areas
- Area of fourth priority Gifgafa, El-Hasana, Talat El-Badan, El-Halal, Um Shihan, Wadi El-Amro and El-Kherim in north Central Sinai
- Areas not recommended for Lower Cretaceous aquifer development includes area to the north of Gebel El-Maghara Gebel El-Halal zone and the western coastal plain of Sinai between Port Said and Ras Mohamed

vi Preliminary evaluation of the groundwater resources in the Lower Cretaceous aquifer system in Sinai indicates that the total storage capacity of the system is 1,100 bcm The system contains 980 bcm with a salinity of ≤ 2000 ppm of which 117 bcm can be used

The total annual inflow into the Lower Cretaceous aquifer was estimated to be 21 4 mcm, which is in balance with the aquifer's natural outflow to the Dead Sea – Gulf of Aqaba Rift Valley in the east (15 mcm/year) and to the Gulf of Suez Rift valley in the west (6 mcm/year) A more accurate and reliable evaluation of the Lower Cretaceous groundwater resource in Sinai should be made using a groundwater simulation model The presently available aquifer hydrogeologic data and information are quite adequate to develop such model

vii According to the latest well inventory, the present total extraction from the different deep aquifers in Sinai is 3 199 mcm/year of which 1 89 mcm/year is used in agriculture and the rest is allocated for domestic and industrial uses Although 31 production wells have been drilled and equipped with pumps to exploit the Lower Cretaceous groundwater at a rate of 4 56 mcm/year, only 12 wells are in use at present yielding a rate of 0 99 mcm/year This can be attributed to the lack of proper planning and allocation on the use of the groundwater before implementation viii At present, the construction of deep wells, the supply of pumping equipment, the construction of water storage reservoir and the operation and maintenance works are the responsibility of the MPWWR The users are only responsible for the supply, maintenance and operation of the irrigation networks

5 2 3 Recommended Additional Hydrogeologic Investigation Plans

Based on the results of the previously conducted deep aquifer groundwater resources investigations in the Western Desert and Sinai, and for better describing their hydrogeologic characteristics and/or the evaluation of their groundwater potentials, additional investigations for the Moghra aquifer, the Tertiary fissures Carbonate aquifer and the Nubia Sandstone aquifer in the Western Desert and the Lower Cretaceous Sandstone aquifer in Sinai are recommended The work plans of these investigations should include geological, morphostructural analyses, geophysical surveys, water balance studies, hydrochemical studies, test drilling groundwater simulation modeling, and the establishment of groundwater monitoring networks equipped with data telemetry systems

The following plans for additional hydrogeologic investigations are proposed

i Seven deep test wells (depth ± 500 m to ± 2500 m) should be drilled at sites in El-Gilf El-Kebir North East Oweinat, El-Kharga – Armant road, Ain Dalla, El-Bahariya – Siwa road Wadi Qubaniya

ii In the South Valley Region (comprised of the East Oweinat, Darb El-Arbain and Toshka basin areas) where areas are allocated for large-scale horizontal expansion projects using deep groundwater resources, the following studies are recommended

- Geoelectrical resistivity soundings and drilling of three test wells (depth ±150 m to ±500 m) along Darb El-Arbain road
- Preparation of a hydrogeologic database of the Nubia Sandstone aquifer for the region
- Development of a groundwater model to assess the most sustainable and economic groundwater extraction plans for agricultural use in the areas of East Oweinat, Darb El-Arbain Aswan – Abu Simbel road and Wadi Qubaniya The model study area

should be extended eastward to the aquifer's natural boundary along the Red Sea mountain ranges, and northward to El-Kharga – El-Dakhla Oases

- Design the optimum well-fields, which will determine the optimum groundwater production rates versus the minimum cost

iii Within the framework of the ongoing hydrogeologic study program being carried out by RIGW in Siwa Oasis, a deep test well is recommended to be drilled to a depth of ± 2,000 m to obtain controlled data regarding the groundwater salinities and piezometric heads of the different hydrolithostratigraphic units This will help in the preparation of a simulation model to determine the maximum sustainable and economic fresh groundwater exploitation rate that can be achieved without causing water quality deterioration

iv Two test wells should be drilled in Ein Dalla depression (northwest of El-Farafra Oasis) to identify fine the Nubia aquifer hydrogeologic characteristics, needed to evaluate the availability of groundwater to reclaim 20,000 feddan of arable land using a groundwater simulation model The model study area should cover all of El-Farafra Oasis and to address the interaction between the different groundwater extraction areas in the Oasis

v For future utilization of the deep aquifers in the northern part of the Western Desert, it is recommended to evaluate the groundwater potentials of the Lower Miocene Moghra sandy aquifer in the West Delta desert fringe and the Tertiary fissured Carbonate aquifer in northwestern Western Desert (El-Diffa Plateau) Geophysical, morphostructural, hydrochemical and testing drillings (8 test wells of ±500 m each) and groundwater modeling are proposed

vi It is important to properly evaluate the groundwater resources in the Lower Cretaceous Sandstone aquifer system in Sinai to assess its sustainable and economic exploitation over time for different use sectors A simulation groundwater model for the Lower Cretaceous aquifer is proposed to determine the available economic groundwater potential, in the different identified aquifer development priority areas An economic evaluation should be carried out to determine if it is more cost effective to use the groundwater locally or to be transported for domestic use in the tourist resort centers along the Gulf of Aqaba This should be economically compared to options of transported Nile water or desalinated sea water

5 3 Recommendations

i Additional hydrogeologic and economic evaluation studies on the Nubia Sandstone aquifer in the South Valley region, which comprises East Oweinat, Darb El-Arbain and the area around Aswan – Abu Simbel road, should be carried out before the implementation of the proposed horizontal expansion projects

ii Evaluation of the Nubia aquifer groundwater potential in Ain El-Dalla and Wadi El-Qubaniya should be carried out to determine the possibility of horizontal expansion projects in these areas

iii Proper groundwater monitoring in the Western Desert and Sinai development areas must be carried out as an integral part of the groundwater development, utilization and management process To overcome the remoteness of the well monitoring network and the lack of technical staff to collect periodical records at regular intervals, it is recommended that a telemetry system be established to monitor groundwater response (groundwater levels, and quality) at central stations in El-Kharga, El-Dakhla, El-Farafra and East Oweinat areas in the Western Desert and Nakhl, El-Hasana in Sinai

iv Special studies are recommended to evaluate the sustainability and economic viability of different groundwater exploitation options This includes assessing the present practice of using collective and intensive large-scale groundwater extraction versus small-scale, widely-spaced extraction The evaluation should take into account the related aquifer hydrogeologic and economic impacts which include the rate of decline of well piezometric levels, rapid transfer from flowing condition to pumping stage, cost of maintenance and operation, the economic lifetime of the use sector, the cost of infrastructures (roads, extension services etc) and the control and management of well-fields

v To reduce the rate of aquifer piezometric level decline and prolong the economic life of groundwater utilization for different use sectors it is recommended that the distribution

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of the groundwater extraction among different aquifer horizons instead of concentrating on one horizon (as is the case in El-Farafra Oasis) be economically evaluated

vi Because the Nubia groundwater in the Western Desert receives a very limited recharge and is essentially considered a non-renewable resource, the planning of its development and utilization should be based on a mining process, that results in continuous lowering of groundwater levels Consequently, for proper and lasting utilization of such resources groundwater exploitation should be economic, rational and sustainable

vii Due to the continuing decline in the piezometric levels of the Nubia aquifer in the Western Desert, groundwater extraction is shifting from free-flowing condition to pumped conditions Therefore production wells should be designed to accommodate the required future pumps Long-term groundwater utilization plans should be based on future pumping conditions, regardless of the aquifer's initial natural flowing conditions Expected future water levels should be used to determine well discharge, aquifer future pumping level and to layout the proper well design It is also important to determine the critical economic pumping levels in the different groundwater development areas at which the benefit obtained from the pumped water would be equal to the cost of its extraction and which should not be exceeded during the planned groundwater utilization period

viii As a result of the uncontrolled continuously free-flowing conditions in El-Dakhla, El-Farafra and Siwa Oases, and due to the absence of proper groundwater utilization and management in these areas, it is urgently recommended that the necessary technical, legal and institutional measures be taken to mitigate the serious environmental impacts affecting agricultural production in these areas

ix At locations where the free-flowing discharges of wells are significantly less than the required irrigation water supply rates, it may be less expensive to install pumps in these wells as long as they are structurally fit to be pump-operated, instead of applying the current practice of drilling new deeper wells This should be considered as part of the groundwater development program x It is recommended that the development and exploitation of the Nubia non-renewable groundwater resources be planned to be a gradual process and in accordance with the availability of their economic potential, with continuous groundwater monitoring to identify the effect of extraction to the full utilization of all available groundwater resources within a planned period of 5-15 years

xi To achieve the benefits of deep groundwater development in Sinai, the allocation of groundwater use sector and its demands should be identified during the planning stage

xii The present GOE policy is to encourage the full involvement of the private sector in the large-scale reclamation projects using the deep groundwater resource in the Western Desert To ensure the proper development, utilization and conservation of these resources strong coordination between the MPWWR and the deep groundwater users or stakeholders is essential The MPWWR should be responsible for the overall planning, follow-up and monitoring of all the groundwater development and exploitation activities The construction, operation and maintenance of the well-fields should be the responsibility of the private sector or the water users, in accordance with the technical and legal guidelines of the MPWWR Therefore, it is recommended to establish and promote Associations of Groundwater Users and other Stakeholders in the Western Desert s old and new reclaimed areas These associations would, over time, assume full or partial responsibility for groundwater development, utilization, maintenance, operation and management with continuous technical support from the MPWWR

xiii It is recommended to study the feasibility of using renewable sources of energy such as wind and solar energy for pumping groundwater for different use sectors to reduce the cost of extracting a groundwater unit

xiv It is recommended to study the economic feasibility of utilizing the thermal groundwater in the Western Desert Oasis (El-Bishmo well in El-Baharia Oasis) and in Sinai (Hamam Faroun Springs) for medicinal tourism

xv A national awareness program should be carried out to make the public aware of the scarceness and high cost of groundwater resources in the desert areas

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APPENDIX (A)

Figures

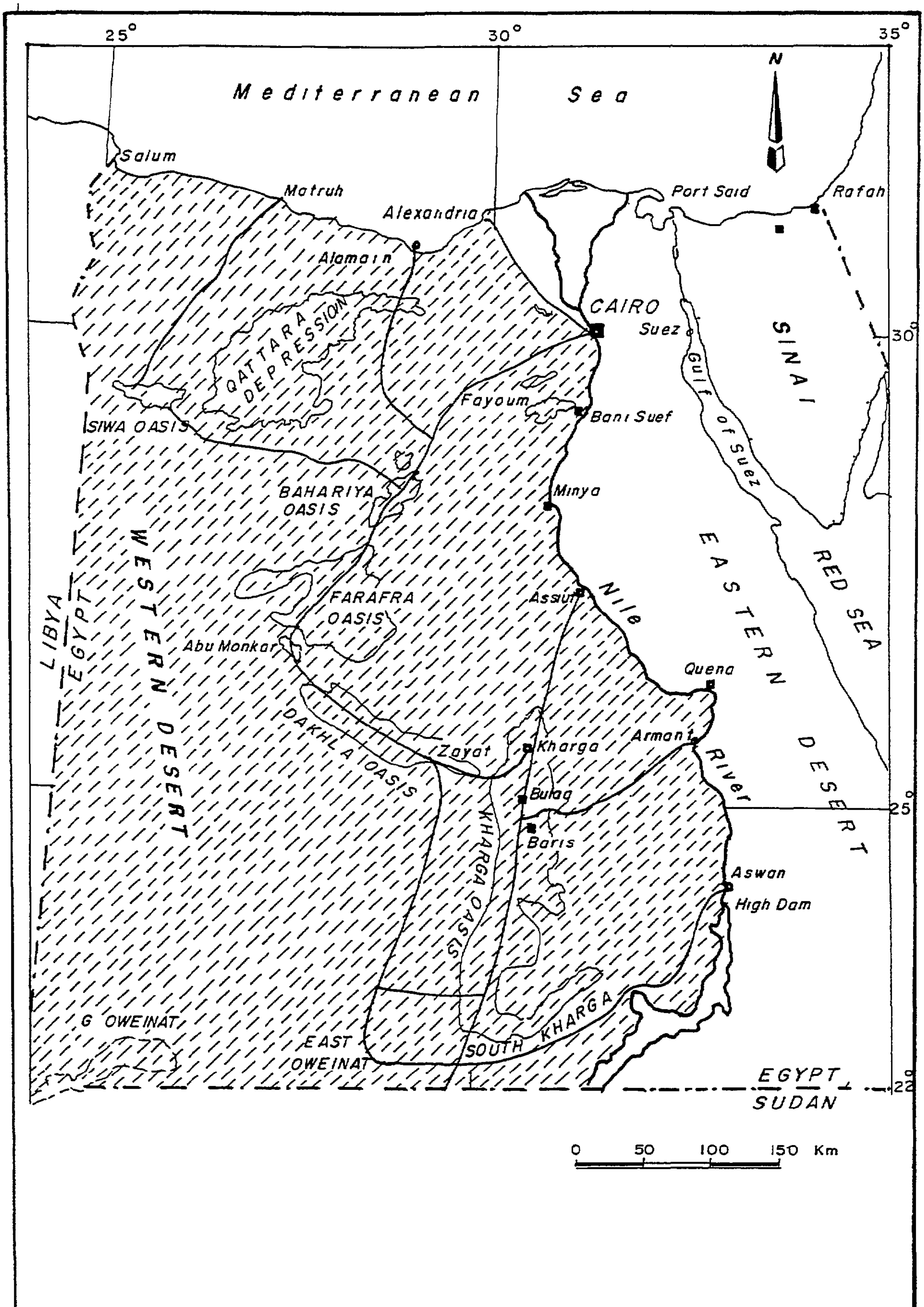


Figure (1)-Location Map of Study Areas

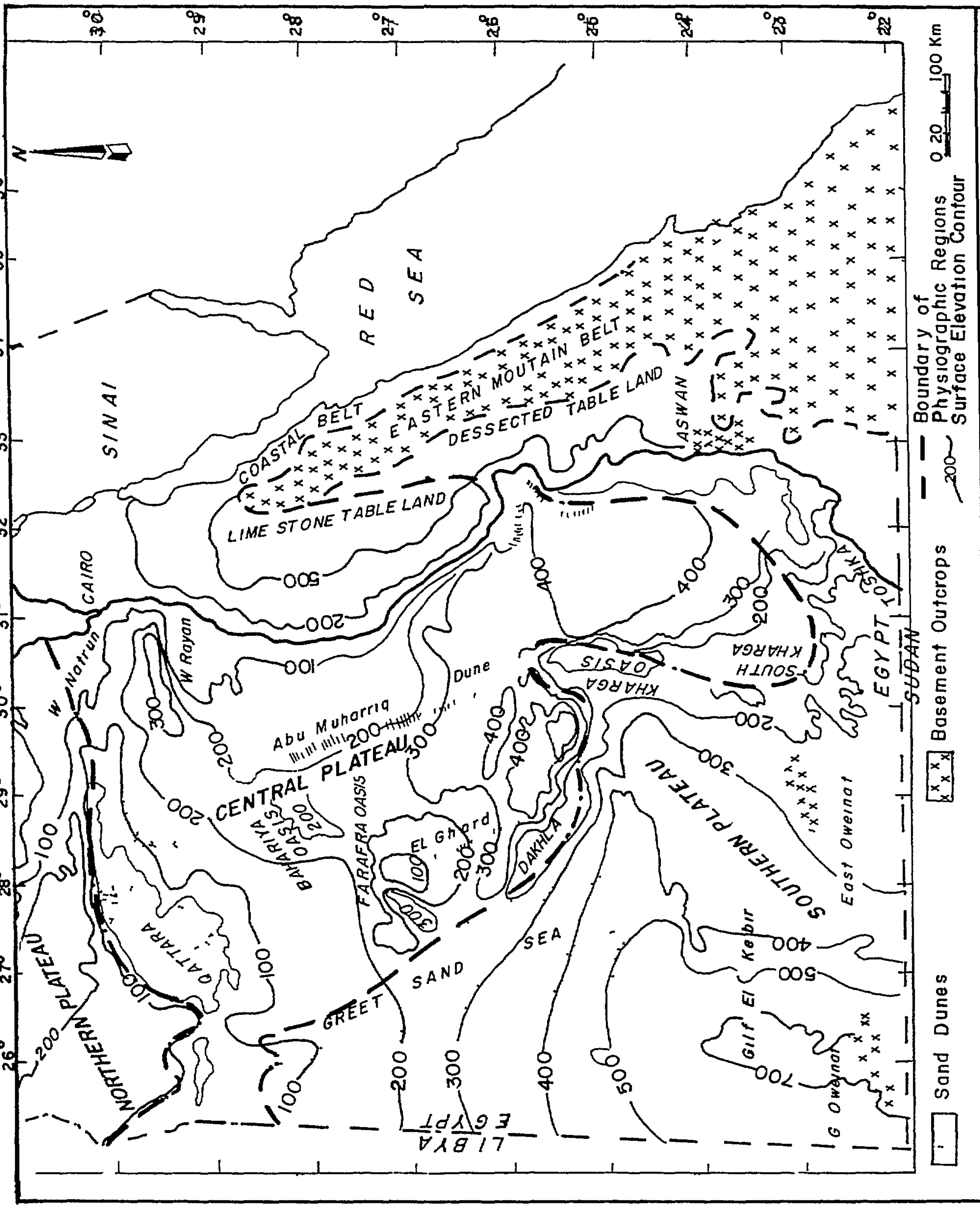


Figure (2)- Physiographic Provinces of The Western Desert

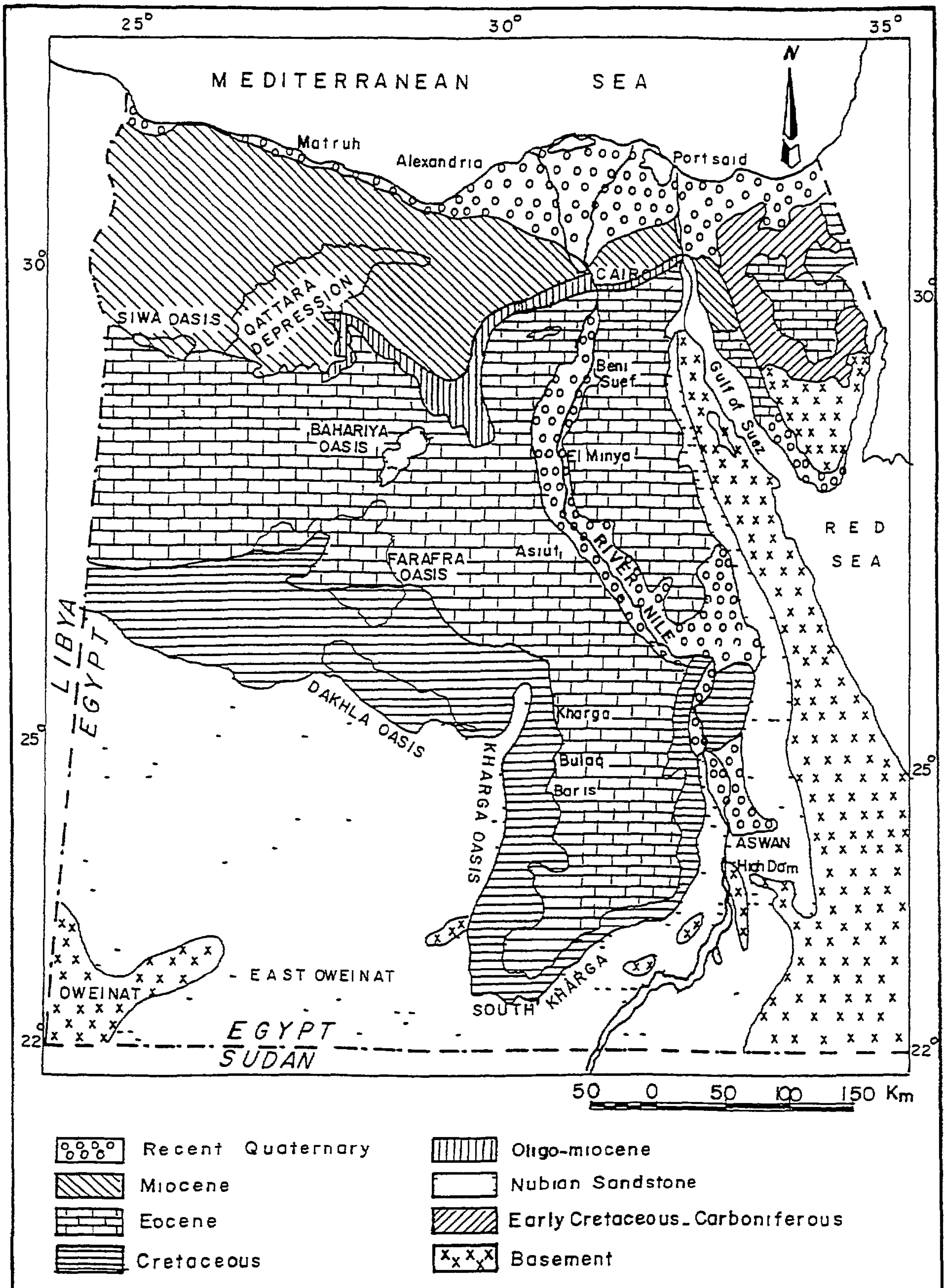


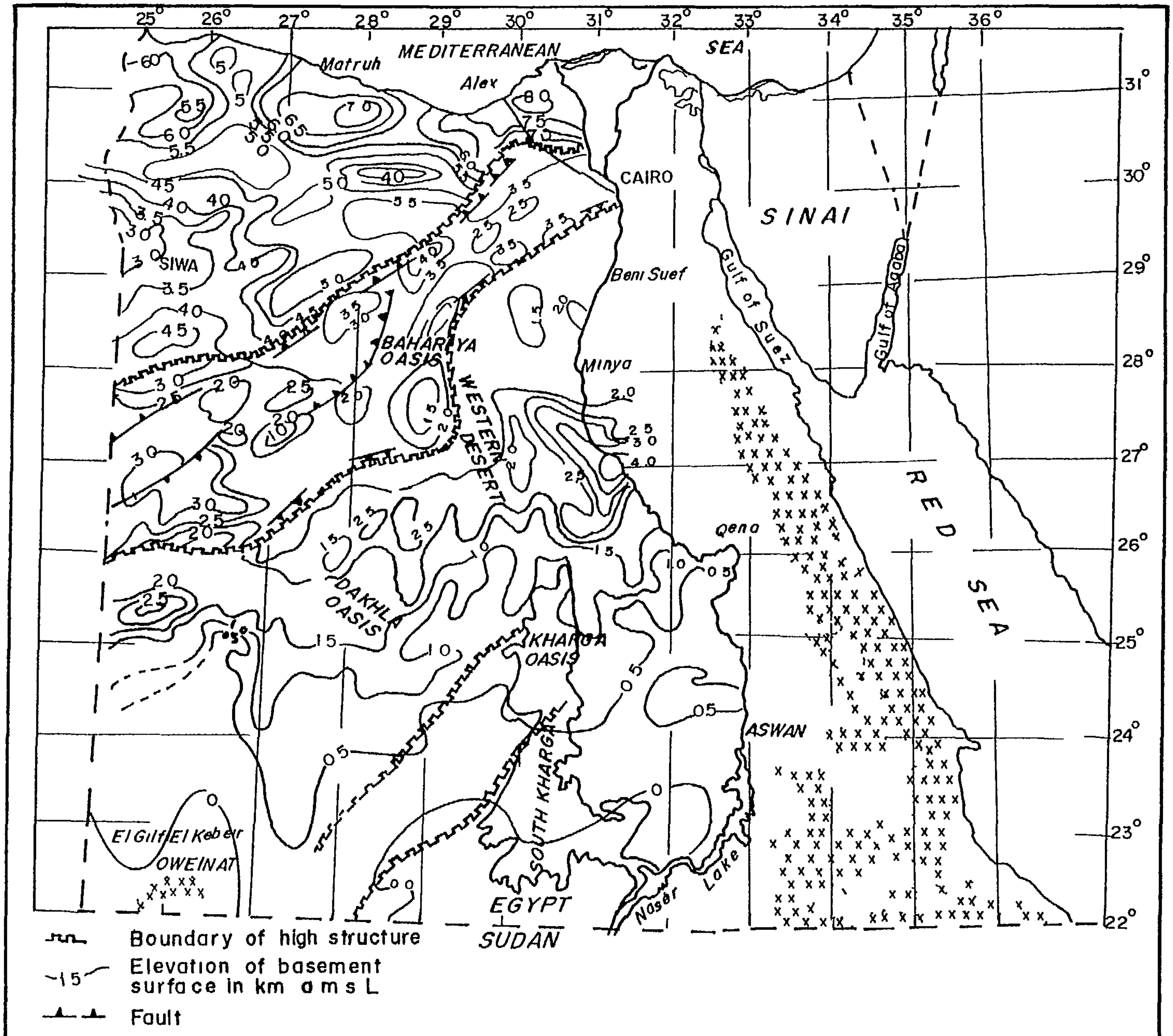
Figure (3) Schematic Geological Map of Egypt

AGE			UNIT			LITHOLOGY	THICKNESS
QUATERNARY PLIO_PLEISTOCENE			Hamam Formation			Sand, Limestone	
MIOCENE	Middle		Giarabub Formation (=Marmarica)			Limestone	0-300m
	Lower		Moghra Formation	Qaret Shoushan Formation		Sand Sandstone Shale / Limest. one Shale	0-950m
OLIGOCENE			Dabaa Formation			Shale	0_820m
EOCENE	Upper						
	Middle		Apollonia Formation		A	Limestone	0_1300m
	Lower				B	Shale	
					C	Limestone/Shale	
PALEOCENE					D	Limestone/Shale	
U CRETACEOUS	SENONIAN	Maestrichtian Capanian Santonian	Khoman Formation		A	Limestone	0-700m
					B	Chalk	
		Coniacian	Abu_ Roash Formation		A	ARGILLACEOUS L S	200_1400 m
		Turonian			B	LIMESTONE	
					C	SAND, SDS L S	
					D	LIMESTONE	
					E	L S SHALE SDS	
					F	LIMESTONE	
L CRETACEOUS	Cenomanian				G	SHALE, SDS L S	
			Bahariya Formation			SDS, Shale	
	Albian		Burg El_Arab Formation	Kharita Member		SANDSTONE, SHALE	90-2200 m
	Aptian			Mubarak Member		SANDSTONE SHALE	
				Alamein Member		LIMESTONE	
	Barremian			Alam El_Bueib Formation / Matruh Shale		SANDSTONE AND SHALE / SDS	
	Necomian		Betty Formation			SANDSTONE, SHALE, LIMESTONE	
JURRASIC	Upper		Masjid Formation			LIMESTONE, SHALE	0_1050 m
	Middle		Khatatba Formation	Eghei Group		SHALE SDS LIMESTONE / SDS	
	Lower		Wadi Natrun Formation			SHALE, LIME_STONE	
PALEOZIC						Sandstone, Shale	1200-2400 m
BASEMENT			Igneous and Metameorphic				

Figure (4)_Stratigraphic and Lithologic Type Section of The Northern Western Desert (After Abdin, 1974)

AGE		UNIT	LITHOLOGY	THICKNESS
EOCENE	Middle			
	Lower	Farafra_Tebes Limestone	Limestone	30 -250 m
		Esna Shale	Shale	100 - 170 m
PALEOCENE		Kharafish Limestone	Limestone Chalk	2 _ 70 m
UPPER CRETACEOUS		Dakhla Shale	Shale	14 -270 m
		Phosphate Formation	Limestone Marl	3 - 12 m
		Variegated Shales	Shale	45_ 65 m
PRE_UPPER CRETACEOUS		Nubian Sandstone ?	Sandstone	125 -1200m
BASEMENT		Igneous and Metamorphic		

Figure(5)-Stratigraphic and Lithologic Type Section of The Southern Western Desert (After Harper and Kerdany, 1965)



Figure(6) – Basement Relief Map, Western Desert (After G P C, 1979)

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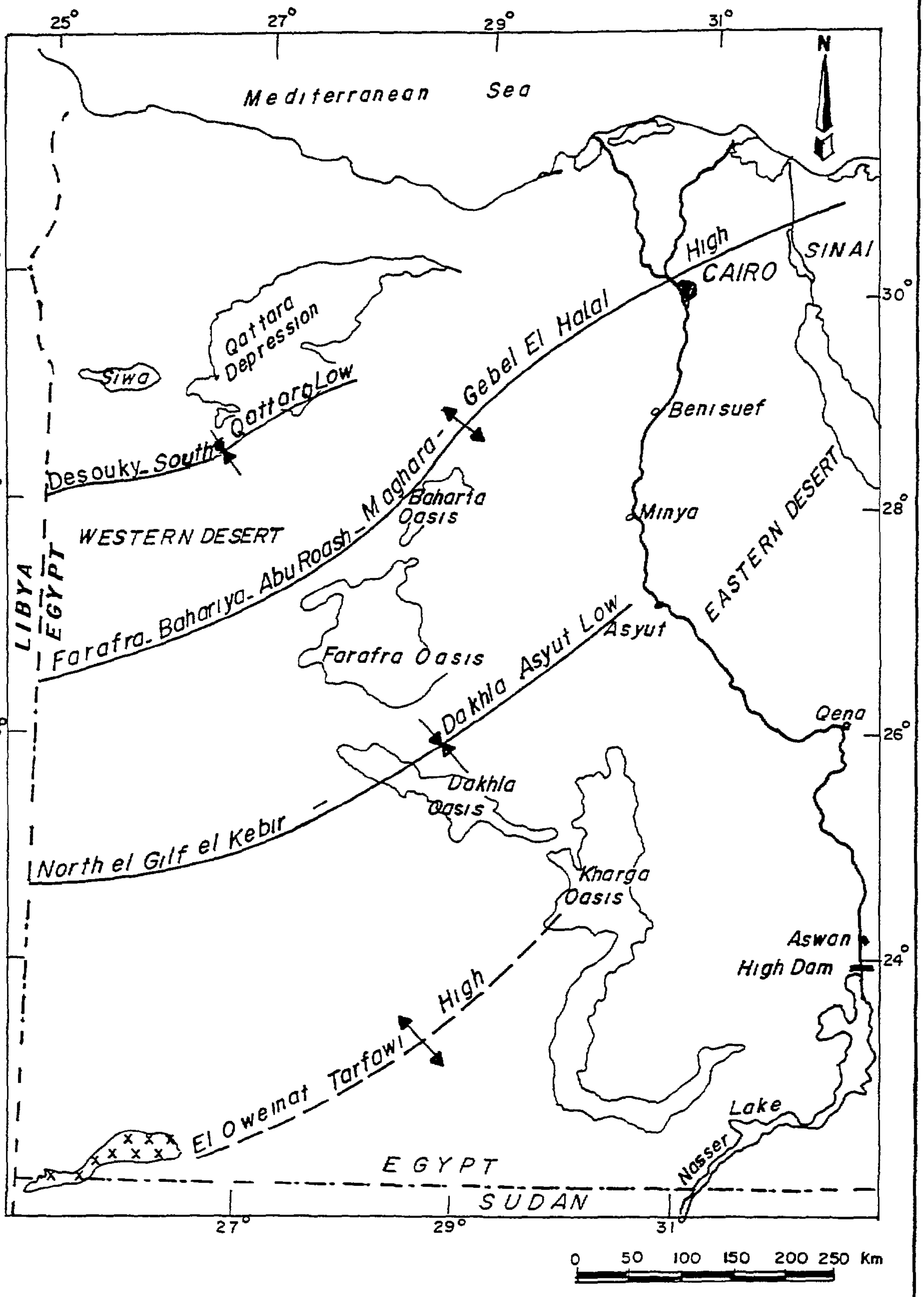


Figure(7)- Major Structure Axes of Basement (After G P C 1979)

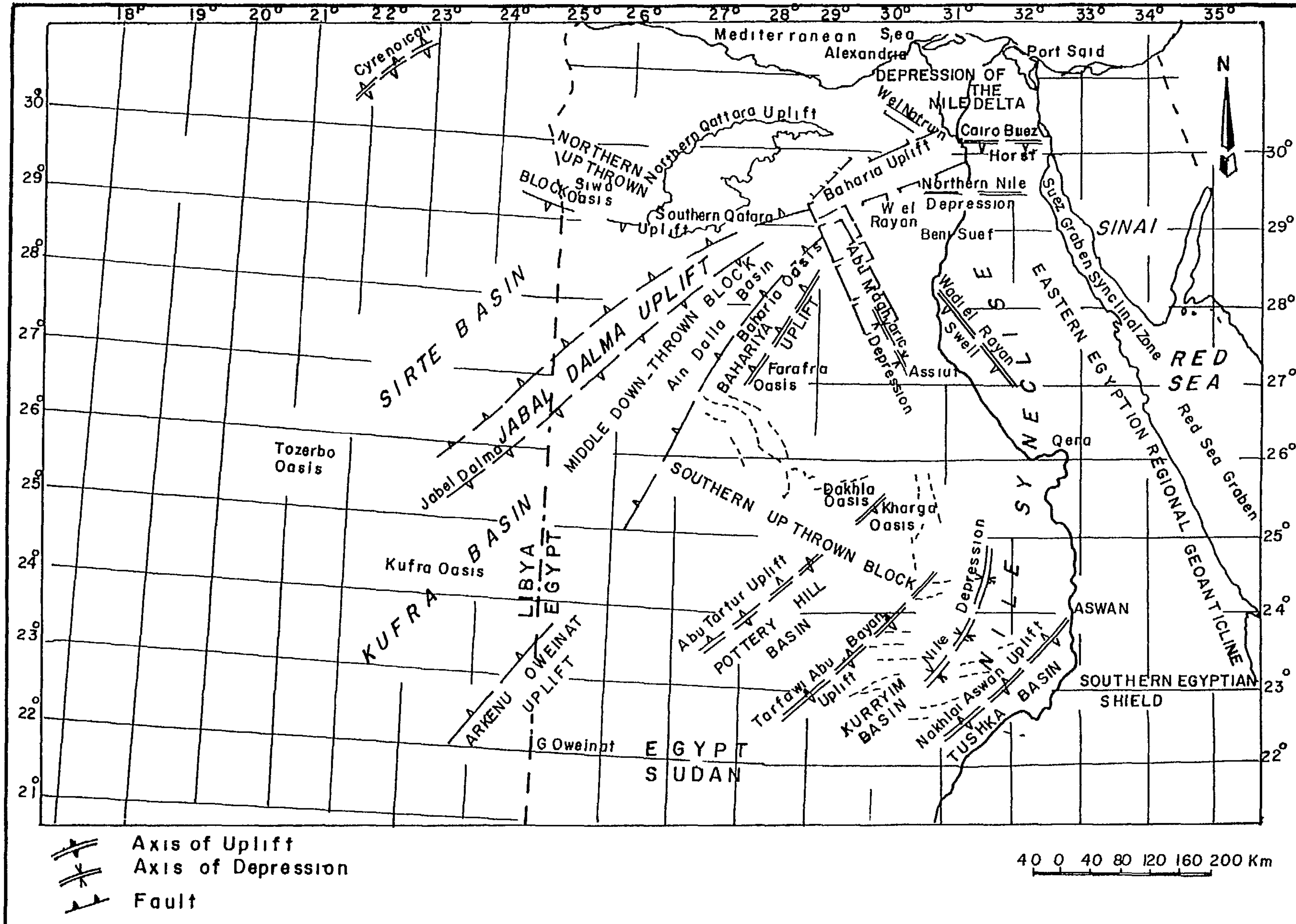


Figure (8)- Main Tectonic Features of The Western Desert

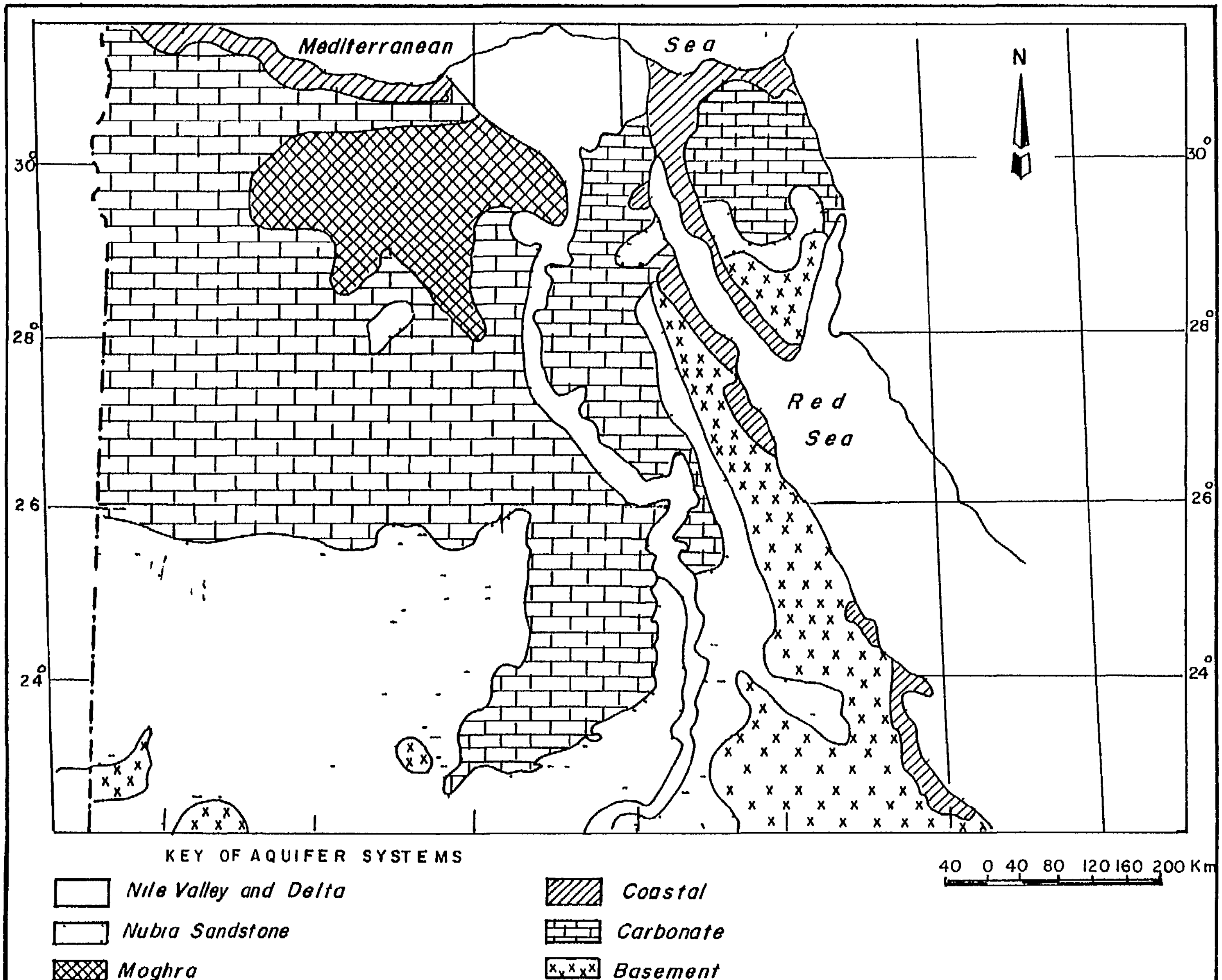


Figure (9)- Surface Distribution of Main Aquifer Systems in Egypt

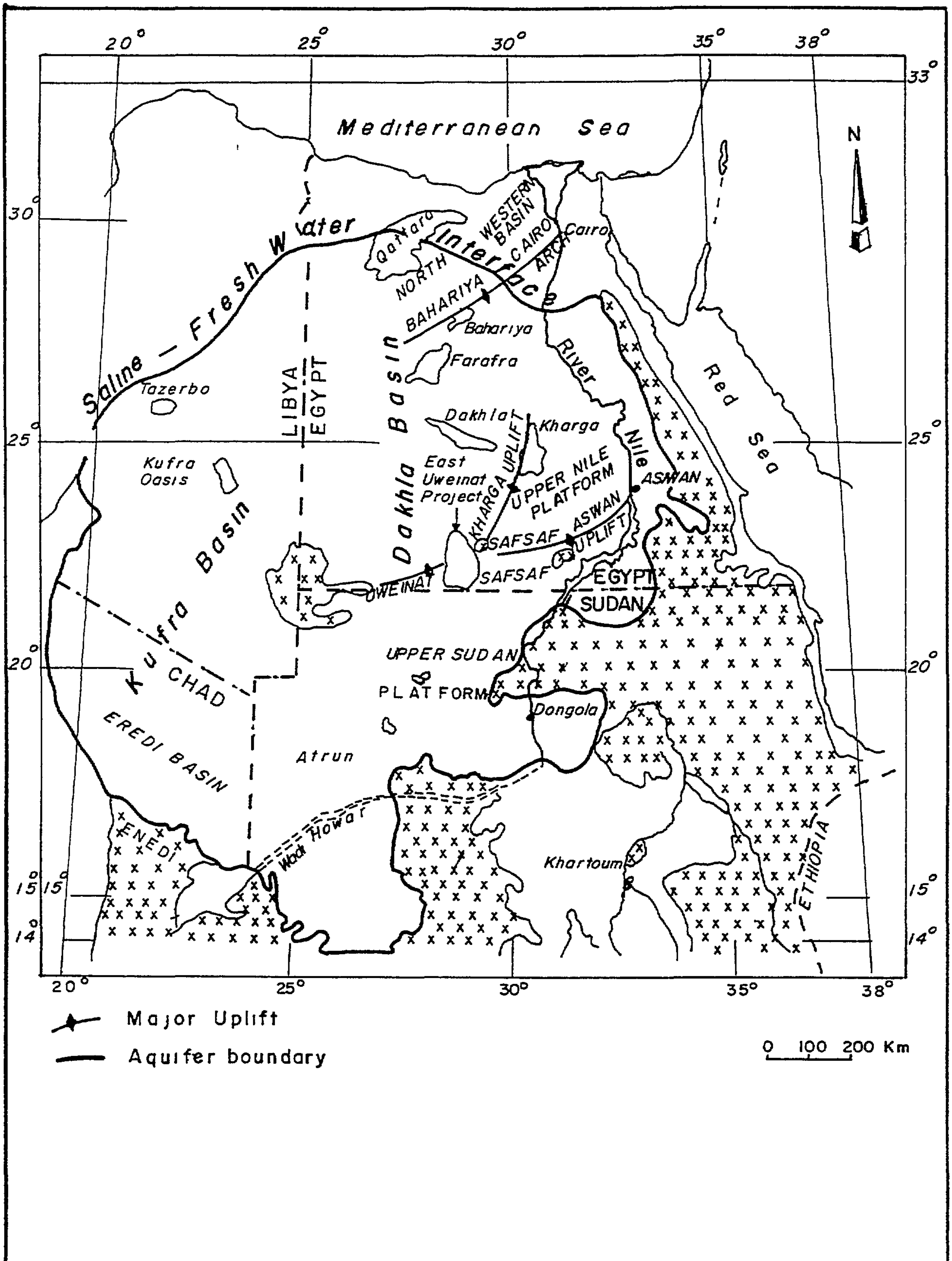


Figure (10)- Boundaries of The Nubia Sandstone Aquifer System
(After Heinel et al, 1987)

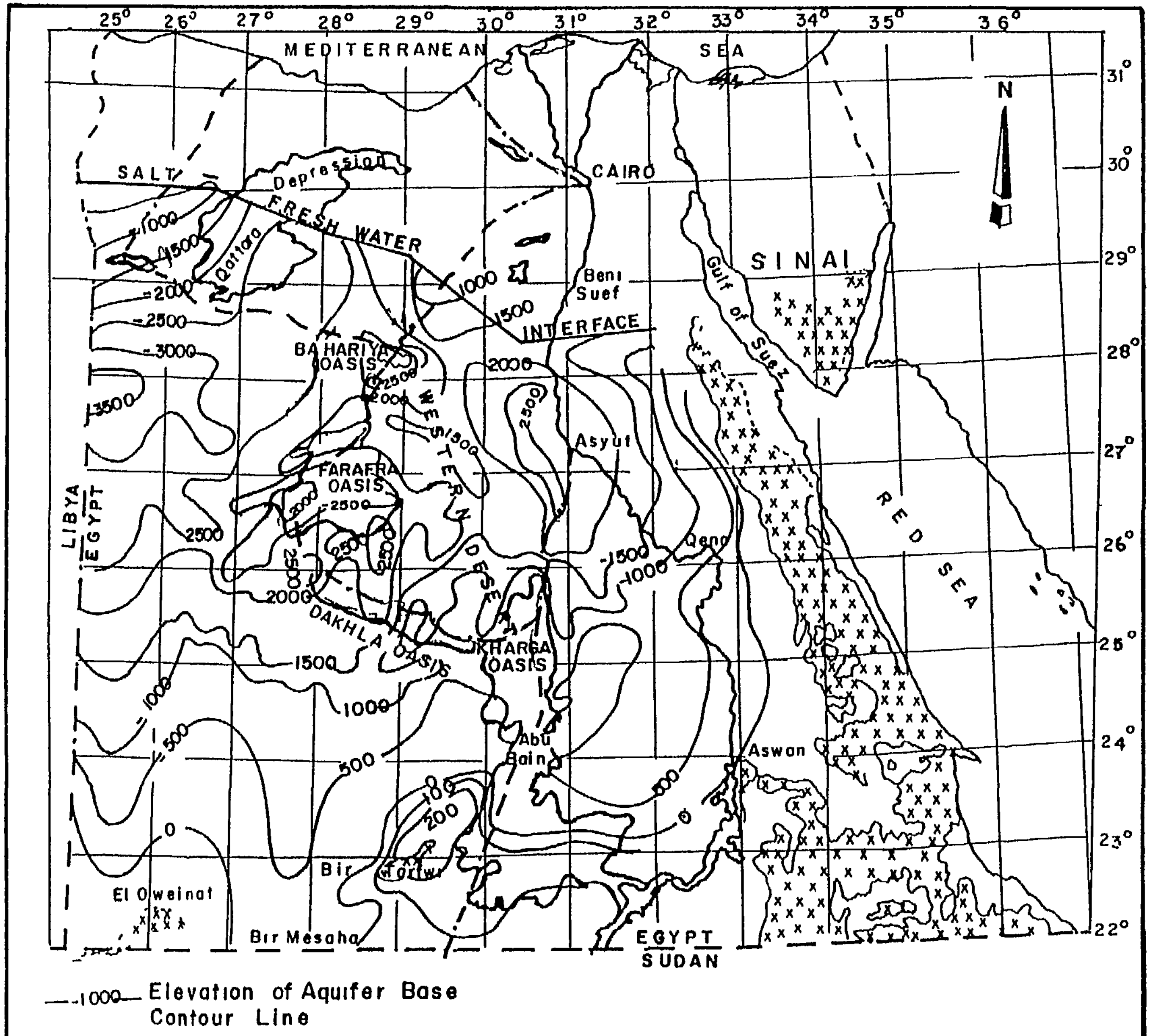


Figure (11)-Elevation of Nubian Fresh Water Aquifer Base

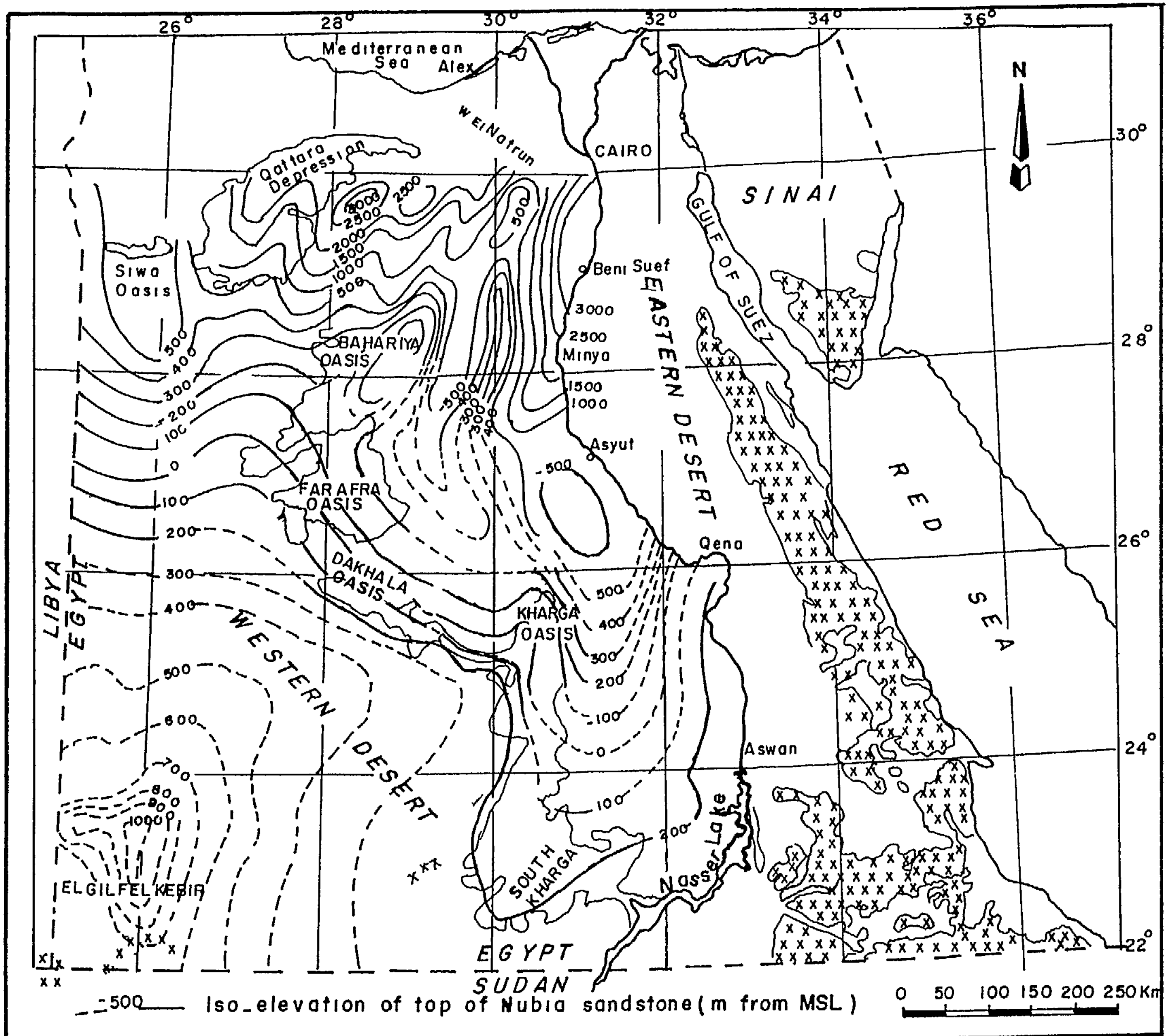


Figure (12). Structure Contour Map on Top of Nubia Aquifer System, Western Desert (After Ezzat, 1981)

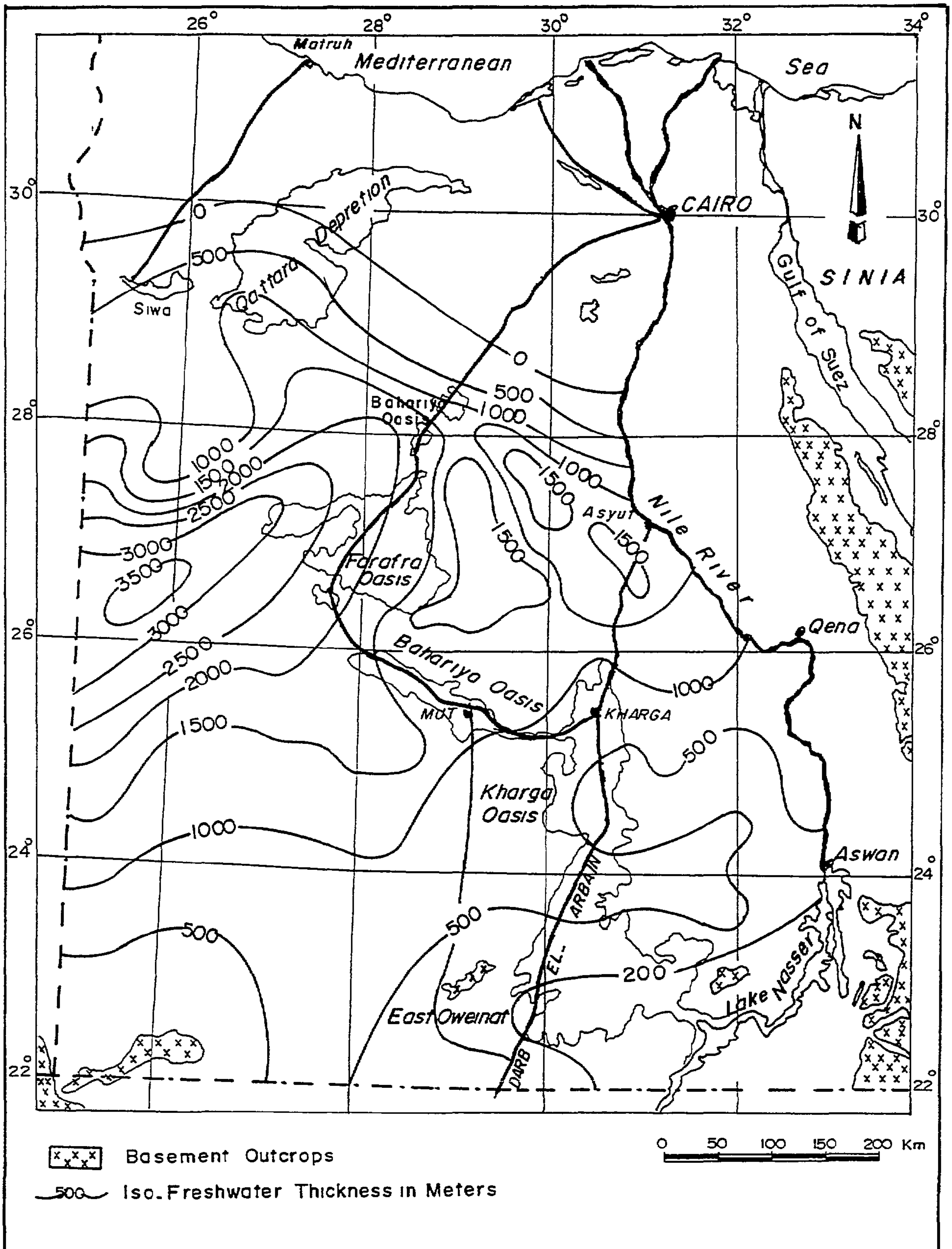


Figure (13) - Isopach Map of Freshwater Nubia Sandstone Aquifer, Western Desert

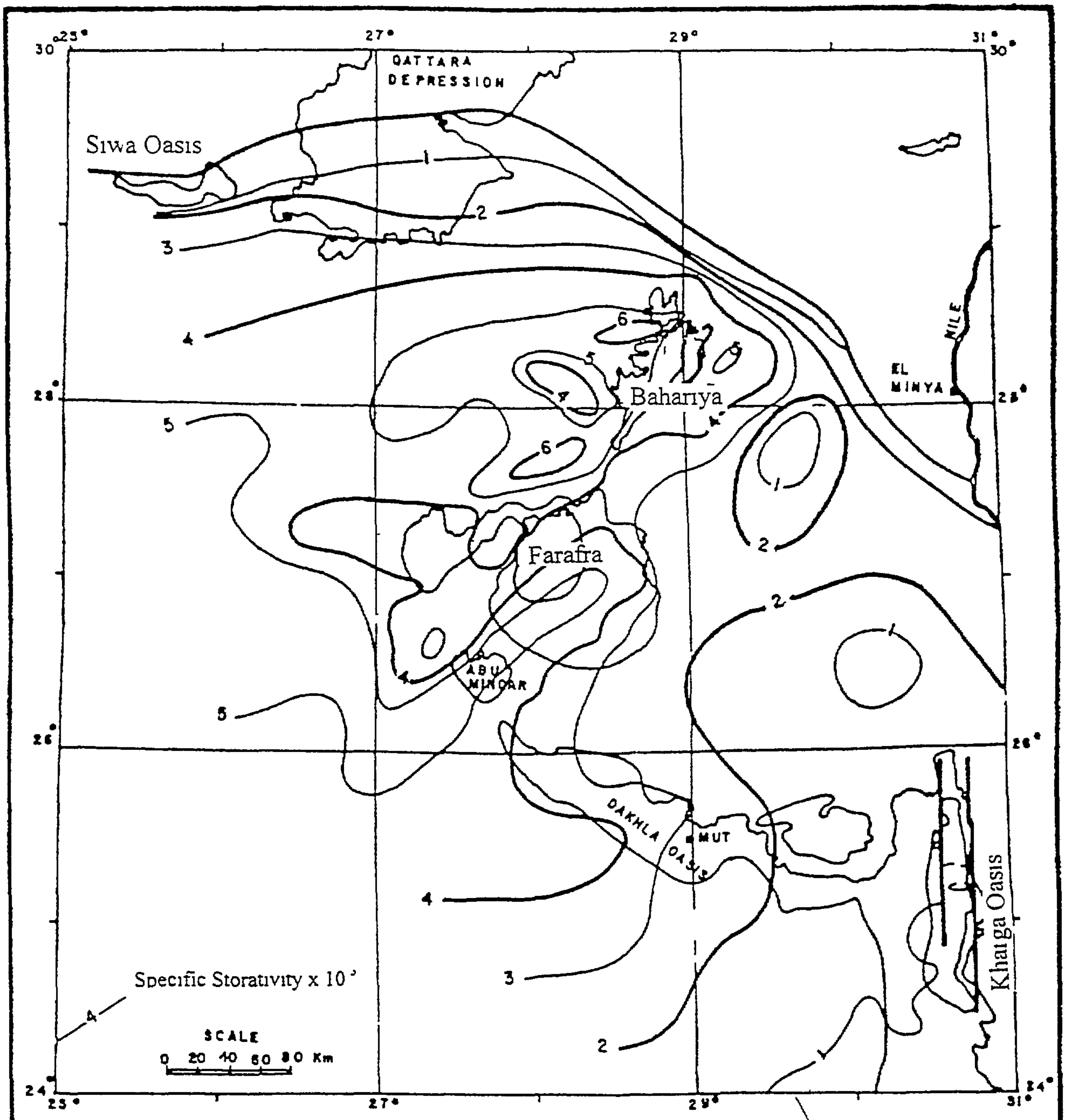


Figure (14) – Map of Specific Storativity of Nubia Sandstone Aquifer, Western Desert

(After Euroconsult / Pacer Consultants, 1983)

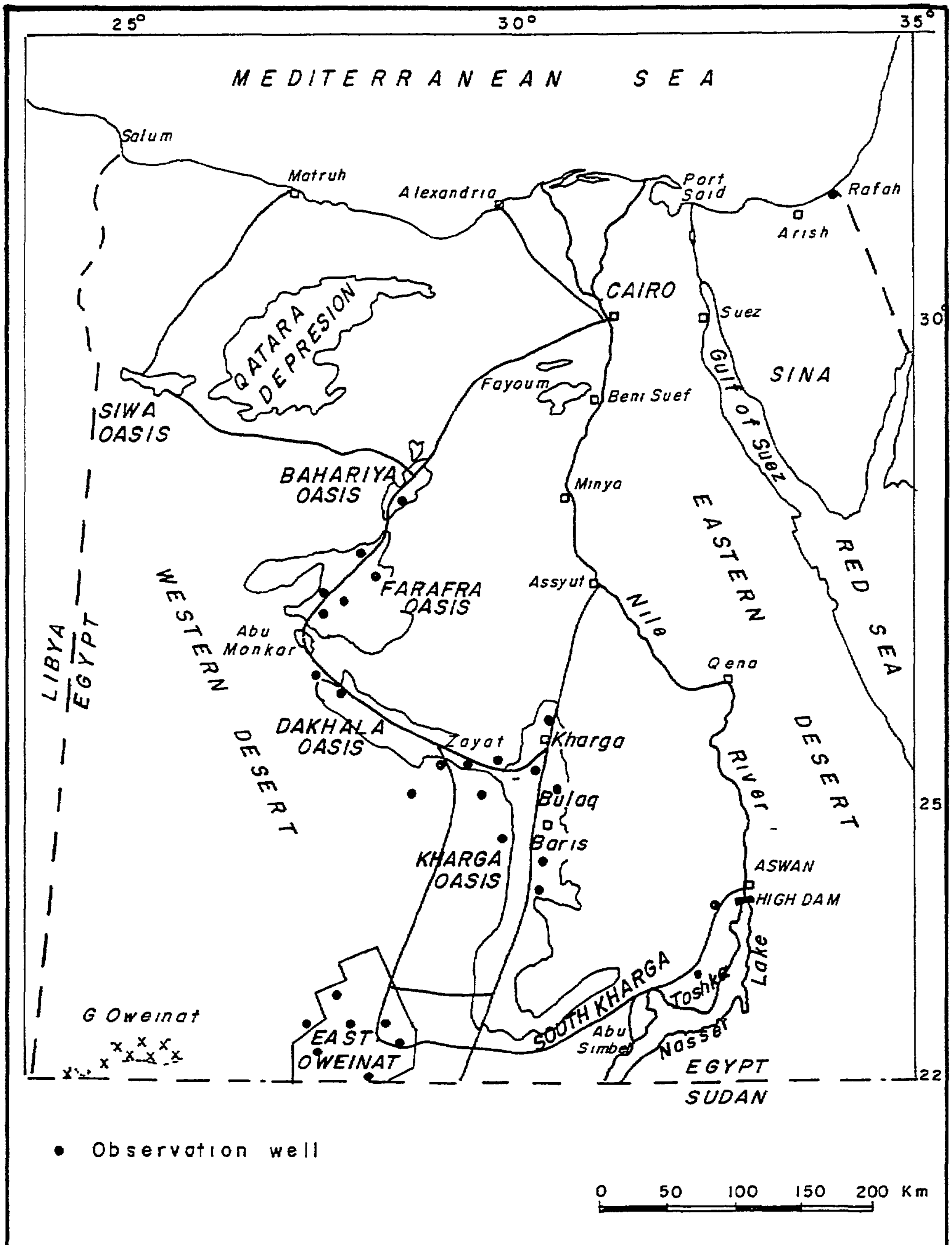


Figure (15) - Location Map of Observation Well in The Western Desert

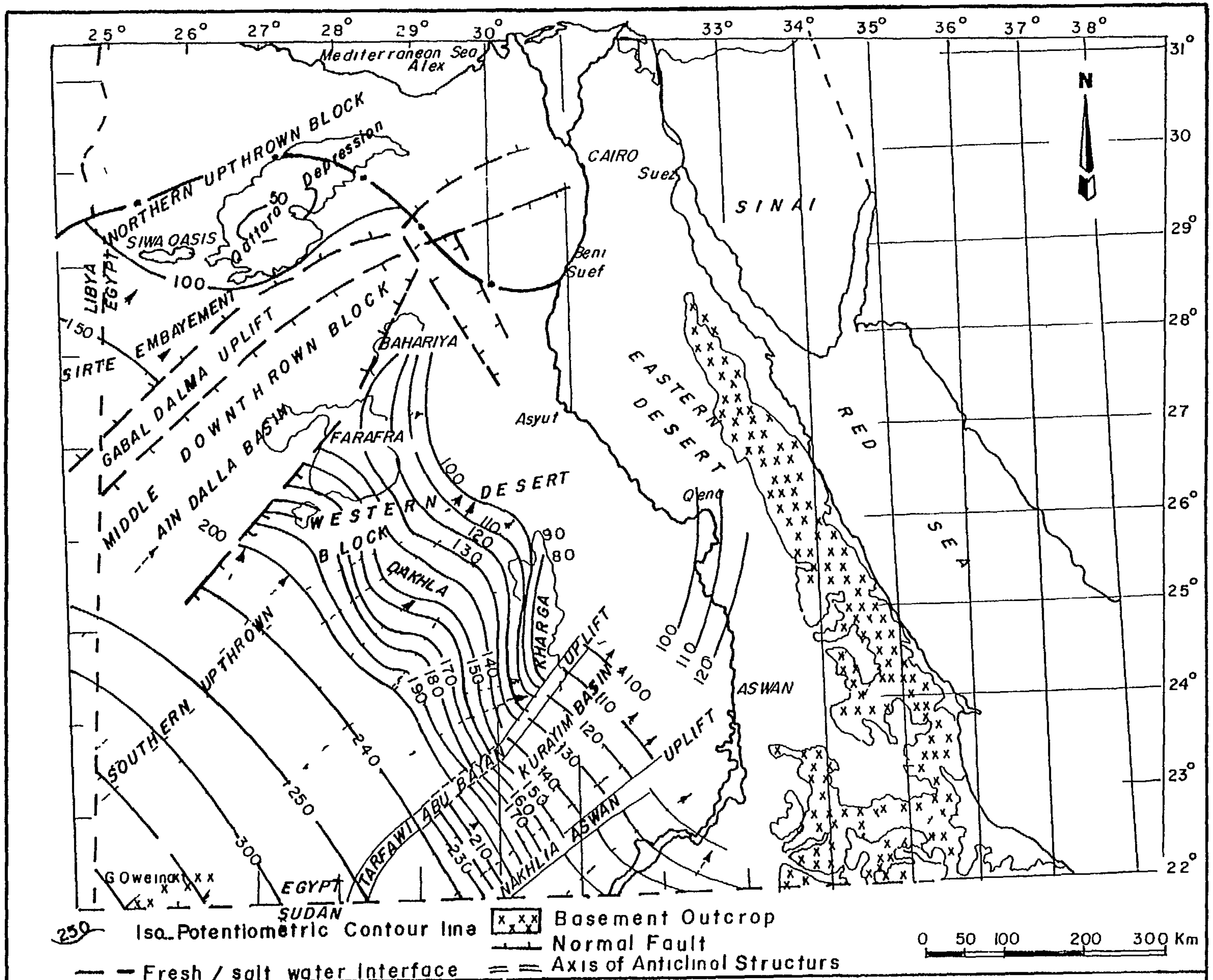


Figure (16)-Groundwater Setting, Nubia Sandstone Formation A R E (After Ezzat, 1974)

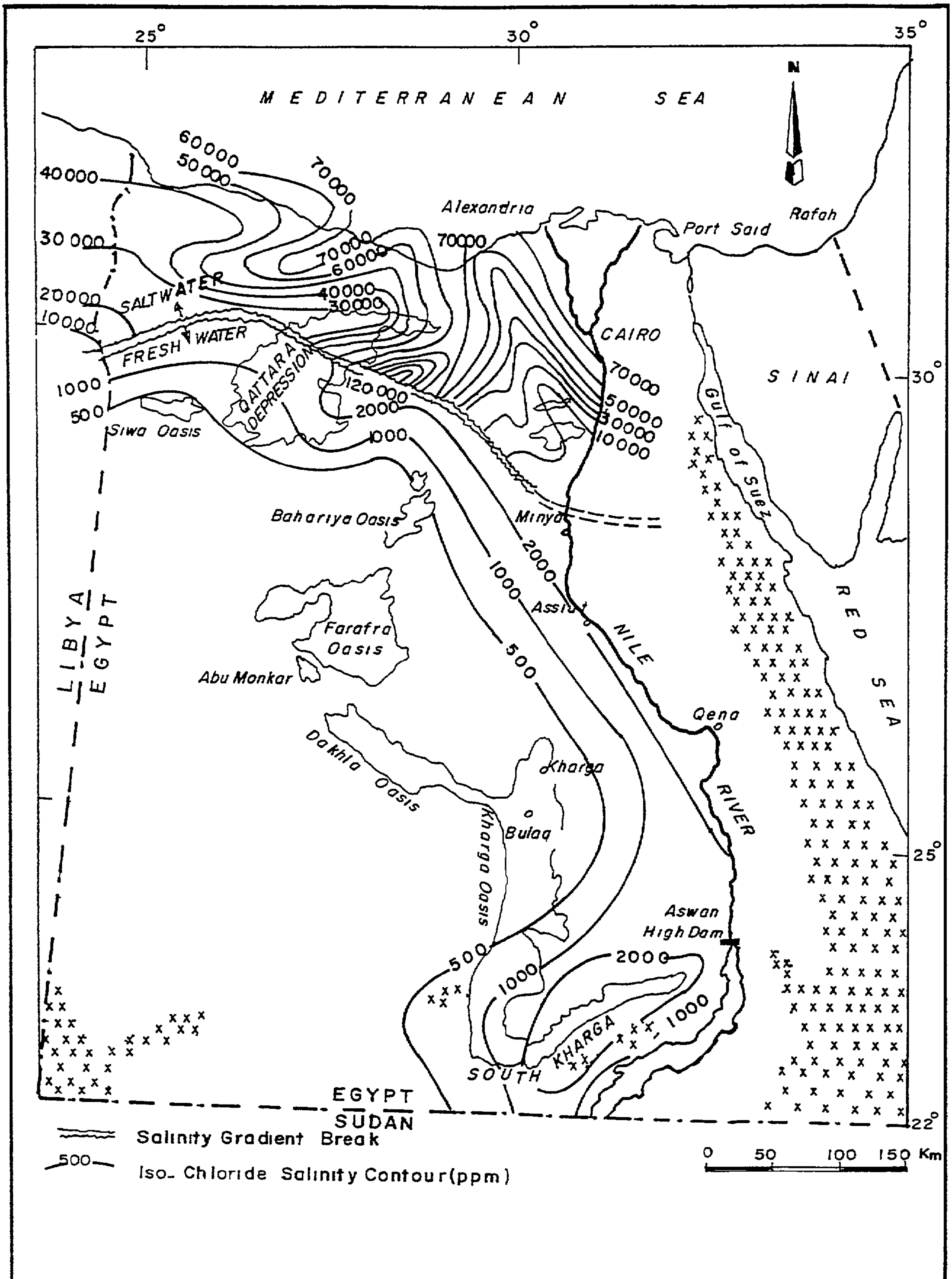
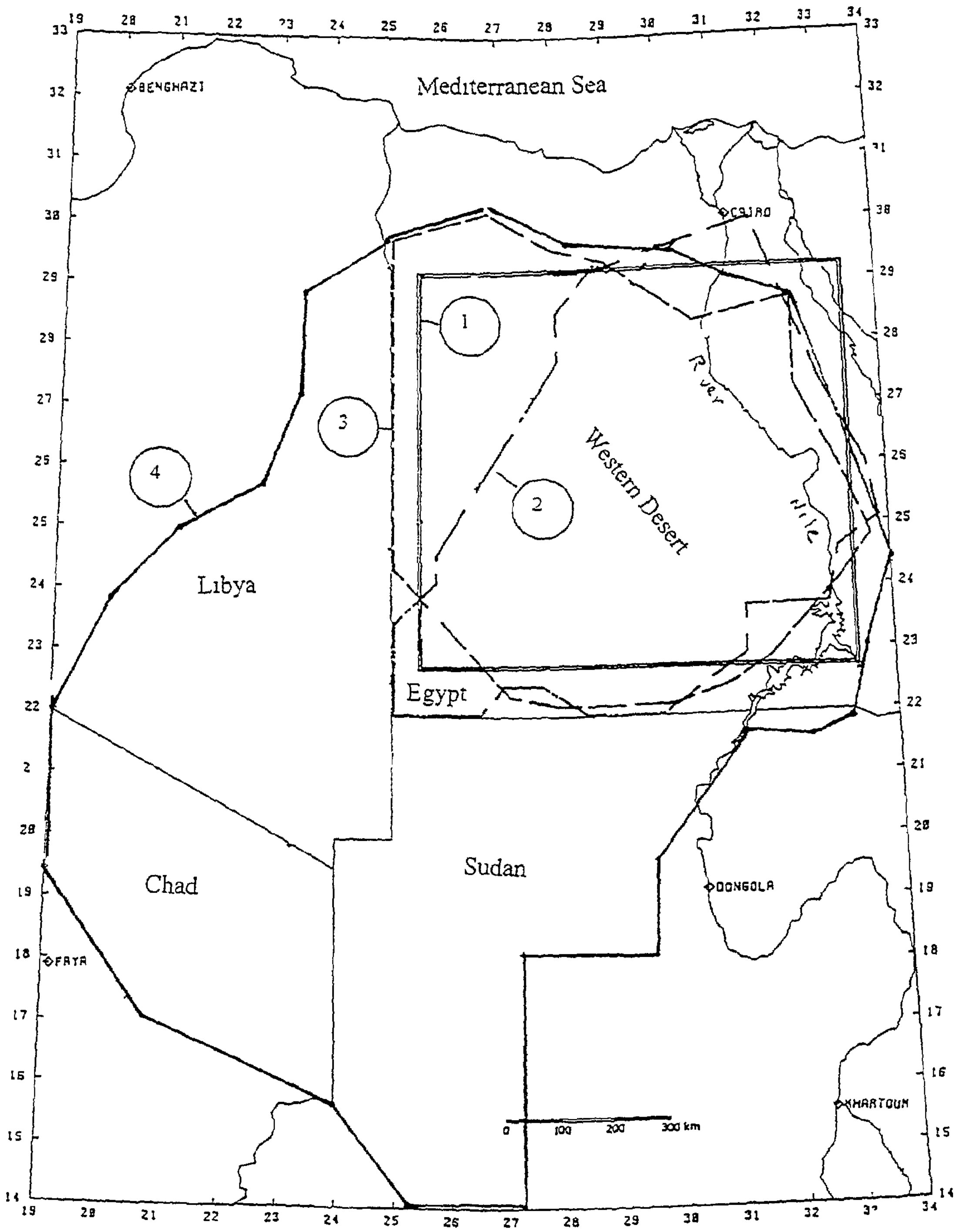


Figure (17)- Iso-Salinity Contour Map, Sandstone Aquifer System, Western Desert (Modified after El-Bishlawy, 1971)



(1) Analogue Model, Borelli et al (1968),
(2) Analogue Model, Ezzat et al (1975),
(3) Mathematical Model, Amer et al (1981),
(4) Heinel & Brinkman (1987)

Figure (18) – Boundaries of Regional Groundwater Models of the Nubian Aquifer System

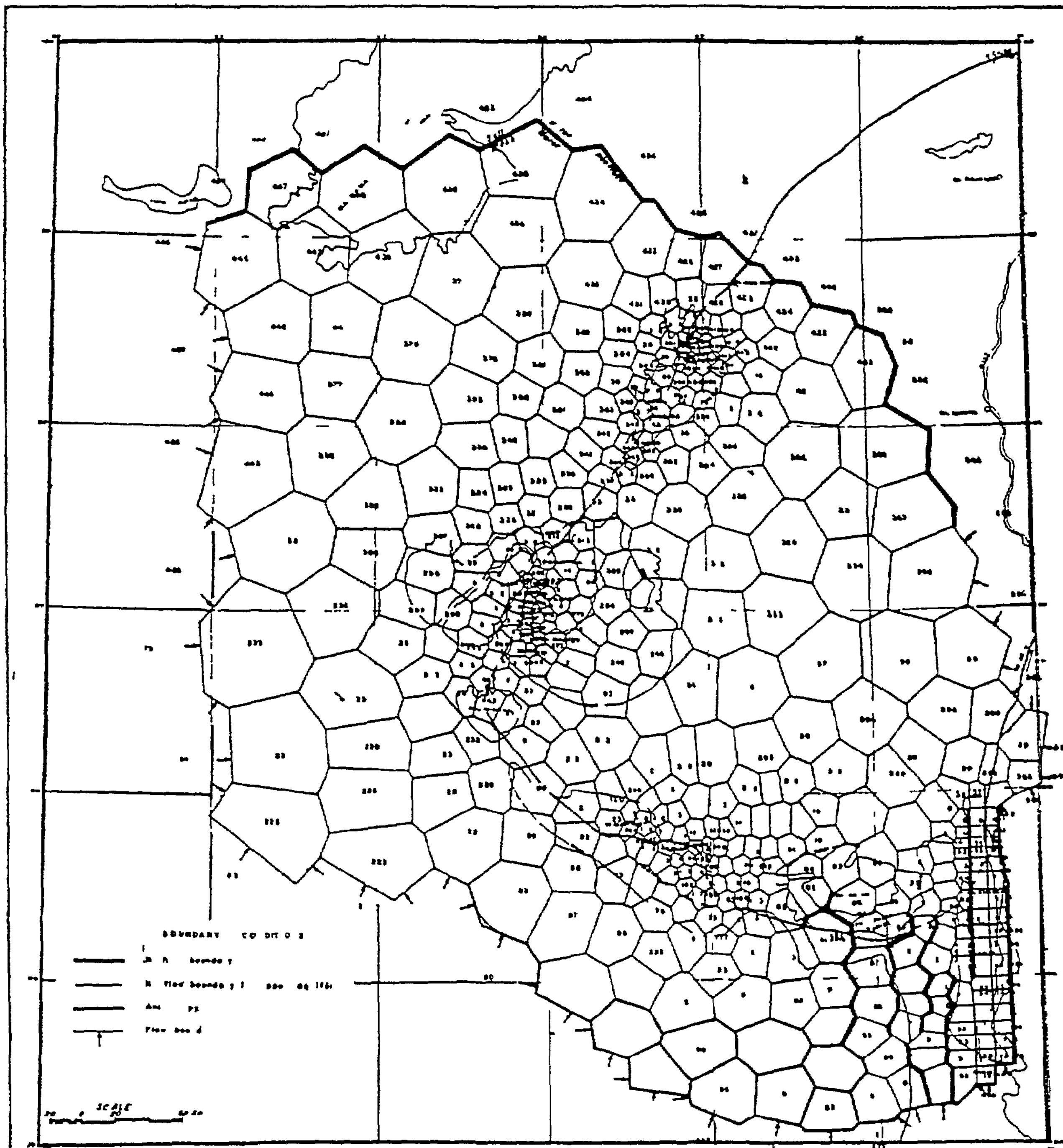
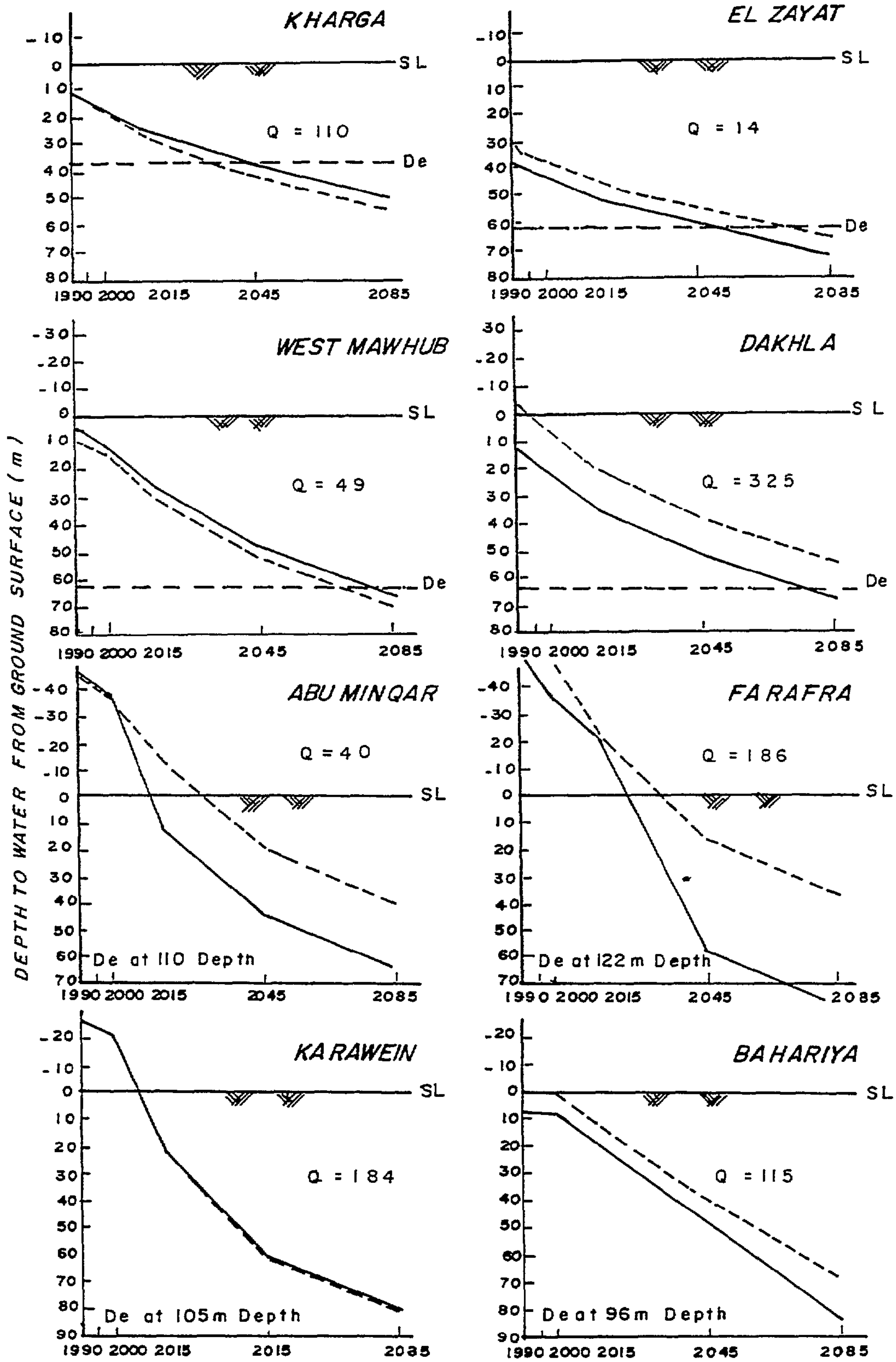


Figure (19) – New Valley Groundwater Model Nodal Network

(After Euroconsult / Pacer Consultants, 1983)



Shallow Aquifer ---Deep Aquifer SL=Surface Level
— — De Economic Pumping Depth (m)
Q = Simulated Economic Extraction (MCM / Year)

Figure(20)-Simulated Future Water_Levels After Development in The New Valley Areas
(After Euroconslt/Pacer Consultants ,1983)

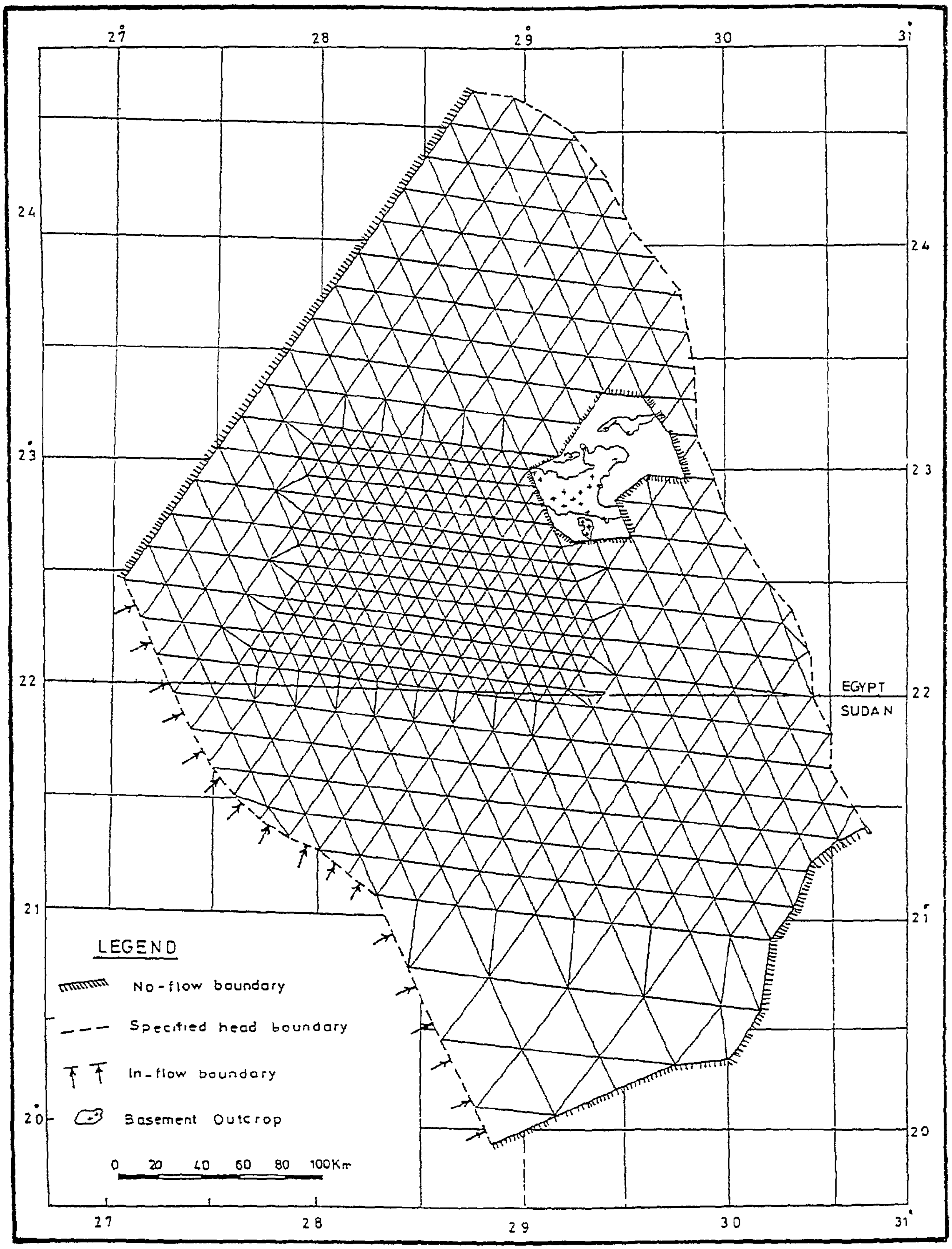


Figure (21) – Groundwater Model, East Oweinat Area

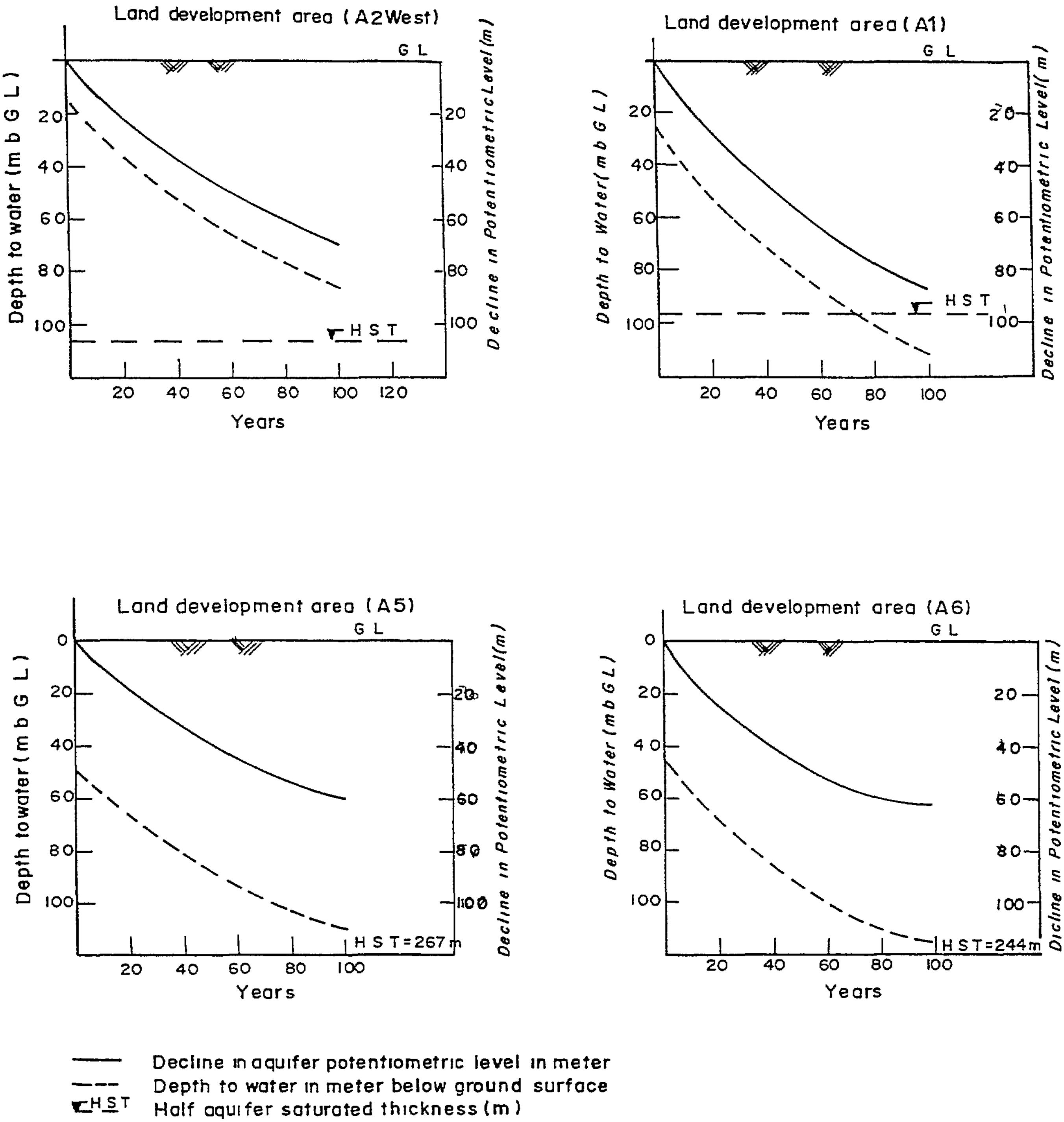


Figure (22) Hydrodynamic Response of Nubia Sandstone Aquifer to Extraction Plan of 474 MCM/day in East Oweinat Area

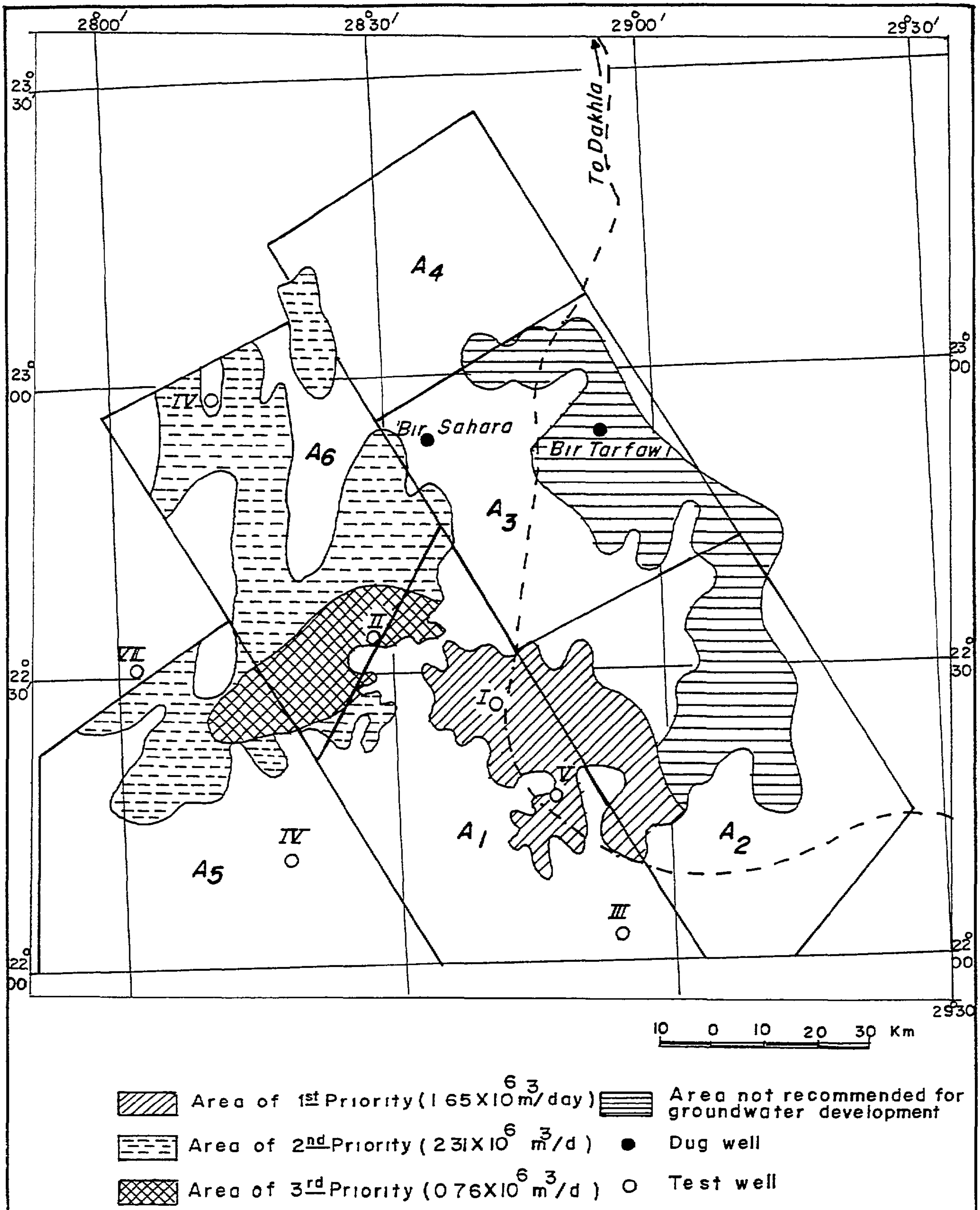


Figure (23)- Priority Areas for Groundwater Development, East Oweinat
(After Development Research and Technological Planning Center, 1984)

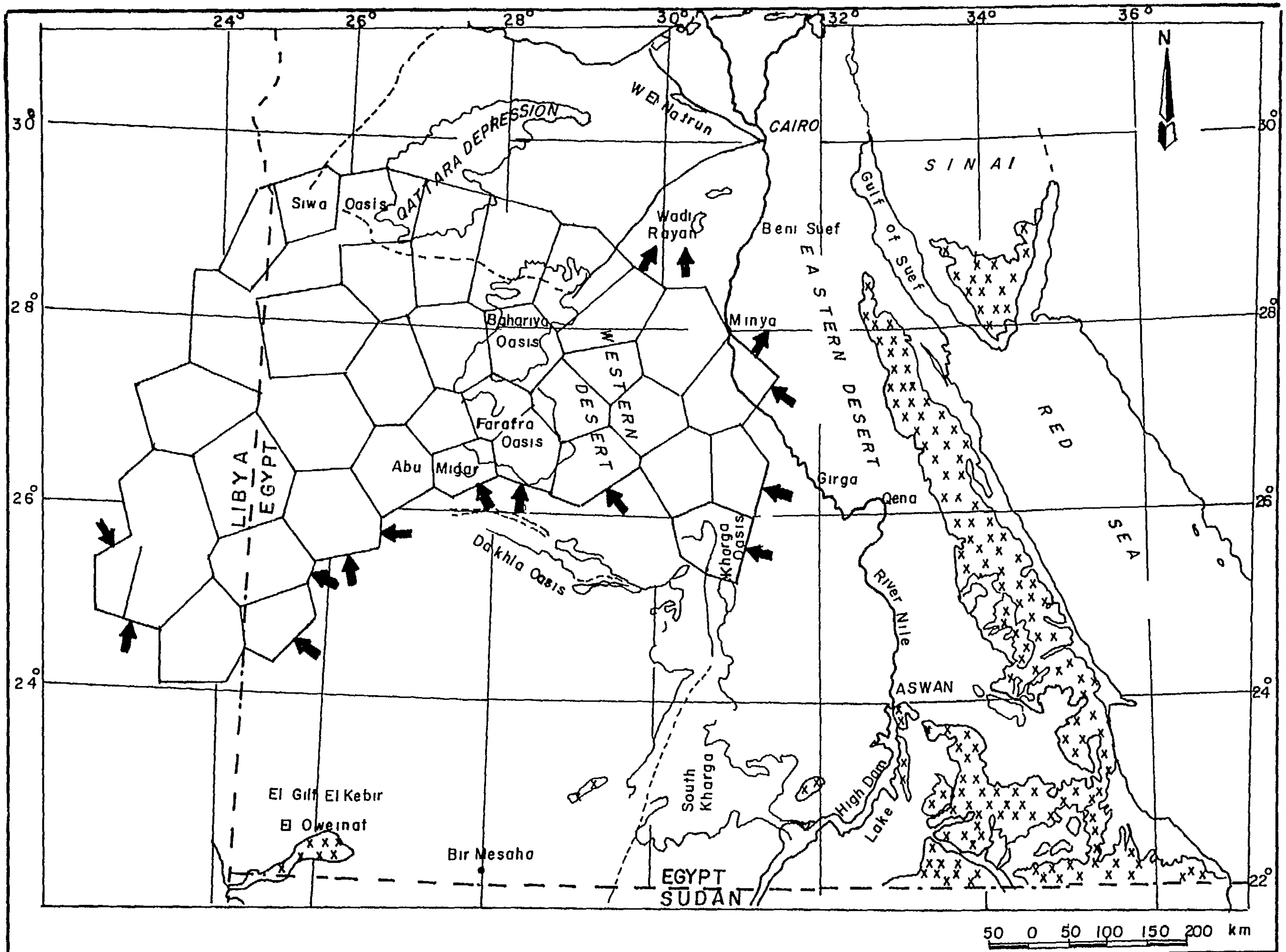


Figure (24)-Groundwater Model, South Qattara Nodal Network (After Ezzat et al, 1977)

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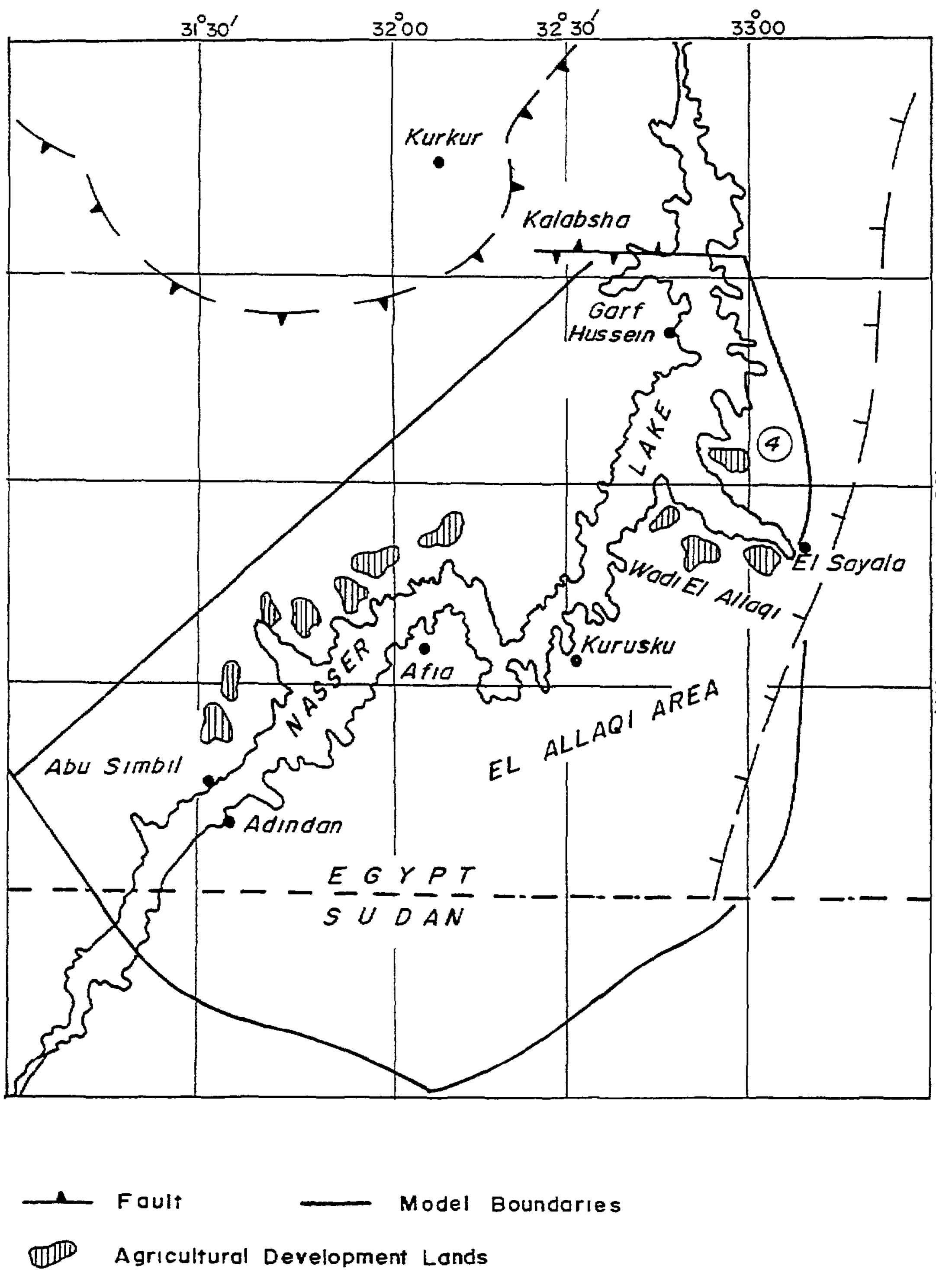

***Figure(25)- Groundwater Model of Lake Nasser Area** (Hefny et al 1988)*

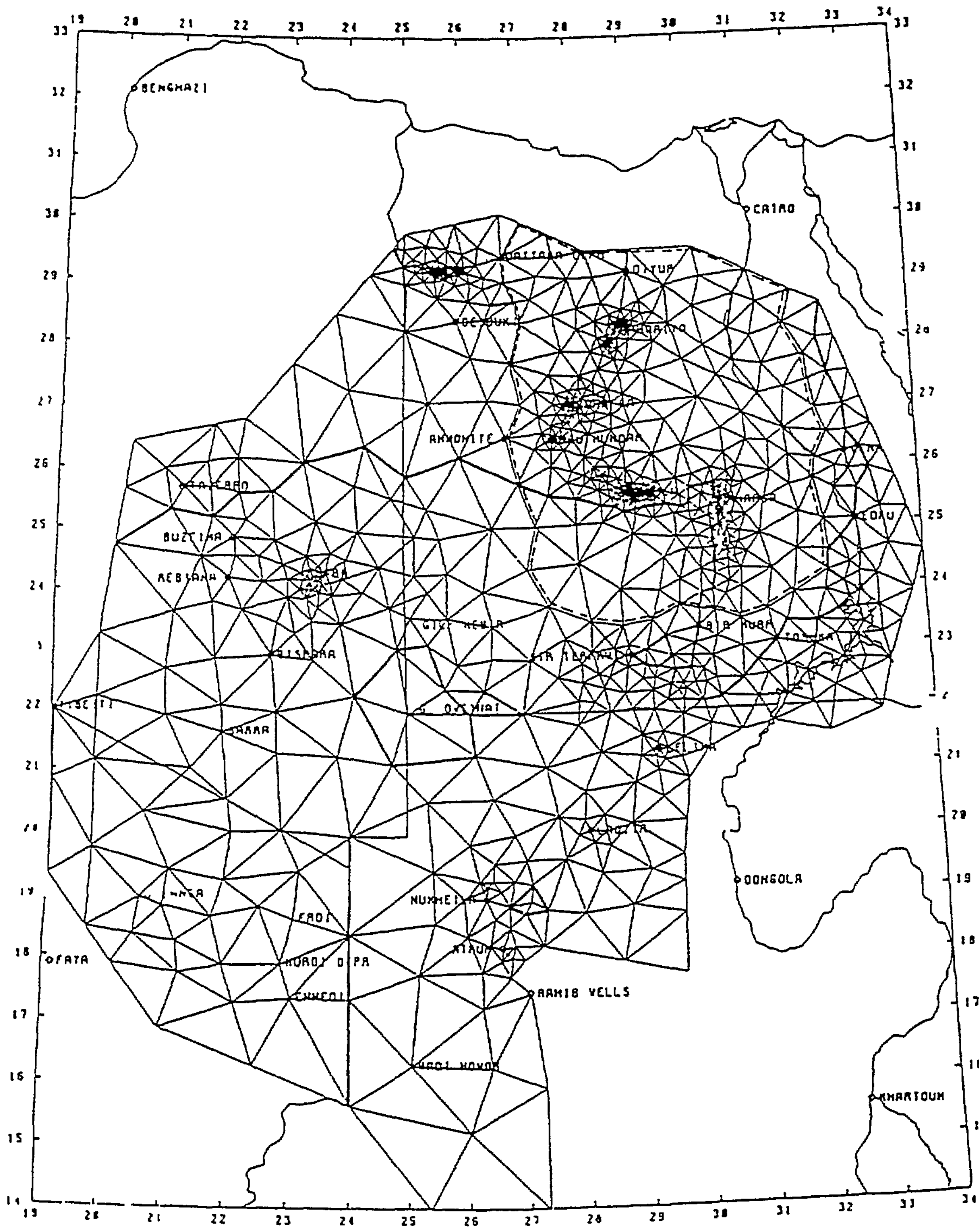

Figure (26) – Finite-Element Network for the Nubian Basin Model

(After Heinel et al 1987)

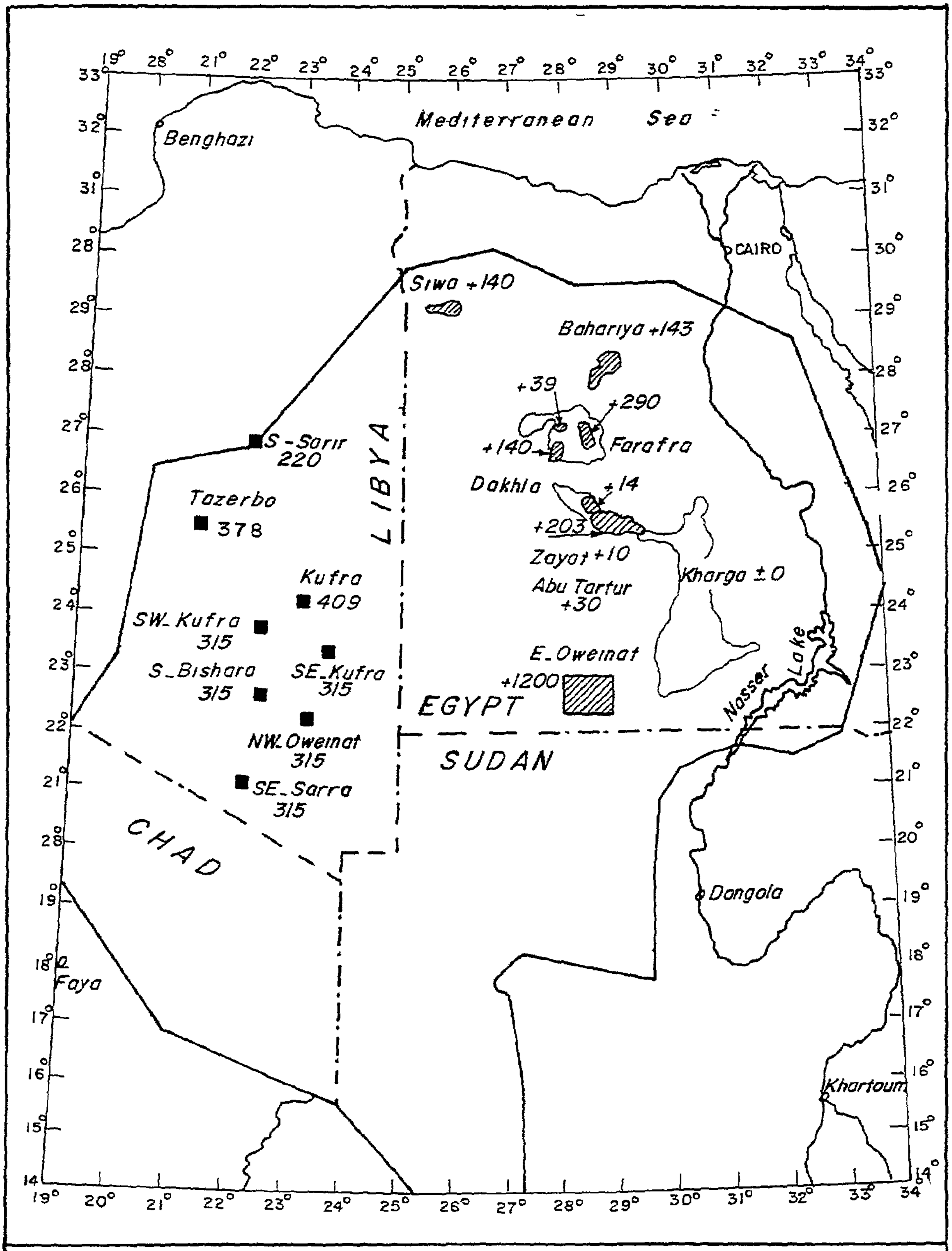

Fig (27) Proposed Future Extraction in Libya (Total) and Egypt (additional Extraction in hm^3/year) (After Heinel et al, 1987)

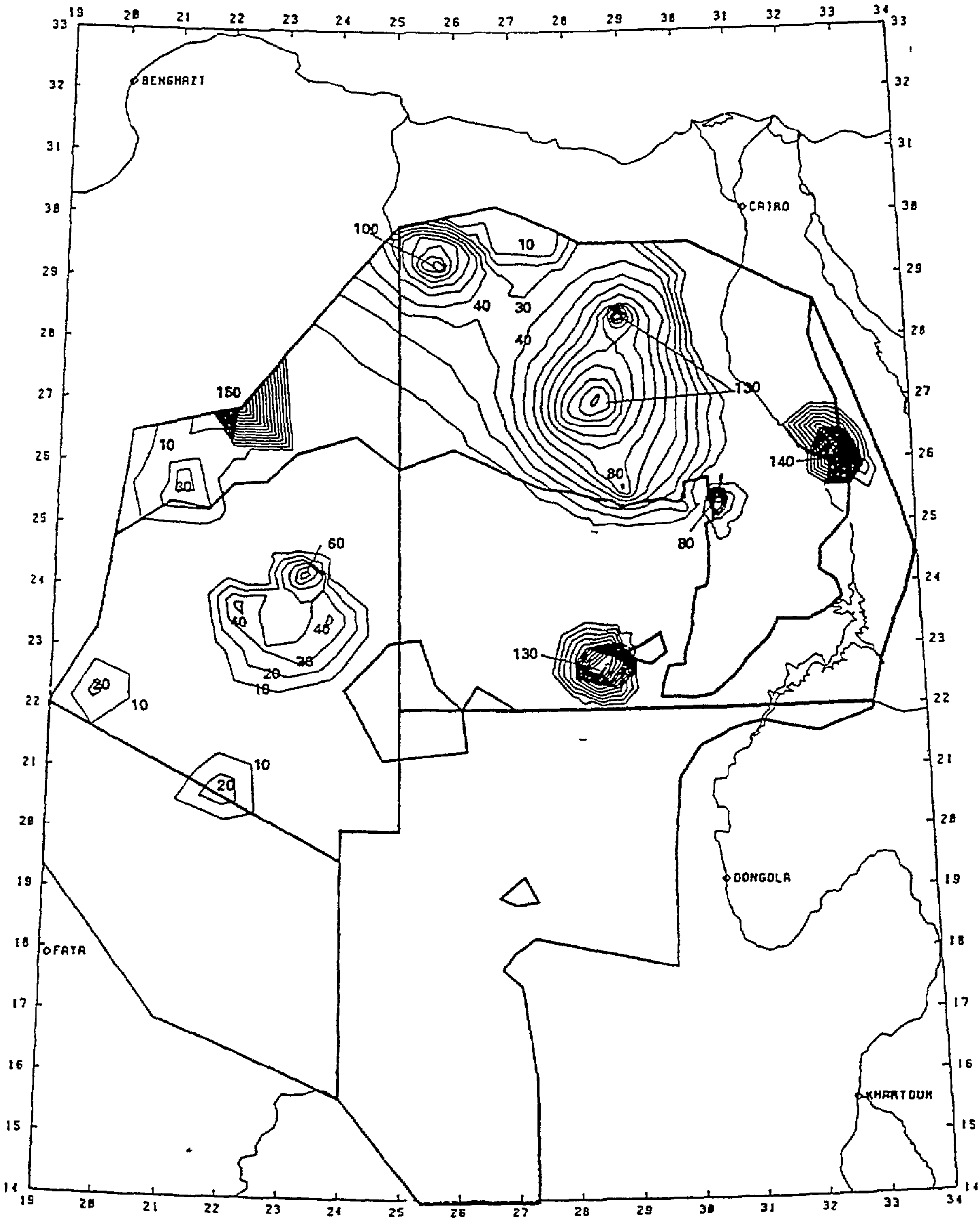

Figure (28) – Drawdown in the Nubia Aquifer 1960 – 2070

(80 years of additional + New Valley extraction)

(After Heinel et al, 1987)

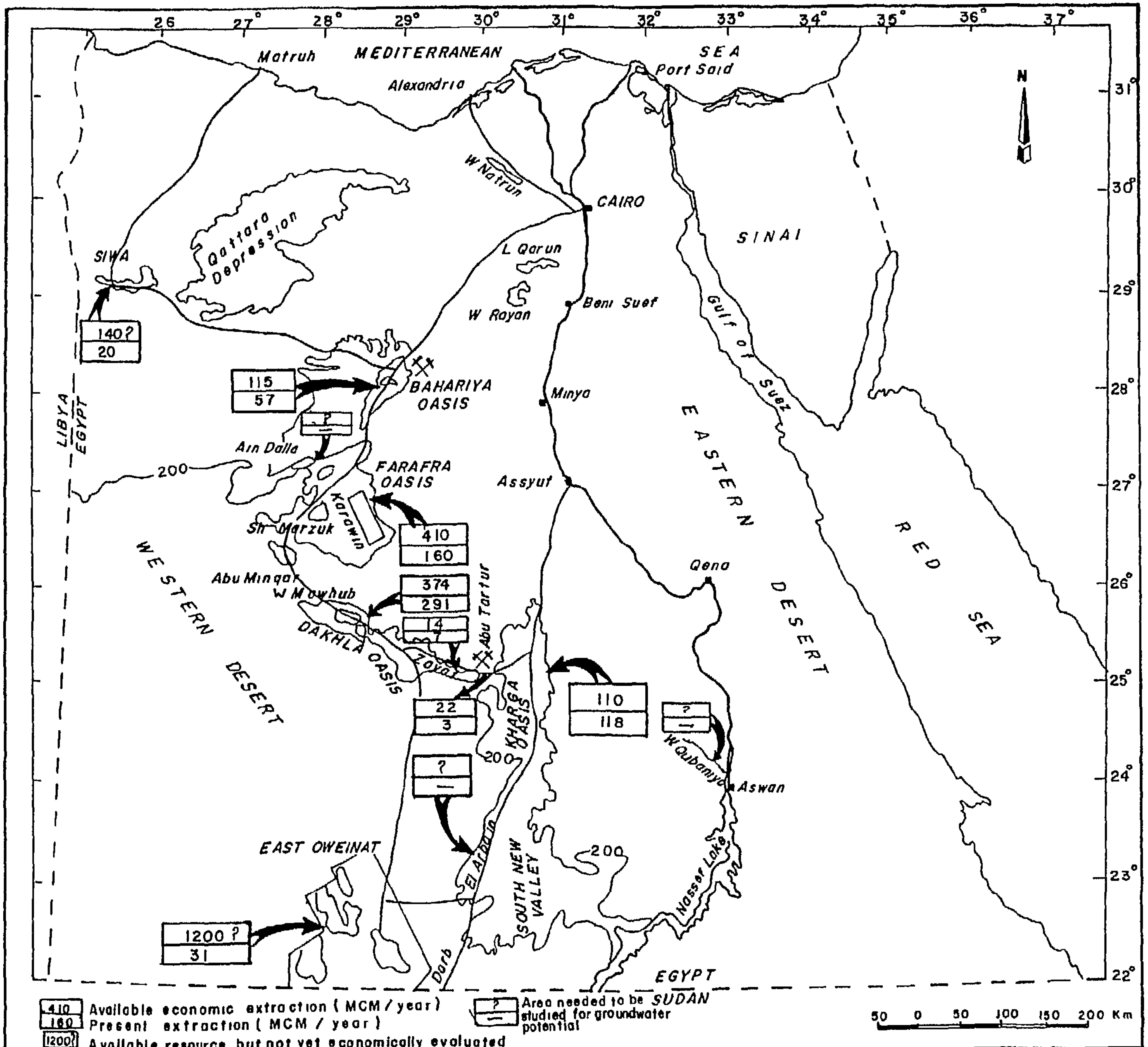

Figure (29) - Groundwater Potentials of The Nubia Sandstone Aquifer in The Western Desert (After Noor 1995)

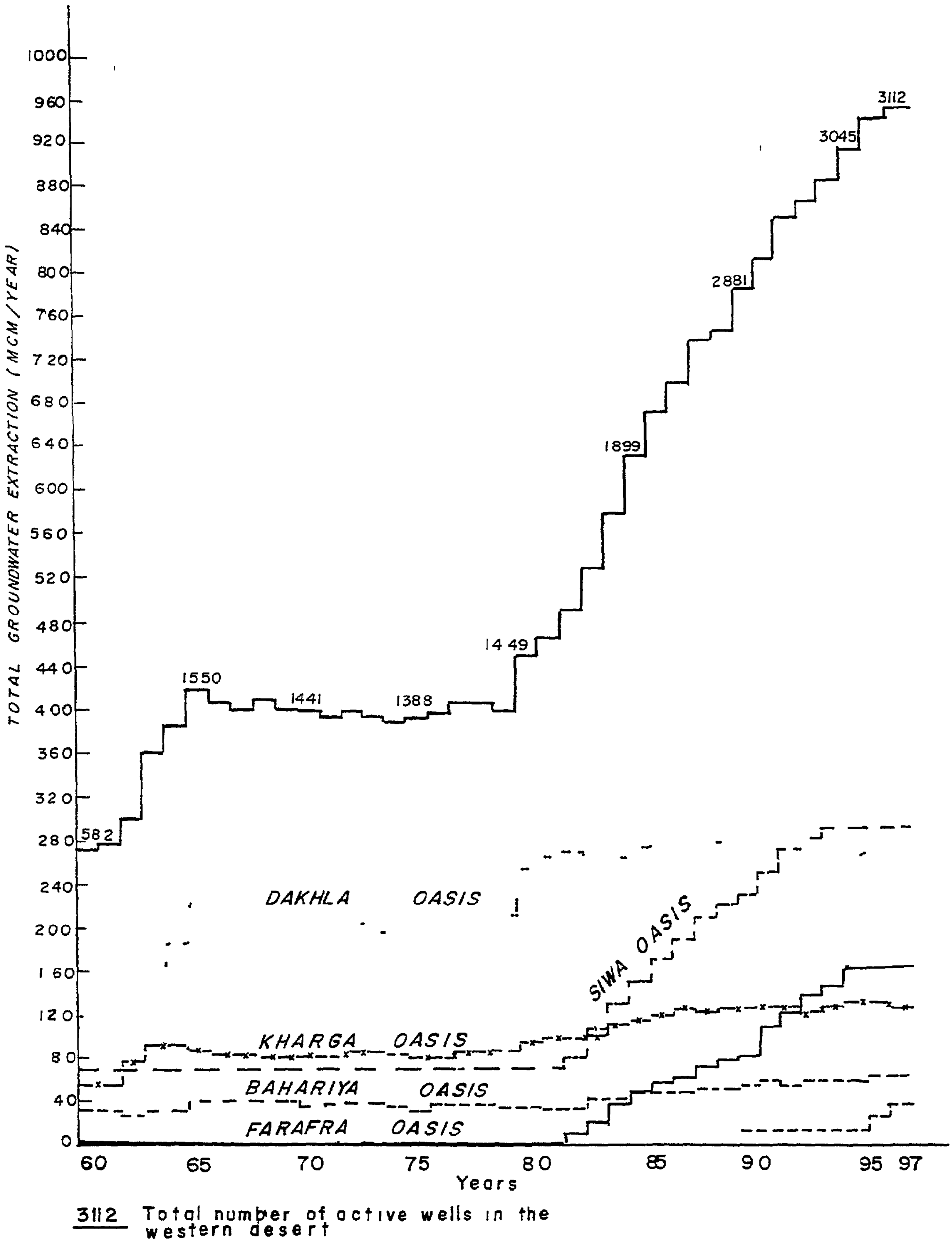

Figure (30)_ Total Groundwater Extraction in The Western Desert (1960_1997)

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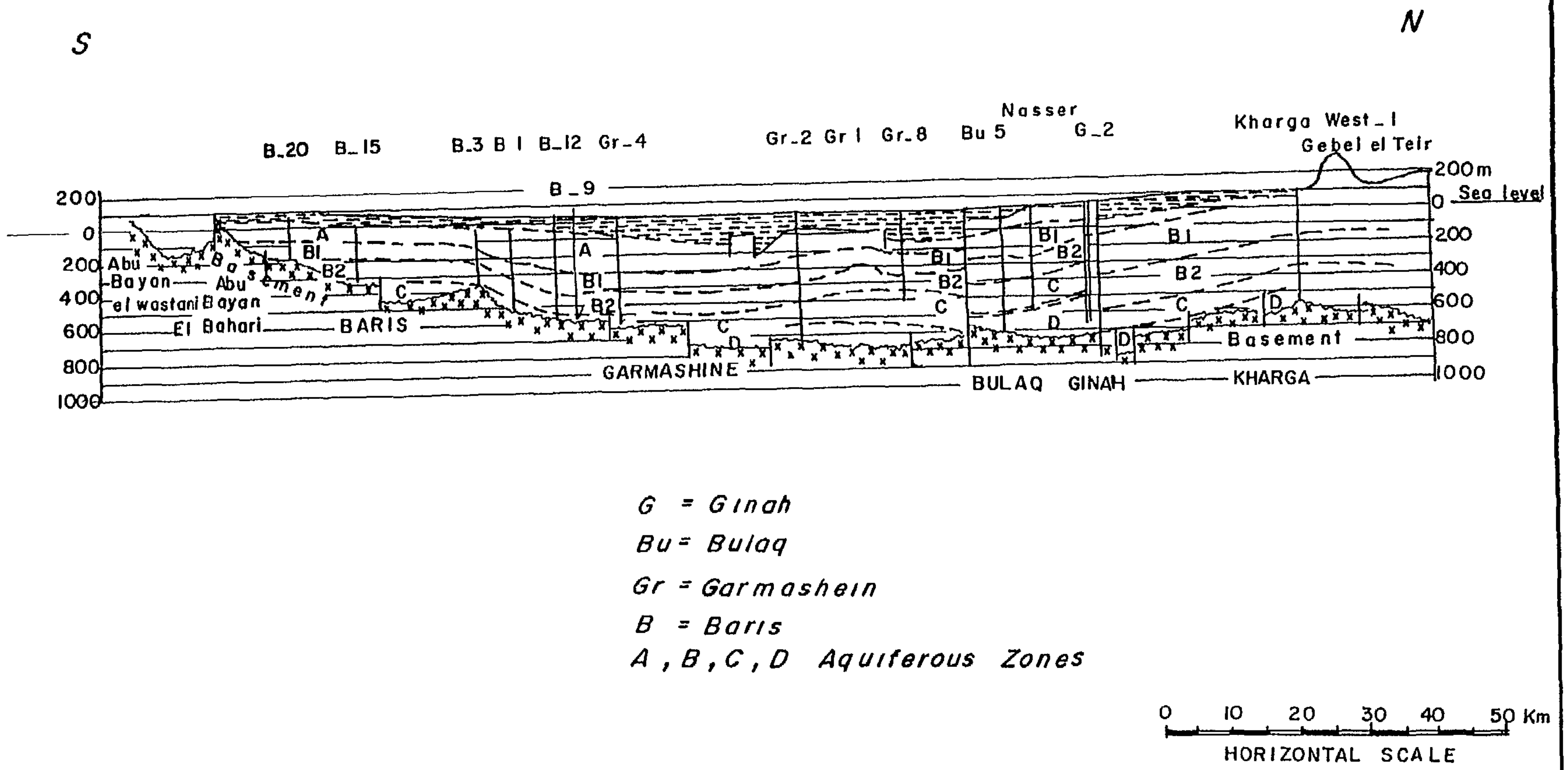
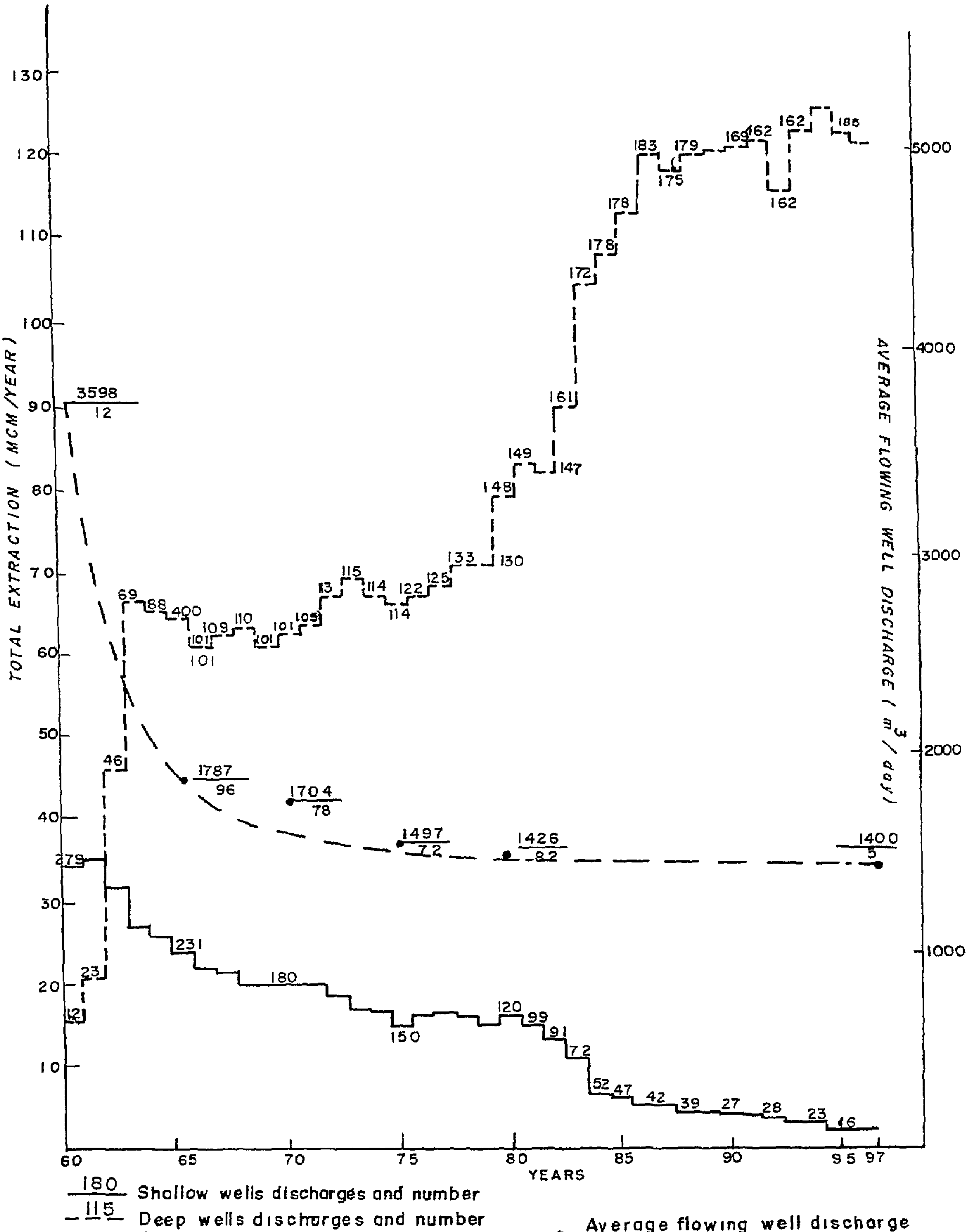


Figure(31)-North_South Hydrogeologic Section, Kharga Oasis (After Ezzat, 1974)



Figure(32)-Groundwater Extraction in El Kharga Oasis (1960-1997)

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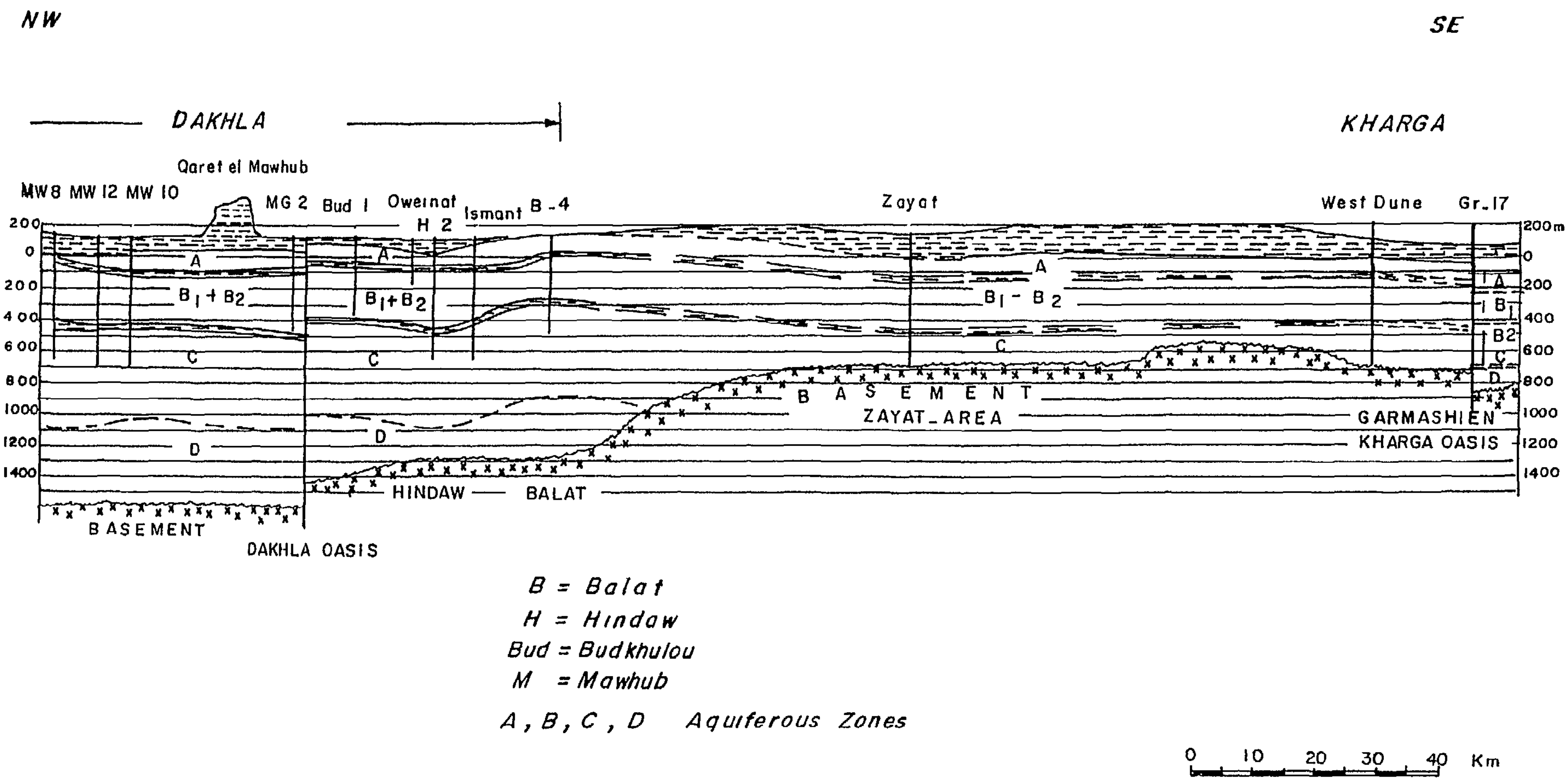

Figure (33) Hydrogeologic Section, Kharga - Dakhla Area (After Ezzat, 1974)

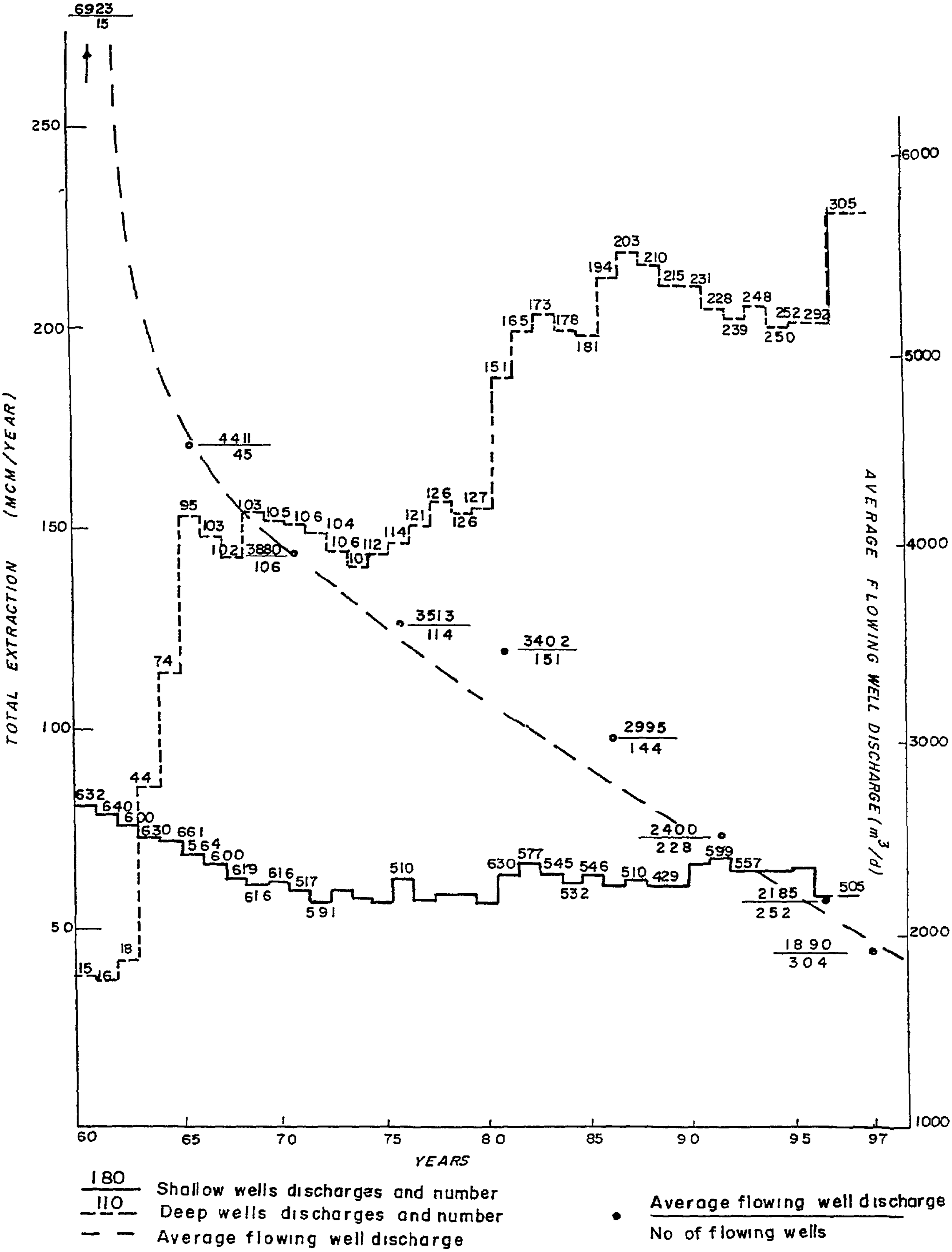

Figure (34)-Groundwater Extraction in El_Dakhla Oasis(1960-1997)

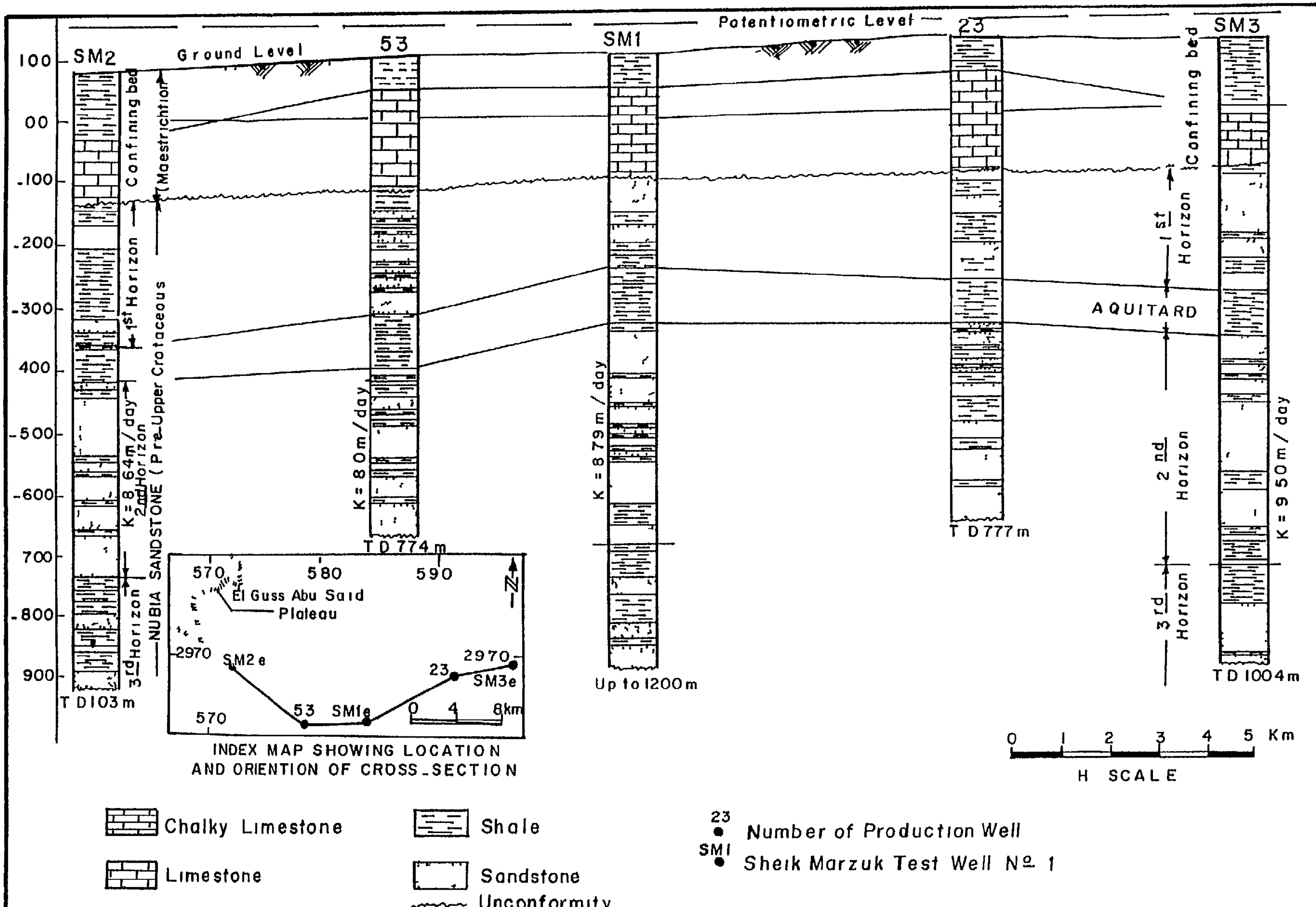

Figure (35)- Hydrogeological Cross Section, Sheik Marzuk Area
(Modified after Elewa, 1996)

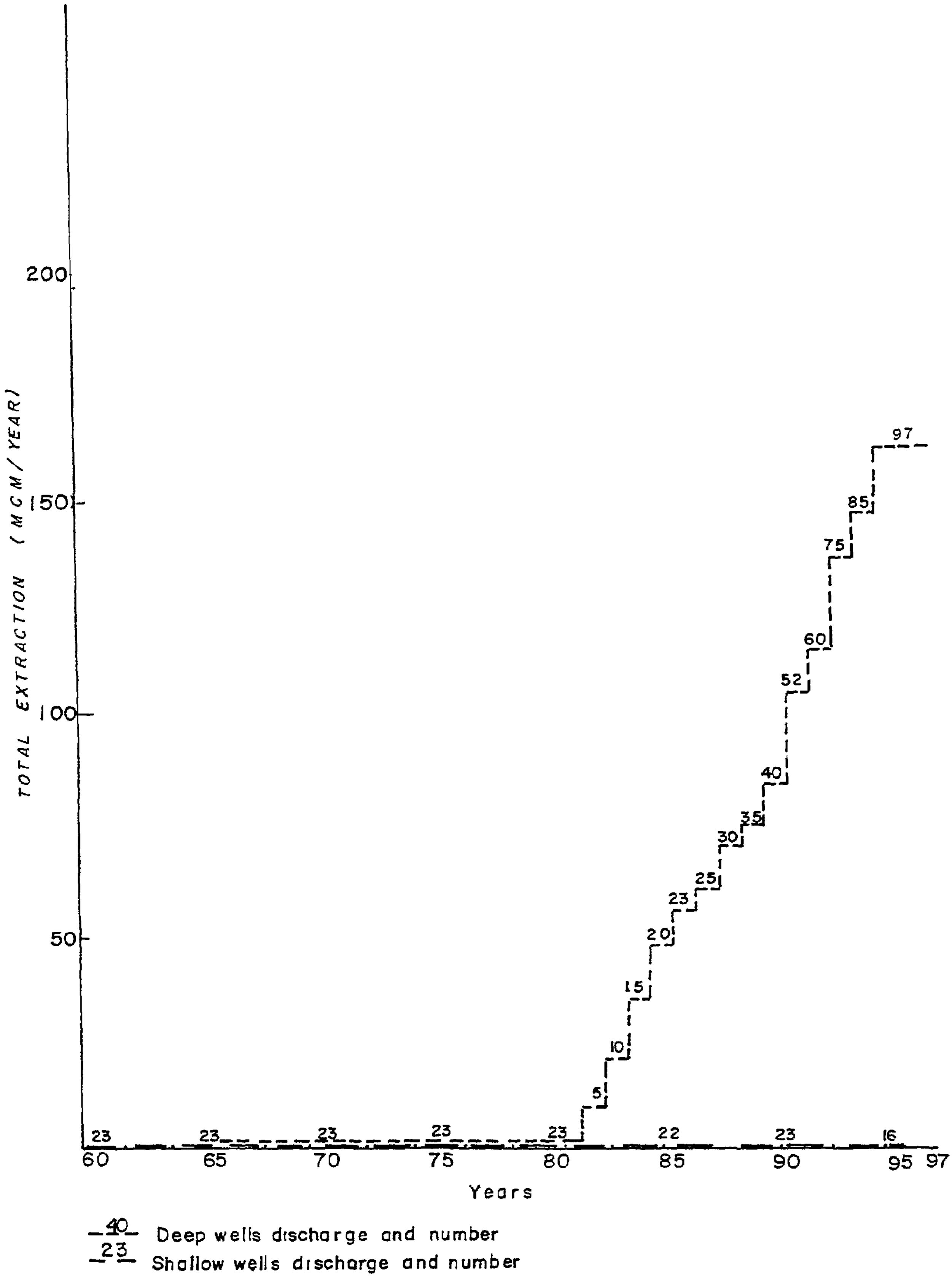

Figure (36)- Groundwater Extraction in El Farafra Oasis (1960-1997)

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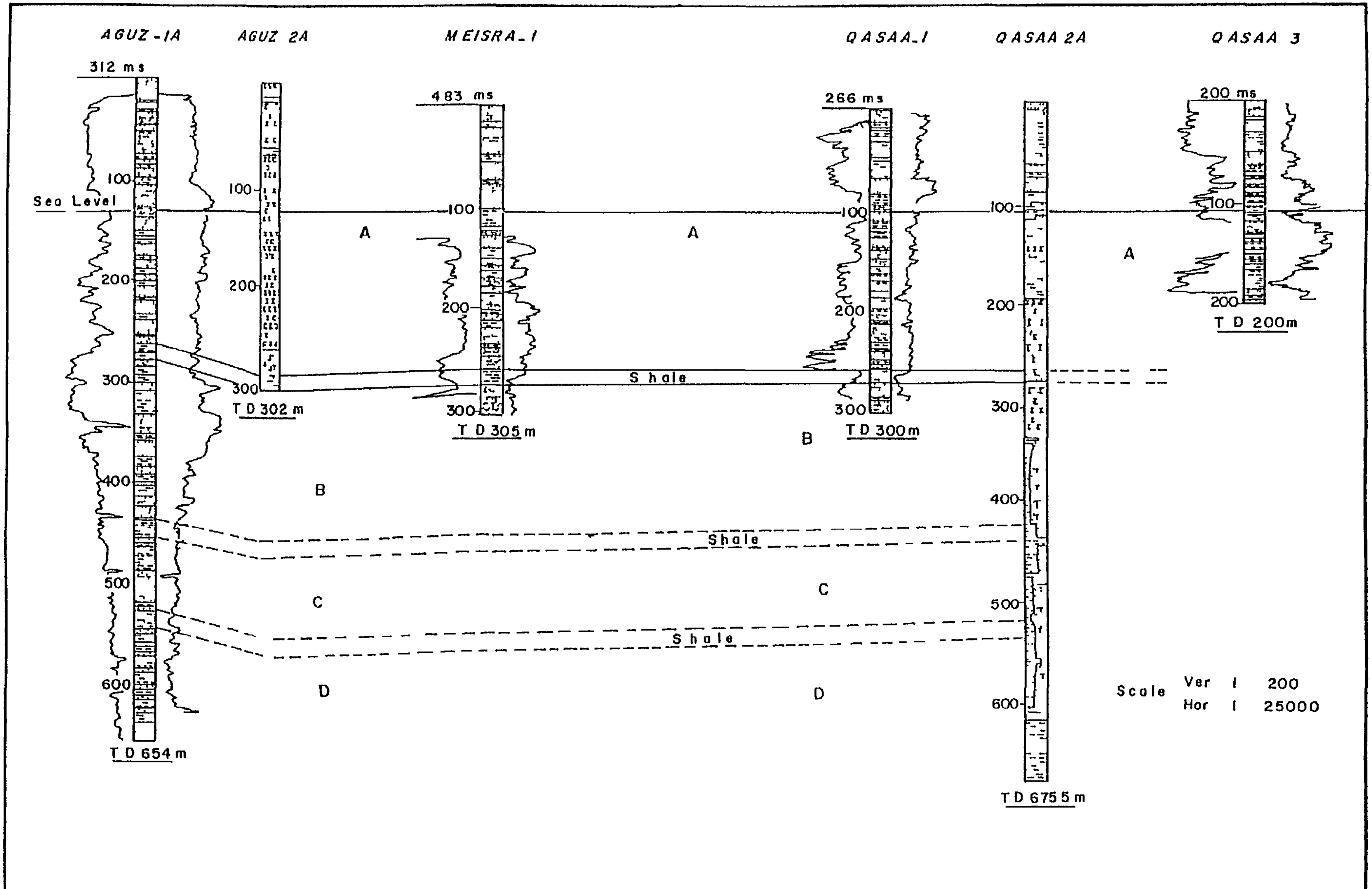


Figure (37)_ Hydrogeologic Section, El Bahariya Oasis

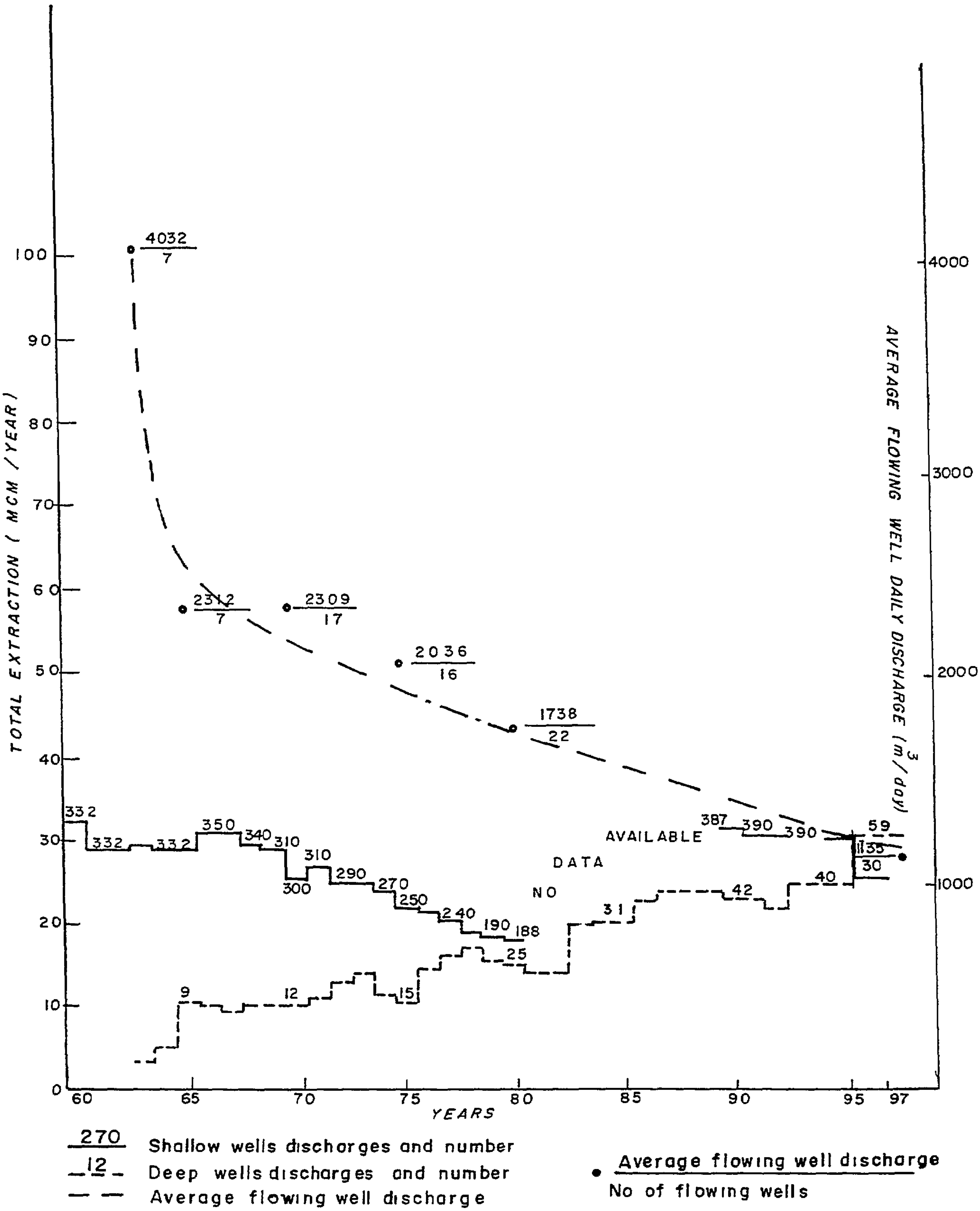


Fig (38)-Groundwater Extraction in Bahariya Oasis (1963-1997)

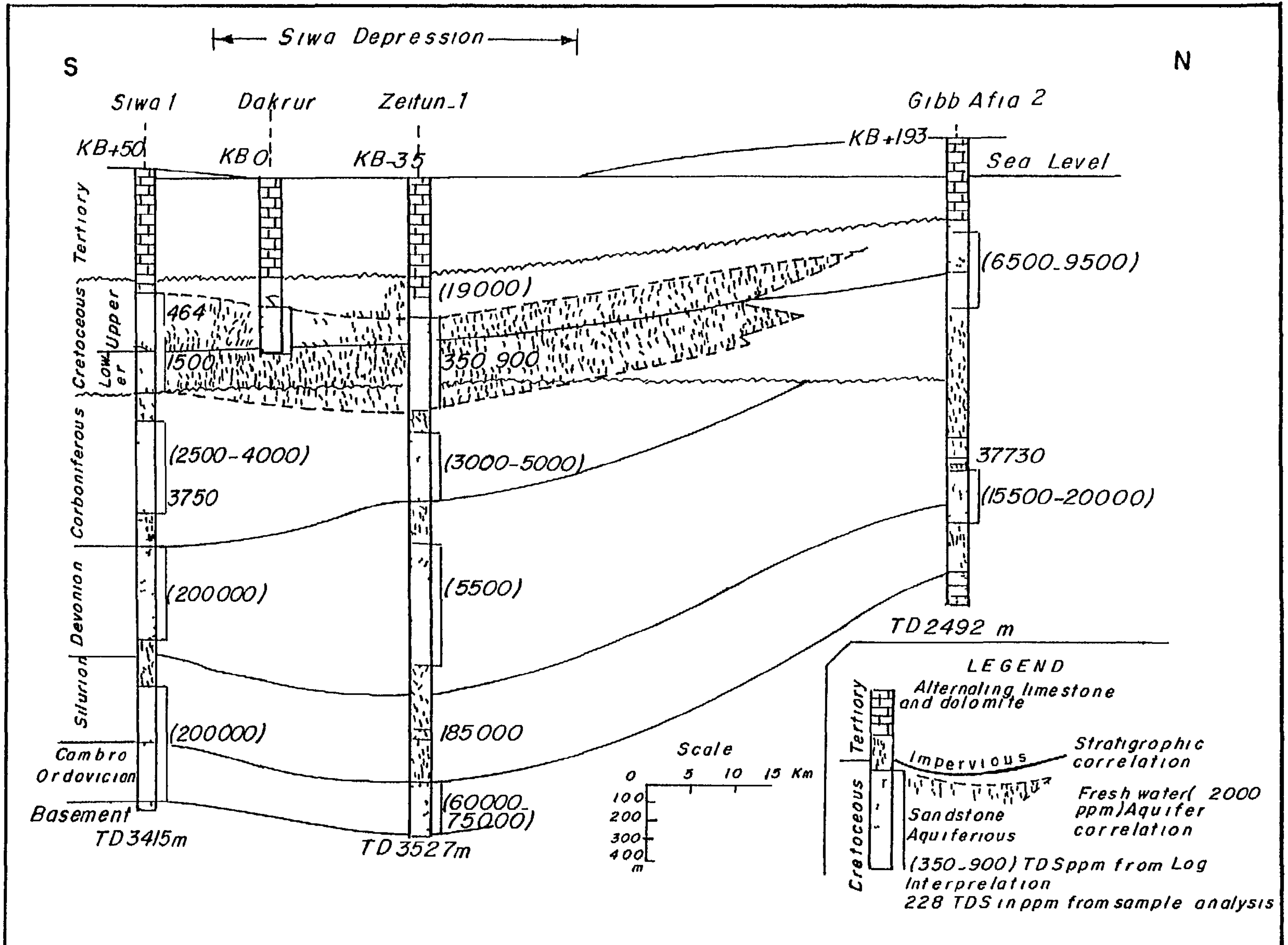


Figure (39)-Hydrogeological Cross_Section Through Siwa Area
(After data collected and processed by General Petroleum Co)

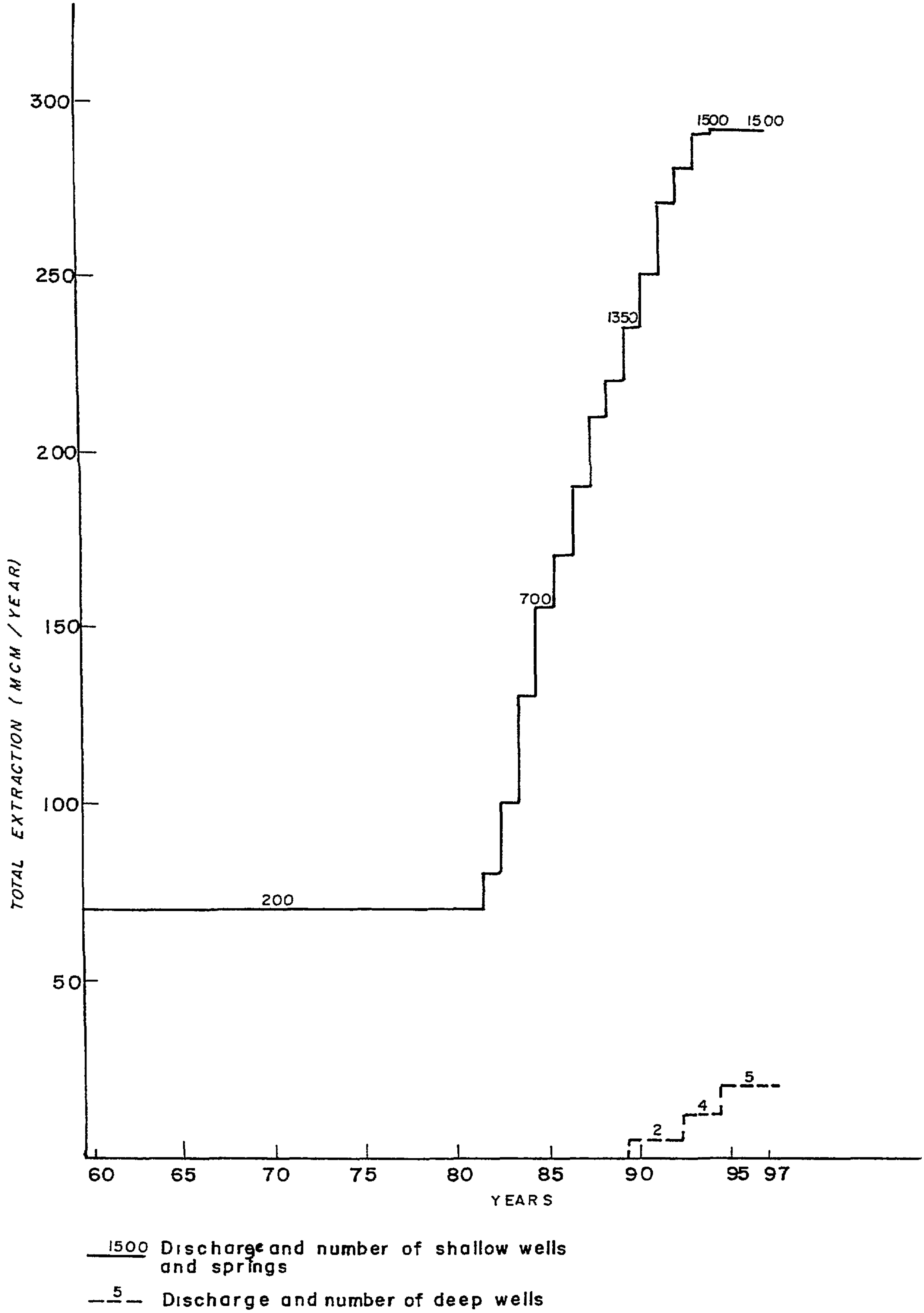
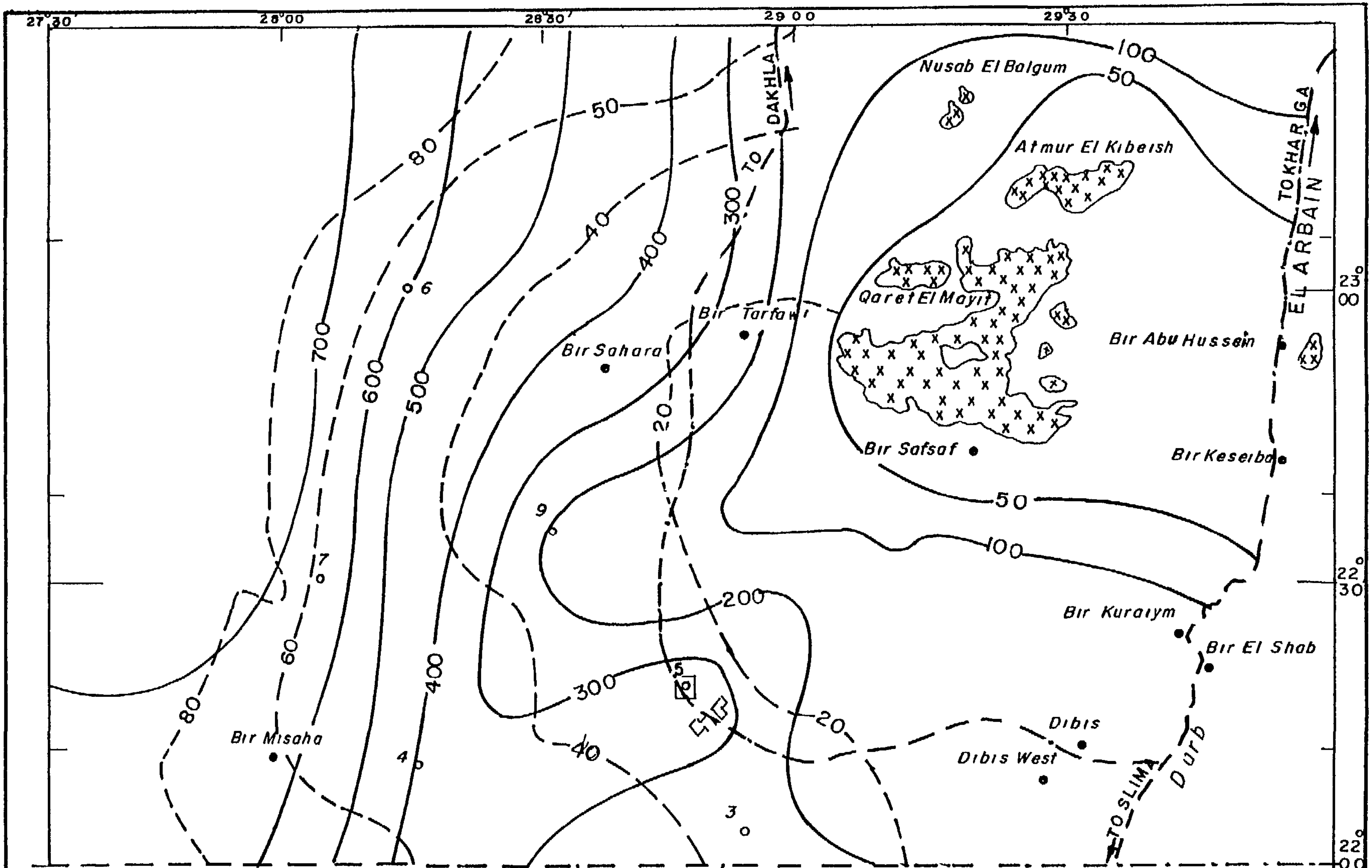


Figure (40)- Groundwater Extraction in Siwa Oasis (1960 - 1997)



500	Iso_ Saturated Thickness Contour Line
40	Iso_ Depth to Water Contour Line

Reclamed Area
Test Well
Dug Well

0 10 20 30 40 50 Km

Figure (41)-Depth to Water And Saturated Thickness Contour Map, East Oweinat Area

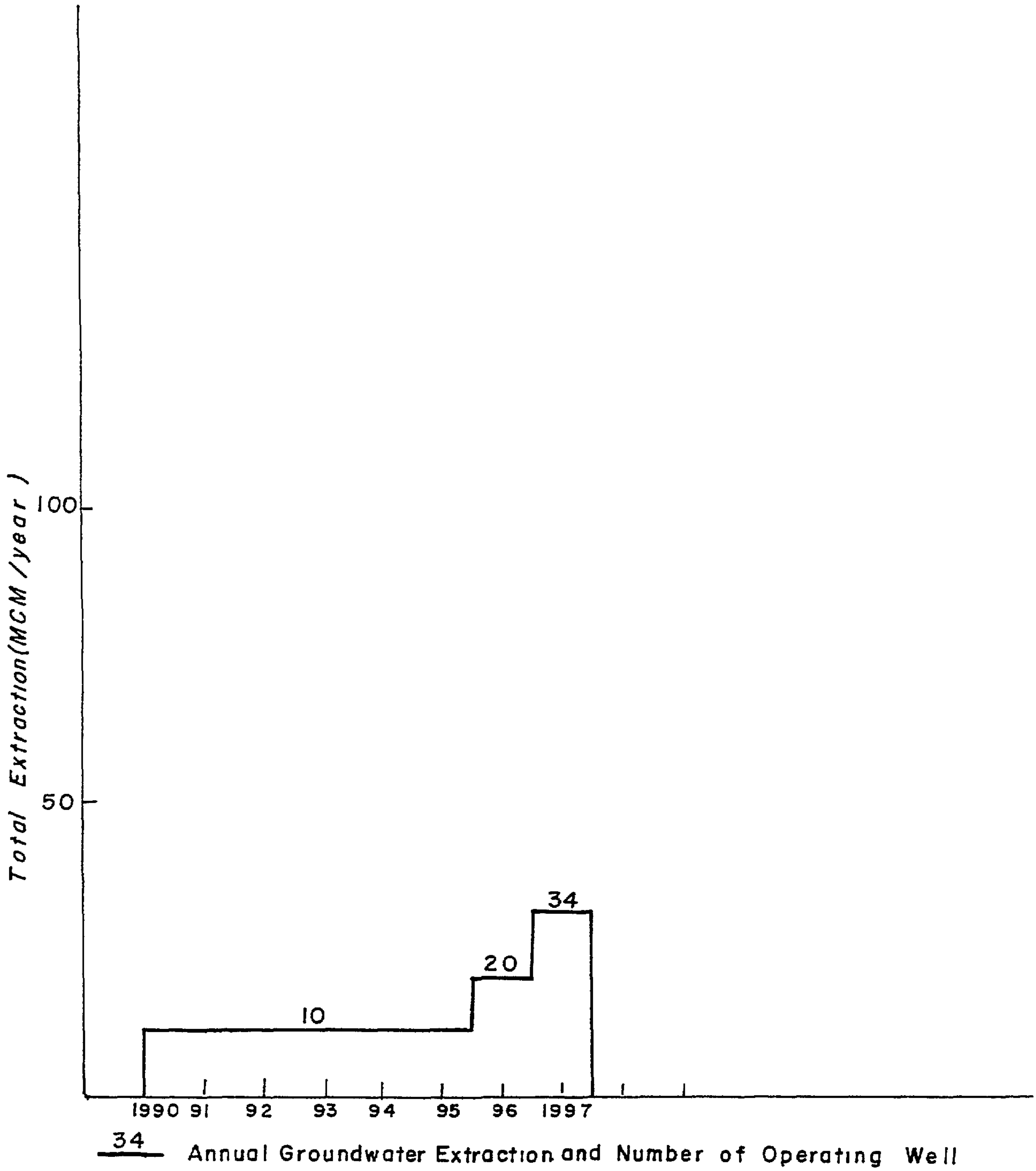
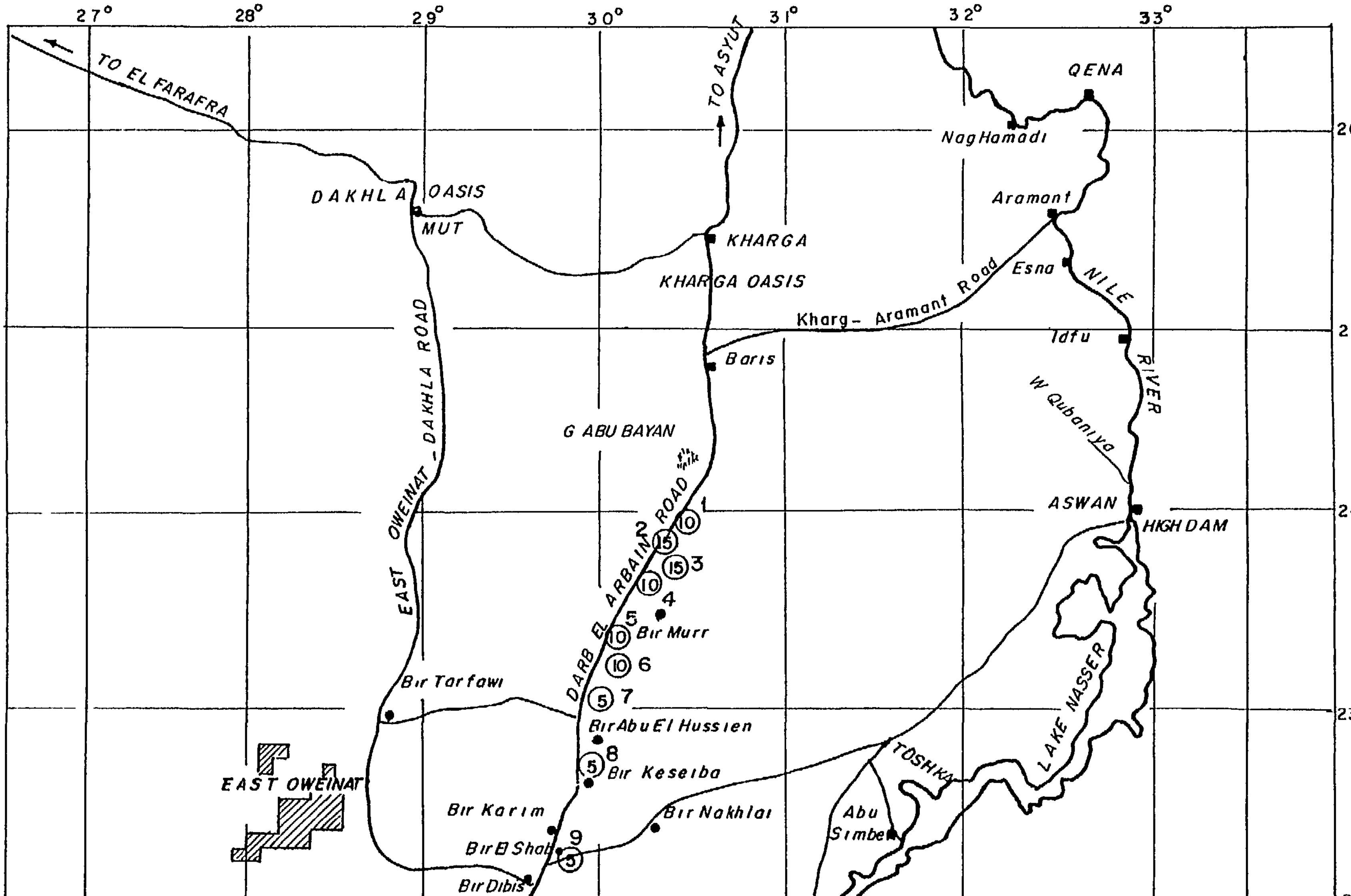


Figure (42)-Groundwater Extraction in East Oweinat Area (1990 - 1997)



9 (5) Well field, and number of wells in proposed agricultural community area

• Existing Dug well

▨ Area allocated for horizontal expansion

Figure (43) - Location Map of Land Reclamation Projects in South Valley Region

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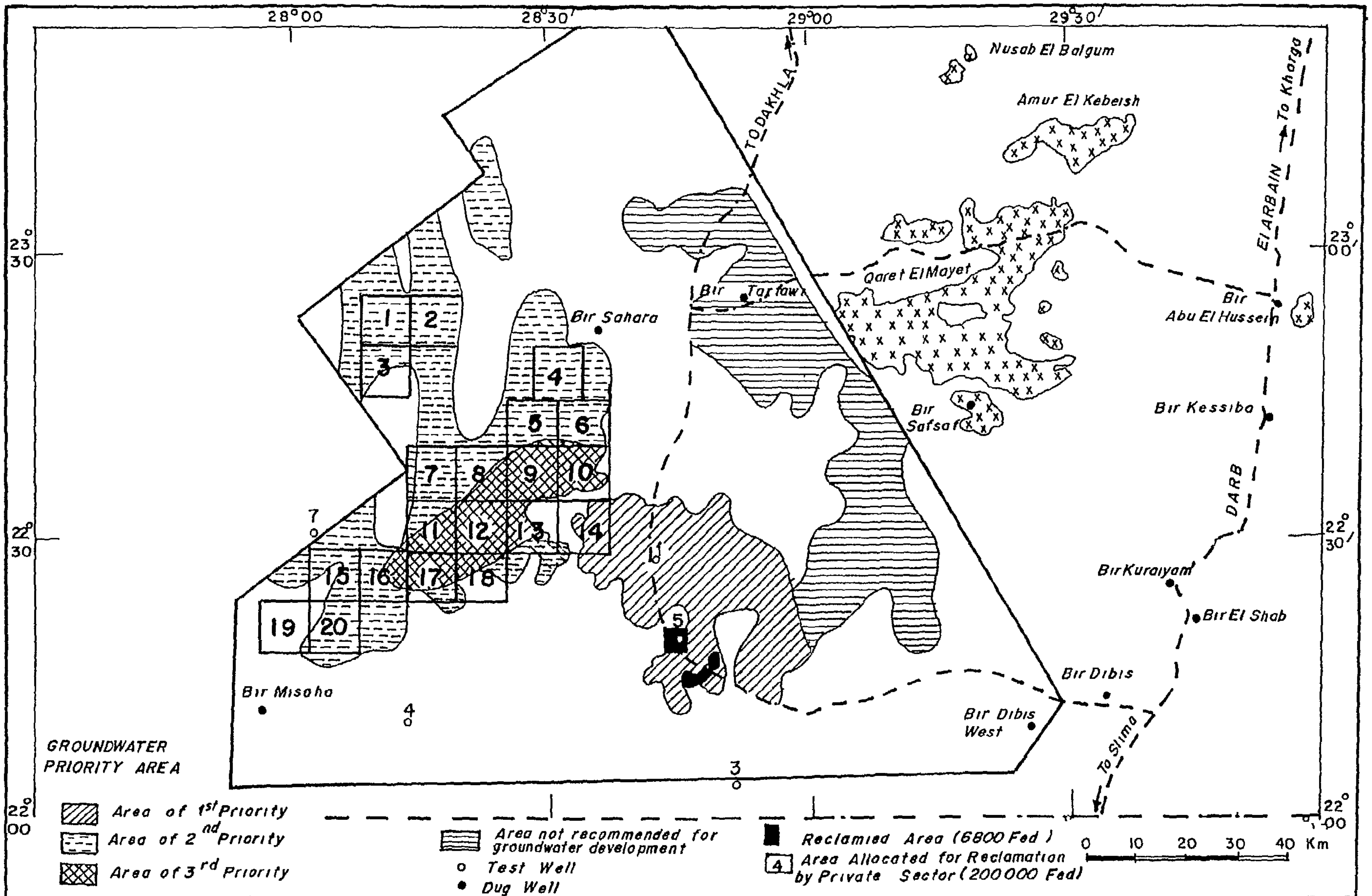

Figure (44)_ Land Reclamation Plan in East Oweinat Area

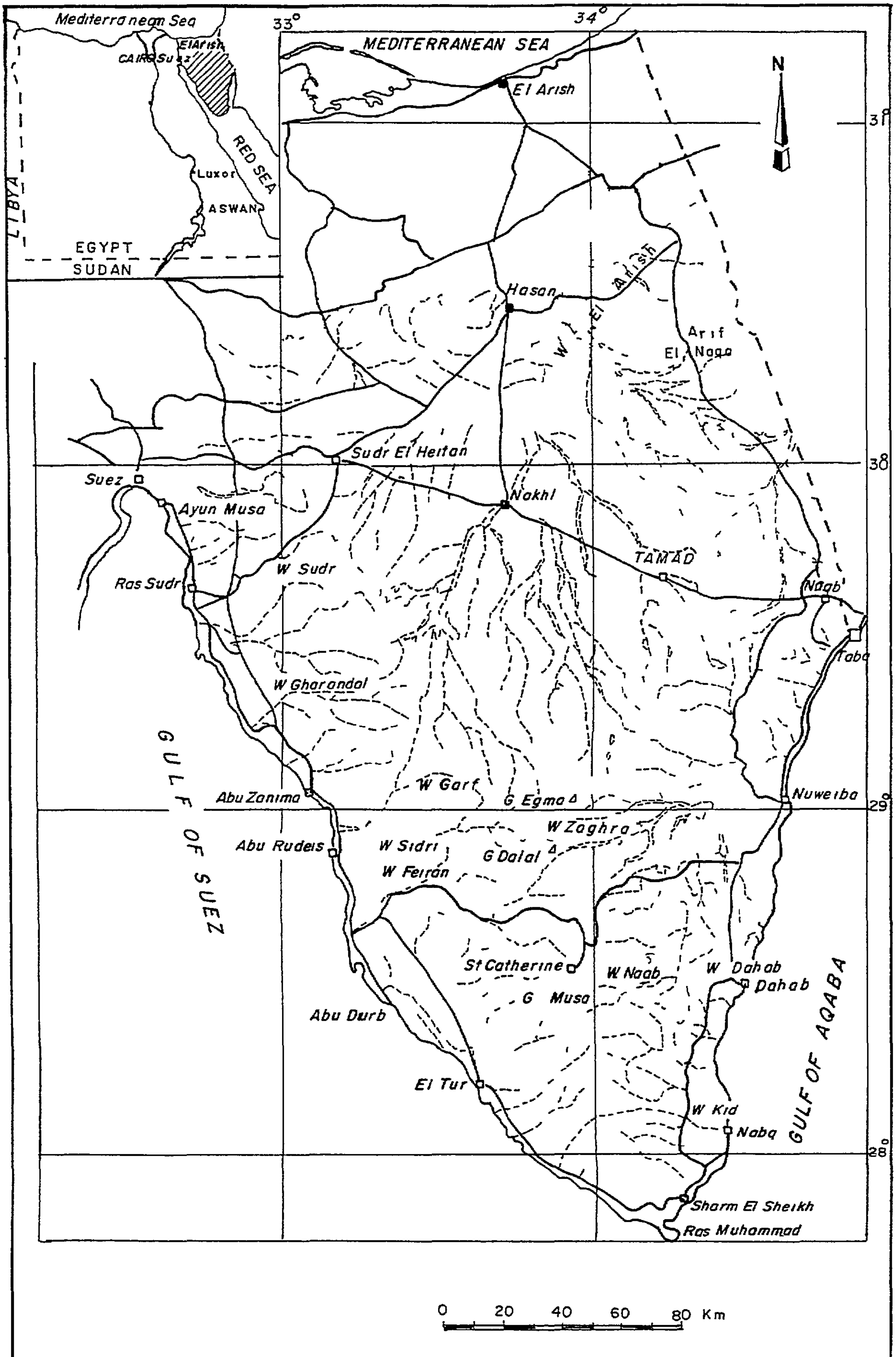

Figure (45)=Location Map of Sinai Peninsula

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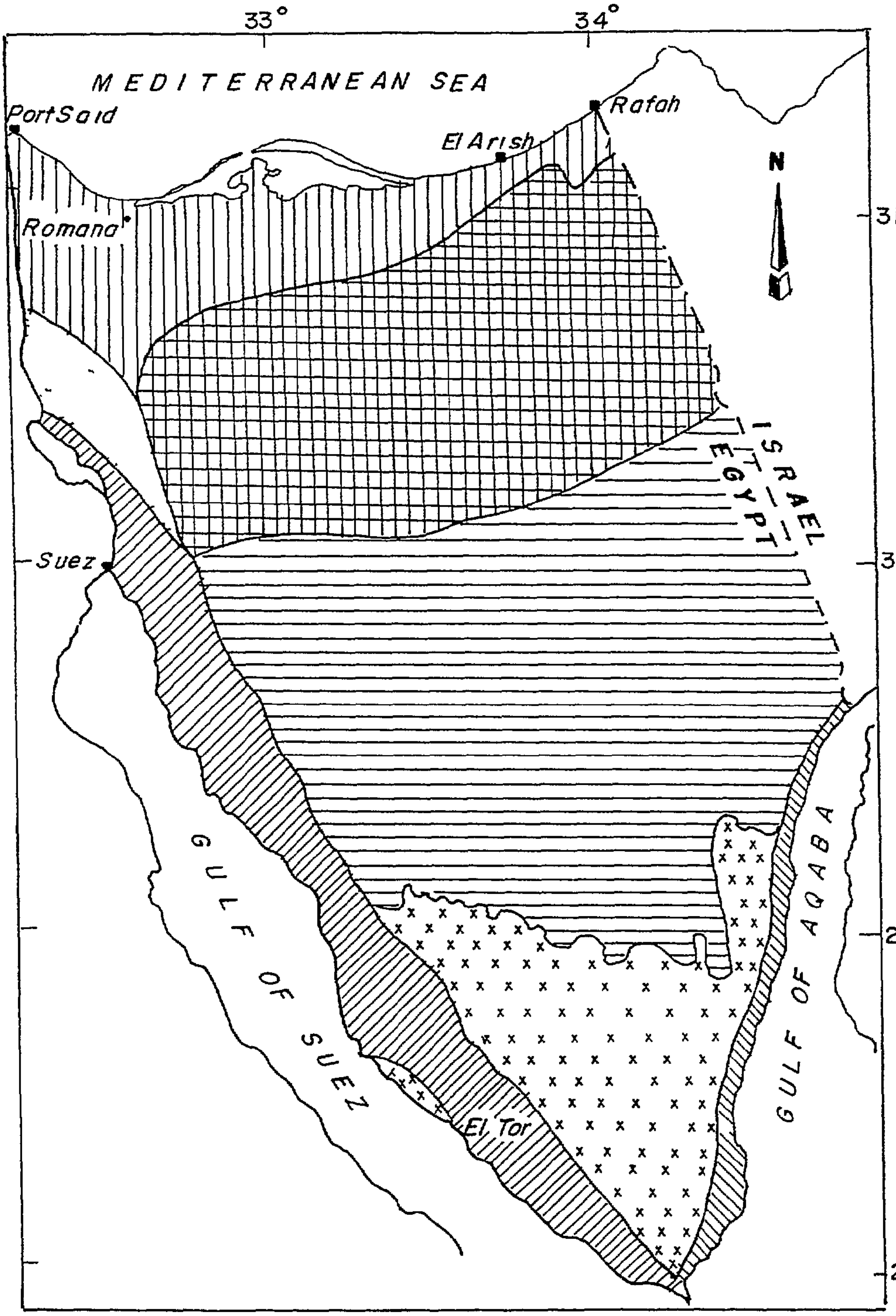


Western rift basin
Eastern rift basin
Basement ridges
Stable plateau
Mobile plateau
North coastal plain
Deltaic plain

0 25 50 Km

Figure (46) _ Geomorphological Units of Sinai

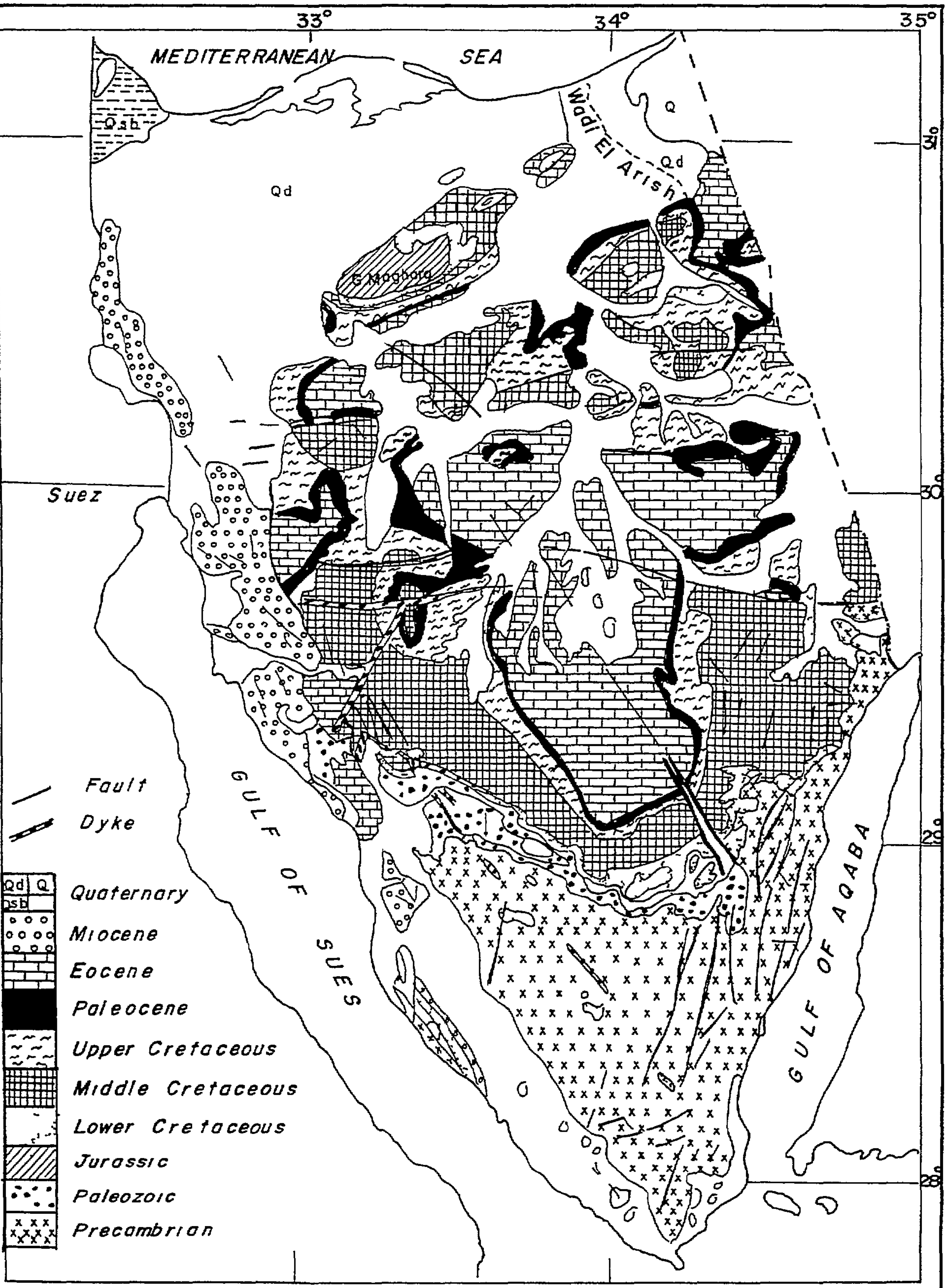


Figure (47)_Geological Map of Sinai Peninsula (After EGSMA 1981)

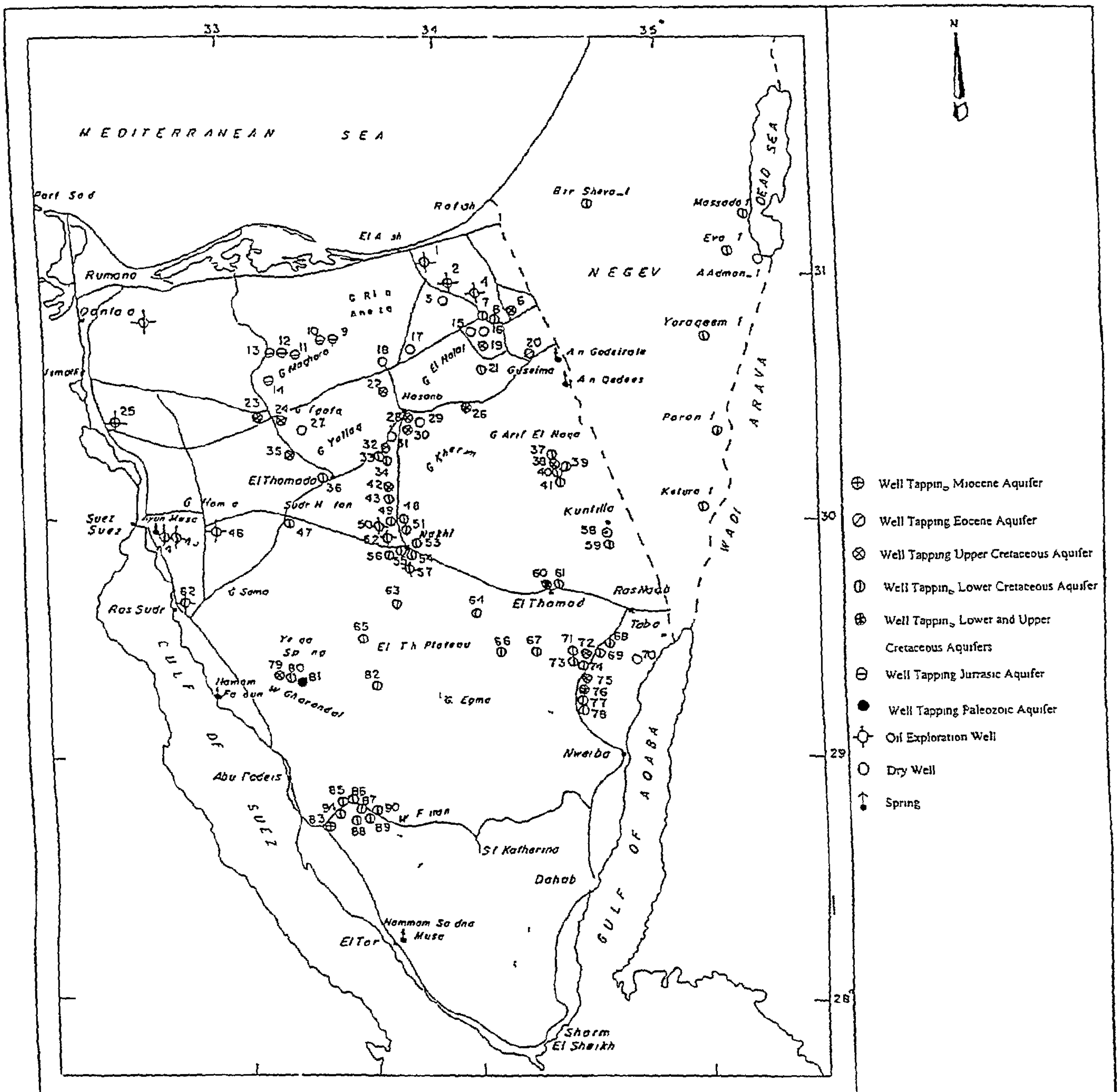
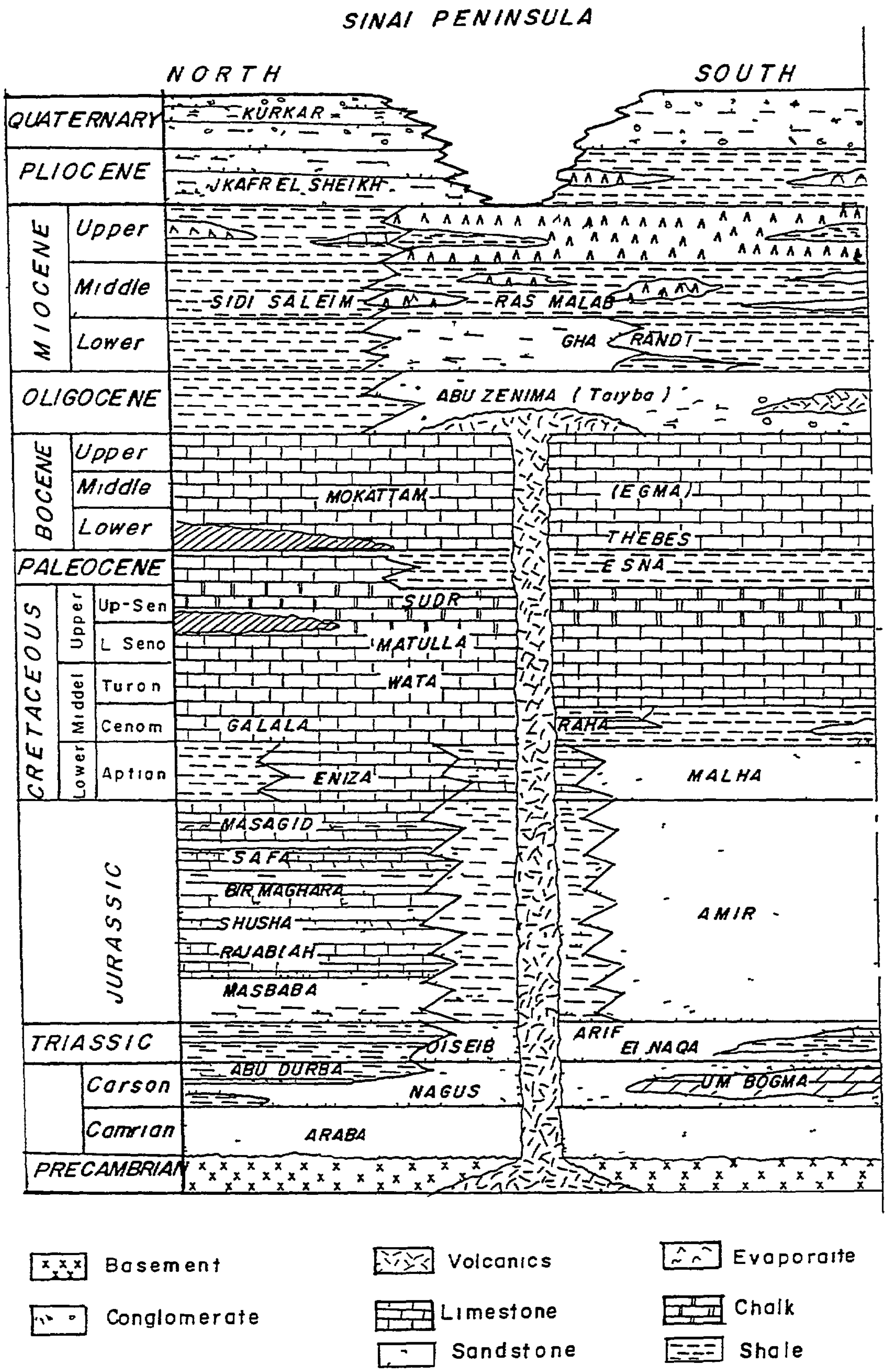


Figure (48) - Location Map of Deep Wells in Sinai



Figure(49)_Schematic Representation of The Litho_Stratigraphic Rock Units For Northern and Southern Sinai
(After Zoghloul, 1983)

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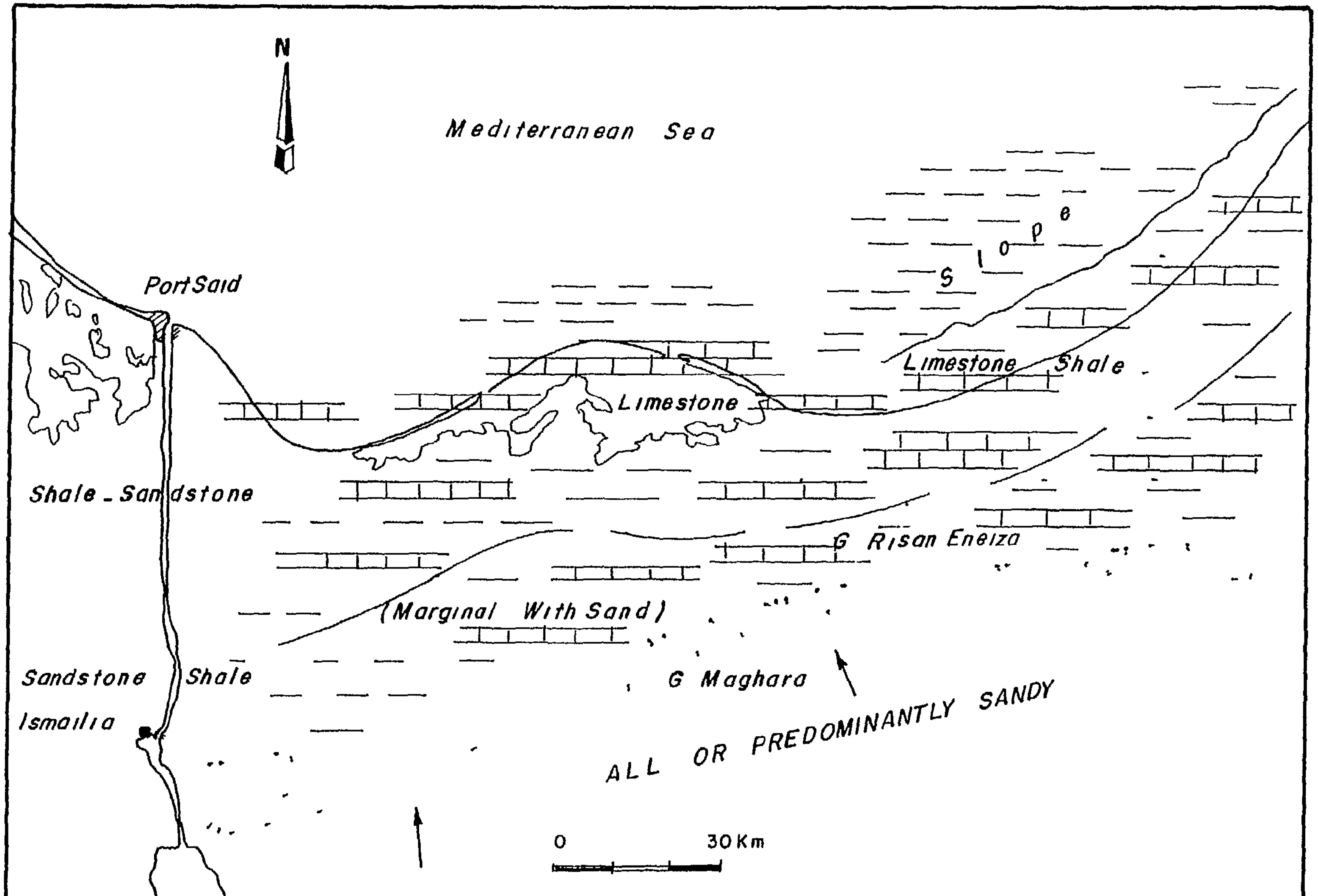


Figure (50)- Paleographic Map Showing The Variation of Lower Cretaceous Deposits in Northern Sinai
(After Zaghloul, 1983)

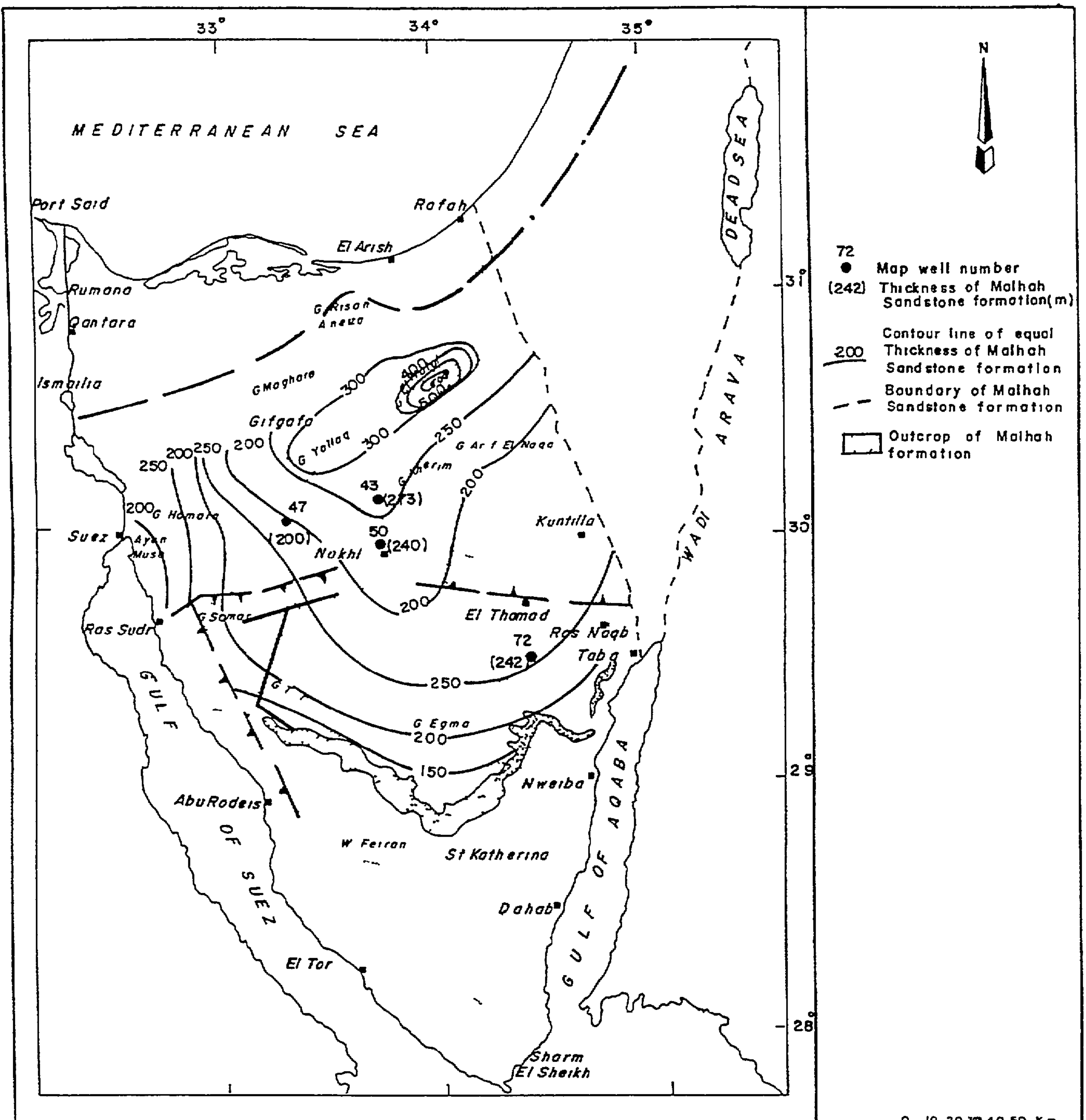


Figure (51) _ Isopach Map of The Lower Cretaceous Malhah Sandstone Formation in Sinai (After Nour, 1993)

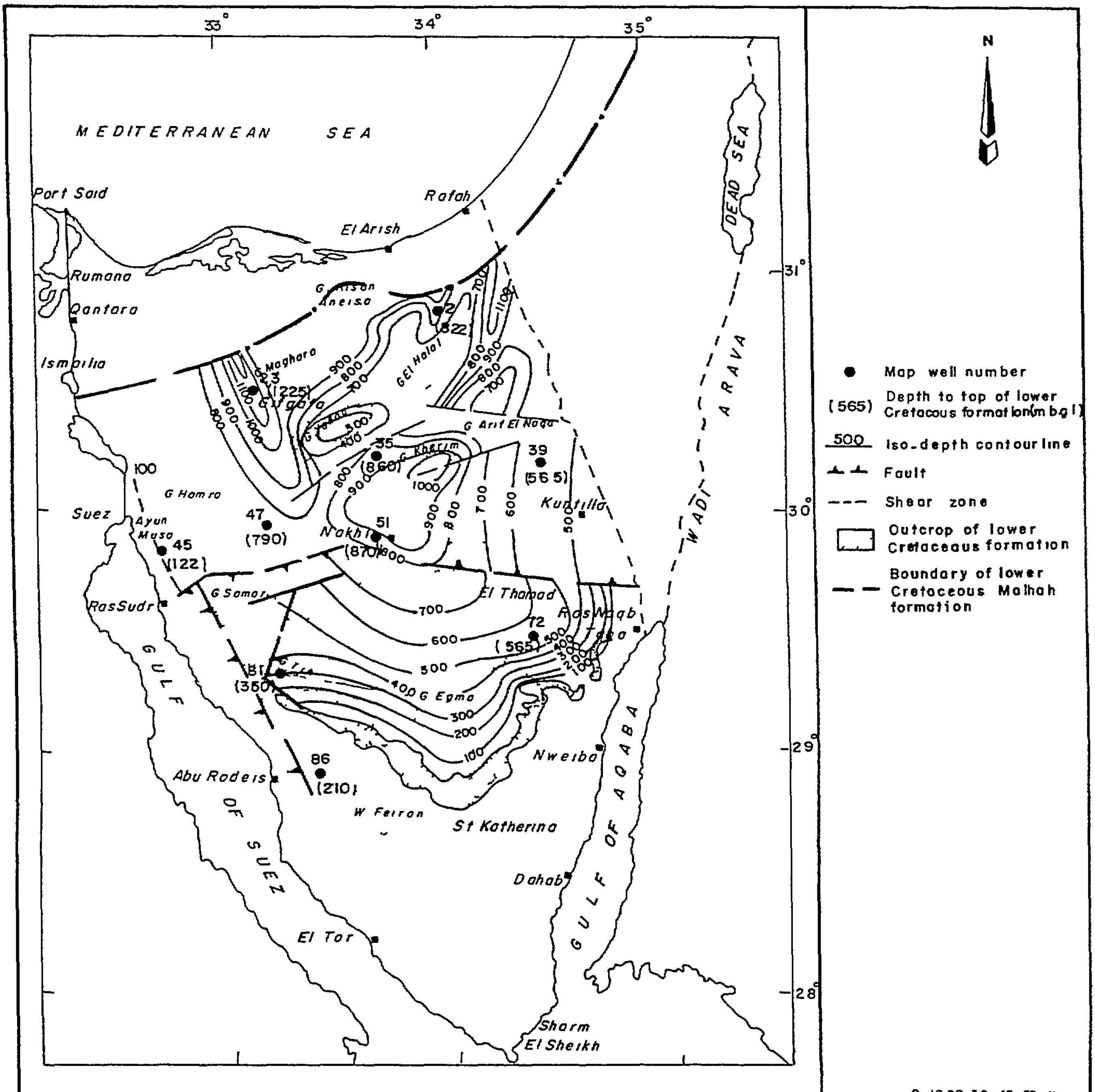
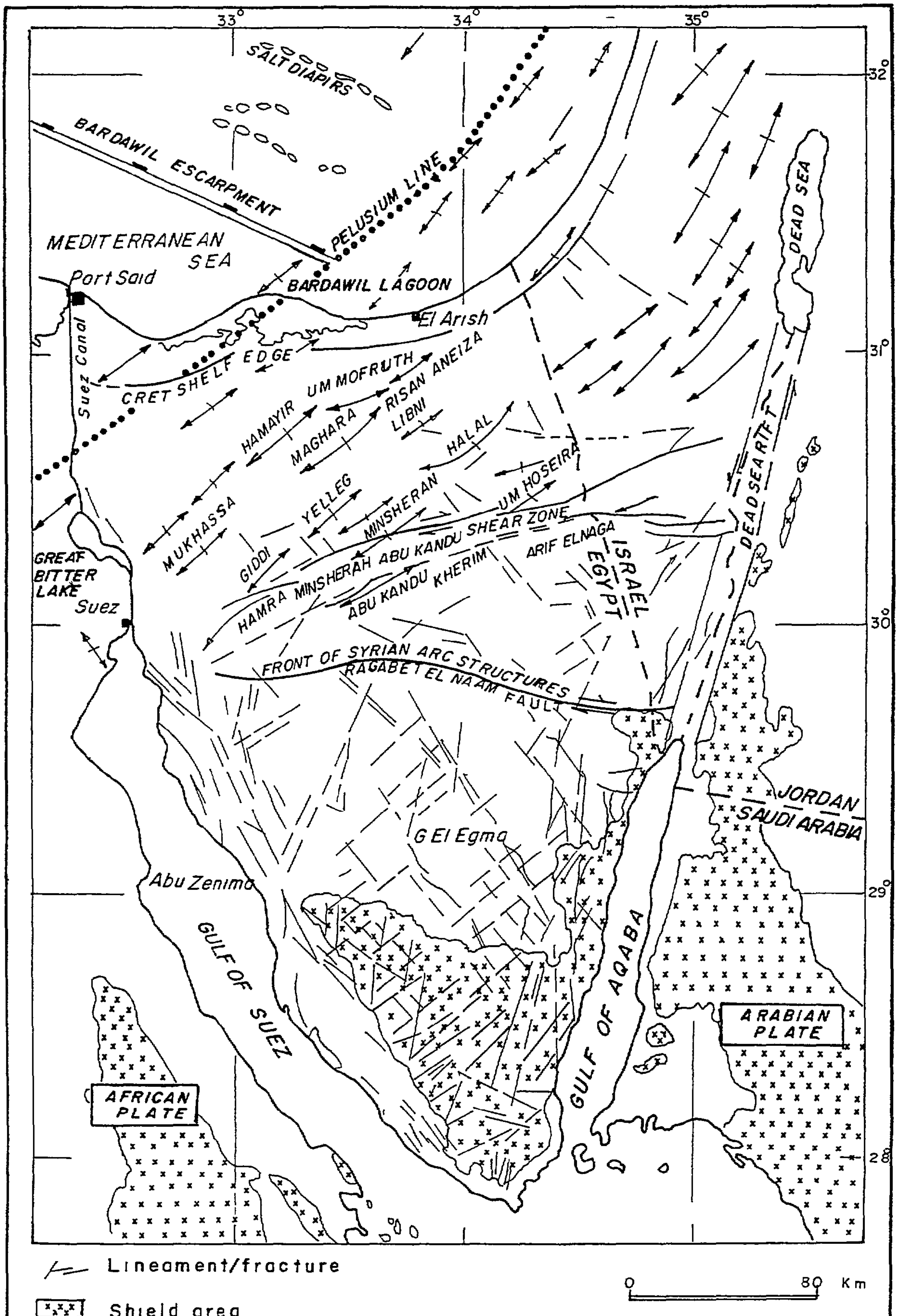


Figure (52)_ Depth to Top of The Lower Cretaceous Malhah Formation in Sinai (After Nour, 1993)



Figure(53)_ Tectonic Map of North and Central Sinai (After Neev, 1975)

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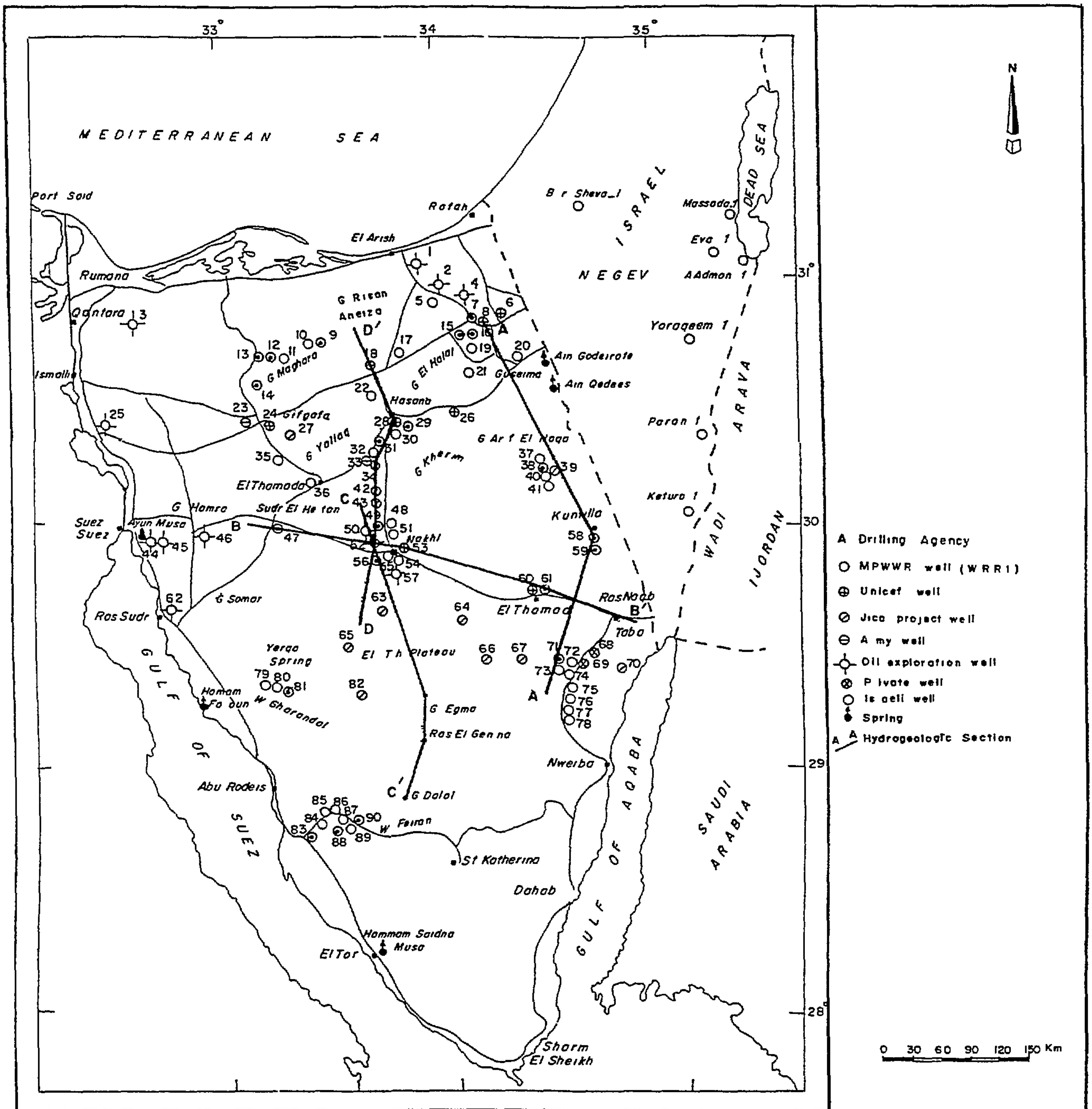


Figure (54) Location Map of Hydrogeologic Sections

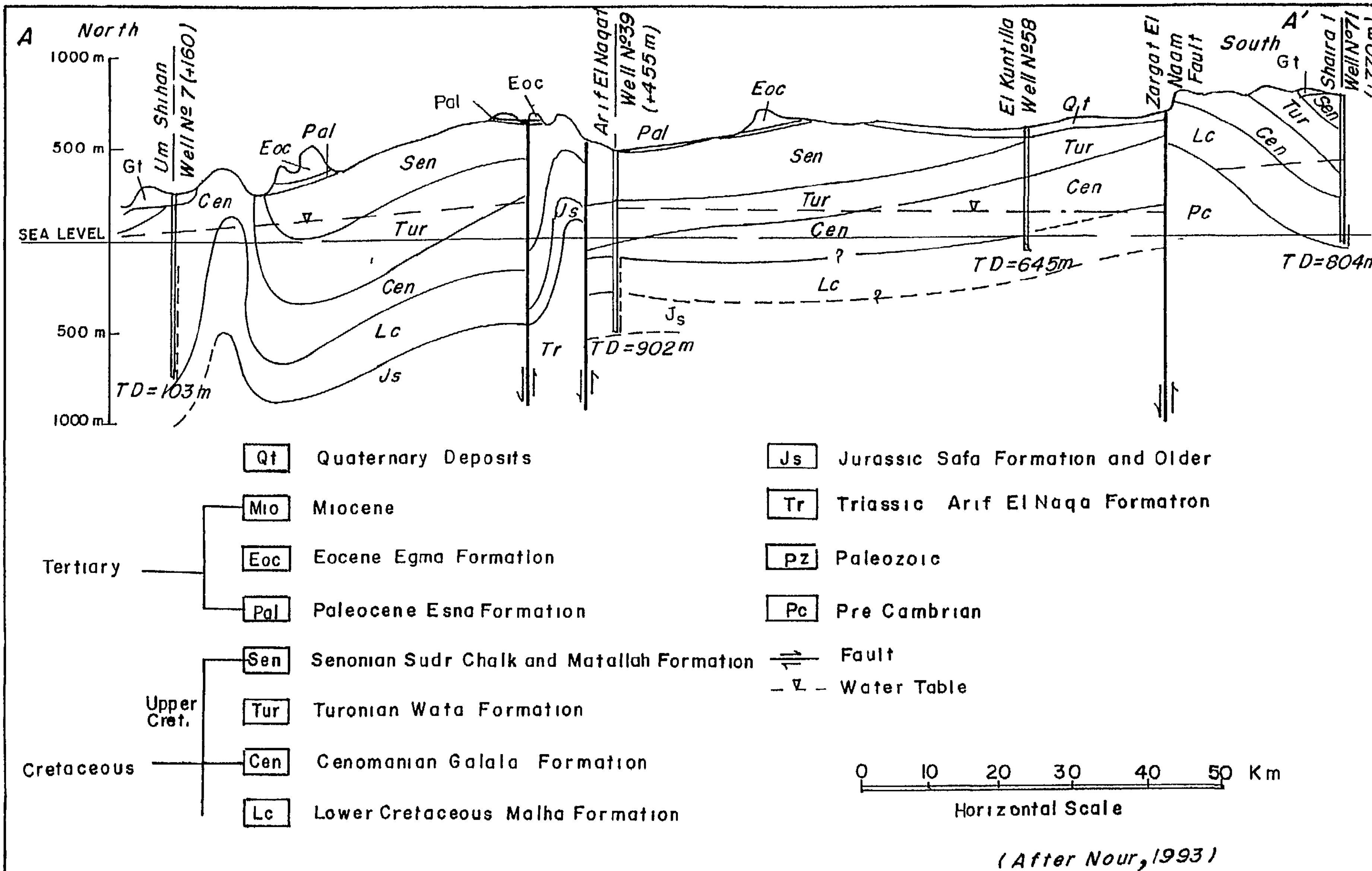


Figure (55)- North-South Hydrogeological Section A-A' Between Um Shihan, Arif El Naqa and Shaira

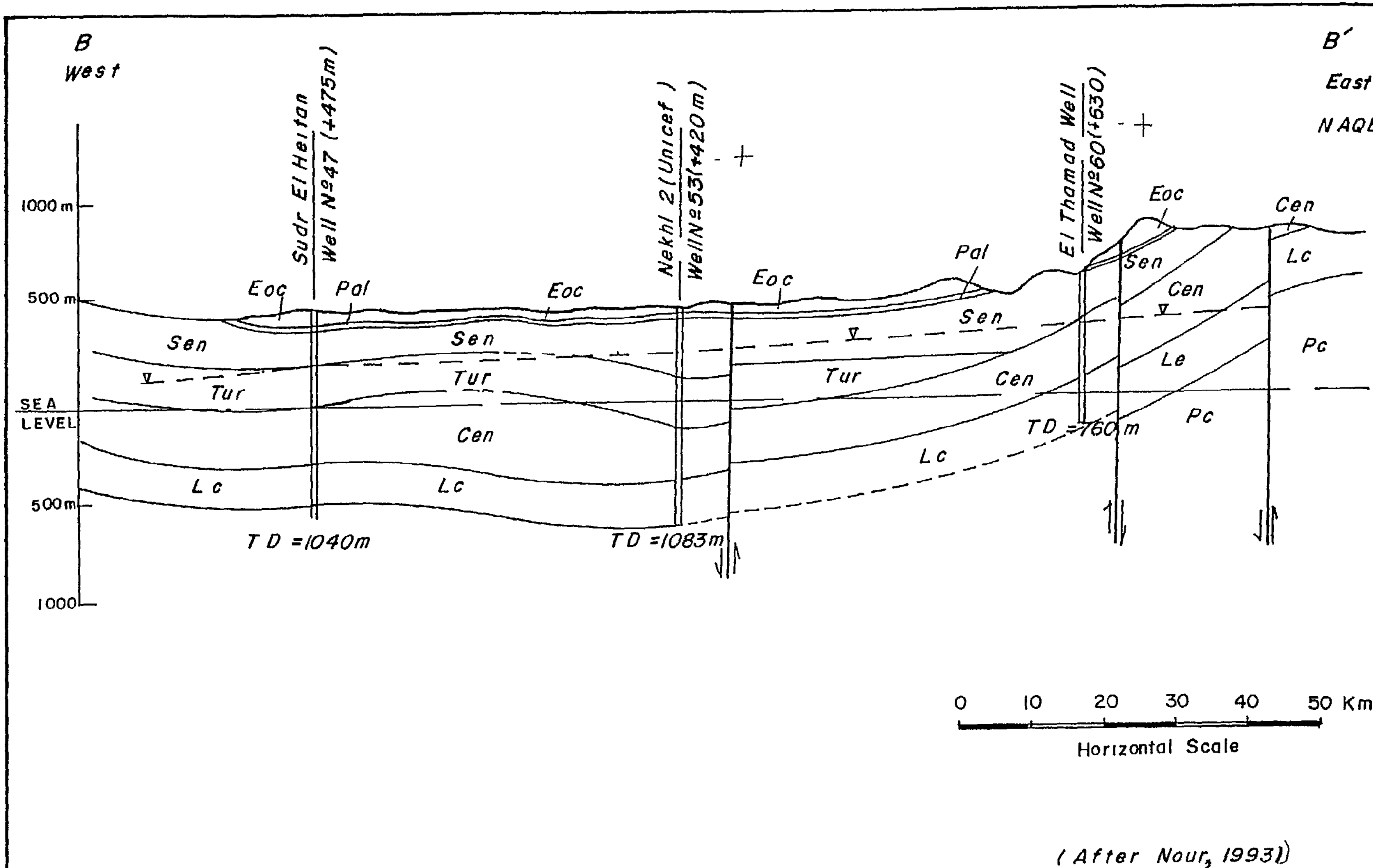
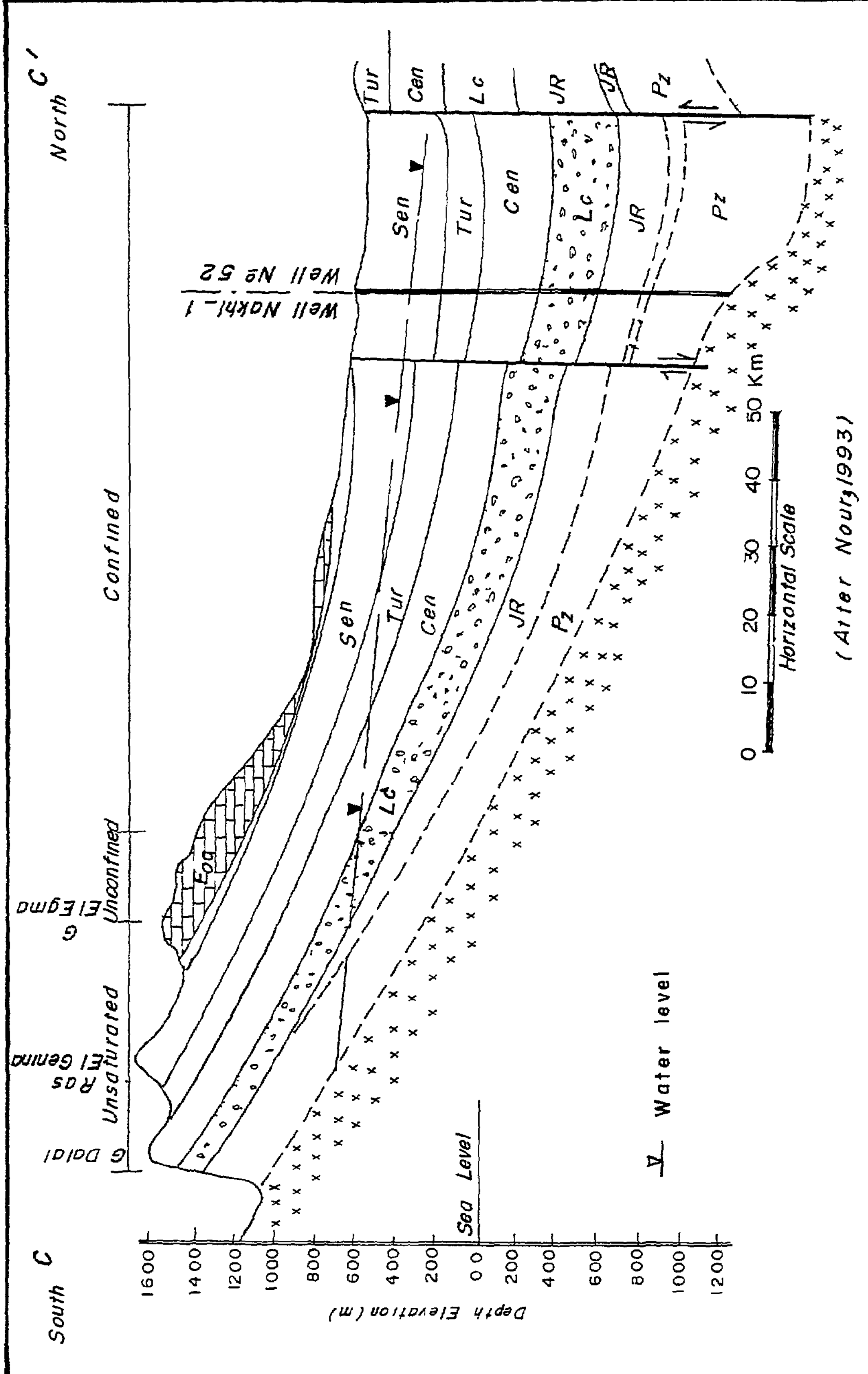


Figure (56) - East_West Hydrogeologic Section B-B′ Along Naqb, El Thamad, Nakhl and Sudr El Heitan



(After Nour,1993)

Figure(57)_ North_South Hydrogeologic Section C_C' Showing Lower Cretaceous Aquifer Setting

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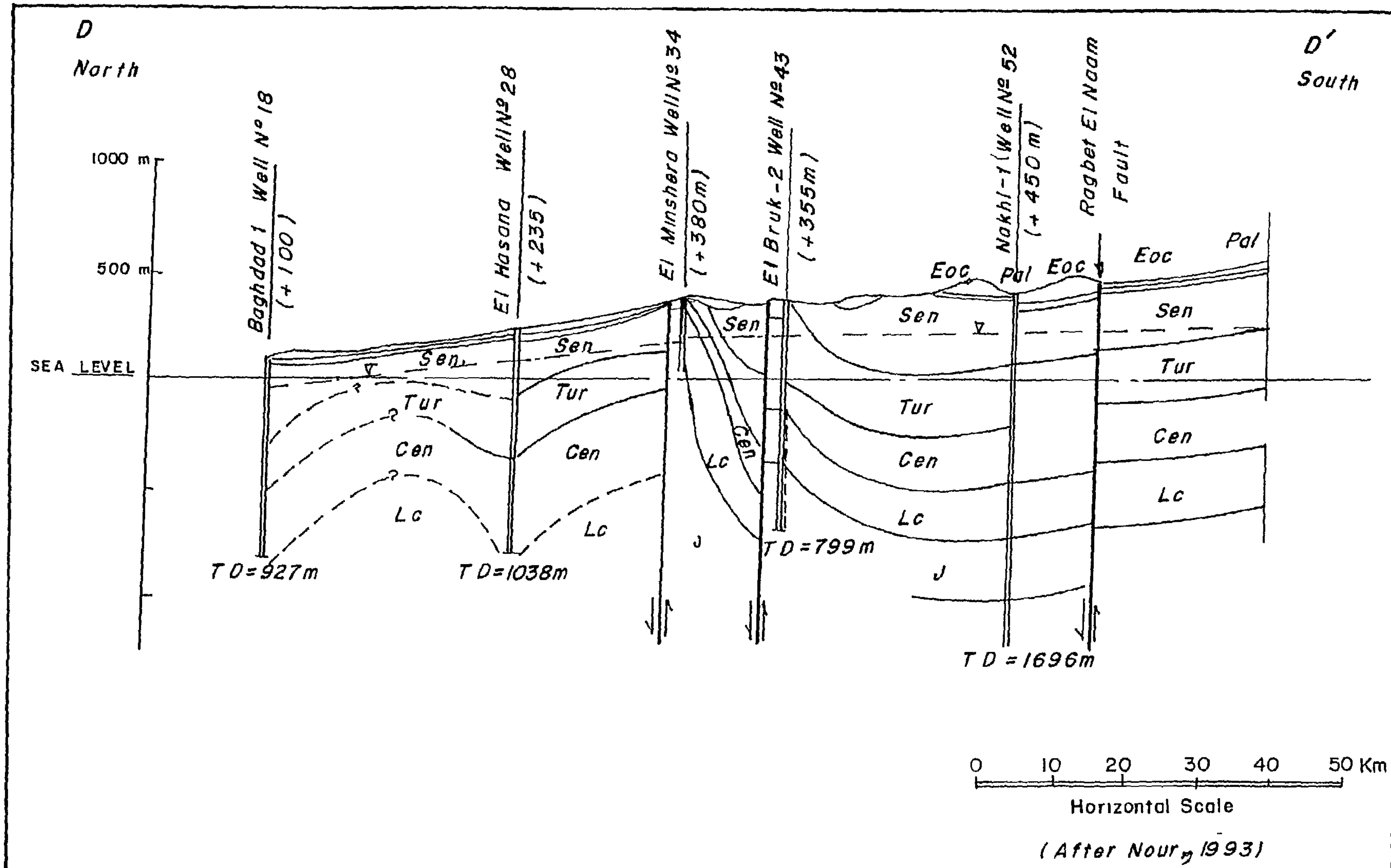

Figure (58) North_South Hydrogeologic Section D_D' Along Nakhl, El Bruk, El_ Minsherah, El Hasana and Baghded

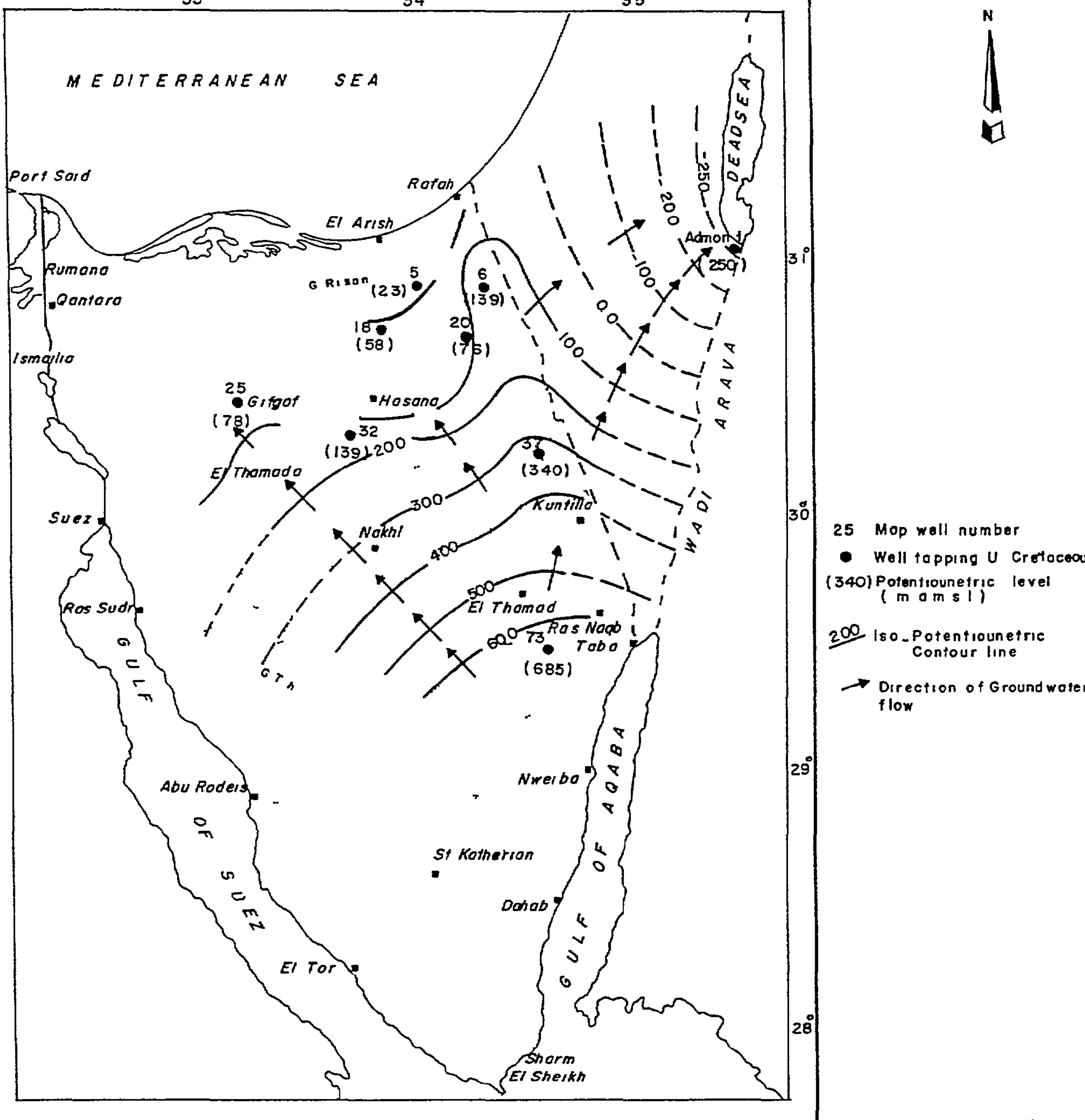

Figure (59)_Potentiometric Surface Map of The Upper Cretaceous Aquifer System in Sinai (After Nour, 1993)

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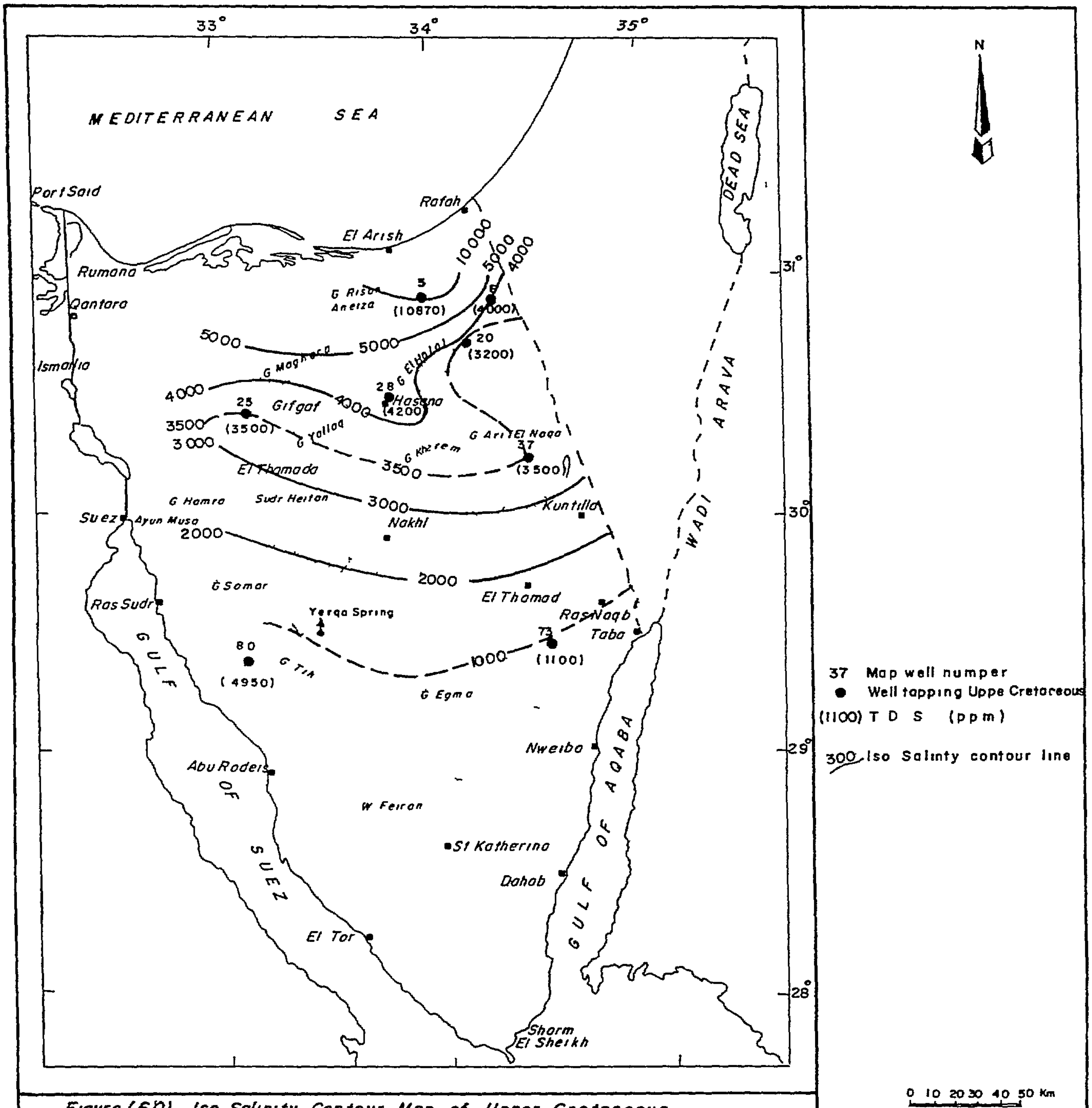

Figure (60)- Iso-Salinity Contour Map of Upper Cretaceous Aquifer System in Sinai (After Nour, 1993)

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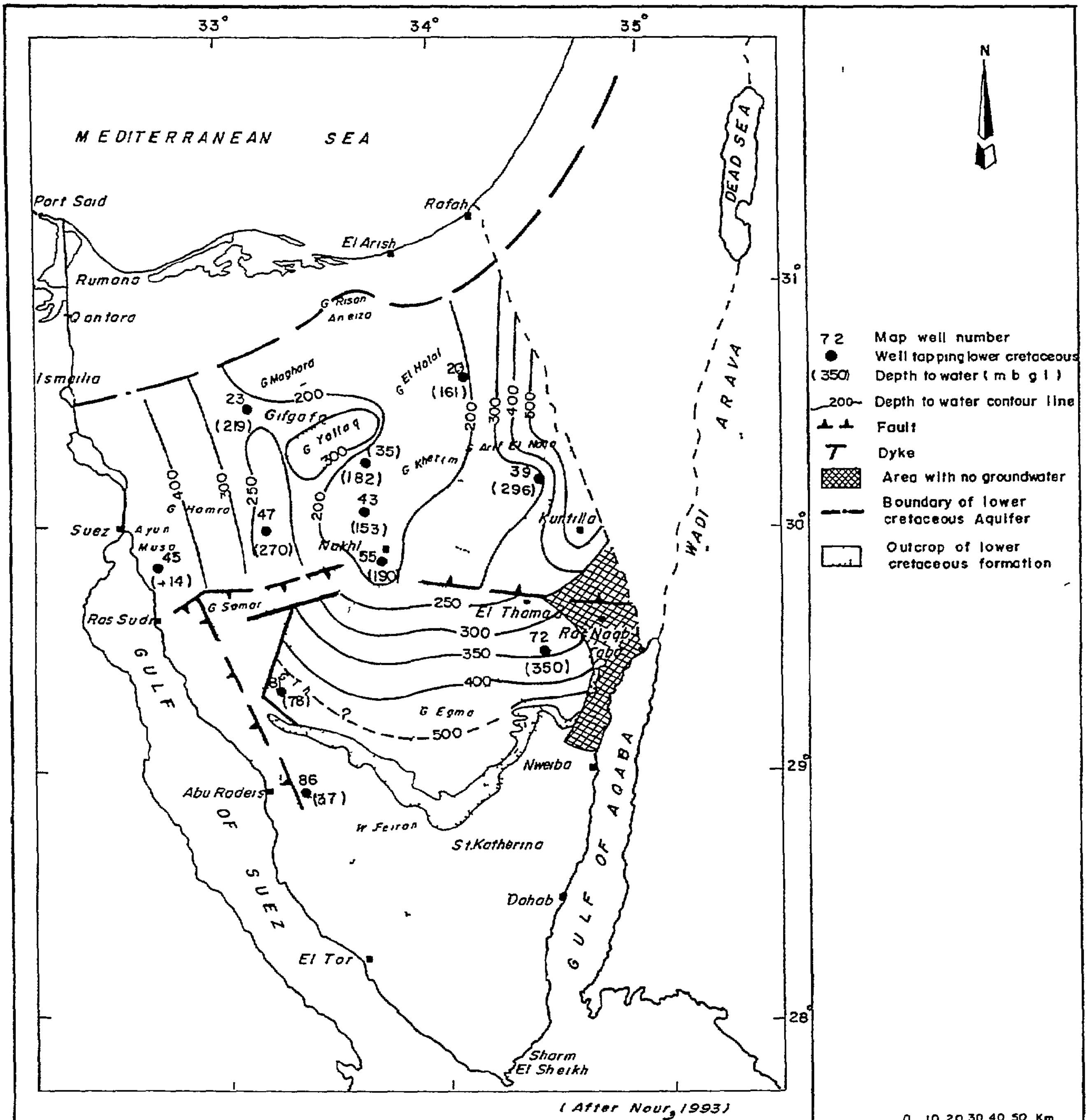


Figure (61)_ Depth to Groundwater in The Lower Cretaceous Aquifer In Sinai

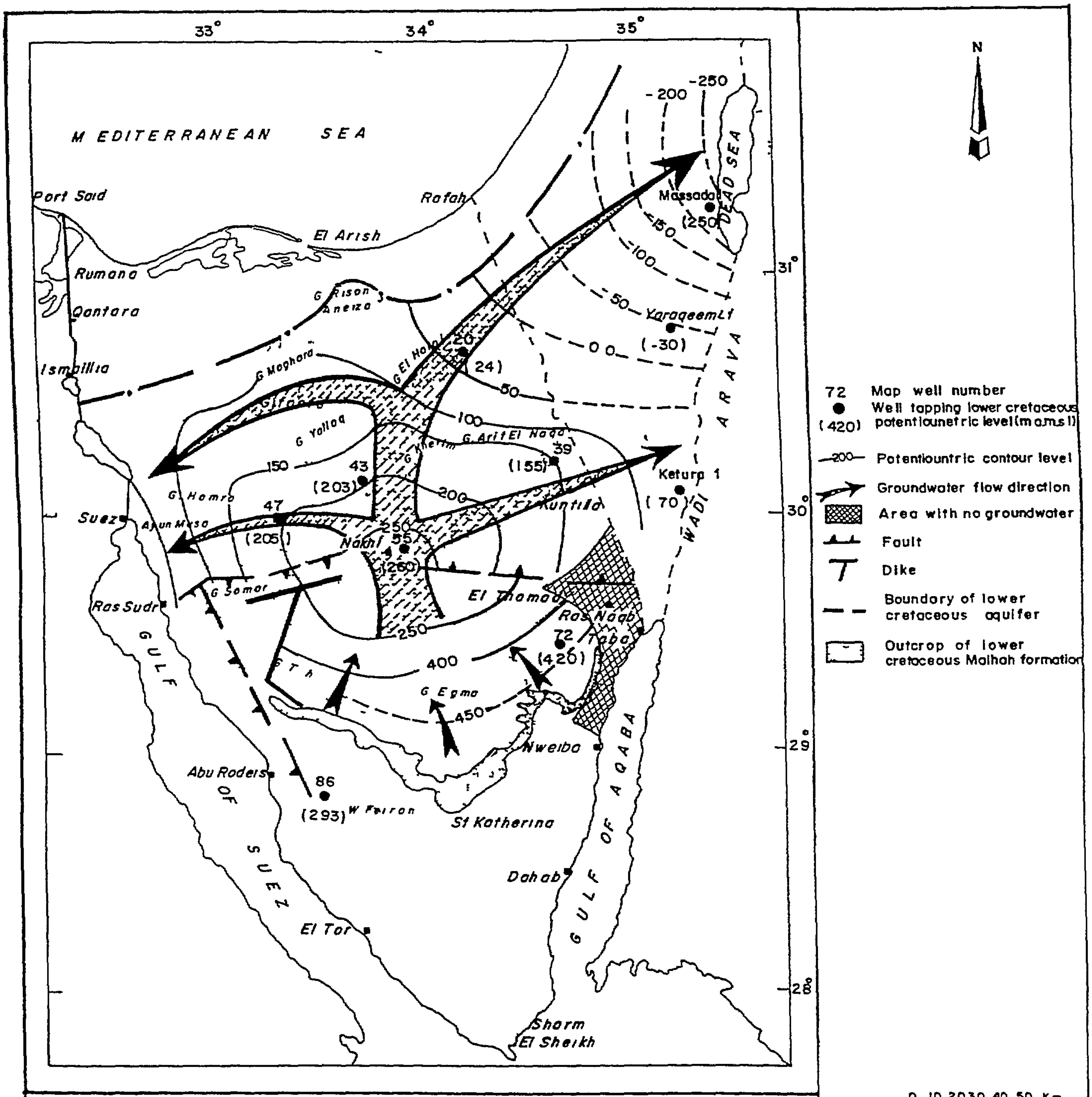


Figure (62) Potentiometric Surface Map of The Lower Cretaceous Aquifer in Sinai (After Nour, 1993)

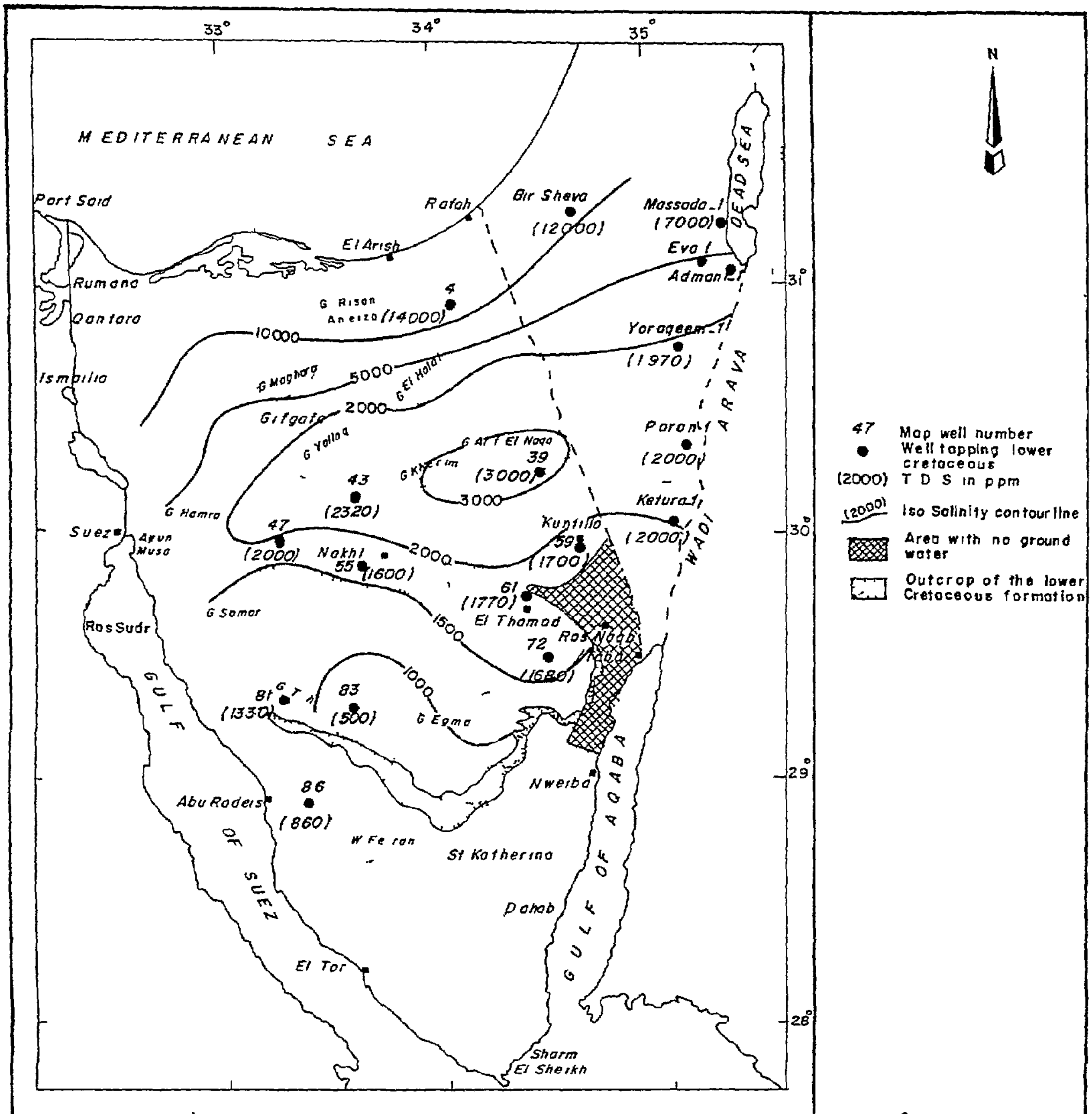
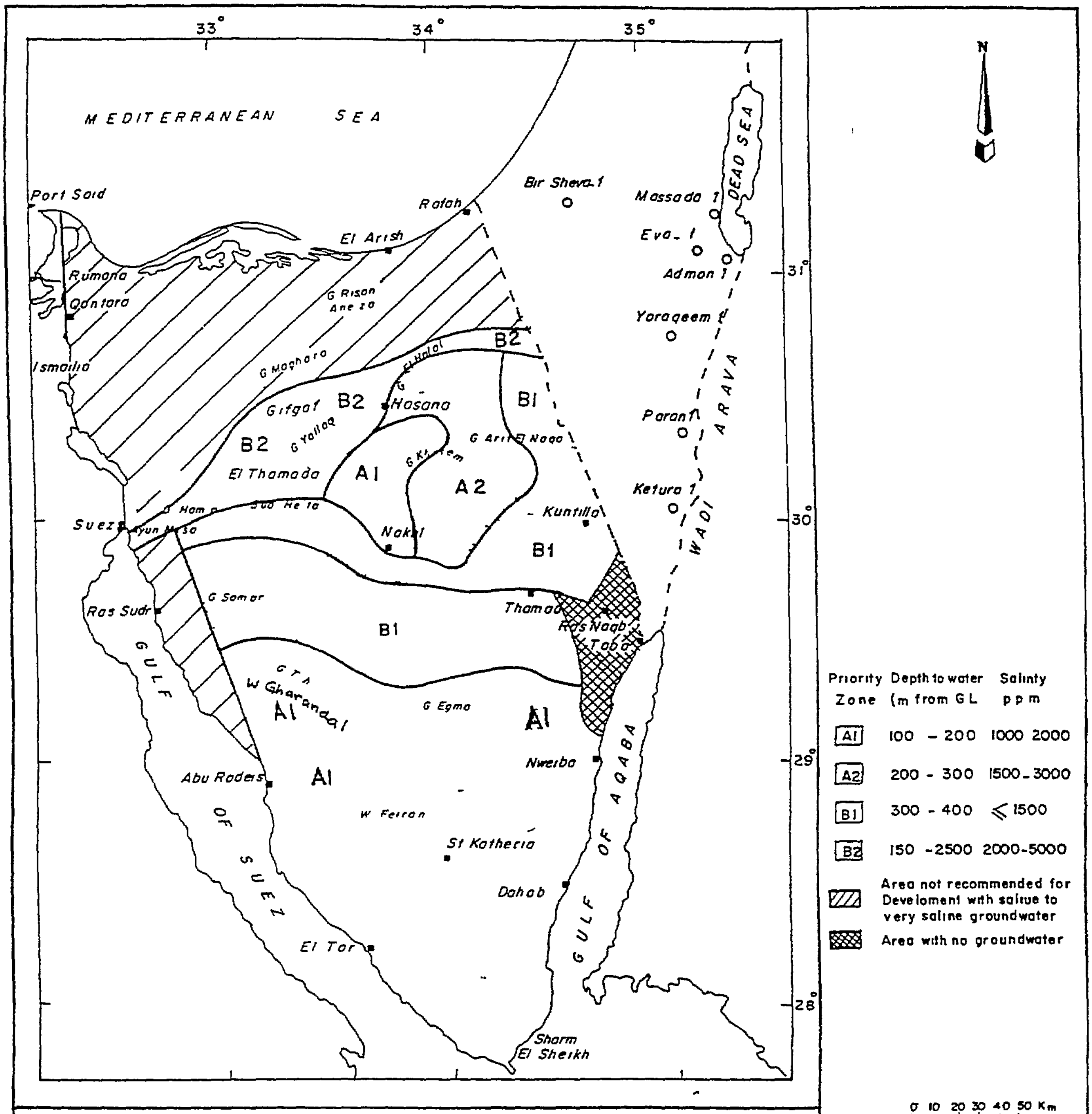


Figure (63) Iso_Salinity Contour Map of The Lower Cretaceous Aquifer in Sinai (After Nour, 1993)



Figure(64)_ Map of Development Priority Areas of Lower Cretaceous Aquifer in Sinai (After Nour, 1993)

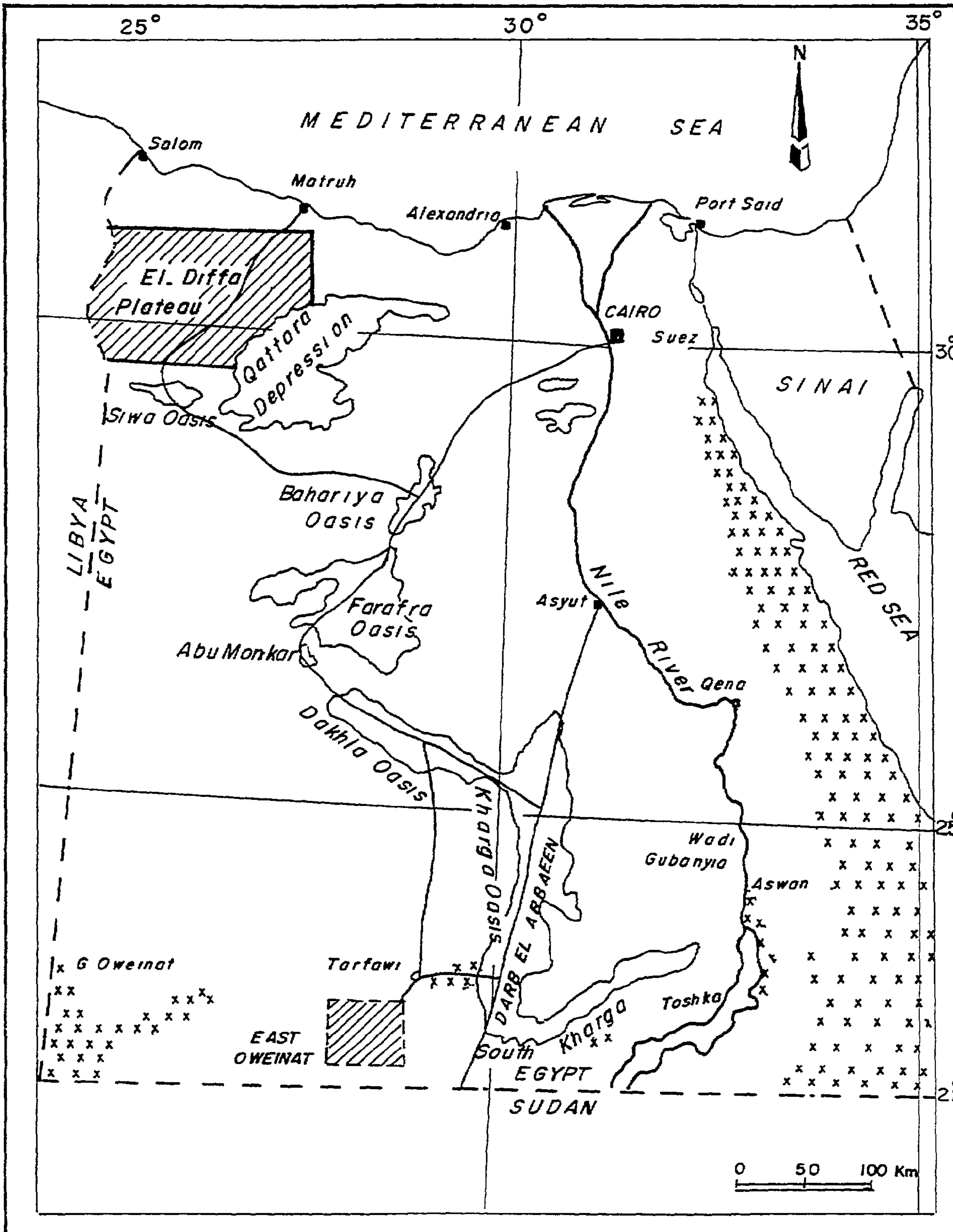
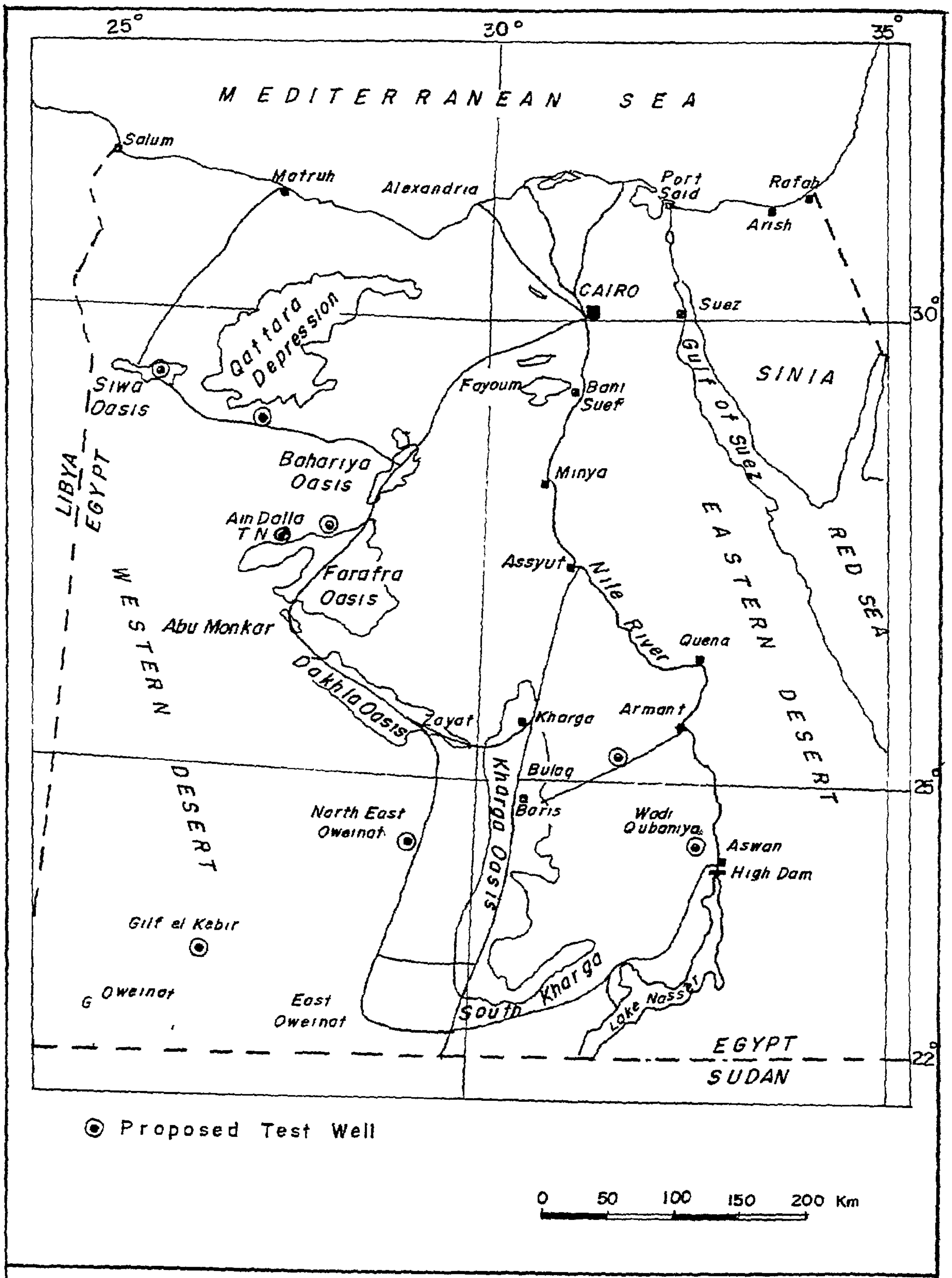


Figure (65) _ Location Map of The Proposed Study Area of Carbonate Aquifer System in The Western Desert



Figure(66)- Location of Proposed Test Wells in The Western Desert

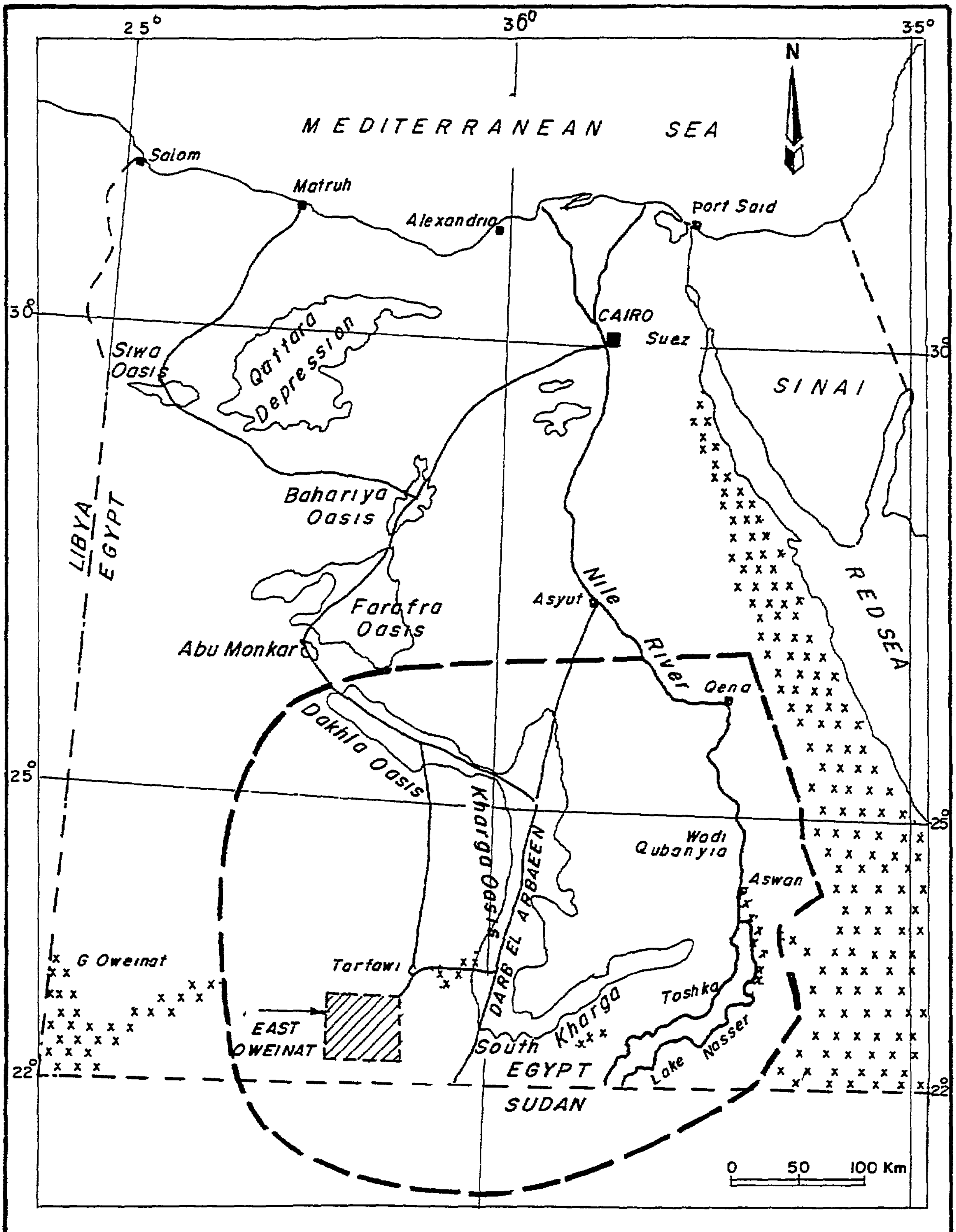


Figure (67)_Location Map of The Proposed Model Study Area, South Valley Region

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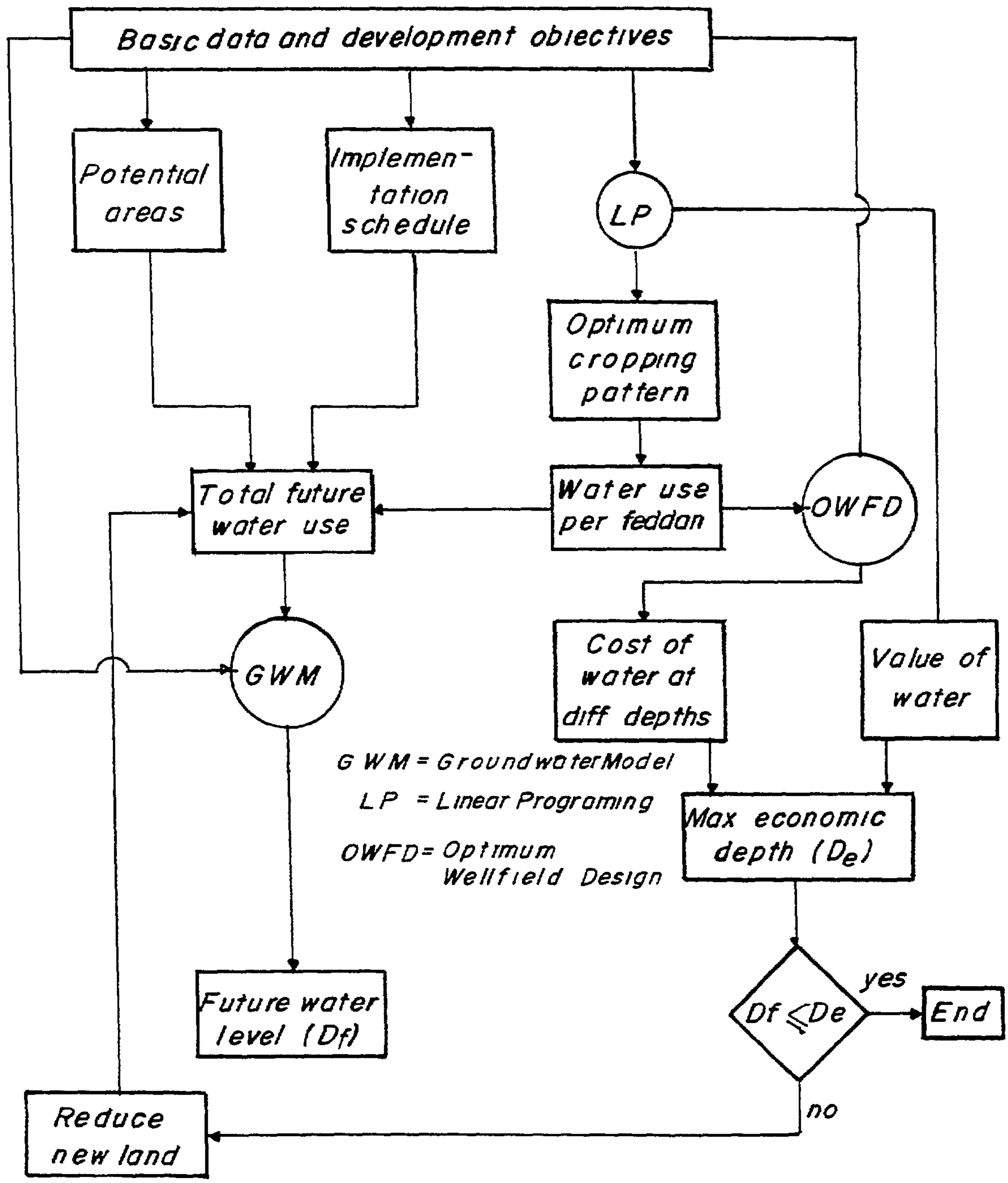

Figure(68) - Planning Procedure for Development of Groundwater Resources in The South Valley Region

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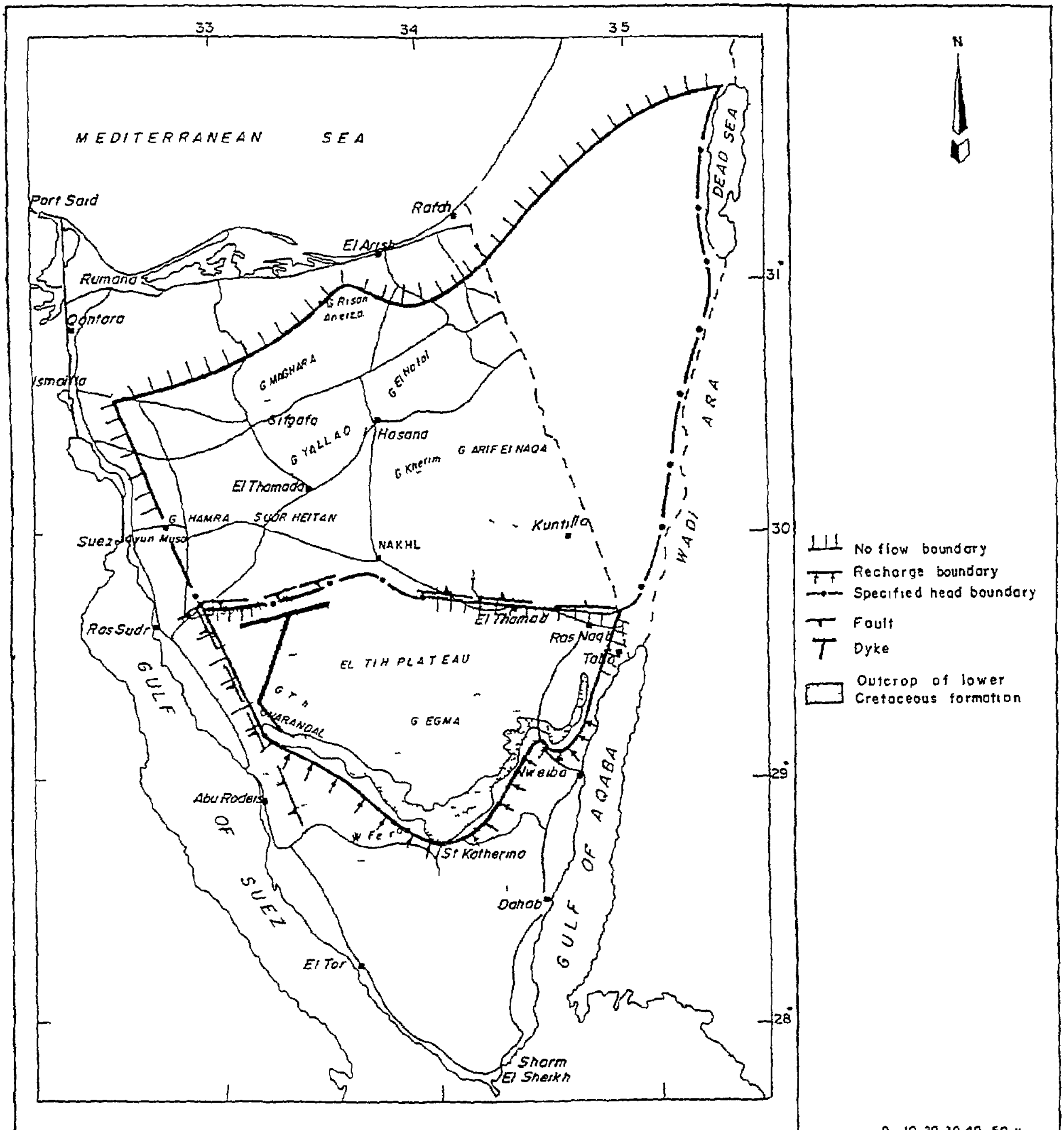

Figure (69) - Conceptual Model of The Lower Cretaceous Aquifer System in Sinai