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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

SUMMARY OF HYDROGEOLOGY AND GROUNDWATER RESOURCES EVALUATION

MARCH 1999

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

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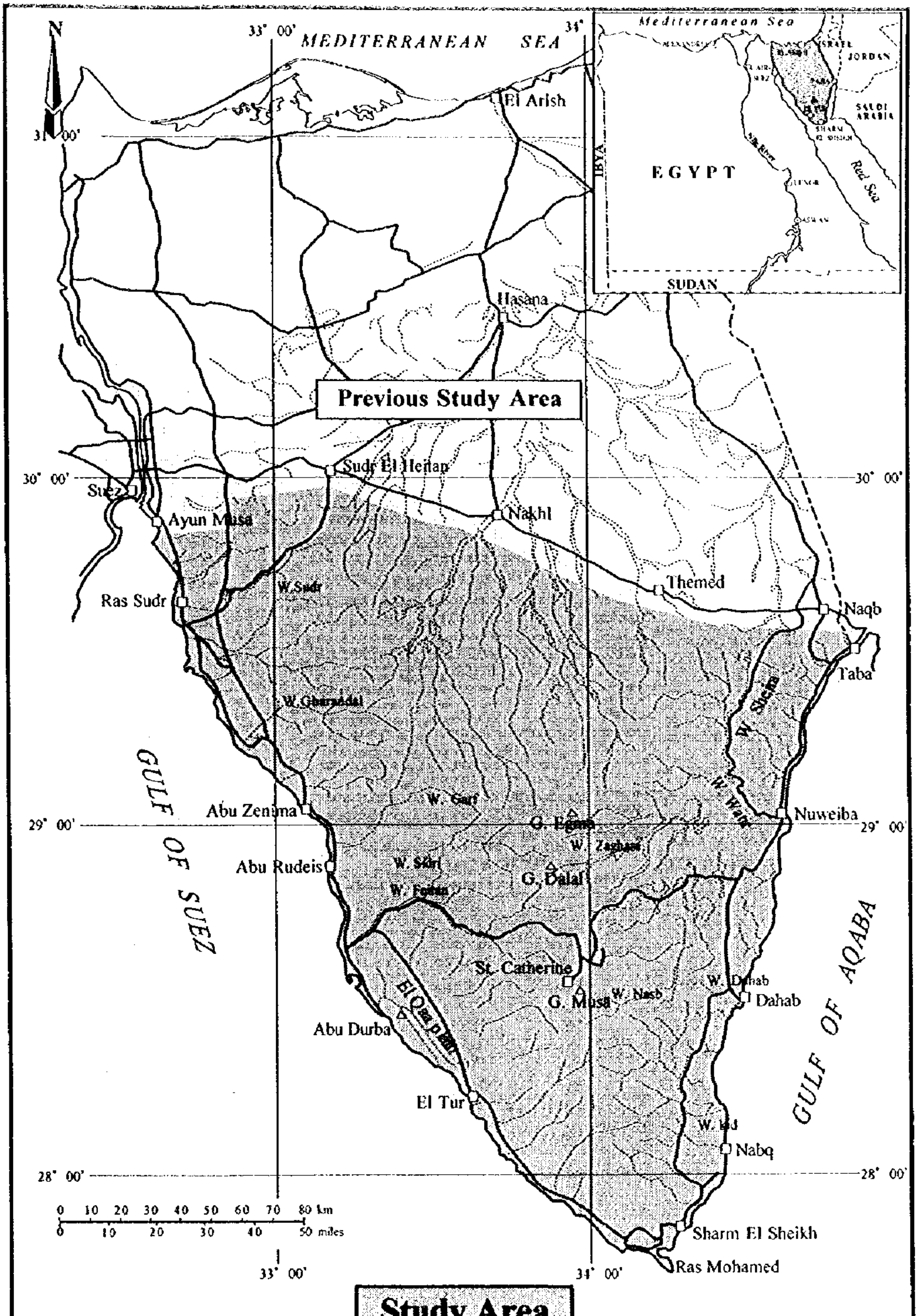

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El Arish
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Red Sea
Hasana
Previous Study Area
Sudr El Heitan
30° 00'
Suez
Ayun Musa
Nakhl
Themed
Ras Sudr
W.Sudr
Naqb
Taba
W.Gharandal
W. Sheira
W. Watir
W. Garf
Abu Zenima
G. Egma
Nuweiba
29° 00'
W. Zaghara
Abu Rudeis
W. Sidri
G. Dalal
W. Feiran
St. Catherine
W. Dahab
Dahab
G. Musa
W. Nasb
Abu Durba
El Qaa plain
GULF OF SUEZ
GULF OF AQABA
El Tur
W. Kid
Nabq
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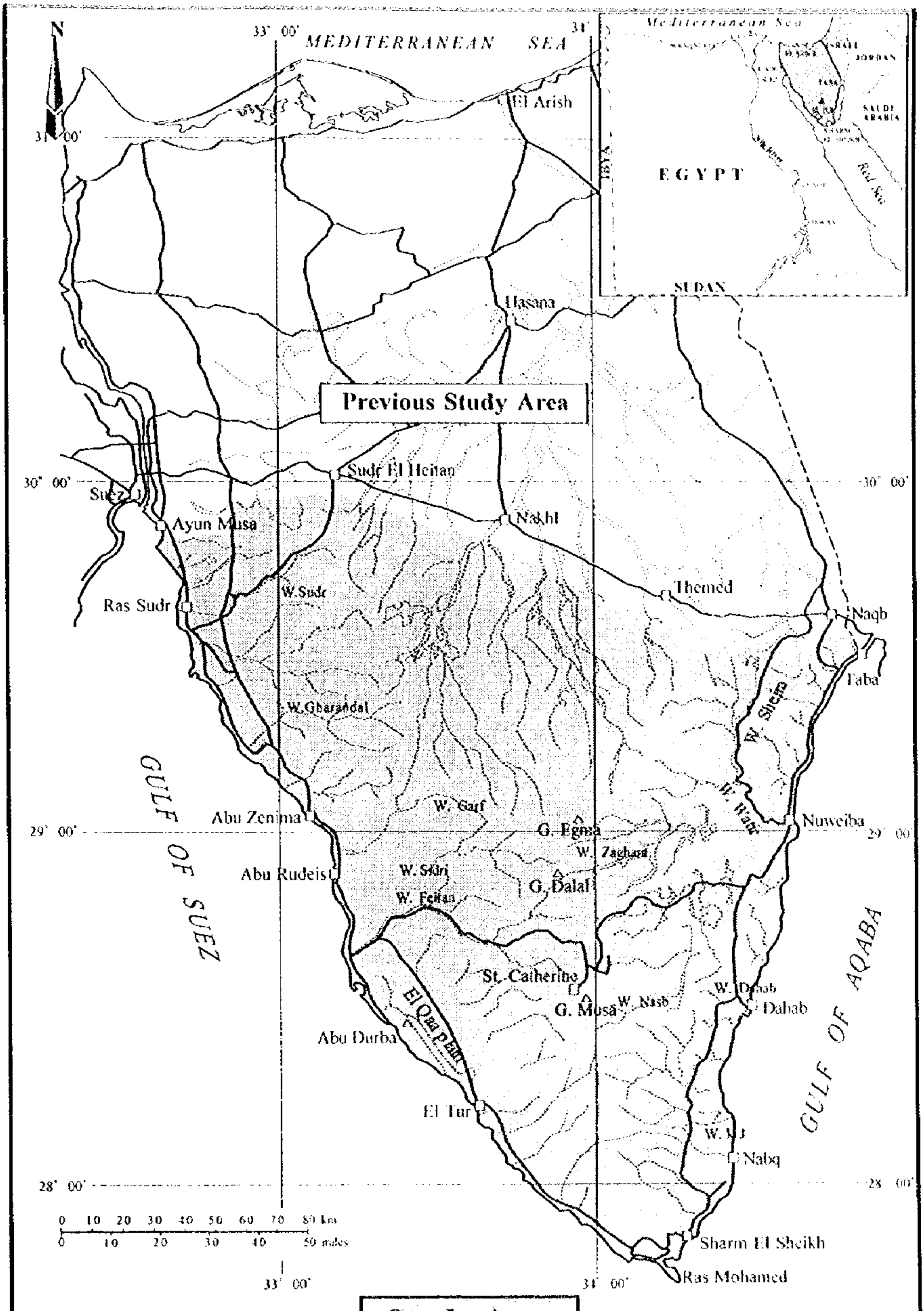
Sharm El Sheikh
Ras Mohamed

Study Area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Study Area

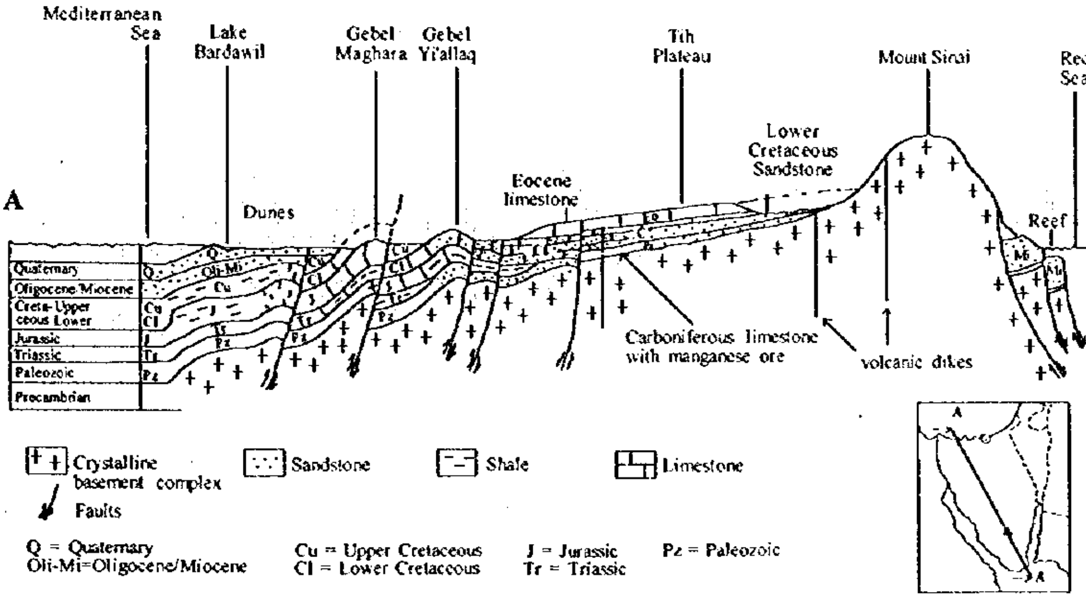
1. GENERAL DESCRIPTION OF SOUTH SINAI

1-1 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.

1-2 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)

1-3 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 (℃)		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 52.92×10^6 m^3/year and about 9.5×10^6 m^3/year, from the W. El Arish totaling 62.42×10^6 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.

1.4 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

1.5 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

2. 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.

2-1 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.

2-2 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	-	-	-

2-3 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.

<u>2-4 Lower Cretaceous Aquifer</u>

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.

2-5 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.

2-6 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.

3. GROUNDWATER POTENTIAL AND EVALUATION

3-1 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^ m³/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.

3-2 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.

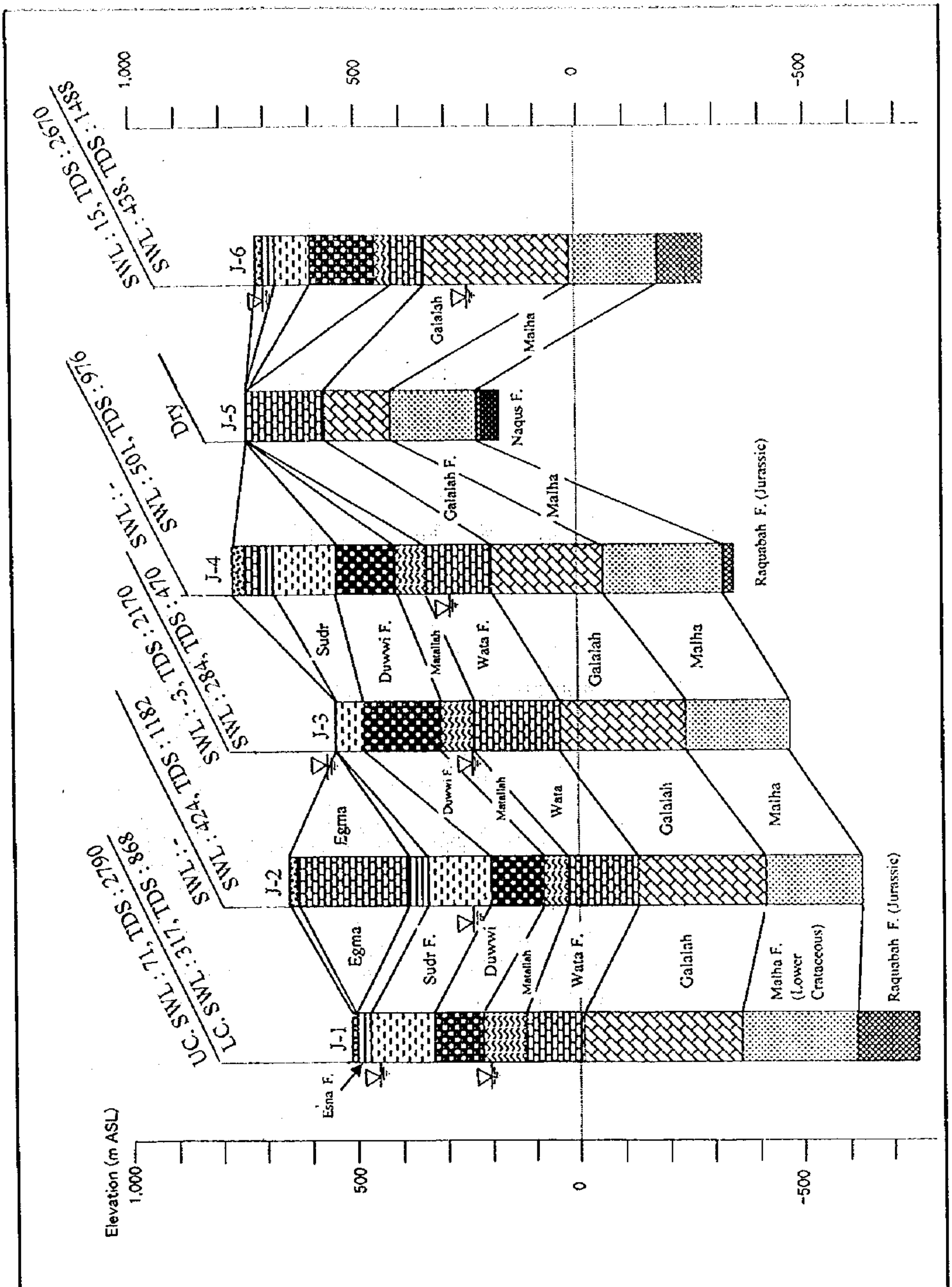


Fig. S-1 Correlation of Stratigraphic Sections Among JICA Test Wells

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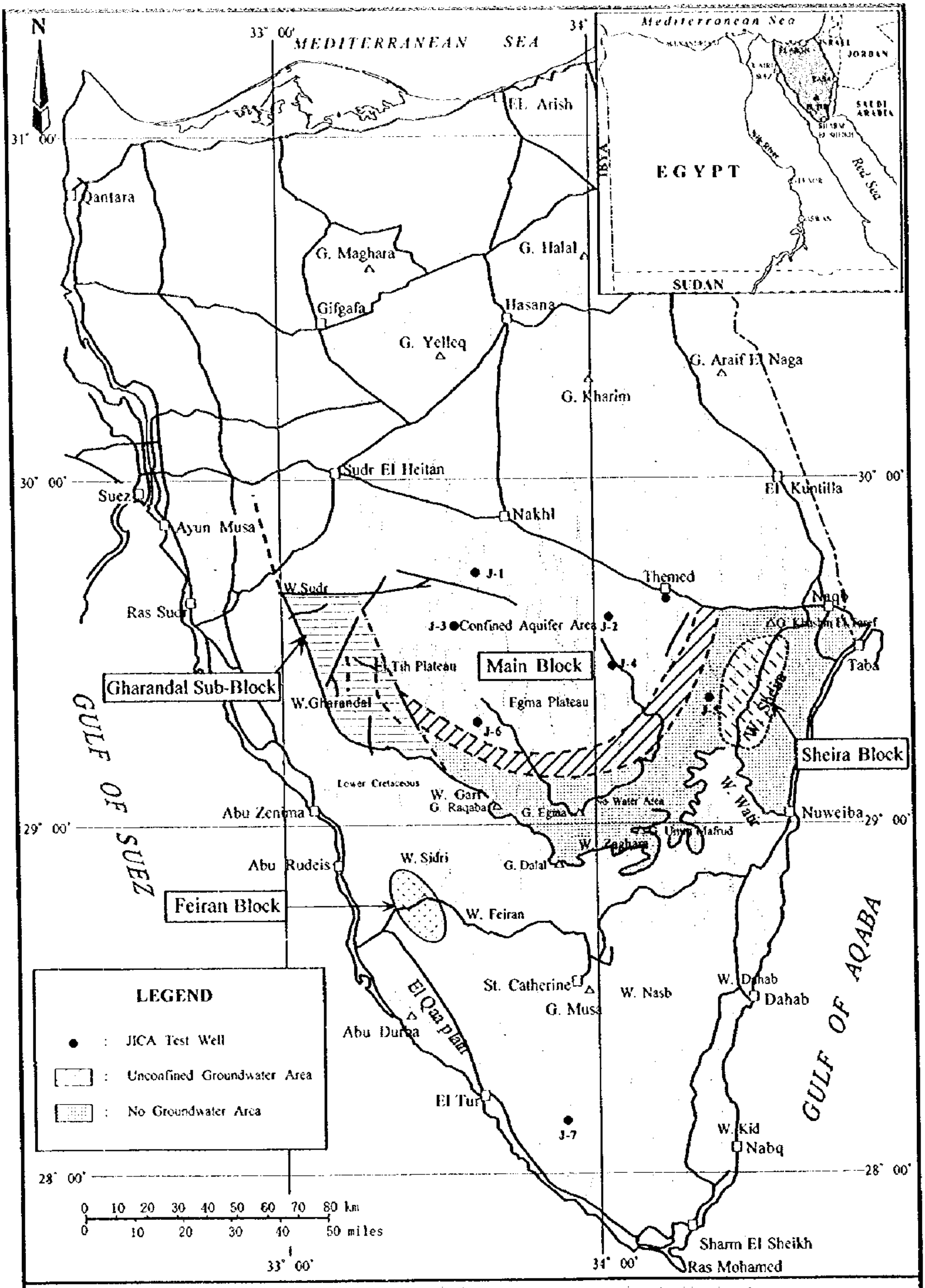

Fig. S-2 Differentiated Groundwater Zone in Main Block (Lower Cretaceous)

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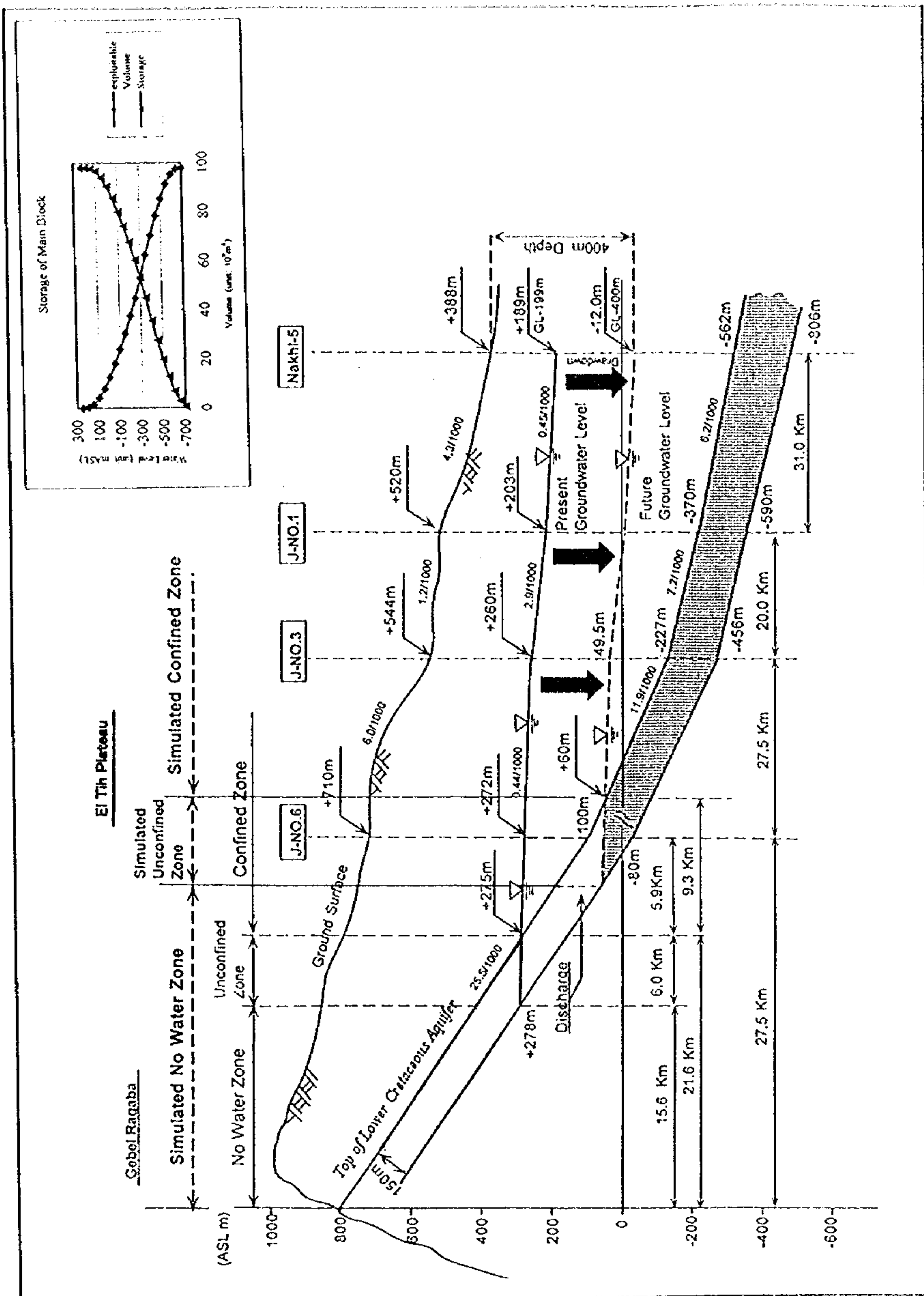

Fig. S-3 Section of Simulated Groundwater Level and Storage (Lower Cretaceous)

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