The final decision was made to determine the age of formations by referring to the results of the fossil analysis.

These reviewed well profiles and geologic columns were compiled as 146 composite columns for the basis of interpretation of the subsurface geology as shown in Technical Report IV.

Composite columns obtained from well profiles provide hydrogeological information in the vicinity of the well. Hydrogeological maps in portfolio were presented.

7-3-3 Geological Cross Section

Based on these composite columns, the geological interpretation was made on the result of geophysical investigation by resistivity prospecting (Fig. 7-3-1 and 7-3-2 (1) to (5)).

7-4 Contour Map of Major Formations

7-4-1 Contour Map of Major Formations in Pre-Quaternary

According to the study mentioned above, it is concluded that the prospecting aquifers develop in the following formations:

1) Tertiary
    - Miocene
    - Eocene
2) Upper Cretaceous
    - Senonian
    - Turonian
    - Cenomanian
3) Lower Cretaceous
4) Jurassic
    - Upper Jurassic
    - Middle to Lower Jurassic

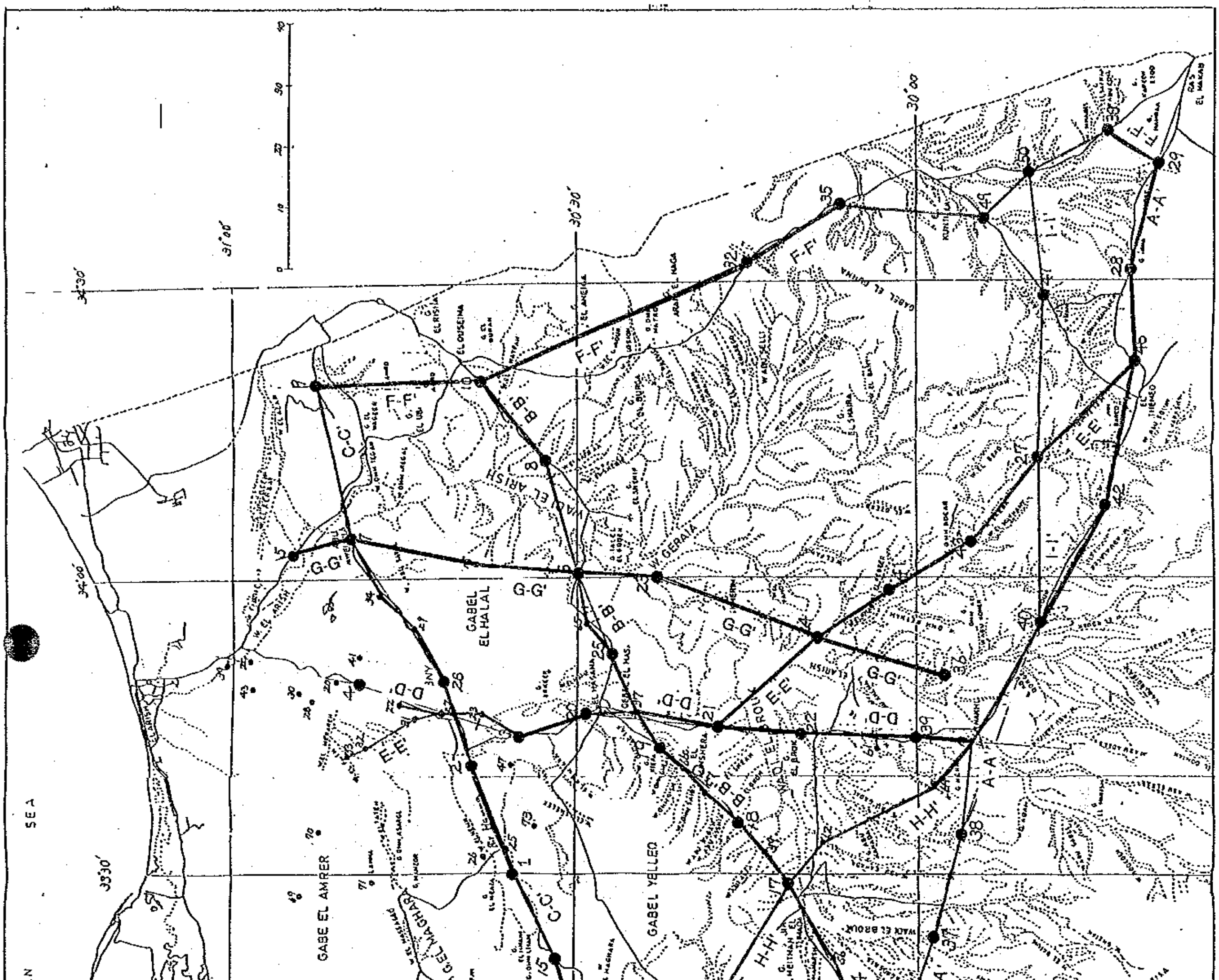


FIG. 7-3-1 LOCATION OF RESISTIVITY PROFILE

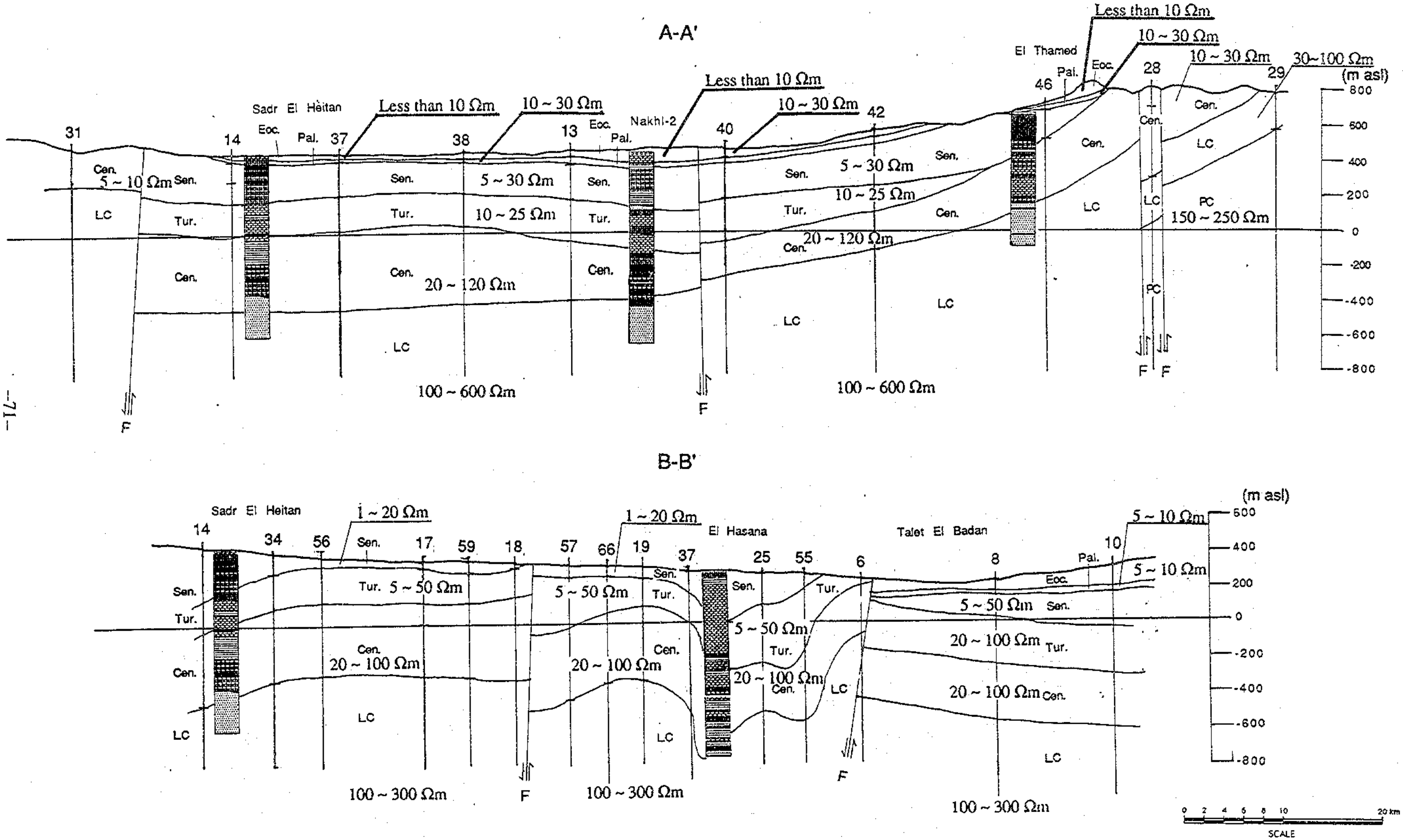


FIG. 7-3-2 (1) RESISTIVITY PROFILE A - A', B - B'

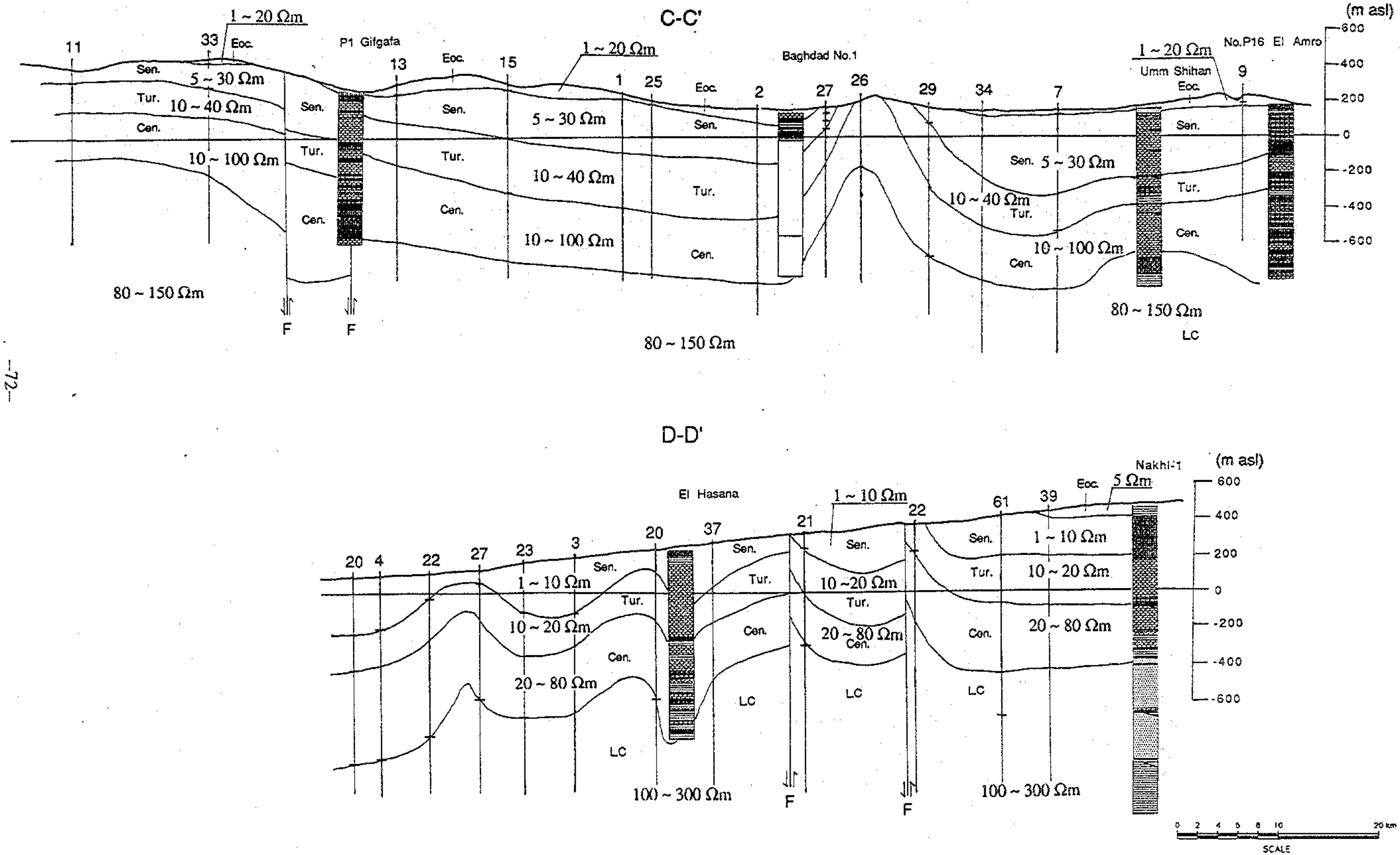


FIG. 7-3-2 (2) RESISTIVITY PROFILE C - C', D - D'

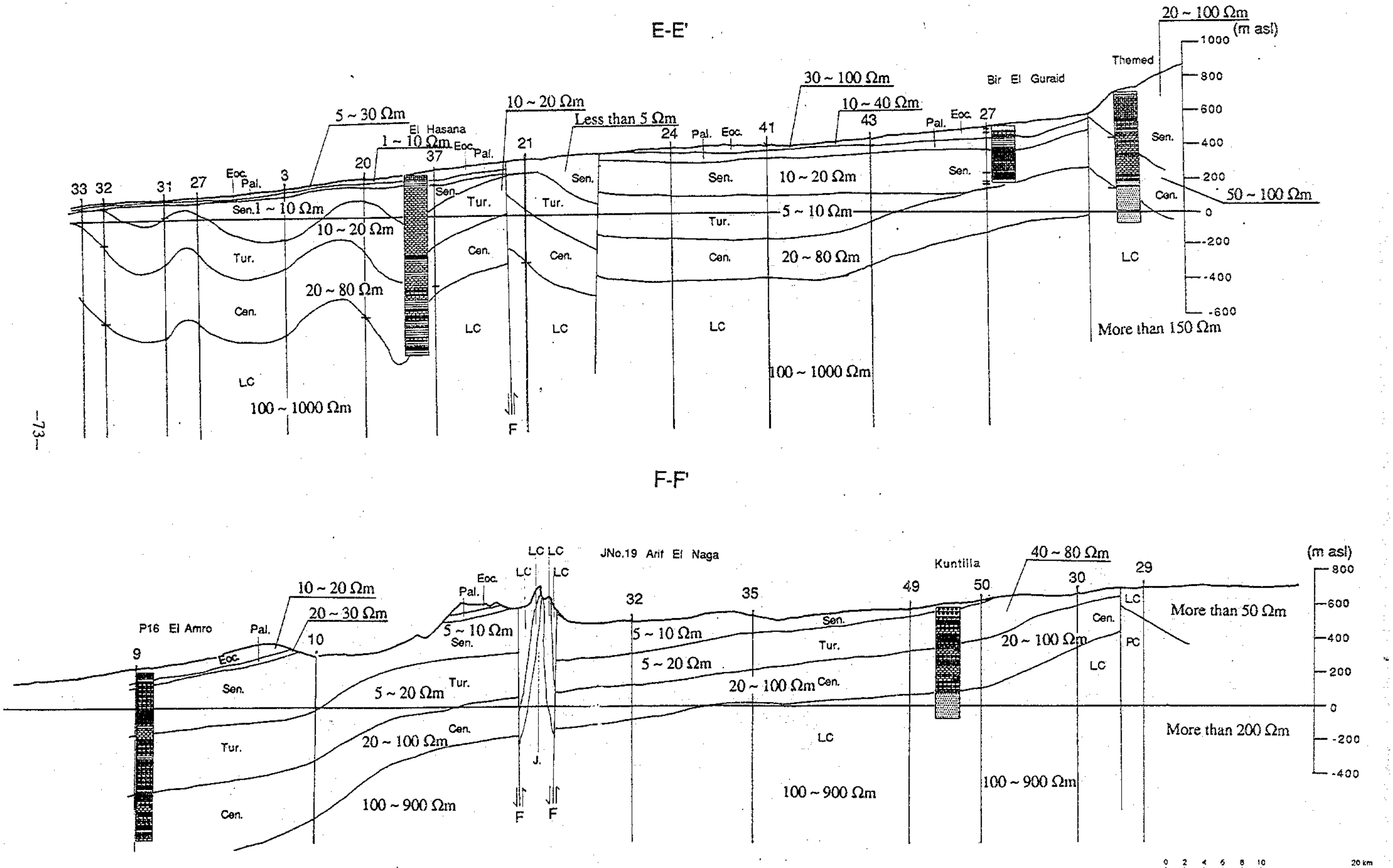


FIG. 7-3-2 (3) RESISTIVITY PROFILE E - E', F - F'

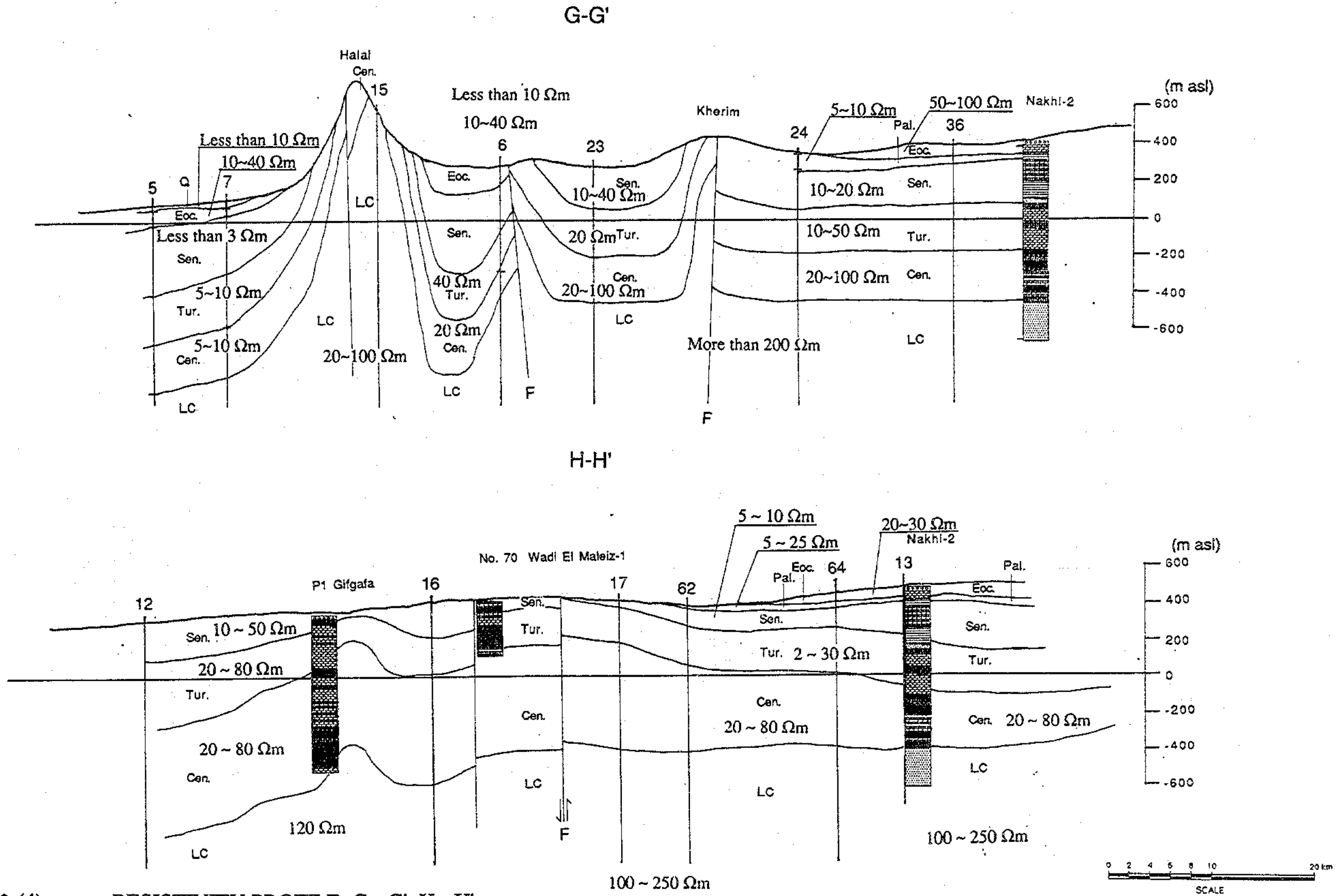


FIG. 7-3-2 (4) RESISTIVITY PROFILE G - G', H - H'

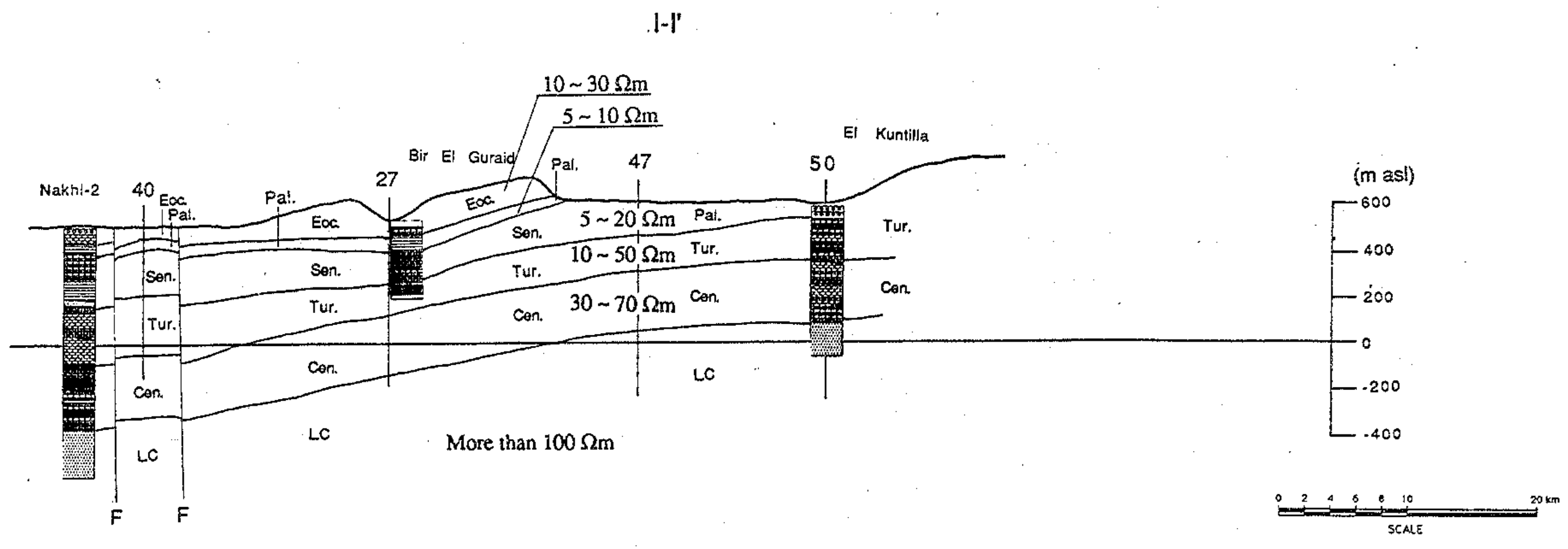


FIG. 7-3-2 (5) RESISTIVITY PROFILE I - I'

Contour maps are constructed for each formation listed above and as a portfolio of the hydrogeological maps,

1) Isobase map
   Lower Cretaceous
2) Top surface
   Upper Cretaceous
   Lower Cretaceous
3) Isopach (Lower Cretaceous)

7-4-2 Isobath Map, of Lower Cretaceous

The map shows the depth to the top of the sanstone of the Lower Cretaceous from the ground surface. The depth tends to be deep in the central part of the study area. It is 800 - 1,000 m around Hasana, 900 m near Nakhl, 500 - 600 m near Kuntilla and 700 - 800 m near Sadr El Heitan (Portfolio sheet No. 19)

7-4-3 Top Surface of Upper Cretaceous.

The location of wells and the confirmed elevation of the Upper Cretaceous are plotted in the map. The outcropping area and the area where the upper Cretaceous is absent are also indicated in the map. Based on the contours drawn, the top levels of the Upper Cretaceous is constructed which indicate the erosion surface of the Upper Cretaceous (Portfolio sheet No. 14).

There are two subsurface valleys on the erosion surface of the Upper Cretaceous. One is observed from Nakhl to Baghdad through Hasana and the other from Gifgafa to Baghdad in an ENE-WSW direction. From the confluence of these two subsurface valleys at Baghdad, it extends in a NE direction passing between Gebel Risan Aneisa and Gebel Libni to the east of El-Arish. The elevation of the valley bottom at Nakhl is 400 m asl and at the east of El-Arish it is -200 m asl with a very gentle slope.

7-4-4 Top Surface of Lower Cretaceous

Location of wells, where the elevation of the top of the sandstone of the Lower Cretaceous were confirmed, are plotted in the map (Portfolio sheet No. 17). Contour limes indicate the relative top elevation of the Lower Cretaceous from the sea level. According to this figure, similar valley-like features like in the Upper Cretaceous formation are observed. It indicates quite a different valley pattern than those on the surface. Elevation of the top of the Lower Cretaceous lies at -400 m asl at Nakhl and at -900 m in the east of El-Arish with a very gentle gradient.

On the contour lines, an influence of faults were observed at some places. A significant influence of the Ragabet El-Naam Fault is recognized - dislocations are observed along the fault at Naqb where the vertical dislocation is estimated to reach few hundreds meters; however, it is insignificant at Nakhl. The Lower Cretaceous formation is supposed to be cut by the fault at this place.

There is a abrupt change in the elevation of the top of the Lower Cretaceous at Gebel Minshera caused by a fault running in an ENE-WSW direction on the northern side of the dome. A similar graben structural is found in the area of Gifgafa which is caused by the faults running in a NW-SE direction. At Talet El-Badan, the Lower Cretaceous thrusts up the Cenomanian northwards due to the reverse fault in a NW-SE direction.

7-4-5 Isopach Map of the Lower Cretaceous.

The Lower Cretaceous tends to be thick in the central and the northern part of the study area. At Gebel Halal it is confirmed to be 660 m thick. In the southern part of the study area the thickness of the Lower Cretaceous is in a range between 200 and 300 m. On the southern side of Ragabet El-Naam Fault the thickness of this formation is confirmed to be 246 m at well Sheira No.1 (Portfolio sheet No. 18).

8 HYDROGEOLOGY

8-1 Introduction

Considering the possibility of the formations to develop groundwater aquifers and the size of the formations distributing in the study area, the target formations are determined to be the Quaternary and the Lower Cretaceous. Much attention has been drawn to these target formations; however, discussions are made on prospecting aquifers in the limestones of the Eocene of the Tertiary and the Turonian of the Upper Cretaceous.

A large-size Quaternary formation is identified in the coastal plain from El-Arish to Sheikh Zuwayid.

8-2 Quaternary

8-2-1 General

The Quaternary formation is distributed broadly in the study area. However, the distribution of prospecting aquifers in it is limited in the coastal plain along the Mediterranean.

There are three kinds of aquifers in the Quaternary: sand, gravel and kurkar. The distribution of the hydrogeological characteristics of each type of aquifer is discussed in the following part of this section.

8-2-2 Distribution of Prospecting Aquifer

Although distribution of the prospecting aquifer in the western part of the coastal plain is subject to future study, it is assumed that the thick Quaternary formation distributes in the coastal plain from El-Arish to Rafah with widths varying from 10 km to 15 km (Fig. 8-2-1).

The base of the Quaternary in this part is estimated as shown in Fig. 8-2-2. Their thicknesses are estimated to range between 80 m and 100 m.

According to the lithological profile of the GDDO test well B drilled at the southern end of El-Arish town, the 10 m thick top sand bed is underlain by a thick clay reaching 100 m from the ground surface. However, some other test wells and piezometers were drilled on the western side of the Wadi El-Arish in the coastal plain, where the thickness of the Quaternary ranges between 60 m and 80 m at AR P5, AR P6, AR T7, AR P10 (Section 2-1-3, Technical Report I). Although subject to future confirmation, the thickness of the Quaternary on the western side of Wadi El-Arish in the coastal plain seems thin compared to the thickness of the Quaternary on the eastern side.

Major aquifers of the Quaternary in this area are sand, gravel and kurkar. Generally, the top layer consists of sand in most of the lithological well profiles in the study area. The thickness of sand bed varies from 20 m to 40 m on the coastal area; it is very thin inland.

The sand bed consists of dune sand and old beach sand. Their differentiation in the lithological well profile, however, is rather difficult. The old beach sand, overlain by dune sand, is assumed to be one of the prospecting aquifers in the area. However, there are only a few wells where screens are installed at sand beds and are not associated with other prospecting aquifers in its section. These wells are found at sand dunes along the Mediterranean in the northeastern corner of the study area : wells No.12-91, 12-97, 12-103, 16-34, 16-86, and 16-105. In most cases, sand beds are associated with underlying gravel or kurkar. Therefore, productivity of the sand beds is subject to future confirmation. The distribution of sand thickness in El-Arish and the coastal plain from Sheikh Zuwayid to Rafah is shown in Fig. 8-2-3.

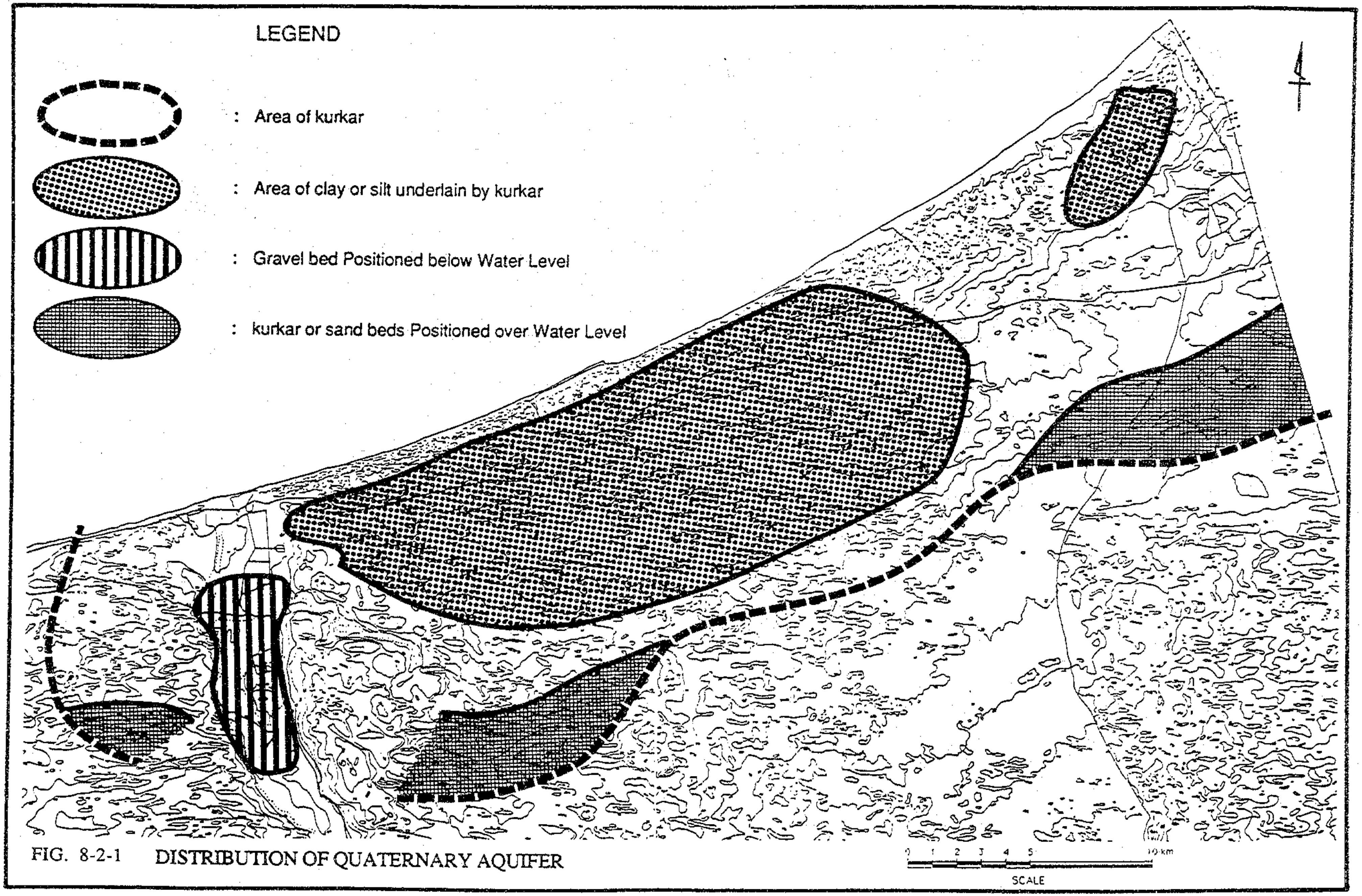
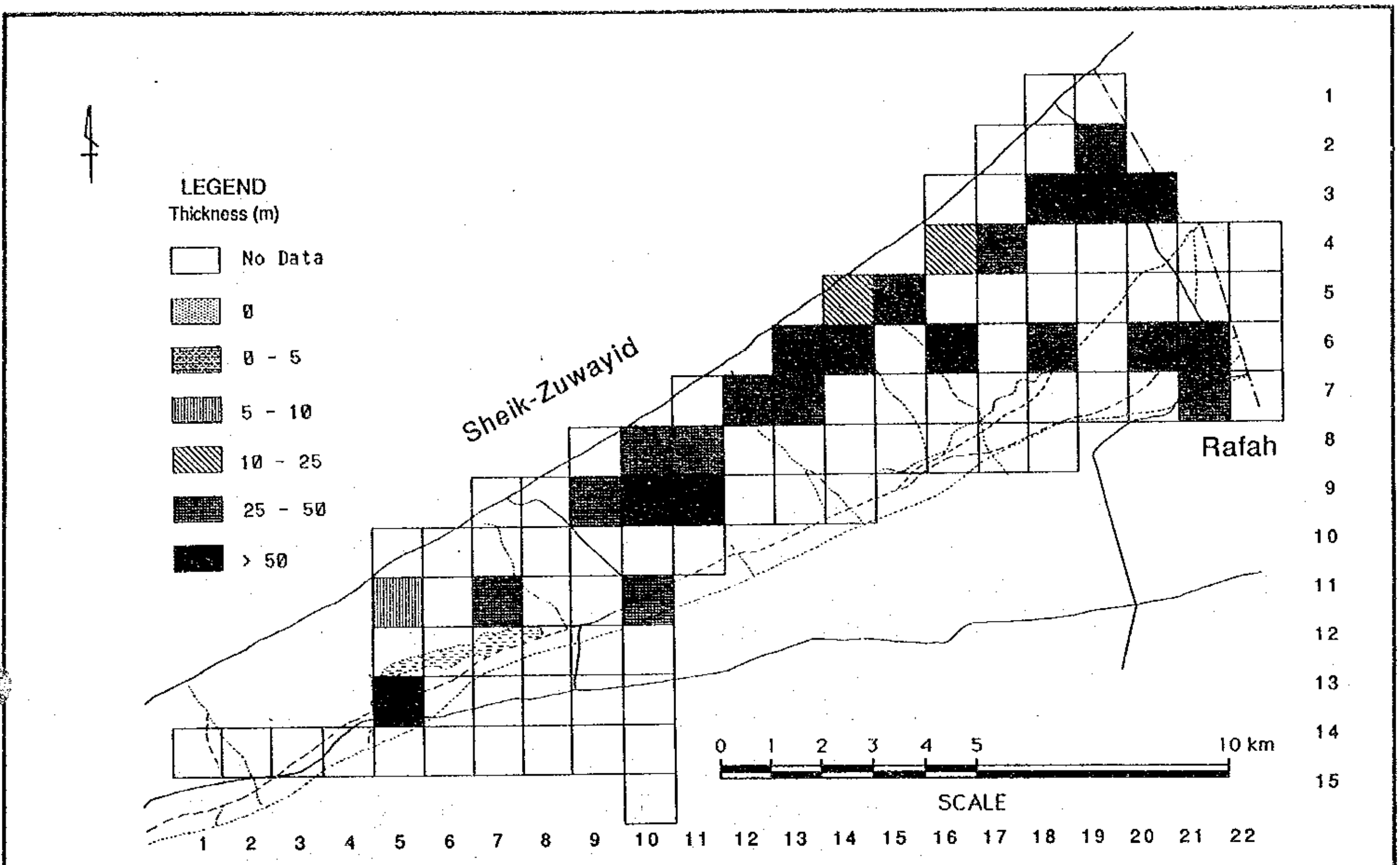
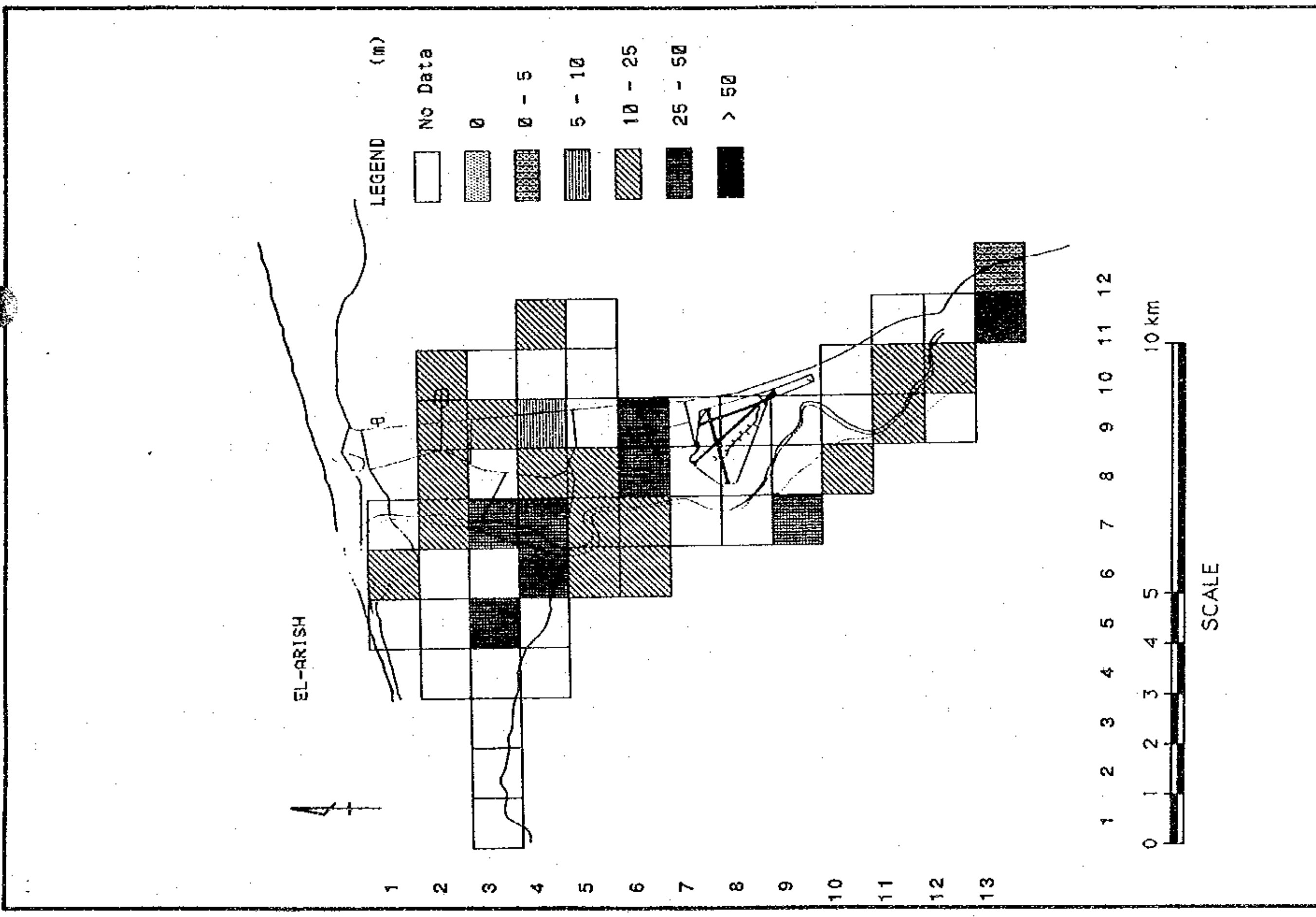


FIG. 8-2-1 DISTRIBUTION OF QUATERNARY AQUIFER

FIG. 8-2-2 ISO-BASE OF QUATERNARY



THICKNESS OF QUATERNARY SAND BED AT SHEIKH ZUWAYID - RAFAH AREA



THICKNESS OF QUATERNARY SAND BED AT EL-ARISH AREA

FIG. 8-2-3 DISTRIBUTION OF SAND THICKNESS

Gravel beds are found at many places in this area. In the well field in the alluvial plain of the Wadi El-Arish it extends about 10 km along the river course from well No. 5-5, 4 km south of the airport to well No. 1-106 in the southeast of El-Arish town. The origin of this gravel bed is unknown. However, it seems to extend beyond the alluvial plain of the Wadi El-Arish in the north of the airport. The wells where screens are installed in the gravel bed are No.1-66, 1-75, 1-93 ,1-109, 1-127, 1-29, 1-30, 2-6, 2-17 and 2-25.

There are many wells in this well field where screens are installed in the gravel bed and kurkar (Section 2-1-6, of Technical Report I). The distribution and thickness of the gravel bed in the well field of the alluvial plain of the Wadi El-Arish is shown in Fig. 8-2-4.

In the coastal plain from Sheikh Zuwayid to Rafah, gravel beds were observed in some locations. However, they are local deposits accumulated in old wadi beds. They are at wells No. 12-99, 11-26, 16-10, 16-11, 16-12, 16-24 and 16-34. At well No. 11-26, on the coastal sand dune in Rafah, the water level stays in the gravel bed. However, the water level is controlled by the piezometric potential of the kurkar aquifer. The screens of this well are installed there, since the kurkar is overlain by shale that is a bew meter thick.

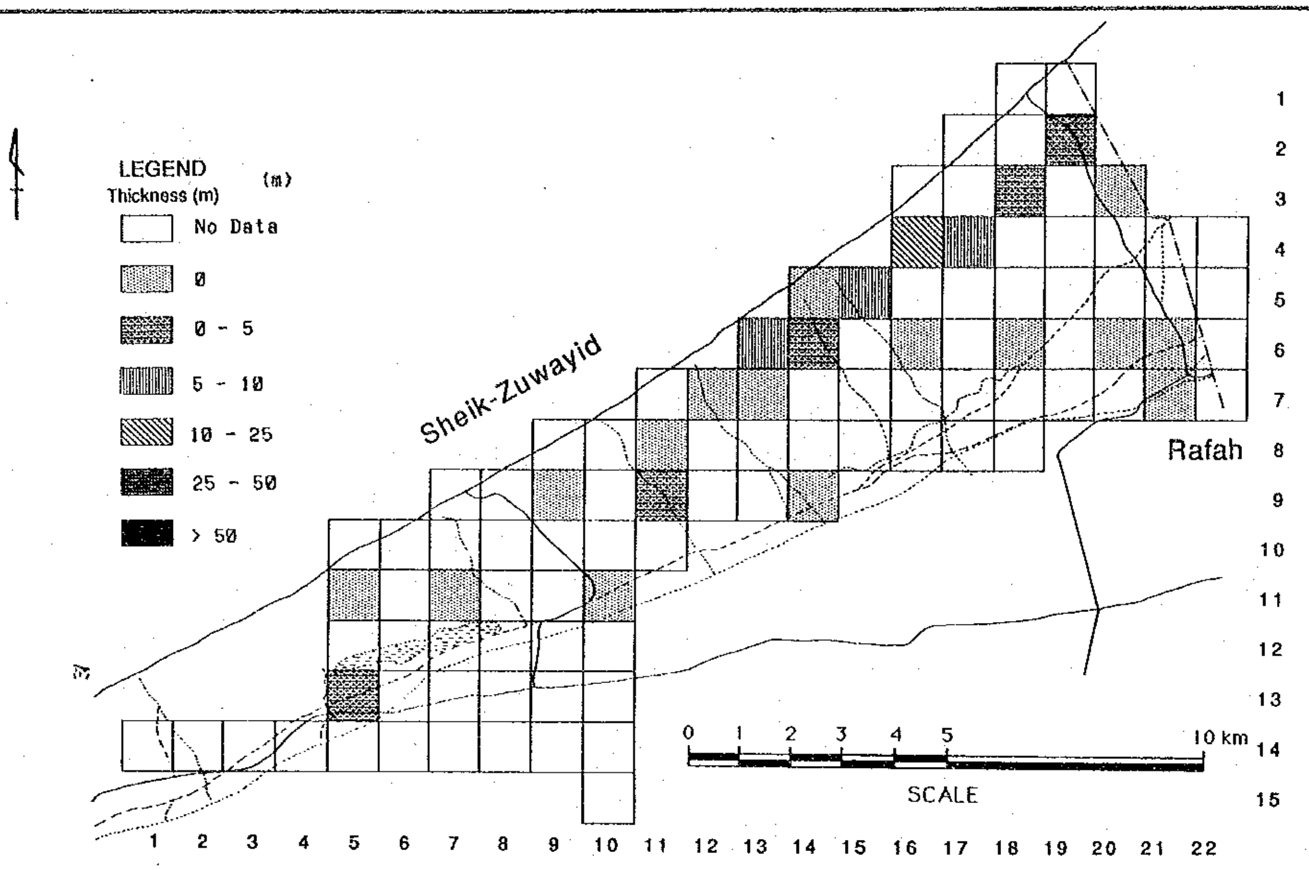
In most cases where a gravel bed was observed in the lithological profile, the water level remains below the gravel bed in the coastal sand dune area. For this reason, the productivity of the gravel bed is presumed not to be high, although further confirmation will be required on this matter in the future (Fig. 7-2-7, Section 7-2).

A gravel bed was also observed at other test wells. However, it is thin (less than 10 m thick), and high productivity cannot be expected.

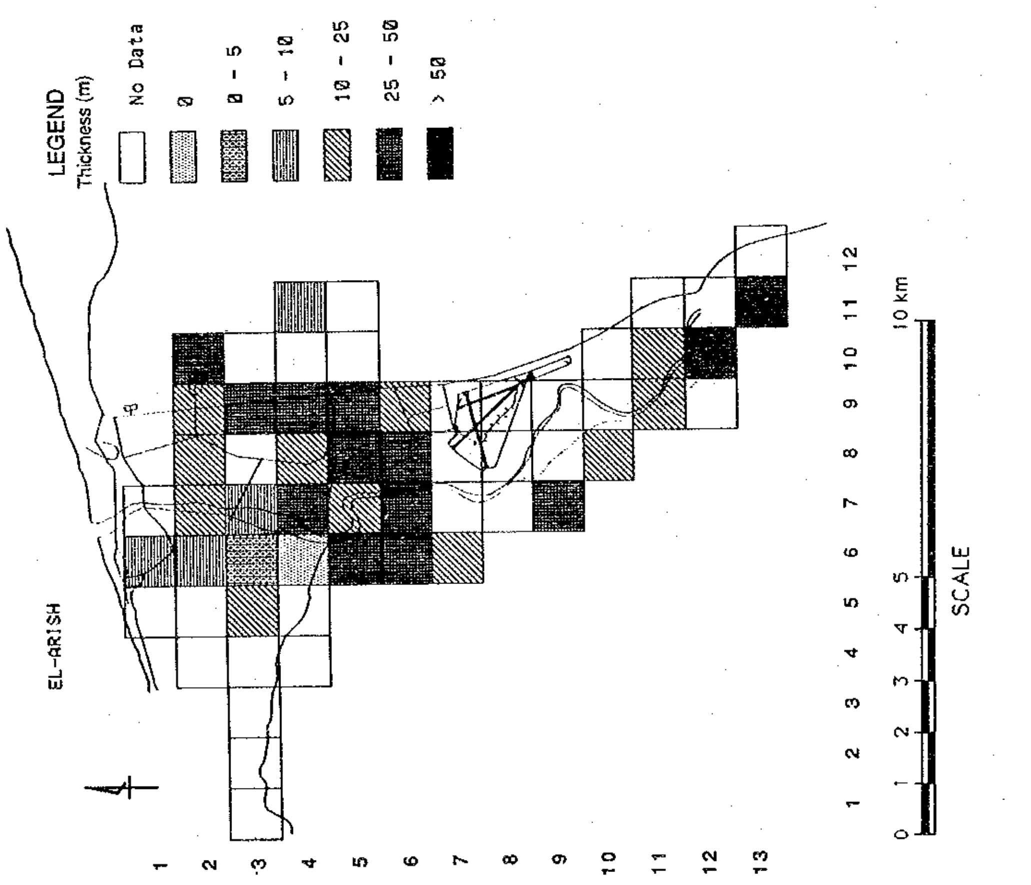
Kurkar is a kind of calcareous sand deposit broadly distributing in the coastal plain. In the well field of the Wadi El-Arish alluvial plain, kurkar is observed along the river channel by 10 km overlain by gravel. In this well field most wells have their screens in kurkar.

Kurkar is also observe under the coastal sand dunes in the area from Sheikh Zuwayid to Rafah. The elevation of the base of kurkar ranges from -60 m asl to -20 m asl. Its thickness varies from 10 m to 40 m. In some parts of the coastal sand dune area kurkar is thinning out.

Kurkar is also found at some test wells and it is assumed that it distributes from El-Arish to the east towards the international border with Israel with width varying from 10 km to 20 km. Distribution of the thickness in the well field in the lower stretch of the Wadi El-Arish and the coastal plain in the northeastern part of the study area is shown in Fig. 8-2-5.

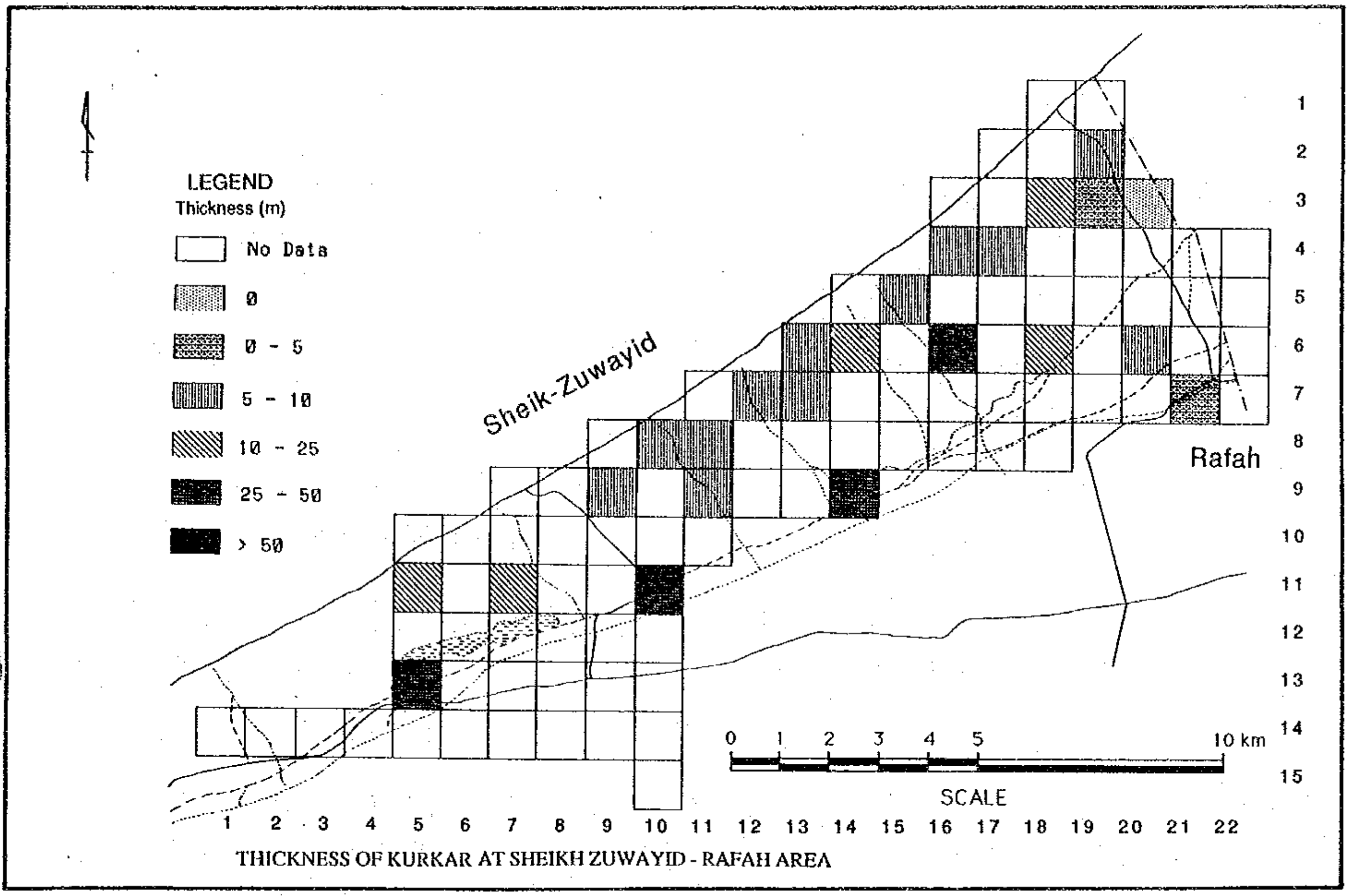


THICKNESS OF QUATERNARY GRAVEL BED AT SHEIKH ZUWAYID - RAFAH AREA



THICKNESS OF QUATERNARY GRAVEL BED AT EL - ARISH AREA

FIG. 8-2-4 DISTRIBUTION OF GRAVEL THICKNESS



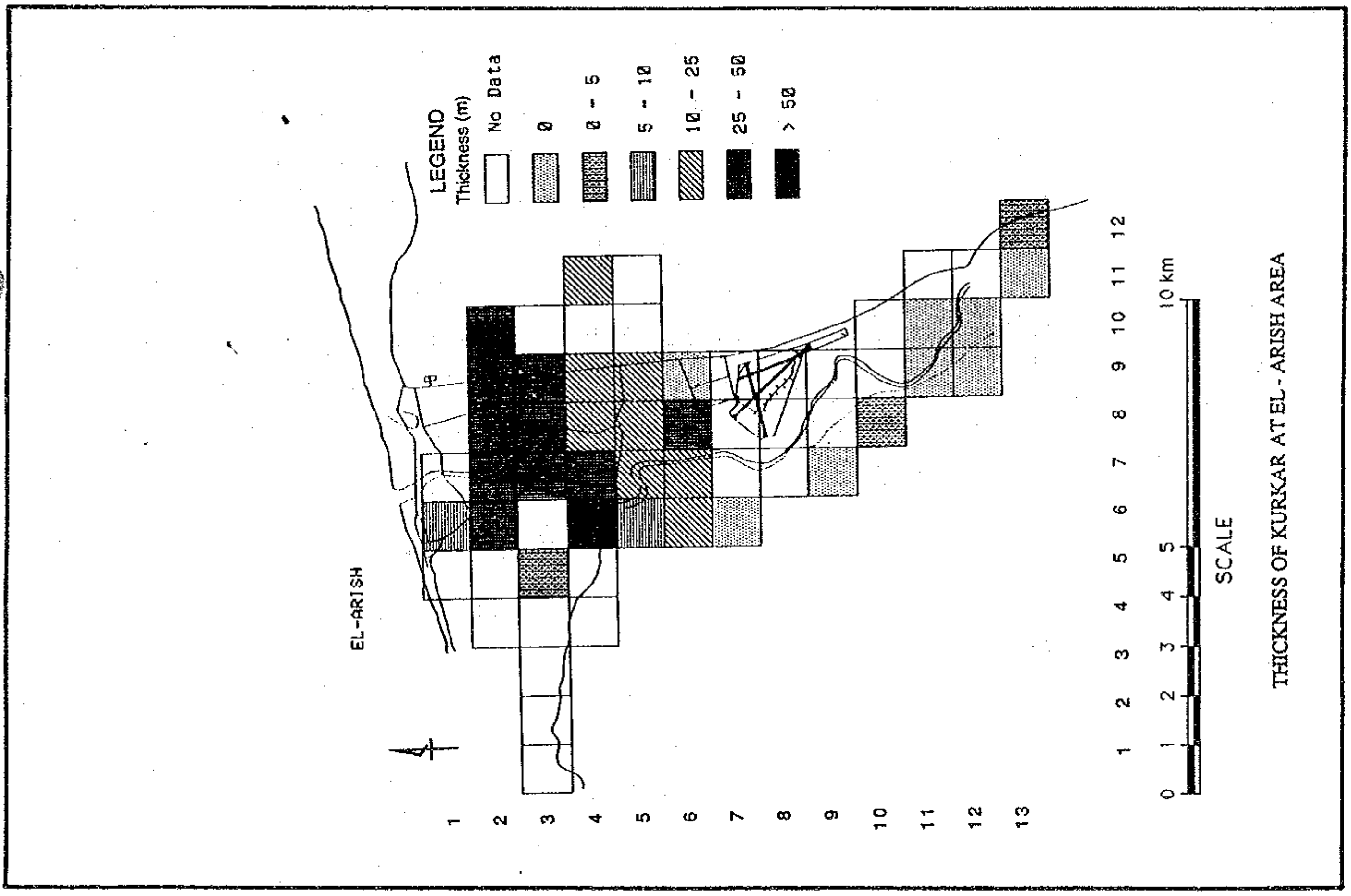


FIG. 8-2-5 DISTRIBUTION OF KURKAR THICKNESS

8-2-3 Hydrogeological Structure of Quaternary Aquifer

The hydrogeological structure has a direct implication on the productivity and quality of the groundwater in the Quaternary formation especially in the arid zone.

Along the channel of the lower stretch of the Wadi El-Arish there distributes gravel overlying kurkar. Also, clayey beds were observed that were intercalated with sand and gravel. The clayey beds are a lenticular type, in general. However, thick broad beds were encountered at some locations. Although the thickness of the lenticular beds intercalated in the Quaternary deposits are thin, the hydraulic condition of the groundwater in kurkar is varies from confined or semiconfined to unconfined according to the localities (Fig. 7-2-5, Section,7-2).

The wells where screens are installed in the gravel overlying the kurkar may easily cause up-seepage from the kurkar by over-pumping. Such wells may continuously provide groundwater from the kurkar. As for the wells having screens installed in kurkar, they may provide water originating from the kurkar aquifer.

In order to draw a general feature of the hydrogeological structure of the Quaternary in the eastern side of the Wadi El-Arish some additional cross sections were drawn at locations shown in Fig. 8-2-6.

The geological cross section (G-G') in the eastern part of the coastal plain indicates kurkar at the bottom of the Quaternary overlain by thick sand with occasional clayey beds. The upper part of kurkar is dry in the southern end of the cross section at well J No. 8. From this point to the north, the aquifer seems to be an unconfined type consisting of sand and the underlying kurkar (Fig. 8-2-7).

FIG. 8-2-6 LOCATION OF GEOLOGICAL SECTIONS

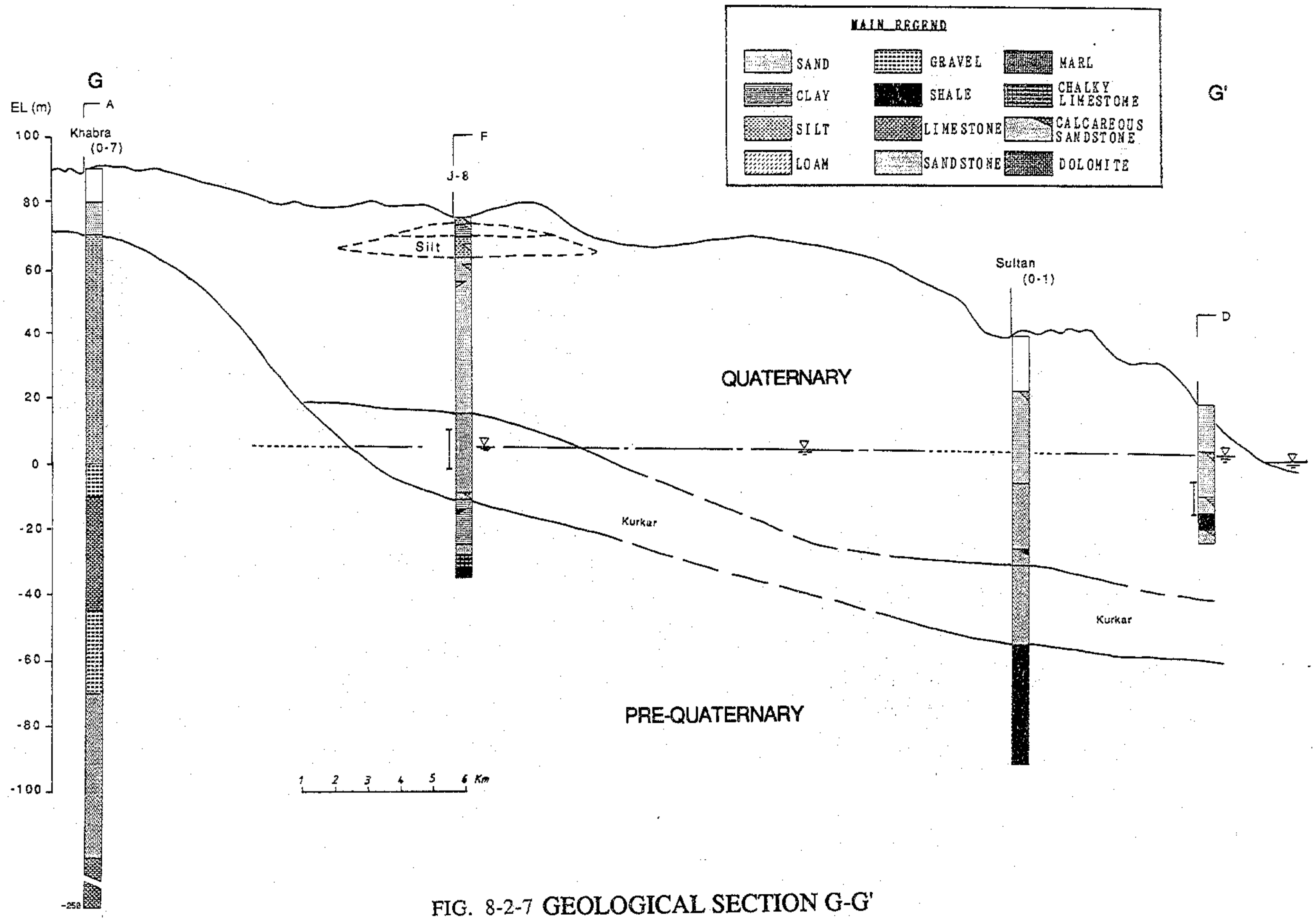


FIG. 8-2-7 GEOLOGICAL SECTION G-G'

In the cross section at H-H', about 6 km west of section G-G', there are thick clay beds in the sand and kurkar is found to be confined aquifer at well J No. 7. Well No. SR6's screen is installed in sand underlain by kurkar. The aquifer of this well is an unconfined type and most probably it has hydraulic continuity with the aquifer of well J No. 7 (Fig. 8-2-8).

The aquifer of well J No. 6 is a confined kurkar overlain by a thick clayey bed. The aquifer of well SR1 in the same section is sand underlain by the clayey bed which overlies on kurkar. So, the sand aquifer presumably has no hydraulic continuity with the kurkar (Fig. 8-2-9).

There is a thin kurkar at the base of the Quaternary in the section K-K' overlain by sand. The southern end of kurkar is assumed to be dry. However, in the sand bed of well AR-12 groundwater is found. Groundwater is also found in the sand bed overlying thin silt at well AR6. Hydraulic continuity of these sand beds probably depend on the extent of the sand bed isolation by the silt bed (Fig. 8-2-10).

Some part of the kurkar forms a confined aquifer which is clearly shown in section F-F' in Fig. 7-2-11. The upper part of the kurkar at the northern end of this section (at well J No. 8) is dry, indicating the aquifer is unconfined in this area. However, kurkar at wells J No. 6 and 7, and at test well No. E are confined and overlain by a thick clayey bed. On the other hand, kurkar at E-E' section is much thinner than that in the section F-F'; it is overlain by a thick sand bed. Two aquifers, sand and kurkar, have hydraulic continuity (Fig. 8-2-12).

Considering the subsurface conditions observed above, a schematic cross section of the Quaternary from El-Arish to Rafah is drawn as in Fig. 8-2-13. Kurkar is underlain by the Pre-Quaternary, mainly consisting of shale. However, in some places, it consists of sandstone or limestone (Section 8-2-2 and 3, Technical Report I).

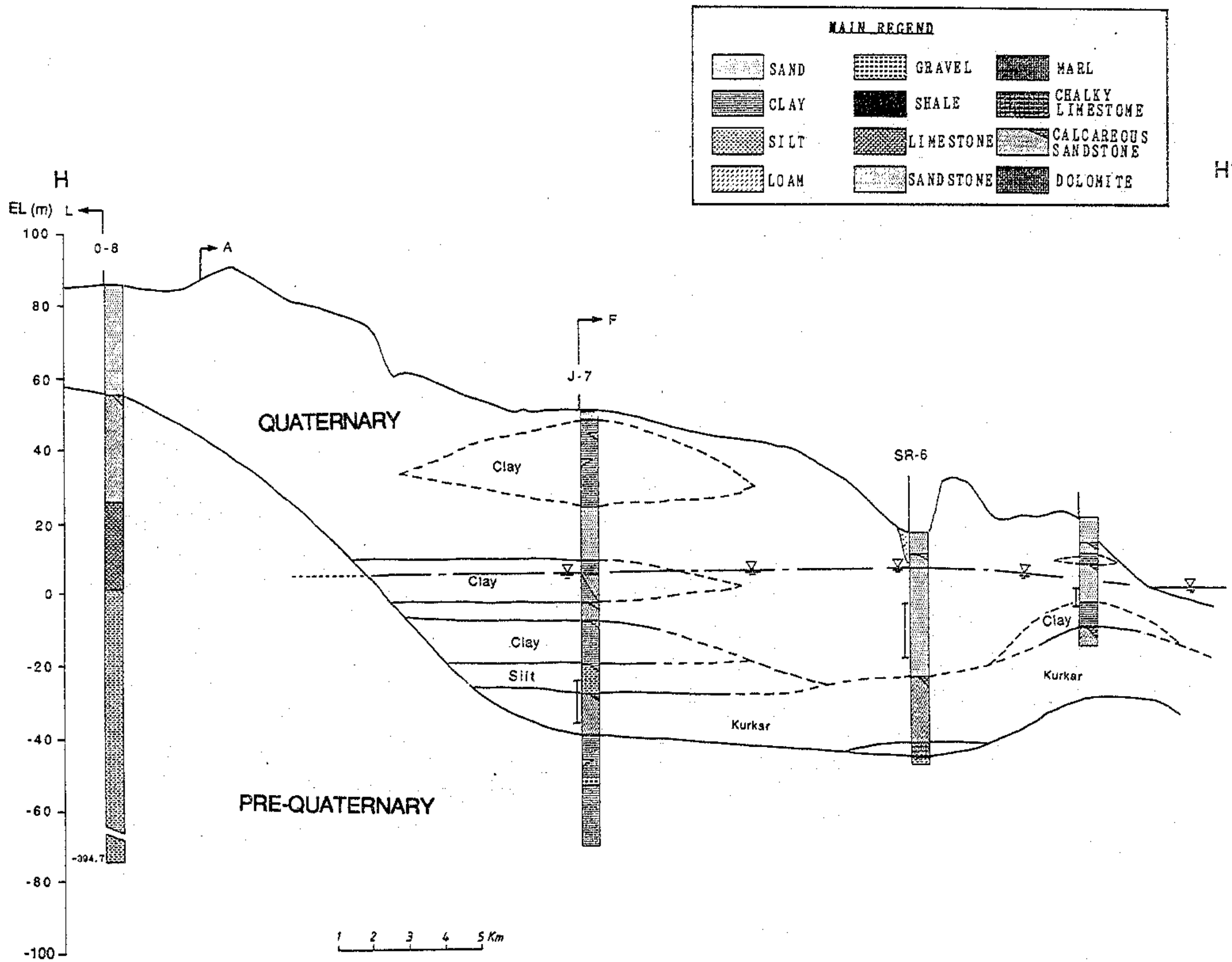


FIG. 8-2-8 GEOLOGICAL SECTION H-H'

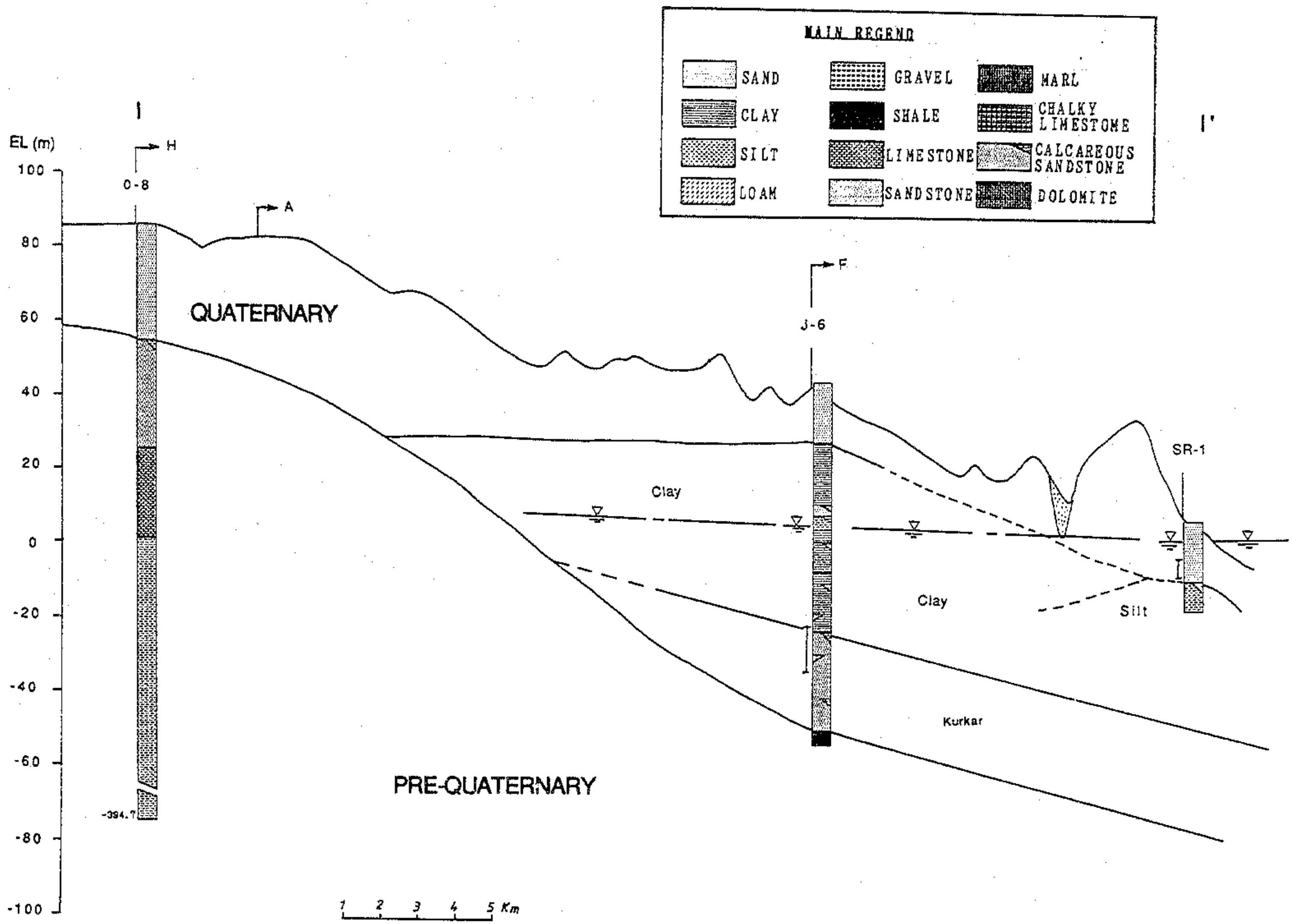


FIG. 8-2-9 GEOLOGICAL SECTION I-I'

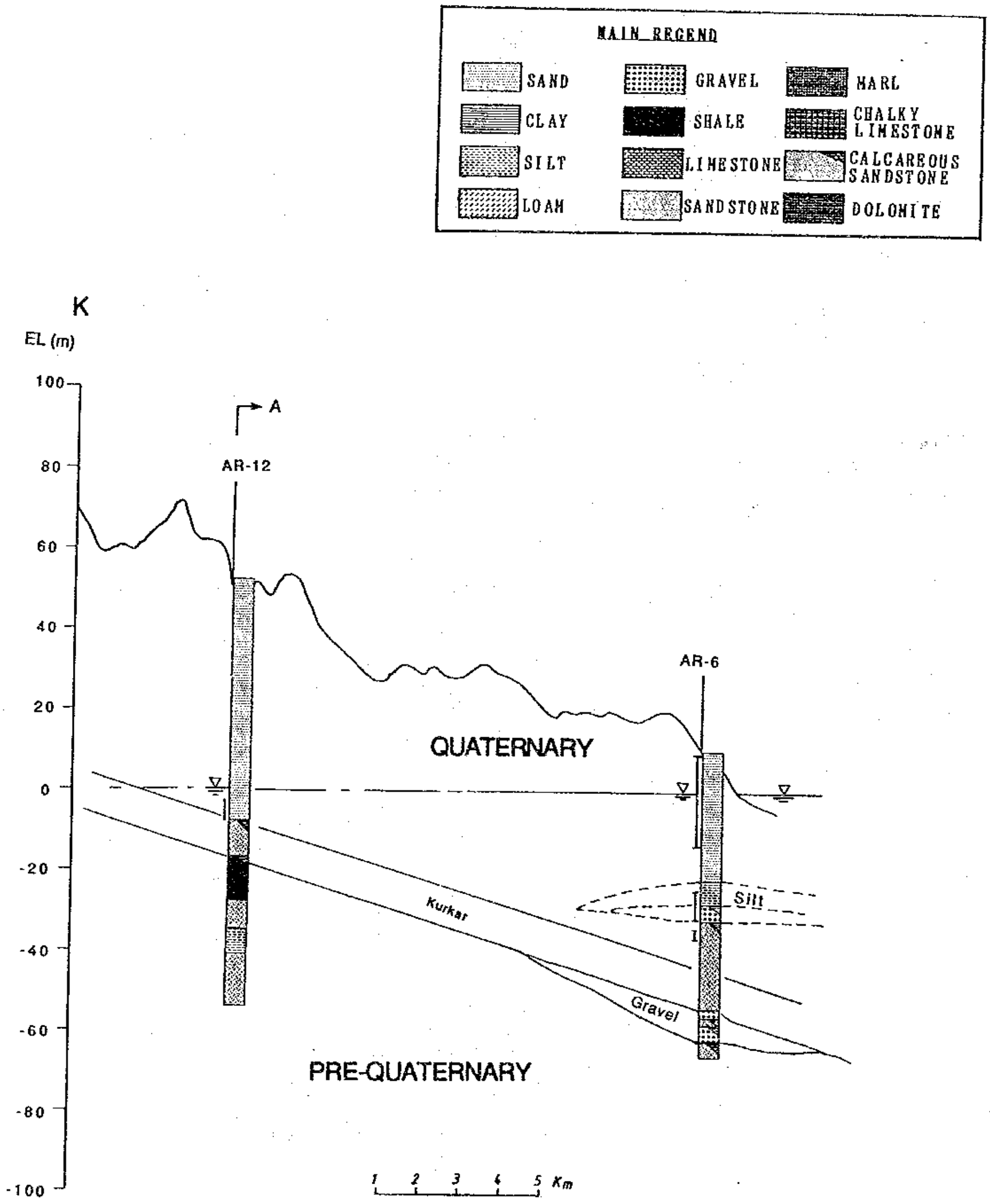


FIG. 8-2-10 GEOLOGICAL SECTION K-K'

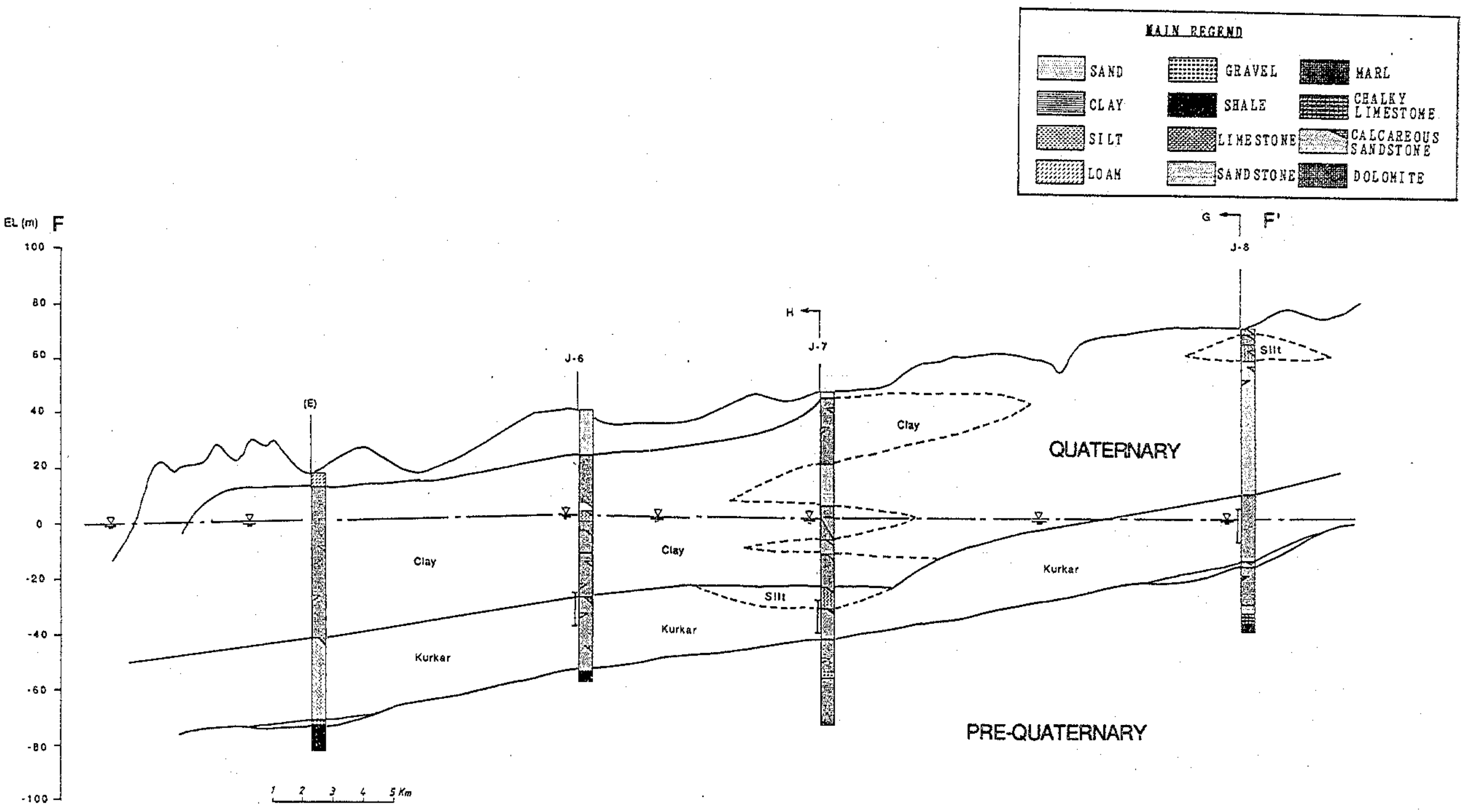


FIG. 8-2-11 GEOLOGICAL SECTION F-F'

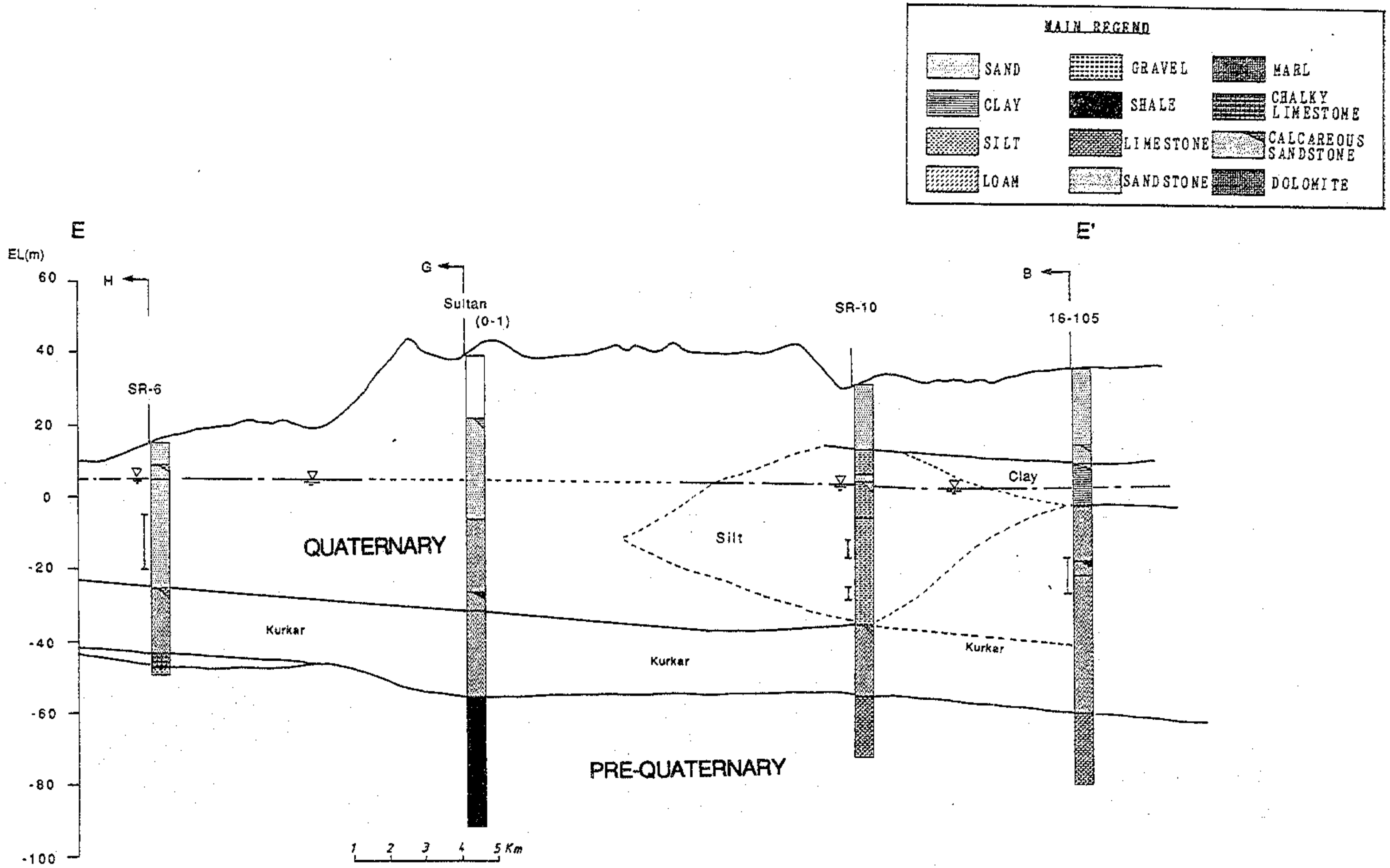


FIG. 8-2-12 GEOLOGICAL SECTION E-E'

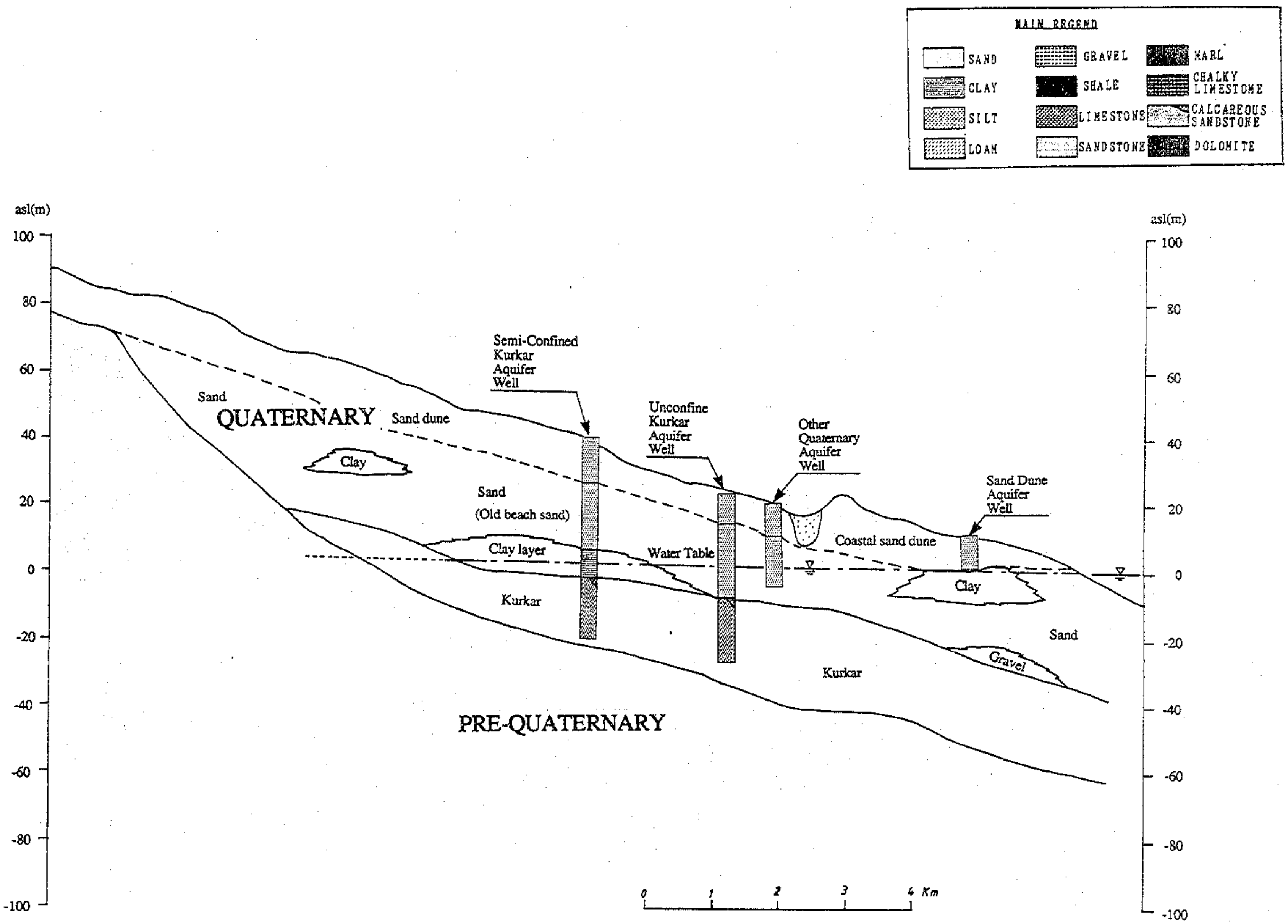


FIG. 8-2-13 SCHEMATIC GEOLOGICAL SECTION OF QUATERNARY IN THE COASTAL PLAIN

At test well J No. 9 there is a sandstone and a gravel bed overlain by Pre-Quaternary shale. This aquifer is assumed to be exposed to the Quaternary aquifer at the boundary between these formations (Fig. 7-2-5, Section 7-2). Similar circumstances are observed in sections G-G', H-H' and L-L' where Pre-Quaternary limestone may be exposed to the Quaternary aquifer.

The thickness of kurkar varies from 10 m to 40 m, but thins out in some places (wells No. 11-18 and 11-20) (section 7-2). Kurkar is replaced by the other Quaternary deposits such as gravel, sand and sandstone in the southern end of the Quaternary.

Kurkar is overlain by old beach sand which underlies dune sand. The boundary between old beach sand and dune sand is unknown in many cases. Clayey beds and gravel are interbedded with each other in different thicknesses. Wherever a thick clayey material overlies kurkar, a confined aquifer is formed.

The groundwater level along the Mediterranean coast near the beach remains at 1 to 2 m asl and is estimated to be 4 to 5 m asl at the southern end of kurkar. When the distribution of kurkar and the groundwater level are compared, some part of the kurkar is found to be dry as shown in Fig. 8-2-7.

In the eastern half of the Quaternary formation a thick bed of intercalated sand and clay occupies a broad area which causes the confined aquifer of underlying kurkar.

8-2-4 Water Quality

8-2-4-1 Characteristics of Water Quality by Aquifer

The high salinity of groundwater is a prevailing problem in the study area. There are different aquifers in the area: sand, gravel and kurkar. The quality of water from each type of aquifer is assumed to be different.

In order to determine the chemical characteristics of groundwater of a specific aquifer, available well profiles were reviewed to select wells tapping a specific aquifer:

Table 8-2-1 Number of Wells in El-Arish

Type of aquifer	Number of wells
Sand	8
Gravel	13
Kurkar	8

Table 8-2-2 Number of Wells from Sheikh Zuwayid to Rafah

Type of aquifer	Number of wells
Dune sand	5
Old beach sand	3
Kurkar	7

A prevailing problem of the groundwater of the Quaternary aquifer in the study area is its high salinity. There are two possibilities which may affect the salinity of groundwater: contamination of old saline groundwater or sea water intrusion since the groundwater in the Pre-Quaternary aquifers has high salinity with various levels of TDS (Section 4-3, Technical Report I) and at the same time these well fields face the Mediterranean. In order to examine the possibility of sea water intrusion and compare the chemical characteristics of the groundwater, the ratio of $(Na^{+}+K^{+})/(Ca^{++}+Mg^{++}) = R_{equ}$ and Na^{+}/Cl^{-} in equilibrium were calculated.

In general, alkali ions are more soluble than alkaline earth ions and the concentration of alkali ions in the sea water is remarkably high. When the water is under the influence of the sea water, R_{equ} becomes very close to the sea water R_{equ}. For the same purpose, Na/Cl ratio in equilibrium is also calculated. Sodium and chlorine are predominating ions in sea water; both of them are very stable in water. The solubility product of sodium salts is higher than that of major cations in the natural water so that when the water is contaminated by sea water this ratio becomes similar to the ratio of the sea water: 1.09.

TDS, R_{equ} and Na/Cl ratio of water samples from the sand aquifer, are listed in Table 8-2-3;

Table 8-2-3
TDS, R_{equ} and Na/Cl Ratio of Water in Sand Aquifer

Well number	TDS	R_{equ}	Na/Cl
Coastal sand dune			
El-Arish			
AR5	818	2.13	1.21
AR7	863	3.37	1.16
Sheikh Zuwayid and Rafah			
SR1	557	2.60	1.77
SR3	506	5.71	2.14
SR4	317	0.77	0.77
Inland sand			
El-Arish			
AR1	2,785	1.15	1.08
AR6	2,738	1.67	1.33
AR11	2,545	1.48	1.30
AR12	3,049	4.69	1.76
Old beach sand			
Rafah			
SR6	1,339	4.51	1.37
SR8	2,740	4.99	1.15
SR9	309	0.88	1.60

The TDS of the groundwater in the sand aquifers of the coastal sand dune is low and ranges from 300 ppm to 800 pm, particularly in the sand dune in *Sheikh Zuwayid* and *Rafah it is the lowest.*

The TDS of the groundwater in the old beach sand aquifer is assumed to be in a range between 1,000 ppm and 3,000 ppm although available data are insufficient. It is remarkable that some R_{equ} of the water from this type of aquifer are extremely high: 4.51 and 4.99. Although well No. SR9 is listed in this group, it is assumed that its hydrogeological conditions are similar to that of the coastal sand dune since the TDS is at a similar level to that of coastal sand dune and the R_{equ} is small.

These wells listed in the inland sand group are tapping sand *aquifer in the coastal alluvial plain of Wadi El-Arish in the lower* reach and inland sand dune. The TDS of these wells range between 2,500 pm and 3,000 ppm. The R_{equ} of these wells are lower than those of other types of aquifer, except for well No. AR12 having an R_{equ} of 4.69.

Gravel bed aquifers are developed only in the Wadi El-Arish alluvial plain since most of groundwater levels of wells in the coastal plain, from Sheikh Zuwayid to Rafah, are above the top of gravel beds and distribution of gravel beds are limited to a small area (Section 7-2-3, Technical Report I).

The TDS, R_{equ} and Na/Cl ratio of the groundwater from gravel aquifer are listed in Table 8-2-4.

Table 8-2-4

TDS, R_{equ} and Na/Cl Ratio of Gravel Aquifer

Well number	TDS	R_{equ}	Na/Cl
1-109	3,977	1.07	0.76
1-110	3,520	1.56	0.81
1-120	3,800	1.08	0.66
1-123	3,110	1.12	0.63
1-127	4,916	1.13	0.64
1-129	3,809	1.31	0.72
1-130	3,415	1.60	0.80
1-136	5,091	1.46	0.84
AR3	1,669	5.7	1.10
AR9	3,822	2.39	1.28
AR13	1,505	2.15	1.04

These wells are distributed in the alluvial plain of the lower reach of the Wadi El-Arish. The TDS of wells AR3 at the northern end of the alluvial plain and AR13 on the river bank of the Wadi El-Arish on the western side of the airport are less than 2,000 ppm. However, the rest of the TDS of the gravel bed's groundwater range between 3,000 ppm and 5,000 ppm.

The R_{equ} of well No. AR3 is extremely high compared to the rest of the R_{equ} of this group. The R_{equ} of well No. AR9 and AR13 exceed 2.0. However, the rest of the R_{equ} are in a narrow range between 1.0 and 1.6.

The Na/Cl ratio of these wells range between 0.6 and 0.84 except at wells No. AR3, AR9 and AR13 where Na/Cl ratios range between 1.0 and 1,28.

The wells tapping the kurkar aquifer are listed in Table 8-2-5;

Table 8-2-5
TDS, R_{equ} and Na/Cl of the Kurkar Aquifer

Well number		TDS	R_{equ}	Na/Cl
El-Arish	1-64	2,554	0.67	0.65
	1-83	3,460	1.09	0.80
	1-104	3,172	0.90	0.79
	1-105	3,494	1.09	0.85
	1-123	2,887	1.12	0.63
	1-131	2,691	0.84	0.56
	AR2	2,517	1.72	1.04
	AR9	3,822	2.36	1.28
	AR8	2,837	1.42	1.20
	Average	3,074	1.22	0.82
Sheikh Zuwayid to Rahah	J No. 3	5,562	2.42	0.92
	J No. 5	4,290	1.73	0.83
	J No. 6	4,830	2.20	0.88
	J No. 7	5,560	3.71	1.06
	J No. 10	3,622	1.26	0.90
	Average	4,308	2.26	0.92

The TDS of the groundwater in the kurkar aquifer ranges between 2,500 ppm and 3,800 ppm in the alluvial plain of Wadi El-Arish, while the TDS of the kurkar aquifer in the inland area of the coastal plain in Sheikh Zuwayid and Rafah area show a higher value: 4,308 ppm on an average, and in a range between 3,600 ppm and 5,500 ppm.

The high salinity is assumed to be the original nature of the kurkar. However, there is a possibility of contamination of a very saline groundwater from the aquifers of the Pre-Quaternary since, in some areas, the Quaternary is underlain by limestone or sandstone of the Pre-Quaternary (Section 7-2-2 and 7-2-3, Technical Report 1).

Wells in the coastal sand dune are shallow, ranging from 20 m to 40 m from the ground surface. The lithology of the aquifer is sandy underlain by an impermeable clayey bed. Therefore, these aquifers are locally isolated and are being recharged under the current hydrometeorological cycle, although its mechanism and quantitative analysis are subject to future confirmation. Spatial conditions of well No. SR1 is the typical case. The aquifer of the well No. AR5 is the kurkar; however, hydrogeological conditions may be the same as the other wells in the coastal sand dunes yielding a low TDS of less than 1,000 ppm.

The aquifers of the wells drilled in the sand aquifer in inland sand and old beach sand are generally underlain by thin kurkar so that the original nature of these aquifers is unknown at present. The hydrogeological conditions of aquifers of wells No.SR9 and SR10 are assumed to be the same as in the coastal sand dune since the TDS of these wells are low.

The TDS of the groundwater in gravel aquifers are in a wide range, between 1,500 ppm and 5,100 ppm. The aquifer at well No. AR13 is a 20 m thick gravel bed underlain by the kurkar that is 10 m thick. The low TDS value of this well may suggest a fresh water recharge under the current meteorological conditions in a same manner as in the coastal sand dunes.

High TDS is found at wells No. 1-109, 1-120, 1-127, 1-129 and 1-136. These wells are located in the area at the outlet of the Wadi Mazaar to the alluvial plain of the Wadi El-Arish. Whether this high TDS value is of an original nature of the gravel aquifer or caused by some other aquifer is not known since the gravel bed has hydraulic continuity with other aquifers (Section 7-2). It should be noted that TDS observed at the confluence of the Wadi Mazaar exceed the highest TDS of kurkar in this area: 3,800 ppm at well No. AR9.

Aquifers consisting of kurkar is broadly distributed in the eastern part of the coastal plain (Fig. 8-2-5). Kurkar is overlain by other Quaternary deposits such as clay, sand and gravel (Fig. 8-2-7 to 8-2-12). Especially in the river bed deposits of the Wadi El-Arish kurkar that is overlain by thick gravel. In some places an impermeable bed is interbedded between the two. In other places gravel directly overlies kurkar. The hydraulic potentiometric surface in the river bed deposit of the Wadi El-Arish is in gravel bed. In this case there is hydraulic continuity between the gravel and the kurkar.

At the inland test wells J No. 4, 5, 6, 7 and 10, the aquifer consists of kurkar. The original nature of the kurkar aquifer is assumed to be indicated at these wells since kurkar is underlain by clay or shale and no other straitfied aquifer exists in the strata above kurkar.

The TDS of the kurkar aquifer in the coastal inland area ranges between 3,600 ppm and 5,500 ppm, while the TDS of the kurkar aquifer in the well field of El-Arish ranges between 2,500 ppm and 3,800 ppm. This difference may be attributed to the clayey strata observed just below the ground surface, which is playing the role as an impermeable layer preventing recharge from the current hydrometeorological events, while the kurkar aquifer in the well field of El-Arish is subject to recharge due to periodical floods once in ten to fifteen years.

8-2-4-2 Dating of Quaternary Groundwater

Although there is little possibility of groundwater recharge under the current hydrometeorological conditions, its rate must not be overemphasized. The age of groundwater in the well field in El-Arish is estimated as shown in Table 8-2-6;

Table 8-2-6 Carbon-14 Dating of Groundwater in Quaternary Aquifer

Sample I.D. and Sampling date	Apparent C-14 Age (Y. BP)	Corrected Age* (Y.BP)	Laboratory** Reference No.
NSN-1 El-Arish RIWR#64 8-/11/13	8,610 ± 240	4,390 ± 240	Gak-14802
NSN-2 El-Arish RIWR#75 89/11/13	5,570 ± 140	1,730 ± 140	Gak-14803
NSN-3 El-Arish RIWR#119 89/11/14	11,020 ± 290	6,770 ± 290	Gak-14804
NSN-4 El-Arish RIWR#123 89/11/14	13,240 ± 420	8,620 ± 420	Gak-14805

Units:

T.U : Tritium Unit 1 T.U. $= -10^{-18}$ T/H
$= -3.2$ pCi/liter

Y. BP : Years Before Present

* : Corrected for the carbonate dissolution process
** : Gakushuin University, Tokyo, Japan

The estimated age of the groundwater in the Quaternary aquifer ranges between 1,700 and 8,600Y.BP (Section 6-3, Technical Report I).

8-2-4-3 Geographical Distribution of TDS

The high TDS in the gravel aquifer in the area at the outlet of the Wadi Mazaar to the alluvial plain of the Wadi El-Arish may suggest that the aquifer in this area is influenced by groundwater from a highly saline kurkar or some other aquifer in the older formations.

Wells are densely located in the well field at El-Arish and in the coastal plain from Sheikh Zuwayid to Rafah and their screens are installed in different aquifers from well to well. So that distribution of the quality of the groundwater varies from well to well within a short distance, depending on the screen position. In order to figure out a general feature of water quality distribution, one square kilometer grids are meshed over these two well fields.

An average TDS of all wells in each mesh is calculated to depict a general feature of TDS as shown in Fig. 8-2-14 and 15. It is remarkable that a very high TDS is observed at grid No. 7-1, 7-2, 9-5 and 10-3. TDS in excess of 3,000 ppm were measured at 12 grids out of 40 grids. The grids with high TDS are distributed in the northern and eastern parts of the well field of Wadi El-Arish. Grids with relatively low TDS were observed in the area on the western side of El-Arish town and the southern half of the well field (Fig. 8-2-14(A)).

In a same manner as TDS distribution at the El-Arish well field, an average TDS in each grid is calculated for Sheikh Zuwayid and Rafah, as shown in Fig. 8-2-15.

Although available data are limited in certain areas, it is observed that an average TDS in each grid shows a much lower value than that in El-Arish well field. The highest TDS (3,400 ppm) is found at grid No. 20-5. There are also some grids indicating a TDS of more than 2,000 ppm in the area around Sheikh Zuwayid and Rafah (Fig. 8-2-15).

Although the grids around Sheikh Zuwayid show a kind of mosaic of high TDS and low TDS. The TDS in sand dunes along the coast show relatively low values in a range between 300 ppm and 700 ppm. While in the inland narrow belt behind the coastal sand dunes. The TDS of grids varies in a higher range than in the coastal sand dune. The highest TDS is 3,400 ppm at grid 20-5 and the lowest is 900 ppm at grids 20-3 and 4 (Fig. 8-2-15).

Comparing TDS, R_{equ} and Na/Cl ratio, the types of the groundwater are classified as shown in Fig. 8-2-16 and 17.

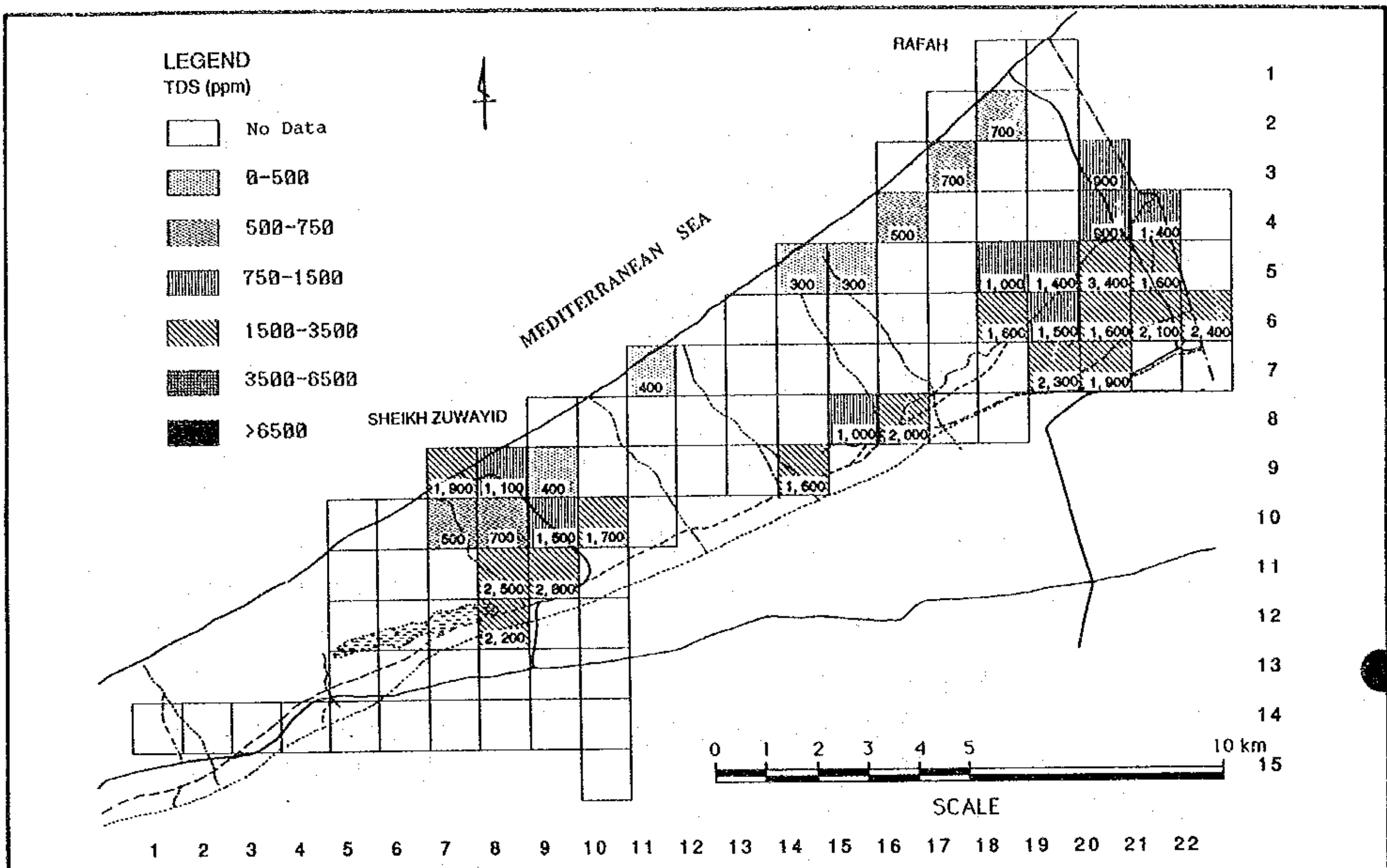


FIG. 8-2-14(B) TDS DISTRIBUTION IN SHEIKH ZUWAYID - RAFAH AREA 1988

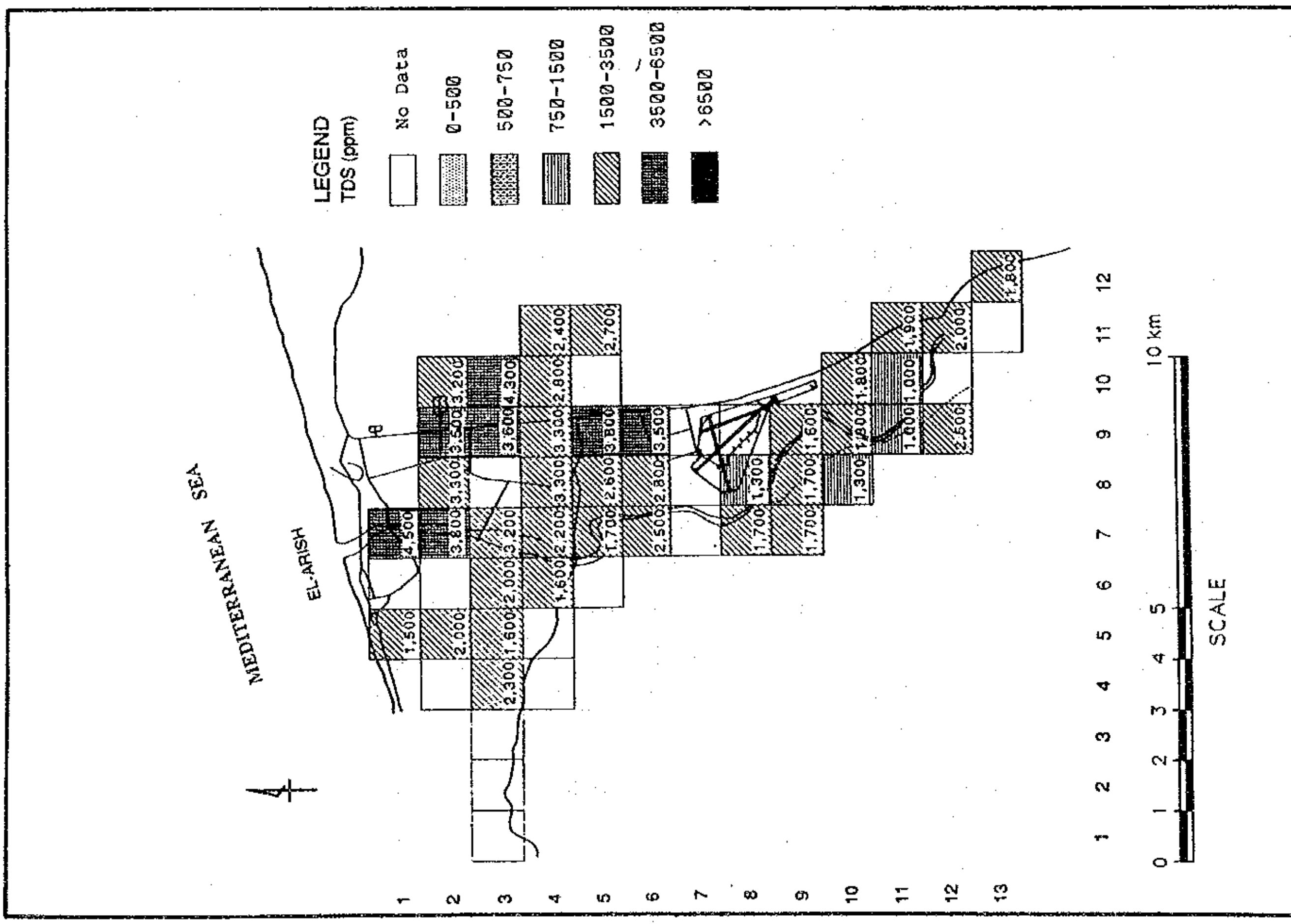


FIG. 8-2-14(A) TDS DISTRIBUTION IN EL - ARISH AREA 1988

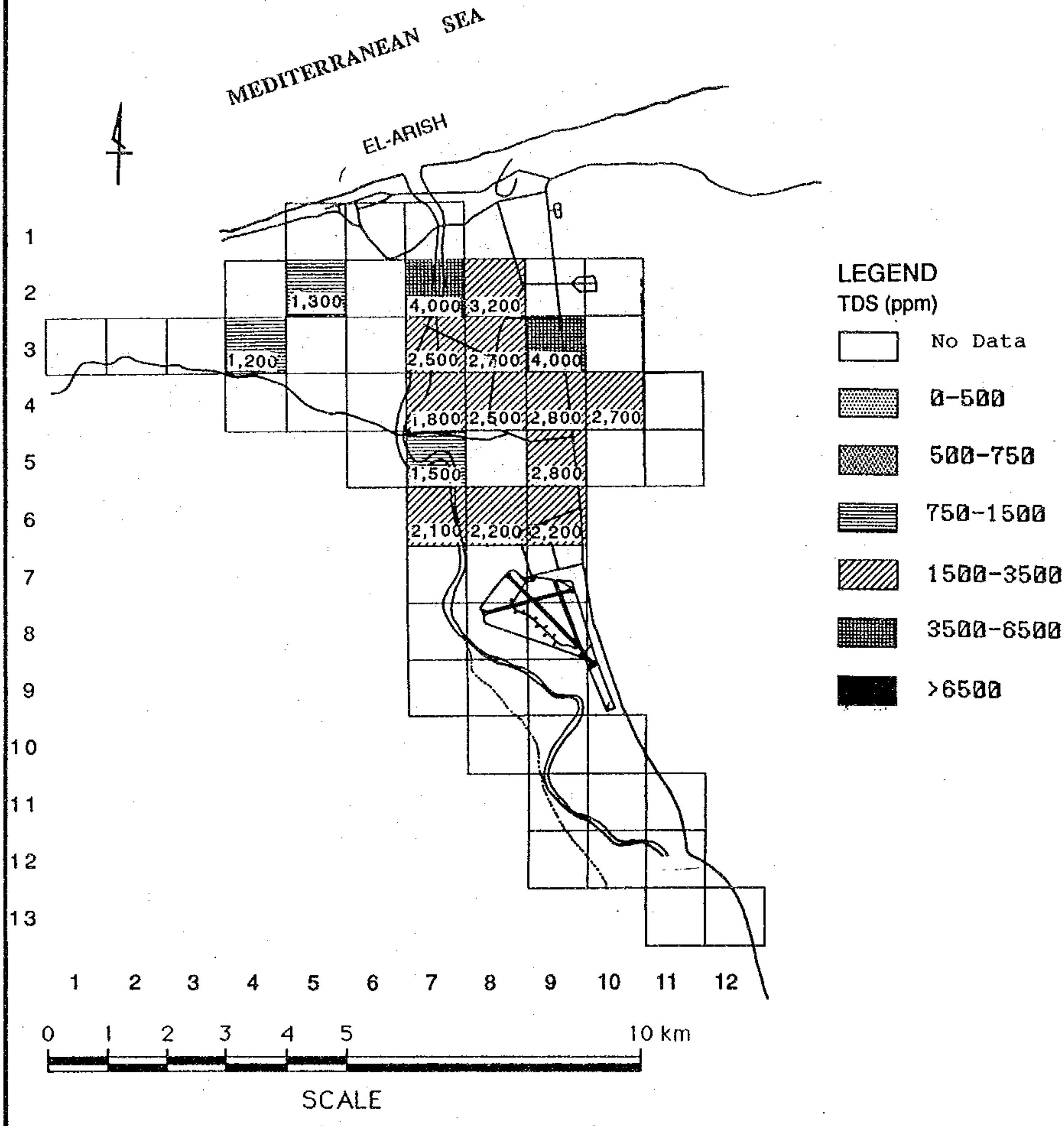
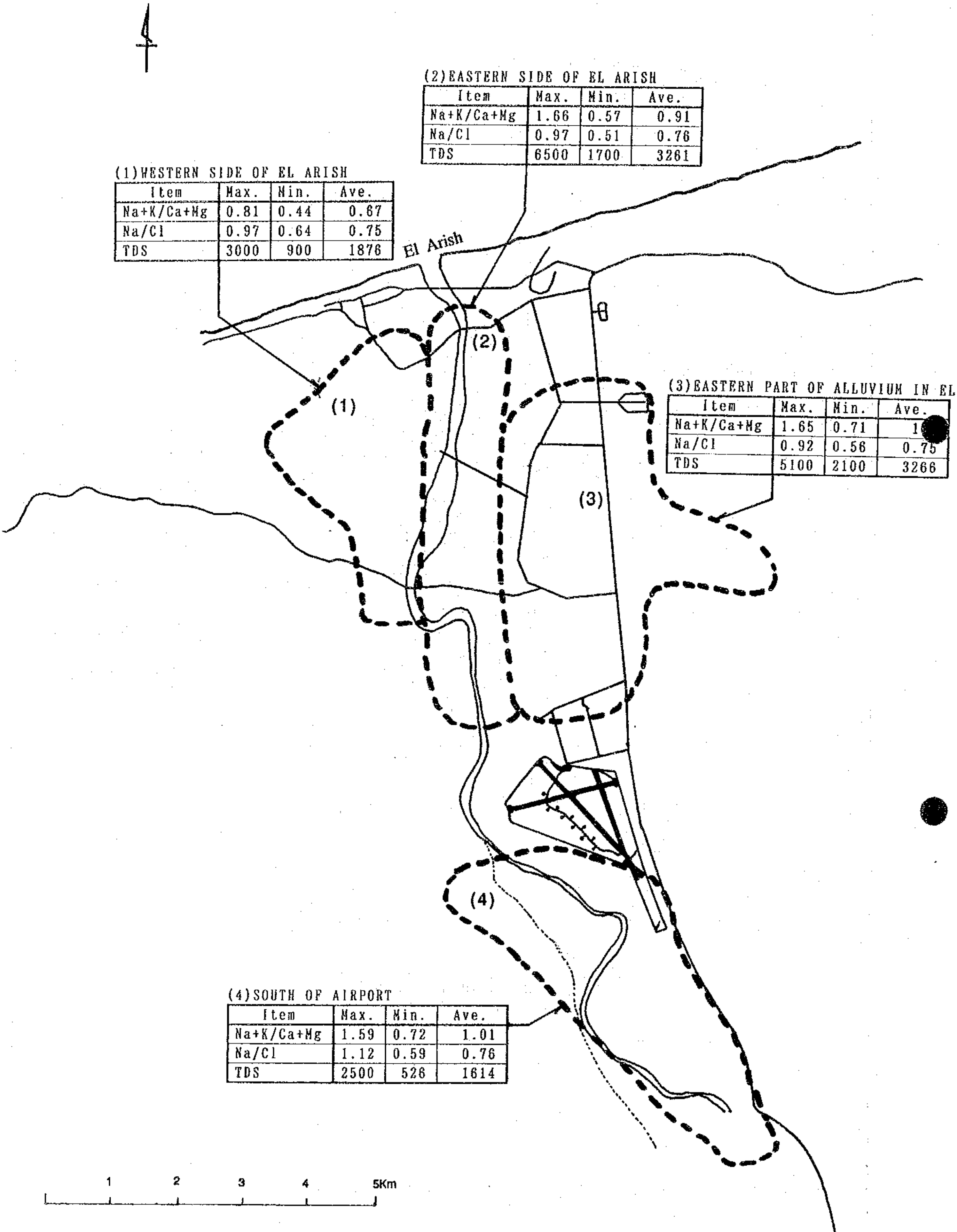


FIG. 8-2-15 SUPPLEMENTED TDS AT EL - ARISH AREA IN 1962



(1)WESTERN SIDE OF EL ARISH

Item	Max.	Min.	Ave.
Na+K/Ca+Mg	0.81	0.44	0.67
Na/Cl	0.97	0.64	0.75
TDS	3000	900	1876

(2)EASTERN SIDE OF EL ARISH

Item	Max.	Min.	Ave.
Na+K/Ca+Mg	1.66	0.57	0.91
Na/Cl	0.97	0.51	0.76
TDS	6500	1700	3261

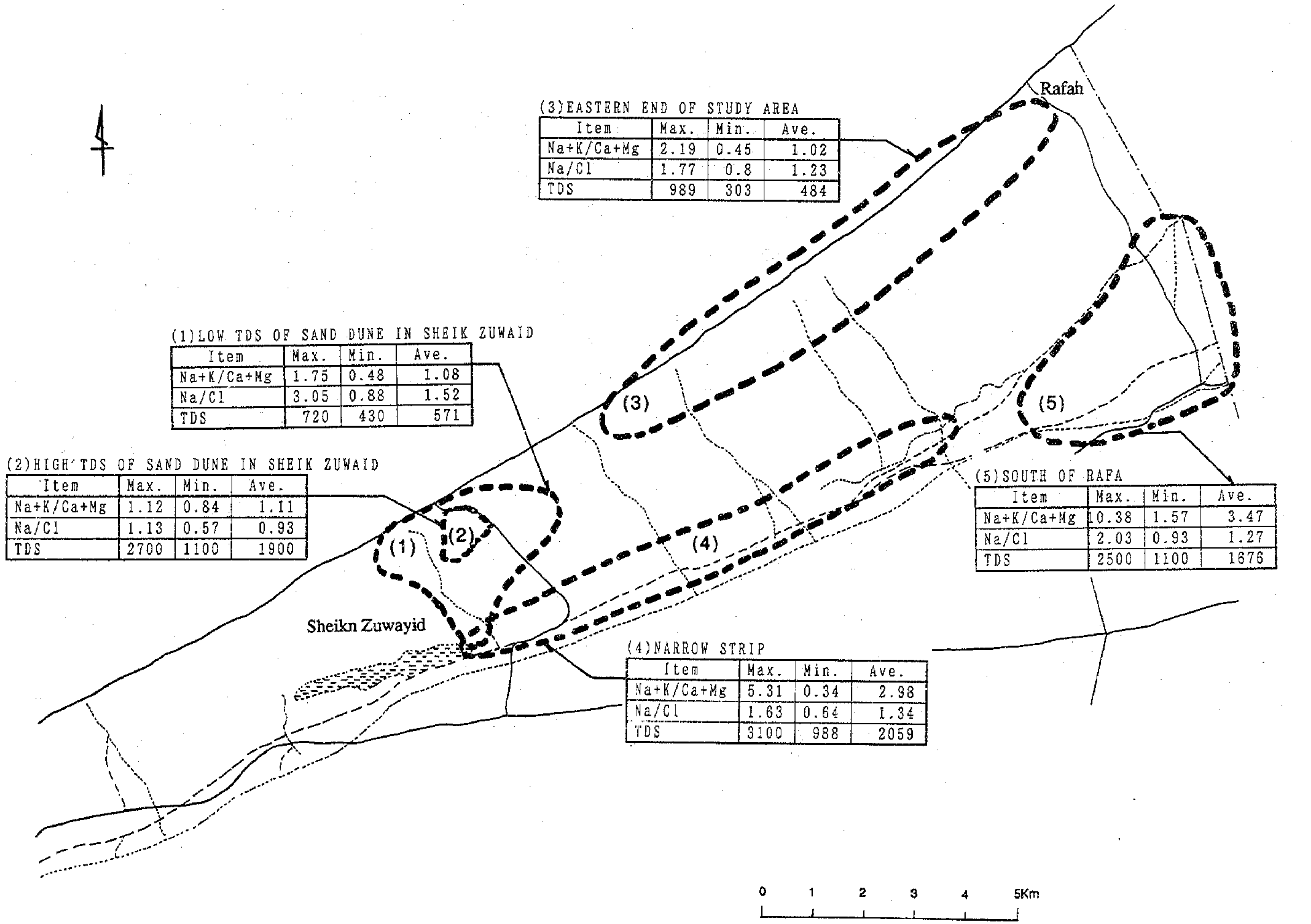
(3)EASTERN PART OF ALLUVIUM IN EL

Item	Max.	Min.	Ave.
Na+K/Ca+Mg	1.65	0.71	1[illegible]
Na/Cl	0.92	0.56	0.75
TDS	5100	2100	3266

(4)SOUTH OF AIRPORT

Item	Max.	Min.	Ave.
Na+K/Ca+Mg	1.59	0.72	1.01
Na/Cl	1.12	0.59	0.76
TDS	2500	526	1614

FIG. 8-2-16 CLASSIFIED WATER QUALITY AT EL - ARISH AREA



(1)LOW TDS OF SAND DUNE IN SHEIK ZUWAID

Item	Max.	Min.	Ave.
Na+K/Ca+Mg	1.75	0.48	1.08
Na/Cl	3.05	0.88	1.52
TDS	720	430	571

(2)HIGH TDS OF SAND DUNE IN SHEIK ZUWAID

Item	Max.	Min.	Ave.
Na+K/Ca+Mg	1.12	0.84	1.11
Na/Cl	1.13	0.57	0.93
TDS	2700	1100	1900

(3)EASTERN END OF STUDY AREA

Item	Max.	Min.	Ave.
Na+K/Ca+Mg	2.19	0.45	1.02
Na/Cl	1.77	0.8	1.23
TDS	989	303	484

(4)NARROW STRIP

Item	Max.	Min.	Ave.
Na+K/Ca+Mg	5.31	0.34	2.98
Na/Cl	1.63	0.64	1.34
TDS	3100	988	2059

(5)SOUTH OF RAFA

Item	Max.	Min.	Ave.
Na+K/Ca+Mg	10.38	1.57	3.47
Na/Cl	2.03	0.93	1.27
TDS	2500	1100	1676

FIG. 8-2-17 CLASSIFIED WATER QUALITY AT SHEIKH ZUWAYID - RAFAH AREA

8-2-4-4 Change in TDS

The increase in the groundwater salinity of the Quaternary aquifer is a serious problem in the study area. An average TDS of all existing wells in one kilometer mesh is calculated to figure out a general feature of TDS distribution in the well field of El-Arish (Section 4-2-5 Technical Report I).

Even in 1962, very high TDS was observed in grids No. 7-2 and 9-3, where the average TDS of all wells in the mesh was 4,000 ppm. Relatively low TDS was found at grids No. 5-2 and 7-5 (1,300 ppm and 1,500 ppm, respectively). The TDS in the rest of the grids range between 2,100 ppm and 3,100 ppm (Fig. 8-2-18).

During the 1980s, many wells were drilled and the well field in the area was greatly extended. The total yield of groundwater in this well field increased remarkably. The total yield in 1988 was estimated at 51,000 m^3/year while the total yield in 1962 was 15,000 m^3/year (Section 8-2-2, Technical Report I).

At the same time, the average TDS at many grids increased significantly (Fig. 8-2-14). High TDS was observed at grids 7-2, 9-3, exceeding 4,000 ppm. There is a significant increase in the TDS at grids No. 7-1, 9-5 and 6. On the other hand, the TDS in the newly extended well field in the south of the airport shows a relatively moderate value.

In this well field, different type of aquifers are stratified even within a same mesh and screen positions. In other word, the aquifers wells are tapping differ from well to well.

After examining the long-term change of TDS, wells are classified into two groups: those where the TDS shows significant increase and those where the TDS shows the changes from 1962 until 1988 as shown in Tables 8-2-7 and 8. In Table 8-2-8, the wells where the TDS did not change during these 26 years show a relatively high TDS (between 2,500 ppm and 4,000 ppm). Wells where the TDS changed during the same period show a relatively low TDS. However, some of them increased to a higher level, reaching 4,900 ppm such as at well 1-127.

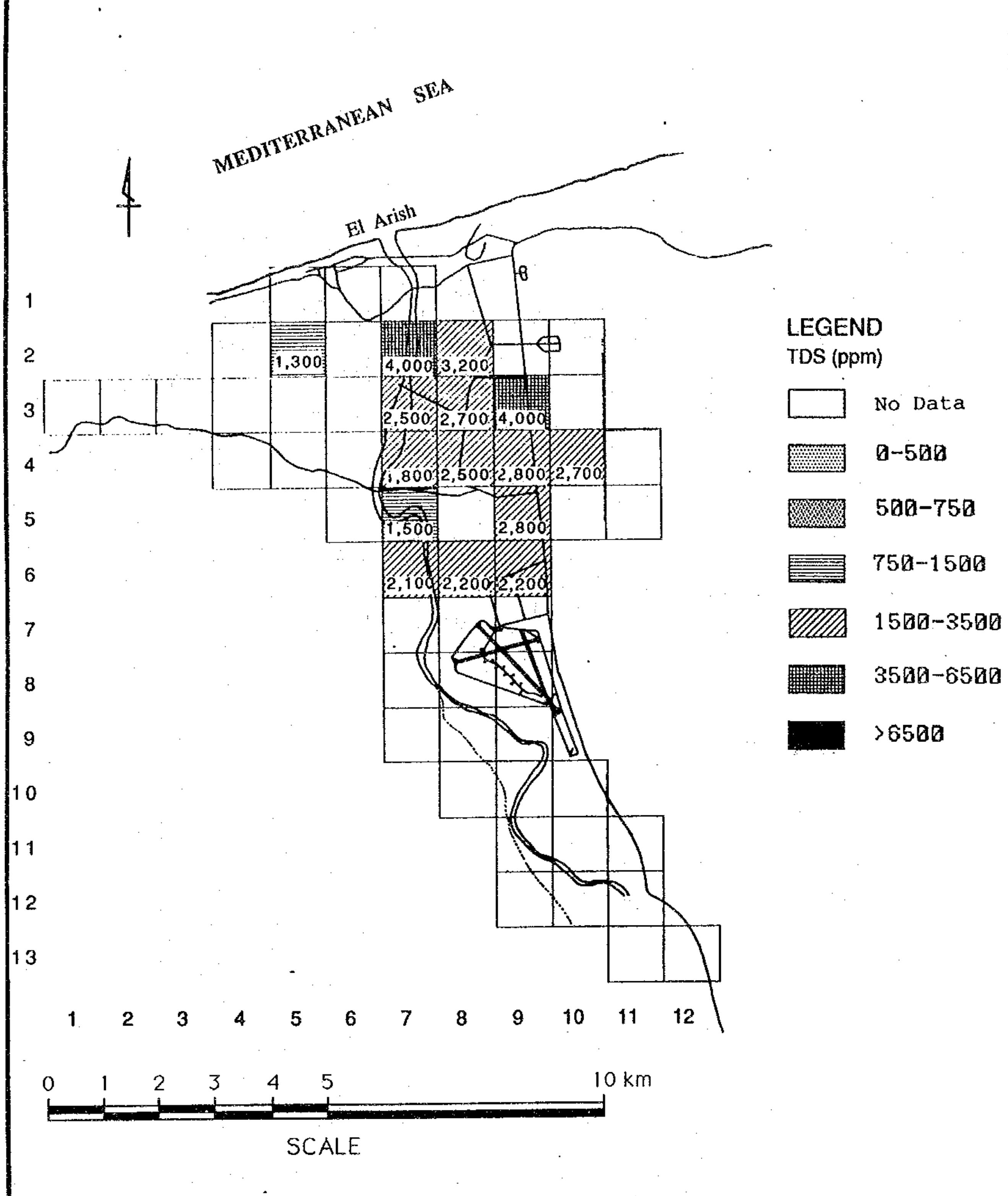


FIG. 8-2-18 TDS DISTRIBUTION AT EL - ARISH AREA IN 1962

Table 8-2-7

Wells With TDS Changes

Grid Number	Well Number	TDS (ppm)		Extraction (m^3/day)
		'62	'88	
4-3	1-9	1,200	2,000	2,000
5-2	1-18	1,300	2,000	105
7-2	1-70	2,000	3,000	624
7-4	1-64	1,700	2,600	3,600
7-6	1-84	2,100	2,700	1,000
8-6	1-107	2,200	3,100	800
9-3	1-128	3,200	3,900	2,550
9-4	1-119	2,300	3,900	880
9-4	1-129	3,200	3,800	
9-5	1-127	2,700	4,900	1,270
9-6	1-115	2,000	3,700	1,610
9-6	1-125	2,000	2,700	
9-6	1-136	2,800	5,100	

Table 8-2-8

Wells Not Having Large Changes in Water Quality

Grid Number	Well Number	TDS (ppm)	
		'62	'88
7-2	1-83	4,000	3,500
7-3	1-82	3,100	2,200
8-2	1-104	3,200	3,200
8-4	1-88	2,700	2,600
8-5	1-112	2,500	2,400
9-4	1-129	3,200	3,800
9-5	1-135	2,900	2,900
10-4	1-137	2,600	2,800
10-4	1-141	2,800	2,900

This may suggest that these wells having no significant increase in TDS have initially tapped an aquifer having a high TDS. Thus the TDS of such wells remain at the same high level. The hydrogeological conditions of these wells are assumed to be the same as at well J No. 7 in Fig. 8-2-8.

On the other hand, the aquifer of wells No. 1-127 and 1-136 is gravel and the hydrogeological condition is assumed to be similar to that of well No. SR6 (See Fig. 8-2-8). The screens are installed at gravel bed underlain by an other type of aquifer such as kurkar. As the pumping operation continued, water in the lower aquifer was extracted, and the original TDS of the gravel aquifer became the same as in the lower aquifer.

8-2-5 Water Level

Since wells are densely distributed in two well fields (the Alluvial plain of the Wadi El-Arish, in the lower reach, and the coastal plain from Sheikh Zuwayid to Rafah), water level data are plentiful. However, since different aquifers are stratified in a narrow area and there are wells tapping different aquifers in small area, the observed water levels indicate the water levels of various aquifers. For this reason, a one square kilometer grid is meshed over the well field in order to figure out a general feature of the water level of the well field by taking an average of all water levels in each grid (Section 3-2, Technical Report I).

In 1962, the water level of the well field in El-Arish was in a range between 2 and 4 m asl, although there were certain areas where the water levels were lower than the rest (Grid 7-3, 7-4, 8-4 and 9-2) probably due to the heavy pumpage (Fig. 8-2-19).

During the 1980s many wells were constructed and the pumpage rate increased significantly. Accordingly, the water level in the El-Arish well field was greatly lowered as shown in Fig. 8-2-20. The water level in most of grids stayed at 0 m, or a little lower, than the mean sea water level. The recession of the water level from 1962 to 1988 in each grid is estimated as shown in Fig. 8-2-21. A significant decrease in the water level (4.5 m) is observed at grids No. 4-3 and 5-2 in the area on the western side of El-Arish town.

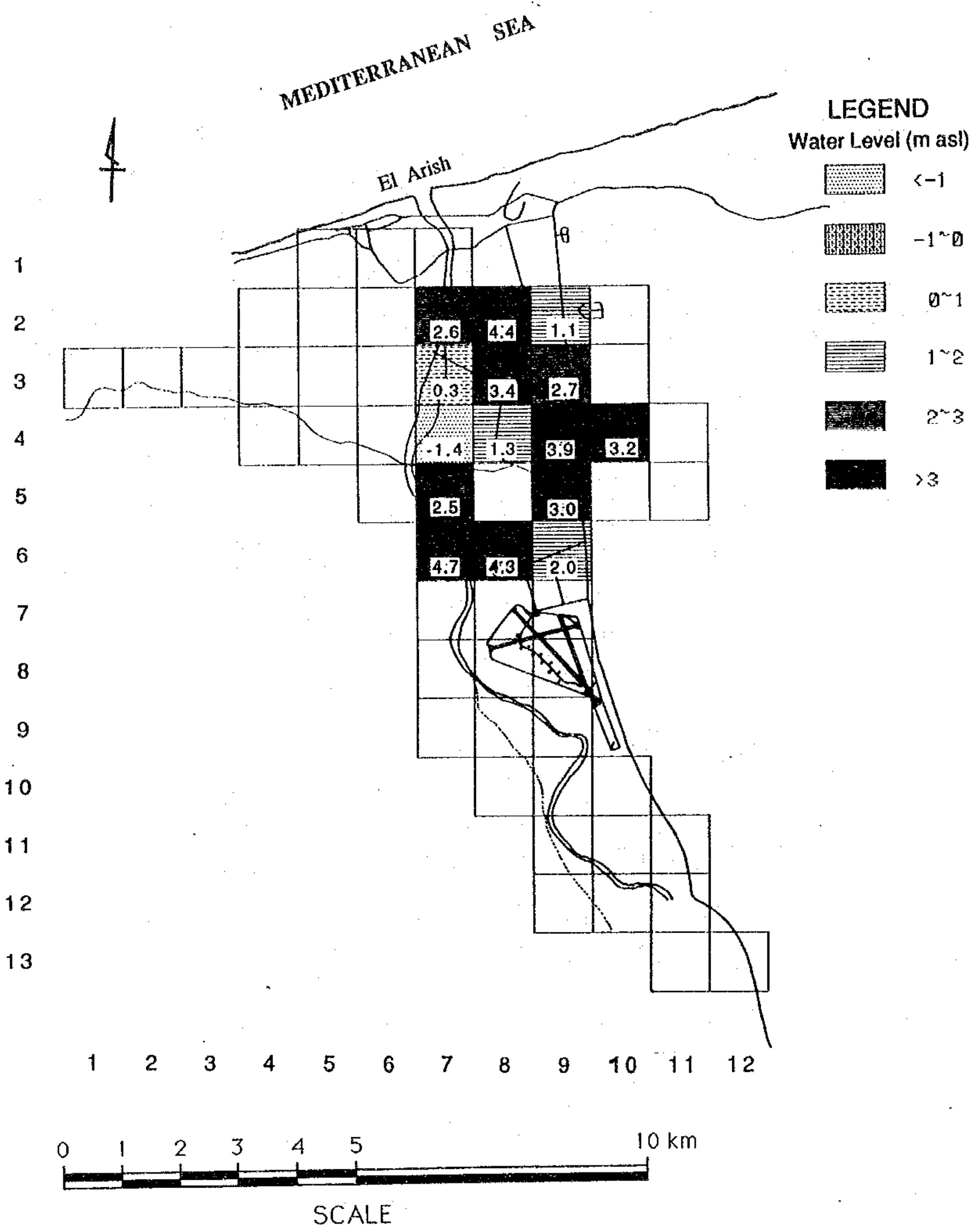


FIG. 8-2-19 AVERAGE WATER LEVEL AT EL - ARISH AREA IN 1962

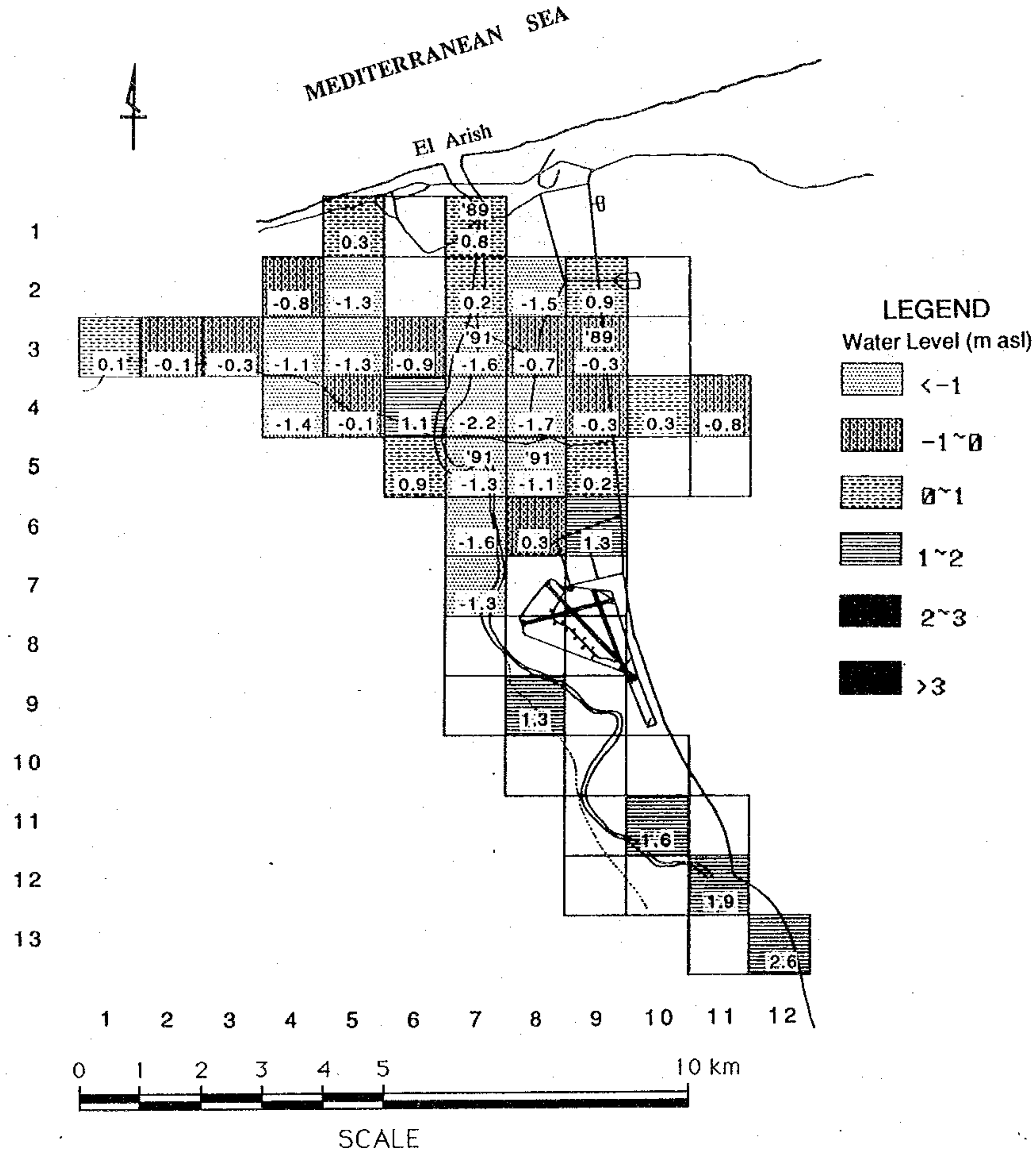


FIG. 8-2-20 AVERAGE WATER LEVEL AT EL - ARISH AREA IN 1988

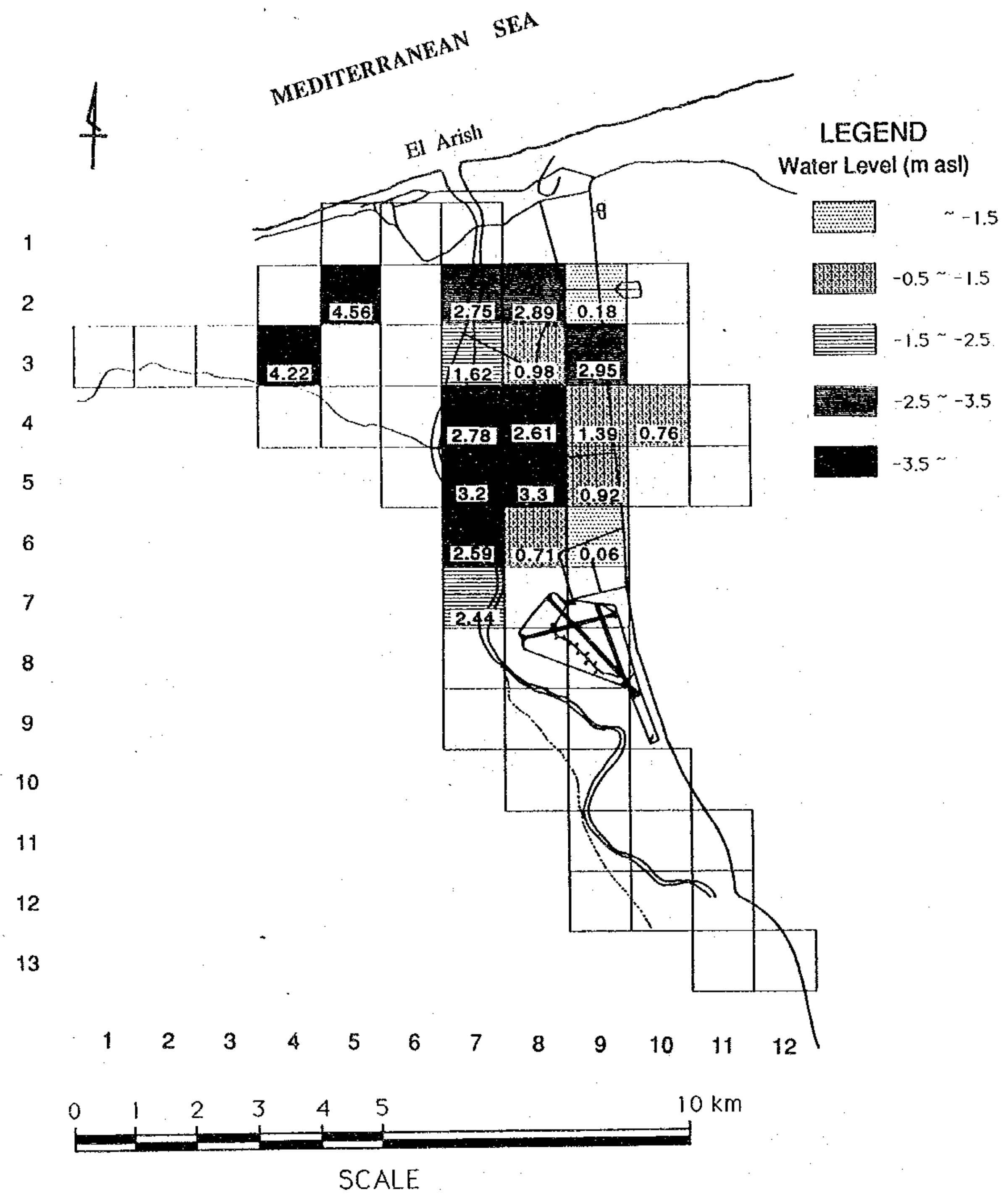
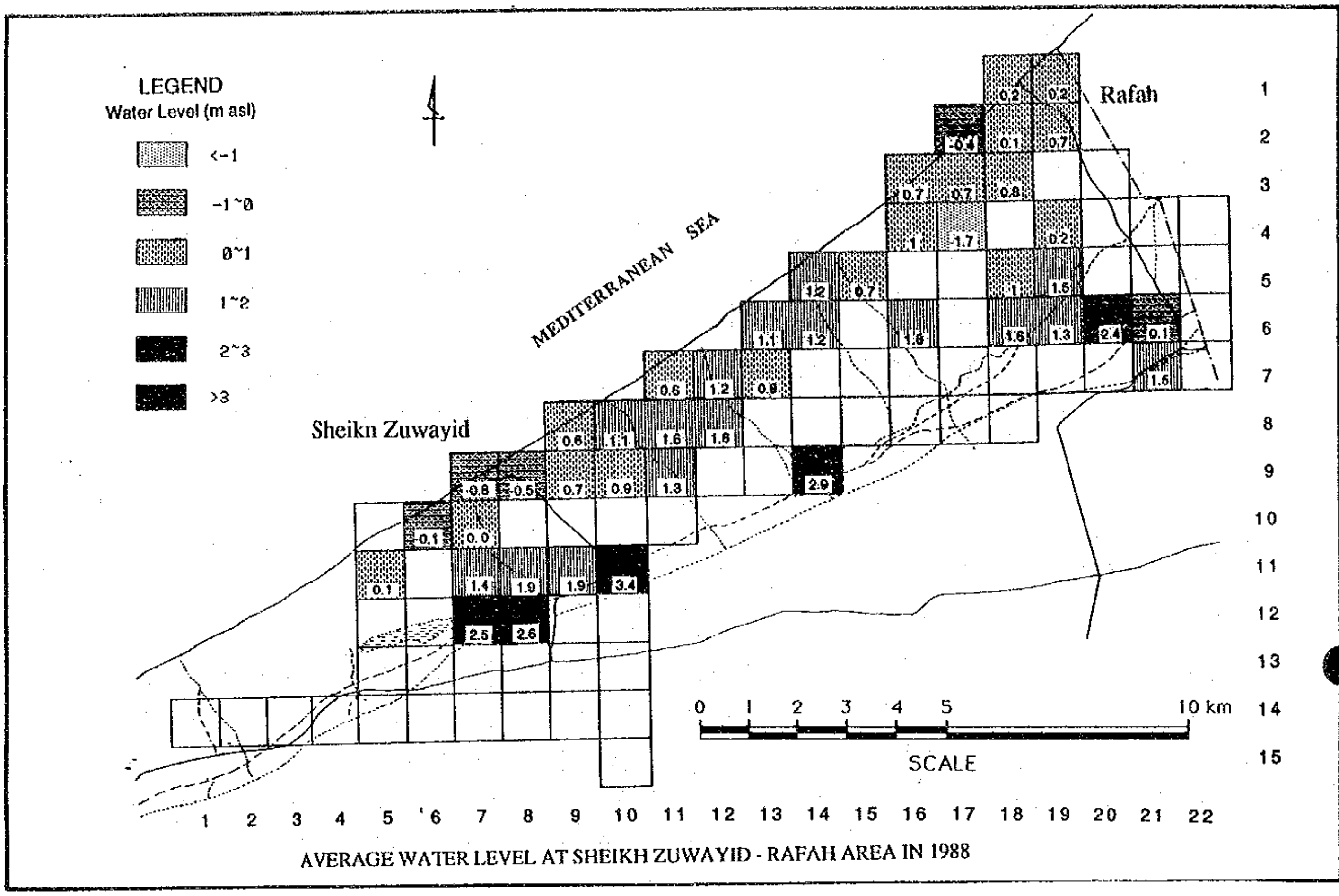


FIG. 8-2-21 RECESSION OF WATER LEVEL AT EL - ARISH AREA '62→'88

In the well field of the coastal plain from Sheikh Zuwayid to Rafah, the water level stays in a range between 0 and 1 m asl along the shoreline. There are some grids where the water level is below the mean sea water level (Grids No. 6-10, 7-9, 8-9, 17-2 and 4). The water level in a narrow strip behind the coastal sand dunes is higher than that of the shoreline and ranges between 2 and 3 m asl. However, at grid 21-6 it is almost at the mean sea water level which may be caused by over pumpage at Rafah town (Fig. 8-2-22).

The water level of the groundwater in the kurkar aquifer is assumed to be about 4 m asl as shown in Fig. 8-2-13. It is estimated to be in the range of 1 to 2 m asl along the shoreline.

As shown in Fig. 8-2-9, wells in the coastal sand dune may have a different type of water level distribution where the sand aquifer is underlain by an impermeable bed. Although extension of such an aquifer is limited to a narrow area and its yield would be limited, it is the only water source for domestic use because of its low TDS.



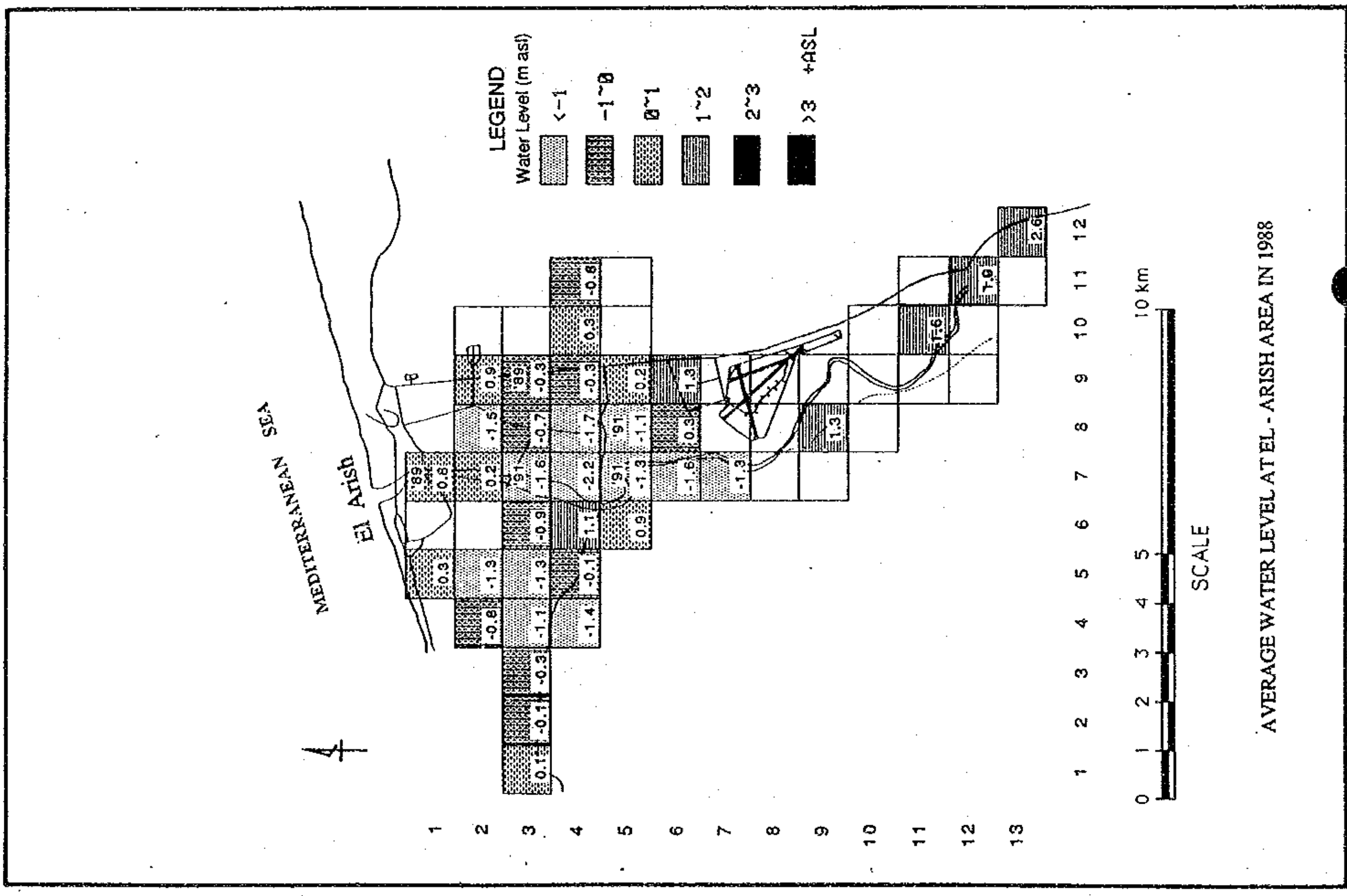


FIG. 8-2-22 AVERAGE WATER LEVEL AT EL - ARISH AND SHEIKH ZUWAYID - RAFAH AREA IN 1988

8-2-6 Water Use

The most extensive groundwater use was observed at El-Arish and in the coastal plain from Sheikh Zuwayid to Rafah. There are many shallow wells in the coastal plain from Bir El-Abd to Romana. Data collection of water use for these wells is underway. In the following part of this section, the present state of the water use in El-Arish and in the coastal plain from Sheikh Zuwayid to Rafah is described. Further details are described in Chapter 8, Technical Report I.

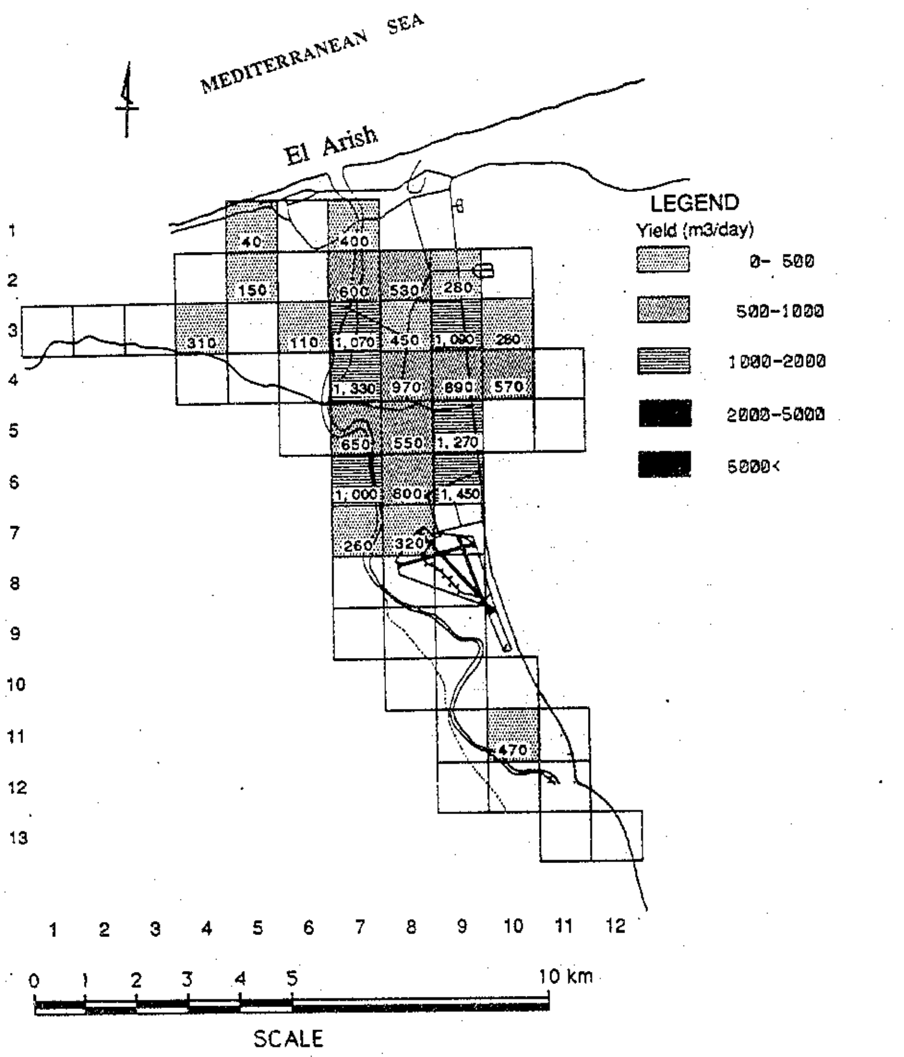
1) Well Field in El-Arish Area

In El-Arish area a well field extends in the coastal plain on the western side of the town and in the alluvial plain of the Wadi El-Arish.

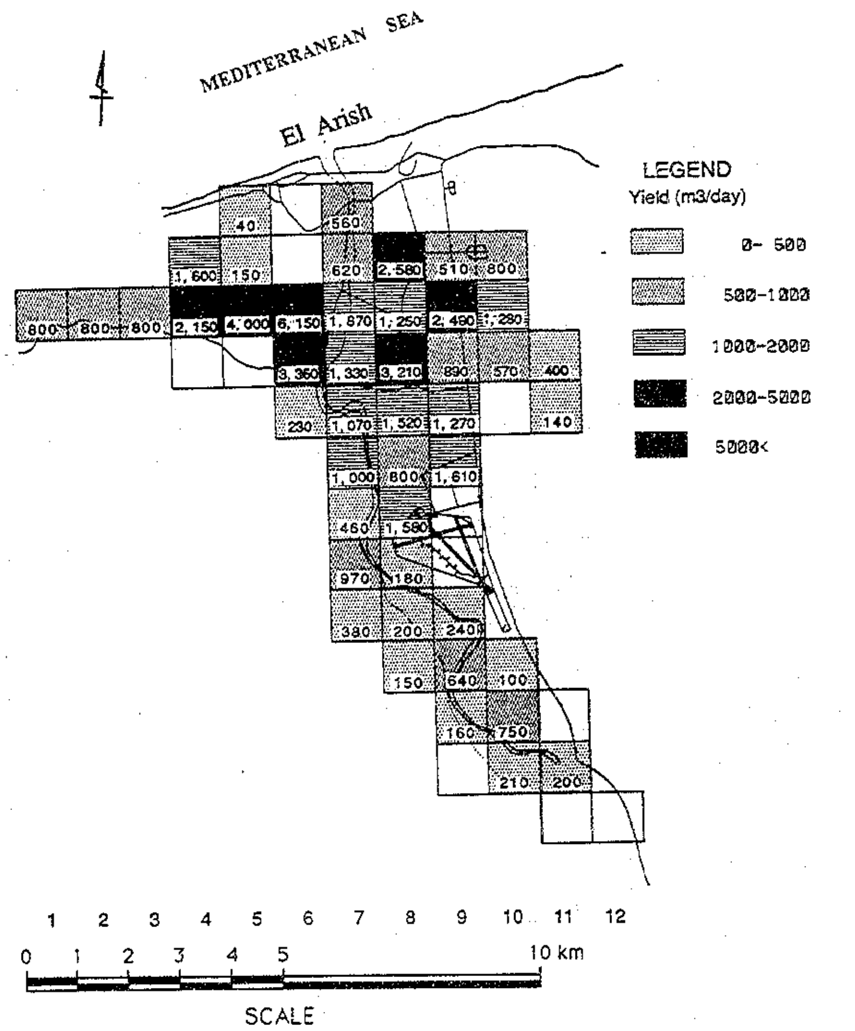
Groundwater use commenced in early times, and, even by the end of the 1940's, there were 12 wells in this area yielding 1,300m^3/day.

By the end of the 1960's, the well field in the Wadi El-Arish plain extended from the southern side of El-Arish town to the south up to the northern end of the airport by approximately 6 km in length on 3 km in width. The total well field at this time is 25 km^2 and the total well yield is estimated at 15,300 m^3/day (2.5 well/km^2 and 245 m^3/day/well) (Fig. 8-2-23).

The well field that had an area of 25 km^2 at the end of the 1960s has remarkably expanded to the west and to the southeast of El-Arish. On the eastern side of El-Arish, the well field stretches out to the south about 10 km (about 3 km wide) beyond the airport, reaching test well 5-5 in grid No. 11-13. The total area of well field is estimated at about 50 km^2; double the size it was at the end of the 1960's.



PUMPAGE RATE AT EL - ARISH AREA AT THE END OF 1960S



PUMPAGE RATE AT EL - ARISH AREA IN 1988

FIG. 8-2-23 GROUND WATER YIELD AT EL - ARISH AREA IN 1962 AND 1988

As the size of the well field increased, the number of wells increased drastically . It is remarkable that a large number of wells exist in the following grids : No. 4-3, No. 5-3, No. 6-3, No. 6-4, No. 7-2, No. 7-3, No. 8-2, No. 8-3, No. 8-7, No. 9-3 and No. 9-6. There are from 5 to 9 wells in a grid and the total number of wells in the mentioned grids that cover an area of 16 km^2 is 61 (Fig. 8-2-24).

By the end of the 1960s, the yield of most of the grids was less than 1,000 m^3/day. However, in 1988, the yield of 15 of the 50 grids exceeds 1,000 m^3/day. Out of these, a pumpage of 6,150 m^3/day is recorded at grid No. 6-3 that is located on the western side of El-Arish town. And, the yield of each of seven grids around El-Arish town exceeds 2,000 m^3/day.

The total amount of groundwater used is estimated at 51,000 m^3/day and the total number of wells in operation is 142 in the Wadi El-Arish plain (3 wells/km^2 and 360 m^3/day/well).

The major water use in this area is for irrigation of the local farmers. This heavy extraction of groundwater has caused recession of the groundwater level and deterioration of the water quality as shown in Fig. 8-2-14 and Fig. 8-2-19 and 20.

As shown in Fig. 8-2-25, the TDS of all grids in the well field at El-Arish indicates a salinity that is hazardous for most crops and is not suitable for domestic use (Chapter 8, Technical Report I).

2) Well Field in the Coastal Plain from Sheikh Zuwayid to Rafah

The oldest record of modern well construction in this area appears in the 1950's. By the end of the 1960's many wells were operating in the area around Rafah town (Fig. 8-2-26).

During this time, the most intensive groundwater use is observed in the grids No. 21-5 and No. 21-6 and the total number of the wells under operation was ten in this two square kilometers. The total yield in these grids at that time was 2,400 m^3/day: 240 m/day/well.

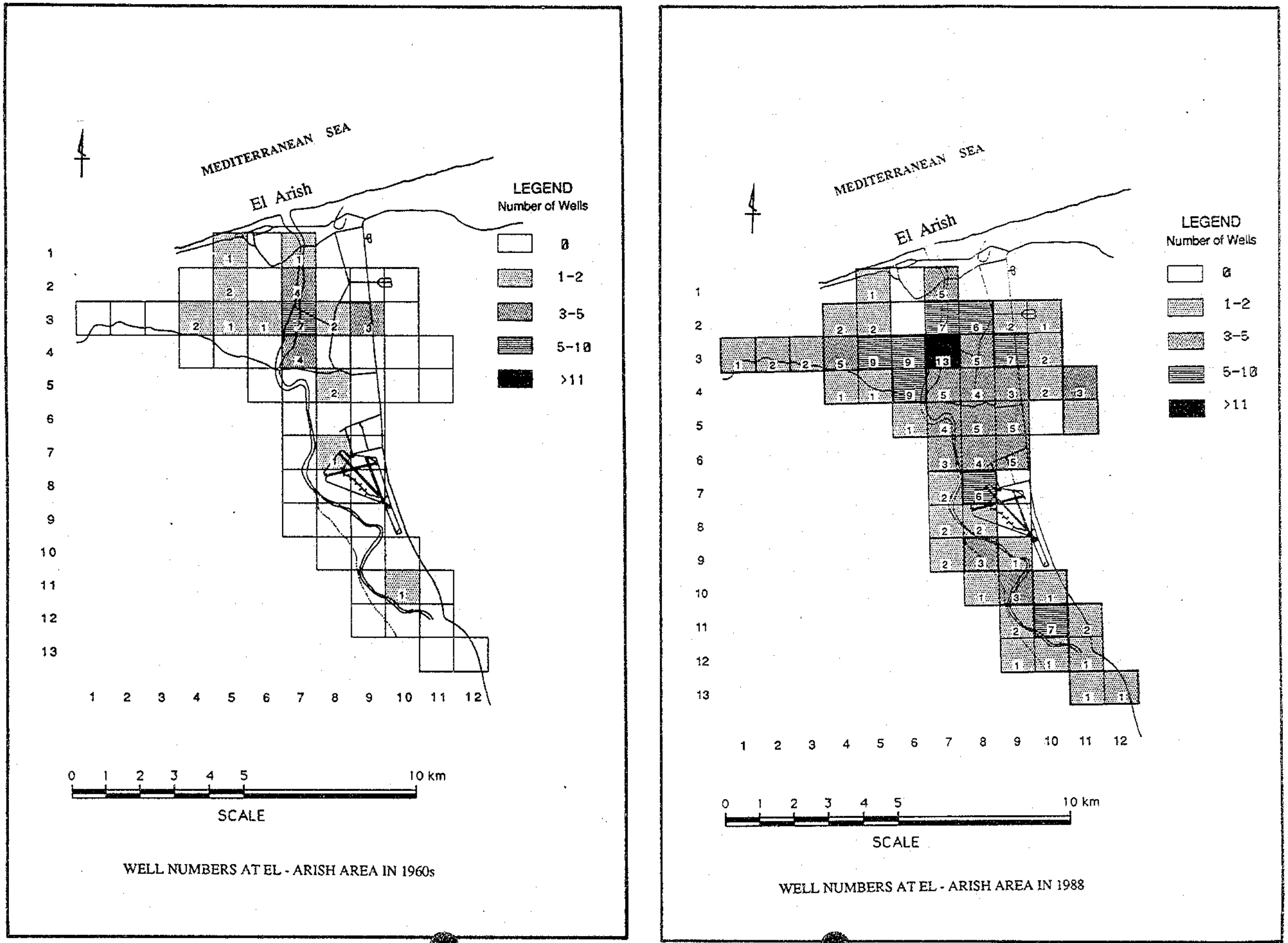
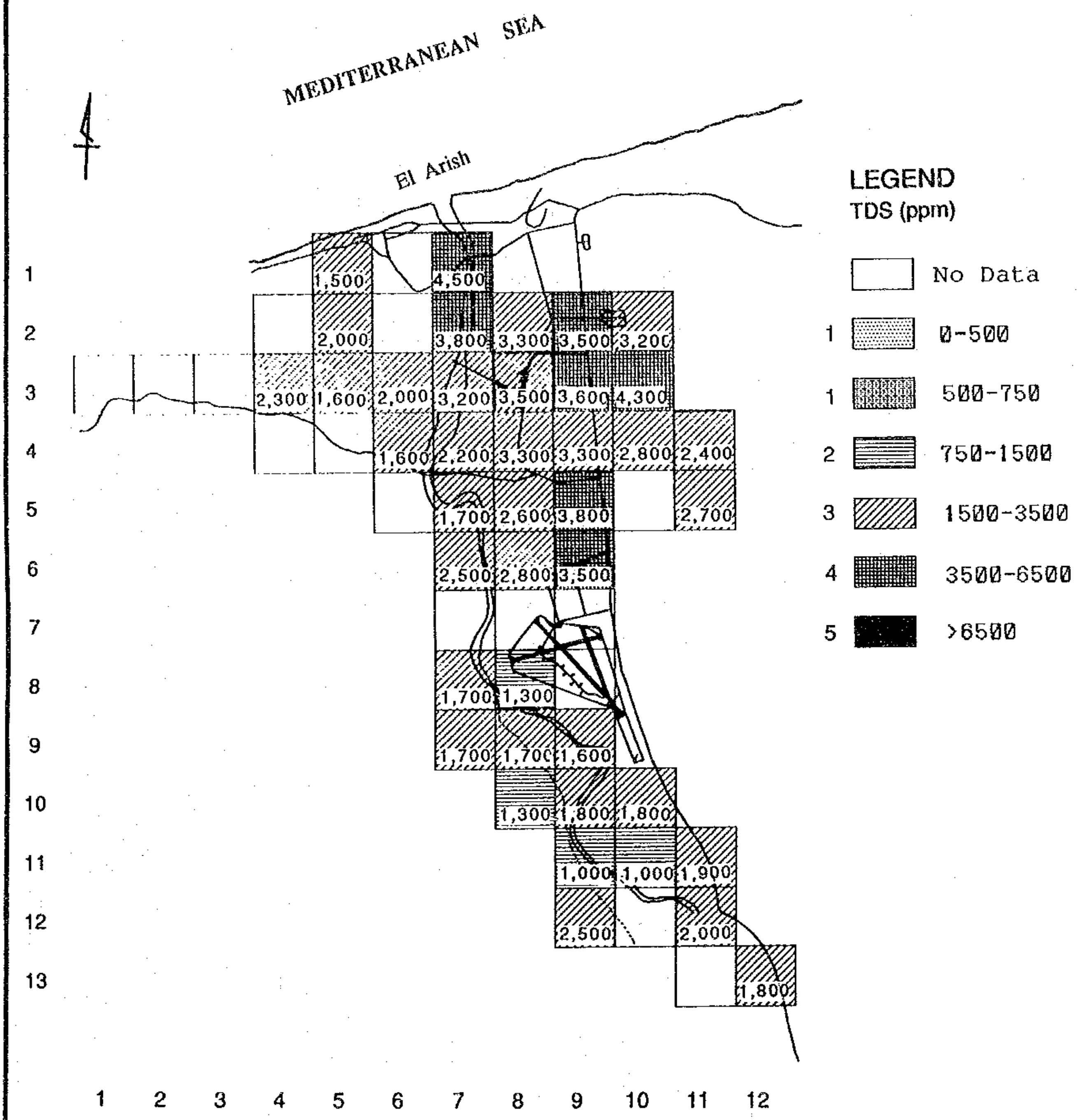


FIG. 8-2-24 WELL NUMBERS AT EL - ARISH AREA IN 1960S AND 1988

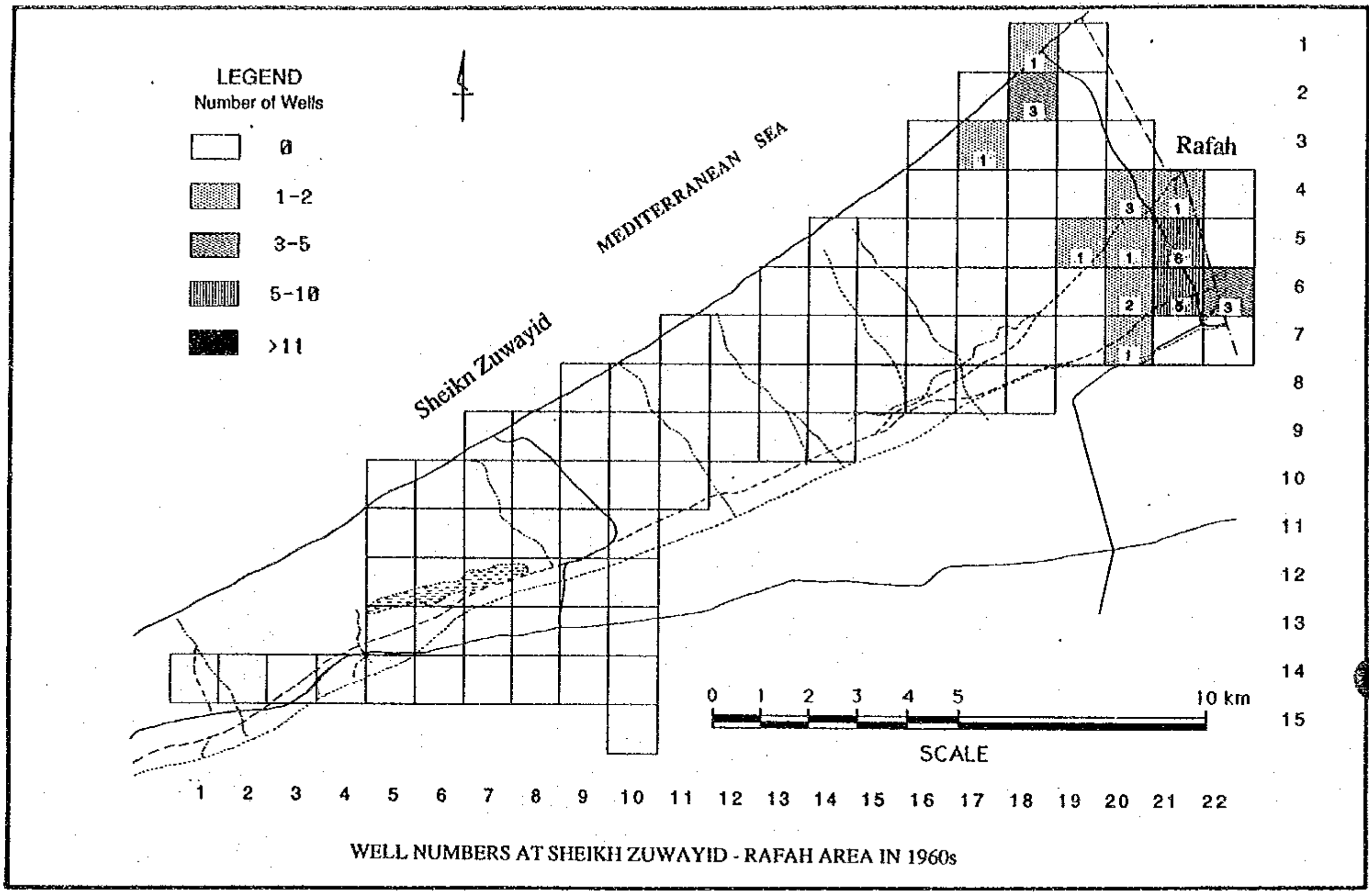


1	Suitable for irrigation	< 750 ppm
2	Hazardous for salinity sensitive crops	750ppm-1,500 ppm
3	Hazardous for most of crops	1,500 ppm-3,500 ppm
4	Only for salinity tolerance crops	3,500 ppm-6,500 ppm
5	Hazardous for salinity tolerance crops	6,500 ppm-8,000 ppm

0 1 2 3 4 5 10 km

SCALE

FIG. 8-2-25 TDS DISTRIBUTION AT EL - ARISH AREA IN 1988



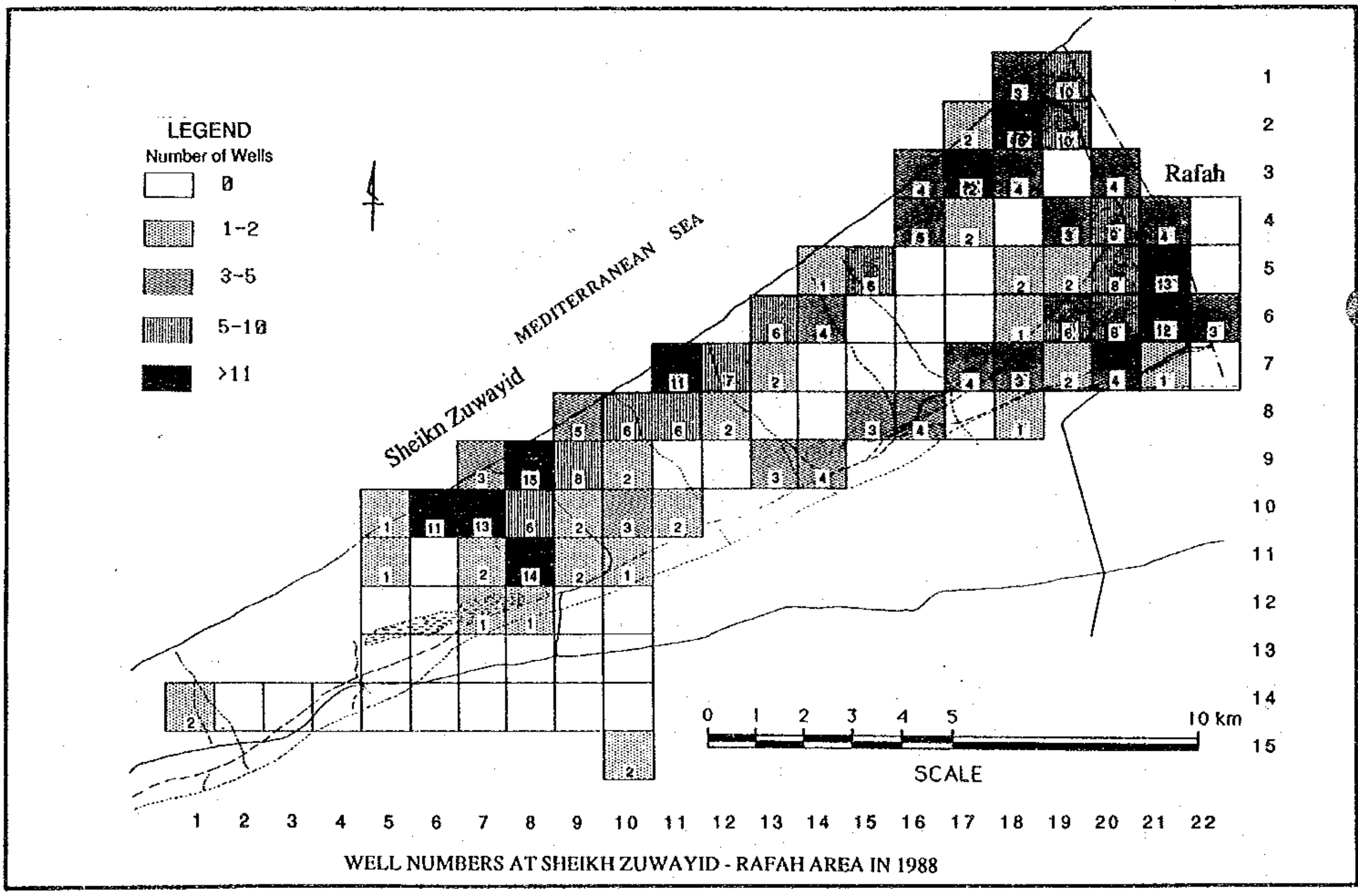


FIG. 8-2-26 WELL NUMBERS AT SHEIKH ZUWAYID - RAFAH AREA IN 1960S AND 1988

Some other wells were also used in the area around Rafah town. These well fields extend over 9 km^2 around Rafah, including the grids No. 21-5 and No. 21-6 yielding 4,800 m^3/day (2 wells/km^2 and 250 m^3/day /well on an average) (Fig. 8-2-27).

Since the end of the 1960's, the well field around Rafah town expanded in a triangle zone with its vertex extending from the base along the international border with Israel on the east of Rafah to the west for about 10 km. The well field around Rafah town now extends over 23 km^2. The number of wells in the previous well field at the end of the 1960's (9 km^2) increased to 63; 24 of them are in operation in the grids No. 21-5 and No. 21-6 yielding 5,700 m^3/day (2,850 m^3/day/km^2 and 26 m^3/day/well). The total yield within the previous well field is estimated at 14,000 m^3/day.

The total yield of wells in this zone is estimated at 26,000 m^3/day and, in 1988, there were 168 wells.

By the end of the 1960's, there were only five wells in grids No. 17-3, No. 18-1 and No. 18-2 in the sand dune along the Mediterranean. However, by 1988 the well field extended over the sand dune from Sheikh Zuwayid to its eastern end. A very intensive extraction of groundwater was observed in the area around Sheikh Zuwayid and the eastern end of the sand dune.

In the area around Sheikh Zuwayid, the density of wells is high at grids No. 6-10, No. 7-10, No. 8-9, No. 8-11 and No. 11-7. There are more than 10 wells within a single grid. There are 93 wells operating in this area that covers 15km^2. The wells yield 7,120 m^3/day.

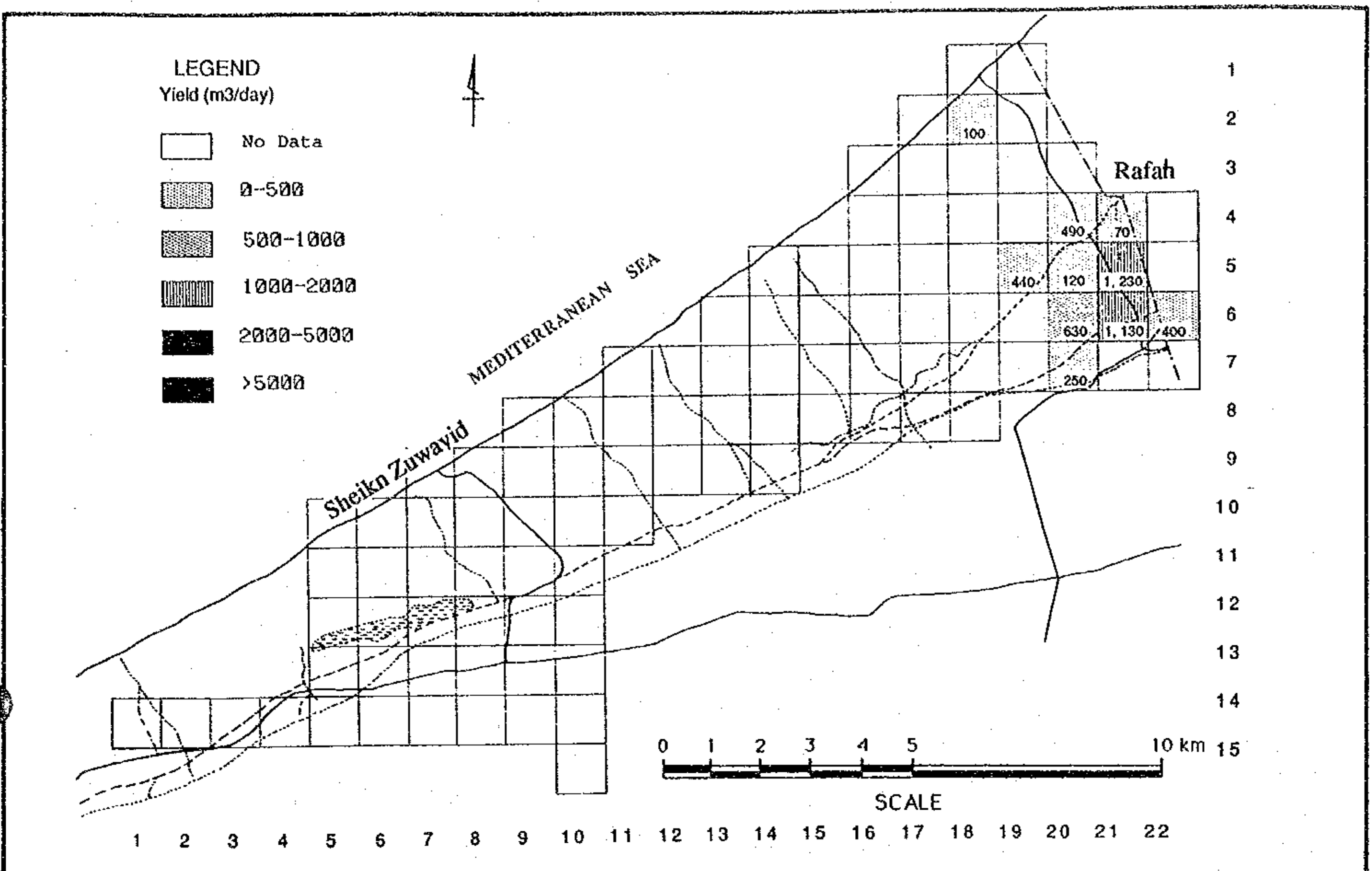
There is also intensive groundwater extraction from the sand dune at the eastern end of the coast. There are more than 60 wells operating in this 10 km^2 well field. The total yield in this area is estimated at 3,000 m^3/day.

In the area between these two highly intensive water use areas there are many wells drilled on the sand dune. There are 43 wells in this 9 km^2 field that yield a total of 3,170 m^3/day.

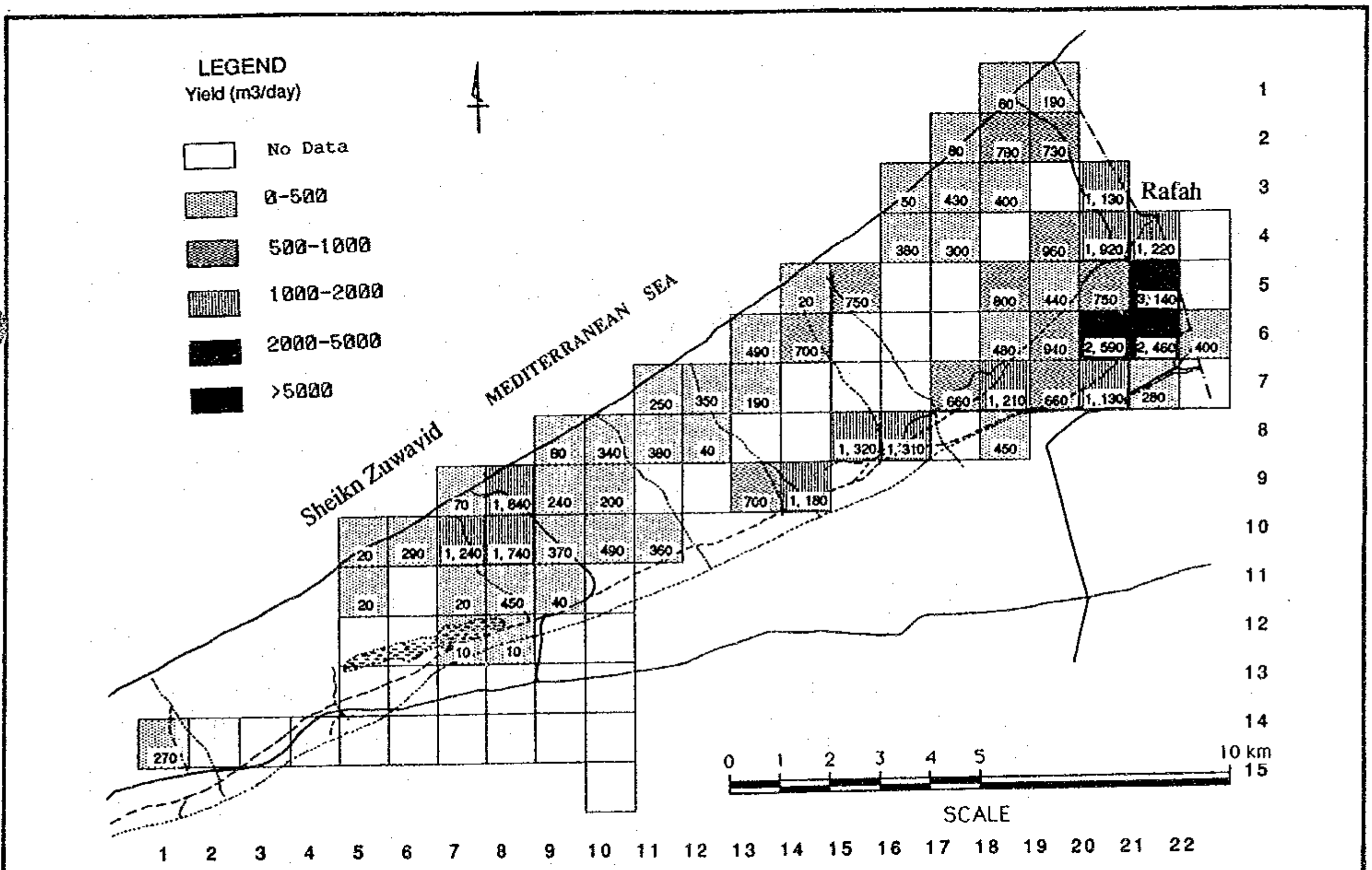
The total amount of groundwater use during 1988 in the Sheikh Zuwayid and Rafah area was estimated at approximately 39,000 m^3/day (Fig. 8-2-27).

As shown in Fig. 8-2-28, the potable and unharmful water for irrigating crops is available along the sand dunes (grids No. 7-10, No. 8-10, No. 9-9, No. 11-7, No. 14-5, No. 15-5, No. 16-4, No. 17-3 and No. 18-2), where the salinity of groundwater is less than 750 ppm.

In the area around Sheikh Zuwayid there are some places where the salinity of the groundwater indicates a salinity hazard. Salinity sensitive crops would be damaged at grids No. 8-9, No. 9-10 and most crops would be affected by irrigating with water from grids No. 7-9, No. 8-11, No. 12-9, No. 12-11 and No. 10-10 (Fig. 8-2-28).



PUMPAGE RATE AT SHEIKH ZUWAYID - RAFAH AREA AT THE END OF 1960s



PUMPAGE RATE AT SHEIKH ZUWAYID - RAFAH AREA IN 1988

FIG. 8-2-27 GROUND WATER YIELD AT SHEIKH ZUWAYID - RAFAH AREA IN 1960S AND 1988

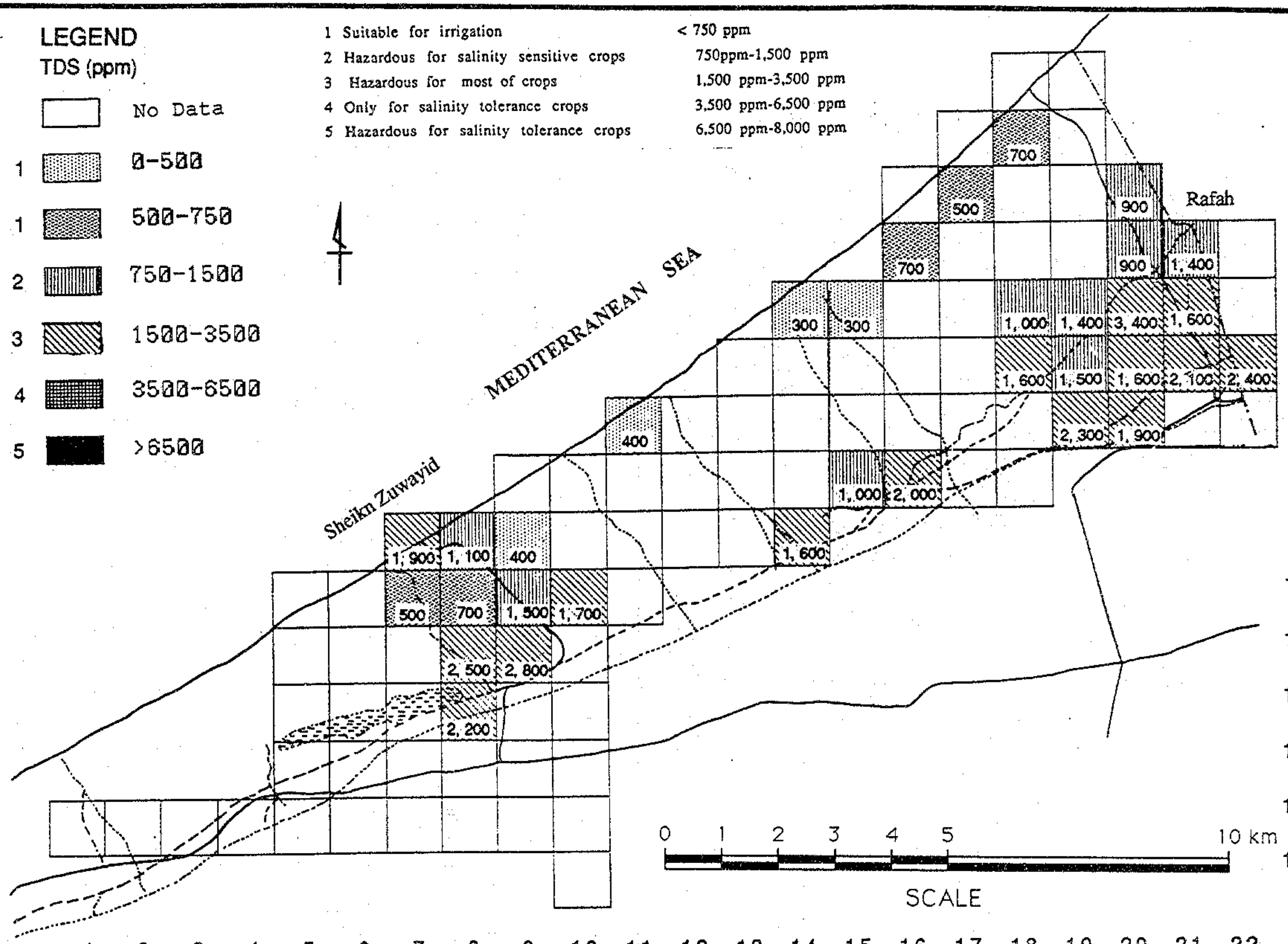


FIG. 8-2-28 TDS DISTRIBUTION AT SHEIKH ZUWAYID - RAFAH AREA IN 1988

8-3 Tertiary

8-3-1 General

Formations of the Paleocene and the Oligocene were observed only in the wells along the Mediterranean coast or offshore at depths of more than one hundred meters. The formations are not identified in the study area. The formations of the Tertiary which have an affect on the hydrogeology of the study area are the Miocene, Eocene and Paliocene.

8-3-2 Miocene

As shown in Fig. 8-3-1, the formation assigned to this age is distributed in the coastal foreshore area. The lithology is represented by shale and clay with interbeds of sandstone and limestone. This formation is usually covered by sand dunes or the Quaternary deposits and are only occasionally found among sand dune deposits as a very small outcrop.

Prospecting aquifers may develop in the limestone and sandstone interbedding with the shale or clay. The shale and clay play a role of impermeable barriers to the aquifers of sandstone or limestone (Technical Report IV).

Sandstone and conglomerate have a suitable nature as aquifers in the coastal foreshore area. The one in limestone is in the well Misri-1.

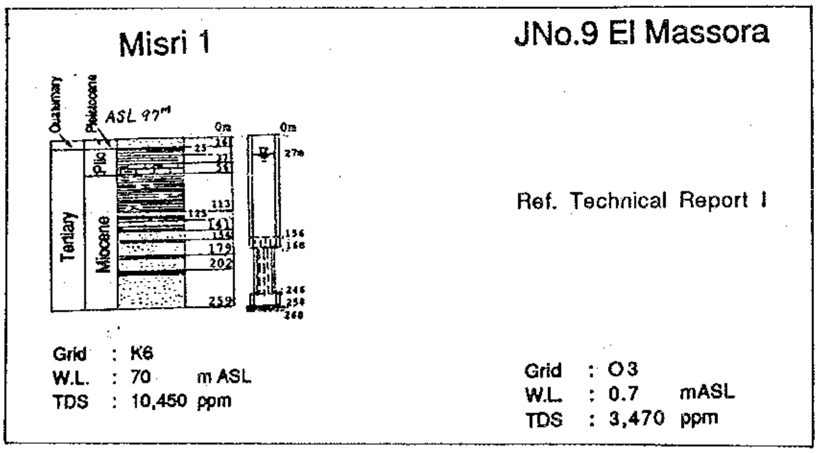


FIG. 8-3-1 MIOCENE WELL

The water level at well Misri-1 is 70 m asl and the depth from the ground surface is 27 m. The depth to the top of the aquifers is 113 m from the ground surface. So, these aquifers are the confined type. The water level is assumed to range between 50 m and 100 m asl in the northeastern corner of the study area (Fig. 8-3-2).

A relatively moderate TDS is observed at well J No. 9 (3,450 ppm) in the south of Rafah while a rather high TDS is recorded at well Misri -1 near Magdabas (10,450 ppm). Thus, the quality of groundwater in the aquifer of the Miocene appears to be rather saline.

The Miocene is assumed to have been deposited under the environment of continental-fluvial, paralic, shelfal and slope with their associated clastic sediments (Marathon, 1981). This environment is thought to be highly saline. The saline water trapped in sandstone or limestone is assumed to be replenished or diluted by the pluvial rain during the Pliocene after the epeirogeny of the Sinai peninsula. However, limestone and sandstone of the Miocene are developed with intercalation of predominating shales.

There is an interesting correlation between the groundwater salinity and resistivity of the Miocene aquifers; there are five sandstone strata interbedded in shale at the well Misri-1 (Fig. 8-3-3). According to the well logging data, the resistivities of sandstone vary at each bed as shown below:

1st bed	:	9 Ω-m
2nd bed	:	8 Ω-m
3rd bed	:	7-8 Ω-m
4th bed	:	5-7 Ω-m
5th bed	:	4-5 Ω-m
6th bed	:	2-3 Ω-m

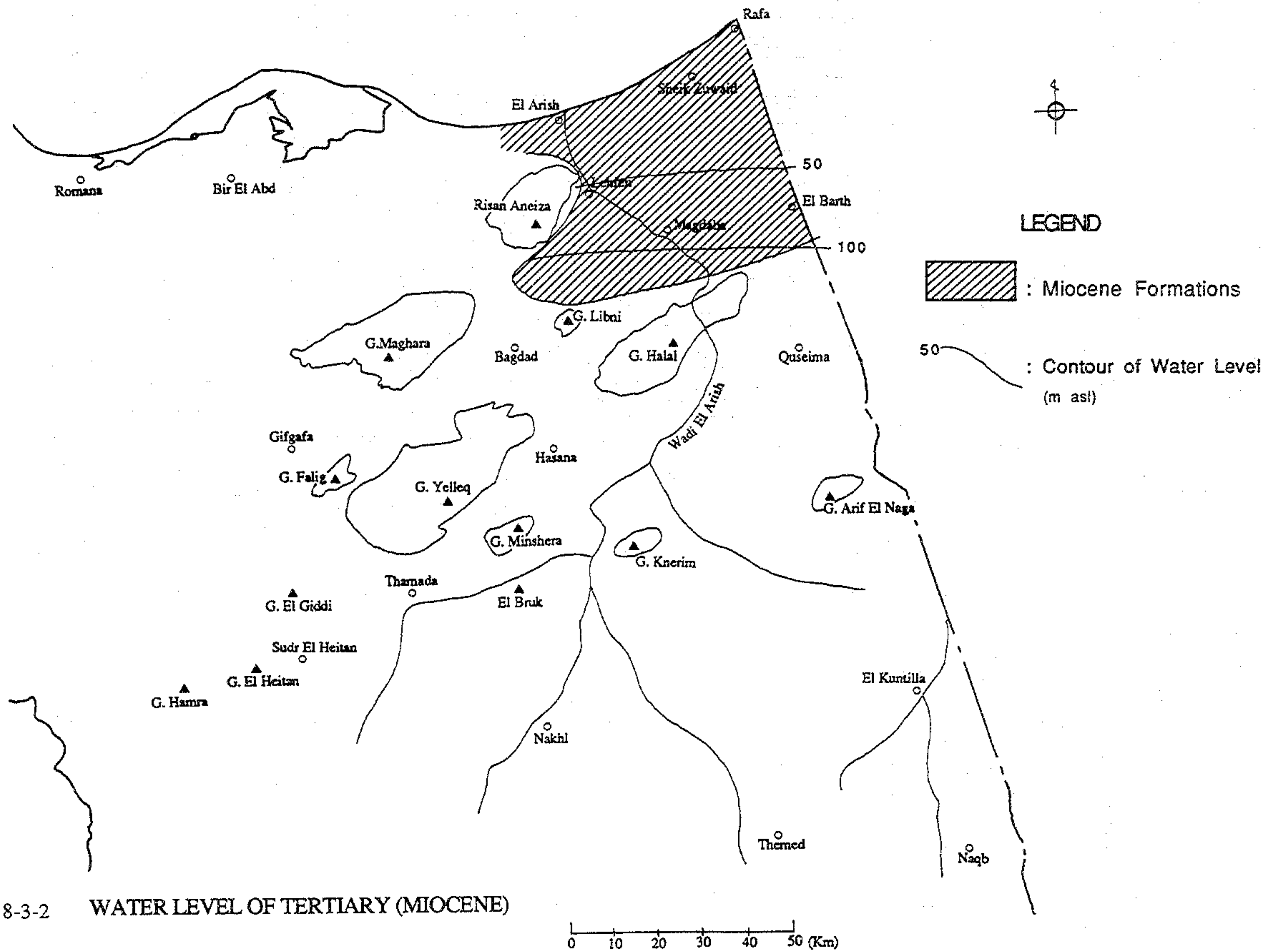


FIG. 8-3-2 WATER LEVEL OF TERTIARY (MIOCENE)

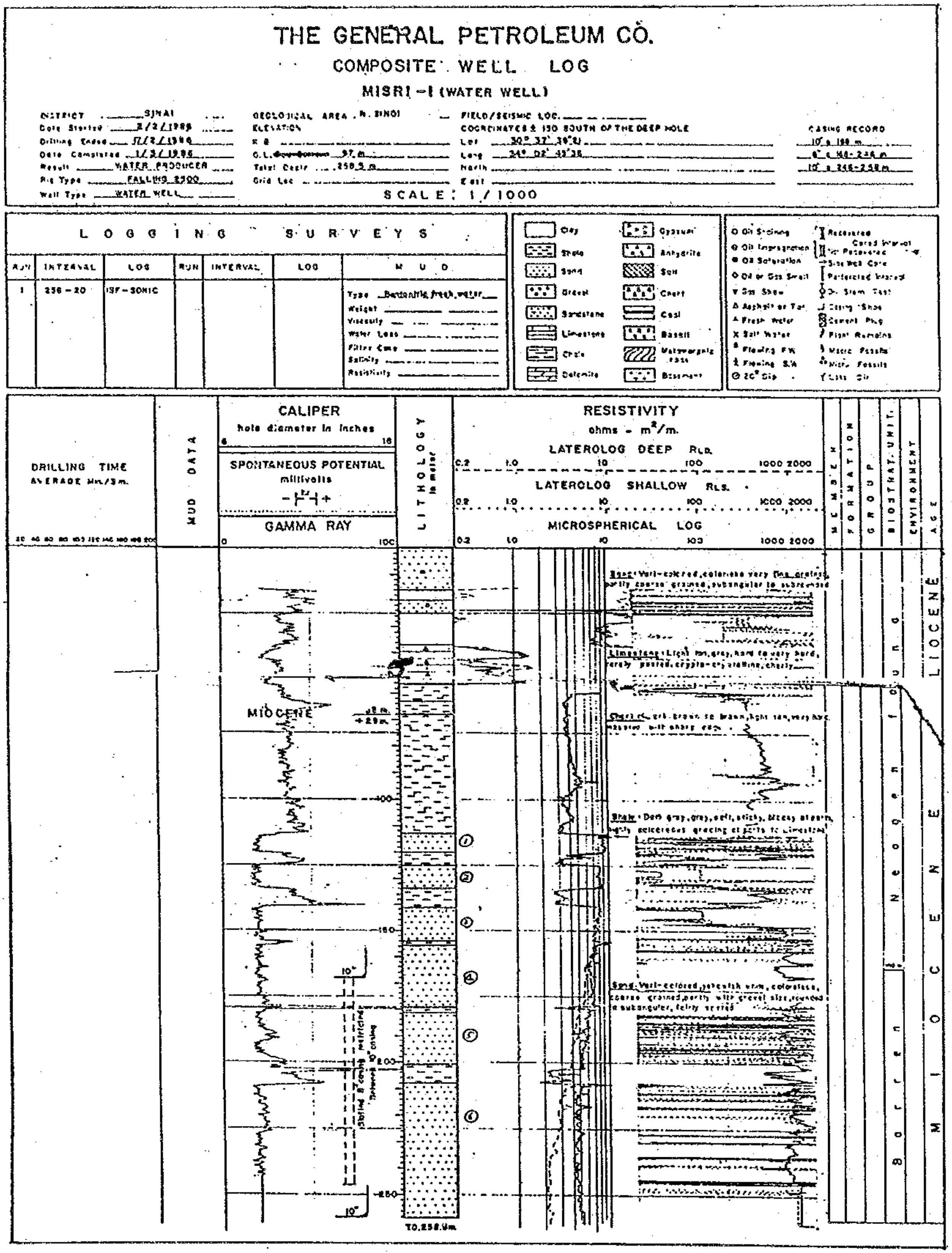


FIG. 8-3-3 WELL LOG (MISRI-1)

The resistivity value of sandstone decreases downward. Screens are installed at the 4th, 5th and 6th beds. The TDS of the groundwater obtained through these screens indicates 10,450 ppm. Looking at the resistivity distribution of these 6 beds of sandstone, it is assumed that the first three beds may have a lower TDS than 10,450 ppm. Therefore, it may be possible to avoid extracting highly saline water, determining the screen position through resistivity logging. The same conditions may be found in the limestone aquifers.

Considering the above findings, the occurrence of the aquifers of sandstone and limestone of the Miocene is illustrated as shown in Fig. 8-3-4.

As discussed in Section 8-2, the water in the aquifers of the Miocene may influence the water in the aquifers of the Quaternary. Further investigation of the aquifers of the Miocene would be important to reveal this affect in the well fields of the aquifers of the Quaternary.

The direct contribution from the current hydrometeorological events to recharge of the aquifers of the Miocene is unlikely, considering the magnitude of the rainfall. Therefore, the water stored in the aquifers of the Miocene is a kind of fossil water without present recharge.

No pump test results are available at present. Therefore, the hydraulic physical constants of these aquifers are unknown.

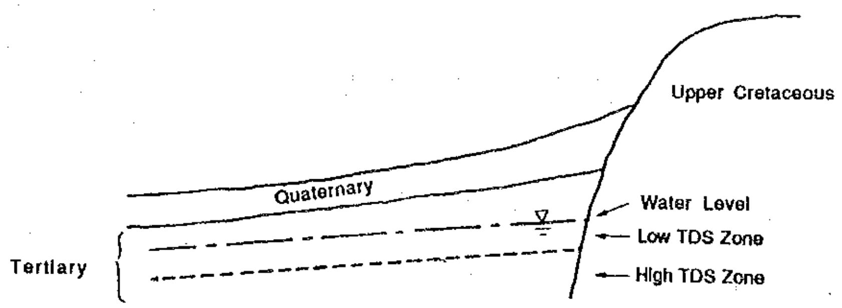


FIG. 8-3-4 SCHEMATIC DISTRIBUTION OF TDS (MIOCENE)

8-3-3 Eocene

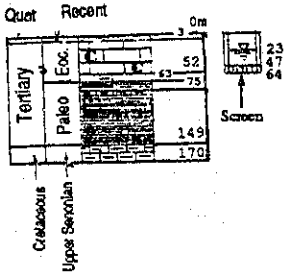
The Eocene is represented by limestone and marl distributed throughout the area south of the line combining Risan Aneiza and Gebel Maghara. Nummulites are the characteristic fossils contained in the limestone. A large scale distribution of the Eocene is found in the areas listed below;

Area around Quseima
Area around Hasana
Area in the northwest of Gebel Giddi
A broad area in the south of the line between Gebel Minshera and Gebel Kherim

All existing wells were found in the aquifers developed only in the limestone. As the transmissivity of marl is very low, no well is found in the aquifer of marl in the study area. A characteristic aspect of the occurrence of the groundwater in the aquifer developed in the limestone is that the groundwater is stored at the basal part of the limestone underlain by the Paleocene Esna Formation, which is observed at the well No. 83 El-Mewaleh No. 1 and Ain Gudeirat spring. The porosity of the limestone itself is not very high; water is stored in the fissures and joints developed in the limestone. A typical occurrence of the groundwater in the limestone in the Eocene is illustrated in Fig. 8-3-5.

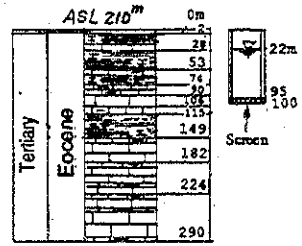
Shale and limestone of the Eocene considerably extend to the east. Ain Gudeirat is located on the axis of the syncline gently plunging to the west. A wadi incised the formation to the boundary level between Eocene limestone and Paleocene Esna Formation and the erosion surface is covered by the wadi deposits. Under these circumstances the groundwater appears as a spring (Fig. 8-3-6).

No. 83
El Mewaleh Well -1



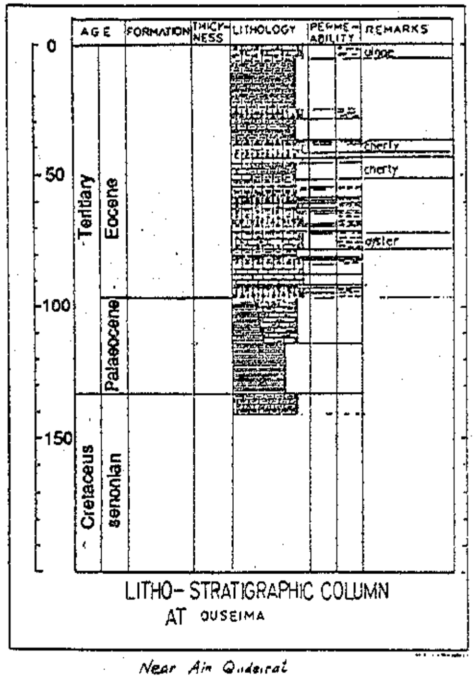
Grid : K6
W.L. : 257 m ASL
TDS : - ppm

No. 45A
El Arish Well No.10



Grid : K5
W.L. : 188 m ASL
TDS : 5,200 ppm

Ain Gudeirat



Grid : K6
W.L : – m ASL
TDS : 1440 ppm

FIG. 8-3-5 TERTIARY WELL (EOCENE)

The aquifers, tapped by the wells, distribute around Quseima and Al-Amro. They are developed in limestone of the Eocene. Also, there are some springs in the area to the southeast of Quseima with the same hydrogeological setup. The wells extracting water from aquifer of the Eocene are also reported at Al-Amro.

The TDS of the groundwater of the Eocene is 1,440 ppm at Ain Gudeirat and 5,200 ppm at the well No. 45A (Fig. 8-3-6).

The Eocene sediments are distributed extensively in the southern part of the study area. In the area, Eocene limestone is the main component of the huge plateau. The plateau is deeply incised by many wadis. But the Eocene limestone is assumed to be a prospecting aquifer. The thickness of the Eocene limestone reaches 200 - 300 m in the area. Some test wells should be drilled in the area for evaluating the Eocene limestone.

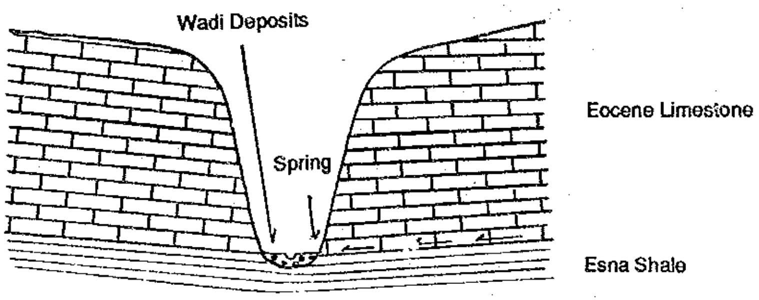


FIG. 8-3-6 SCHEMATIC SECTION OF EOCENE (AIN GUDEIRAT)

Although the Eocene is not covered by any other beds in the study area except by wadi deposits in the wadis, the groundwater of these aquifers are confined type. Therefore, some part of unfractured limestone is probably playing a role of the aquiclude creating the confined conditions.

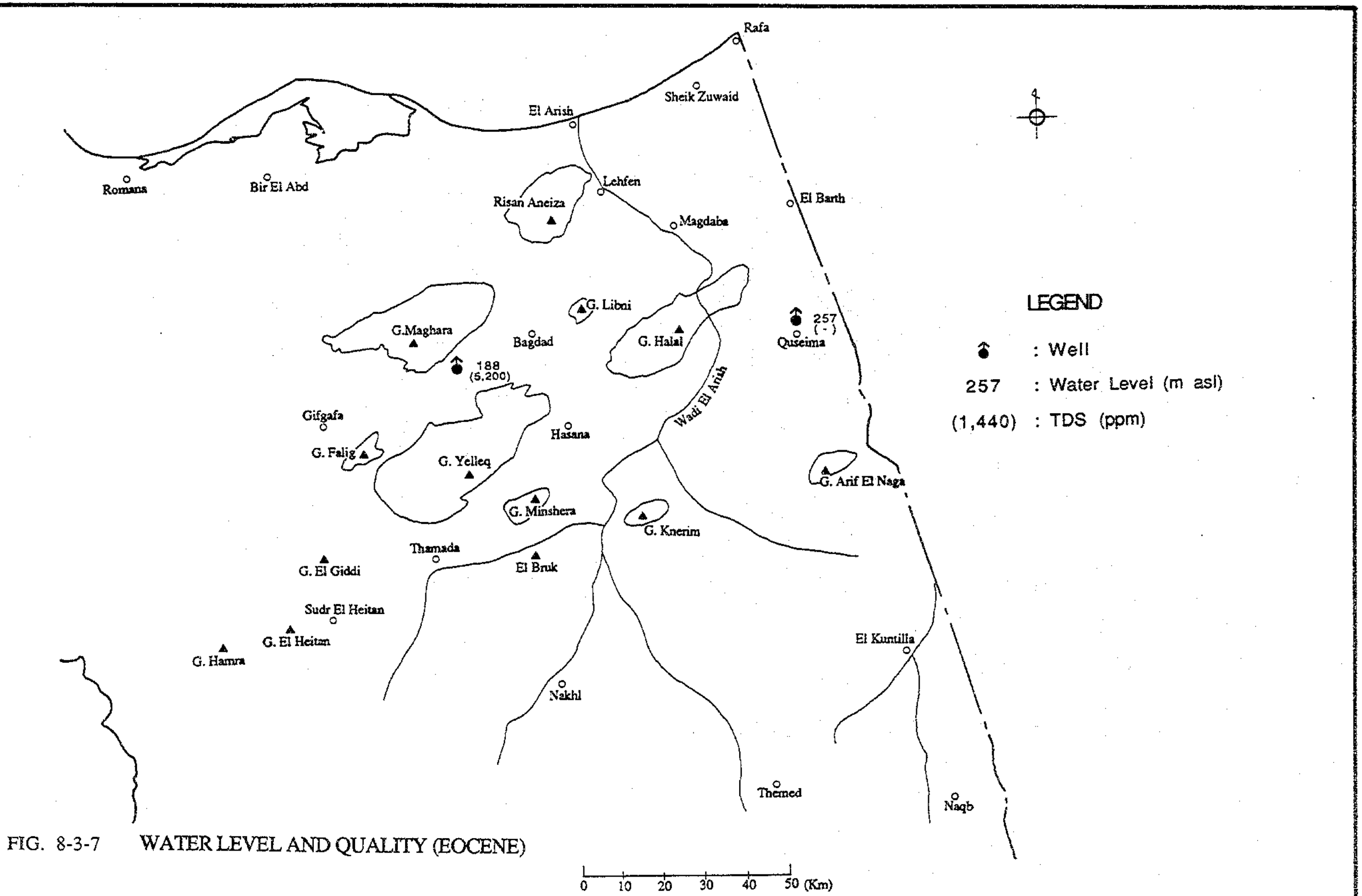


FIG. 8-3-7 WATER LEVEL AND QUALITY (EOCENE)

The age of the groundwater at the spring of Ain Gudeirat is determined as 14,000 yr.BP (Gak-14806). So, it is assumed that the recharge is not modern but in the Pleistocene. As mentioned above, Ain Gudeirat is situated in the syncline which is gently plunging to the west. The geological situation is suitable for hydrogeological conditions to concentrate groundwater. The spring water indicates a relatively moderate TDS of 1,440 ppm.
No pump test data are available. Therefore, aquifer parameters for these aquifers are unknown. However, the yield of Ain Gudeirat is estimated to be in the order of 1,500 m^3/day.

8-3-4 Paleocene

The Palaeocene in the North Sinai is represented by the Esna Formation consists mainly of shale with occasional marl. The thickness of this shale ranges from a few meters to tens of meters. The shale sometimes plays the role as the aquifer bottom of the limestone of the Eocene due to its impermeability.

8-4 Upper Cretaceous

8-4-1 General

The upper Cretaceous occupies a broad part of the study area where the Tertiary is absent. Aquifers occur in the Senonian, Turonian and Cenomanian strata.

The water level and TDS of the groundwater in the Upper Cretaceous vary widely depending on the locality, and relatively high TDS value is prevailing.

8-4-2 Senonian

The Senonian is broadly distributed in the study area. However, it is absent around Gebel Maghara and Yelleq due to heavy erosion. The upper part is eroded in some areas.

The upper part of the Senonian is represented by chalk with limestone and the lower part is characterized by marl with limestone and shale (Fig. 8-4-1). These lithological characteristics and stratigraphic succession are observed widely over the study area with continuity of the similar conditions.

The aquifers are developed in the limestone of both the upper and lower Senonian. The limestone is rather compact in general, but are lithologically porous in some places. Groundwater is stored in the porus and/or fractured parts of the limestone.

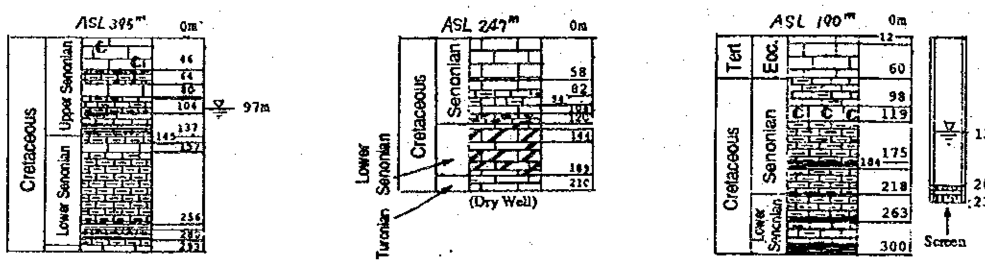
Chalk has a very low transmissivity — in the order of 10^{-5} m^3/day/m — and it is unlikely to develop aquifers. Marl and shale are impermeable forming aquicludes in the bed. Multiple limestone beds separated by interbedded shale or clay possibly form aquifers.

There are four wells tapping the water from the aquifer of limestone of the Senonian of which water levels are confirmed. These wells are distributed in the Hasana, Gebel Libni and Gifgafa areas. No wells tap the water from the Senonian aquifer distributed in the area south from the Ragabet El Naam Fault (Fig. 8-4-2).

The water level of the wells sunk into this type of aquifer is 107 m asl at Hasana and 58 m asl at Gebel Libni. Their hydraulic gradient is approximately 2 to 1,000.

The water level at well Wadi El Meleiz No. 1 in the southern part of Gifgafa is recorded at 208 m asl which is extremely high compared to water levels at other wells. This may be attributed to the fact that the area from this site to Gifgafa is located in the graben isolated from the surrounding area. But at the present time there is no available field evidence to prove such a hydrogeological phenomenon. The TDS is rather high (2,200 ppm at Hasana, 4,500 ppm at Gebel Libni and 8,480 ppm at Gifgafa).

No. 70 Wadi El Maleiz-1 | No. 49 El Arish Well No.14 | No. 63A Gebel Libni No.1



	Grid	W.L.	TDS
No. 70	K1	298 m ASL	8,480 ppm
No. 49	K2	107 m ASL	2,200 ppm
No. 63A	K5	58 m ASL	4,500 ppm

FIG. 8-4-1 SENONIAN WELL

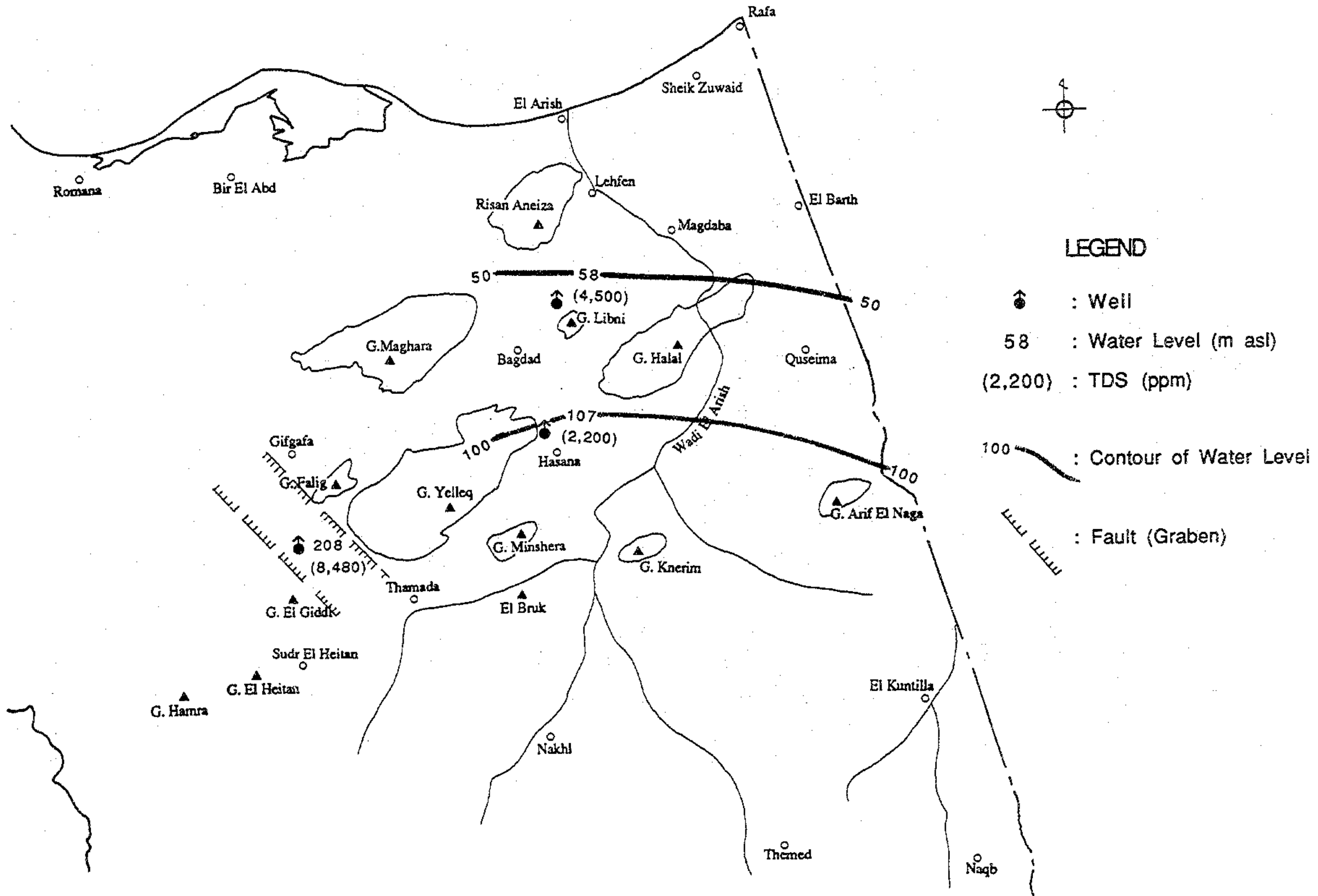


FIG. 8-4-2 WATER LEVEL AND QUALITY (SENONIAN)

The recharge to the aquifers in the Senonian are assumed to have taken place during the Pleistocene. It is very unlikely that the recharge takes place under the current climate. Taking the confined condition of the Senonian groundwater system into consideration, it is assumed that recharge might have taken place further south during the Pleistocene age.

The TDS value variation over a wide range is one of the characteristics of the water in the aquifers of the Senonian. It is highly possible that the saline water was originally trapped in the rocks. The salinity was diluted or saline water was replaced by the less saline water along the movement of the groundwater mass in the aquifer. In the aquifer, where joints and fissures are well developed, the water body can easily move diluting the original salinity in the aquifer. However, where the transmissivity is low, the amount of water movement might be less than otherwise so that the salinity of the groundwater remains at a high level without becoming diluted..

This may have resulted in the relatively low TDS value (2,200 ppm) at the well at Hasana where the geological disturbance is small in the Syrian Arc and the geological structure allows the groundwater to pass through. On the other hand, the aquifers at the well at Wadi El Meleiz are isolated in the graben and movement of the groundwater body is rather restricted which resulted in a rather high TDS value (8,480 pm).

No pump test were undertaken at these wells and aquifer parameters of these aquifers are unknown.

8-4-3 Turonian

The Turonian is represented by the fossiliferous (especially foraminifera) limestone with shale at the base.

The aquifers develop in the limestone. There are three recorded wells tapping the aquifers in the limestone of the Turonian (at Hasana, Naqb and Sheira) (Fig. 8-4-3). Of these, the well at Naqb is located on the northern side of the Ragabet El-Naam Fault; the one at Sheira is on the southern side.

The water level at Naqb is 290 m asl. At Sheira it is 679 m asl. The difference is assumed to be caused by the fault (Fig. 8-4-4).

The TDS value at Sheira indicates a rather low value of 1,100 ppm. However, the value at Naqb is much higher (35,000 to 40,000 ppm) which is equivalent to the TDS of sea water.

In the central part of the Sinai peninsula, there is a general tendency for the groundwater to move from south to north, restricted by the geological structure. At the same time, the Regabet El-Naam Fault, running in the east-west direction, crosses through the central Sinai and is assumed to play a role as a barrier to the groundwater movement. These hydrogeological setups cause the groundwater to be stored on the southern side of the fault. On the other hand, movement of the groundwater to the northern side of the fault is somehow restricted by the fault.

Under the circumstances the groundwater at Sheira has more of an opportunity to get diluted of its original salinity by the recharged groundwater, while the groundwater salinity remains at a higher level on the northern side since the groundwater movement from the south is restricted by the fault.

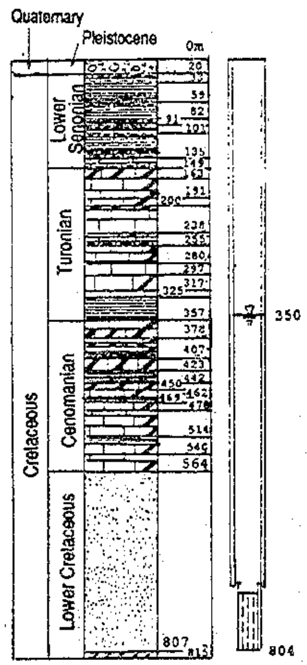
The aquifer parameters of the Turonian are estimated by the aquifer test at well Sheira-2 as shown below:

Transmissivity	$T = 0.94\ m^3/d$
Specific capacity	$Sc = 2.01\ m^3/d/m$

Although there is only one aquifer parameter data for the Turonian, at Sheira, this type of aquifer is assumed to be favorable in the southern side of the fault.

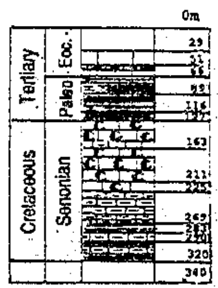
The age of groundwater at well J No. 17 is estimated to be 22,670 Y.BP.

Sheira Well 1



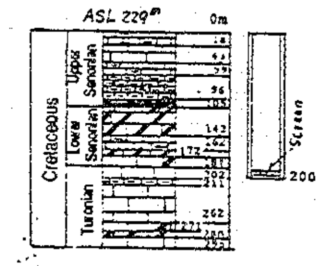
Grid : H3
W.L. : 420 m ASL
TDS : 1,575 ppm

Naqb 3



Grid : H4
W.L. : 290 m ASL
TDS : 35,000 ~40,000 ppm

No. 50
El Arish Well No.15



Grid : K2
W.L. : 39 m ASL
TDS : 7,000 ppm

FIG. 8-4-3 TURONIAN WELL

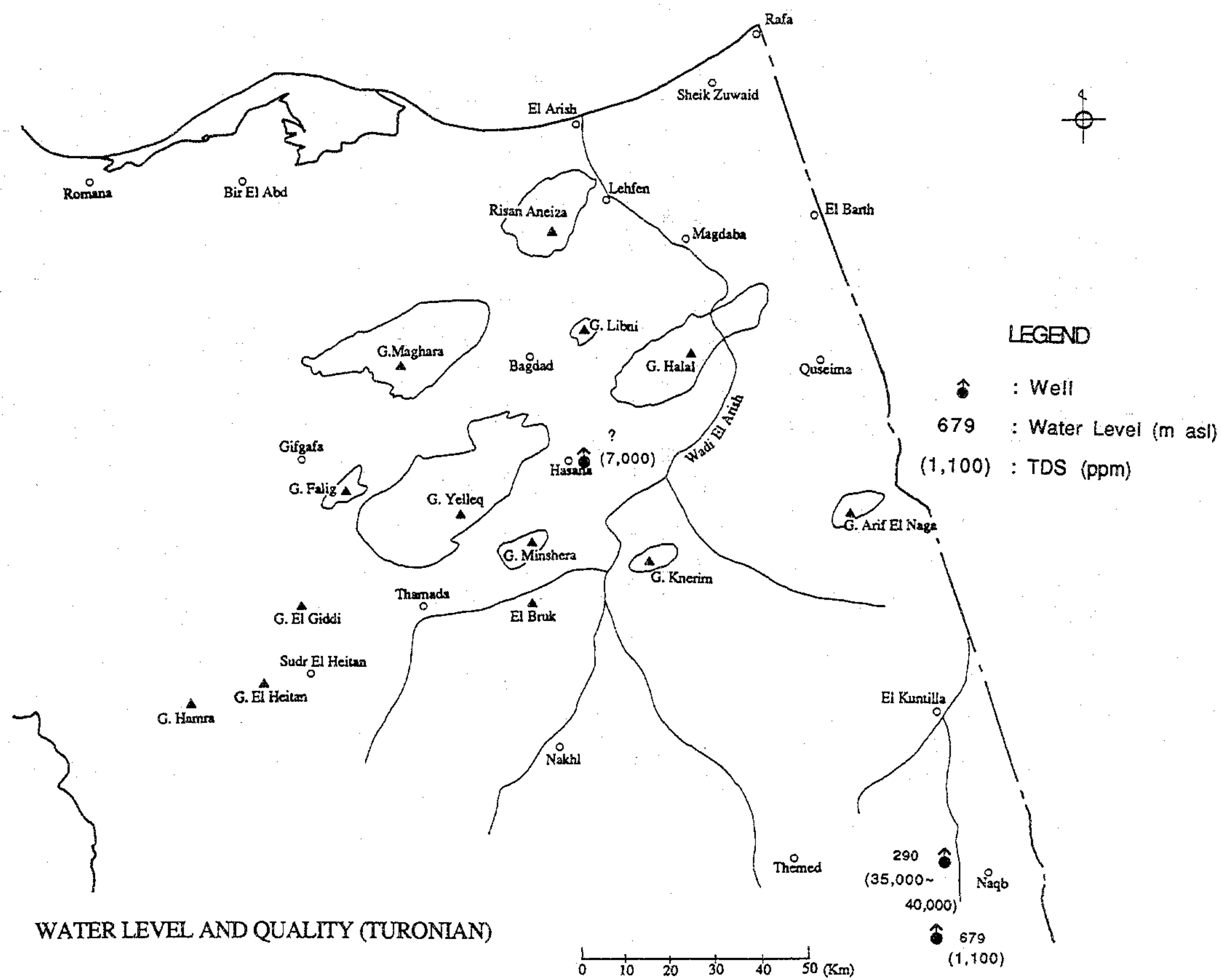


FIG. 8-4-4 WATER LEVEL AND QUALITY (TURONIAN)

8-4-4 Cenomanian

The lithology of the base of the Cenomanian overlying the Lower Cretaceous is calcareous sandstone. In the upper part of the Cenomanian, the lithology is represented by limestone, dolomite and dolomitic limestone. Although it crops out only at domes where the overlying beds are eroded, the Cenomanian is distributed in a broad area overlain by other beds.

The porosity of the limestone is important from a hydrogeological point of view. As karstic caves and fissures may easily be developed in the given lithology, these limestone beds are recognized to be permeable. Therefore, aquifers developed in this bed are localized types rather than continuous and homogeneous regional types like aquifers in the sandstone of the Lower Cretaceous.

Lithology of this bed in the lower most part is hard and compact calcareous type with occasional intercalation of shale. These shales intercalated in dolomitic facies are continuous and their thickness is about 20 m, so they are recognized as aquiclude.

Five wells are sunk into the aquifer of the Cenomanian. The depth to the aquifer from the ground surface is 138 m at well J No. 17. The remaining wells are in a range between 400 m at well P1 Gifgafa and 818 m at well P16 El-Amro. Well J No. 17 was drilled in a dome at El-Bruk where the overlying bed of the Cenomanian was eroded, so that the depth to the aquifer is rather shallow (Fig. 8-4-5).

The water level of these wells are at 223 m asl at El-Bruk, at 169 m and 63 m asl at Hasana which suggest the piezometric potential surface of the groundwater in the aquifers declining from the south to the north (Fig. 8-4-6).

The salinity of groundwater of these wells is rather high, ranging between 2,740 ppm and 5,630 ppm. The salinity of well No. 57A is 2,740 ppm. However the salinity of the UNICEF well, 10 km from well No. 57A is 4,120 ppm. This may indicate that the extent of fissures and joints developed in the limestone are not universal but are localized types.

The age of the groundwater at well J No. 17 is estimated to be 2,670 Y.BP (Gak-15949).

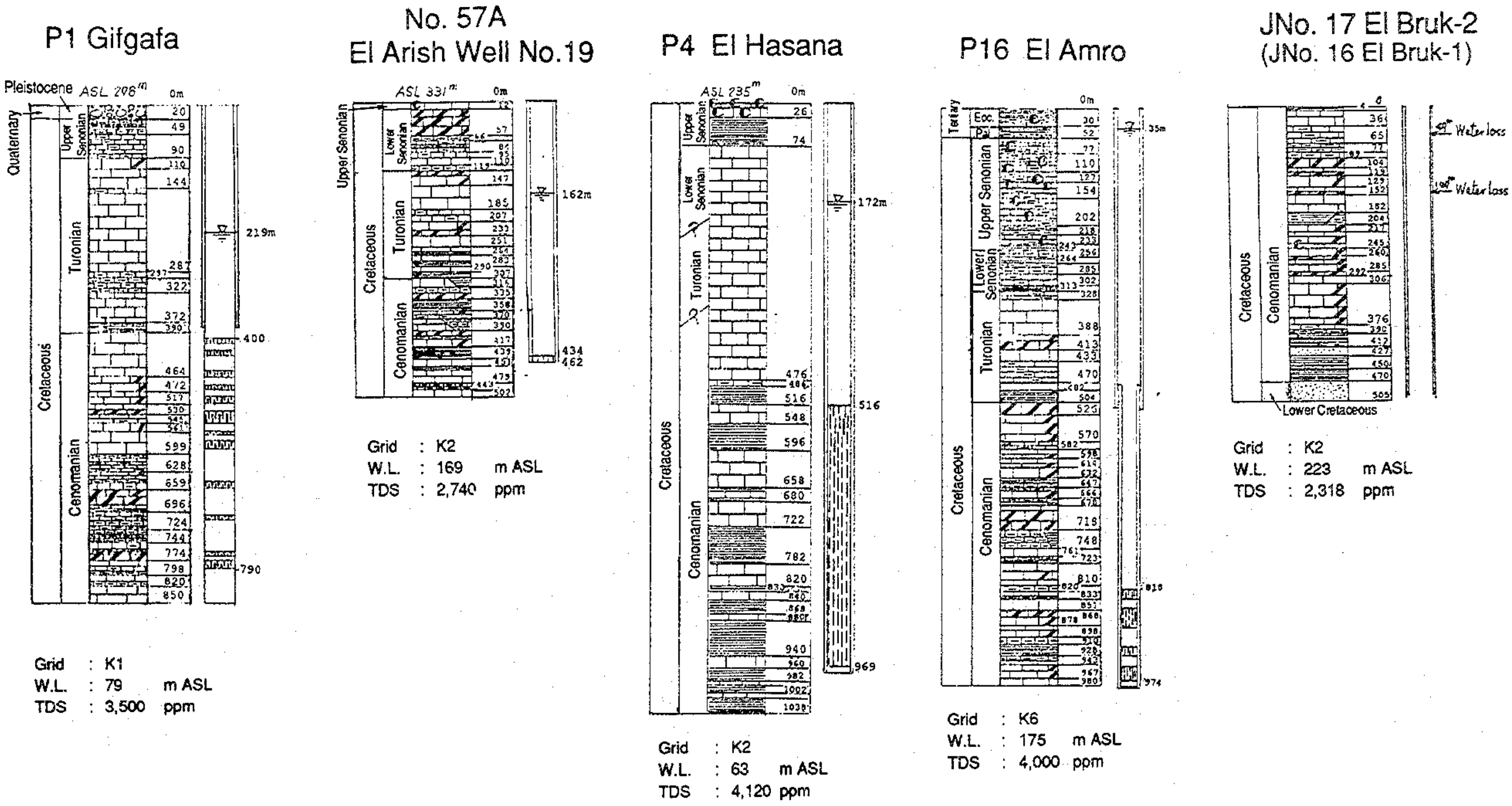


FIG. 8-4-5 CENOMANIAN WELL

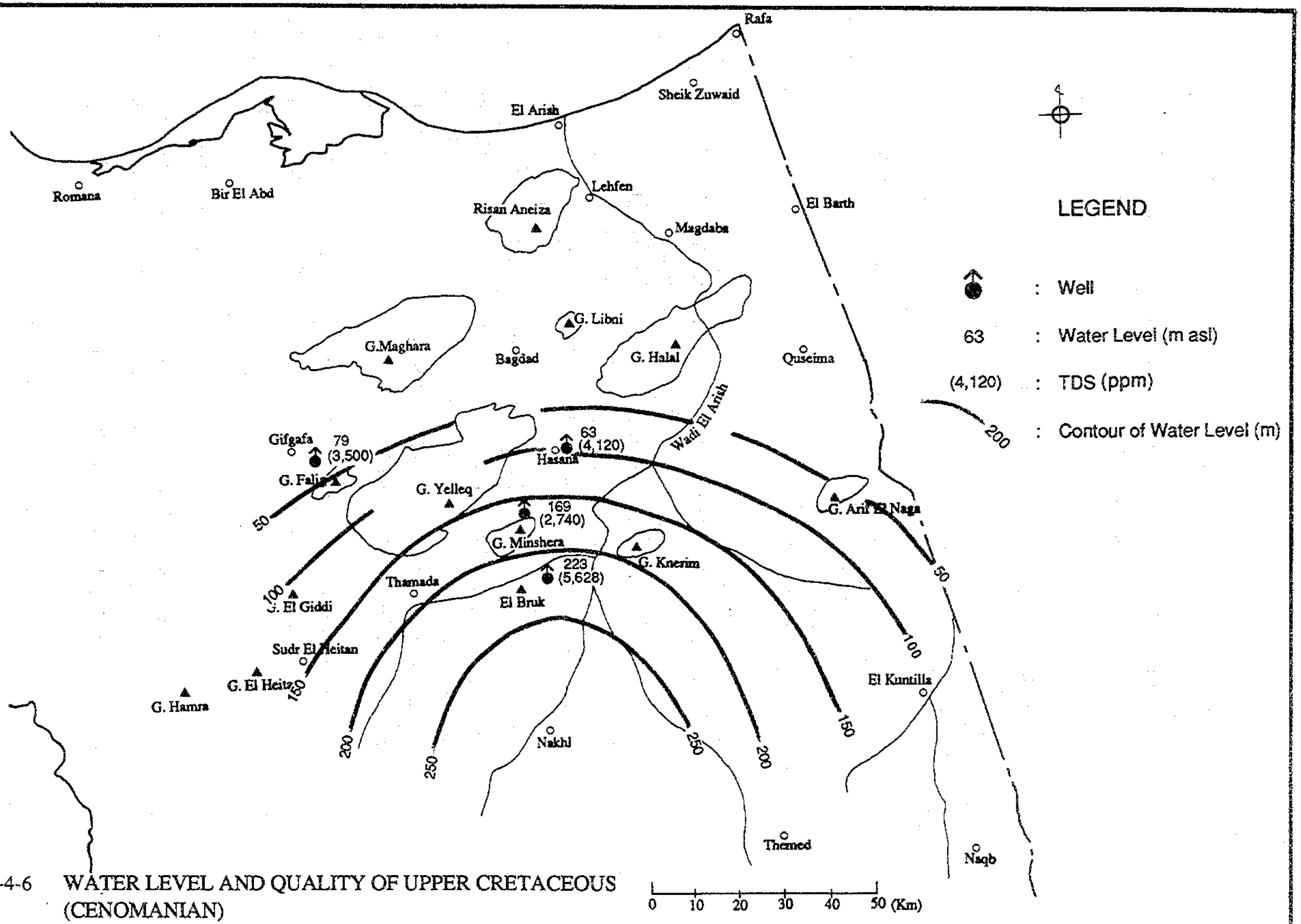


FIG. 8-4-6 WATER LEVEL AND QUALITY OF UPPER CRETACEOUS (CENOMANIAN)