8.2.13 Wadi Saal

1) General Features of Basin

Wadi Saal starts from the northeast area of St. Catherine Town and merges to the Wadi Zaghara. The catchment area is completely underlain by the Precambrian Basement Rocks consisting mainly of granite. Main village in the wadi is Wadi Saal Village which is located approximately 40 km northeast of St. Catherine Town. The village is a kind of basin formed in the basement area. 11 dug wells were newly confirmed in the village during the Study. After Wadi Saal village, the wadi changes its name to the Wadi Safra.

2) Well Inventory

11 dug wells were newly confirmed in the village during the Study. After Wadi Saal village. 13 dug wells were also newly confirmed in the Wadi Safra.

Inventory and location map are shown in Table 8.1.1-1 (13) and Fig. 8.2.13-1 respectively. Number of dug wells tend to increase because construction works are vigorously going on in the village.

3) Groundwater Level

Static water level is in a range from 4.81 to 11.12 mBGL averaging 7.02 mBGL in the Wadi Saal and from 2.60 to 8.87 mBGL averaging 6.54 mBGL in the Wadi Safra (Fig. 8.2.13-2).

Groundwater gradient is 11/1000 in the Wadi Saal and 13/1000 in the Wadi Safra.

4) Groundwater Quality

(1) Obtained Data

As for Wadi Saal, JICA Study Team has carried out field water quality survey for 19 Dug Wells (June, 1997). A range of depth of Dug Wells is 7m to 12m.

(2) TDS Distribution

A groundwater quality map of shallow aquifer in the area is provided as shown as Fig. 8.2.13-2. In Wadi Saal, the groundwater salinity is low in the central of wadi, and relatively high in the both bank. A range of TDS value in the central of wadi is less than 500 mg/l.

A similar salinity is distributed in Bir Safra Area. A range of TDS value is 1100 to 1800 mg/l.

5) Hydrogeological Characteristics of Aquifer

The aquifer occurred in the wadis is the Quaternary Wadi Deposits consisting of sand and gravel. No drilling data and geophysical survey data are available. Depth of dug wells is from 5.35 to 12.68 m in the Wadi Saal averaging 10.0 m. Dug Well No. 2 (Salem) in the wadi Saal is extracting groundwater from the weathered granite overlain by the Quaternary Deposits. Considering this fact, thickness of aquifer seems to be less than 10 m.

In the Wadi Safra, although Dug well No. 8 was dry, it was 6 m depth and reached to the weathered granite. Thickness of aquifer is estimated to be about 10 m.

The catchment area of both wadi is completely underlain by the Precambrian Basement Rocks. Therefore, the aquifer of the wadis, the Quaternary Wadi Deposits and the weathered granite, is recharged by surface water precipitated in the area.

6) Groundwater Extraction

Groundwater in the wadis is exploited for both irrigation and domestic use. No information is available on groundwater extraction. According to the interview by the Study Team, population of Wadi Saal Village is 1,000 and groundwater consumption is 20 l/capita/day. Therefore, total consumption is estimated as 7,300 m^3/year.

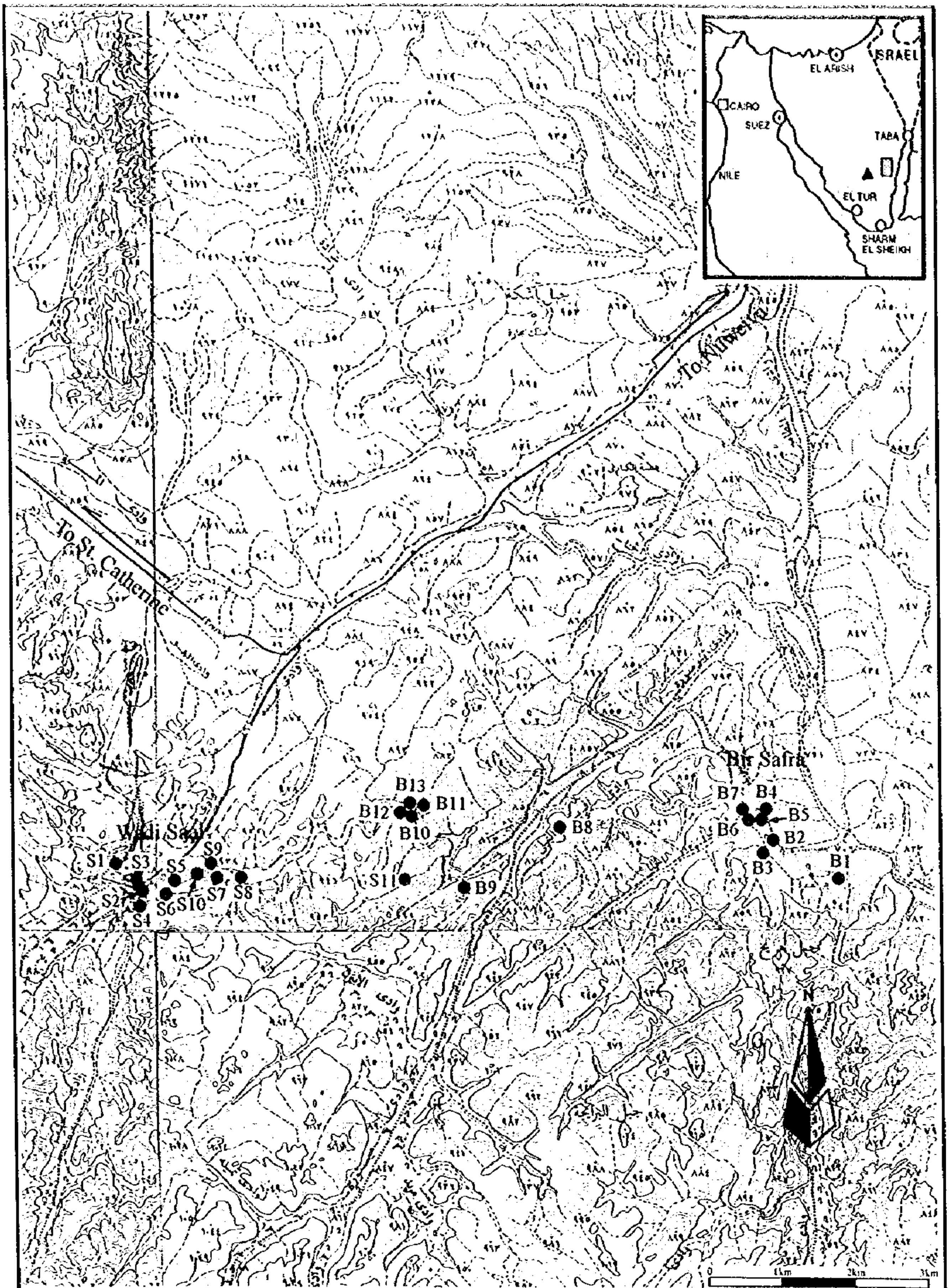

Fig. 8.2.13-1 Well Location (Wadi Saal)

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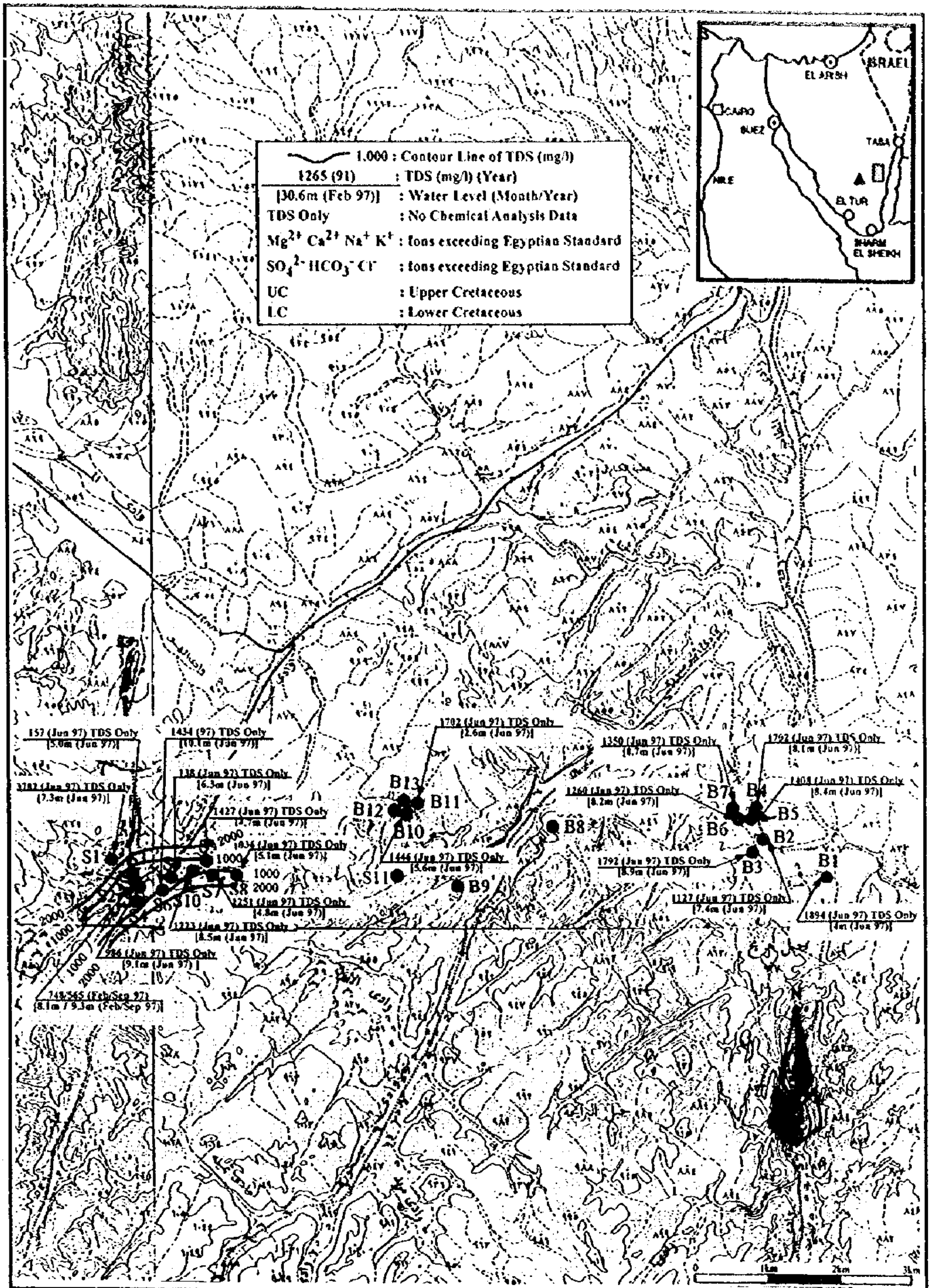

Fig. 8.2.13-2 Groundwater Level/Quality: W. Saal (unit: mBGL)

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8.2.14 Wadi Dahab

1) General Features of Basin

Wadi Dahab is located in the southeastern part of the Sinai Peninsula; Approximately 80 km northeast from Sharm El Sheikh. After merging of two (2) wadis, W. Zaghara and W. El Ghaib, the wadi is called as W. Dahab; It is in a section between Dahab city and the National Highway to Nuweiba. Wadi Dahab is approximately 6 km in length.

The area is mainly occupied by the Precambrian Basement Rocks overlain by the Quaternary Wadi Deposits. A fan is formed in the mouth of the wadi (Dahab city).

The groundwater is extracted for the domestic use in Dahab City except drinking because of its high salinity (TDS: 3,000 mg/l).

2) Well Inventory

There are eight (8) production well of TAAMIR in the Wadi (Fig. 8.2.14-1). However, geological columns are not available. The inventory of these wells is shown as Table 8.1.1-1 (14).

3) Supplementary Geological Survey

Although there are eight (8) cased wells in the wadi, no geophysical survey data is available. The TEM survey is to be conducted to estimate the thickness and distribution of the Quaternary aquifer in the wadi. The location of sections is shown in Fig.6.2.3-16. Surveyed sections were allocated in the field to avoid the interference by the electric power cable line constructed in the wadi. The profiles are compiled with an interval of approximately 1 km measuring station and analyzed depth of 300 to 400m depth.

In the W. Dahab, a profile of Line-M was established as shown as Fig. 8.2.14-2.

In this profile, four (4) layered model is applied based on the apparent resistivity. The area is covered by Precambrian rocks. Hence there are no existing well, the details of Lithology is can not be estimated.

The interpretation of the each geoelectrical profiles are as follows;

Layer	Resistivity Rang (ohm-m)	Estimated Lithology	Hydrogeological Interpretation
(I)	100 - 300	weathered basement rocks	Precambrian Rocks
(II)	50 - 150	wadi deposit at surface and weathered basement rocks at lower	Precambrian Rocks
(III)	200 - 500	basement rock	Precambrian Rocks
(IV)	> 1,000	basement rock	Precambrian Rocks

4) Groundwater Level

In the W. Dahab area, the data of groundwater level are recorded for eight (8) cased wells. These data are listed in the Well Inventory. A narrow range of 28 to 35 m BGL with a average value of 32.37 m BGL of groundwater level is distributed.

5) Groundwater Quality

It is said that groundwater quality in Wadi Dahab is of high salinity. However, no data are available.

6) Hydrogeological Characteristics of Aquifer

The basin is completely occupied by the Precambrian Basement Rocks. Groundwater is recharged from the Precambrian Rocks. At about 0.5 km upstream of the police check point, a spring is occurred in the left side of the National Highway. The spring is occurred in a dorelitic dyke, however, open fractures were observed in the basement rocks near the dyke. Accordingly, the spring may controlled by the dorelitic dyke and open fractures in the basement rocks. There is a possibility that same kind of springs are occurred in the underground of the basin; The Quaternary Deposits are recharged by this salty water as well as the other groundwater in the basement rocks .

This spring is located just upstream of the basin. Water quality (TDS) is high. It springs out during the winter and is dried up in summer. High TDS value of production wells in the wadi may have some relation with this spring.

7) Groundwater Extraction

Production of groundwater is reported as 500 m^3/day from wells.

Main water source to Dahab City is desalinated water from saline groundwater. Saline water is extracted from newly constructed wells along the coast and existing wells. Its volume reaches 2,000 m^3/day.

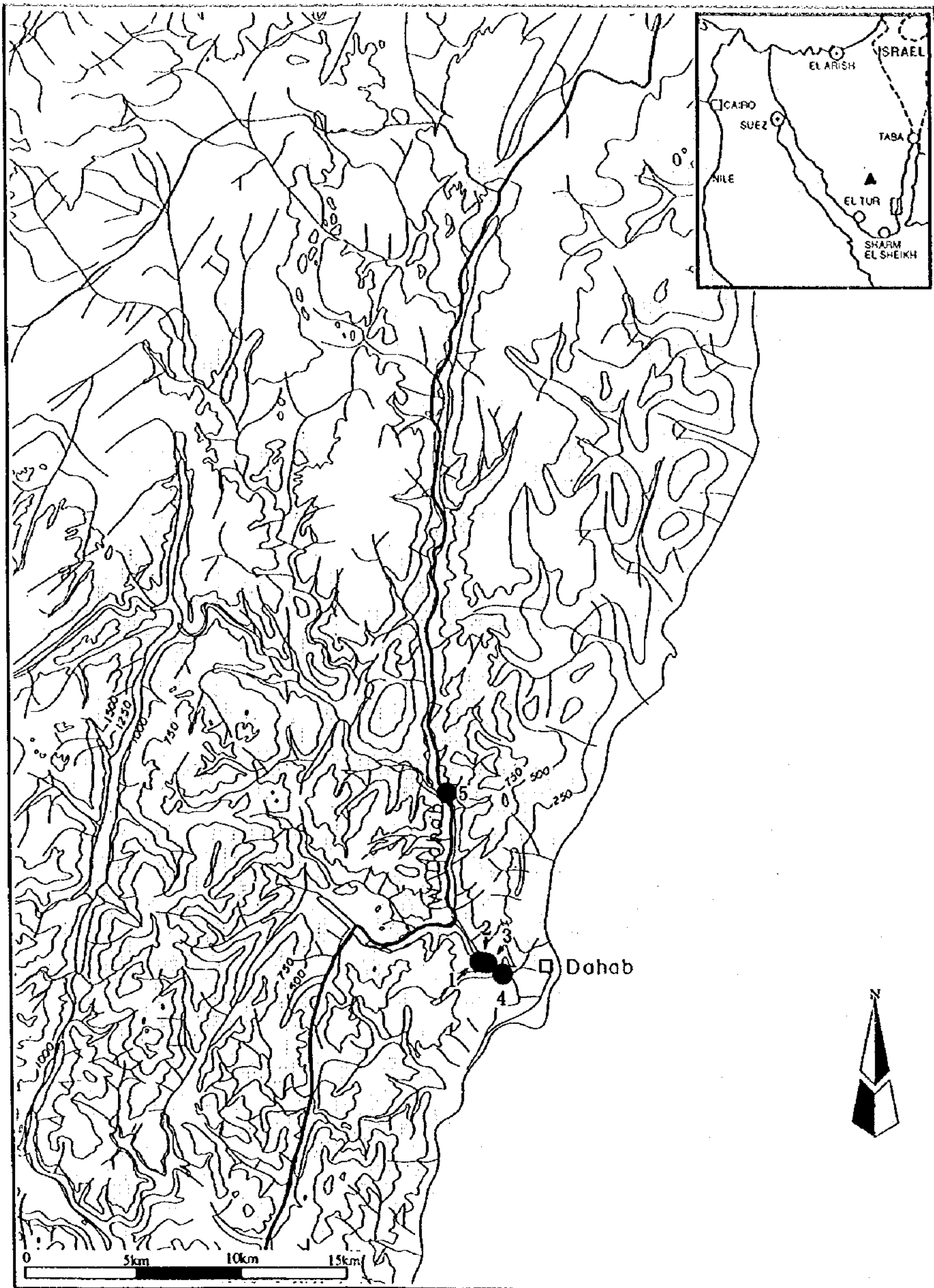

Fig. 8.2.14-1 Location Map (Wadi Dahab)

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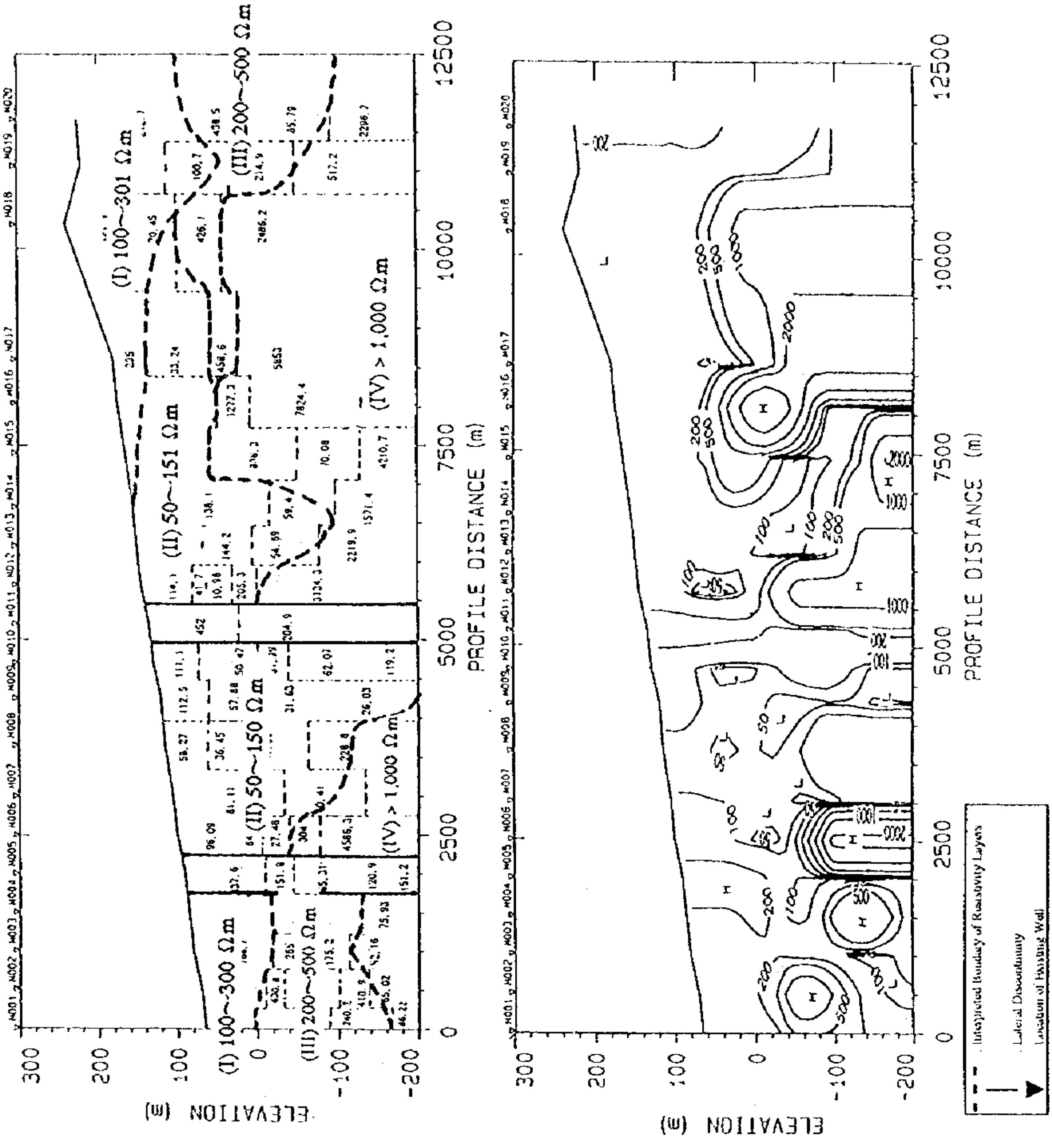

Fig. 8.2.14-2 Geoelectric Profile (Line M: W. Dahab)

8.2.15 Wadi Kid

1) General Feature of Basin

Wadi Kid is located in the southeastern part of the Sinai Peninsula; Approximately 30 km northeast from Sharm El Sheikh (Ref. Fig. 8.2.15-1).

The section, the down stream from the National High Way, is called the W. Kid. The W. Kid has main tributary of W. Madsos.

Precambrian Basement Rocks are predominant in the area. Overlying the Basement Rocks, the Quaternary Wadi Deposits are distributed in the wadi. The thickness of the Deposits reaches to 70 m. A fan is formed in the mouth of the wadi. A village, Nabq is located on the fan.

2) Well Inventory

Only one (1) cased well has been known in the downstream of Highway. However, inventory survey revealed that two (2) dug wells exist in the upstream and surface water is utilized for irrigation by small simple facilities. The Inventory and location map are shown in Table 8.1.1-1 (15) and Fig. 8.2.15-1, respectively.

WRRI conducted a geophysical study on the Wadi Deposits in 1993 to evaluate the thickness of the deposits and to locate groundwater reservoir within the deposits. The study area covers 2.6 km of the section.

3) Supplementary Geological Survey

WRRI conducted geological and geophysical survey in the wadi. The results are available. Therefore, no geophysical survey was executed in this Study.

According to the study, the deposits are divided into three (3) units as shown in the table below.

Unit	Resistivity (Ω-m)	Thickness (m)	Depth (m)	Geology
Upper Unit	188 - 3600	32 - 73		Alluvium Deposits (Dry unit)
Middle Unit	25 - 82	183 - 257	32- 73	Weathered Granite (Aquifer)
Deeper Unit	226 - 520 (West)	(Depth) 220 - 330	150 ~	Weathered Granite
	60 - 90 (East)		150 - 230	Weathered Granite (Salty water)

A geoelectrical cross section of the wadi is shown in Fig. 8.2.15-2. The main aquifer appears in the middle unit and contains fresh water. Thickness of the unit increases toward the west.

4) Groundwater Level

Static water level is 53 m BGL in the tube well and from 3.6 to 7.2 mBGL in the dug wells.

5) Groundwater Quality

(1) Obtained Data

JICA Study Team has carried out field water quality survey for a Dug Well (February, 1997). A groundwater quality map is provided as shown as Fig. 8.2.15-3..

(2) TDS Distribution

A groundwater quality map of shallow aquifer in the area is provided as shown as Fig. 13. The measured TDS value is very low. It is less than 500 mg/l. It seems that groundwater quality of the wadi is generally good and suitable for drinking water.

6) Hydrogeological Feature of Basin

Main source of recharge to the aquifer is precipitation and the fissure water derived from the fractured granite distributed tin he surrounding area. Transitional zone exists in the eastern part of the deeper unit, where the resistivity is relatively low.

It is considered that the sea water intruded to the eastern part of the Fan. Static water level is detected at the depth of 50.3 mBGL and the water is fresh.

A few small structures were constructed in the upstream of the wadi for detention of surface water after flood.

7) Groundwater Extraction

Groundwater is extracted form only dug wells for domestic and irrigation use. However, most of domestic water in the downstream area is supplied by tank lory from other source.

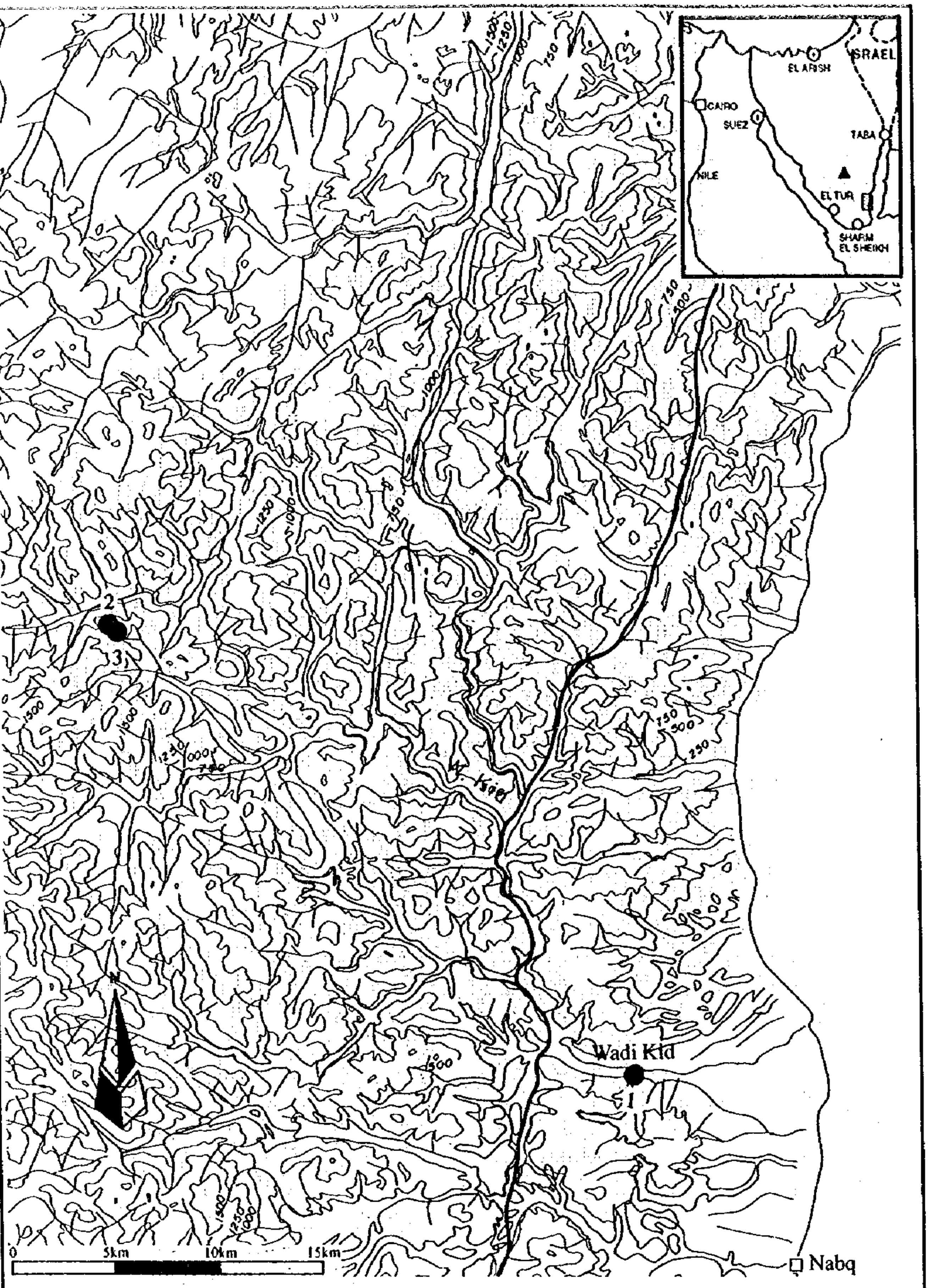

Fig. 8.2.15-1 Well Location (Wadi Kid)

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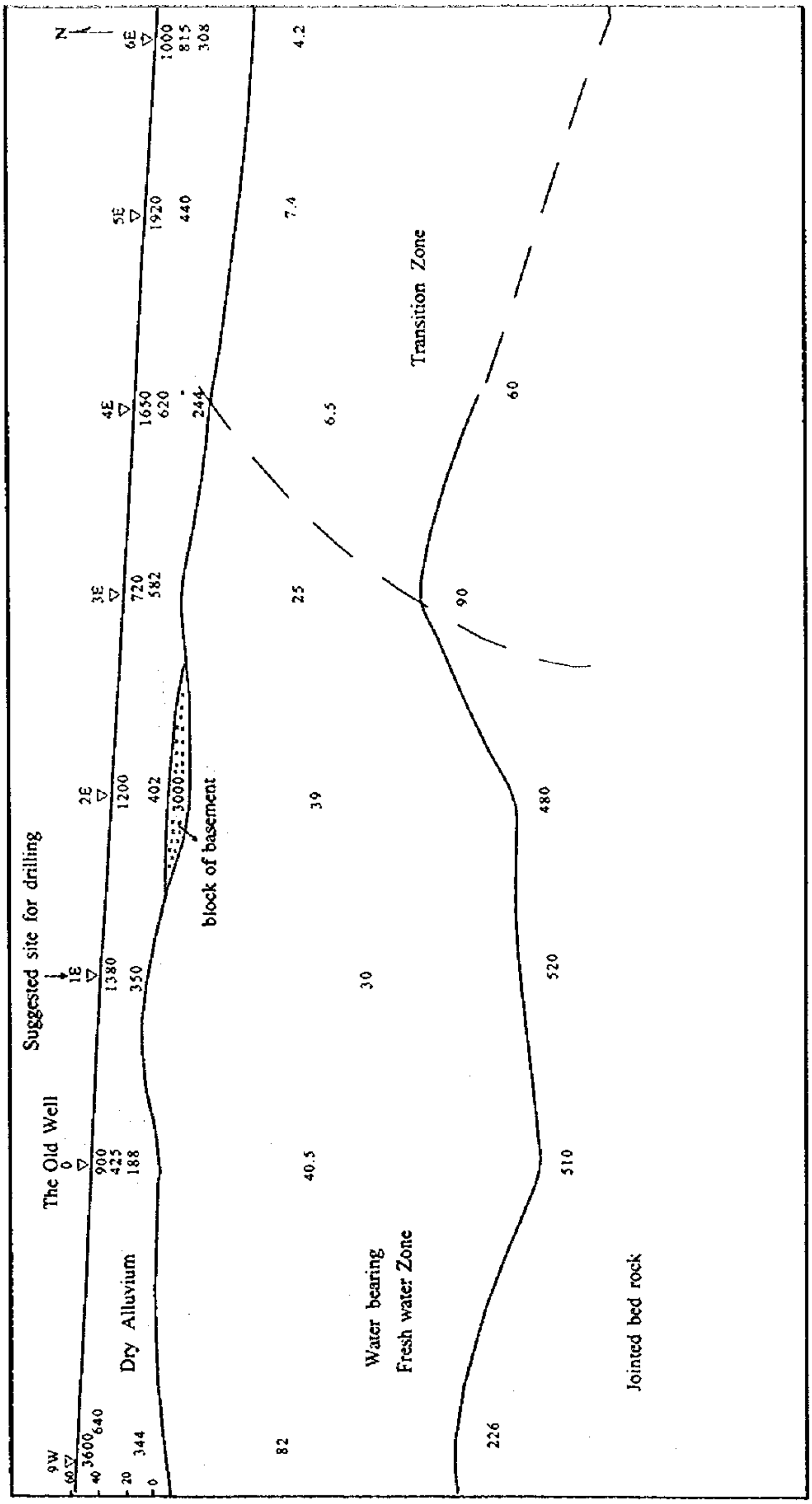

(Source : Groundwater Exploration in Wadi Kid)

Fig. 8.2.15-2 Geoelectric Section (W. Kid)

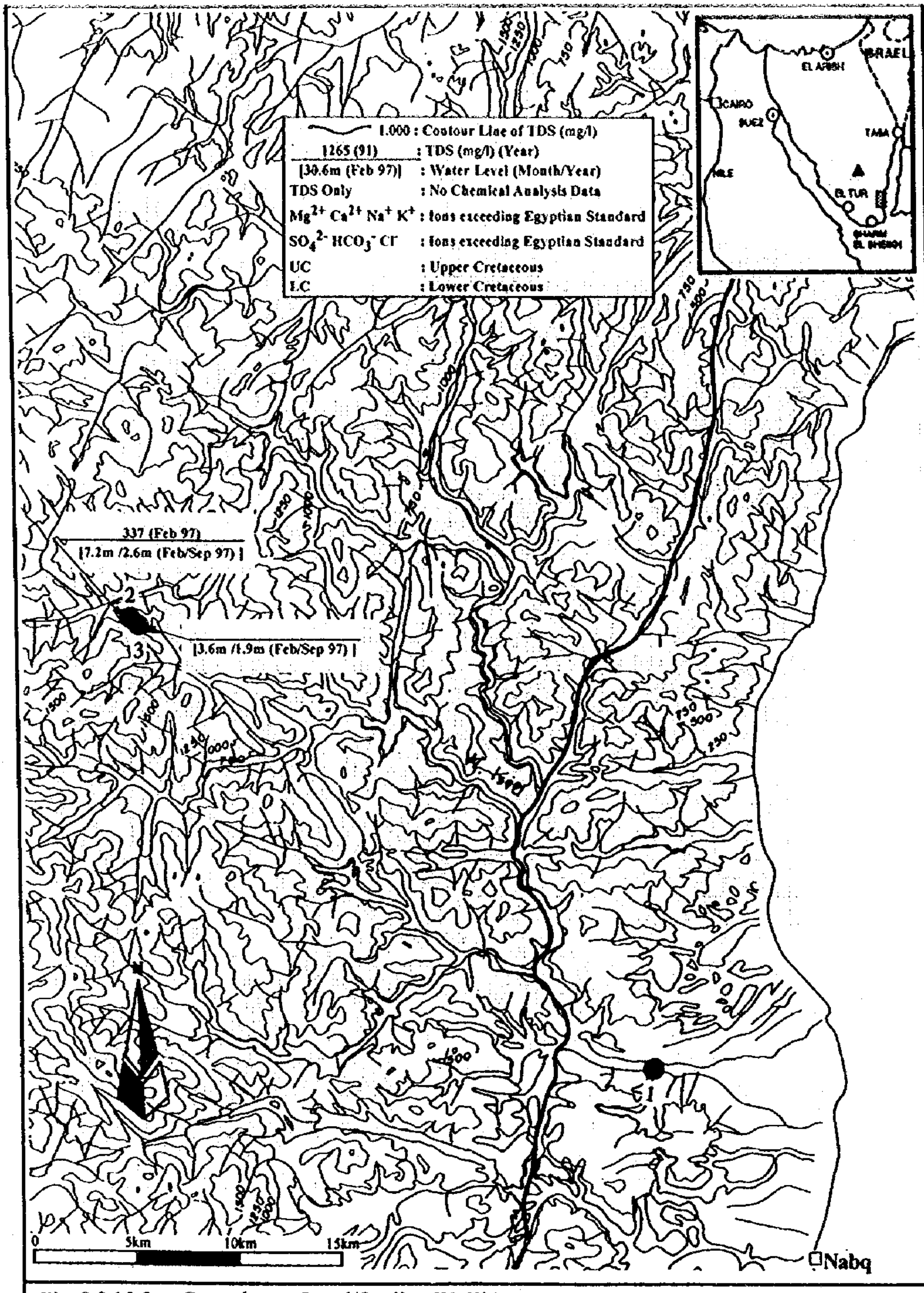

Fig. 8.2.15-3 Groundwater Level/Quality: W. Kid (unit: mBGL)

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8.2.16 Upstream of Wadi El Arish

1) General Feature of Basin

The Wadi El Arish is the most largest wadi in Sinai which originates near Gebel Egma in South Sinai and flows out to the Mediterranean Sea at El Arish in North Sinai. It covers 16,306 km^2 in total. The Study area includes the upstream of the wadi of which area is about 8,191 km^2.

El Malha is the most major village in the wadi. In the village there are many farms using both surface water and groundwater. In other area, distribution of water sources is scarce.

2) Available Data

No inventory was available in the area, therefore, inventory survey was carried out especially concentrating into El Malha area. A total of 19 dug wells and two (2) cased wells were listed as the result. Among them, only two (2) dug wells are extracting groundwater from the Quaternary Formation. One is in the El Malha and other is far from El Malha (Table 8.1.1-1 (16) and Fig. 8.2.16-1). Others 17 wells are tapping groundwater from the Upper Cretaceous Aquifer.

3) Groundwater Level

Groundwater level is shown in Fig. 8.2.16-2; They are 4.97 mBGL in the well (Sr. No. 1) and 11.15 mBGL in the well (Sr. No. 2).

4) Groundwater Quality

TDS value of both well is high, more than Egyptian Drinking Standard; They are 3,250 mg/l in the well (Sr. No. 1) and 3,150 mg/l in the well (Sr. No. 2) (See, Fig. 8.2.16-2).

5) Hydrogeological Characteristics of Basin

Dug well (Sr. No.2) in the main stream of the Wadi El Arish and is near to JICA Well No.3. Another (Sr. No.1) is located in the branch of the Wadi. Both wells are extracting groundwater from the Wadi Deposits for irrigation. It seems that groundwater is recharged by the flood water occurred in the Wadi El Arish.

6) Groundwater Extraction

No data is available.

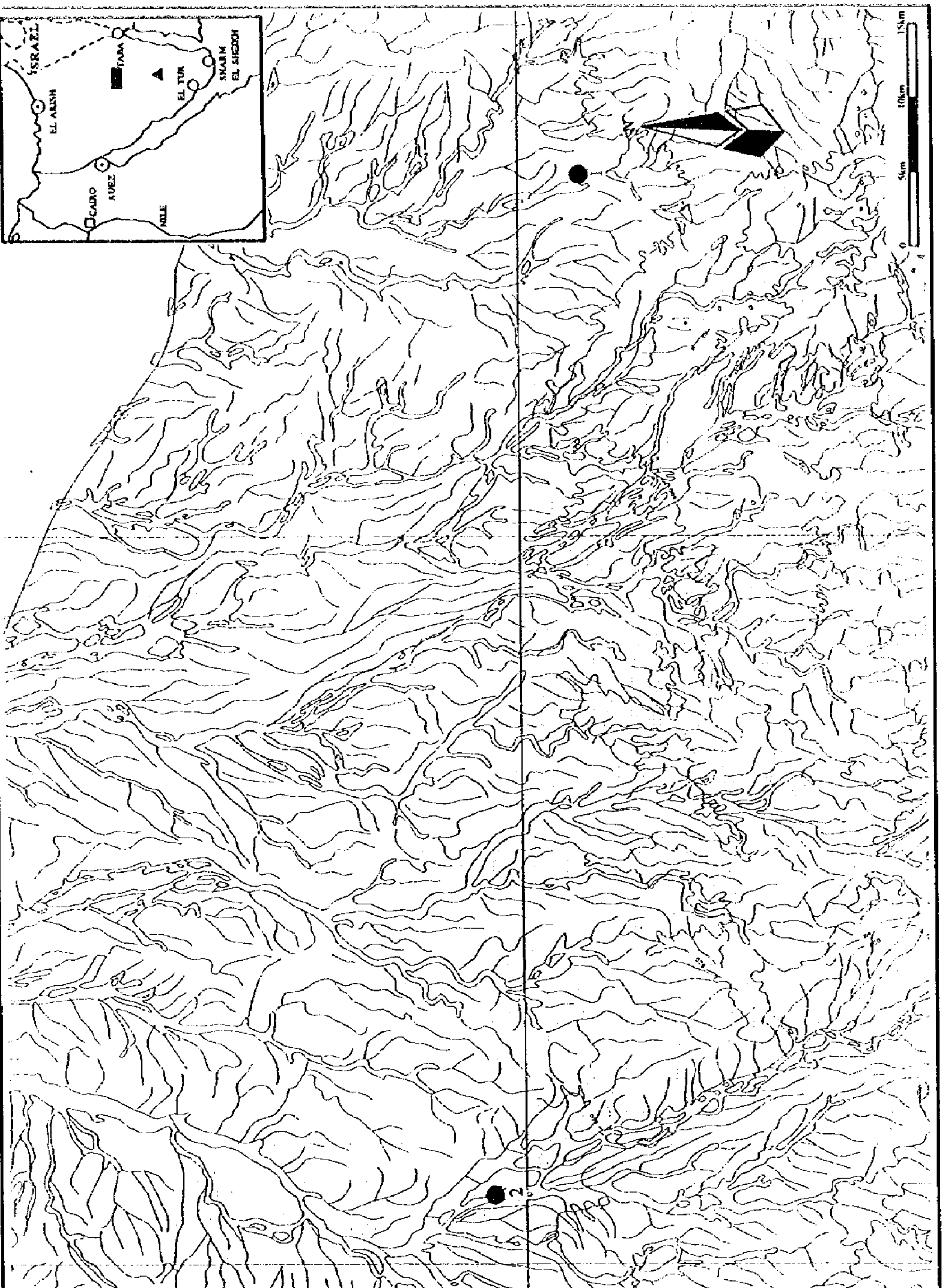

Fig. 8.2.16-1 Well Location (Wadi El Arish)

SOUTH SINAI GROUNDWATER RESOURCES STUDY IN THE ARAB REPUBLIC OF EGYPT | JICA

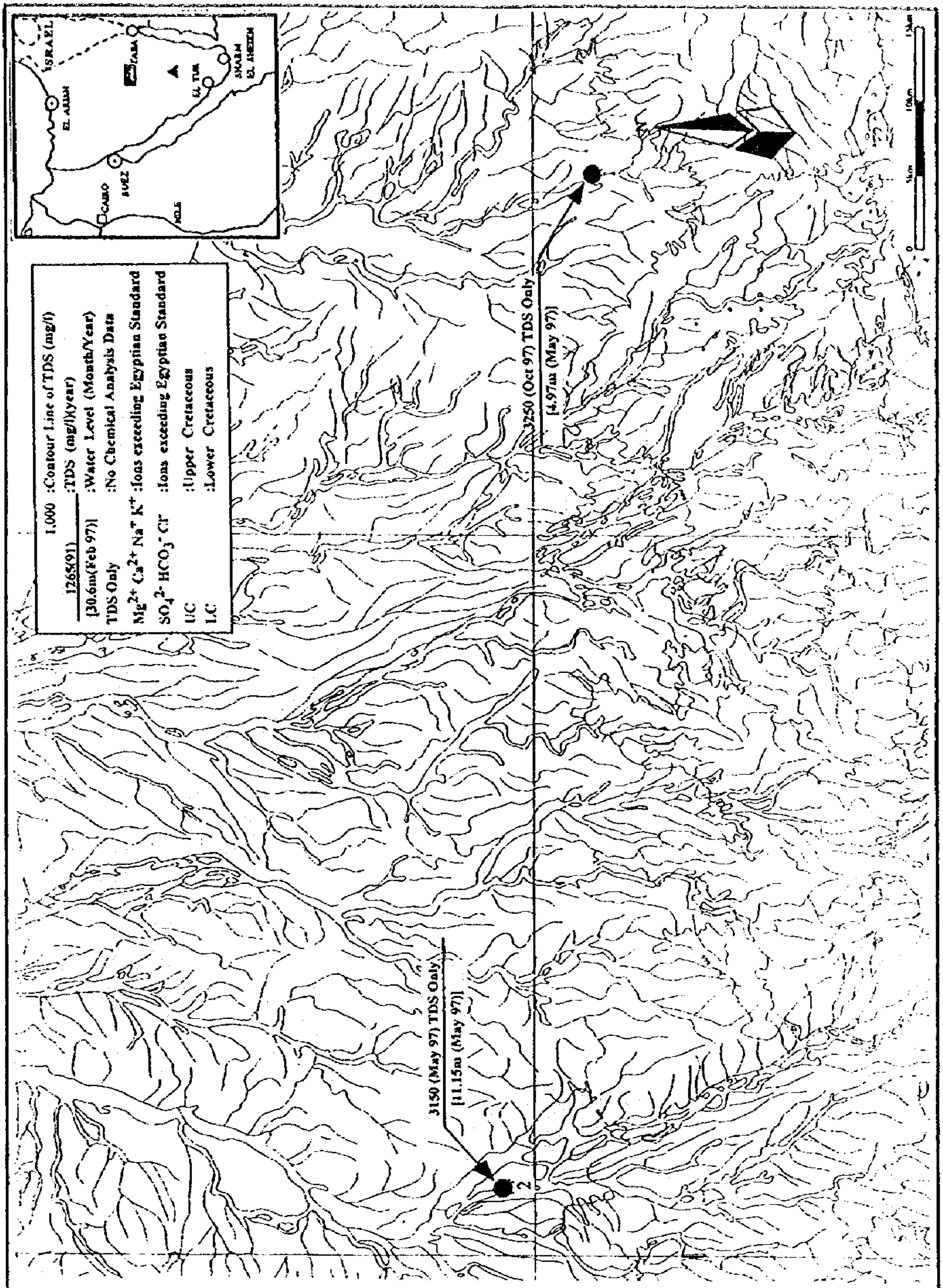

Fig. 8.2.16-2 Groundwater Level/Quality: W. El Arish (unit: mBGL)

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8.3 Pre-Quaternary Aquifers

Main Pre-Quaternary aquifers in South Sinai appear in the following three (3) units;

(1) Upper Cretaceous Sedimentary Rocks

(2) Lower Cretaceous Sedimentary Rocks

(3) Precambrian Basement Rocks

Previous studies on the Pre-Quaternary aquifers have been executed in the limited areas such as Wadi Feiran, Wadi Gharandal and Wadi Sheira, and no study was carried out in the central plateau area (Egma and El Tih Plateaux). Many wells have been drilled into the Pre-Quaternary aquifers for test, observation, production and oil exploration, etc,.. An inventory of these wells is shown in Table 8.1.2-1. Location of existing well is shown in Fig. 8.3-1.

8.3.1 Upper Cretaceous

1) General Features of Aquifer

Upper Cretaceous Sedimentary Rocks are divided into four (4) geological units by age.

Age	Formation	Main Facies
Senonian	Sudr Formation	chalk
	Matallah Formation	marl
Turonian	Wata Formation	limestone, dolomitic limestone
Cenomanian	Galalah Formation	limestone

The Upper Cretaceous Formations are predominant in the central plateaux area (Egma and El Tih Plateaux) overlying the Lower Cretaceous Formation and overlain by the Tertiary Formations.

Egma Plateau is widely underlain by the Upper Cretaceous Formations and forms a steep cliff of the Formations at its fringe. The Formations are covered by the Esna Formation which is overlain by the Egma Formation.

The Upper Cretaceous Formations in the central plateaux area have not been studied until test well drilling at El Malha area by WRRI. Therefore, information about the Upper Cretaceous in the central plateaux area was scarce. However, fissured limestone, which is the Turonian Limestone, is considered as a main aquifer.

Groundwater extraction in the Turonian Limestone is confirmed in the Wadi Sheira and in the Wadi Gharandal. One (1) well was recently drilled in the Wadi Sudr for military. This well reached the Upper Cretaceous. Furthermore, many dug wells are tapping groundwater from the Sudr Formation of the Upper Cretaceous at El Malha area.

In this Study, aquifer test by air-lifting was performed in six(6) wells, No. J-1 to J-6, to confirm the existence of groundwater in the Upper Cretaceous Formation. Among them groundwater appeared at three (3) wells while groundwater in the Lower Cretaceous appeared in all the wells except J-5.

2) Well Inventory

Hydrogeological data and location of wells which are penetrated the Upper Cretaceous Formations are shown in the Table 8.3.1-1 and Fig. 8.3.1-1. In addition, detailed location maps were prepared as Fig. 8.3.1-2 for Wadi Gharandal and Fig. 8.3.1-3 for El Malha area. There are four (4) cased wells, 17 dug wells and two (2) hot springs, totaling 23 water sources.

At El Malha Village, about 60 km south of Nakhl, these dug wells are tapping groundwater form chalk of Sudr Formation, Upper Cretaceous. Some spring also occurs in the same formation in the south of El Malha Village and in the upstream of the Wadi Sudr.

Groundwater level was measured at three (3) JICA Wells by air-lifting, however, it could not be confirmed at J-2, J-4 and J-5. It is also confirmed at El Malha-2 and dug wells at El Malha as shown below;

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-3	382-420	Turonian	Flow out	548	40.0	2,170
J-6	220-260	Turonian	115.08	595	11.0	2,670
El Malha-2	(pumping)	Senonian	14.50	625	3.86	1,906
Ain Erga	(spring)	Senonian	-	-	-	1,894
Ain Miteguna	(spring)	Senonian	-	-	-	-
Ain Sudr	(spring)	Senonian	-	-	-	704
Ain Resha	(spring)	Senonian	-	-	-	-
Ain El Desa	(spring)	Senonian				

3) Configuration of Aquifer

The Upper Cretaceous Formations crop out in the total area of Egma Plateau and are overlain by the Tertiary Formations. Although the Sudr Formation is eroded in a certain degree from place to place, elevation of top surface of the Upper Cretaceous and thickness of the Upper Cretaceous are presented in Fig. 8.3.1-4. Thickness of each age of the Upper Cretaceous is summarized as following table.

Age		J-1	J-2	J-3	J-4	J-5	J-6	Sheira-1	Average
Senonian	Maastrichtian	170	140	60	268	0	40	129	223
	Campanian	110	120	169		0	140		
	Santonian-Coniacian	55	56	72		0	30		
Turonian		175	151	194	380	80	80	208	181
Cenomanian		370	280	276	430	230	320	207	302
Total UC*		880	747	771	1078	310	610	544	706

UC: Upper Cretaceous

In South Sinai, the Upper Cretaceous aquifer appears in Senonian and Turonian. The Senonian is from 40 to 170 m thick. It decreases toward the south and increases to the north.

The Turonian, main aquifer in the Upper Cretaceous in South Sinai, is between 80 and 380 m in thickness, averaging 181 m.

4) Groundwater Level

In Wadi Gharandal, the groundwater level was measured as 20.7m B.G.L at Wadi Gharandal-2 as shown in Fig. 8.3.1-5. As to JICA wells, groundwater level was measured at three wells. Assuming that their groundwater is connected each other, the gradient of the groundwater is calculated as below table.

Well	SWL (mA.S.L)	Distance (km)	Gradient
No. J-6	695	0	
No. J-3	547	27.5	1.7/1,000
No. J-1	449	20.0	4.8/1,000

It is remarkable that groundwater flowed out automatically from the top of surface casing without air-lifting at J-3. This is the first time to confirm the artesian well which piezometric head was 3.5m high from ground surface in the Upper Cretaceous all over the Sinai Peninsular.

In the Wadi Gharandal, only one (1) groundwater level is reported as 20.7 mBGL at the well Gharandal-2 (Fig. 8.3.1-6). Dug wells in El Malha area is between 3.2 and 11.4 mBGL as shown in Fig. 8.3.1-7.

5) Groundwater Quality

(1) Availability of Data

A total of seven (7) chemical analysis data of groundwater quality of Upper Cretaceous aquifer is available. These data includes two (2) samples of aquifer test from the newly drilled JICA test wells (J-3 and J-6). In addition, the samples are collected and analyzed from two (2) springs (Ain Abou Ragem and Hamman Faraoun) and two dug wells in El Malha by JICA Study Team. Existing data for the cased well of Gharandal-2 (Code No. 36AC-001) was collected from the drilling report.

(2) Groundwater Quality of Upper Cretaceous Aquifer

The obtained groundwater quality data for Upper Cretaceous aquifer are as follows;

No.	Location	Well Name	TDS (mg/lit.)
1	Rus Sudr	Ain Abou Ragem	5,650
2	El Malha	Abd Allah Seleman -1	1,648
3	El Malha	Abd Allah Seleman -2	1,572
4	El Gharandal	Hammam Faraoun	12,930
5	W. Gharandal	Gharandal-2	8,,048
6	El Tih	J-3	6,738
7	El Tih	J-6	2,952

In order to facilitate comparison and grouping of the groundwater type, all data are plotted on the Piper diagram and Schoeller graph (See, Fig. 8.3.1-8).

Among the above data, the TDS values of Gharandal, J-3 and Hammam Faraoun are very high. It is more than 5,000 mg/l. Moreover, major ion components of Ca^{2+} , Mg^{2+} , Cl^- and SO_4^{2-} are exceeding Drinking Water Standard. The distribution of TDS together with water type is shown in Fig. 8.3.1-9. The TDS of groundwater of Upper Cretaceous aquifer shows rather a high value, except 2 dug wells in El Malha area. The range of TDS value varies widely from1,500 to 13,000 mg/lit. Moreover, no particular tendency on its distribution is found. These results suggest that the groundwater of Upper Cretaceous aquifer is discontinuous.

A groundwater quality map of shallow aquifer in El Malha area is provided as shown as Fig. 8.3.1-7. There are 16 dug wells with upper cretaceous aquifer are located in the area. The depth of the Dug Wells is 3m to 14m. A range of TDS value of these wells is 1,500 to 2,000 mg/l, except two dug well of No. 15 and 17. The salinity of groundwater of these well is very high. It is 4,505 mg/l at No.15, and 9,274 mg/l at No.17. The chemical analysis of 2 wells of Abd Allah Seleman-1 and 2 have been conducted by JICA Study Team (1997). The results of chemical analysis shows that the TDS value increase slightly during summer season. Therefore, it is suggestive of groundwater recharge in winter.

In spite of the TDS varies widely, the groundwater type of the aquifer is mostly the NaCl type. In only two wells in El Malha area, a seasonable variation on groundwater type from $MgSO_4$ (winter) to NaCl (summer) is confirmed. This phenomenon is a similar with the Quaternary aquifer. These wells in El Malha are the shallow dug wells. Therefore, it is considered that the $MgSO_4$ is the also representative of the recharged groundwater.

6) Hydrogeological Characteristics of Aquifer

JICA Wells, J-1, J-3 and J-6 at the section mentioned above and revealed that groundwater exists in the fractured Turonian limestone. Aquifer of El Malha-2, springs and dug wells is chalky limestone of the Sudr Formation of the Senonian.

It is considered that existence of groundwater in the Upper Cretaceous has close relation with geological structure because groundwater is mainly stored in fractures as shown in Fig. 8.3.1-10 which presents locations of water sources in the Upper Cretaceous and geological structures such as faults and dykes.

The western fringe of Egma Plateau is controlled by faults running in NW-SE direction. The main stream of the Wadi El Arish flows toward the northwest at first, then suddenly changes its direction to northeastward near J-3. Flow direction of the wadi also seems to be governed by faults. J-6, Malha-2 and J-3 are very close to structures in NW-SE direction. Springs, Ain Erga and Ain Abu Miteguna are also close to another faults.

Some springs are occurred in the upstream area of the Wadi Sudr: Ain Sudr, Ain El Resha and Ain El Desa. They are plotted near a group of faults.

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

It is considered that the Upper Cretaceous Formation is one of the aquifers in Sinai, which is a fractured/fissured aquifer, not like granular aquifer like the Lower Cretaceous formation. Groundwater in the Upper Cretaceous is connected with fractures and fissures, therefore, the Upper Cretaceous does not always yield aquifer in anywhere, but near the fractured zone.

Table 8.3.1-1 Hydrogeological Data (Upper Cretaceous)

Sr. No.	Well Identification WRRI Code No.	Well Name	Elev. (mASL)	S.W.L (mBGL)	S.W.L (mASL)	D.W.L (mBGL)	D.W.L (mASL)	TDS (mg/l)	Discharge Rate (m^3/h)	Specific Capacity (l/s/m)	Trams-missivity (m^2/day)
	Pre- Quaternary Cased Well										
4	65DA-002	Sheira 2	825	85.00	740.00			1100	5		
23	36AC-002	Wadi Gharandal 2	290	20.66	269.34	77.34	212.66	8048	5	0.02	1.3
39		El Malha 1									
40		El Malha 2		14.50		113.29		1906	3.86	0.01	0.226
41		JICA 1	520	71.08	448.92			2790			
43	45CA-001	JICA 3	544	-3.80	547.80			2170	35.55	1.64	470.3
46	46AB-001	JICA 6	710	115.08	594.92			2670	9.62	3.66	114.79
	Pre-Quaternary Dug Well (W.Qideira & Malha area)										
1	56AD-001	Bir Qideira	785					2253			
2	45EA-001	Abd Allah Seleman 1	635	9.60	625.40			1648			
3	45EA-002	Abd Allah Seleman 2	640	9.95	630.05			1572			
4	45EA-003	Salama Abu Aid	620	9.50	610.50			1485			
5	45EA-004	Aid Salah	620								
6	45EA-005	Kedel Saad 1	625	9.45	615.55			1059			
7	45EA-006	Gamaan	625								
8	45EA-007	Lefy Amhamed	630	13.80	616.20			1498			
9	45EA-008	Salama Aid 1	630								
10	45EA-009	Salama Aid 2	630								
11	45EA-010	Kedel Saad 2	625								
12	45EA-011	Salah Aid (farm)	630								
13	45EA-012	Shaleh Slaiman	620								
14	45EA-013	Hosein Sriman (1)	620	8.67	611.33			1734			
15	45EA-014	Hosein Sriman (2)	620	7.66	612.34			4505			
16	45EA-015	Bir El Malha	620	6.26	613.74			1581			
17	45EA-016	Salha Hamad	640	14.60	625.40			9274			
	Pre-Quaternary Spring										
2	35BA-001	Hammam Faraoun	0					12930			
4		Hamam Musa	0					9378			
5	34EB-001	Ain Sudr		0.39				704	35		
6	35AB-003	Ain Resha		0.86				890			
7	35AB-001	Ain Desa		0.55				1150	112		
8		Ain Erga						1894			
9		Ain Abu Miteguna									

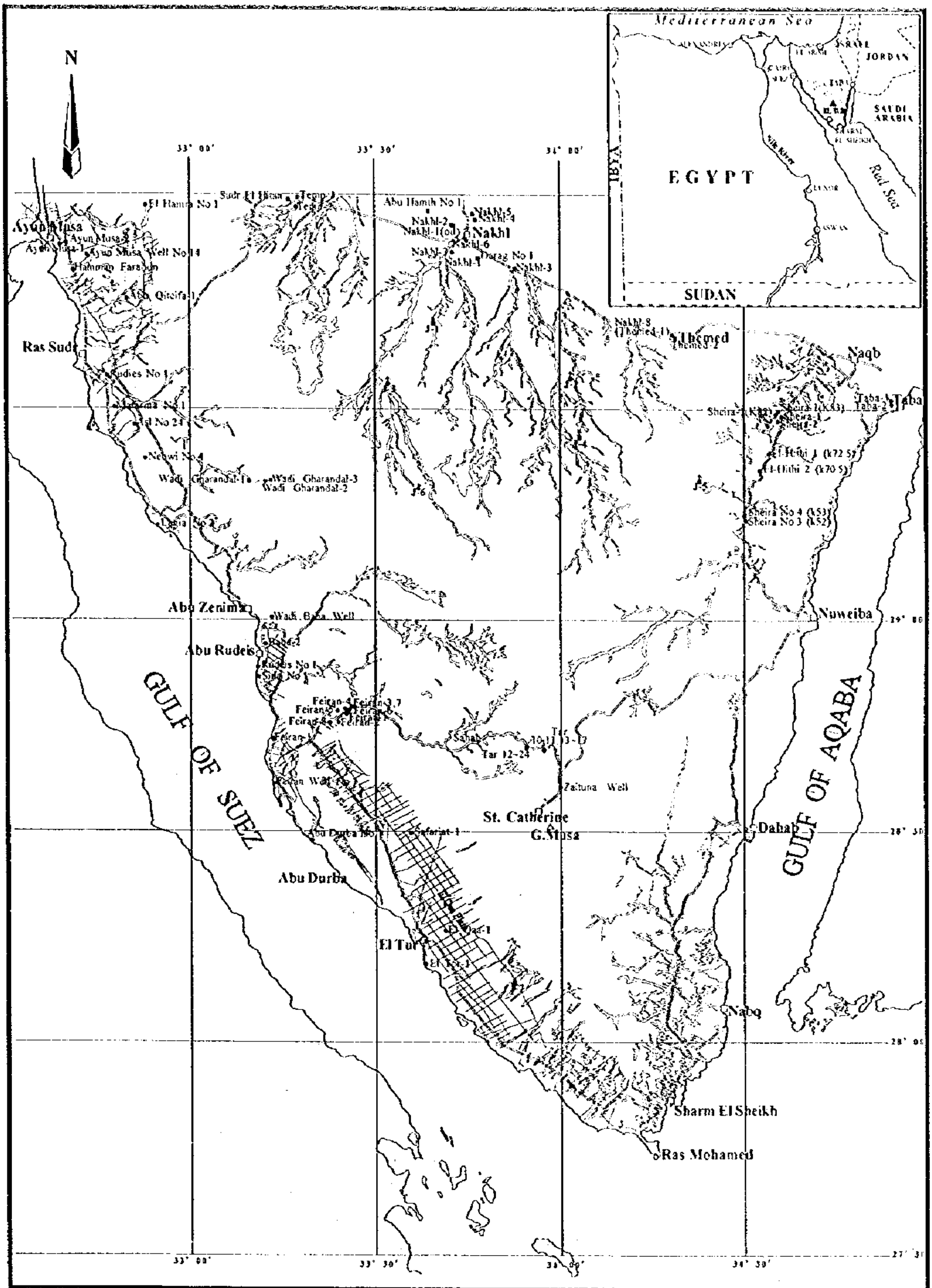

Fig. 8.3-1 Well Location (Pre-Quaternary Aquifer)

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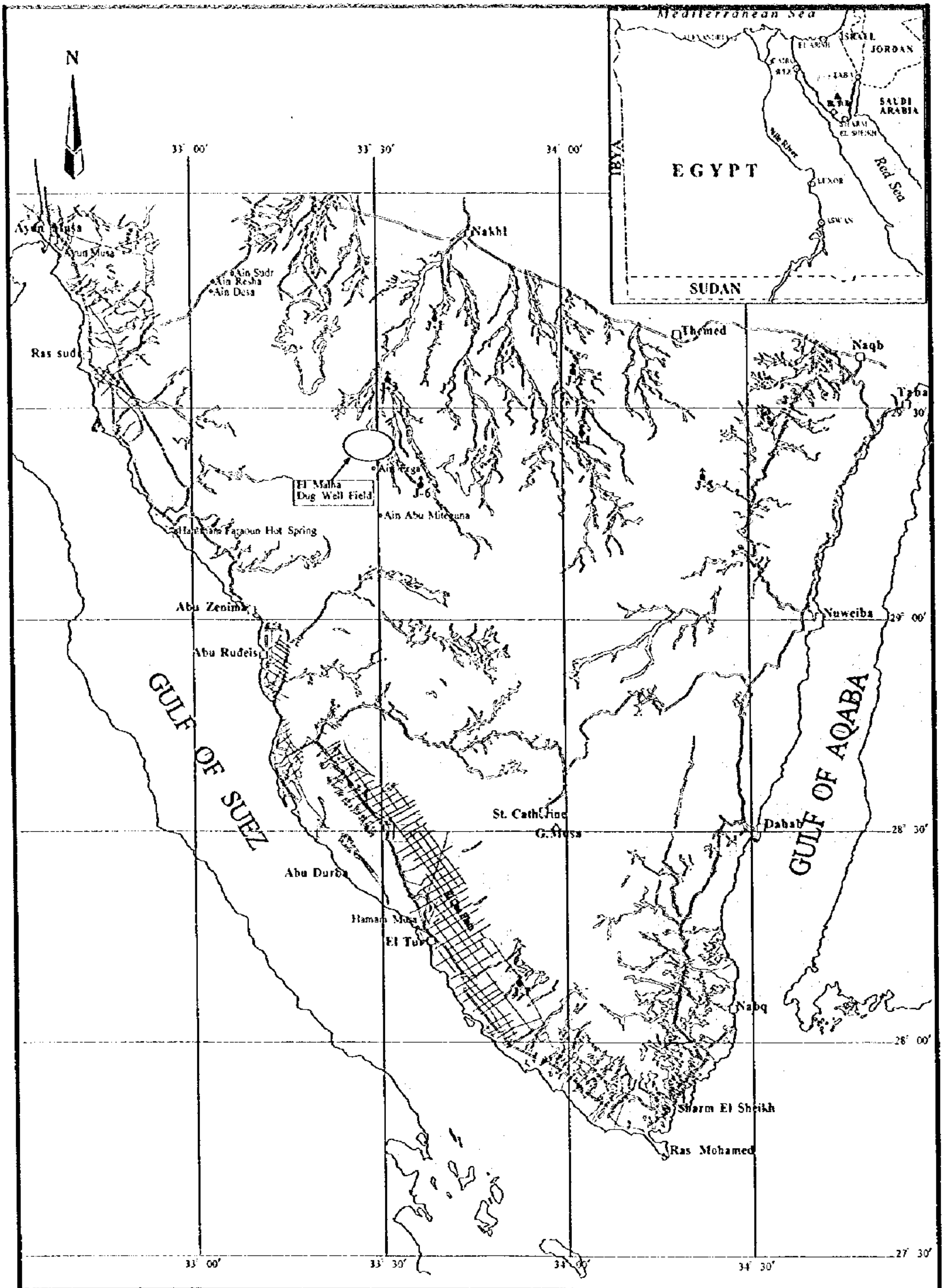

Fig. 8.3.1-1 Well Location (Key Map :Upper Cretaceous)

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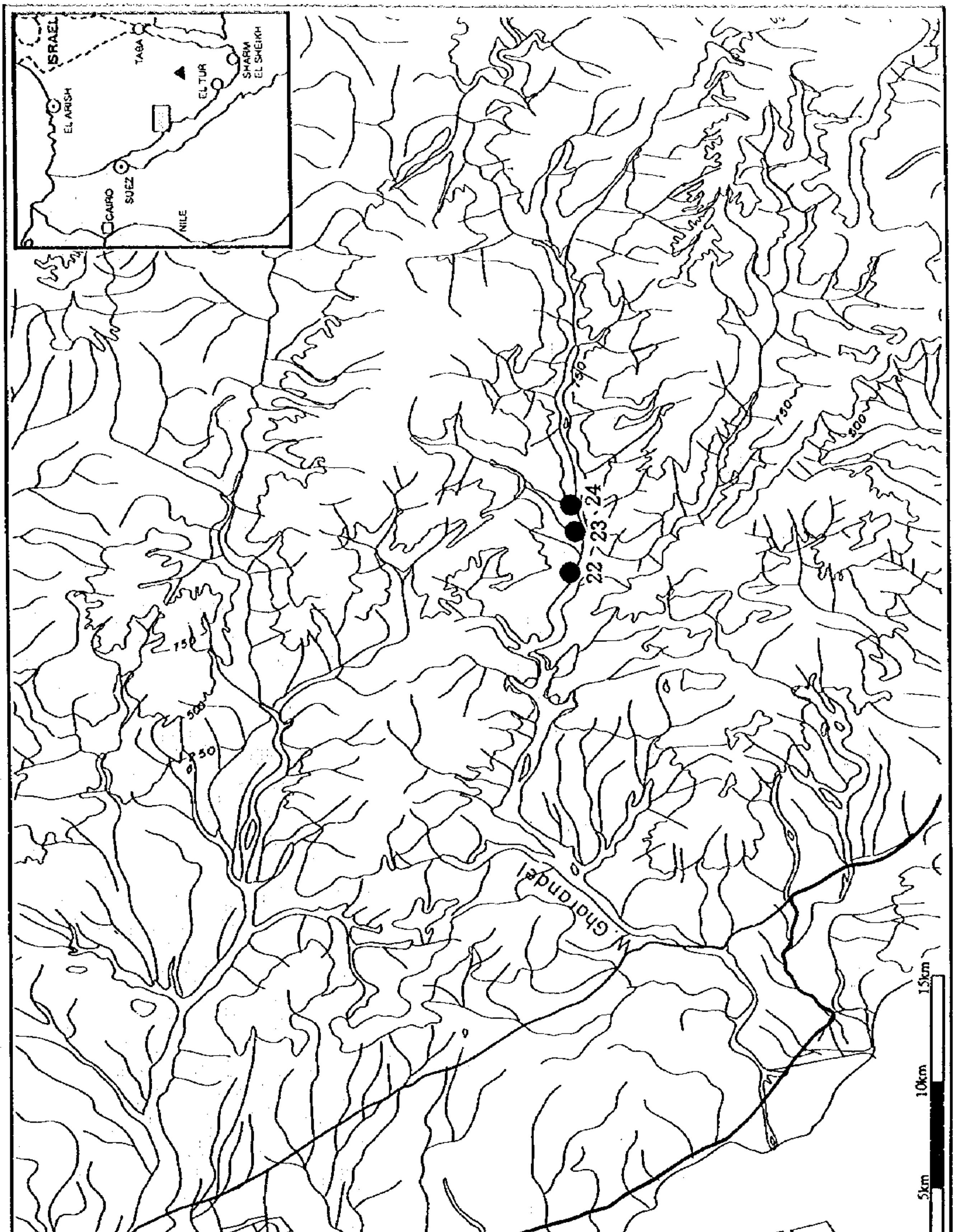


Fig.8.3.1-2 Well Location (Pre-Quaternary Cased Well : Wadi Gharandal)

SOUTH SINAI GROUNDWATER RESOURCES STUDY IN THE ARAB REPUBLIC OF EGYPT | JICA

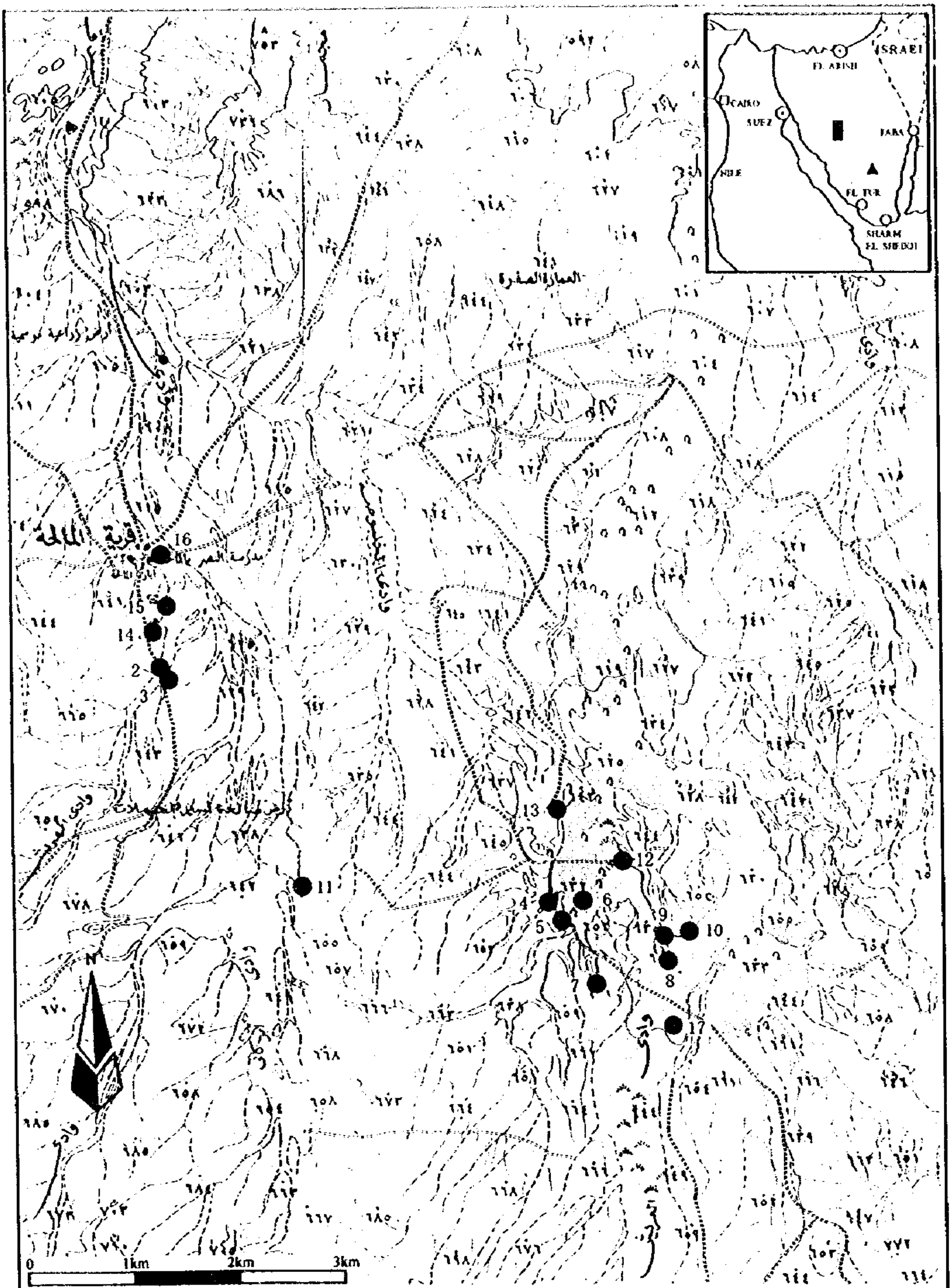


Fig.8.3.1-3 Location of Dug Well (Pre- Quaternary : Malha)

SOUTH SINAI GROUNDWATER RESOURCES STUDY IN THE ARAB REPUBLIC OF EGYPT	JICA

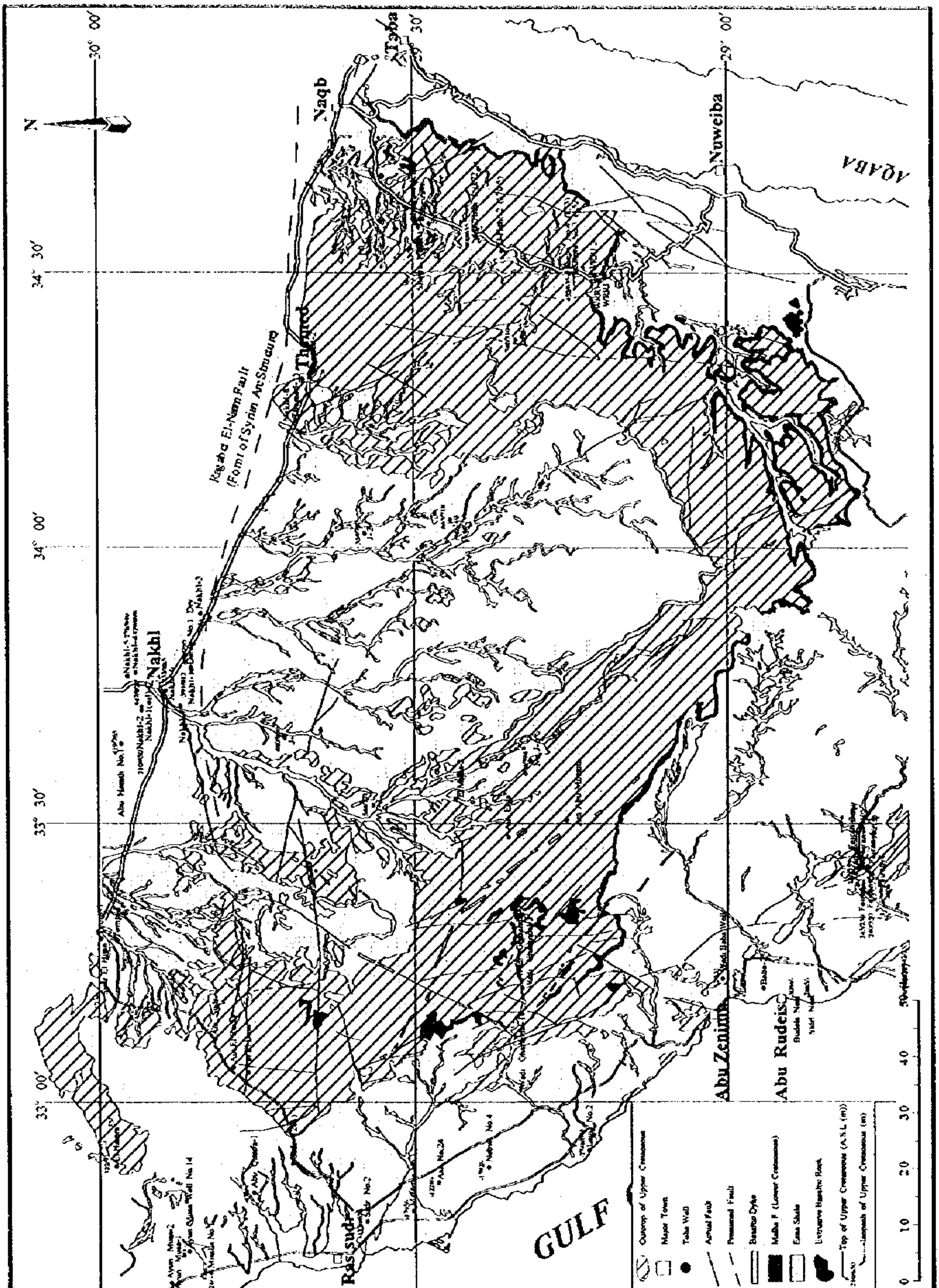


Fig. 8.3.1-4 Isopach and Top of Upper Cretaceous

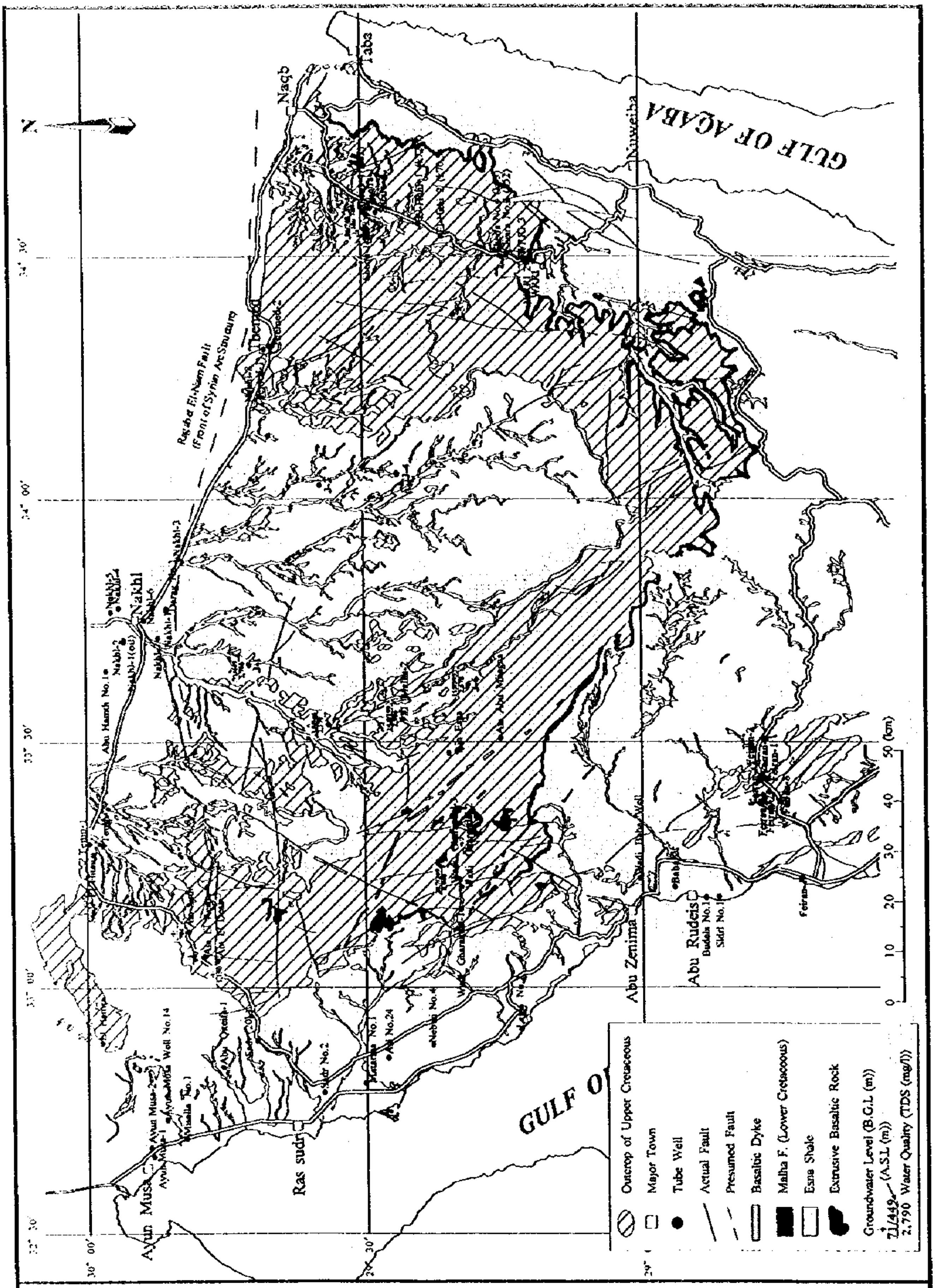


Fig. 8.3.1-5 Groundwater Level/Quality (Upper Cretaceous)

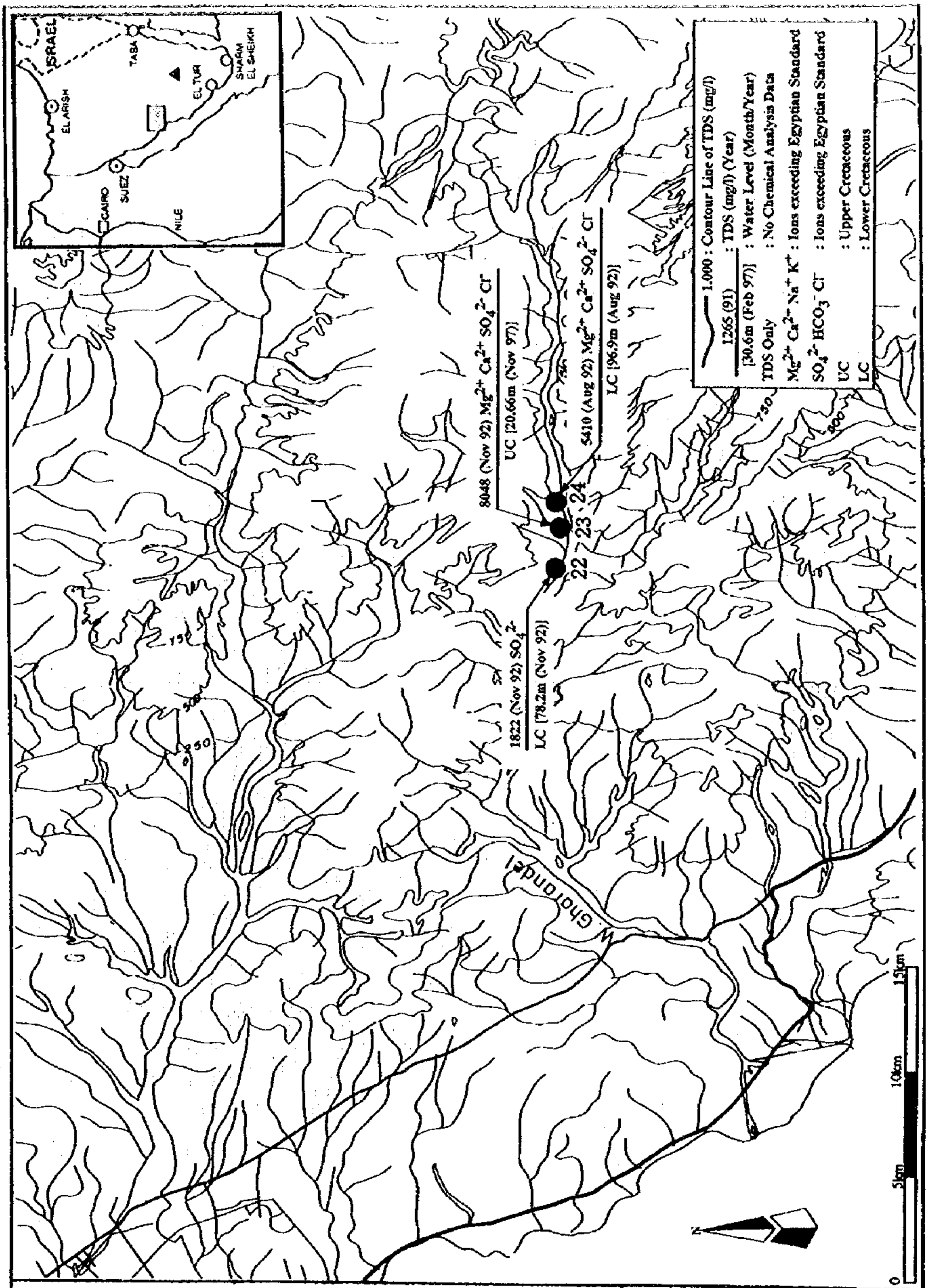


Fig.8.3.1-6 Groundwater Level / Quality (W.Gharandal : Upper Cretaceous)

SOUTH SINAI GROUNDWATER RESOURCES STUDY IN THE ARAB REPUBLIC OF EGYPT | JICA

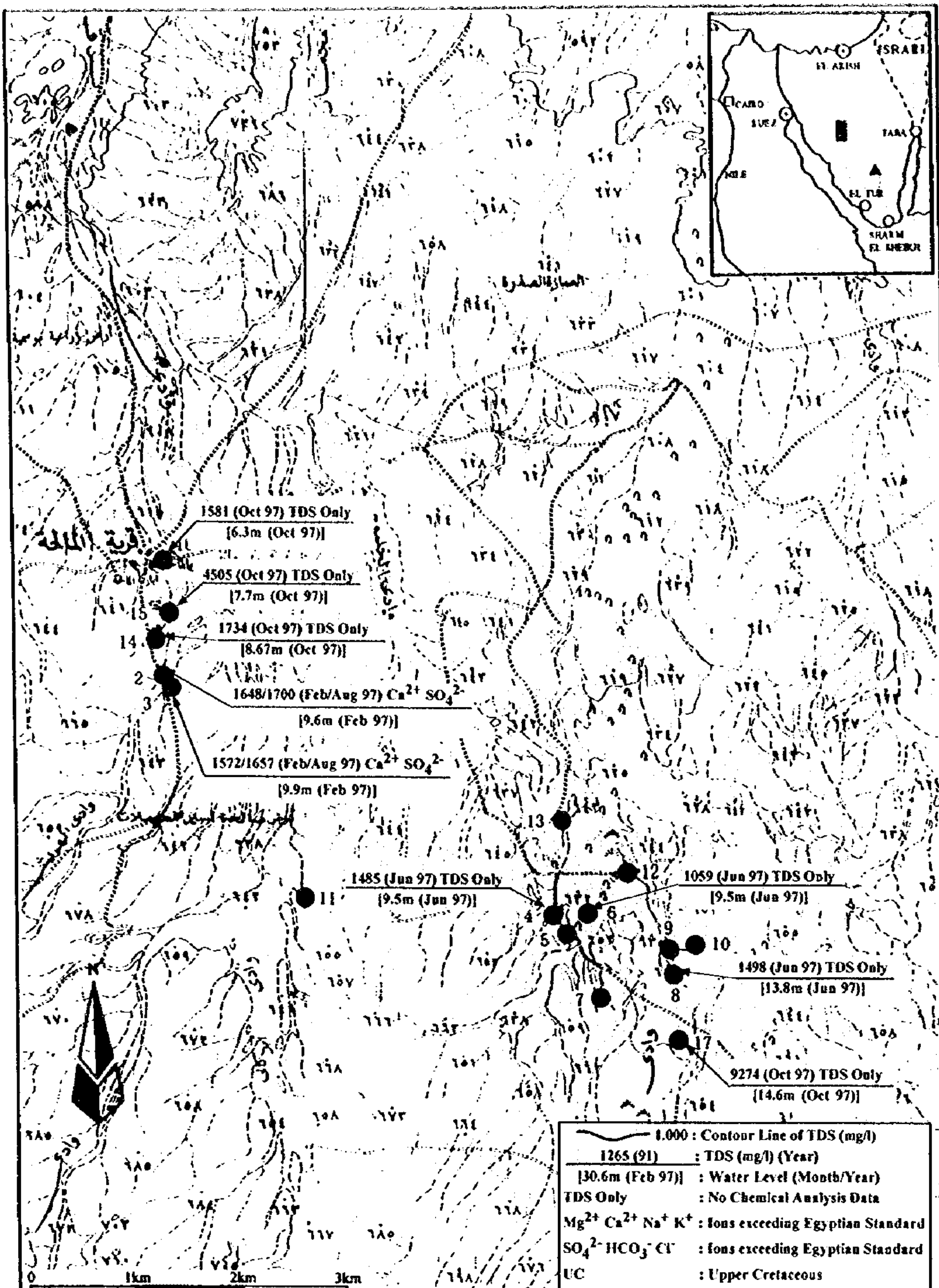
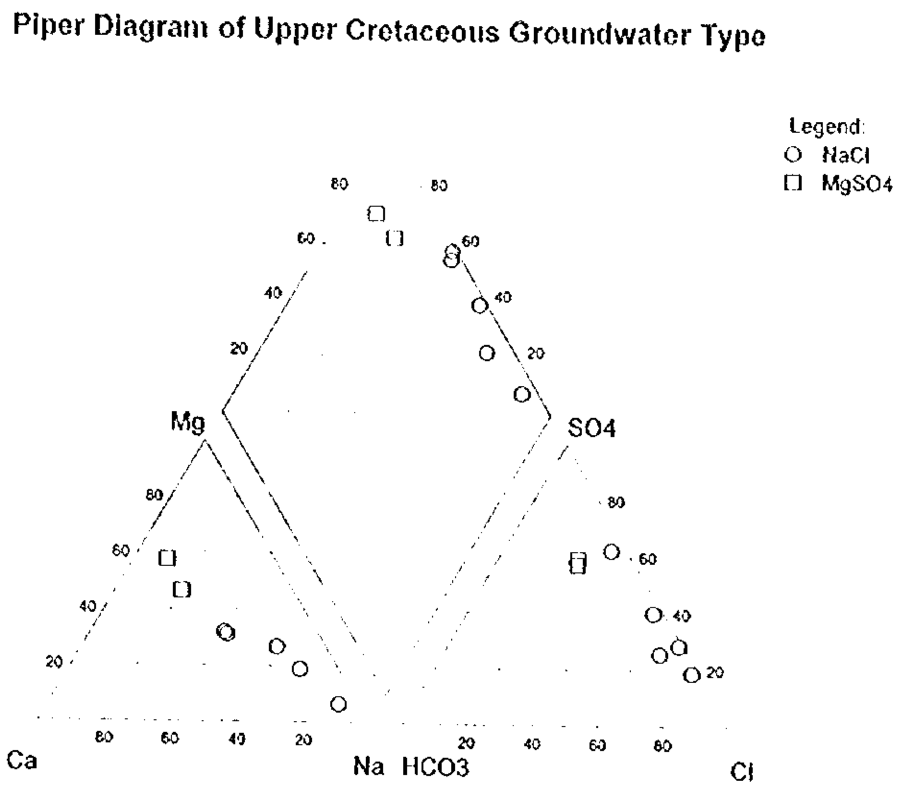


Fig.8.3.1-7 Groundwater Level / Quality (El Malha : Upper Cretaceous)



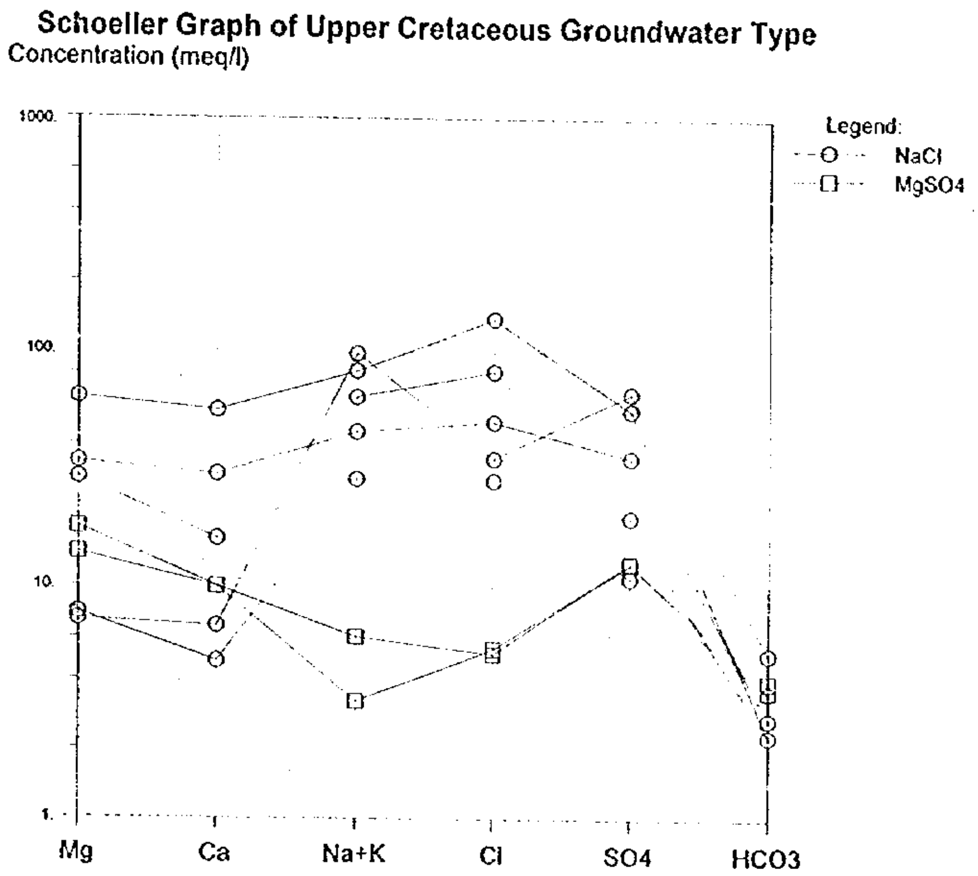


Fig.8.3.1-8 Piper Diagram and Schoeller Graph (Upper Cretaceous Aquifer)

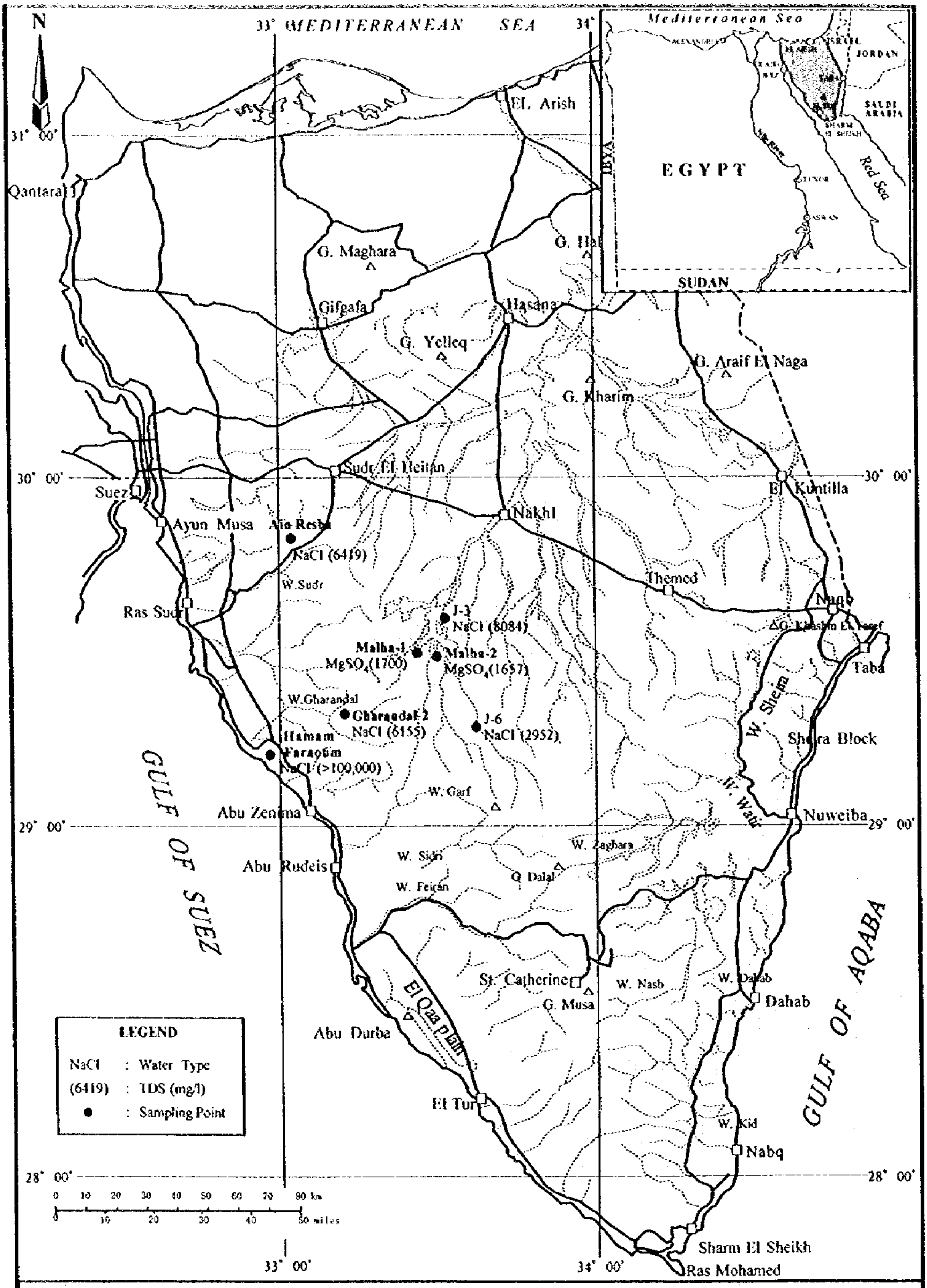


Fig. 8.3.1-9 TDS Distribution and Water Type of Upper Cretaceous Aquifer

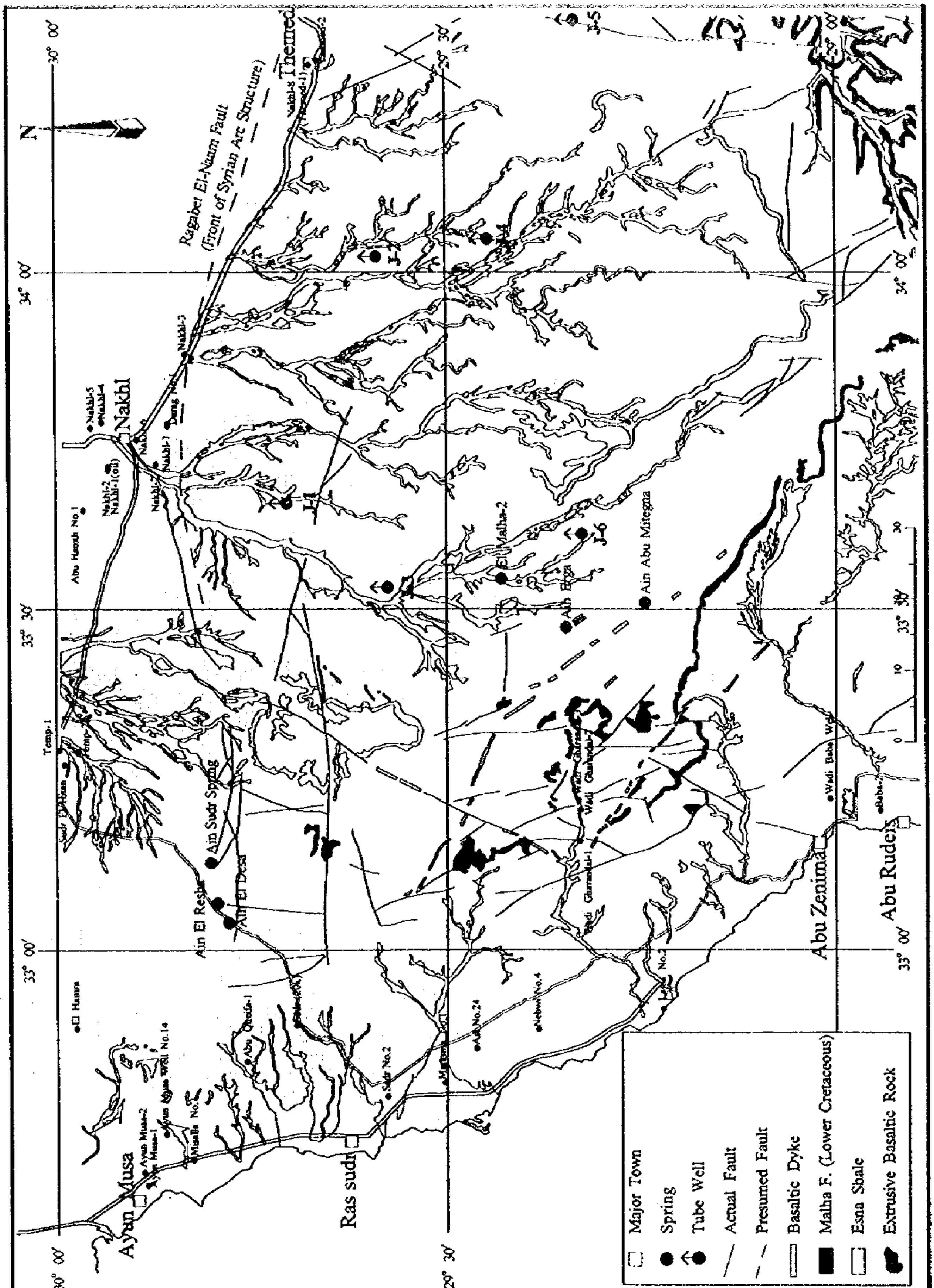


Fig. 8.3.1-10 Hydrogeological Situation of Wells (Upper Cretaceous)

SOUTH SINAI GROUNDWATER RESOURCES STUDY IN THE ARAB REPUBLIC OF EGYPT | JICA

8.3.2 Lower Cretaceous

1) General Features

The Precambrian Basement Rocks gently dip toward the north and overlain by the Paleozoic to the Cenozoic Formations in Egma and El Tih Plateaux. Their sequence is the Precambrian, the Paleozoic, the Mesozoic and Cenozoic in ascending order. The Lower Cretaceous Malhah Formation overlies the Jurassic Formation and overlain by the Upper Cretaceous Formations.

The Lower Cretaceous is represented by quartzose sandstone and shale. The sandstone forms an aquifer and it is the most prospective aquifer in the Study Area. Thickness of the Lower Cretaceous is about from 200 m to 300 m although it changes from place to place. The most significant aquifer occurs in the quartzose sandstone and its thickness is generally more than 100 m.

The Lower Cretaceous Sandstone has been considered as the most prospective aquifer in Sinai, however, actual study and development have been continued mainly in the marginal area of the Sandstone such as Wadi Gharandal, Wadi Feiran and Wadi Watir (including W. Sheira). Therefore, the area on the Egma and El Tih Plateaux (hereinafter referred to as "Main Block" in this report) is the vast virgin area of hydrogeological information.

Taking these circumstances into consideration, most of effort was paid to this area for evaluation of groundwater potential.

Isolated distribution of the Lower Cretaceous Sandstone was confirmed in the downstream of the Wadi Feiran and the Abu Durba area. The former forms a important aquifer to supply water in the area, since groundwater is recharged from the underlain Precambrian Basement Rocks. On the other hand, the latter has no chance to receive groundwater recharge from the basement rocks because precipitation in the Abu Durba area is scarce.

As the results of the Study, the Lower Cretaceous Aquifer is divided into following three (3) blocks considering the hydrogeological situation as shown in Fig. 8.3.2-1;

(1) Main Block: Aquifer, distributed in the El Tih and Egma Plateau except Wadi Sheira area.

(2) Sheira Block: Aquifer, distributed in the Wadi Sheira and the upstream of the Wadi Watir hydrogeologically isolating from the Main Block.

(3) Feiran Block: Aquifer, distributed in the downstream area of the Wadi Feiran without any hydrogeological connection with other blocks.

In addition, (4) Gharandal Sub Block was identified in the Wadi Gharandal area with hydrogeological connection with the Main Block.

Details of the blocks are mentioned below.

2) Well Inventory

Wells reached to the Lower Cretaceous are shown in Table 8.3.2-1. Among them, following wells penetrated to the bottom of the Lower Cretaceous.

Well Name	Coordination		Well Name	Coordination	
	Lat.	Long.		Lat.	Long.
No.J-1*	294231	333908	Gharandal-3	292003	331131
No.J-4*	292621	340256	Ayun Musa-1	295309	323858
No.J-5*	292018	342241	Ayun Musa-2	295308	324020
No.J-6*	291940	333648	Abu Hamth No.1	295757	333847
Sheira-1	292904	343538	El Hamra No.1	295818	325402
Feiran-1	284712	332552	Ayun Musa No.14	295130	324230
Feiran-2	284645	332435	Wadi Baba Well	2900??	331330
Feiran-5	284718	332424	Nakhel-1	295545	334241

*: JICA Wells

In addition, a lot of oil exploration wells were drilled penetrating into the Lower Cretaceous. These wells are shown in Fig. 8.3.2-2. Detailed location maps were prepared for JICA Wells in Fig. 8.3.2-3, Nakhl area and Sudr El Heitan area in Fig. 8.3.2-4, Sheira Block in Fig. 8.3.2-5, Feiran Block in Fig. 8.3.2-6 and Ayun Musa area in Fig. 8.3.2-7.

3) Supplementary Geological Survey

Geophysical survey by Schlumberger method was executed in the El Tih Plateau and adjacent area where the Lower Cretaceous underlies. Furthermore, six (6) test wells were drilled by the Study Team in the area reaching the Lower Cretaceous Sandstone. Details of the surveys are described in Chapter V and Chapter VI respectively.

The geology of the Study Area is classified into seven (7) layers in terms of apparent resistivity. The analysis result of geophysical survey is shown in the following table.

Layer	Resistivity Rang (ohm-m)	Estimated Lithology	Geological Interpretation
1	5 - 71	sand and gravel, limestone	Quaternary Deposits (Q) Egma Formation (Tel)
2	13	shale	Esna Formation (Tpe)
3	27 - 37	chalk, marl	Sudr Formation (Ks)
4	4 - 92	limestone	Matallah Formation (Km)
5	4 - 19 (rarely 98)	limestone, shale, sandstone	Wata Formation (Kw) Galala Formation (Kg)
6	36 - 90	sandstone, shale	Malhah Formation (Kl)
7	180 - 4100<	sandstone, basement rocks	Pre-Cretaceous

Drilling result of the six (6) wells are summarized as follows;

	J-1	J-2	J-3	J-4	J-5	J-6
Elevation (mASL)	520	657	544	775	740	710
Drilling Depth (m)	1,254	1,260	1,000	1,130	557	900
Top of L.C. (mBGL)	865	1,050	771	845	310	610
Bottom of L.C. (mBGL)	1,110	1,260+	1,106+	1,108	500	795
Thickness (m)	245	210+	229+	261	190	185

Thickness of aquifer is from 185 to 261 m, averaging 220 m. Judging from the result, the Lower Cretaceous Formation is about less than 300 m in thick in the Egma and the El Tih Plateaux.

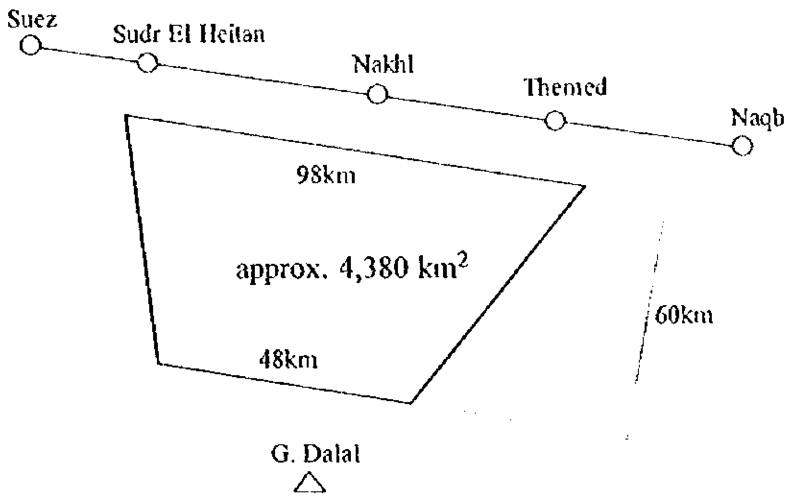
4) Configuration of Aquifer

The Lower Cretaceous Aquifer was figured out as follows;

- Top of Lower Cretaceous (Fig. 8.3.2- 8)
- Bottom of Lower Cretaceous (Fig. 8.3.2-9)
- Isopach of Lower Cretaceous Aquifer (Fig. 8.3.2-10)

The Lower Cretaceous Formation underlies in the wide area of Sinai Peninsula from southern fringe to the Gebel Maghara area in North Sinai. The north side of the Study Area is almost to the boundary between South Sinai and North Sinai which runs on the south side of the National Highway (Suez-Naqb Road).

Shape of the area where Lower Cretaceous distributes is trapezoidal, of which longer side is about 190 km long and shorter side is about 100 km long and distance of both side is 85 km long as shown below.



< Schematic Area of Main Block >

Schematic Distribution Area of Main Block of Lower Cretaceous Aquifer in South Sinai

The area of the Lower Cretaceous is roughly estimated as approximately 12,300 km^3 in South Sinai.

The Lower Cretaceous generally increases its thickness toward the north: It is 185 m thick at Well No.J-6 and more than 229 m at Well No.J-3.

The Wadi Gharandal is located in the western fringe of Egma Plateau and the marginal area of the Lower Cretaceous Formation. Drilling result of two (2) wells, Gharandal-1 and 3, reveals that the Lower Cretaceous is 89m and 147m thick respectively.

In the southeast of Naqb, Wadi Sheira area, is also underlain by the Lower Cretaceous Formation forming prospective aquifer. The formation is cut by faults in both eastern and western sides, therefore, the area forms a "graben".

Furthermore, same aquifer is confirmed in the down stream of the Wadi Feiran. The area of the Formation is about 160 km^2. It was confirmed from 203 to 286 m thick, averaging 240m thick by six (6) deep wells.

5) Groundwater Level

Inventory (Table 8.3.2-1) shows hydrogeological data of the Lower Cretaceous. On the basis of the data, a series of maps were prepared to show groundwater distribution as follows;

- Groundwater Level in mBGL (Fig. 8.3.2-11)
- Groundwater Level in mASL (Fig. 8.3.2-12)
- Groundwater Level in mBGL for Nakhl area and Sudr El Heitan area (Fig. 8.3.2-13)
- Groundwater Level in mBGL for Sheira Block (Fig. 8.3.2-14)
- Groundwater Level in mBGL for Feiran Block (Fig. 8.3.2-15)
- Groundwater Level in mBGL for Ayun Musa area (Fig. 8.3.2-16)
- Groundwater Level in mBGL for Gharandal Sub-Block (Fig. 8.3.1-6)

In the Main Block of the Lower Cretaceous, static water levels were confirmed by five (5) JICA wells (J-1, J-2, J-3, J-4 and J-6) for the first time. In advance of this, static water level was confirmed by WRRI at Nakhl, Sudr El Heitan and El Themed areas in North Sinai.

Contour lines drawn in Fig. 8.3.2-12 shows that groundwater gently flows from south to north (from the fringe of Egma Plateau to Nakhl). Confirmed static water level is 272 mASL at J-6 and 274 mASL at J-4, which are located in the southernmost. In northern part of the study area, it is 203 mASL at J-1 and 233 mASL at J-2. At Nakhl area it ranges from 190 mASL to 204 mASL. Gradient of water level is calculated as shown below.

Well	SWL (mASL)	Distance (km)	gradient
No. J-6	272	0	-
No. J-3	260	27.5	0.4/1,000
No. J-1	203	20.0	2.9/1,000
Nakhl-5	190	31.0	0.4/1,000

Groundwater gradient from the south to the north is generally less than 1/1,000 as shown above. Significant change of gradient appears between J-3 and J-1. Groundwater gradient is 2.9/1,000 in this section. This is rather large compared with other sections. Geological map indicates that there is a series of basaltic dykes between J-3 and J-1 running E-W direction. These dykes act as a kind of dam because they are generally massive so that groundwater flow is preventing to across them.

This phenomenon is also confirmed in the section between J-6 and Gharandal-1 where another series of basaltic dykes run in NW-SE direction.

Well	SWL	distance	gradient
No. J-6	272.0	0	-
Gharandal-1	191.8	45	1.8/1,000

Gradient is 1.8/1,000 in this section, while it is 0.4/1,000 in the Main Block.

The Wadi Gharandal area is the western marginal area of Main Block of the Sandstone. Static water level here is 78 mBGL and 192 mASL. Drawdown is small, 9.6 m.

The Wadi Sheira and the Wadi Watir (Sheira Block) is isolated from the Main Block from geological and hydrological point of view (Fig. 8.3.2-1). The Sheira Block is tectonically subsided by two (2) faults running in the N-S direction. On the other hand, the Basement Rocks are uplifted between the Main Block of the Lower Cretaceous and the Sheira Block. Water level in the Sheira area is more than 400 mASL. In contrary to this, water level in the eastern side of Main Block is less than 270 mASL. There is a significant gap of water level between both area.

In the Sheira Block, groundwater level is 467 mASL at Sheira 2 and 421 mASL at Sheira 3. Groundwater flows gently toward the south with 1.5/1000 of gradient.

The Wadi Feiran area is isolated from other Lower Cretaceous Formation (Main Block) as mentioned in 1) of this clause. Static water level is from 38 m to 67 m depth (mBGL) and 203 m to 286 mASL. Drawdown during extraction is generally small, in a range between 5.9 m to 16.5 m.

6) Groundwater Level Monitoring

It was the first attempt to conduct test well drilling for the Lower Cretaceous Aquifer on El Tih Plateau and install Automatic Groundwater Level Monitoring Equipment for long term monitoring. Every an hour is adopted for a time span for measurement. This monitoring result has very important and interesting aspect because El Tih Plateau is virgin area for the aquifer study from hydrogeological point of view. Furthermore, there is no withdrawal from the aquifer as like Nakhel area. This means that it is possible to monitor the natural condition of groundwater movement in the aquifer.

Fig. 8.3.2-17 and 18 present fluctuation of the groundwater table at J-1 to J-4. J-3 can be representative of monitoring results because of its whole yearlong duration. It is clear that about 20cm drawdown of water level at J-3 was recorded between Nov. 1997 to Nov.1998. However, continuing the monitoring for years is very important to confirm its general tendency. Although other wells have not enough monitoring duration, it is remarkable that the general tendency of groundwater fluctuation at J-1 was almost no change during two-month and half. It may be affected by hydgrogeological structure, then the data storage for long term is essentially important.

<Correction of water level at Nakhl area in North Sinai: Previous Project>

In the construction of North Sinai Hydrogeological Maps in 1992, groundwater level data at Nakhl area were derived from oil exploratory wells because no other data were available at that time. They are as follows:

Well Name	SWL (mASL)
Darag-1	263
Nakhl-1	269
Nakhl-2	260

After the completion of the previous Project, six (6) production wells were constructed by the Ministry of Public Works and Water Resources in Nakhl area. WRRI acted as the supervisor to the contractor during these constructions, therefore, reliable data were accumulated at present. According to the results of them, the static water level is in a range from 190 mASL to 208 mASL. There is about 60 m of difference between the oil exploratory wells and newly constructed production wells.

Previous data were carefully reviewed in this study to solve this problem. Three (3) oil exploratory wells reached the Lower Cretaceous. It was confirmed by drilling logs. Nakhl-1 reached the Carboniferous, however, casing program was not described. Nakhl-2 reached the Lower Cretaceous and casing was installed to the Lower Cretaceous. But, section of screen was not shown in the log. Although Drag-1 also reached the Lower Cretaceous, penetration depth to the Lower Cretaceous was only 30 m. Considering the above circumstances, the question arises whether screen was properly installed only in the Lower Cretaceous section or not.

Since such reliable data is available now, those data from oil exploratory wells should be omitted in case of the construction of Hydrogeological Map

The Study Team conducted a supplemental survey in summer, 1998 in order to revise the hydrogeological map of North Sinai. During this survey, the Study Team tried to get aculeate elevation and coordination of reliable wells around Nakhl from hydrological point of view. It is also important for the hydrogeological map of South Sinai.

6) Groundwater Quality

(1) Availability of Data

The chemical analysis data of groundwater quality of Pre-Quaternary aquifer, were collected from the Drilling Completion Report submitted by the drilling contractor. In addition, water samples were taken from newly drilled JICA Wells during pumping test.

The chemical analysis data obtained from six (6) wells consisting three (3) well in W. Sheira, two (2) in W. Feiran and one (1) in W. Gharandal. All the data obtained are plotted on the Piper and Stiff diagram.

(2) Groundwater Quality of Lower Cretaceous Aquifer

The groundwater quality data including JICA wells for lower Cretaceous aquifer are summarized block by block as following table. Based on the table, water quality of the aquifer is chiefly good to drink. However, SO_4^{2-} of Gharandal-1 and J-1, and TDS of Gharandal-1 don't satisfy the standard.

Water Quality of the Lower Cretaceous Aquifer (unit: mg/l)

	Well Name	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO^{3-}	CO_3^{2-}	Cl^{-}	SO_4^{2-}	TDS
Feiran	Feiran-1	70.4	22.8	135	5.9	180	n.d.	222	100	848
	Feiran-2	25.6	66.1	162	4.6	180	n.d.	224	200	862
Gharandal Sub-Block	Gharandal-1	96.0	97.2	265	7.1	64	n.d.	460	[illegible]	[illegible]
Sheira Block	Sheira-1(K83)	89.6	77.8	180	14.4	176	n.d.	360	330	1,228
	Sheira-3(K52)	102.4	54.4	102	7.8	160	n.d.	152	320	899
	Sheira-4(K53)	70.4	45.6	100	8.8	136	n.d.	152	280	793
Main Block	JICA-1	130.0	63.0	138	13	207	n.d.	152	[illegible]	868
	JICA-2	128.0	46.7	190	19.50	92	n.d.	296	375	1,182
	JICA-3	41.6	28.2	60	7.80	88	n.d.	72	190	470
	JICA-4	106.0	54.0	123	12	283	n.d.	160	306	976
	JICA-6	147.0	69.0	253	8	194	n.d.	483	361	1,488
Drinking Water Quality Standard in Egypt		200	150	-	-	-	-	600	400	1,500

(Remark: Darken values don't satisfy the standard)

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Water Quality of the Lower Cretaceous Aquifer (unit: mg/l)

	Well Name	Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	CO_3^{2-}	Cl^-	SO_4^{2-}	TDS
Feiran	Feiran-1	70.4	22.8	135	5.9	180	n.d.	222	100	848
	Feiran-2	25.6	66.1	162	4.6	180	n.d.	224	200	862
Gharandal Sub-Block	Gharandal-1	96.0	97.2	265	7.1	64	n.d.	460	450	1,822
Sheira Block	Sheira-1(K83)	89.6	77.8	180	14.4	176	n.d.	360	330	1,228
	Sheira-3(K52)	102.4	54.4	102	7.8	160	n.d.	152	320	899
	Sheira-4(K53)	70.4	45.6	100	8.8	136	n.d.	152	280	793
Main Block	JICA-1	130.0	63.0	138	13	207	n.d.	152	506	868
	JICA-2	128.0	46.7	190	19.50	92	n.d.	296	375	1,182
	JICA-3	41.6	28.2	60	7.80	88	n.d.	72	190	470
	JICA-4	106.0	54.0	123	12	283	n.d.	160	306	976
	JICA-6	147.0	69.0	253	8	194	n.d.	483	361	1,488
Drinking Water Quality Standard in Egypt		200	150	-	-	-	-	600	400	1,500

(Remark: Darken values don't satisfy the standard)

Based on the above data the groundwater quality maps were provided as follows;

- Water Quality in TDS for whole area (Fig. 8.3.2-25)
- Water Quality in TDS for Nakhl area and Sudr El Heitan area (Fig. 8.3.2-13: same map of water level)
- Water Quality in TDS for Sheira Block (Fig. 8.3.2-14: same map of water level)
- Water Quality in TDS for Feiran Block (Fig. 8.3.2-15: same map of water level)
- Water Quality in TDS for Gharandal Sub-Block (Fig. 8.3.1-6: same map of water level)
- Water Quality in TDS for Ayun Musa area (Fig. 8.3.2-16: same map of water level)

i) Main Block

Water quality in the Main Block is generally less than 1,500 mg/l in TDS value except in a small area around the well Nekhel-7 where TDS value is 2,220 mg/l.

Excellent water quality appeared around the well J-3, of which TDS value is 470 mg/l. The area where TDS value ranges from 500 to 1,000 mg/l is wide spread in the surrounding area including wells J-1 and J-4; TDS value is 868 mg/l and 976 mg/l respectively. Piper and Stiff diagram of the Main Block are shown in Fig. 8.3.2-20 and Fig. 8.3.2-21.

It is suggested that groundwater in the Main Block is almost suitable for both drinking water and irrigation water.

ii) Sheira Area

TDS value is shown in the Groundwater Quality Map (Fig. 8.3.2-14). The contour line is mainly set in the parallel direction of North - South which is exactly along the Wadi. The range of the TDS value is narrow, it is approximately 1,000 to 1,500 mg/l. It is shown that the TDS value is relatively high as towards the East. All components of major ions and TDS value at all the wells, satisfy the Drinking Water Standard in Egypt. Piper and Stiff diagrams of the Sheira Block are shown in Fig. 8.3.2-22 and Fig. 8.3.2-23 respectively.

iii) Feiran Block

TDS value is shown in the Groundwater Quality Map (Fig. 8.3.2-15). The range of TDS value is from 800 to 1,100 mg/l. Chemical analysis data is obtained from two

(2) wells of Feiran-1 and 2 (map no. 14 and 15). TDS value only obtained from other two (2) wells.. However, a similar and stable value of TDS is distributed. All components of major ions and TDS value at all the wells, satisfy the Drinking Water Standard in Egypt. Piper and Stiff diagrams of the wells are shown in the Fig. 8.3.2-24 and Fig. 8.3.2-25 respectively.

iv) Gharandal Sub-Block

Relatively high TDS value is distributed in middle stream of W. Gharandal (Fig. 8.3.1-6). TDS value is 1,822 mg/l, it somewhat exceeds the standard value. Piper and Stiff diagrams of the Gharandal Block are shown in the Fig. 8.3.1-8 and Fig. 8.3.1-9 respectively.

v) Groundwater Type of Lower Cretaceous Aquifer

Generally, the range of TDS value is low and narrow, it is approximately 500 to 1,800 mg/lit. Compared with other aquifer's water, a similar range of TDS value is distributed. These facts suggest that the Lower Cretaceous aquifer is continuously distributed in the area.

7) Groundwater Age

In order to analyze the recharging mechanism, stable isotope and radio-isotope were analyzed on existing wells and JICA wells. Samples were collected from eight (8) wells and results are shown in Fig. 8.3.2-26. C-14 ages including North Sinai are summarized in the following table.

Well No.	C-14 Age (y.BP)	Remarks
J No.16 El Bruk	29,690 ± 1,190	Gak*-15769
J No.19 Arif El Naga	34,780 <	Gak*-16033
Sheira-1	22,350 ± 2,160	Gak*-16032
Ayun Musa	30,900 <	Issar 1981
Nakhl-5	27,000 ± 2,000	AEA**, Egypt
Sudr El Heitan	26,000 ± 2,000	AEA**, Egypt
Sheira-1(Km83)	22,000 ± 2,000	AEA**, Egypt
J-1	20,000 ± 2,000	AEA**, Egypt
J-2	23,200 ± 2,000	AEA**, Egypt
J-3	21,500 ± 2,000	AEA**, Egypt
J-4	18,000 ± 2,000	AEA**, Egypt
J-6	14,000 ± 2,000	AEA**, Egypt

* Gakusyuin University, Japan
** Atomic Energy Authority, National Center for Nuclear Safety and Radiation Control

In Negev desert, C-14 ages are reported by Issar et al., in 1981. They are shown in the Following table except data of water from mixed origin.

Well No.	C-14 Age (y.BP)
Tamar 3	28,500 ± 350
Makhtesh Qatan 3	22,000 ± 1,000

In South Sinai (including adjacent area), C-14 age of groundwater rages from 21,500 y.BP at J-3 to 27,000 y.BP at Nakhl-5. The most oldest age appears at Ayun Musa spring of which age is more than 30,900 y.BP. In North Sinai, the age becomes more older: It is 29,690 y.BP at J-15 (El Bruk-1) and more than 34,780 y.BP at J-19 (Araif El Naga).

These data indicate that groundwater in the Lower Cretaceous Sandstone was recharged more than 20,000 years ago when the area had received more rainfall than present.

Based on the above data, velocity of groundwater flow in the Lower Cretaceous is estimated as shown in the tables below.

Location	C-14 Age (y.BP)	Distance (km)	Accumulated Distance (km)	Velocity (m/year)	Velocity (cm/day)
Outcrop	-	0.0	0.0	-	-
- J-3	21,500	42.5	42.5	1.98	0.54
- Nakhl-5	27,000	50.0	92.5	9.09	2.49
- J No.16 El Bruk	29,690	20.0	112.5	7.43	2.04

Location	C-14 Age (y.BP)	Distance (km)	Accumulated Distance (km)	Velocity (m/year)	Velocity (cm/day)
Outcrop	-	0.0	0.0	-	-
- J-2	23,200	75.0	42.5	3.23	0.89
- J No.19 Arif El Naga	34,780	85.0	127.5	7.34	2.01

The most striking feature of above assumption is that velocity of groundwater shows much difference between in South Sinai and in North Sinai. In the western section from the recharge area in the south to the Well No. J-3, velocity of groundwater is 0.5 cm/day while it is 2.5 cm/day in the section between J-3 and the Well Nakhl-5. After Nakhl-5, it is 2 cm/day. In the eastern section from the outcrop to the Well No. J-2, velocity is slow, 0.9 cm/day. However, it becomes fast, 2 cm/day in the section from

J-2 to the Well J No. 19 Araif El Naga in North Sinai.

As described in 6) of this clause, gradient of groundwater in the Lower Cretaceous Aquifer is small, 0.4/1000 in the south of J-3 and it is rather large, 0.5/1000 in the north of J-3. This fact supports the assumption of groundwater flow velocity mentioned above.

8) Hydrogeological Characteristics of Aquifer

Geological field survey and six (6) drilling results revealed the facies of the Lower Cretaceous and the underlying Jurassic Formation.

The Lower Cretaceous is generally composed of shaly facies, quartzose sandstone facies, and intercalation of sandstone and shale. The Jurassic Formation consists of sandstone and shale. In most case, both formations are separated by shaly facies. Its thickness is 40 m at Well J-1, more than 24 m at J-4, about 20 m at J-5 and about 15 m at J-6.

On the one hand, shaly facies becomes sandy facies toward the south. A few thin shaly strata appear at Gebels Dalal and El Gineina (Refer to Fig. 5.4-8).

Therefore, the Lower Cretaceous and Jurassic are hydrogeologically separated each other, while there is scarce aquifuge in the southern area.

(1) Main Block

The Lower Cretaceous Formation and underlying formations such as the Jurassic and the Paleozoic drop out in the southern fringe of the Egma Plateau. It is apparent at the Wadis Zalaga and Garf as shown in Fig. 8.3.2-27 and 8.3.2-28. Erosion surface of both wadi reached the Jurassic/Paleozoic horizon. Therefore, elevation of the Lower Cretaceous is higher than that of the Wadi Deposits. The Wadis Zalaga is one of the active wadi, therefore, the Wadi Zaghara area is supposed to be main recharge area to Pre-Quaternary aquifers as well as the Wadi Garf area. As shown in Fig. 8.3.2-27, the Quaternary Wadi Deposits directly overlies the Jurassic Formation in most places in the Wadi Zaghara and its tributaries. The Lower Cretaceous Sandstone crops out along the wadi, mainly at the lower part of the cliff. The channel of the wadi is filled by the Quaternary Wadi Deposits and it is underlain mainly by the Jurassic Formation. The Lower Cretaceous Sandstone has a few chance to contact with the Quaternary Deposits.

Same hydrogeological situation is confirmed at the Wadi Garf.

The hydrogeological features described above suggest that the Lower Cretaceous

Sandstone cannot be recharged by the flood water, while the Jurassic Formation is directly recharged by the flood water occurred in the wadi area.

As results of discussion above, although the Lower Cretaceous cannot receive direct recharge from flood water, there is a possibility that the Lower Cretaceous has a chance to be recharged from other sandstone in the southern area of its distribution after other sandstone is saturated by groundwater.

In contrary with this situation, no groundwater leakage can be happened between the Lower Cretaceous Sandstone and other sandstone except faulted areas.

This is supported by the water quality data. TDS value is less than 1,500 mg/l in the Lower Cretaceous Sandstone, while that of the Jurassic and the Paleozoic formations are more than 5,000 mg/l.

(2) Sheira Block

The Sheira Block is basically formed by faults and hydrogeologically independent from the other blocks. The Lower Cretaceous Formation is completely overlain by younger formations in the area (Fig. 8.3.2-29). Groundwater age by C-14 is 22,360 y.BP and 22,000 y.BP. It suggests that groundwater was recharged in ancient age. Extremely low content of Tritium is 0.1 T.U means that no groundwater is recharged or scarce amount of groundwater recharge is occurred.

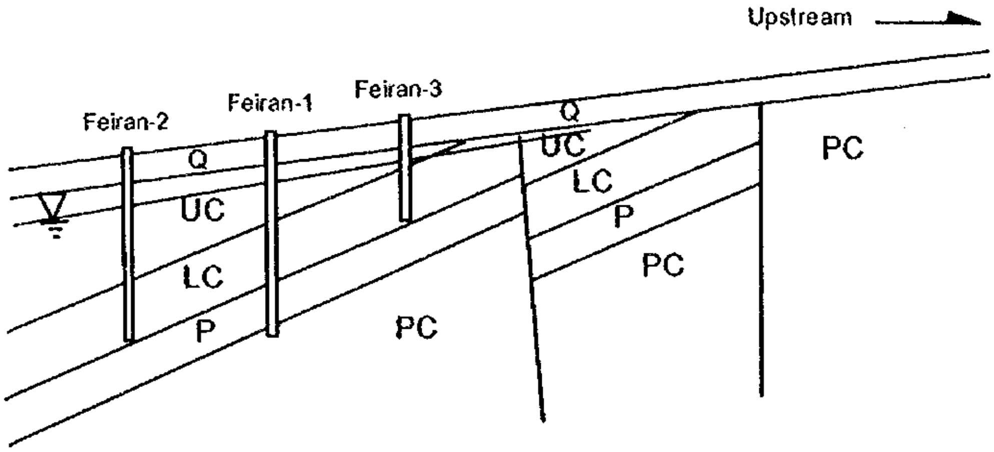
As mentioned in 5) of this Clause, groundwater table is gently inclined to the south with 1.2/1000 of gradient. On the other hand, the Sheira Block is hydrogeologically independent from other blocks. However, groundwater in the Sheira Block shall outflow to other places. Otherwise, groundwater table in the south end of the Block can be raised up. The south of the Block contacts with the Precambrian Basement Rocks in which Ain Furtaga Spring occurs about 17 km south from the southern end of the Block. While the Ain Furtaga Spring yields groundwater continuously good enough to supply to Nuweiba city, the area receives 20 mm of annual rainfall.

On the basis of above situation, it seems that groundwater in the Sheira Block supplies groundwater to Ain Furtaga in some extent through fissures and faults developed in the Basement Rocks.

From the above, groundwater extraction in the Sheira Block will drain the aquifer of its resources. Therefore, it is necessary to monitor groundwater table periodically because number of wells are increasing in the area.

(3) Feiran Block

The Feiran Block of the Lower Cretaceous Formation distributes in a narrow area in the downstream of the Wadi Feiran. The Block contacts with the Precambrian Basement Rocks in the east and cut by faults in the west. It seems that groundwater in the Feiran Block is stored in a small area. It size is estimated as about 90 km^2 (= 6 km x 15 km). In some part, the Block is directly overlain by the Quaternary Wadi Deposits. A schematic section is presented below;



(Schematic Section of Wadi Feiran)

As mentioned in "Chapter V Geology", the Precambrian Rocks are densely intruded by dolerite dykes elongated in mainly NNE-SSW direction. Therefore, the Precambrian Rocks could act as conduit of groundwater infiltrated to the fissures and joints in the Rocks. Hydrogeological situation above will make the Lower Cretaceous Formation easy to be recharged through both the Precambrian Rocks and the Quaternary Wadi Deposits.

(4) Differentiation of Groundwater Zone

Distribution of the Lower Cretaceous Aquifer and groundwater in the Aquifer were revealed by the Study. Relation between the aquifer and groundwater gradient was analyzed to determine the confined zone, unconfined zone and dry zone in the Aquifer. For this purpose, following one map and four (4) profiles were prepared analyzing groundwater level based on JICA wells and existing wells.

- Fig. 8.3.2-30 Differentiated Groundwater Zone (Lower Cretaceous)
- Fig. 8.3.2-31 Section of Groundwater Table (Lower Cretaceous)
  - (1) Section (1): from J-2 to W. Zalaga through J-4
  - (2) Section (2): from J-4 to Gebel Dalal

(3) Section (3): from J-3 to Gebel Raqaba

(4) Section (4): from Gone Khashm El Taraf to J-2 through El Themed-5

Based on the figures above, three (3) aquifer zone in the Main Block were differentiated as follows;

i) Dry Zone: Till about 16 to 24 km north from the outcrop at the fringe of El Tih Plateau (hereinafter boundary with unconfined zone is referred to as "groundwater front").

ii) Unconfined Zone: Till 6 to 12 km north from the groundwater front (hereinafter boundary with unconfined zone is referred to as "confined front")

iii) Confined Zone: All the area of Main Block except dry zone and unconfined zone. It distributes in the north of confined front.

In Sheira Block, dry zone and confined zones were differentiated. Because the Block was formed by faults, unconfined zone is quite narrow even if it exists.

It is also meaningless to identify groundwater zones in the Feiran Block because possible groundwater development area is limited in the narrow area along the downstream of the Wadi Feiran.

(5) On Difference of Groundwater Quality between the Lower Cretaceous and other Aquifers

Groundwater quality data show much difference in TDS value among the Upper Cretaceous, the Lower Cretaceous and the Jurassic to Paleozoic Aquifers: TDS value of the Lower Cretaceous aquifer is from 470 to 1200 mg/l while that of other aquifers is generally more high.

This phenomena could be explained by difference of recharge amount to each aquifers. Sandstone of the Lower Cretaceous and older formation were deposited in the continental margin, therefore, no saline water was generally stored in them. In the age of Upper Cretaceous, transgression caused the deposition of limestone. So far limestone is a kind of marine deposits, it can be stated that the area was under sea water during the Upper Cretaceous age. It means that groundwater in sandstone was contaminated by saline water from the sea.

After the Egma Formation deposited in Eocene, the area was uplifted and rivers cut deep valleys eroding limestone of the Eocene and Upper Cretaceous ages. When erosion surface reached the top of the Lower Cretaceous Sandstone, it was the start of recharge to the Sandstone by flood water which was fresh water, and it ended after erosion surface reached the bottom of the Sandstone.

C-14 ages of groundwater in the Lower Cretaceous is between 14,000 y.BP and 27,00 y.BP and it is just back and forth of climax in the Wurm Glacial Age. In this period, it was more rainy than the present, so called "Pluvial Age". During this period, the Lower Cretaceous Sandstone received enough fresh water from the surface water and water quality in the Sandstone accordingly became fresh.

The Lower Cretaceous Formation had been completely eroded in the Wadi Zalaga and Garf areas. On the other hand, the Jurassic to Paleozoic Sandstone had no chance to encounter surface water. Thus, finish of recharge to the Lower Cretaceous aquifer means start of recharge to the older aquifers.

The Jurassic to Paleozoic sandstone was covered by the Wadi Deposits, which consist of sand, gravel and silt. In the recharge area, silty material is dominant in the deposits so that recharge to the sandstone is prevented in a certain degree.

Thus it can be said that the Jurassic to Paleozoic sandstone has not received enough recharge of fresh water by surface water.

Process mentioned above caused the difference of water quality between the Lower Cretaceous and the Jurassic to the Paleozoic Formations.

9) Estimation of Groundwater Storage

(1) Main Block

Groundwater storage of the Main Block of the Lower Cretaceous is estimated based on the isopach map. Total volume of groundwater storage is estimated as,

$$S_{\text{Total Storage}} = 98 \times 10^9 \text{ m}^3$$

The estimation was made based on the Isopach map (Fig. 8.3.2-10) assuming the aquifer thickness as 62% of the total thickness of the Lower Cretaceous Formation and effective porosity as 0.15. The volume mentioned above is rather conservative estimation because aquifer thickness is calculated considering the total screen length as aquifer thickness.

(2) Sheira Block

Thickness of the Lower Cretaceous is about 200 m. Then, the aquifer in the area is calculated as 128 m in thick.. Other condition is same as that of the Main Block.

The area of the aquifer is 675 km^2.

Total volume of groundwater is estimated to be approximately 13 x 10^9 m^3.

(3) Feiran Block

Thickness of the Lower Cretaceous Aquifer is estimated as 122m considering as screen length installed in the wells as thickness of aquifer. Other condition is same as that of the Main Block. The area of the aquifer is 90 km^2 as mentioned above.

Total volume of groundwater is estimated to be approximately 1.6 x 10^9 m^3.

10) Groundwater Extraction

Groundwater in the Lower Cretaceous is used for domestic and/or irrigation water supply. Extraction rate in each area is summarized as follows.

Area	Number of Production Well	Extraction (m^3/year)	Irrigation Area (feddan)
<Main Block>			
Sudr El Heitan	1	40,000	10
Nakhl	6	480,000	300
Themed	3	240,000	150
Sub-Total	10	760,000	460
Gharandal Block	3	240,000	150
Feiran Block	6	720,000	300
Sheira Block	4	360,000	150
Total	23	2,080,000	1,050

Extraction of groundwater from the Main Block is estimated as,

$$Q_{\text{Total Extraction}} = 760{,}000\ m^3/year$$

11) Groundwater Potential Area

A groundwater resources evaluation map was constructed based on the results of the Study as shown in Fig. 8.3.2-32. Selected evaluation criteria are groundwater quality and depth groundwater table from the ground surface (mBGL) due to following reasons.

(1) Groundwater quality is the most important criteria for both drinking and irrigation use.

(2) Groundwater level (mBGL) controls availability of submersible pump and operation cost of extraction.

(3) Depth of aquifer from ground surface will affect construction cost of wells. However so far as the Lower Cretaceous is concerned, necessary drilling depth is around 1000 m. Even if there is a difference of depth, it is within 100 m. Therefore, this factor is not selected to evaluate the sandstone of the Lower Cretaceous.

(4) Thickness of aquifer is not selected. Although it is generally important factor in selection of well locations, it has less importance to evaluate the Lower Cretaceous Aquifer. Because the Aquifer is generally more than 100 m thick in the entire area. It is enough to install screen in the well. In this case difference of aquifer thickness will affect less to yield of wells.

(5) Aquifer constants such as permeability and transmissivity are also important factors, which control yield of wells. In the sandstone of the Lower Cretaceous, cross bedding and lamination are well recognized. Therefore, grain size distribution frequently changes in the section. On the other hand, yield of wells during pumping test was more than 30 m^3/hour. Large differences among wells are not recognized. In general, facies of the sandstone changes so frequently because it is of the continental margin deposit. It will not allow making zoning of aquifer constants. Heterogeneity of aquifer is reflected in water quality. Therefore, it is possible to take this factor into consideration as water quality. Thus this factor is not selected. Classification matrix for groundwater resources evaluation and the result of groundwater resources evaluation are shown below.

Classification Matrix for Groundware Resources Evaluation of Lower Cretaceous Aquifer

Groundwater Quality: TDS (mg/l)	Ranking	Allotment	Groundwater Depth: B.G.L (m)					
			Ranking	i	ii	iii	iv	-
			Depth	Less than 100	100-200	200-300	300-400	More than 400
			TDS \ Allotment	5	4	3	2	-
	S	15	Less than 1000	Si (20)	Sii (19)	Siii (18)	Siv (17)	-
	A	12	1000-1500	Ai (17)	Aii (16)	Aiii (15)	Aiv (14)	-
	B	9	1500-2000	Bi (14)	Bii (13)	Biii (12)	Biv (11)	-
	C	6	2000-2500	Ci (11)	Cii (10)	Ciii (9)	Civ (8)	-
	D	3	More than 2500	Di (8)	Dii (7)	Diii (6)	Div (5)	-

( ): Evaluation Point

Better ↑ ↓ Worse

Better ← → Worse

Groundwater Resources Evaluation of Lower Cretaceous Aquifer

Evaluation	Points	Classification Type of Aquifer
Excelent	18-20	Si, Sii, Siii
Very good	16-17	Siv, Ai, Aii
Good	13-15	Aiii, Aiv, Bi
Fair	10-12	Biii, Biv, Ci, Cii
Moderately Fair	7- 9	Ciii, Civ, Di, Dii
Poor	5- 6	Diii, Div

Based on the criteria above, groundwater potential areas are estimated. At present, the maximum capacity of submersible pump is 400m head. Water quality standard is adopted that TDS 1,500 mg/l is for drinking water and TDS 3,00 mg/l is for irrigation. Two kind of potential area maps were prepared as Fig.8.3.2-33 and 34 using combination of both criteria as shown below.

(1) Drinking; TDS: less than 1,500 mg/l, Groundwater level: less than 400 mBGL.
Prospective area is a triangular area wide spread in the southward from Nakhl of which area is about 1,050 km^2 as shown in Fig. 8.3.2-33.

(2) Irrigation; TDS: less than 3,000 mg/l, Groundwater level: less than 400m BGL.
Prospective area is a triangular area wide spread in the south of Nakhl of which area is about 2,500 km^2 as shown in Fig. 8.3.2-34.