JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

WATER RESOURCES RESEARCH INSTITUTE
NATIONAL WATER RESEARCH CENTER
MINISTRY OF PUBLIC WORKS AND WATER RESOURCES
THE ARAB REPUBLIC OF EGYPT

SOUTH SINAI GROUNDWATER RESOURCES STUDY
IN
THE ARAB REPUBLIC OF EGYPT

EXECUTIVE SUMMARY

MARCH 1999

PACIFIC CONSULTANTS INTERNATIONAL, TOKYO
IN ASSOCIATION WITH
SANYU CONSULTANTS INC., TOKYO

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In this report, project costs are estimated based on March 1998 prices with an exchange rate of US$1.00 = Egyptian Pound (LE) 3.39 = Japanese Yen ¥ 128.69

PREFACE

In response to a request from the Government of the Arab Republic of Egypt, the Government of Japan decided to conduct a master plan study on the South Sinai Groundwater Resources Study and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA selected and dispatched a study team headed by Mr. Yasumasa YAMASAKI, Pacific Consultants International (PCI) and consist of PCI and Sanyu Consultants Inc., to Egypt five times between March 1996 and March 1999.

The team held discussions with the officials concerned of the Government of Egypt, and conducted field surveys at the study area. Upon returning to Japan, the team conducted further studies and prepared this final report.

I hope that this report will contribute to the promotion of the project and to the enhancement of friendly relationship between our two countries.

Finally, I wish to express my sincere appreciation to the officials concerned of the Government of the Arab Republic of Egypt for their close cooperation extended to the Study.

March 1999

Kimio FUJITA
President
Japan International Cooperation Agency

SOUTH SINAI GROUNDWATER RESOURCES STUDY
IN
THE ARAB REPUBLIC OF EGYPT

March 1999

Mr. Kimio Fujita
President
Japan International Cooperation Agency

LETTER OF TRANSMITTAL

Dear Sir,

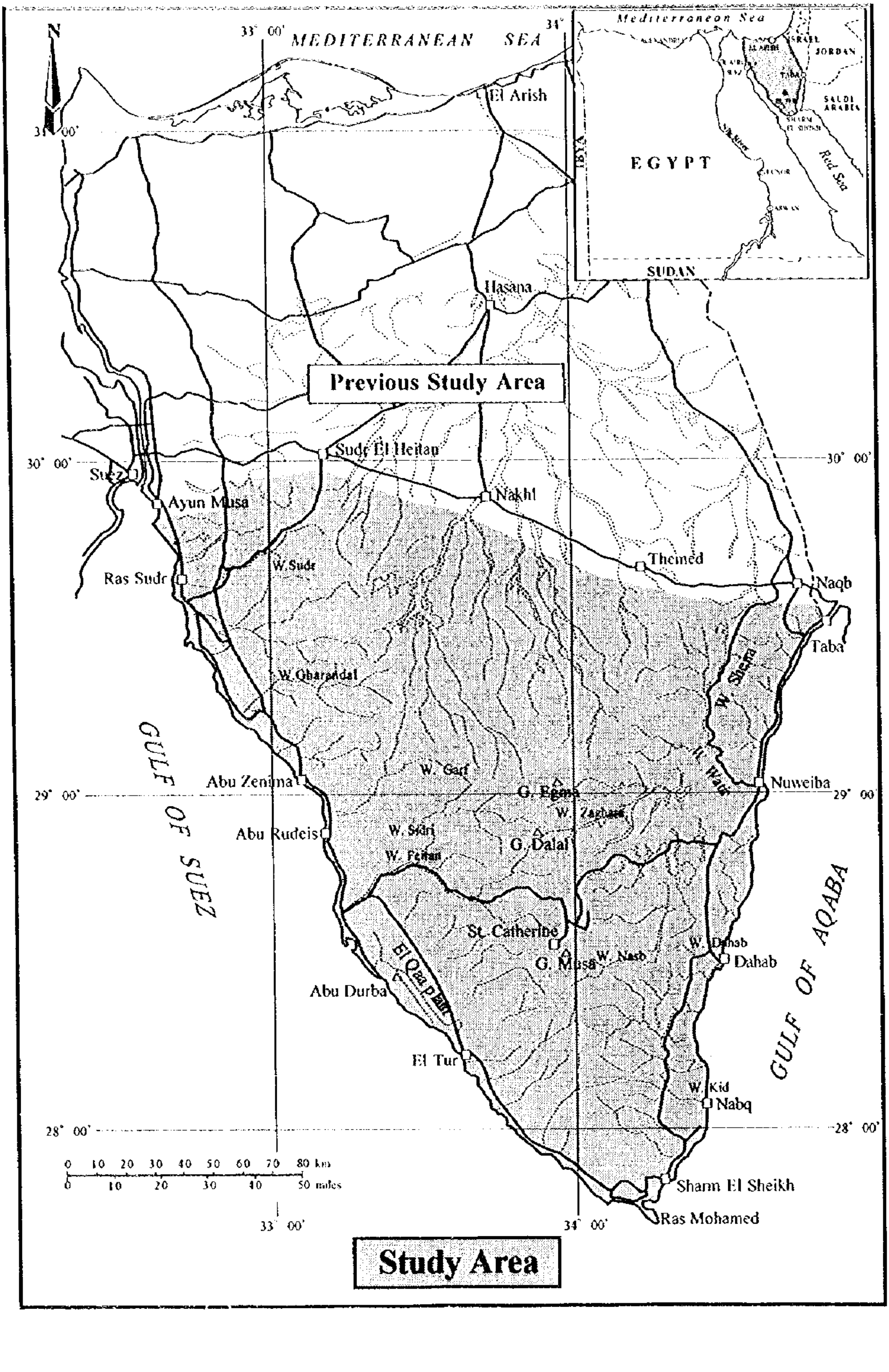
We are pleased to submit the final report entitled "SOUTH SINAI GROUNDWATER RESOURCES STUDY ". The Study Team has prepared this report in accordance with the contract between Japan International Cooperation Agency and Pacific Consultants International in association with Sanyu Consultants Inc.

This report presents the results of the evaluation of the groundwater resources development potential and the groundwater development plan. In addition, a set of hydrogeological map and groundwater resources evaluation map of whole Sinai Peninsula were prepared as "Water Resources Maps" and submitted herewith.

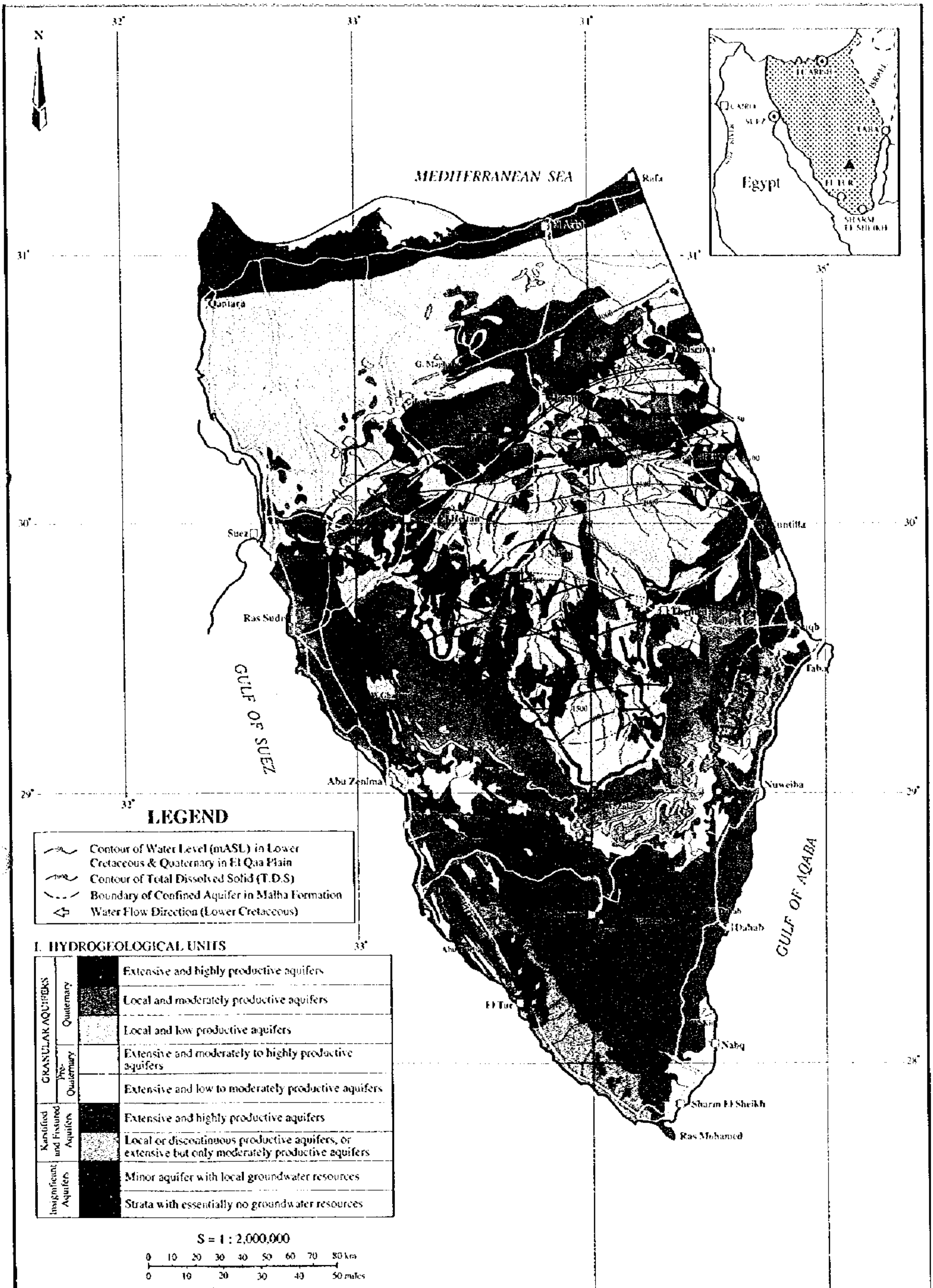
All members of the Study Team wish to express grateful acknowledgments to the personnel of your Agency, Ministry of Foreign Affairs, and Embassy of Japan in Egypt, and also to officials and individuals of the Government of Egypt for their assistance extended to the Study Team. The Study Team sincerely hopes that the results of the study will contribute to the implementation of NPDS (National Plan for Development of Sinai) and other relevant projects.

Yours faithfully,

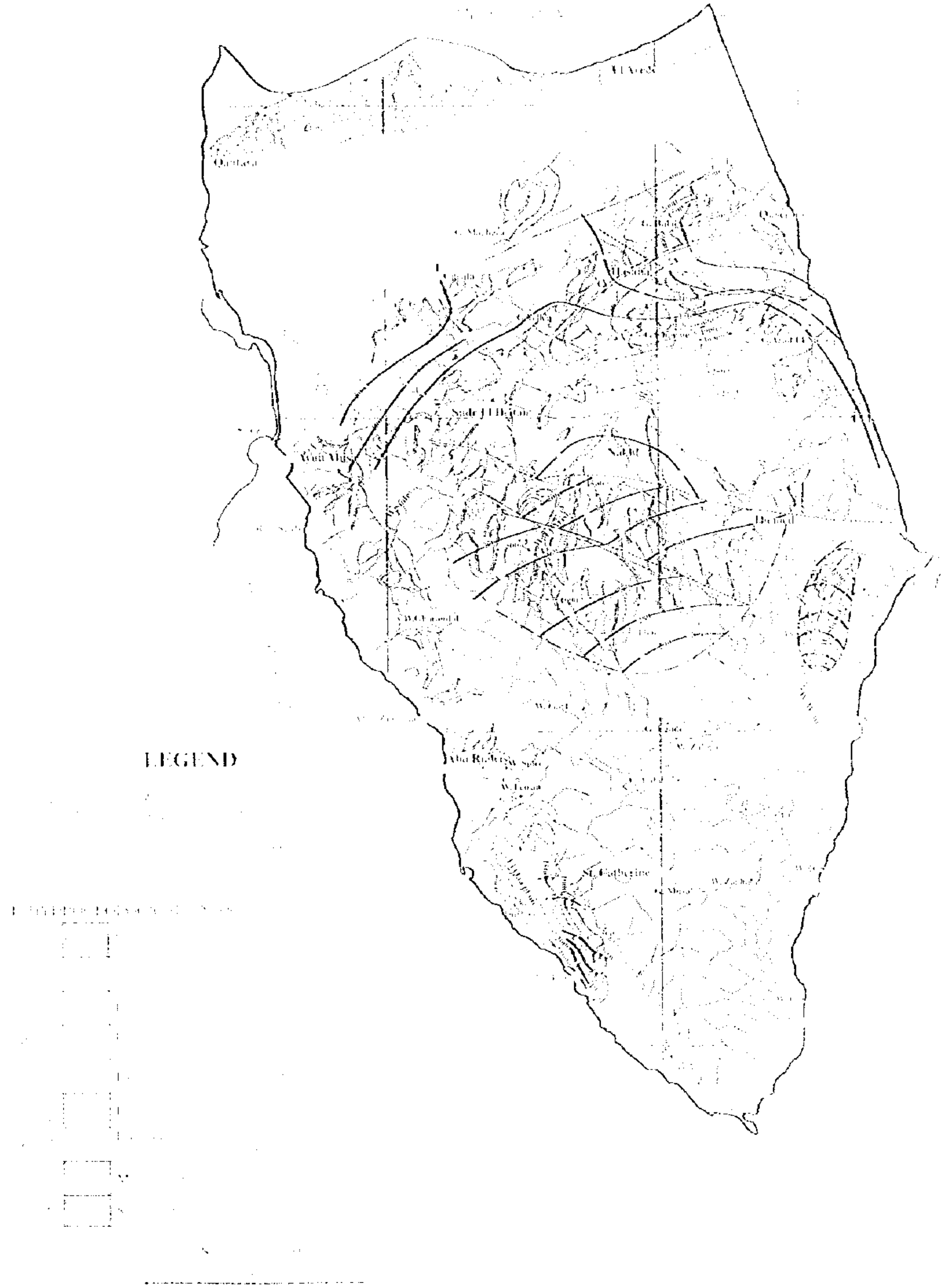
Yasumasa YAMASAKI
Team Leader
South Sinai Groundwater Resources Study
in The Arab Republic of Egypt



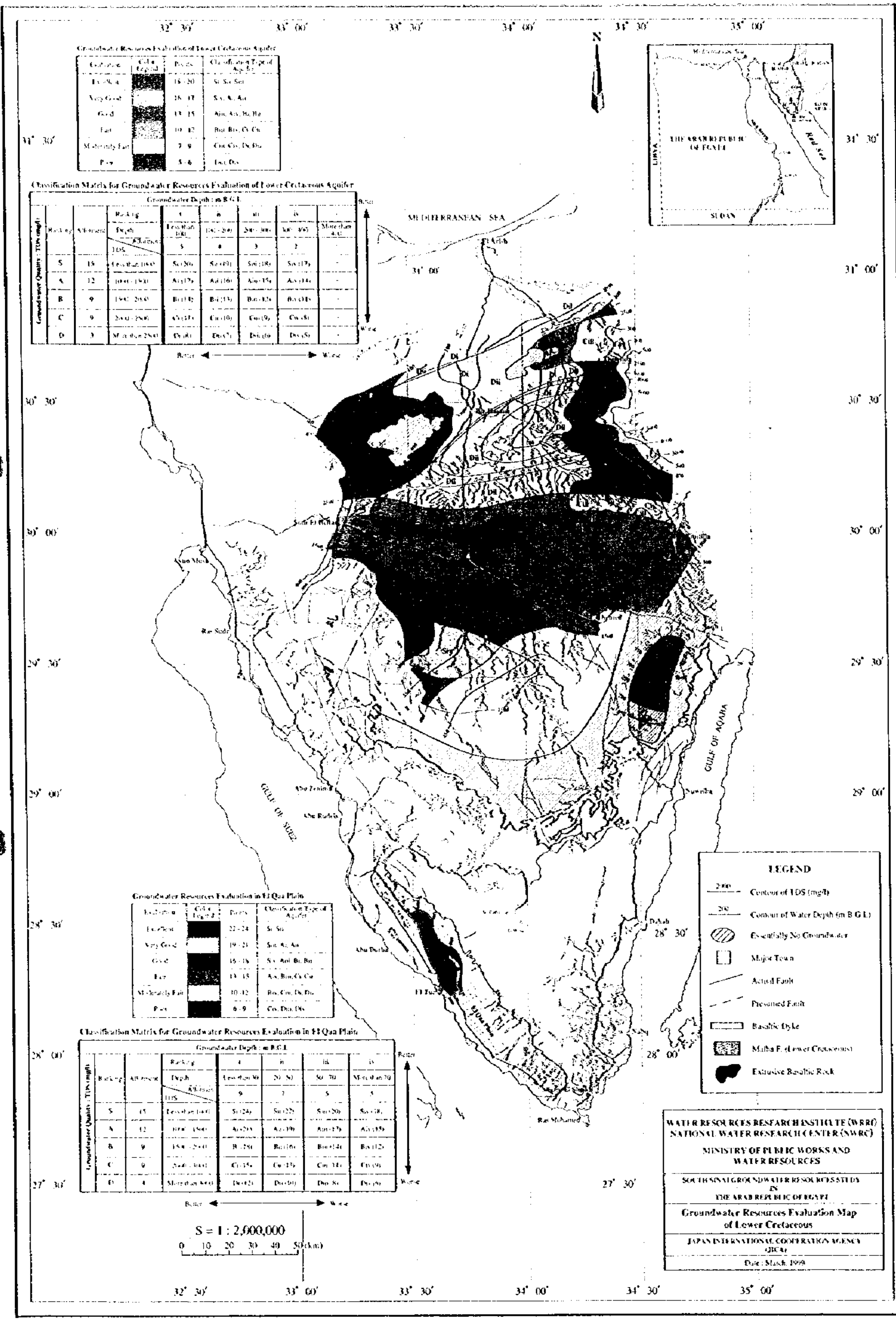
N
MEDITERRANEAN SEA
33° 00'
34°
31° 00'
El Arish
Hasana
Previous Study Area
Sudr El Heitan
30° 00'
Suez
Ayun Musa
Nakhl
Themed
Naqb
Taba
W. Sudr
Ras Sudr
W. Gharandal
W. Sheira
GULF OF SUEZ
W. Garf
Abu Zenima
29° 00'
G. Egma
Nuweiba
W. Zaghara
Abu Rudeis
W. Sidri
G. Dalal
W. Feiran
GULF OF AQABA
St. Catherine
W. Dahab
Dahab
G. Musa
W. Nasb
El Qaa plain
Abu Durba
El Tur
W. Kid
Nabq
28° 00'
0 10 20 30 40 50 60 70 80 km
0 10 20 30 40 50 miles
Sharm El Sheikh
Ras Mohamed
34° 00'
Study Area
Mediterranean Sea
ISRAEL
JORDAN
SAUDI ARABIA
EGYPT
Red Sea
SUDAN

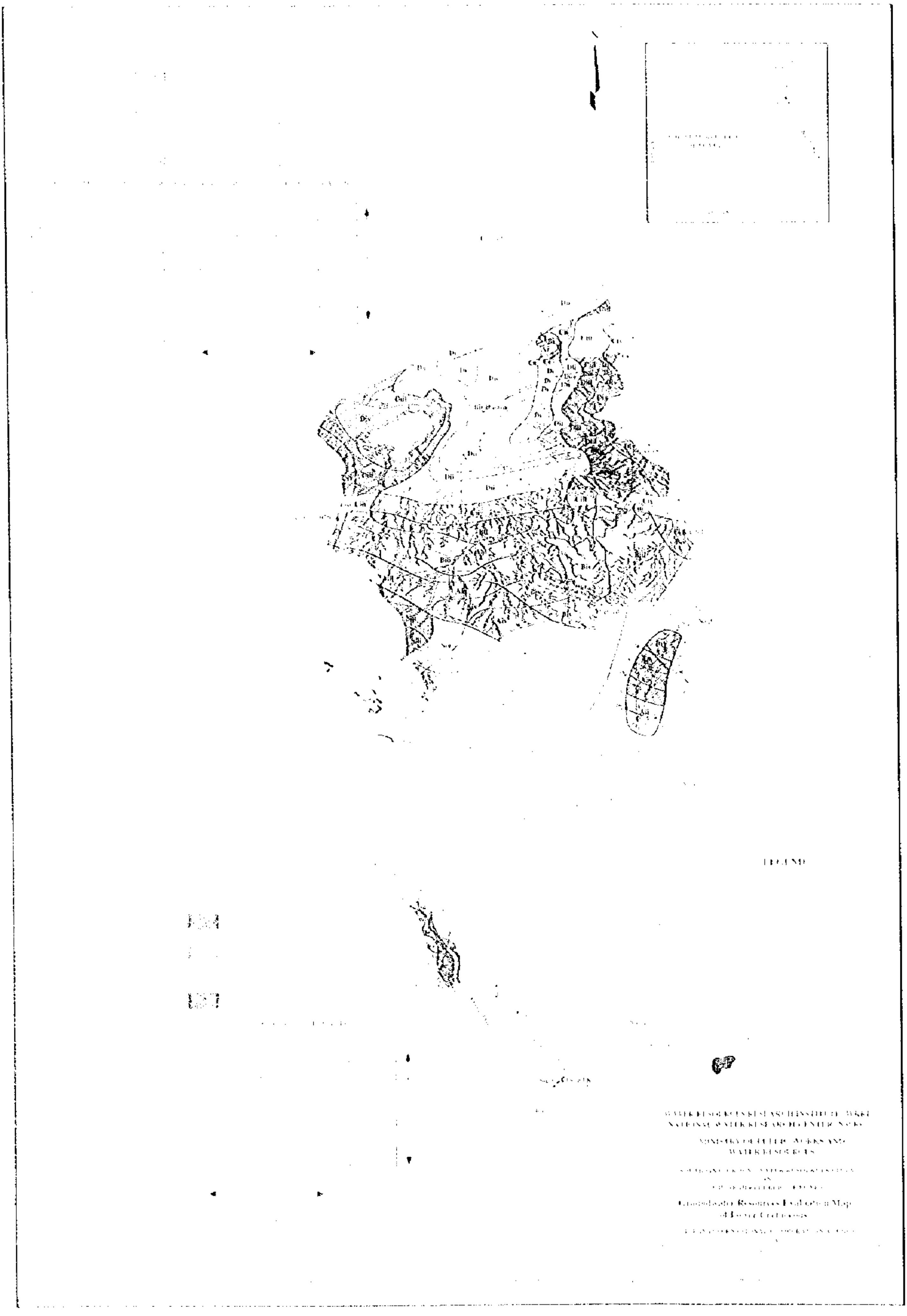


Hydrogeological Map of Sinai Peninsula



Hydrogeological Map of Sinai Peninsula


Groundwater Resources Evaluation of Lower Cretaceous Aquifer
Classification Matrix for Groundwater Resources Evaluation of Lower Cretaceous Aquifer
Groundwater Depth : m B.G.L
Better
Worse
MEDITERRANEAN SEA
THE ARAB REPUBLIC OF EGYPT
LIBYA
SUDAN
Red Sea
GULF OF SUEZ
GULF OF AQABA
Abu Zenima
Abu Rudeis
Abu Durba
El Tur
Ras Sudr
Ras Mohamed
Nuweiba
Dahab
Groundwater Resources Evaluation in El Qaa Plain
Classification Matrix for Groundwater Resources Evaluation in El Qaa Plain
LEGEND
Contour of TDS (mg/l)
Contour of Water Depth (m B.G.L)
Essentially No Groundwater
Major Town
Actual Fault
Presumed Fault
Basaltic Dyke
Malha F. (Lower Cretaceous)
Extrusive Basaltic Rock
S = 1 : 2,000,000
0 10 20 30 40 50 (km)
WATER RESOURCES RESEARCH INSTITUTE (WRRI)
NATIONAL WATER RESEARCH CENTER (NWRC)
MINISTRY OF PUBLIC WORKS AND WATER RESOURCES
SOUTH SINAI GROUNDWATER RESOURCES STUDY IN THE ARAB REPUBLIC OF EGYPT
Groundwater Resources Evaluation Map of Lower Cretaceous
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)
Date : March, 1999


LEGEND
WATER RESOURCES RESEARCH INSTITUTE (WRRI)
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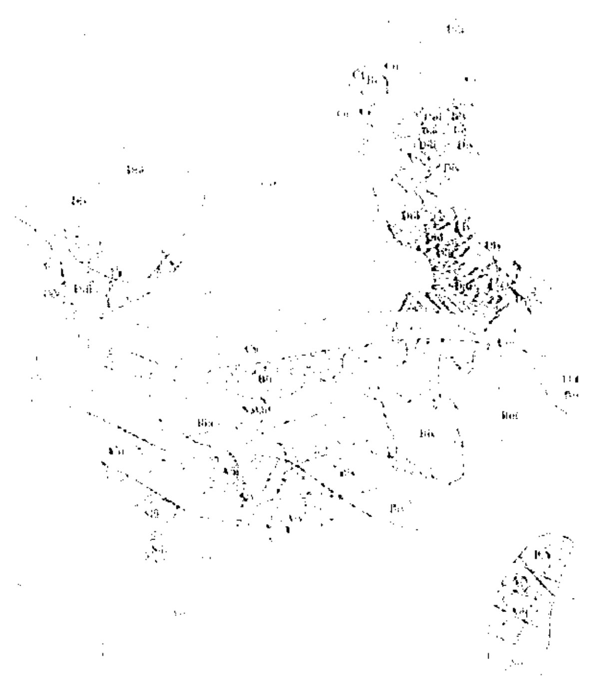
MINISTRY OF PUBLIC WORKS AND
WATER RESOURCES
Groundwater Resources Evaluation Map

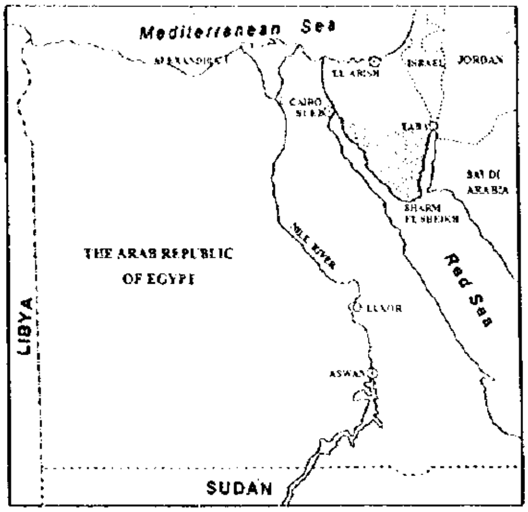


OUTLINE

Background of Study

Egypt is mainly covered by desert and only 4 % of its land is arable, mainly the alluvial plain of the Nile and its delta. In order to cope with the rapid population increase and urbanization, moreover, the controlled international water right of the Nile, the government of Egypt has been pressed into the development of the Sinai Peninsula based on the "National Plan for Development of Sinai" (NPDS) from 1994 to 2017.

There are three alternatives of water sources for Sinai Development, namely, (1) Nile water transmission, (2) Groundwater development and (3) Desalination of seawater. The second one has so much unknown information that it is indispensable to evaluate the potential of groundwater resources for the development of the Sinai Peninsula.



< Location map of Study Area >

The potential of groundwater resources in the Northern part of Sinai was estimated within the "North Sinai Groundwater Resources Study" conducted by Japan International Cooperation Agency (JICA) in the period between 1988 and 1992. However, the potential of groundwater resources in South Sinai has not been evaluated because the available data were limited.

Under these circumstances, the Government of the Arab Republic of Egypt requested the Government of Japan to conduct a water resources development study for South Sinai.

Study Area

The study area covers the South Sinai Governorate (approximately 34,000 km^2) as shown in the opening page (location map of Study Area).

Objectives of Study

The main objectives of the Study are listed as follows;

(1) To prepare a series of water resources maps to evaluate groundwater potential in South Sinai.

(2) To formulate water resources development master plan in South Sinai.

(3) To perform the technology transfer to Egyptian counterpart personnel in the courses of the Study.

(4) To up-date the hydrogeological map of North Sinai basically based on the data prepared by WRRI (Water Resources Research Institute).

Conclusion

(1) Through the Study, Hydrogeological Map and Groundwater Evaluation Map has been prepared covering the both South Sinai and North Sinai. (Refer to frontispieces and printed maps) These investigations included the following:

a) Revision of the Geological map for South Sinai.

b) Preparing a complete inventory for all the existing wells in the study area.

c) Conducting geophysical surveys, which resulted in the preparation of geoelectric, profiles for Egma and El Tih Plateaux, El Qaa Plain and Major wadi areas, and the delineation of the basement of the Lower Cretaceous in the Central Sinai zone.

d) A total of 6351m of test wells were drilled concentrating mainly in the El Tih and Egma plateau where no test wells had been drilled before. The well drilling program included observation of stratigraphy, pumping tests, water quality analysis, age dating analysis, grain size analysis and fossil analysis.

The compilation of the above mentioned two maps is the main and most important output of this Study because they serve as the basis for any future groundwater development and insure efficient use of investment in this field.

(2) The study concluded that the groundwater volume in the Main Block of the Lower Cretaceous aquifer is about 100 billion cubic meters of good quality water (TDS less than 1500 mg/l, drinking water quality). Hydrogeological analysis and age dating analysis revealed that this water is non-renewable fossil water. Estimating that about 14% of this stored water could be tapped for consumption, the available resources could meet the water demand level of the target year of NPDS of about 50×10^6 m^3/year for more than 280 years.

(3) Due to the importance of the aquifer in the El Qaa Plain because it is the main water resource for the South Sinai Capital of El Tur City, detail investigation of that aquifer

was made including computer simulation. The results of the study revealed that due to the limited recharge of that aquifer, it could meet the water demand level of El Tur City in 2007 without serious saline water intrusion. Water demand beyond that level should be met through as water resources such as Nile water or desalination of seawater.

(4) A water development scheme based on the water demand of the NPDS is proposed. Preliminary investigation of the feasibility of the proposed projects has been conducted. Although the results of the feasibility show that the EIRRs for the proposed projects are relatively low, this does not mean that the proposed projects should be discarded. In arid zones such as Sinai, the availability of groundwater resources could be one of the most important factors for the execution of the projects. Since the Study concluded that groundwater development potential of the Quaternary aquifer in El Qaa Plain and the Lower Cretaceous aquifer could meet the water demand of NPDS, the proposed projects are worth to execute as basic infrastructure for NPDS.

(5) An Initial Environmental Examination was conducted for the proposed projects which revealed that the implementation of the proposed projects will not seriously affect the environment and thus an Environment Impact Assessment is not required.

(6) Existence of a new groundwater aquifer has been confirmed at the southern reaches of El Qaa Plain.

Recommendations

(1) New groundwater aquifer was confirmed in the south El Qaa Plain. However, its distribution and hydrogeological features shall be studied in detail.

(2) Detailed feasibility study including the assessment of the water supply impact on the NPDS should be started as soon as possible. Such study should cover both groundwater and surface as well. The study should include the establishment of groundwater monitoring system to avoid excessive extraction. The study for wastewater treatment and disposal should be also included in the schemes.

(3) The availability of good quality groundwater at Central Sinai should encourage the settlement of Bedouin in that area. This in return will have a very positive impact on the living standards of these people. More comprehensive plans should be prepared for the Bedouin settlement in central Sinai.

(4) Number of production well is increasing in both South and North Sinai. They are tapping groundwater in the Lower Cretaceous Aquifer. Groundwater in the Lower Cretaceous Aquifer is essentially of fossil water although a little recharge is expected

from the surface water. Groundwater development of the Lower Cretaceous Aquifer will lead recession of groundwater level. Considering this situation, groundwater development in Sinai shall be carried out under proper control system. Especially, careful attention shall be paid to the change of groundwater level in the development. From this point of view, groundwater level monitoring shall be properly continued using automatic water gauges installed in the Test Wells.

SUMMARY

1. INTRODUCTION

1-1 Background of Study

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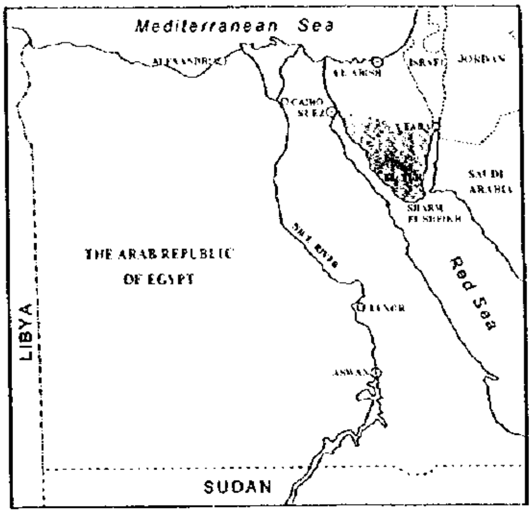

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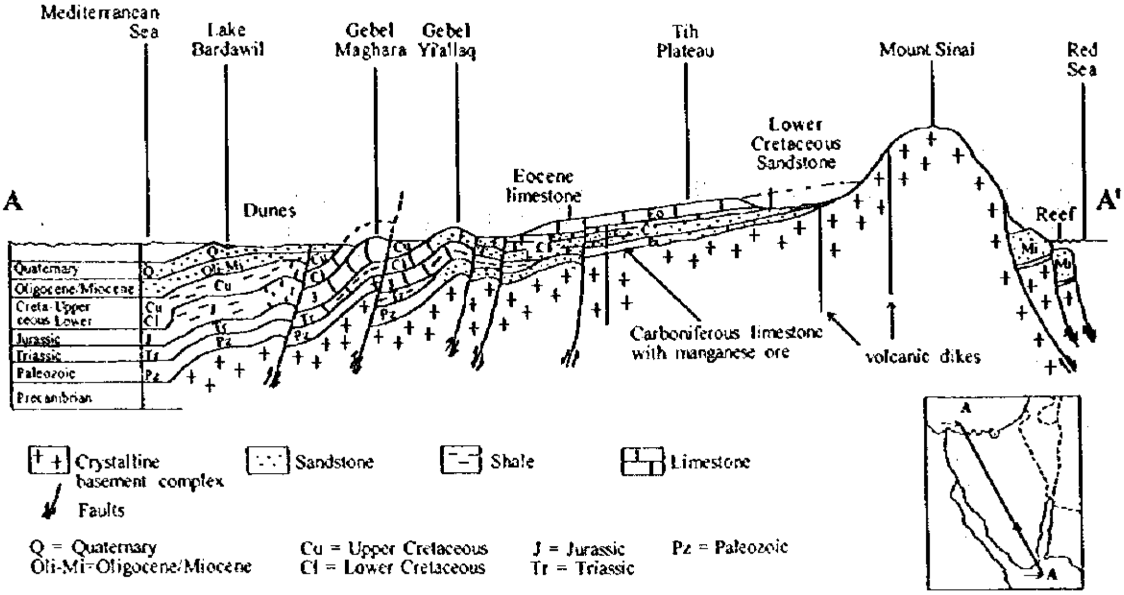
2. GENERAL DESCRIPTION OF SOUTH SINAI

2-1 Geomorphology

Geomorphology in South Sinai is divided into eight (8) kinds of topography: (1) Sinai Plateau, (2) El Tih Plateau, (3) Egma Plateau, (4) Sedimentary Hills, (5) Basement Hills, (6) Flat Plain, (7) Alluvial Fan (including El Qaa Plain) and (8) Terrace. The highest peak rises on the Gebel Catherine at 2,641m ASL.

2-2 Geology

Geology in South Sinai is classified as (1) Precambrian Basement Rocks, (2) Paleozoic Formations, (3) Mesozoic Formations and (4) Quaternary Formations. The Mesozoic Formations include the Lower Cretaceous Formation and the Upper Cretaceous Formations. General situation of geology in the Sinai Peninsular is shown in geological cross section (north to south) below.



< Geological Cross section of Sinai Peninsula >

(Rosel und Wolfgang Jahn (1997): Sinai and the Red Sea)

2-3 Climate and Hydrology

(1) Climate

The climate of the Sinai Peninsula is characterized by desert areas. Outline of it in the Study area is listed as following table by monthly average parameters at Nakhl, St. Catherine, Sharm El Sheikh and Nuweiba. It includes extreme aridity, long hot rainless summer months and mild winter. During the winter months some areas of Sinai experience brief but high intensity of rainfall that makes wadi beds to overflow and sometimes causes severe flush floods which damage the roadways and human lives.

(2) Hydrology

1) Hydrological condition

There is no natural stream in Sinai. The only source of fresh water is rainfall in the wet season. The hydrology is governed by the surface water flow through the wadis due to the rainfall depth, duration and intensities.

<Outline of Climate in South Sinai>

	Temperature (°C)		Humidity (%)		Evaporation (mm/day)		Wind Speed (m/sec)		Sunshine (hr/day)	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Nakhl	9.6	30.9	37	71	-	-	2.9	4.4	-	-
	Jan.	Aug.	Jun.	Feb.	-	-	Jul.	Dec.	-	-
St. Catherine	9.5	24.9	26	45	5.9	17.7	3.6	5.4	-	-
	Jan.	Jun.	Apr.	Feb.	Dec.	Jul.	Dec.	Feb.	-	-
Sharm El Sheikh	-	-	-	-	11.6	25.8	-	-	-	-
	-	-	-	-	Jan.	Jul.	-	-	-	-
Nuweiba	-	-	-	-	-	-	-	-	7.5	12.4
	-	-	-	-	-	-	-	-	Jan.	Jun.Jul.

2) Analysis of rainfall

The highest daily and annual rainfall was found as 76.2 and 123.2 mm in St. Catherine in 1937. In the recent years daily rainfall varies from 10 to 35mm and annual average varies between 7 to 33mm. Annual average rainy days (of more than 5mm) are very few, varies 1 to 3 days only. The intensity is very high and duration is very short.

3) Drainage catchments

The study area is divided into 40 drainage catchments (16 in eastern block and 24 in western block). Total area is 29,162 km^2. including El Arish catchment.

4) Major and active wadis

Although there are 40 wadis in the area, a few of them are active. They are W. Watir, W. Feiran, W. Sudr, W. Gharandal, W. Sidri, W. Dahab, W. Garf, W. Kid etc. In floods, they cause damages to the road communication systems and sometime to the human lives.

5) Surface runoff

Main wadis experience flood once in two years. Surface runoff has been calculated using existing study results. The average annual surface runoff from the eastern and western blocks was estimated as $52.92 \times 10^6 m^3$/year and about $9.5 \times 10^6 m^3$/year, from the

W. El Arish totaling $62.42 \times 10^6 m^3$/year. This amount is equal to the 14% of the annual rainfall.

6) Calculation of recharge amount

Amount of recharge was calculated subtracting the assumed evaporation loss and surface runoff from the total amount of rainfall. According to the calculated highest ratio of recharge amount was found in El Arish catchment, which is about 67% of rainfall followed by the western and eastern blocks, 57 and 31% respectively. In the whole study area, the average annual shares of recharge, loss and runoff are 253 $\times 10^6 m^3$/year, 146 $\times 10^6 m^3$/year and 62 $\times 10^6 m^3$/year, respectively.

2.4 Socio-economic Condition and Prospect

The following socio-economic items are summarized on the basis of the latest information and data collected in the Study.

< Socio-Economic Condition >

Population	Area	Population	Average Growth Rate
1996 Census	Egypt	59,9,272,392	2.1% (86-96)
	South Sinai	54,495	6.5% (86-96)
2017 (NPDS)	South Sinai	676,600	13.1% (1994-2017)
National Economy	Item	Amount	Real Growth Rate
1996 (Actual)	GDP	LE 225 Billion	4.9% (1994/95-1995/96)
	GDP per Capita	LE 3,840 (US$1,130)	2.8% (1994/95-1995/96)
2002 (Prospect)	GDP	LE 335 Billion (1998 constant)	6.9% (1997/98-2001/02)
	GDP per Capita	LE 5,000 (US$1,470)	4.8% (1997/98-2001/02)
Inflation	Consumer Price	2.1% (Annual)	Nov. 1996 – Nov. 1997
	Wholesale Price	3.3% (Annual)	Sept. 1996 – Sept. 1997
Foreign Trade	Export	LE 12 Billion	Oil, Cotton, Fruits, Garment, etc.
1996	Import	LE 44 Billion	Foods, Machines, Chemicals, etc.
	Balance	LE –32 Billion	
Major Items of	Oil & Its Products	LE 5 Billion	37% of Export
Foreign Currency	Suez Canal Dues	LE 6 Billion	20% of Service Export
Earning	Tourism	LE 10 Billion	32% of Service Export
1996	Private Transfer	LE 9 Billion	75% of Transfer
	ODA (Grant)	LE 3 Billion	25% of Transfer
Public Finance	Revenue	LE 61 Billion	Tax Revenue: 38 Billion (63%)
1995/96	Expenditure	LE 64 Billion	28% of GDP
	Balance	LE -3 Billion	1.3% of GDP
Household Economy	Area	Annual Expenditure	Housing & Utility Expenditure
1995/96 Survey	Egypt	LE 6,660	LE 660
	Sinai	LE 5,850	LE 850

2.5 Present Condition of Environment

South Sinai has a desert climate and its vegetation is scarece under the climate. Grass grows up temporally after rain along many wadis and gullies. 480 species of flora in all including pteridophyta, gymnospermae and anigiospermae are recorded and 389 of them are rare species.

- Mammal: 34 species of Mammal fauna in South Sinai which include *Caracal, Leopard, Ibex* and *Dorcus gazelle* are recorded as endangered species.
- Bird: There are 264 species of birds and approximately 50 species of them breed in South Sinai.
- Reptile: total 45 species of Herpetofauna are recorded in South Sinai and 14 of them are restricted to Sinai in their distribution in Egypt.
- Fish: Total 180 fish species are recorded in the Gulf of Aqaba and 95% of them can be seen around Ras Mohamed area.
- Coral: 56 Coral Species are found in the three (3) sites, namely, Ras Mohamed, Nabq and Abu Galum.
- Mangrove: There are five (5) mangrove areas in South Sinai: one is in Ras Mohamed protected area and others are in Nabq protected area.

Five (5) protected areas out of 16 in Egypt have been designated in South Sinai as follows.

- Ras Mohamed National Park
- Saint Catherine Protectorate
- Nabq Managed Resource
- Abu Galum Resource
- Taba Protectorate

3. HYDROGEOLOGY

Main aquifers in the Study Area are occurred in the Quaternary Formations, the Upper Cretaceous Formations and the Lower Cretaceous Formation. Among them, the most prospective aquifer is the Lower Cretaceous Aquifer, which distributes in Egma and El Tih Plateau The Precambrian Basement Rocks acts as a conduit of groundwater to other aquifers.

Through the Study, Hydrogeological Map and Groundwater Evaluation Map has prepared covering the both South Sinai and North Sinai. Their maps on scale of 1: 2,000,000 are shown in frontispieces.

3-1 Well Inventory

Well Inventories and Location Maps were constructed covering most of water sources in 16 areas in South Sinai, which include deep wells, dug wells and springs. A total of 454 water points were listed: 157 cased wells, 256 dug wells and 41 springs.

3-2 Quaternary Aquifer

The Quaternary aquifers in South Sinai are distributed in El Qaa Plain, coastal plains and major wadis.

1) El Qaa Plain

There are three (3) aquifers in El Qaa Plain. The first aquifer is unconfined and the second one is considered to be unconfined to semi-confined. The third aquifer is leaky confined.

The first aquifer is only distributed around El Tur, which is exploited by dug wells for irrigation in the area. The water table contour map of the aquifer indicates a possibility that the aquifer may be a part of the second aquifer.

Most of the boreholes in El Qaa Plain were drilled to the second aquifer. The aquifer has been developed mainly for irrigation and domestic supply for El Tur in the northern part of El Qaa Plain.

In the third aquifer, there are some observation boreholes and few production wells reaching the aquifer.

TDS is in a range between approximately 450 and 10,000 mg/l in the whole area and less than 500 mg/l in the present well filed for domestic water supply to El Tur.

In the southern part of El Qaa Plain, the basement is expected to occur at the shallow depth. However, one JICA test well (J-7) could confirm the possibility of another aquifer in the downstream of Wadi Thiman.

The bottom contour and the isopach map of the second aquifer indicate that there are actually two groundwater basins in the area. One is in the area northwest of Gebel Safariat and another is in the lower area of Wadi Mir and Wadi Shadk, which is located in El Tur. The result of water quality analysis suggests that the northern part of the aquifer is mainly recharged from the Sedimentary Rocks in the northern mountains and the southern part of the aquifer is recharged from the Precambrian Basement. Their hydrogeological data is shown the below table.

<Hydrogeological Data on Quaternary Aquifer in El Qaa Plain>

	Yield (m^3/h)	Specific Capacity (liters/sec/m)	Transmissivity (m^2/day)	Hydraulic Conductivity (m/day)
Northern part of the Second aquifer	56.7	2.64	768	23.9
Southern part of the Second aquifer	67.2	4.36	989	25.5
The third aquifer	34.6	0.54	85	2.0

2) Coastal Plains

Coastal plains are formed in Ras Sudr and Nuweiba. In both areas, groundwater has been extracted for domestic and irrigation uses.

(1) Ras Sudr Coastal Plain

Groundwater is extracted by 35 dug wells for private sector. The well field distributes in front of the outlet of the Wadi Sudr. The shape of the well field is like an oval elongated in N-S direction.

Static water level in this area is generally less than 4 mASL and its TDS is in a range between 2,450 and 7,624 mg/l. All TDS values are over the drinking water standard. Contour line of static water level and TDS show that groundwater flows into the coastal plain from the Wadi Sudr.

(2) Nuweiba Coastal Plain

Nuweiba Coastal Plain is formed in the outlets of the Wadi Watir and other small wadis. The plain is composed of three Fan Deposits derived from each wadi. There are Nuweiba City and agricultural farm.

Groundwater is extracted by 30 wells, consisting of 25 dug wells and five(5) cased wells. Cased wells are constructed in the fanhead, while dug wells are located at the foots of the Fans.

Static water level, water quality and groundwater extraction rate are classified into the four (4) groups depending on the locations as shown below.

< Characteristics of Wells in Nuweiba Coastal Plain >

Well Group	SWL (mBGL)	TDS (mg/l)	Extraction (m^3/day/well)
Cased Well (Fantop of Fan I)	28.5 - 40.15	1,783 – 9,470	2,500*
Dug Well (Northern Fanfoot of Fan I)	6.68 - 14.4	1,639 – 3,961	20 - 80
Dug Well (Southern Fanfoot of Fan I)	7.4 - 11.95	2,741 – 8,823	10 - 80
Dug Well (Fanfoot of Fan IIIa)	2.5 - 10.24	2,788 – 11,790	1 - 20

* : total extraction of cased wells

At all the wells, TDS is over the drinking water standard. Total extraction rate from groundwater is approximately 3,200 m^3/day.

3) Major Wadis

Groundwater has been used in many wadis by Bedouin people for domestic and irrigation. It is exploited by dug wells through the Quaternary Wadi Deposits, which consist of sand and gravel. Most of the Wadi Deposits are underlain and surrounded by the Precambrian Basement rocks except the Wadis El Garf, Babaa, Gharandal and, the upstream of the Wadi El Arish and Wadi Watir.

Thickness of wadi deposits, static water level and TDS in major wadis are listed below. Most wells are dug wells in the Wadi area, therefore, static water level is within 16 mBGL.

TDS is relatively low in the Wadi Feiran area including St. Catherine, the Wadi Zaghara and the upstream of the Wadi Kid where it is less than 1,000 mg/l. These areas are distributed in the Precambrian Basement Rocks area. High TDS values appear in the area where sedimentary rocks are distributed.

< Characteristics of Major Wadis >

Area	Thickness of Wadi Deposits (m)	SWL (mBGL)		TDS (mg/l)	
		Range	Average	Range	Average
Wadi Feiran					
-Tarfa	70 - 170	10.87 – 41.91	15.96	257 - 796	573
-Oasis Feiran	15 - 100	11.70 – 26.00	15.36	384 - 707	574
St. Catherine	-				
-(shallow well)	-	2.40 – 14.40	7.67	160 - 676	430
-(deep well)	-	29.70- 48.80	38.14	337 - 575	456
Wadi El Garf	-	7.52 – 14.90	11.89	788 - 3117	2,032
Wadi Babaa	-	5.88 – 11.41	8.52	1,549 - 1,805	1,685
Wadi Gharandal	10 - 50	13.00 – 31.49	20.45	834 - 2,944	1,625
Upstream of Wadi El Arish	-	4.97 – 11.15	8.06	3,150 - 3250	3,200
Taba area	20 - 80	24.50 – 32.43	28.47	2,131 - 2,800	7,579
Wadi Watir					
-Sheikh Attia	20 - 60	4.30 – 14.30	9.43	640 - 1,802	1,021
-Wadi El Hathy	80 - 100	12.75 – 43.89	21.32	1,100 - 1,969	1,535
Wadi Zalaga	20 - 160	2.82 – 10.20	5.81	1,241 - 2,234	1,735
Wadi Saal	About 10	2.60 – 10.12	6.86	138 - 3,782	1,341
Wadi Zaghara	20 - 160	2.00 – 11.67	5.01	609 - 900	725
Wadi Dahab	80 - 240	28.00 – 35.00	32.38	2,500 - 3,000	2,750
Wadi Kid	About 70				
-upstream		3.60 – 7.16	5.38	337	-
-downstream		50.29	-	-	-

3-3 Upper Cretaceous Aquifer

Limestone in the Turonian (Wata Formation) is called as "fissured limestone" and it has been considered as the main aquifer in the Upper Cretaceous. On the other hand, many dug wells are tapping groundwater from the Sudr Formation (Senonian) at El Malha area.

1) Aquifer Condition

Test Wells were drilled at the six (6) sites. (see Fig.S-1) Aquifer test by airlifting was carried out in the section of the Upper Cretaceous to examine the hydrogeological condition of it. The results are shown below.

< Hydrogeological Condition of Upper Cretaceous Aquifer >

Well	Tested Section (mBGL)	Aquifer	SWL (mBGL)	SWL (mASL)	Q_{max} (m^3/hour)	TDS (mg/l)
J-1	402-500	Turonian	71.08	449	5.5	2,790
J-2	620-650	Turonian	dry	-	-	-
J-3	382-420	Turonian	-3.8*	548	40.0	2,170
J-4	380-450	Coniacian -Turonian	dry	-	-	-
J-5	-	Cenomanian -Albian	dry	-	-	-
J-6	220-260	Turonian	115.08	595	11.0	2,670

*: Automatically flown out.

2) Groundwater Level

The Upper Cretaceous Aquifers are classified into confined one and unconfined one. The former is represented by the Turonian aquifer and the latter is the Senonian aquifer outcropping out in El Malha.

Groundwater level of the Upper Cretaceous is shown in table below.

< Groundwater Level of Upper Cretaceous Aquifer >

Well	Elevation (mASL)	SWL (mBGL)	SWL (mASL)
J-1	520	71.08	449
J-3	544	-3.80	548
J-6	710	115.08	595
El Malha 2	640	14.50	625
Gharandal 2	290	120.70	169
Dug wells in Malha	620-630	3.2 – 11.4	609-627

Artesian flow of groundwater was observed at J-3 during the aquifer test. It was the first time in the whole Sinai that this phenomenon was confirmed.

3) Groundwater Quality

TDS value ranges from 1,572 mg/l to 12,930 mg/l. In general, it exceeds the limit value of the Drinking Water Standard.

4) Hydrogeological Characteristics of Aquifer

In the Egma and El Tih Plateau, noteworthy geological structures are recognized from the hydrogeological point of view. These structures are faults and dykes. 26 groundwater points were confirmed in the Upper Cretaceous Aquifers. Except dug wells in El Malha, other groundwater points are located near faults.

It is considered that groundwater in the Upper Cretaceous is mainly stored in fractures formed by faults. This is suggested by the fact that groundwater was not confirmed in the Upper Cretaceous Formations of J-2 and J-4, that were located far from faults.

Groundwater level in El Malha area decreases in dry season and quickly recovers after rainfall. This fact means that groundwater in the area is recharged by present surface water through fissures and fractures developed in the chalky limestone.

3-4 Lower Cretaceous Aquifer

The Lower Cretaceous Aquifer is divided into three (3) independent blocks and one (1) sub-block by area: (see Fig, S-2)

- Main Block: Main target of the study distributes in the central part of the study area (Egma and El Tih Plateaux).
- Sheira Block: Independent from other blocks in terms of hydrogeology, mainly distributes in the Wadi Sheira.
- Feiran Block: Independent from other blocks in terms of hydrogeology, mainly distributes in the downstream area of the Wadi Feiran.
- Gharandal Sub-Block: Connected with the Main Block in terms of hydrogeology with hindrance on groundwater flow by basaltic dykes, distributes in the upstream area of the Wadi Gharandal.

While the Sheira Block has been considered as a part of the Main Block, the study revealed that it is separated from the Main Block by uplifting of the Basement Rocks in NNE-SSW direction.

1) Aquifer Zone of Main Block

The aquifer of Main Block is divided into following three (3) zones based on the condition of groundwater (Fig. S-2).

- **Dry zone**: Zone with a width of 16 to 24 km from the southern fringe of the Main Block toward the north, where no groundwater is stored.
- **Unconfined zone**: Next zone to the dry zone, with 6 to 12km width, where

groundwater exists, but the aquifer is not saturated.

- **Confined zone**: Next to the unconfined zone, occupies the most of area of the Main Block.

2) Groundwater Flow

Groundwater in the Main Block gently flows toward the north in a speed of 0.5 to 2.5 cm/day and flow out to the same aquifer in North Sinai after crossing the Ragabet El-Naam Fault. Gradient of groundwater table is approximately 0.4/1000. It changes to more steep in a section between wells J-3 and J-1. It is supported that this is due to the interference of basaltic dykes intruded between two (2) wells in the E-W direction.

Groundwater in the Sheira Block gently flows to the south: Groundwater gradient is 1.5/1000. Groundwater seems to infiltrate to the Precambrian Rocks in the south.

3) Groundwater Level Monitoring

On the basis of the water level monitoring during this study, approximately 20cm/year of drawdown was recorded at J-3. It is very important to continue the monitoring and analyze together with other 4 monitoring stations.

4) Recharge Condition

The Lower Cretaceous Formation distributes higher elevation compared with that of the Wadi Deposits in the Wadi Zalaga and Wadi Garf which is supposed to be recharge area. Therefore, it is considered that the Main Block of the Lower Cretaceous Aquifer receive no recharge or scarce recharge from the surface water.

Groundwater in the Main Block and the Sheira Block are hydrogeologically independent from other blocks and receive no or scarce recharge from surface water at present. Therefore, groundwater development in the areas will cause recession of groundwater level.

Recharge condition was also studied by isotope analysis. The age of the groundwater in the lower Cretaceous aquifer ranges from 14,000± 2,000 Y.B.P to 27,000±2,000 Y.B.P (year before present). It tends to be older from south to north in the study area. It is recorded more than 30,000 Y.B.P in the north Sinai. It depends on groundwater movement.

Moreover, the age means that the recharge to the aquifer was mainly done by not prsent but the ancient precipitation in the Würm glacial stage. Scarce contents of Tritium in it also supported this matter.

Hydrogeological data of the Lower Cretaceous Aquifer at JICA test wells are listed in the following table.

< Hydrogeological Data of Lower Cretaceous Aquifer in South Sinai >

Well Name	S.W.L (mBGL)	D.W.L (mBGL)	Discharge Rate (m^3/h)	Specific Capacity (l/s/m)	Trans-missivity (m^2/day)	TDS (mg/l)
JICA 1	312.8	317.9	39.6	2.2	950.4	1,206
JICA 2	424.0	443.4	23.0	0.3	109.2	1,182
JICA 3	284.4	290.38	35.6	1.6	470.3	470
JICA 4	501.0	501.2	10.6	2.5	19.9	1,047
JICA 6	438.5	439.3	9.6	3.7	114.8	1,520

5) Water Quality of Lower Cretaceous Aquifer

Water quality of the Lower Cretaceous Aquifer is chiefly good to drink based on the water quality analysis of it including existing data. TDS of each block is summarized as follows.

< TDS of Lower Cretaceous Aquifer >

Location	Measured TDS Value (mg/l)			Remarks
	Lowest	Highest	Average	(Well Name)
Main Block (El Tih Plateau)	470	1,520	997	JICA-1 to 6
Gharandal Sub-Block	-	-	1,822	Gharandal-1
Nakhl and Themed area	1,536	1,768	1,667	Nakhl-1 to 8
Sheira Block	1,080	1,562	1,173	Sheira-1, 3, 4
Feiran Block	784	840	812	Feiran-1, 2

TDS values satisfy the drinking water quality standard in the Main Block, the Sheira Block and the Feiran block. Although TDS don't satisfy the standard in other blocks, it is suitable for agricultural use.

3-5 Paleozoic Aquifer

The Paleozoic Formations are outcropped in the upstream area of Wadi Zalaga and Wadi Garf and completely overlain by the younger formation in Wadi Gharandal area. Then the Paleozoic Aquifer is recharged by rain and flood water in Wadi Zalaga and Garf. However, its TDS value is generally much higher than the Drinking Water Quality Standard, for example, 5,060 mg/l in Wadi Gharandal.

3-6 Precambrian Rocks

Some springs are occurred in the Precambrian Basement Rocks in the area such as St. Catherine, the Wadi Zalaga and the Wadi Watir areas.

< Springs in Precambrian Rocks >

Area	Name of Spring	TDS (mg/l)	Geological Situation
St. Catherine	El Rabba	160	Joints in granite
Wadi Watir	Ain Furtaga	1,088 – 1,368	Fissures in granite and contact zone with dorelite
Wadi Zaghara	Ain Umm Ahmed	5,123	Contact zone between granite and dorelite

The Precambrian Rocks are generally impermeable, however, groundwater infiltrates to the fissures, joints and faults formed in the Rocks and flows down reaching the Quaternary Wadi Deposits. Thus, the Precambrian rocks act as the sources of recharge and conduit of groundwater to the Quaternary Aquifers. Basically it is almost impossible to develop groundwater directly from the Basement Rocks by wells.

4. GROUNDWATER POTENTIAL AND EVALUATION

4-1 Quaternary Aquifer in El Qaa Plain

1) Existing Water Balance

The existing water balance in El Qaa Plain is calculated as follows.

Item	(10^6 m^3/y)
Recharge	5.9
Extraction	3.4
Discharge to the Sea	2.5
Balance	0.0

2) Groundwater Development Potential and Evaluation

Existing water balance means that the groundwater in El Qaa Plain is keeping balance between recharge and discharge amount and it suggests that there is no surplus amount of groundwater for further development in terms of sustainable development. However, it doesn't mean that there's no potentiality of development.

The Quaternary Aquifer in El Qaa Plain stores approximately 12.5 x 10^9 m^3 of groundwater.

The potential is confirmed by the computer simulation through the five case studies as follows.

< Condition of Groundwater Simulation for El Qaa Plain > Unit: $10^6 m^3/year$

Case	Recharge	Decrease of Storage	Total	Present Withdrawal	Increase of Withdrawal	Discharge to the Sea	Total
Present	5.90	0.00	5.90	3.44	0.00	2.47	5.91
Case 1	5.90	3.36	9.26	7.30	3.86	2.10	9.40
Case 2	5.90	2.01	7.92	5.48	2.04	2.34	7.81
Case 3	5.90	1.01	7.01	4.56	1.12	2.49	7.05
Case 4	5.90	0.36	6.26	3.65	0.21	2.62	6.27
Case 5	5.90	2.09	7.99	5.48	2.04	2.42	7.89

In Case1 to 5, groundwater for domestic water supply is planned to product in the prospective aquifer area. In Case5, plan of irrigation water is added to the Case2 for prevention of saline water intrusion to the prospective aquifer area from the north of the El Qaa Plain where saline water is widely distributed.

<Criteria for Water Balance Constraint>

Rank	Annual Residual Drawdown (m)	Description
A	0.00 - 0.02	Not surely safe, but allowable if there is no alternative plan
B	0.03 - 0.01	The aquifer storage will be possibly depleted in future
C	0.11 <	The aquifer storage will be probably depleted in near future

<Criteria for Environmental Constraint>

Rank	TDS	Description
A	< 1,000	Good : Good quality
B	1,000 -1,500	Allowable : Slightly poor quality, but not exceed drinking water quality standards
C	1,500 <	Not allowable : Exceed drinking water quality standards

<Criteria for Environmental Constraint>

Rank	Total Residual Drawdown (m)	Description
A	0.00 - 0.50	Allowable: No problems for practical use
B	0.51 - 2.00	Undesirable : Partly damaged
C	2.00 <	Not allowable : Damaged

Results of the model simulation of each case are summarized as below:

Case	Pumpage (m^3/day)	Add (m^3/day)	Water Balance	Water Quality	Environmental Impact	Economic
1	20,000	10,585	UD	A	NA	G
2	15,000	5,585	UD	G	NA	G
3	12,500	3,085	A	G	UD	G
4	10,000	585	A	G	A	G
5	15,000	5,585	UD	G	NA	G

Remarks; G: Good, A: Allowable, UD: Undesirable, NA: Not Allowable
Pumpage: Total pumpage, Add: Additional pumpage

Both development plans of Case3 and Case4 are acceptable. In Case3, additional groundwater abstraction amounts to about 3,000 m^3/day. This value will be a groundwater extraction potential in the El Qaa Plain. However, it can be expected that the development causes slight influence on the existing dug wells.

Comparing with Case2, the result of Case 5 indicates that extraction for irrigation at the north of domestic well field is effective to preserve the existing domestic wells.

4-2 Lower Cretaceous Aquifer

1) Groundwater Storage

Groundwater storage of each block in the aquifer is estimated as follows:

< Groundwater Storage of Lower Cretaceous >

Block	Area (km^2)	Average thickness (m)	Effective porosity	Storage* (x 10^9 m^3)
Main Block	4,380	240	0.15	98
Sheira Block	675	200	0.15	13
Feiran Block	90	197	0.15	1.6

*: Strage without groundwater in the unconfined zone.

2) Development Potential of Main Block

In order to evaluate the groundwater development potential of the Main Block, available volume of groundwater is estimated under the following conditions.

- Present deficit of water balance is 2.38 x 10^6 m^3/year
- Recharge to the aquifer is neglected considering the safety side.
- Outflow from South Sinai to North Sinai through the Ragabet El-Naam Fault is estimated as 1.38 x 10^6 m^3/year.
- Outflow to Gharandal Sub-Block is ignored to make estimation simplified.
- Groundwater will be developed in the area from Nakhl to its southern adjacent area.
- Groundwater table decreases keeping present gradient of water table.
- It is allowed to extract groundwater till water level becomes 400 mBGL at Nakhl considering the maximum ability of existing submersible pump.

Supposing the lowering of groundwater table as 201 m from the present level, available amount of groundwater is estimated as 13.9 x 10^9 m^3, which is 14 % of the total storage. (see Fig. S-3)

Groundwater evaluation map of Lower Cretaceous was drawn in terms of water depth and water quality (TDS) as shown in one of the frontispieces.

5. EXISTING WATER USE AND FUTURE WATER DEMAND

5.1 Existing Water Supply Facilities

Water sources of existing water supply in South Sinai are classified into three categories.

- Nile water for Ras Sudr, Abu Zenima and Abu Rudeis along Gulf of Suez.
- Desalinated water for Sharm El Sheikh, Nuweiba and Dahab.
- Groundwater for El Tur city, St. Catherine city and rural communities in inland areas.

Actual water production capacity and water demand in 1997 are shown in the table below. They are 33,820 and 39,289 m^3/day respectively. The present deficit of water production capacity against demand reaches approximately 5,500 m^3/day.

5.2 Existing Sewerage System

The existing sewerage systems in South Sinai are classified into three categories as listed below.

- Treatment in wastewater treatment system.
- Infiltration into natural soil following primary treatment.
- Dispose to the desert by lorries.

Oxidation pond system is applied for all wastewater treatment systems in the cities. However, in El-Tur City, an activated sludge process is added and treated wastewater is reused for trees lining a street.

5.3 Estimation of Future Water Demand

The future water demand consists of potable water for the residential, tourism, industrial, and agricultural use. It is estimated as follows based on "National Plan for Development of Sinai".

< Actual water production capacity and water demand in 1997 >

City Name	Water Source	Production Capacity	Water Demand in 1997 Residents	Tourists	Others*1	Loss	Total	Balance
1. El Tur	Groundwater	6,000	4,014	120	1,498	240	5,872	128
2. Sharm El Sheikh		10,260	2,041	9,590	2,561	410	14,602	-4,342
	Groundwater from El Tur City	1,000	-	-	-	-	-	-
	Seawater	9,260	-	-	-	-	-	-
3. Dahab		2,000	1,066	1,155	499	80	2,800	-800
	Groundwater*2	[500]	[500]	-	-	-	[500]	-
	Seawater	2,000	-	-	-	-	-	-
4. Nuweiba		3,560	1,604	2,041	639	102	4,386	-826
	Groundwater*2	[2,700]	[2,700]	-	-	-	[2,700]	-
	Spring Water	2,560	-	-	-	-	-	-
	Seawater	1,000	-	-	-	-	-	-
5.St.Catherine	Groundwater	450	1,196	674	112	18	2,000	-1,550
6. Abu Rudeis	Nile River	2,750	2,109	0	661	110	2,880	-130
7. AbuZenima	〃	2,700	1,580	0	424	68	2,072	628
8. Ras Sudr	〃	6,100	1,844	1,066	1,523	244	4,677	1,423
Total		33,820	15,454	14,646	7,917	1,272	39,289	-5,469

Note:*1: mainly for industrial, public office, shops, restaurants [unit: m³/day]
*2 : blackish water

< Future Water Demand Based on NPDS > (unit : m³/day)

Consumer \ Year	1997	2002	2007	2012	**2017**
Residents (Urban Area)	7,495	11,040	28,357	66,390	**152,412**
Residents (Rural Area)	3,217	3,445	5,372	6,460	**7,698**
Tourists (Hotels)	9,338	16,034	19,862	23,691	**26,728**
Industries	2,140	2,568	3,210	3,852	**4,494**
Agriculture	9,872	36,655	50,114	62,357	**73,743**
Others (loss, etc.)	1,110	1,654	2,840	5,020	**9,567**
Total	33,172	71,396	109,755	167,769	**274,643**

6. GROUNDWATER DEVELOPMENT PLAN

6-1 Design Condition

Several groundwater development plans were proposed as shown in Fig.S-4 and following table to deal with the future water demand based on "National Plan for Development of Sinai".

Water quality required is TDS 1,500 mg/l of Drinking Water Quality Standard in Egypt.

< Outline of Groundwater Development Plans >

Development Plan	Target Year	Development Capacity (m^3/day)	Service Area	Main Purpose of Supply	Water Source Aquifer
Plan 1	2017	57,500	Ras Sudr, Abu Zenima, Abu Rudeis	Residential use	Lower Cretaceous
Plan 2		35,000	Nuwiba, Taba		
Plan 3	2007	5,300	El Tur		Quaternary
Plan 4 A	2017	11,700	Sudr El Heitan	Agricultural use	Lower Cretaceous
Plan 4 B		13,700	Malha		
Plan 4 C		11,700	Themed		
Plan 5		5, 25, 50	Bedouin Community	Common use	Wadi deposits

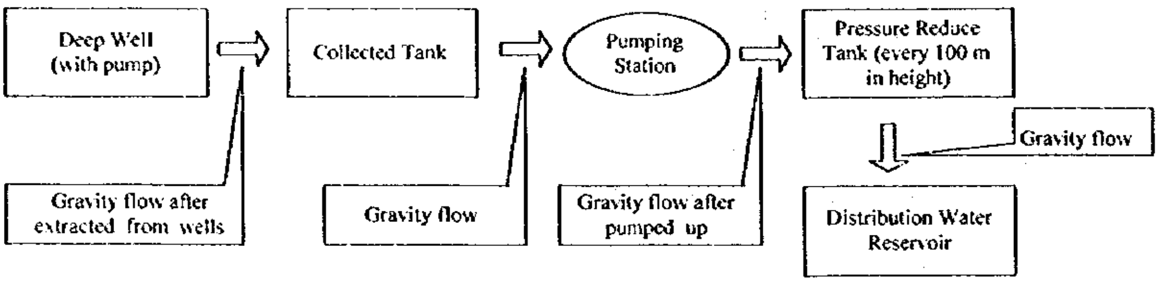
The daily averages of unit water demands of each category are as follows.

- Residential Use (urban area) :240 liter/capita/day
- Residential Use (rural area) :120 liter/capita/day
- Tourism Use : 400 liter/capita/day
- Industrial Use :107 m^3/ha/day
- Agriculture Use : 16.3 m^3/ha/day

6-2 Water Development Facility Plan

Capacity of the facilities was planned considering the future water demand until 2017 plan by plan. However, Plan 3 was planned on the basis of the future water demand in 2007 from the environmental point of view. Therefore, after 2007, other water source such as River Nile Water should be considered.

Flow diagram of typical groundwater supply system and outline of the plans are shown below.



< Flow Diagram of Typical Groundwater Supply System >

< Outline of Facility for Development Plan>

	Development Capacity (m^3/day)	Intake Facility			Conveyance Facility		
		Intake Well		Pipeline	Pumping Station	Pipeline	Reservoir
		No.	Depth (m)	Length (m)	No.	Length (m)	(m^3) x No.
Plan 1	57,500	92	1,000	109	1	64	7,250 x 4
Plan 2	35,000	56	1,000	70	4	181	7,250 x 4
Plan 3	5,300	9	155	19	0	9	1,400 x 2
Plan 4A	11,700	19	1,000	7	0	0	360 x 19
Plan 4B	13,700	22	1,000	7	0	0	360 x 22
Plan 4C	11,700	19	1,000	7	0	0	360 x 19
Plan 5A	5	1	20	0.1	0	0	5 x 1
Plan 5B	25	1	20	0.1	0	0	25 x 1
Plan 5C	50	2	20	0.1	0	0	50 x 1

6-3 Management, Operation and Maintenance Plan

Important matters for the indices of water control are mentioned below, and establishment and execution of them are expressly matters of weight for South Sinai with insufficient water sources.

- Establishment of management organization for municipalities.
- Establishment of an impartial water tariff system
- Thorough review of the water quantity and quality control
- Diffusion of economization concept to increase water consumption awareness and improvement of the water implements
- Prevention of water sources pollution

The important matters of daily works, which are indispensable for the maintenance works and for which even greater efforts should be made, are as follows.

- Detectors for water meter and automatic control system.
- Disinfection facility for direct influence to human bodies

7. PROJECT EVALUATION

7.1 Concept of Project Evaluation

Groundwater development will bear various benefits, both tangible and intangible ones. As mentioned in NPDS, water resource is the essential key to its realization. In project evaluation, not only tangible factors but also intangible factors shall be evaluated. In this chapter, evaluation is made concerning the following factors.

- Evaluation by intangible factors
- Economic and financial evaluation (tangible factors)
- Environmental evaluation
- Evaluation of groundwater storage

7.2 Evaluation by Intangible Factors

Major presumed intangible benefits from the prepared development Plan 1 to 5 are as follows.

- Mitigation of overpopulation in Cairo area by resettlement
- Saving the Nile water
- Others

1) Mitigation of Overpopulation in Cairo Area by Resettlement

Ninety nine percent of the total population is excessively concentrated in the limited arable land along the Nile River and its delta. The government of Egypt has been faced to this problem. One of the main purposes of NPDS is to make sure the resettlement program from the Cairo area to Sinai.

Groundwater potential evaluation revealed that the potential of the Lower Cretaceous aquifer meets the water demand level of NPDS in target year for more than 280 years. Therefore, contribution of groundwater development is estimated to be huge for the resettlement program in terms of water supply.

2) Saving the Nile Water

Big projects other than NPDS are in progress in El Toshka, Shark El Oveirat, Gulf of Suez and so on. These projects will require huge amount of water resources relying mainly on the Nile water. However, it will cause heavy deficit of the Nile water in future.

Water demand of NPDS in target year requires an amount of 134,900 m^3/day of water source. If this amount of water is covered by groundwater, same amount of the Nile water can be saved and used for other projects. At present it is difficult to specify usage of saved water in other project. Saving the Nile water itself is considered as big benefit.

3) Others

Other benefits are listed as follows.

- Reduction of water-borne diseases
- Reduction of infant mortality
- Improvement of living standard
- Contribution to tourism promotion
- Land value hiking
- etc.

7. 3 Economic and Financial Evaluation

1) Economic Evaluation

The results of economic evaluation for each plans are tabulated below.

< Result of Economic Evaluation >

Project	EIRR (%)	NPV (LE Million)*	B/C*
Water Supply Projects			
Plan 1	5.2	-124	0.57
Plan 2	3.3	-181	0.45
Plan 3	24.0	19	2.41
Irrigation Projects			
Plan 4A	0.5	-32	0.44
Plan 4B	0.6	-36	0.43
Plan 4C	0.5	-32	0.44

Note: * Discounted at 10%.

The EIRR of Plan 3 is 24.0%, exceeding ten percent of the opportunity cost of capital.
In the report of "Investing in Development, Lessons of World Bank Experience" in 1985, the water supply project is mentioned as follows: "Water supply and sanitation agencies serving poorer consumers and providing a basic need have rarely been permitted to earn returns higher than 6 to 8 percent". Thus, the rate of 5.2% might be not so low as the general water supply projects in the developing countries. Incidentally, if the estimated costs decreased to 45% of the original estimation, the EIRR would be more than 10%.
The EIRR of Plan 2 is 3.3%. Incidentally, if the estimated costs decreased to 55% of the original estimation, the EIRR would be more than 10%.

The EIRRs of the Plan 4 are much less than 10%. From the economic point of view, accordingly, the viable project is Plan 3 only. In consideration of the speciality in Sinai, Plans 1 and 2 might be viable as well.
The Nile River Water is utilised in many areas all over the country. However, the water must not be able to completely cover the increasing future water demand. Considering this trend, the benefit of Plan 1 and 2 may increase in future, because the value of Nile Water goes up due to its scarcity.

As for the irrigation projects, the initial investment and O/M costs of water resources are too high to realise the proposed projects from the economic viewpoint. However, they are important to promote agricultural project to raise self-sufficiency rate of foods in South Sinai.

2) Financial Evaluation

Although the financial evaluation index was calculated for the respective projects, the FIRR of all the projects were negative. Thus, all the proposed projects would not be viable, if the projects are based on the "cost-recovery" policy under the present tariff and financial situation. The total costs are greatly in excess of the revenues from the management of the proposed projects. The projects can not be managed without any financial supports by the government.

In the water supply projects, it might be difficult to raise the rates of water tariff because of the NPDS policy. If so, the following financial support would be necessary, that is,

- the capital costs of the projects are covered by the government and the O/M costs are covered by 50% of the government.
- the rest 50% of the O/M costs is covered by the revenue from the water charges on beneficiaries under present tariffs. In that case, the FIRR could exceed 10%. Although this is a heavy burden for the government, there is no way to bring the proposed projects into fruition.

In the irrigation projects, it might be impossible for the beneficiaries to get the net returns of three times more than the present ones. For making the projects having more than 10% of FIRR, 70% and more subsidies than the all costs have to be committed by the government.

7-4 Environmental Evaluation

The results of IEE (Initial Environmental Examination) for each plan are as follows.

Category	Plan 1	Plan 2	Plan 3	Plan 4	Plan 5
A	0	0	0	0	0
B	0	2	2	3	3
C	*23	21	21	20	20

A: Impact is strong. B: Some impact is expected. C: Impact is very small.

(*: number means each category numbers)

It is concluded that the environment will not be seriously affected by the implementation of the development plans. The reasons supporting this conclusion are listed as follows:

- Most of South Sinai consists of scarce natural condition under desert climate; the habitats of plants and animals are limited. The development plan is not proposed in such limited area. Therefore, the natural environment in the Study Area will not be directly affected by development plan.
- Facilities consist of small-scale size and a large-scale reclamation is not needed. Thus, development plan does not seriously affect environment.
- Development plan will rather contribute to the economic activities and the improvement of public health condition.

7-5 Evaluation of Groundwater Storage

Total discharge from the Lower Cretaceous Aquifer including future water demand in the development plan and outflow to the North Sinai is 49.45 x 10^6 m^3/year. An available duration for planning withdrawal can be calculated as follows.

$13.9 \times 10^9 m^3 \div 49.45 \times 10^6 m^3/year$ = **281 (year)**

Therefore, an expected duration of the development plan in the Main Block is estimated to be 281 years after 2017.

On the other hand, since NPDS plans to use surface water for the irrigation use, the total water demand for the development plan decreases to 35.91 x 10^6 m^3/year. In this case, the duration is estimated as **387 years**.

7-6 Conclusion of Project Evaluation

Water is essentially basic requirement to promote NPDS. There are three kinds of water sources such as Nile Water, Desalinated Water and Groundwater. Through above project evaluation, the potential of groundwater development in terms of quality and quantity was ascertained. Furthermore, the development price of groundwater is cheapest among them so far. As a matter of course, the EIRR and FIRR of the proposed groundwater development plans were not adequate value except for Plan-3 of which groundwater would be withdrawn from the shallow "Quaternary Aquifer" near the capital city, El Tur in South Sinai Governorate. Because the groundwater in other plans would be withdrawn from the deep "Lower Cretaceous Aquifer" in the undeveloped desert. However, they are rather worth implementing since such water supply projects would play as one of the most important infrastructures in order to realize NPDS.

8. RECOMMENDATION

(1) New groundwater aquifer was confirmed in the south of El Qaa Plain. However, its distribution and hydrogeological features shall be studied in detail.

(2) Detailed feasibility study including the assessment of the water supply impact on the NPDS should be started as soon as possible. Such study should cover both groundwater and surface as well. The study should include the establishment of groundwater monitoring system to avoid excessive extraction. The study for wastewater treatment and disposal should be also included in the schemes.

(3) The availability of good quality groundwater at Central Sinai should encourage the settlement of Bedouin in that area. This in return will have a very positive impact on the living standards of these people. More comprehensive plans should be prepared for the Bedouin settlement in central Sinai.

(4) Number of production well is increasing in both South and North Sinai. They are tapping groundwater in the Lower Cretaceous Aquifer. Groundwater in the Lower Cretaceous Aquifer is essentially of fossil water although a little recharge is expected from the surface water. Groundwater development of the Lower Cretaceous Aquifer will lead recession of groundwater level. Considering this situation, groundwater development in Sinai shall be carried out under proper control system. Especially, careful attention shall be paid to the change of groundwater level in the development. From this point of view, groundwater level monitoring shall be properly continued using automatic water gauges installed in the Test Wells.

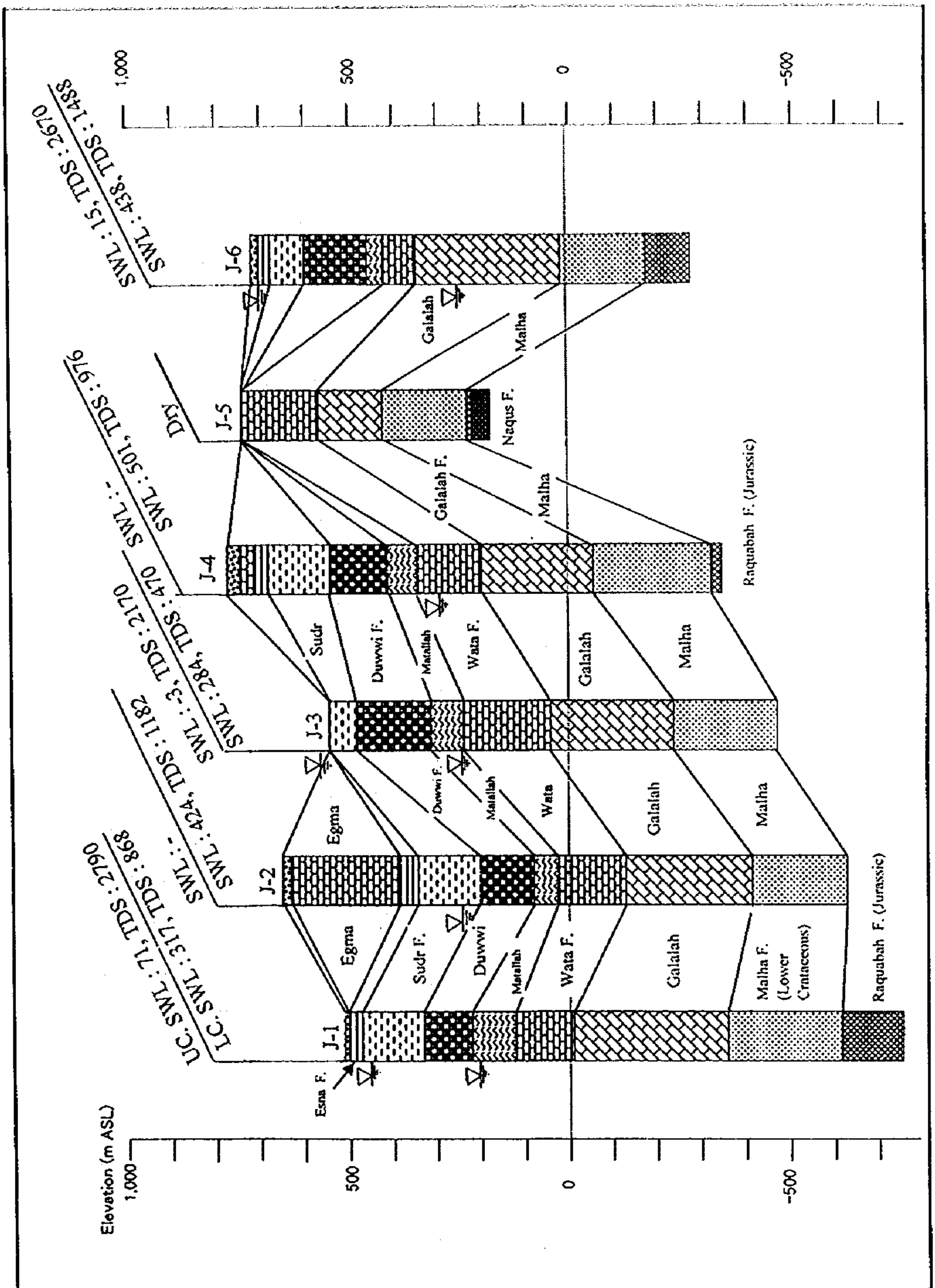


Fig. S-1 Correlation of Stratigraphic Sections Among JICA Test Wells

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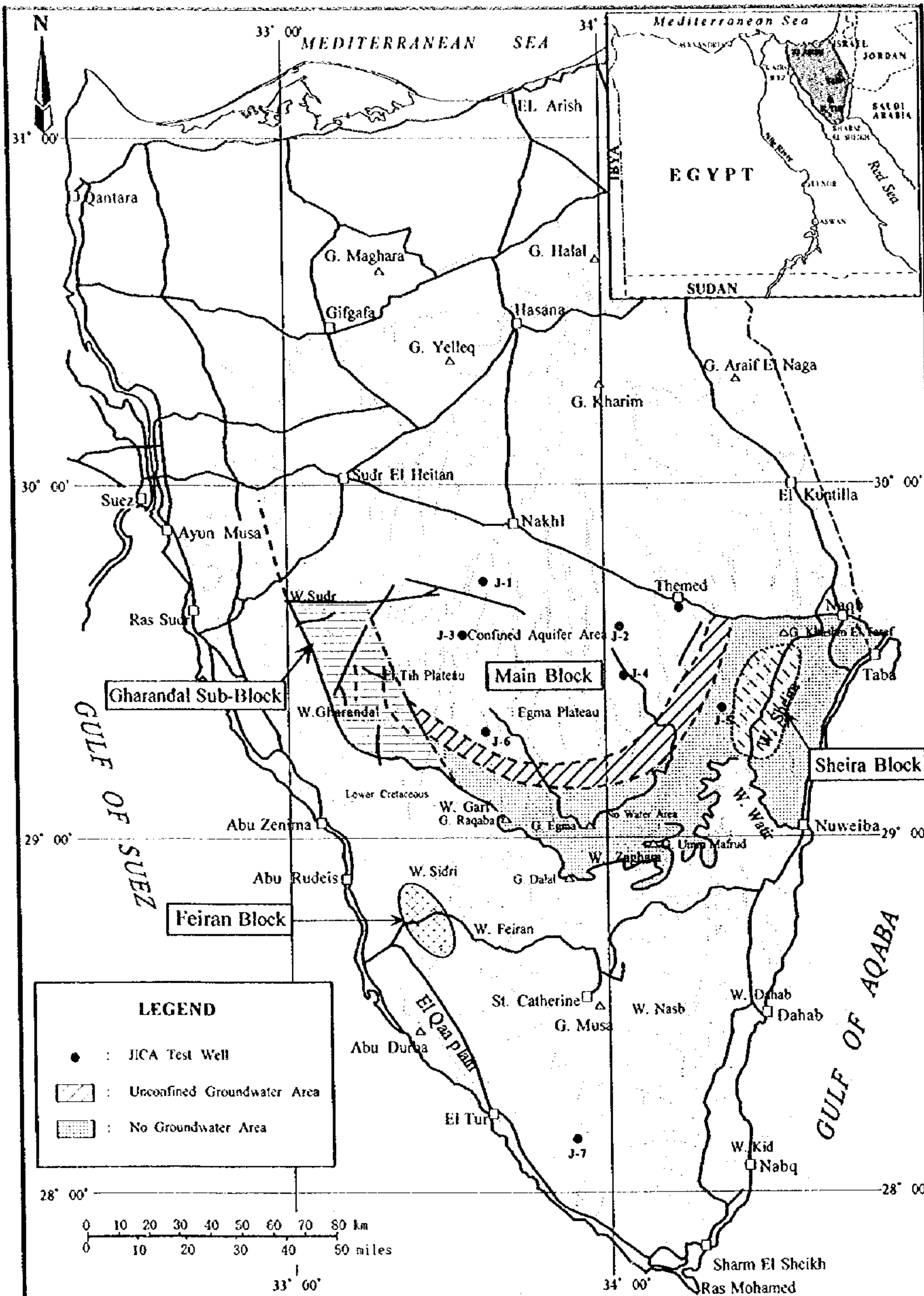

Fig. S-2 Differentiated Groundwater Zone in Main Block (Lower Cretaceous)

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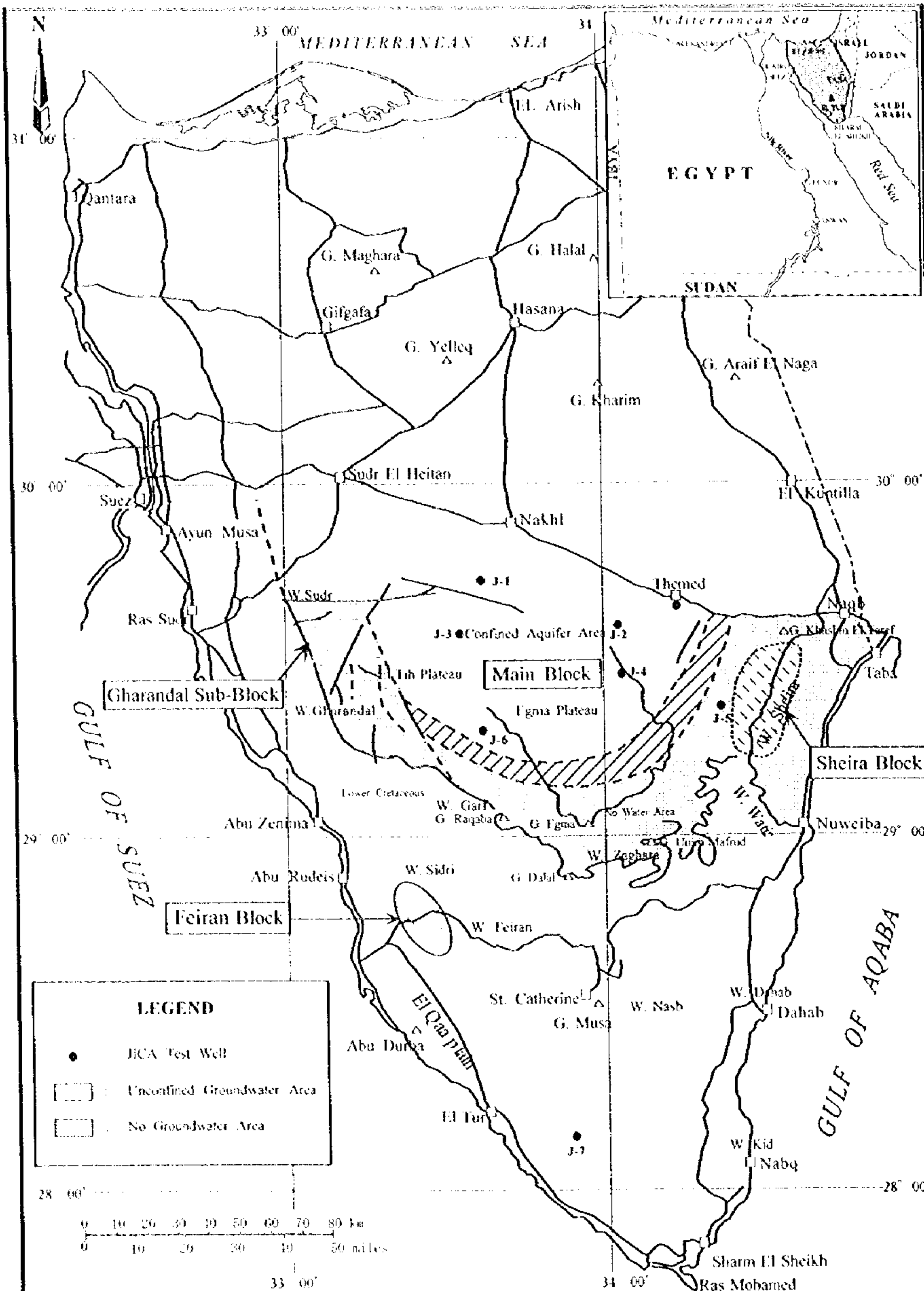

Fig. S-2 Differentiated Groundwater Zone in Main Block (Lower Cretaceous)

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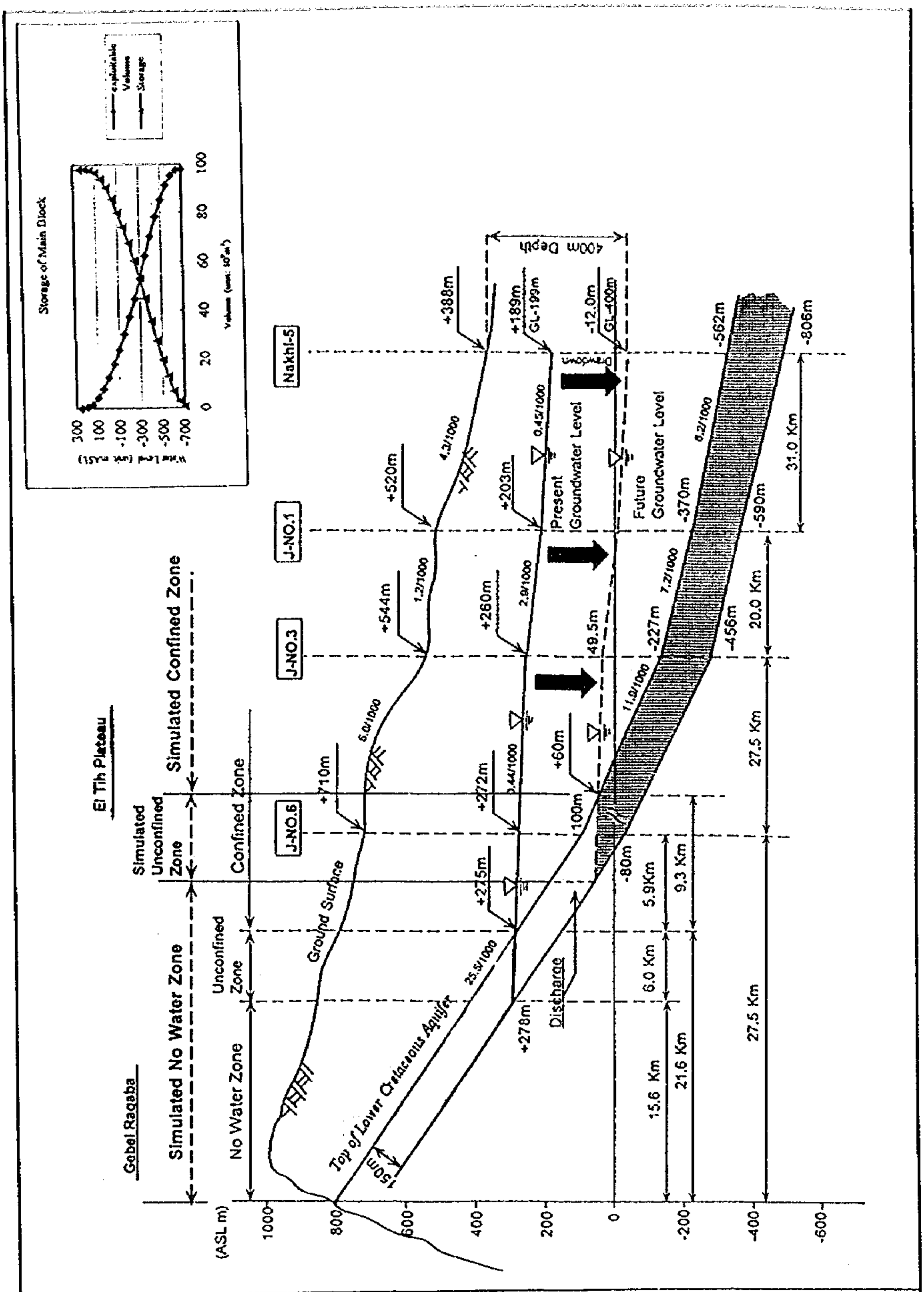

Fig. S-3 Section of Simulated Groundwater Level and Storage (Lower Cretaceous)

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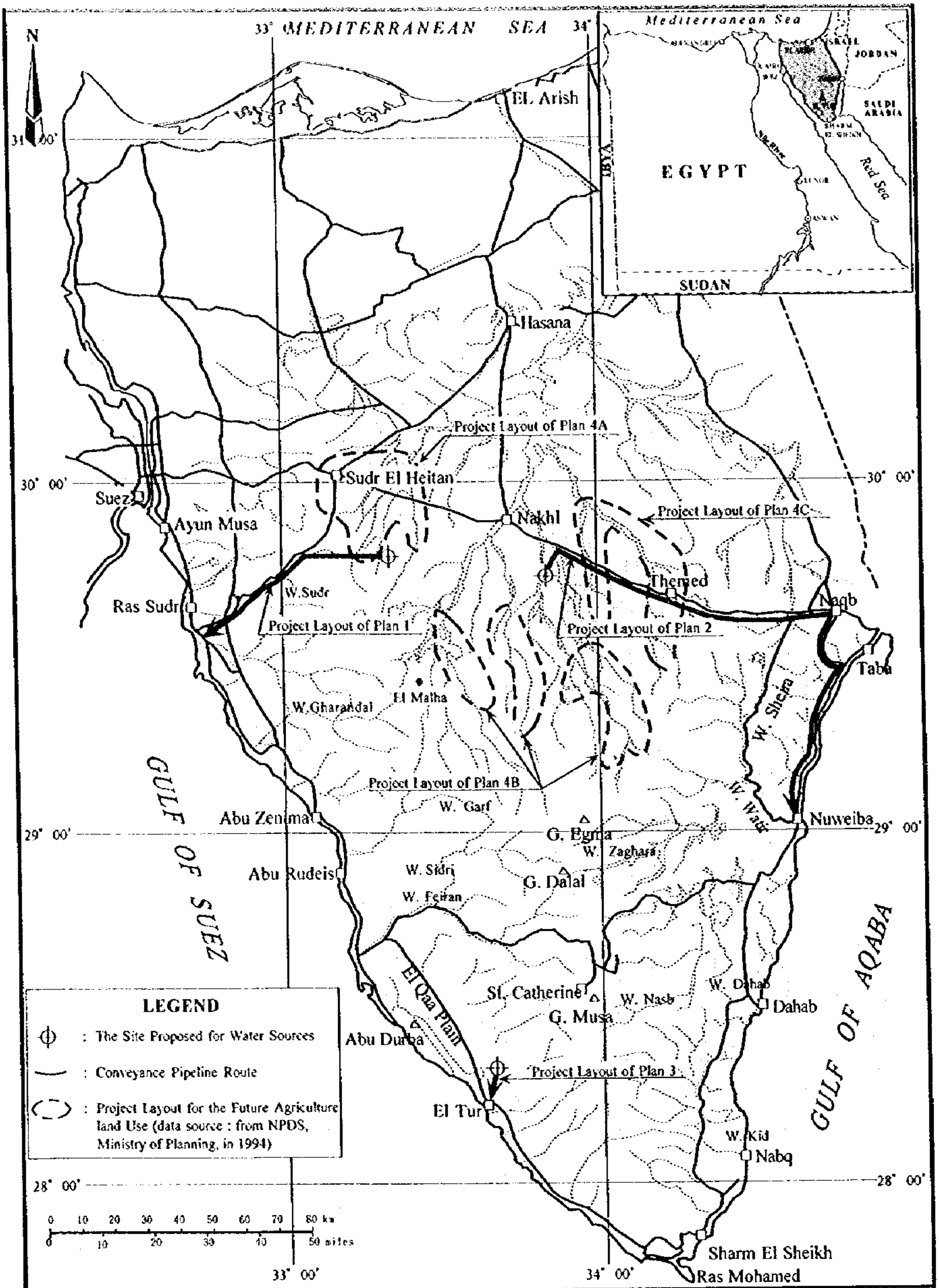

Fig. S-4 Project Layout

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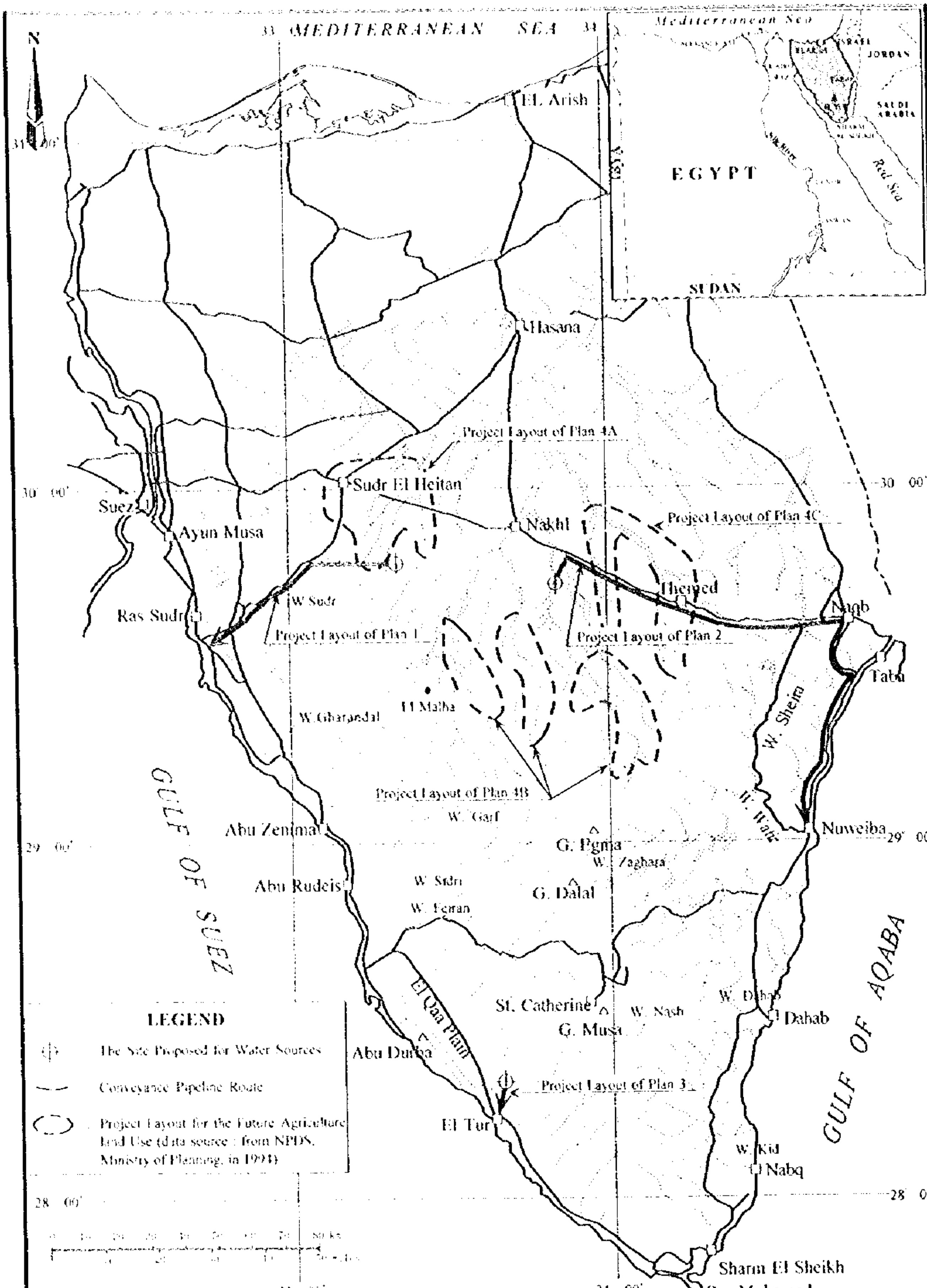

Fig. S-4 Project Layout

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