8-5 Lower Cretaceous

The Lower Cretaceous extends over a great part of the study area. The whole sequence of the Lower Cretaceous is observed at four sites (Technical Report III):

Maghara
Minshera
Arif El-Naga
Naqb

The whole sequence of the Lower Cretaceous is also interpreted on 8 lithological profiles of the test wells (Technical report IV):

Nakhl-1
Sheira-1
Sadr El-Heitan
J No. 12 (See Section 2-2-3, Technical Report 1.)
J No. 13 (See Section 2-2-3, Technical Report 1.)
J No. 14 (See Section 2-2-3, Technical Report 1.)
J No. 16 (See Section 2-2-3, Technical Report 1.)
J No. 19 (See Section 2-2-3, Technical Report 1.)

Lithology of the Lower Cretaceous is represented by quartzose sandstone with occasional interbeddings of shale. The thickness of the Lower Cretaceous varies from palace to place. It is generally in a range between 200 m and 300 m; however, a very thick sequence of this bed is observed at Halal reaching 600 m thick (Fig. 8-5-1).

The interbedded shale is rare in the area of Gebel Alada, Gebel Al-Mostadul, Gebel Kherim and Gebel Minshera, while the shale appears interbedding frequently in the upper part of the formation at Gebel Maghara and Gebel Mafuruth. On the other hand, a thick shale was observed in the lower part of the formation at Arif El-Naga and Gebel Halal. The interbedded shale is a lenticular type rather than a continuous massive type except at the lower part at Arif El-Naga and Gebel Halal.

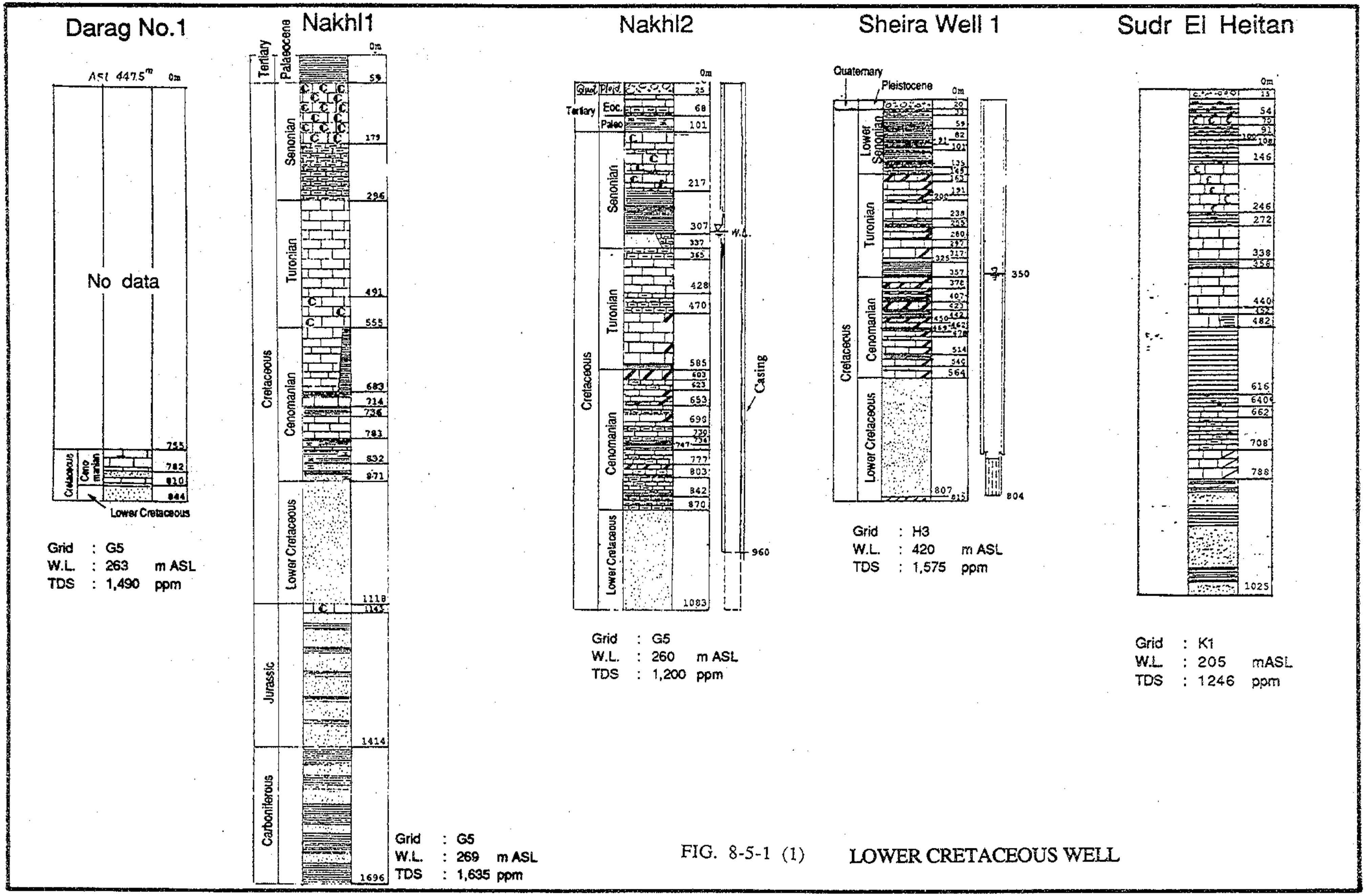
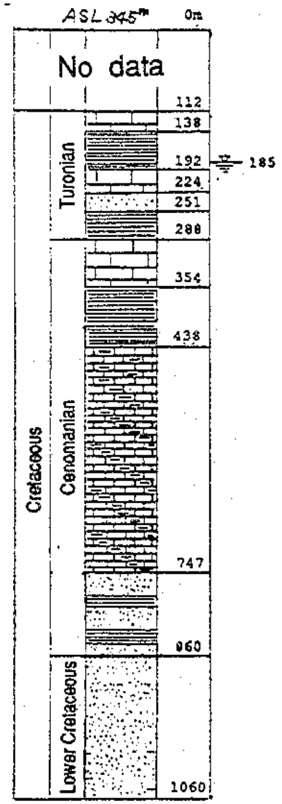


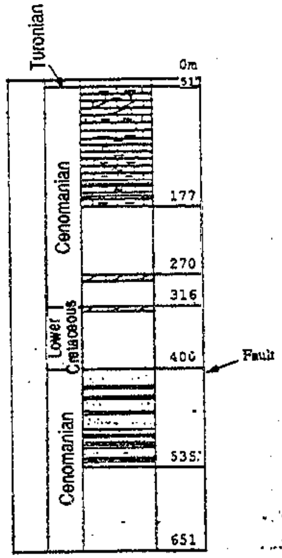
FIG. 8-5-1 (1) LOWER CRETACEOUS WELL

No. p18
Epytian Army Hasana



Grid : K2
W.L. : 160 m ASL
TDS : 1,500 ppm

Talet El Badan



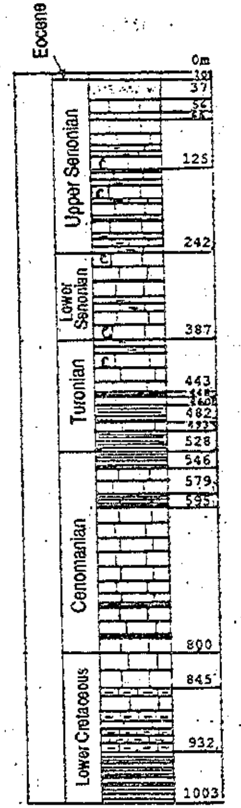
Grid : K3
W.L : 72 mASL
TDS : 5360

El Halal Israeli Well

No data

Grid : K6
W.L : 24 mASL
TDS : 1410 ppm

Umm Shihan



Grid : K6
W.L : 25 mASL
TDS : - ppm

FIG. 8-5-1 (2) LOWER CRETACEOUS WELL

JNo.12 Minsherah	JNo.13 Falig	JNo.14 Halal	JNo.16 El Bruk-1	JNo.19 Arif El Naga
Ref. Technical Report I	Ref. Technical Report I	Ref. Technical Report I	Ref. Technical Report I	Ref. Technical Report I
Grid : K2	Grid : K1	Grid : K6	Grid : K2	Grid : K3
W.L : 198 mASL	W.L : 67 mASL	W.L : - mASL	W.L : 203 mASL	W.L : 159 mASL
TDS : 2,973 ppm	TDS : - ppm	TDS : - ppm	TDS : 2,318 ppm	TDS : 3008 ppm

FIG. 8-5-1 (3) LOWER CRETACEOUS WELL

The lithological facies changes from quartzose sandstone to limestone in the northern part of the study area along the Mediterranean to the north of Gebel Maghara and Gebel Halal. From this area to the south the quartzose sandstone is distributed over 20,000 km^2 with thickness ranging between 200 to 300 m.

Although the information of the hydraulic properties of sandstone is rather limited, the permeability coefficients and the transmissivities of the aquifers in the sandstones are obtained at six places (Chapter 5, Technical Report I):

Table 8-5-1
Physical Property of Aquifer in Sandstone

No.	Well No.	Discharge (m^3/day)	Transmissivity Coefficient (m^2/day)	Permeability Coefficient (cm/sec)
1	J No. 12	71.3	54.4	8.1×10^{-4}
2	J No. 16	700.8	11.9	1.5×10^{-4}
3	J No. 19	480.0	399.3	2.7×10^{-3}
4	Sheira-1	528.0	214.8	3.6×10^{-3}
5	Nakhl-2	1,440.0	108.0	6.3×10^{-3}
6	Talet El-Badan	2,001.0	302.8	3.2×10^{-3}

As shown in Table 8-5-1, the permeability coefficients of these aquifers vary in a range between 10^{-4} and 10^{-3} cm/sec, and the variation range of the transmissivities is between 12 and 400 m^2/day. Among these wells, two of them (J No. 12 and J No. 16) are located at the dome structure and the physical properties of the aquifers seem to be lower than those of the others.

The physical constants of the limestone of the Lower Cretaceous are also available at Umm Shihan. The permeability coefficient is 8.4×10^{-4} cm/sec and the transmissivity is 117.7 m^2/day.

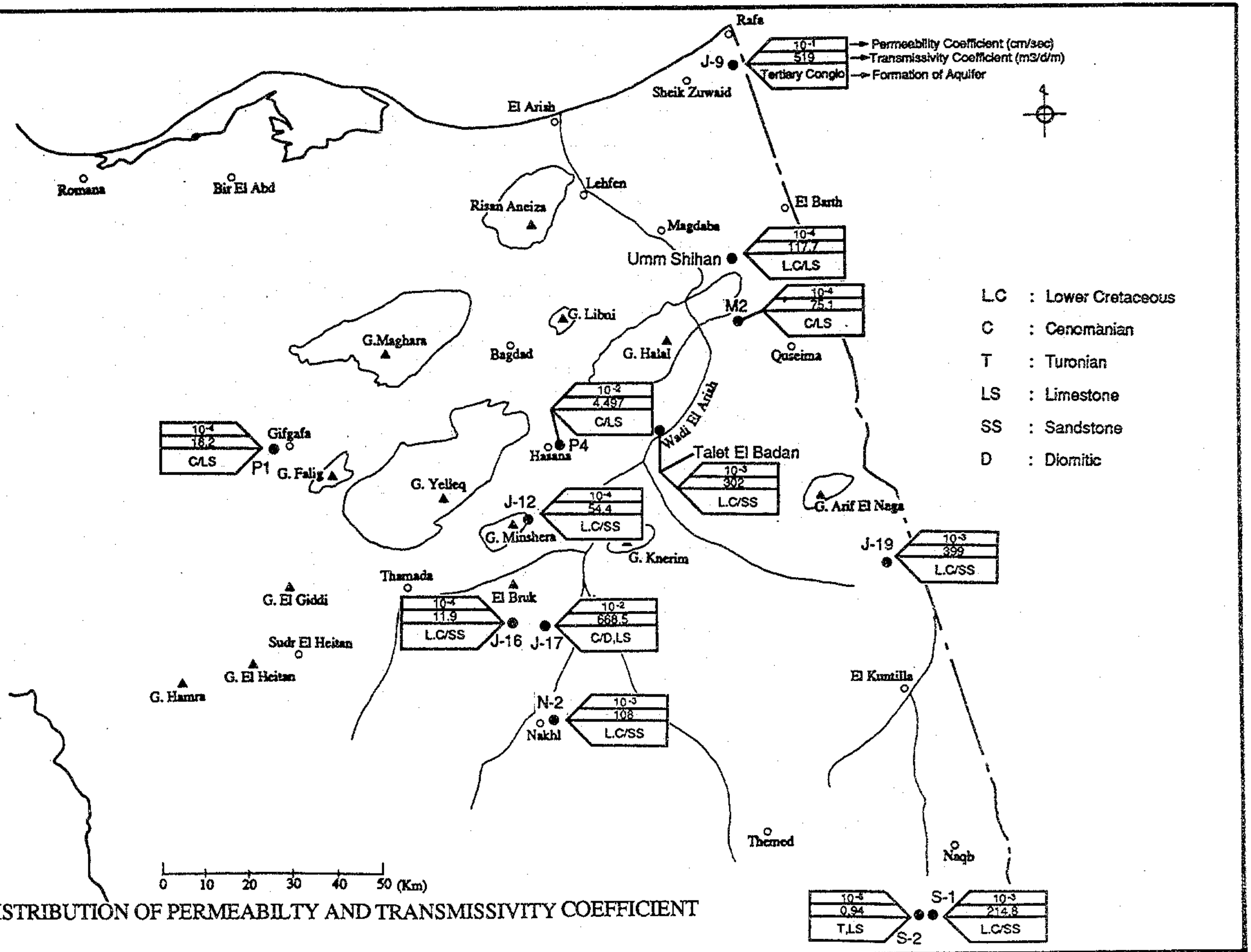


FIG. 8-5-2 DISTRIBUTION OF PERMEABILTY AND TRANSMISSIVITY COEFFICIENT

Since the number of the physical constants of the aquifers of the Lower Cretaceous was limited, a grain size analysis was undertaken to interpret the continuity of the sandstone facies and to estimate the permeability in the area.

The permeability of each layer is estimated by the passing D_{20} value (Technical Report III). Most of the estimated permeability of the sandstone sequence falls into a narrow range between 10^{-3} and 10^{-2} cm/sec (Fig. 8-5-3). The proportion of the thickness which indicates the permeability between 10^{-3} and 10^{-2} cm/sec is summarized below (Table 8-5-2):

Table 8-5-2

Estimated Permeability of Sandstone Sequence

Observation site	% of thickness with k between 10^{-3} and 10^{-2}cm/sec	Thickness observed(m)
Minshera	80	350
Alada	77	> 150
El-Mostadul	71	> 150
Maghara	28	200
Arif El-Naga	67	300
Halal	64	150
Kherim	74	250
Mafruth	56	250

The sandstone facies changes to the limestone facies in the northern part of the study area, and Gebel Maghara and Mafruth are located on the transitional area. The lower percentage of the permeability, between 10^{-3} and 10^{-2} cm/sec, may be attributed to the above fact.

Thick shale occupies the lower part of the Lower Cretaceous at Halal and Arif El-Naga; however, 100 m to 150 m of the top of the Lower Cretaceous consists of sandstone which may reflect on the figures in Table 8-5-2.

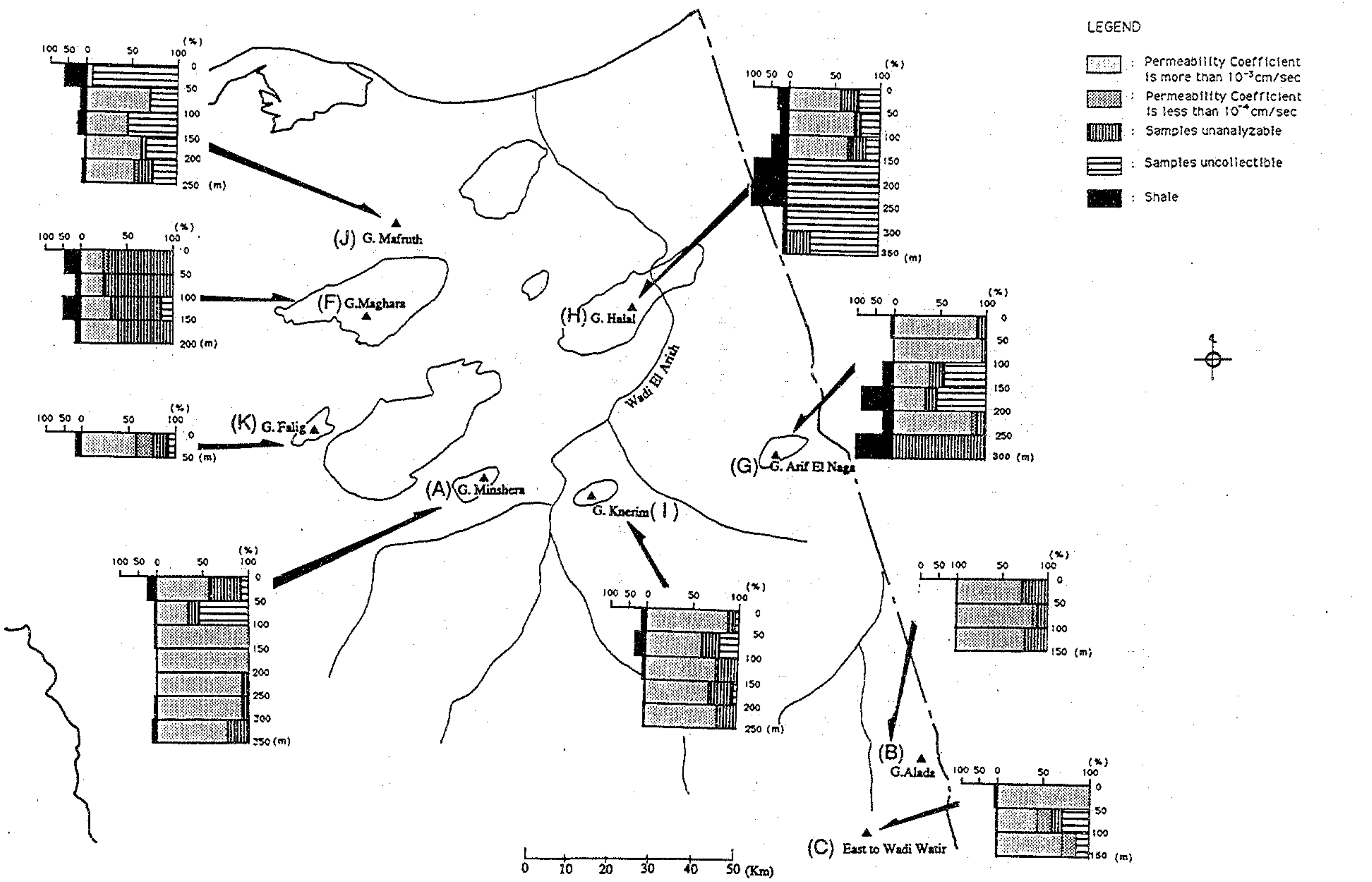


FIG. 8-5-3 DISTRIBUTION OF PERMEABILITY OF EACH 50m LAYERS

The permeability of the aquifers in the sandstone of the Lower Cretaceous, obtained by the aquifer test, falls into a narrow range between 10^{-4} and 10^{-3} cm/sec which may indicate the aquifers are homogeneous and highly permeable.

The estimated permeability by the passing D_{20} also falls into narrow range between 10^{-3} and 10^{-2} cm/sec; one order higher than these obtained by the aquifer test. This may be attributed to the fact that the samples of the grain size analysis are once dispersed and the estimated permeability tends to be higher than the one obtained by the aquifer test.

Considering the narrow range of distribution of these permeabilities, it is assumed that the aquifers in the sandstone of the Lower Cretaceous have a very similar value of permeability, ranging between 10^{-3} and 10^{-4} cm/sec widely in the study area.

The Lower Cretaceous crops out high up on the dome structures, except at Naqb. But the depth to the top of this bed from the surface reaches approximately 1,000 m in the northern part of the study area. Distribution of the depth to the top of this bed is summarized below:

Table 8-5-3

Depth to Top of Lower Cretaceous Concealed Under the Surface

Location	Depth (BGL) (m)
Sheira	560
El-Themed	600
Kuntilla	500
Nakhl	870
Sadr El-Heitan	800
Hasana	1,100
Baghdad	1,100
Gifgafa	1,000
Quseima	900

The top surface of the Lower Cretaceous seems to be a very gentle and broad underground valley descending gently from south to north in a N-S direction. Gebel Minshera, Gebel Kherim and Gebel Halal appear to be inselbergs in the gentle and broad valley. There are narrow depressions on both sides of Gebel Yelleq and Gebel Halal extending in an ENE-WSW direction (Fig. 8-5-4).

The Paleozoic sandstone overlies the Precambrian unconformably in Naqb. However, in the rest of the area the Lower Cretaceous is underlain by the Jurassic rocks which unconformably overlie the basement. The lithology of the Jurassic varies from place to place, and common facies are either limestone, sandstone or shale.

Table 8-5-4

Lithological Sequence Between Lower Cretaceous and Jurassic

Well Number	Location	Facies of Jurassic
Nakhl-1	Nakhl	Chalky sandstone
Sheira-1	Naqb	(No Jurassic) (Pre-Cambrian)
J No. 12	Minshera	Limestone
J No. 13	Falig	Shale
J No. 14	Halal	Shale
J No. 16	El-Bruk-1	Sandstone
J No. 19	Arif El-Naga	Shale

There is apparent unconformity between Lower Cretaceous and underlying Jurassic. In the area where the Lower Cretaceous sandstone unconformably overlies the sandstone of the Jurassic there is no hydrogeological boundary between the two formations.

The quality of the groundwater in the aquifers of the Lower Cretaceous shows a moderate TDS level ranging between 1,500 and 3,000 ppm; however, there are some wells where the TDS reaches approximately 3,000 ppm or more (El-Bruk, Minshera, Arif El-Naga, Talet El-Badan and Umm Shihan). The lithological facies of the aquifer at Umm Shihan changes to limestone and the groundwater body is assumed to be stagnant due to the lower permeability of the aquifer compared to that of the sandstone aquifers.

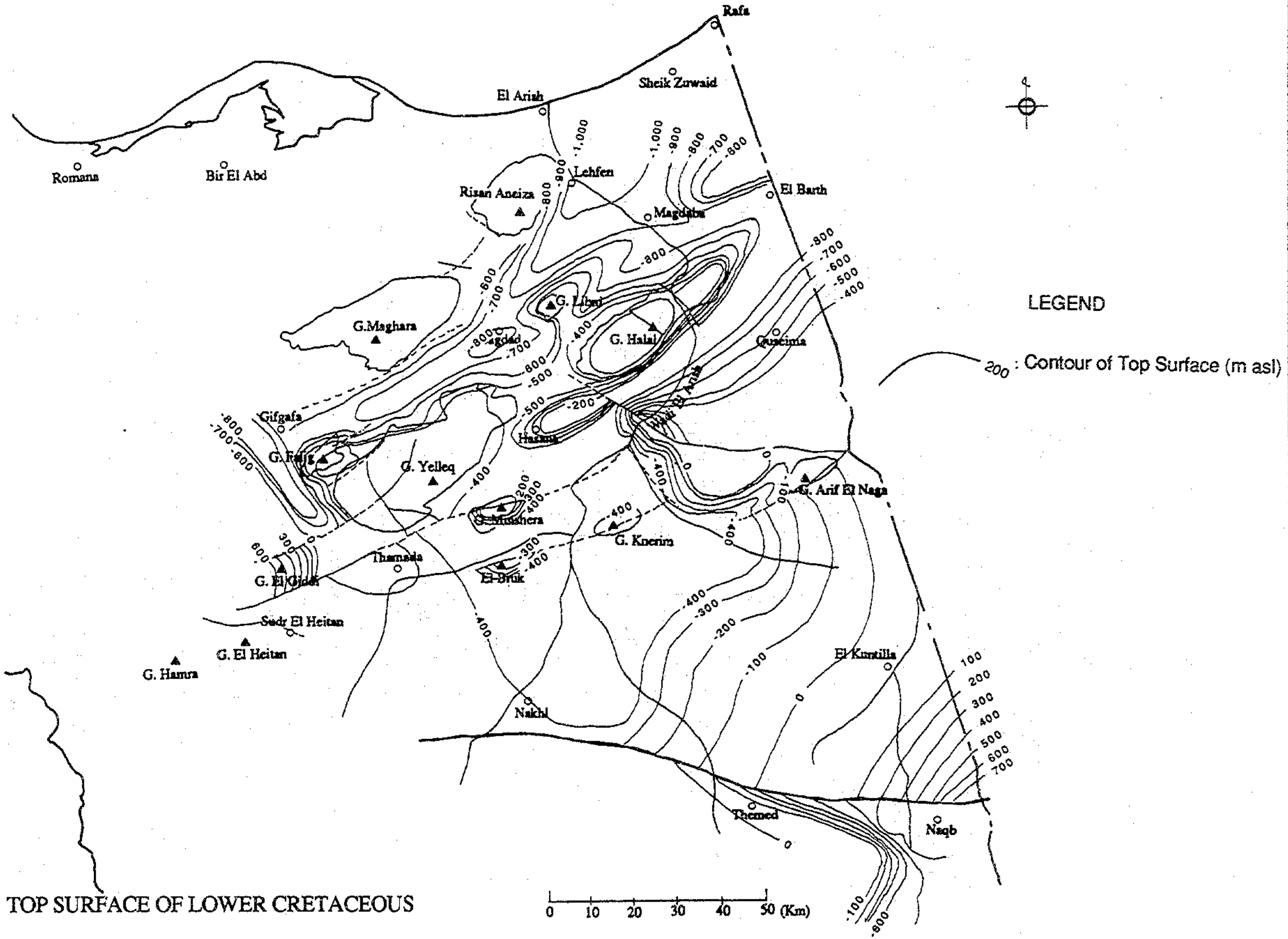


FIG. 8-5-4 TOP SURFACE OF LOWER CRETACEOUS

The aquifer in the sandstone of the Lower Cretaceous at Talet El-Bedan makes direct contact with the limestone of the Cenomanian so that the TDS of the water in the sandstone aquifer may have influence on the high salinity in the aquifer of the limestone.

The wells at Minshera, El-Bruk and Arif El-Naga penetrate into the Jurassic formation. However, the resistivity curve shows no significant differentiation between the Lower Cretaceous and the Jurassic. This may suggest that the TDS value of the groundwater observed at these wells indicates the salinity of the groundwater of the aquifer in the Lower Cretaceous. The local condition of the geological structure may have influence on the salinity of the water in the vicinity of domes, but the subject is to be confirmed in the future (Fig. 8-5-5).

The TDS value of the groundwater in the aquifer of the Lower Cretaceous tends to be lower than that in the northern area since there is no disturbance of the dome structures.

14 wells are sunk into the aquifer of the sandstone of the Lower Cretaceous. The highest water level (420 m asl) was observed at well Sheira 1 on the southern side of the Ragabet El-Naam Fault. The lowest water level (24 m asl) was measured in the northeastern part of Gebel Halal at the Israeli well. According to all the well data it is suggested that the piezometric potential surface of the groundwater in the aquifer of the sandstone of the Lower Cretaceous gently descends from the south to the north with a gradient of 2/1,000 to 3/1,000 (Fig. 8-5-6).

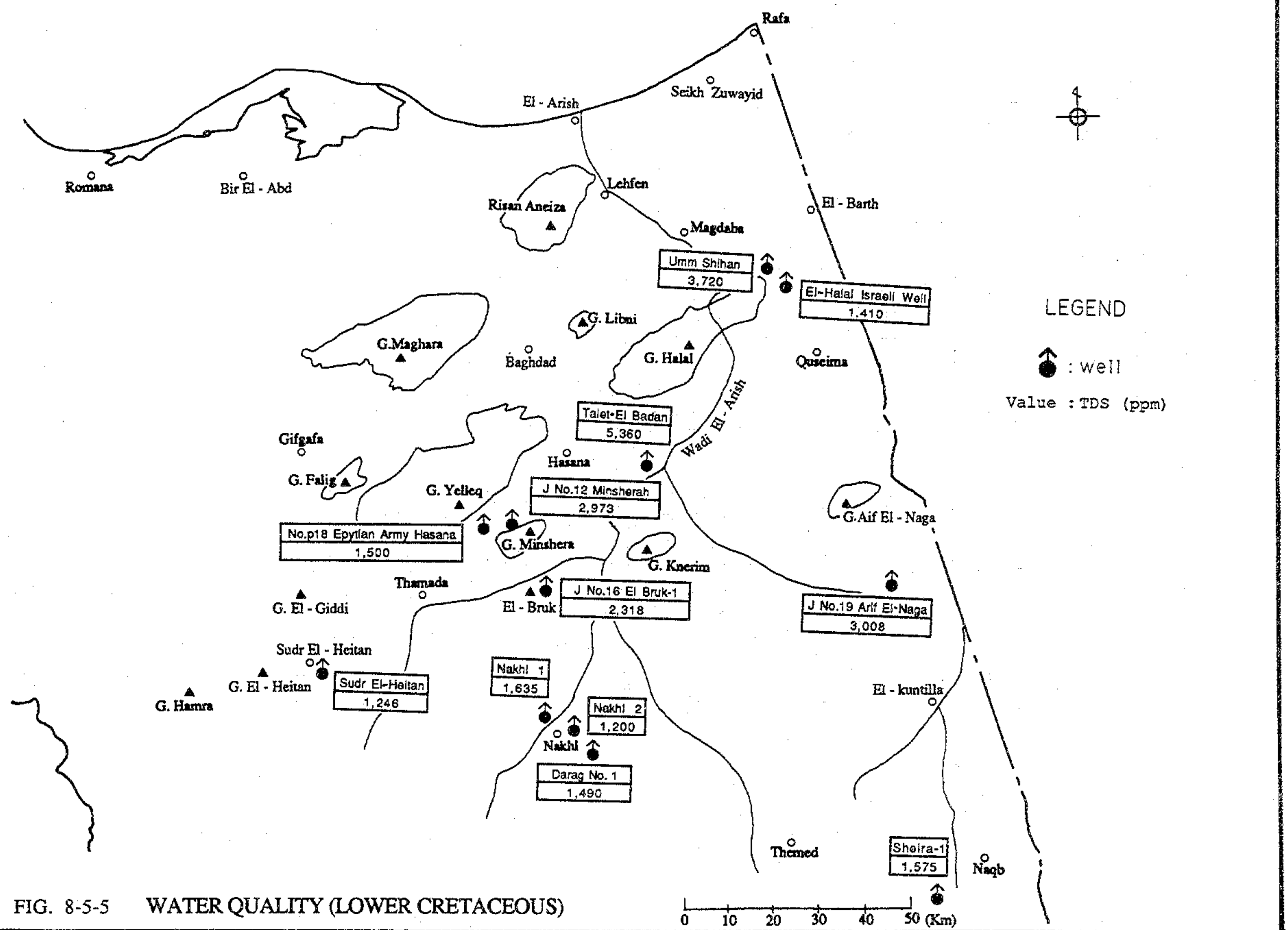


FIG. 8-5-5 WATER QUALITY (LOWER CRETACEOUS)

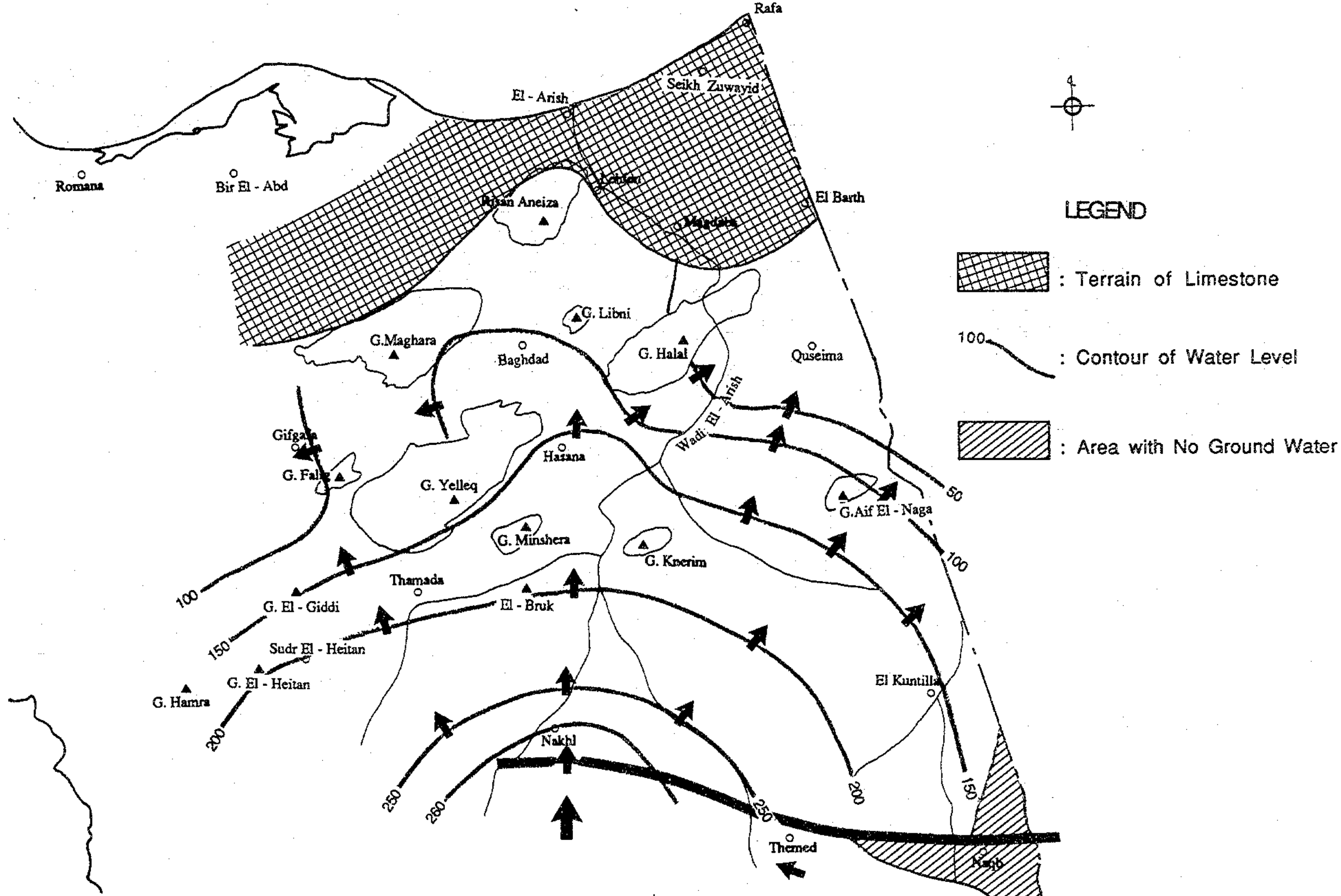


FIG. 8-5-6 WATER LEVEL OF WELLS IN LOWER CRETACEOUS

In addition to the influence of the geological structure of domes on the aquifer, there would be a remarkable influence on this aquifer caused the Regabet El-Naam Fault which extends from Naqb to the west, crossing the central Sinai. The southern side of the fault is an uplifted block, but the vertical displacement in the central part of the fault at Nakhl seems to be insignificant. However, the vertical displacement of the fault in the western and eastern part is significant. At Naqb, the vertical displacement of the fault is estimated to exceed 200 m and the Pre-Cambrian rocks are exposed in the southern block. It is suggested that the Lower Cretaceous sandstone, which is demarcated by the fault, is disrupted at the western and eastern terminus of this fault.

The water level at well Sheira-1 is at 420 m asl which is extremely high compared with the rest of the water levels of the wells sunk into the sandstone of the Lower Cretaceous. On the other hand, the water levels of the aquifer of the Lower Cretaceous at Nakhl (well Nakhl-1 and 2, and Drag No. 1) are estimated to be in a range between 260 and 269 m asl. It envisages that the groundwater in the northern side of the fault has a high piezometric potential surface, being disrupted on the western and eastern part of the fault, and the movement of the water body is allowed only through the Nakhl area to the north. This may be the reason why there is the descending piezometric potential surface gradient from well Sheira-1 to wells at Nakhl. Through this underground flow in the sandstone of the Lower Cretaceous around Nakhl, the groundwater in the Lower Cretaceous moves further toward north.

Being restricted by the fault, the groundwater in the Lower Cretaceous aquifer moves from the south to the north through the hindrance of dome structures, turning its direction towards a NE direction at the Syrian Arc. The barrier of this flow at the northern end is the limestone of the Lower Cretaceous (Fig. 8-5-6).

The TDS value of the groundwater from the wells sunk into the aquifer of the sandstone of the Lower Cretaceous in the dome structure tends to become high. Consequently, it is assumed that the groundwater in these geological structures is stagnant rather than flowing isolated from the movement of the major water body.

Therefore, the water with a relatively low TDS is available in the area where the formation is not structurally disturbed.

In order to estimate the volume of the Lower Cretaceous formation in the study area, an isopach map of the Lower Cretaceous is provided (Section 7-4-5). The estimated thickness of the Lower Cretaceous is shown in Fig. 8-5-3 excluding the area occupied by domes and mountains. The Lower Cretaceous contains shale in the northern part of the study area. Also, the percentage of the shale in the sandstone of the Lower Cretaceous is estimated as shown in Fig. 8-5-7. Based on these assumptions, the volume of the sandstone of the Lower Cretaceous is calculated for each well and outcrop to estimate the volume of the sandstone aquifer of the Lower Cretaceous.

The volume of the sandstone aquifer of the Lower Cretaceous is estimated at 120 x 10^9 m^3 and the volume of the groundwater storage in this aquifer is 30 x 10^9 m^3 assuming the effective porosity of 25% .

Results of pump test of the sandstone aquifer of the Lower Cretaceous is available at seven wells (Table 8-5-5, Fig. 8-5-7).

Table 8-5-5

Aquifer Test Results of Sandstone Aquifer of Lower Cretaceous

Well name	Discharge (m^3/day)	Max. draw down (m)	Specific capacity (m^3/day/m)
J No. 16 El Bruk-1	700.8	54.5	13
J No. 19 Arif El Naga	480.0	2.5	195
Sheira-1	528.0	4.5	118
Sadr El Heitan	456.0	2.6	179
Nakhl 2	1,440.0	30.0	48
Talet El Badan	2,001.0	8.9	225
Umm Shihan	960.0	16.2	59

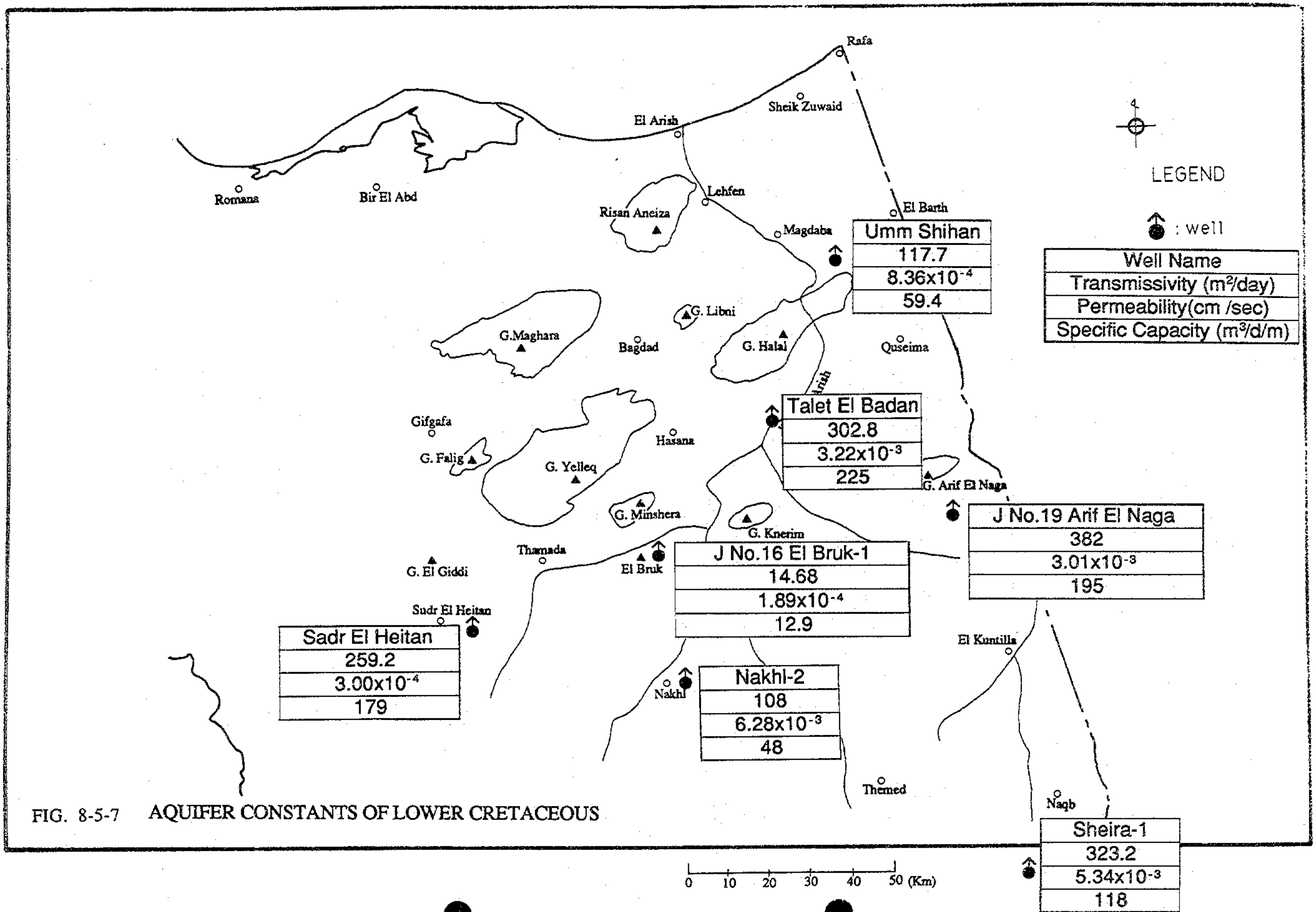


FIG. 8-5-7 AQUIFER CONSTANTS OF LOWER CRETACEOUS

In general, the maximum draw down is small at these wells. The maximum draw down is observed at well J No. 16 El-Bruk-1 (54.5 m against 700.8 m^3/day discharge). The rest of the wells show the draw down in a range between 2.5 and 30 m against discharge ranging between 480 and 2,000 m^3/day/m.

Although the specific yield of the well at El-Bruk is small, the specific yield of the rest of the wells range between 48 and 225 m^3/day/m which indicates that the productivity of these wells is satisfactory. The small value of the specific capacity of the well El-Bruk may suggest an influence of the geological structure on the hydrogeological conditions due to location of fault.

The groundwater is assumed to be old. According to the dating by ^{14}C, the age of the groundwater is in a range between 22,000 and 30,000 Y.BP and the age of the groundwater at J No. 19 Arif El-Naga is estimated to be more than 34,780 Y.BP (Table 8-5-6).

The result of the age determination of the groundwater in the sandstone aquifer of the Lower Cretaceous was made previously by Issar et al. in 1981, which gives the same range of the groundwater age (Section 6-4, Technical Repot 1). It may suggest that the recharge of the groundwater occurred during the Pleistocene.

The age of the groundwater at Arif El-Naga (> 34,780 Y.BP) is probably caused by spatial condition of geological structure due to the dome structure and the effect of the fault so that the water is presumably in a stagnant condition and the TDS of the well water sample shows a high value (3,000 ppm).

Table 8-5-6
Age of Groundwater in Lower Cretaceous

Well name	Laboratory reference number	Age(Y.BP)
J No. 16 El Bruk-1	Gak-15769	29,690 ± 1,190
J No. 19 Arif El-Naga	Gak-16033	>34,780
Sheira-1	Gak-16032	22,350 ± 2,160
El Meleiz 1	Gak-14808	29,960 ± 1,680
El Meiz 2	Gak-14809	22,790 ± 870

8-6 Jurassic

8-6-1 General

The Jurassic formations found in North Sinai are the Upper Jurassic and the Middle to Lower Jurassic formations. The Middle to Lower formations are represented by sandstone and shale interbedded by thin coal beds. Rock salt is found in the coal mine. The Upper Jurassic formation is represented by limestone. These formations are found in the dome structures in the study area. The wells sunk into the aquifer in these formations are found only in Gebel Maghara area (Fig. 8-6-1).

There are ten wells confirmed by the composite columns in the study area. The majority of these well are distributed in the area around the coal mine and in the northern part of Gebel Maghara. The lithological columns of these wells are shown in Figs. 8-6-2 and 3.

8-6-2 Upper Jurassic

There are seven wells sunk into the aquifers in the limestone of the Upper Jurassic formation distributed along the northern fringe of the dome at Maghara. The water levels of these wells in the central part of the northern margin stay in a range between 147 m and 167 m asl (Fig. 8-6-4). The TDS of the water samples of these wells is in a range between 1,650 and 3,450 ppm (Fig. 8-6-5). The yield of these wells varies between 5 m^3/hr and 35 m^3/hr and the larger yield tends to indicate a lower TDS.

On the other hand, the water levels of the wells distributed on the western and the eastern ends of the northern fringe of the dome indicate higher levels: 210 m - 232 m asl. The TDS of water samples of these wells fall in a range between 3,600 and 3,800 ppm.

The origin of the groundwater in the Upper Jurassic formation is assumed to have been recharged at the northern fringe of the dome.

8-6-3 Middle to Lower Jurassic

There are three wells sunk into the aquifer of the sandstone of the Middle to Lower formation. The water levels stay at a similar level between 301 and 305 m asl (Fig. 8-6-4). However, the TDS of water samples vary area a wide range between 4,140 and 7,400 ppm (Fig. 8-6-5). The yields of these wells are in a range between 3.8 and 5.8 m^3/hr, and the TDS of the groundwater rapidly increases as the pumping goes on. In addition to the small yield, the draw down is rather high (15 m - 25 m).

At present, the groundwater in the aquifer of the Middle to Lower formation is assumed not to be productive both in qualitative and quantitative aspects.

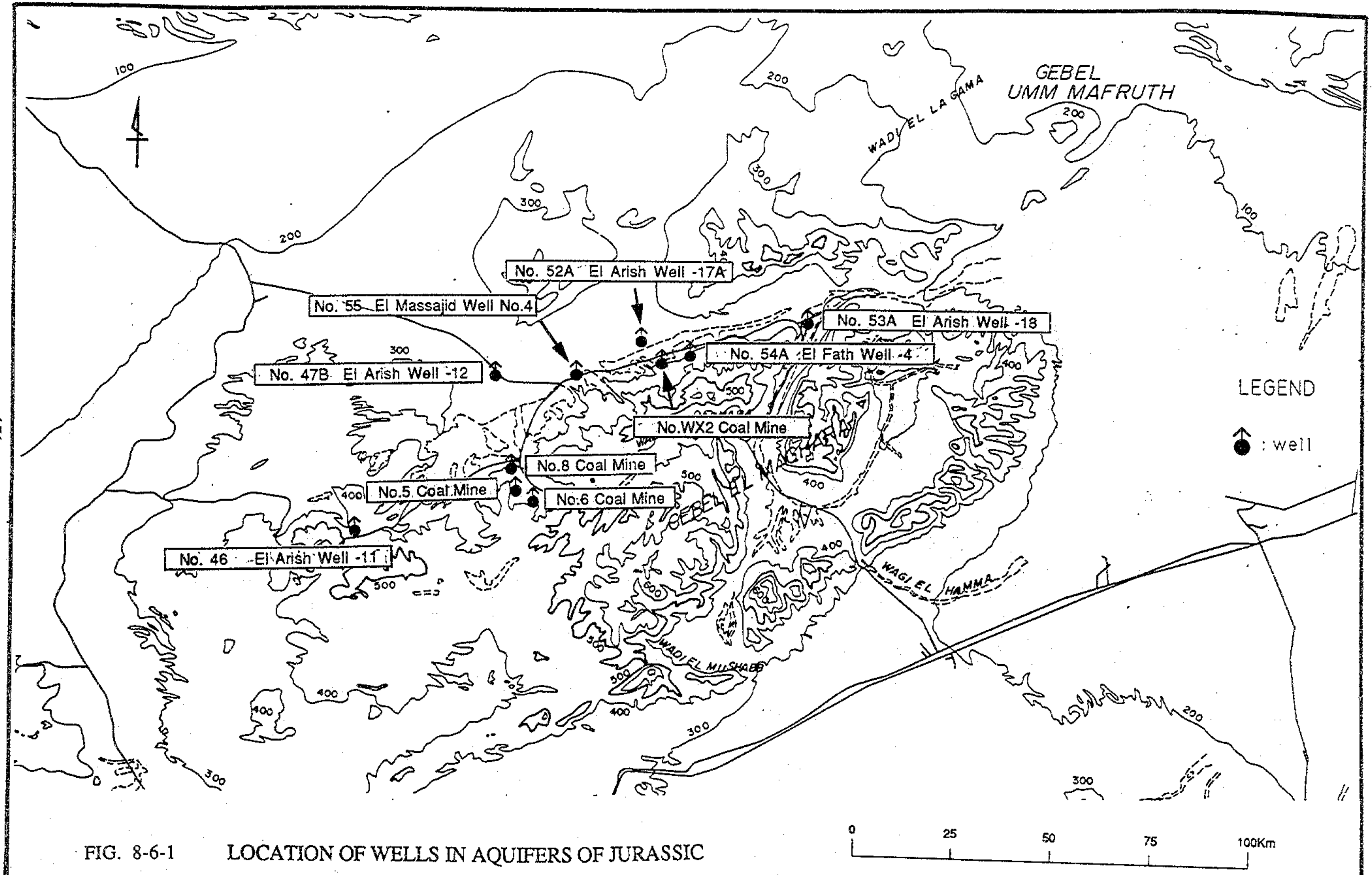
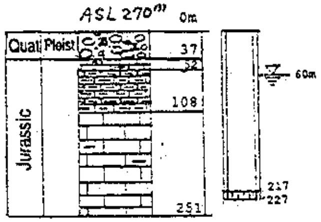


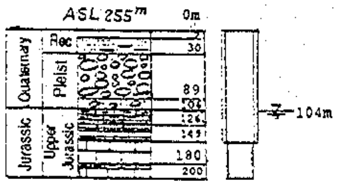
FIG. 8-6-1 LOCATION OF WELLS IN AQUIFERS OF JURASSIC

No. 46
El Arish Well -11



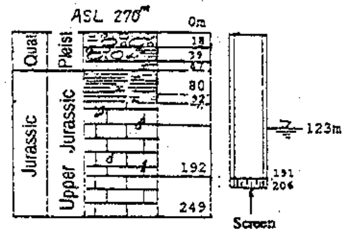
Grid : K4
W.L. : 210 m ASL
TDS : 3,600 ppm

No. 47B
El Arish Well -12



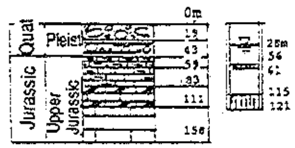
Grid : K4
W.L. : 151 m ASL
TDS : 1,650 ppm

No. 52A
El Arish Well -17A



Grid : K4
W.L. : 147 m ASL
TDS : 3,450 ppm

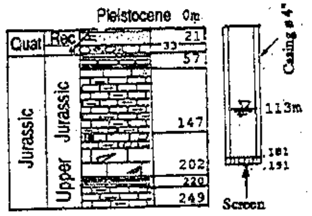
No. 53A
El Arish Well -18



Grid : K4
W.L. : 232 m ASL
TDS : 3,810 ppm

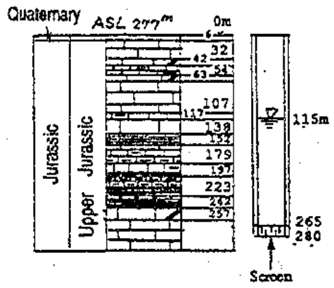
FIG. 8-6-2 (1) WELL OF UPPER JURASSIC FORMATION (1)

No. 54A
El Fath Well -4



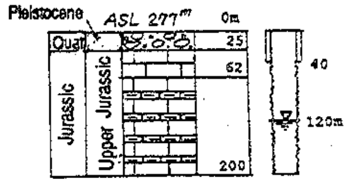
Grid : K4
W.L. : 167 m ASL
TDS : - ppm

No. 55
El Massajid Well No.4



Grid : K4
W.L. : 162 m ASL
TDS : 2,800 ppm

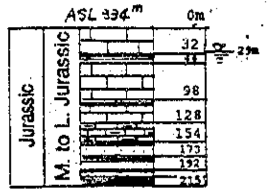
No.WX2
Coal Mine



Grid : K4
W.L. : 157 m ASL
TDS : 2,700 ppm

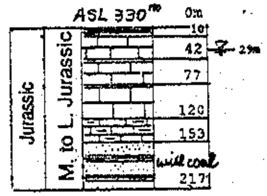
FIG. 8-6-2 (2) WELL OF UPPER JURASSIC FORMATION (2)

No.5 Coal Mine



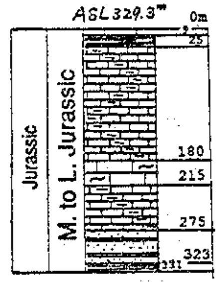
Grid : K4
W.L. : 305 m ASL
TDS : 4,140 ppm

No.6 Coal Mine



Grid : K4
W.L. : 301 m ASL
TDS : 7,300 ppm

No.8 Coal Mine



Grid : K4
W.L. : - m ASL
TDS : 7,455 ppm

Note M. to L. : Middle to Lower

FIG. 8-6-3 WELL OF MIDDLE TO LOWER JURASSIC FORMATION (3)

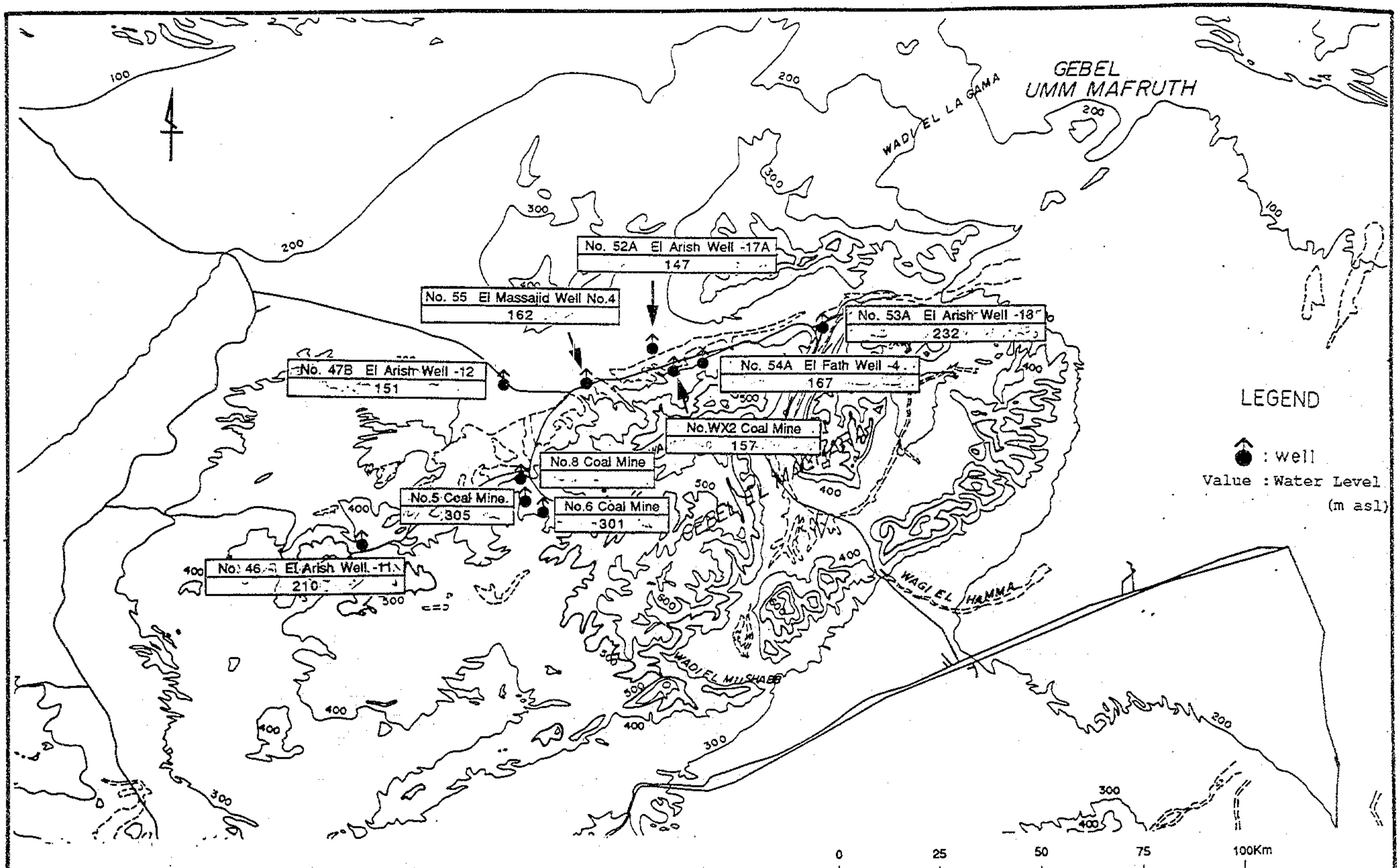


FIG. 8-6-4 WATER LEVEL OF WELLS IN JURASSIC

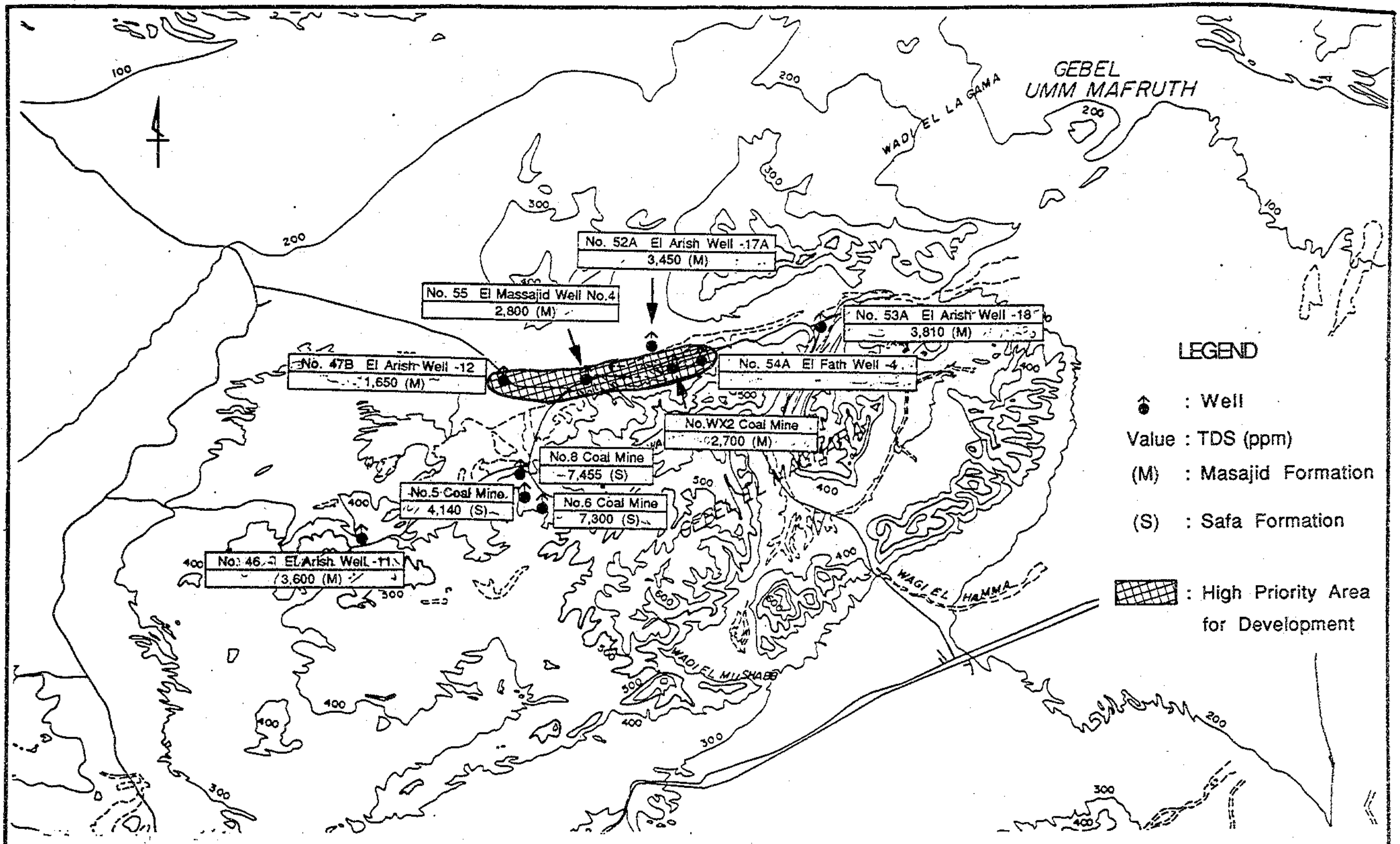


FIG. 8-6-5 WATER QUALITY OF WELLS IN JURASSIC

9 EVALUATION OF GROUNDWATER RESOURCES

9-1 Introduction

Based on the hydrogeological analysis of the all aquifers in the various formations, the prospecting aquifers are evaluated.

The most promising aquifers are found in the Quaternary and the Lower Cretaceous. The major concern in the aquifer in the Quaternary is to prevent seawater intrusion in the well field extensively utilized at present and further data collection will be urgently required in the coastal plain from El-Arish to Sheik Zuwayid for development of an additional well field.

Distribution of favourable aquifer of the sandstone of the Lower Cretaceous is identified and the total volume of the groundwater storage in favourable conditions is estimated at 30×10^9 m^3.

Discussions are made for future study of the aquifers in the Tertiary, the Upper Cretaceous and Jurassic formations. These are considered to be the second priority aquifers compared to those in the Quaternary and the Lower Cretaceous; however, the final conclusion is subject to further study.

9-2 Quaternary Aquifer

The Quaternary formation, with prospecting aquifers, extends for 30 km in the coastal plain from El-Arish to Rafah with widths ranging between 10 and 15 km along the coast. Its thickness is estimated to be 80 to 100 m. The thickest part is 120 m. However, the base level of the Quaternary in the area is estimated by the interpretation of resistivity survey so that further conformation is required before the final conclusion (Fig. 8-2-9).

The western limit of this Quaternary formation is still subject to future confirmation. However, according to the test well results on the western side of El-Arish, it is assumed that this formation extends beyond El-Arish town.

A schematic cross section of the Quaternary in a NS direction is shown in Fig. 8-2-13. Kurkar is underlain by the Pre-Quaternary consisting mainly of shale. However, sandstone or limestone are encountered at some places

(Section 7-2-2 and 3, Technical Report I). Although the kurkar is assumed to occupy most of the bottom of the Quaternary in this area, it is absent in some areas (Section 6-2). The sand dune is underlain by old beach sand overlying kurkar. Clay and gravel beds are interbedded in these sandy formations in various thickness and varying scales.

The gravel is assumed to be old wadi deposits, incising the sandy formations in the N-S. Distribution is assumed to be limited. In general, the water levels of the wells having gravel beds in their profiles stay below the gravel bed. Therefore, it is thought that the gravel beds in this Quaternary formation are of no importance from a hydrogeological point of view (Fig. 8-2-7, Section 7-2).

The elevation of the gravel bed in the Wadi El-Arish deposits is low so that the lower half of the gravel is within the piezometric potential surface of the underlying kurkar aquifer. For this reason there are some wells having screens installed at the gravel bed (Fig. 6-2-6, Section 6-2).

Where kurkar is overlain by thick clay, a confined aquifer occurs in kurkar as shown in Fig. 8-2-9. However, where the extension of the clay bed is limited, the hydraulic continuity is maintained between kurkar and the aquifer of the overlying Quaternary and the water level is determined by the piezometric potential of the kurkar aquifers shown in Fig. 8-2-8 and 11. In general, the piezometric potential level is assumed to be determined by the hydraulic head of the kurkar aquifer as far as the aquifer is not isolated from kurkar by a certain aquiclude..

The aquifer in the coastal sand dune is thought to be the one isolated from the kurkar by clay (Fig. 7-2-9).

Total extraction of the groundwater from the well field of El-Arish and of the coastal plain between Sheikh Zuwayid and Rahaf is estimated to be 51,000 m^3/day and 39,000 m^3/day, respectively. Due to the heavy pumpage in these well fields there is an assumed decrease in the water levels. The recession of the water level at some part of the well field in the western side of El-Arish has exceeded 4 m since 1962 (Fig. 8-2-21).

The heavy extraction also resulted in deterioration of the water quality at many wells (Section 4-2-5, Technical Report I). According to the comparison of the TDS between 1962 and 1988 at wells where TDS records are available, there are two groups of wells. In the first group, a remarkable change in TDS is observed, but in the second group, the TDS remained at the same level during this period in spite of a heavy extraction of groundwater (Table 8-2-5 and 6). The TDS of the second well group is rather high compared to the first group which has remarkably increased TDS during this period. This may be attributed to the fact that the aquifer in this Quaternary formation belongs to one unit in a broad sense. The wells of the second group have conditions similar to well J No. 7. These wells where the TDS have increased are in the same situation as well No. SR 6 (See Fig. 8-2-8).

A significant recession of groundwater level took place at grids No. 4-3 and 5-2 on the western side of El-Arish Town (more than 4 m). The lowered water level at grids No. 7-5 and 8-5 in the well field of the Wadi El-Arish alluvial plain exceed 3 m (Fig. 8-2-21).

This recession of the groundwater level is most probably caused by the heavy pumpage especially during the 1980's. As shown in Fig. 8-2-24, there is heavy pumpage in many grids: The highest extraction of groundwater in the well field at El-Arish was observed at grid No. 6-3 (6,150 m^3/day). The groundwater extraction rate exceeds 2,000 m^3/day at seven grids. This heavy groundwater extraction was observed in areas southwest and southeast of El-Arish town.

Assumptions were made that the recession of the groundwater level is caused by over extraction compared to inflow into the aquifer where the over extraction is taking place.

Although available data are limited in 15 km^2 of the well field in the the Wadi El-Arish, this area is the central part of this well field. The estimated annual recharge is in a range between 94 mm/year and 876 mm/year which exceeds the total depth of an average annual rainfall. The estimated recharge exceeds 800 mm/year at grids No. 8-2 and 9-3, although the estimated annual recharge at grids 7-7, 9-2 and 10-4 is less than 200 mm/year. In the remaining grids, it is in a range between 200 mm/year and 80 mm/year. Considering the magnitude of this recharge it should be ascribed to the inflow of groundwater from other aquifers into these Quaternary aquifers (Fig. 9-2-1).

The grids where high inflow is indicated coincides with the grids indicating high TDS of the groundwater (grid 8-2, 8-4 and 9-3) (Fig. 8-2-25). The TDS at grids No. 8-2 and 9-3 was also high even in 1962 (3,200 ppm and 4,000 ppm respectively) (Fig. 4-2-7, Section 4-2, Technical Report I). Accordingly, it is assumed that the hydrogeological conditions at these two grids have been greatly influenced by the wells similar to the well in the semiconfined kurkar aquifer shown in Fig. 8-2-13. Hydrogeological conditions of these wells have been characterized as being of high salinity since 1962, and have a high yield and high inflow of groundwater from outside.

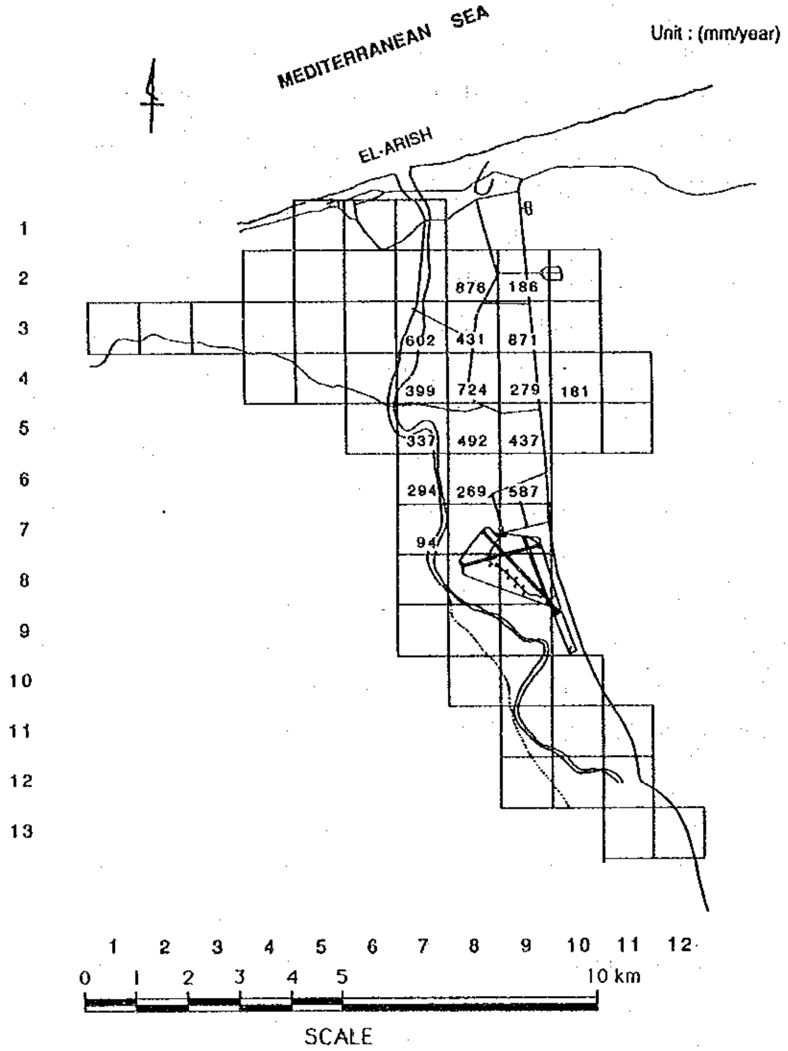


FIG. 9-2-1 ESTIMATED RECHARGE AT EL - ARISH AREA

On the other hand, grids No. 8-4 and 9-6 are assumed to be influenced by wells having the same situation as the well in the other Quaternary deposits other than kurkar as shown in Fig. 8-2-13. The hydrogeological conditions are characterized by a remarkable increase in TDS since 1962, high yield and high inflow of groundwater. The TDS of the grid No. 8-4 was 2,500 ppm in 1962 and increased to 3,300 ppm in 1988. The yield is estimated at 3,210 m^3/day.

The most broadly extending Quaternary aquifer is developed in kurkar. And the TDS of groundwater in the kurkar aquifer is in a range between 2,500 ppm and 3,800 ppm in the well field in the Wadi El-Arish alluvial plain and between 3,500 ppm and 5,600 pm in the well field in the coastal plain from El-Arish to Rafah (Table 8-2-3).

The difference in these two ranges of TDS may be caused by the influence of flash floods which occur once every 10 to 15 years. Although its occurrence is very rare, the highly saline groundwater of the aquifer in the Quaternary deposits may be diluted to a certain extent in the well field in the lower stretch of the Wadi El-Arish, while there is little opportunity to recieve recharge at coastal plain from El-Arish to Rafah due to clayey beds overlying kurkar..

According to the C-14 dating, the age of groundwater at wells No. 1-123 and 1-119 are estimated to be 8,620 ±420 and 6,770 ±290Y.BP, respectively. These wells are located on the eastern end of the alluvial plain. While the age of groundwater at wells No. 1-75 and 1-64, located on the eastern bank of the Wadi El-Arish are estimated to be 1,730 ±140 and 4,390 ±240Y.BP, respectively which may suggest influence of recharge in the current climate.

On the other hand, kurkar in the coastal plain, where these test wells with high salinity were drilled, is overlain broadly by clay, so that the TDS of groundwater in this aquifer may maintain its original level.

However, the extent to which groundwater in the aquifer of kurkar in the alluvial plain of the Wadi El-Arish could be diluted, is thought to be limited as shown in the age of the groundwater. This means that the recharge by fresh water, under the current hydrometorological conditions, to the aquifers in the coastal plain, is limited only to a certain extent.

Accordingly, when over extraction of groundwater takes place, groundwater with the original low TDS that is stored in the aquifer in the Quaternary deposits other than kurkar as fresh water lense may easily be exhausted and replenished by the groundwater which had been stored in the kurkar aquifer.

Therefore, to prevent an increase in TDS of groundwater, the allowable extraction must be within the amount of the recharge of the current climate. However, it would be limited to a very small amount considering the amount of rainfall. For this reason it is unable to prevent the increase in the TDS, and the ultimate level of the TDS would be the level of the original TDS of kurkar or that of the mother aquifer providing the groundwater to the kurkar aquifer..

However, over extraction may easily cause the recession of the groundwater level. Although there is no proof of seawater intrusion, it may occur immediately when the recession of the water level exceeds a certain level. To prevent further deterioration, the safe yield for preventing seawater intrusion must be determined.

The safe yield to prevent water level recession could be estimated by referring to the estimated inflow rate. Take grid No. 8-1 for instance, the annual inflow rate is 876 mm/year and the surface area of the grid is 1 x 10^6 m^2 so that the total amount of the groundwater extraction is 0.876 mm x 10^6 = 876,000 m^3/year, which is equivalent to 2,400 m^3/day. Present extraction at this grid is estimated at 2,680 m^3/day (Fig. 8-2-24).

Comparing the pumpage rate and the recession of the water level, an annual recharge rate is estimated as shown in Fig. 2-7-29 (Section 8-4, Technical Report). In the same manner, the safe yield for preventing the groundwater level recession is estimated in the rest of the grids where necessary data is available (Table 9-2-1):

Table 9-2-1

Safe Yield for Preventing Water Level Recession

Grid number	Safe yield (m^3/day)	Present extraction (m^3/day)
7-3	1,650	1,870
7-4	1,090	1,330
7-5	920	1,070
7-6	810	1,000
7-7	30	460
8-2	2,400	2,580
8-3	1,180	1,250
8-4	1,980	3,210
8-5	1,350	1,520
9-2	740	800
9-3	510	510
9-4	2,390	2,490
9-5	760	890
9-6	1,610	1,619
10-4	500	570

Major groundwater sources in the Quaternary in the coastal plain from El-Arish to Rafah is in kurkar. Assuming the distribution of kurkar to be 10 km wide and 30 km long with an average thickness of 10 m, the total volume of kurkar is estimated to be 3,000 million m^3. Taking an effective porosity of 0.25, the amount of total storage in the kurkar aquifer is approximately of 750 million m^3.

As calculated elsewhere, the total extraction of groundwater in these well fields (El-Arish and the coastal plain) is estimated to be 90,000 m^3/day (Chapter 8, Technical report I). When this amount of extraction continued for 8 years from 1981 to 1988, the total extraction was 262.8 million m^3 which is an enormous amount, considering the total volume of the storage in the kurkar aquifer (750 million.m^3). This may suggest that there would be groundwater inflow into the Quaternary aquifer from some other older formations since limestone and sandstone of the Pre-Quaternary are in contact with kurkar (Section 7-2, Technical Report I). It should be clarified how these aquifers of the Pre-Quaternary are implicated with the Quaternary aquifer in the vicinity of the coastal plain.

9-3 Tertiary Aquifer

9-3-1 Aquifer in Miocene

The formations assigned to this age are distributed in the coastal foreshore area. The lithology is represented by shale and clay with interbedded sandstone and limestone. Aquifers are contained in these sandstone and limestone in the coastal foreshore. The aquifer developed in the sandstone is represented by well J No. 9 El-Massora and the one in the limestone by well Misri-1. These two are the only wells of this type of aquifer at present (Section 8-3-2).

Table 9-3-1
Wells in the Miocene Aquifer

Well number	Depth to water (m BGL)	Depth to aquifer (m BGL)	TDS (ppm)
J No. 9 Massora	68	76	3,470
Misri-1	27	141	10,450

It is important to collect further information about this aquifer, since this formation is overlain by the Quaternary and the TDS of the groundwater in the aquifer is in a high range. There is an indication which may suggest the up-coning of the groundwater of the aquifer in the Miocene into the aquifer in the Quaternary (Section 8-2).

The hydrogeological properties of the groundwater in the Miocene aquifer are unknown at present. Although the groundwater is available at a shallow level from the ground surface, development of this aquifer would be of insignificant importance since its TDS is assumed to be high. However, additional data collection of this aquifer is required to clarify the influence of this aquifer on the Quaternary aquifer, especially in the coastal plain.

9-3-2 Aquifer in Eocene

The Eocene is represented by limestone and marl distributed in the area south of the line combining Risan Aneiza and Gebel Maghara. A large scale outcrop is found in the areas listed below:

Quseima area
Hasana
The northwest of Gebel Giddi
The area south of the line between Gebel Minshera and Gebel Kherim

These formations are distributed independently in each area and aquifer develops in the limestone (Section 8-3-2).

There are three wells sunk into the aquifer of the Eocene;

Table 9-3-2
Wells in the Eocene Aquifer

Well number	Depth to water (m BGL)	Depth to aquifer (m BGL)	TDS (ppm)
El-Mewaleh No.1	47	23	-
El-Arish well No. 10	95	22	5,200

Hydrogeological data of this type of aquifer remain scarce. However, the depth to the water level and the aquifer is rather shallow in the above cases, and the groundwater is outcropping at Ain Gudeirat. The yield is estimated at 1,500 m^3/day and the TDS is 1,440 ppm..

Two wells are dug in the area 10 km south of Ain Gudeirat. These wells are extracting water at the boundary between the Esna shale and the overlaying Eocene limestone.
Priority for the future study on this aquifer should be given to the area on the northern side of the line combining Nakhl and Themed, since the geological setup is similar to that in Ain Gudeirat.

9-4 Upper Cretaceous Aquifer

9-4-1 Aquifer in Senonian

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

The aquifers develop in the limestone of both of the upper and the lower Senonian. These limestones are partly porous, although it is lithologically compact. So, the groundwater is stored in the joints or fissures (Section 8-4-2).

There are three wells sunk into this type of aquifer;

Table 9-4-1 Wells of the Senonian Aquifer

Well number	Depth to water (m BGL)	Depth to aquifer (m BGL)	TDS (ppm)
Wadi El-Maleiz 1	157	97	8,480
El-Arish well No. 14	?	140	2,200
Gebel Libni No. 1	205	132	4,500

Based on the above data there is a possibility of developing this aquifer along the Wadi El-Arish where the water with low TDS is available. Otherwise the TDS would be too high.

9-4-2 Aquifer in Turonian

The Turonian is represented by the foraminifera rich limestone with shale at the base. This bed is distributed in the area around Kuntilla and in the area to the west from Arif El-Naga (Section 8-4-3).

The aquifers develop in the limestone. There are three wells which are assumed to be sunk into the Turonian aquifer at Hasana No,50, Naqb No.3 and Sheira-2. However, the well drilled at Naqb and Hasana require further confirmation of their details. The TDS of these wells are more than 7,000 ppm.

The water level at well Sheira-2 is at 81 m below the ground surface and the depth to the aquifer is 149 m. The TDS of this well is 1,100 ppm. According to the pump test, the physical parameter of this aquifer is;

$T = 0.94\ m^2/day$
$Sc = 2.01\ m^3/day/m$

Although the salinity of the groundwater is high in the aquifer of the Turonian in the North Sinai, further confirmation will be necessary for the final decision. The aquifer of the Turonian in the southern part of Ragabet El-Naam Fault is assumed to be productive with a low TDS value. However, further data collection will be required since the physical parameters of the aquifer are favorable and the TDS value of the groundwater at well Sheira-2 is the lowest among all groundwaters of the Pre-Quaternary aquifers in the study area.

9-4-3 Aquifer in Cenomanian

This formation is distributed over the study area except at domes. 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.

The aquifer develops in the limestone. There are five wells sunk into the aquifer of the Cenomanian limestone (Section 8-4-5). The depth to the aquifer is in a range between 150 m and 516 m, and the top of the aquifer is shallow in the area near the dome. The depth to the water level is in a range between 35 m and 219 m, and the water level is shallow in the area around El-Amro.

The TDS is distributed in a range between 1,800 ppm and 5,600 ppm. A relatively low TDS value was observed in the area of Hasana and Gifgafa.

The transmissivity of this type of aquifer is in a wide range between 75 m^2/day and 4,500 m^2/day. A large value of transmissivity was observed at Hasana and El-Bruk. The lowest value was at Gifgafa. It seems that the aquifer in the Cenomanian produces groundwater with relatively low TDS. The largest transmissivity was observed at Hasana. Further testing will be necessary to confirm the property of the aquifer in the area of Hasana.

9-5 Lower Cretaceous Aquifer

This formation is distributed throughout most of the study area. However, the facies changes to limestone in the northern part (Fig 8-5-5, Section 8-5). This formation consists of porous quartzose sandstone with occasional shale. The content of shale is higher in the north and almost absent in the south.

The thickness of the formation varies from place to place; however, in general, it is in a range between 200 m and 300 m. It is very thick at Halal, where it reaches 600 m. Excluding the thickness of the interbedded shale, the thickness of the aquifer of the Lower Cretaceous is estimated to be 200 m.

The TDS of the groundwater of this aquifer is in a range between 1,200 ppm and 3,000 ppm. The high TDS value was observed at the limestone facies (Umm Shihan), and in the area near the dome structure where the geological structure is significantly disturbed. It is assumed that the movement of the groundwater is restricted where the geological structure is significantly disturbed. At Talet El-Badan, an extremely high TDS (5,360 ppm) was observed. It is assumed that the aquifer of the Lower Cretaceous is influenced by the highly saline water in the aquifer of the Upper Cretaceous due to the reverse fault in the area. The same situation may occur in Minshera and Arif El-Naga where the reverse fault was observed.

The TDS of the groundwater in the Lower Cretaceous sandstone aquifer is in a range between 1,200 ppm and 1,500 ppm, where there is no significant disturbance of the geological structure. Such groundwater is found in the area surrounded by Hasana, Nakhl and Kuntilla.

The depth to the aquifer is in a range between 300 m and 1,000 m. It is the deepest in the central part of the study area and most shallow in the area around the dome.

The depth to the water level is in a range between 161 m and 340 m. The shallower water level was observed at the central part of the study area and the deeper water level was observed at Quseima, Kuntilla and Sudr El-Heitan. The water level is also deep at Sheira on the southern side of the Ragabet El-Naam Fault.

The transmissivity of the sandstone of the Lower Cretaceous is in a range between 12 m^2/day and 400 m^2/day. The smaller value of transmissivity was observed in the area near domes where there is significant structural disturbance. The higher value of transmissivity was observed in the area where no significant structural disturbance was observed. Such an area occupies a broad area in the central part of North Sinai (Chapter 5, Technical Report I).

The Specific capacity at Sheira-1, is 118 m^3/day/m and the draw-down is only 4.5 m.

The thickness of the aquifer is an important parameter for the evaluation of the aquifer. The aquifer of the sandstone of the Lower Cretaceous has high transmissivity in the broad area where there is no significant disturbance of the geological structure. In this respect, the thickness of the aquifer is of no significant importance since the transmissivity includes the concept of the thickness of the aquifer.

From the viewpoint of water usage, important parameters for evaluating the aquifer of the sandstone in the Lower Cretaceous are the TDS and the depth to the water. The TDS determines the restriction of the water use and the depth to the water determines the operation cost of the water source.

For this reason, the TDS and the depth to the water are taken as parameters for evaluating the groundwater of the Lower Cretaceous aquifer. The contour map of the TDS is meshed over the contour map of the depth to water level, as shown in the groundwater evaluation map. It should be noted that this evaluation is based on the assumption that the base map of TDS and depth to water level indicate the general feature of these aspects of the groundwater in the sandstone aquifer of the Lower Cretaceous (Table 9-5-1).

Table 9-5-1 Evaluation of Aquifer in the Lower Cretaceous

TDS (ppm) \ Depth to Water (m)		1 Less than 100	2 100 ~ 200	3 200 ~ 300	4 More than 400
A	Less than 1,500	A1	A2	A3	A4
B	1,500 ~ 2,000	B1	B2	B3	B4
C	2,000 ~ 2,500	C1	C2	C3	C4
D	More than 2,500	D1	D2	D3	D4

The area indicated as A1 shows that there is a high possibility of obtaining groundwater having a TDS less than 1,500 ppm within 100 m from the ground surface. However, exact conditions are subject to further confirmation. The areas indicated by B1, B2, B3, C4 and D3 are also in the same situation since these are narrow areas circumscribed by two kinds of contour lines.

It is found that a broad area surrounded by Hasana, Sudr El-Heitan, Nakhl and Arif El-Naga is classified as A2. A2 is categorized as the area where the groundwater of the sandstone aquifer of the Lower Cretaceous is obtainable at the water level between 100 m and 200 m from the ground surface, with TDS less than 1,500 ppm, except the area around domes where there is significant disturbance of the structure. The first priority for groundwater development shall be given to this area; its boundary shall be verified by actual well data..

Area A3 is A2's surrounding area. The TDS of the groundwater is expected to be the same magnitude as A1's. However, the depth to the water is expected to be deeper, in a range between 200 m and 300 m. The area under this category is found around Sudr El-Heitan, Nakhl and Quseima.

In area A4, the depth to water is more than 300 m although the TDS of the water is expected to be less than 1,500 ppm.

The rest of the area may produce water with a high TDS. It is assumed that the high TDS is caused by structural disturbance which restricts water movement. This is also subject to further confirmation by sufficient information.

With all this information, it is proposed to place a high priority on the areas classified as A1 and A2. Immediate investigations shall be made of the area listed below:

Hasana
Surrounding areas of Gebel Kherim
Quseima
Kuntilla
El-Themed

In addition, the sandstone of the Lower Cretaceous is distributed broadly in the study area. It extends beyond Regabet El-Naam Fault which is assumed to be a barrier of the groundwater movement in the sandstone of the Lower Cretaceous. The importance of the aquifer in the southern side of the fault is that it is part of the sandstone aquifer assumed to be the source of the groundwater to the north. For this reason, it is necessary to determine the function of the aquifer in the southern side of the fault within the entire aquifer system of the sandstone of the Lower Cretaceous.

Fig. 9-5-1 WATER RESOURCES EVALUATION MAP

TDS (ppm) \ Depth to Water (m)		1 Less than 100	2 100~200	3 200~300	4 More than 300
A	Less than 1,500	A_1	A_2	A_3	A_4
B	1,500~2,000	B_1	B_2	B_3	B_4
C	2,000~2,500	C_1	C_2	C_3	C_4
D	More than 2,500	D_1	D_2	D_3	D_4

9-6 Jurassic Aquifer

The Jurassic formations found in North Sinai are the Upper and Middle to Lower formations. The Middle to Lower Jurassic formation is represented by sandstone and shale interbedded by thin coal beds. Rocksalt is found in the coal mine in Maghara. The Upper Jurassic formation is represented by limestone. These formations are found in the dome structures in the study area. The wells sunk into the aquifer in these formations are found only in the Gebel Maghara area.

The aquifer develops in the limestone of the Upper Jurassic formation, and the depth to the aquifer is in a range between 111 m and 265 m from the ground surface. The depth to the water is in a range between 28 m and 123 m from the ground surface. Although the TDS is in a wide range between 1,650 ppm and 3,800 ppm, the yield is relatively high in a range between 120 m^3/day and 840 m^3/day.

At present, these wells are found only in the area at Gebel Maghara. The TDS of the groundwater in this type of aquifer is at a high level, so there is a high possibility of contamination of the low TDS water in the sandstone aquifer by the high salinity water in the underlying limestone aquifer since hydraulic continuity between the two aquifers is assumed.

The aquifer of the Middle to Lower Jurassic develops in the sandstone distributed in the dome at Gebel Maghara. Depth to the aquifer is in a range between 153 m and 275 m. However, depth data is very scarce and are available only at the coal mine at Gebel Maghara (29m from the ground surface).

The TDS is rather high, ranging between 4,140 ppm and 7,455 ppm. This is assumed to be one of the characteristics of this groundwater, since rocksalt is occasionally interbedded in this formation.

10 PROPOSED GROUNDWATER DEVELOPMENT

10-1 Introduction

Through the study, many facts about the hydrogeology in the study area were found. There are also many items that are subject to further confirmation. In the following part of this chapter additionally required study items are summarized followed by the recommended groundwater development. Additionally, general technical considerations that will be useful in the future investigation of the hydrogeology are briefly described. Also, required study items are summarized followed by the recommended groundwater development.

10-2 Priority and Proposed Groundwater Development Sites

10-2-1 Quaternary Aquifer

The Quaternary aquifer has been intensively utilized especially in the well field at El-Arish and in the coastal plain from Sheikh-Zuwayid and Rafah. In these areas, the Quaternary aquifers are subjected to strict control to prevent further recession of the water level rather than further development. It is of utmost importance to determine the safe yield in each locality of the aquifer to control the extraction amount of groundwater to prevent seawater intrusion.

For this purpose, an establishment of a monitoring network for the Quaternary aquifer is urgently required, utilizing the existing test wells as a part of the monitoring network.

However, since a thick Quaternary formation was identified in a vast area extending in the coastal plain from El-Arish and Sheikh Zuwayid, confirmation of the extension of the aquifer and its hydrogeological properties shall be studied immediately.

Also, determination of the hydrogeological mechanism and properties of the aquifer in the coastal sand dunes is urgent. The same type of aquifer will be available even in the coastal sand dune on the western side of El-Arish.

10-2-2 Pre-Quaternary Aquifer

There are two concepts for determining the priority and proposed groundwater development sites:

1) Priority for immediate development and

2) Priority for evaluation of the groundwater.

For immediate development of the groundwater priority should be given to the sites which meet the following conditions:

1) TDS is satisfactorily low,
2) Depth to the water is small,
3) Demand of the water is high, and
4) Easy access to the site.

The areas which meet these requirement are those where the aquifer of the sandstone of the Lower Cretaceous is available and classified as A1, A2 and A3 in the groundwater evaluation map (Portfolio sheet No. 23)

A1 area

The area near Hasana where the groundwater is possibly available at the water level less than 100 m from the ground surface with TDS less than 1,500 ppm. This site is easily accessible from El-Arish.

A2 area

The area around Hasana surrounding A1. The depth to the water is assumed to be between 100 m and 200 m from the ground surface.

The area around Nakhl where well No. Nakhl-2 exists having a TDS of 1,200 ppm. This is a terminal point of the west-east highway.

The area between Minshera and El-Bruk has similar conditions to those of the above two areas.

A3 area

The area at Sheira falls on this category where the groundwater is available at 320 m from the ground surface with a TDS of 1,500 ppm. Accessibility and water demand are satisfactory in this area. However, the depth to the water and TDS shall be compared with the water from the aquifer of the Turonian of the Upper Cretaceous.

10-3 Recommendation for Groundwater Development

10-3-1 Quaternary Aquifer

The Quaternary aquifers have been intensively utilized especially in the well field at El-Arish and in the coastal plain from Sheikh Zuwayid to Rafah. In these areas, the Quaternary aquifers are subject to strict control to prevent further recession of the water level rather than further development. It is of utmost importance to determine the safe yield of the aquifer to prevent sea water intrusion.

Through the study, it was revealed that the Quaternary aquifers extend to the coastal plain between El-Arish and Sheikh Zuwayid. These aquifers should be studied in greater detail because they were found only by the virtue of the resistivity survey.

This coastal plain is the prospecting area for groundwater development. Important items to be recommended in the development are summarized as follows:

(1) The Isopach Map and Isobase Map of Quaternary should be confirmed and revised by further study, especially by drilling.

(2) The safe yield for preventing water level recession should be determined based on the observation of the groundwater level change.

(3) The nature and distribution of the groundwater should be analyzed based on the water quality analysis, especially the TDS value and ion content.

(4) The groundwater recharge system should be investigated on the basis of the C-14 Dating result, water quality analysis and water level observation.

(5) Attention should be paid to the underlying Tertiary aquifers in the drilling study because they are supposed to supply groundwater to the Quaternary aquifers.

(6) Continuous observation of water level change and water quality should be carried out to examine the influence to the existing well field by the new groundwater development.

10-3-2 Pre-Quaternary Aquifer

(1) In the Pre-Quaternary aquifer, the following two aquifers are presently applicable for groundwater development:

- The aquifer in the sandstone of the Lower Cretaceous
- The aquifer in the limestone of the Turonian at Sheira area.

(2) For groundwater development, careful consideration should be given to these aquifers since they contain fossil water.

(3) The Hydrogeological Map and the Groundwater Evaluation Map are available for selecting the development area of the sandstone of the Lower Cretaceous.

(4) The A1 and A2 areas in the Groundwater Evaluation Map have high priority for development. Considering the development in the entire area of North Sinai, A3 area should be included in the groundwater development planning and for future study.

(5) The well screen should be installed strictly in the sandstone of the Lower Cretaceous because groundwater of other aquifers has a high TDS value. This method of installation prevents deterioration caused by groundwater salinity except in the Lower Cretaceous.

(6) As mentioned in Item 9-3-2, the water quality analysis and C-14 Dating should be performed to determine the water quality distribution and to interpret the mechanism of the groundwater recharge. The interpretation will be helpful when preparing the groundwater development plan, because the groundwater of Pre-Quaternary aquifer is fossil water.

10-4 Additional Studies Required

10-4-1 Quaternary Aquifer

The extension of the Quaternary formation which may include prospecting aquifers, is assumed to extend in the coastal plain from El-Arish to Rafah. However, its thickness and limit of its southern end is estimated by interpretation of the resistivity survey and general geology. Confirmation of the extent of the quaternary aquifer in this area will be urgently required since the size of the area is significant.

It is also urgent to confirm the limit of the above mentioned Quaternary in the west beyond the El-Arish town.

It would be urgent to determine the recession of the water level at some selected monitoring wells especially in the well field of El-Arish and in the area around Rafah. Based on the observation of the precise behavior of the water level, the safe yield shall be determined for the control of extraction for preventing seawater intrusion.

Since it is suggested that the groundwater flows from the aquifer of the Pre-Quaternary into the Quaternary aquifer, the location and its behavior shall be identified especially in the area where the the Quaternary formation is underlain by the permeable Pre-Quaternary beds. Identification of the transmissivity and the chemical components of such groundwater in the Pre-Quaternary should be of the first importance.

In addition, the determination of the location and dimensions of the aquifer of the coastal sand dune is urgent since this is the only potable water source. The same type of the aquifer would be expected in the area on the western side of El-Arish town. Necessary measures shall be taken for the conservation of this type of aquifer.

10-4-2 Pre-Quaternary Aquifers

10-4-2-1 Tertiary Aquifer

Although available data is scarce, the groundwater in the Miocene aquifer is assumed to have high TDS (10,450 ppm at well No. Misri-1 and 3,470 ppm at well J No. 9). At the same time, it is suggested that the Quaternary aquifer is supplied with groundwater from the aquifer of the Pre-Quaternary in the coastal foreshore (El-Arish, Sheikh Zuwayid, and Rafah). It would be important to confirm the behavior of these Miocene aquifers where they are overlain by the Quaternary.

As for the Eocene aquifer, additional data will be required to determine its properties since the spring water of the Miocene aquifer at Quseima has a reasonably low TDS (1,440 ppm). This aquifer is located on a plateau and the same geological setup was observed at other places. Investigation of such areas will be required at the sites listed below:

1) The plateau extending to the south from Gebel Risha in Quseima area,

2) The plateau at Gebel El-Shara near El-Kuntilla,

3) Plateau in the south of Nakhl.

The Eocene formations in these area are underlain by the Esna Formation — the hydrogeological setup is similar to Ain Gudeirat at Quaseima. The plateau in the south of Nakhl would be very important since the Eocene bed in this area extends over a broad area in the south.

10-4-2-2 Upper Cretaceous Aquifer

The Senonian is the uppermost formation of the Upper Createceous. The top of the formation is usually at a shallow level from the ground surface which may result in an advantageous situation:

1) Recharge may take place through joints and fissures where there is supply of water,

2) In general, the depth to the water is rather shallow.

The TDS of the groundwater in this type of aquifer is rather high. However, the TDS of the well No. 49 El-Arish No. 19 is 2,200 ppm and it is assumed that this water is diluted by the recharge of the fresh water. Therefore, it is proposed to obtain additional data to confirm the property of the groundwater in the Senonian at selected places near the river channel of Wadi El-Arish.

The groundwater in the Turonian has an extremely high TDS in the northern part of the Ragabet El Naam Fault. However, the TDS at well No. Sheira -2 on the southern side of the fault is favorable (1,100 ppm), and the yield is also promising (95 m^3/day). For this reason, a high priority will be given to determine the property of this type of aquifer, especially in the area to the south of Nakhl in relation to the behavior of the the Lower Cretaceous aquifer.

The Cenomanian is assumed to be distributed over a broad section of the study area. Data is available for five wells of which TDS covers a wide range (between 1,800 ppm and 5,600 ppm). Its importance is subject to the further investigation. However, an aquifer of this type has higher transmissivity where the TDS is relatively low. Such an area is observed around Hasana and Gifgafa.

10-4-2-3 Lower Cretaceous Aquifer

The aquifer of this formation has the most advanced information among aquifers in the study area as shown in the hydrogeological map and portfolio. This is the most promising groundwater source in the North Sinai. Although, a practical development of this aquifer is ready to start, it would be useful to undertake further investigation in the following two categories:

1) To supplement insufficient data,

2) To confirm the mechanism of hydrogeology, and

3) To confirm the conclusion of the evaluation shown in Table 8-1.

Supplementary Data Required

Confirmation of area A1 in the evaluation map. The major water body is assumed to pass the area at Hasan in the course of its movement from the south to the north so that this would be the basis for evaluation of this type of aquifer in both meaning of quantity and quality.

Confirmation of the groundwater flow at Kuntilla is still subject to confirmation. It is assumed that one of the major groundwater flow passes through this area, but no supporting data is available at present neither water quality nor water level.

No data is available in the area around Gebel Kherim that is the central part of a vast data-missing-area in the eastern side of the line between Hasana and Nakhl. Data collection will be urgently required. However, as there is structural disturbance at Gebel Kherim, data collection shall be undertaken in an area 20 km away from the dome.

The data for the Lower Cretaceous are missing in the area around Quseima where it is assumed that one of the courses of the major groundwater flow passing through the southern side of Gebel Halal.

Monitoring system of the groundwater in the sandstone shall be established. Observation shall commence at wells No. J No.16, J No. 19, Sheira-1 and Sadr El Heitan.

Confirmation of Hydrogeological Mechanism

Confirmation of the groundwater flow from south to the north passing through Ragabet El Naam Fault. The major flow is assumed to pass through the area around Nakhl.

Through the study, it is observed that the TDS tends to be higher in the area near domes compared with the TDS in the area where there is no significant disturbance of structure. The reasons and the manner of how this change in TDS take place is subject to further confirmation. Investigation shall be required on detailed change in water quality in relationship with geological conditions.

A high TDS was also observed at an area where a reverse fault was encountered that is similar to that at Talet El-Badan. Confirmation will be required to clarify the interrelationship between the TDS and the effect of the reverse fault, especially at Minshera, El-Bruk, Arif El-Naga and Talet El-Bedan.

10-4-2-4 Jurassic Aquifer

The aquifers of the Jurassic formations are classified in two categories according to the TDS of the groundwater: the aquifer in the Upper Jurassic and the aquifer in the Middle to Lower Jurassic. The aquifer in the Upper Jurassic is available at Gebel Maghara area with the TDS ranges between 950 ppm and 3,800 ppm. Identification of the favorable aquifers will be useful.

11 PROPOSED GROUNDWATER DEVELOPMENT AT NAQB AND THEMED

11-1 Introduction

The entire study area is under an arid climatic conditions. Except for large towns like El-Arish and Rafah, most villages and towns are suffering from an acute shortage of domestic water. This problem is rather serious, especially at Naqb and Themed since there is no water source for domestic use in the vicinity of these villages.

In order to solve this problem, a preliminary design of the water supply facilities was made. The proposed water source will be groundwater. The availability of water and water quality were confirmed by test well No. Sheira-2 recently drilled by RIWR

11-2 Water Demand

There are nine communities in Themed village and eleven communities in Naqb. According to the national census in 1986 the total population at Themed is 614 and at Naqb 374 as shown in Table 10-1. The population of these villages, surveyed by the North Sinai Governorate, is 730 at Themed and 445 at Naqb as shown Table 11-2-1;

Table 11-2-1
Population Growth

Area/year	1986	1991
Themed	614	730
Naqb	374	445
Total	988	1,175

The growth rate of population of each town was estimated by comparing the above populations of the year 1986 and 1991.

Table 11-2-2 Design Water Served Area and Population

CENTRES OF TOWN	S.N.	VILLAGES	SUBURB	NO. OF BUILDINGS	NO. OF FAMILIES	NO. OF PERSONS
		THEMED		170	122	614
			AL MASHETY		30	184
			AL HAWA		6	40
			AL MATAK		6	27
			ERK EL NAKA		7	43
			AL GOHAIR		0	0
			UM EL BARED		9	48
			UM SOWAN		0	0
			AL MOHASHAM		25	145
			ALKEBASH		14	96
		NAQB		110	80	374
			KHASHM ELTAREK		33	173
			EL GARANY		20	108
			EL HAMRAA		6	24
			UM SEDRA		14	74
			GHABIT UMHUSEN		0	0
			AL SAFRA		11	61
			AL MANDARA		9	45
			KARN ATOOT		0	0
			ABO SLY		0	0
			ALKAREEN		0	0
			SEL ALMASHASH		21	124

Themed

$(730 / 614)^{1/5} = 1.035$

Naqb

$(445/374)^{1/5} = 1.035$

The design period was determined for the year of 2000 since this is one of the target areas for future development by the Ministry of Development. By that time the final regional development plan will be available.

Under the circumstances, the design population was estimated as shown below:

Themed
$730 \times (1 + 0.035)^9 = 994$

Naqb
$445 \times (1+0.035)^9 = 605$

11-3 Design Capacity

At present there is no project which requires a specific amount of water. Therefore, the design capacity was determined based on the domestic demand. The water consumption was determined as 30 l/cap/day considering the living pattern under arid conditions.

An average daily demand is estimated as below:

Themed
$0.030\ m^3/cap/day \times 994 = 29.82\ m^3/day$

Naqb
$0.030\ m^3/cap/day \times 605 = 18.15\ m^3/day$

Total $47.97\ m^3/day$

The design factors were determined by considering the living pattern under the arid climate as shown below:

Daily maximum	1.3
Hourly maximum	2.0
Leakage and loss	0.1

Based on the above design factors, the design capacity of the water supply system was determined as shown in Table 10-3-1;

Table 11-3-1 Design Capacity

Area	Daily average	Daily maximum	Hourly maximum
Themed	32.8	42.6	65.6
Naqb	20.0	26.0	40.0
Total	52.8	68.6	105.6

11-4 Water Source

For both Themed and Naqb the only available water source is groundwater. However, these two villages are located in an area where it is difficult to obtain potable groundwater.

In the area on the southern side of Ragabet El-Naam Fault, a promising well field of the sandstone of the Lower Cretaceous is assumed to be located. However, there is no confirmation of the water quality at present. For this reason it is proposed to draw the water from the well field at Sheira. In this well field there is one test well that was drilled by RIWR (well No. Sheira-2) which indicates there is an aquifer in the limestone of the Upper Cretaceous that yields in the order of 100 m3/day and has a TDS of 1,100 ppm. This level of TDS is slightly higher than the allowable TDS for drinking water proposed by WHO:

Table 11-4-1 Comparison of Ion Contents

Item	Sheira-2	WHO guide line
p h	6.2	6.5-8.5
TDS	1.100	< 1,000
Mg^{++}	82.7	-
Ca^{++}	22.4	-
Na^{+}	223	-
K^{+}	14.1	-
HCO_3^{-}	-	-
CO_3^{--}	-	-
Cl^{-}	274.8	< 250
$SO4^{--}$	410.2	< 400

Although some chemical items exceed the level of allowable level of the WHO guideline, it could be acceptable as a domestic water source since there is no alternative source.

The source of water shall be two wells; one for production and the other for emergency and maintenance use.

11-5 Design of Water Supply Facilities

The water supply facilities consists of following items:

- Water source
- Transmission pipeline
- Distribution pipeline
- Distribution reservoir
- Public taps

The outline of water supply facilities is shown in Fig. 11-5-1. The service area for Thamed and Naqb are shown in Fig. 11-5-2 and Fig. 11-5-3.

11-6 Detail Design

(1) Transmission Pipe Facility

The diameter and length of pipeline were determined as follows:

Table 11-6-1 Diameter and Length

Point	Daily Maximum Demand (m3/day)	Length (km)	Diameter (mm)
Intake ~ A	68.6	2.6	ø 80
A ~ B	68.6	22.7	ø 80
B ~ C	26.0	7.5	ø 50
B ~ D	42.6	21.0	ø 80
D ~ E	42.6	10.3	ø 80
E ~ F	42.6	8.0	ø 80
Total	-	72.1	-

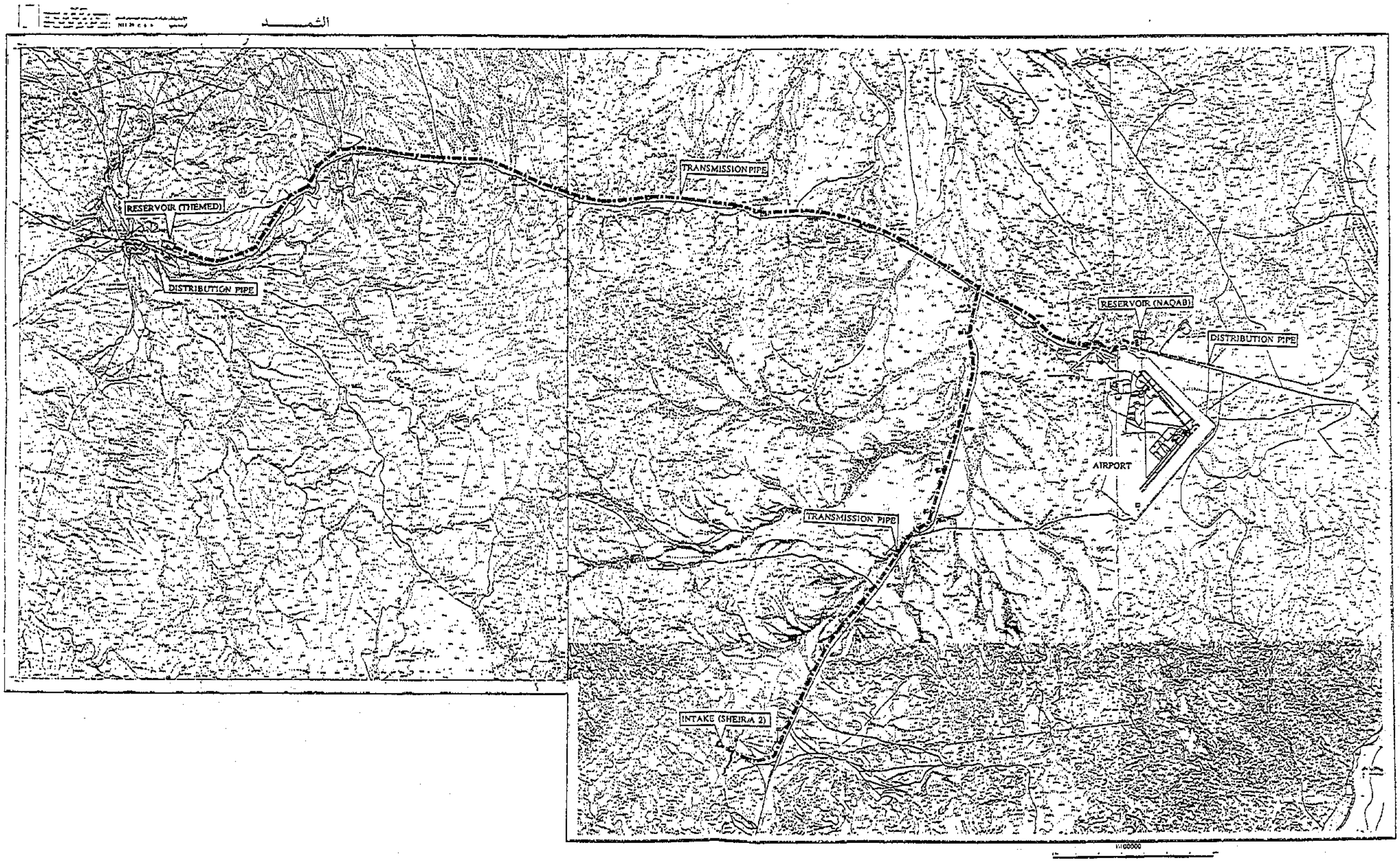


FIG. 11-5-1 OUTLINE OF WATER SUPPLY FACILITIES

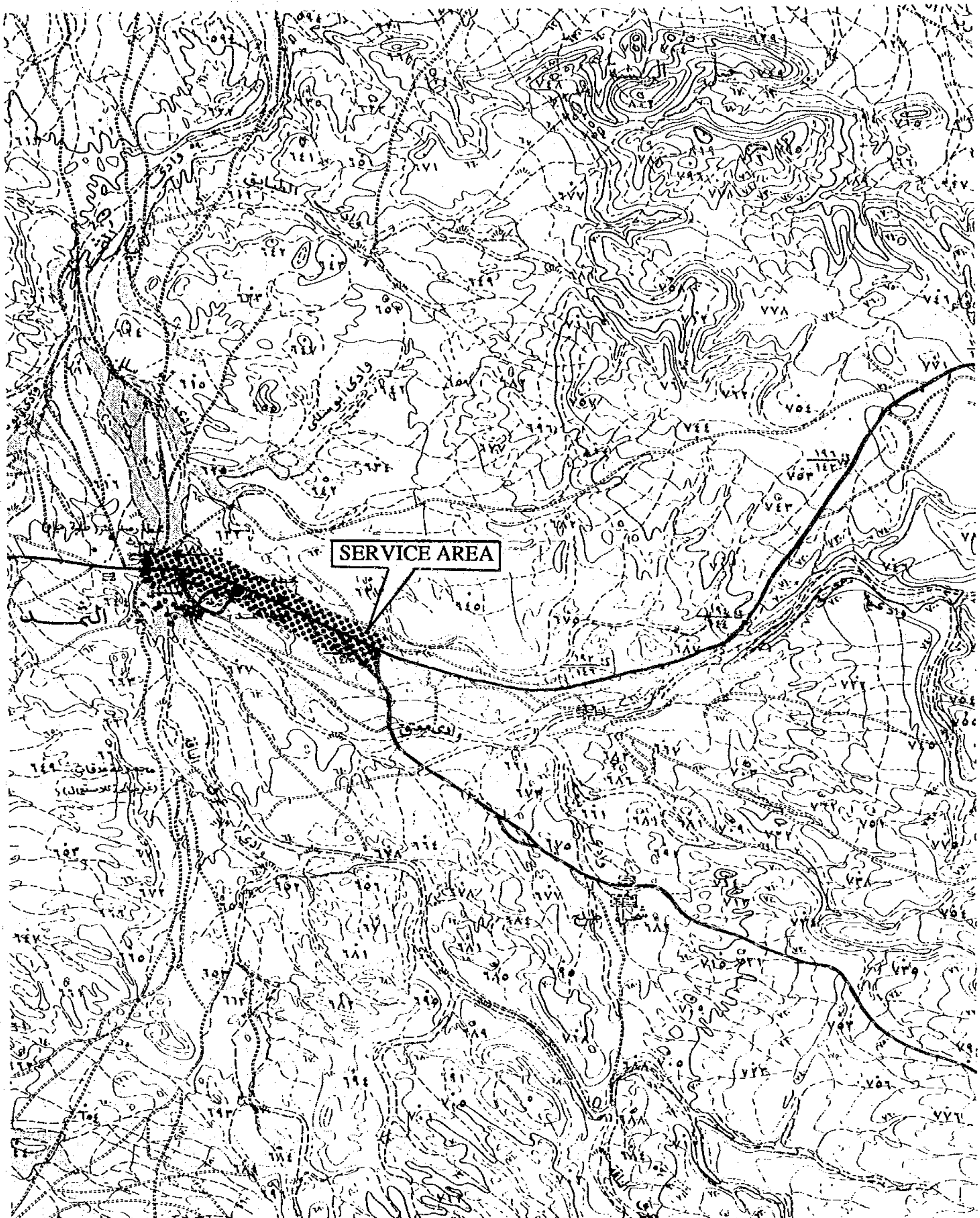


FIG. 11-5-2 SERVICE AREA (THEMED) 1 : 50,000

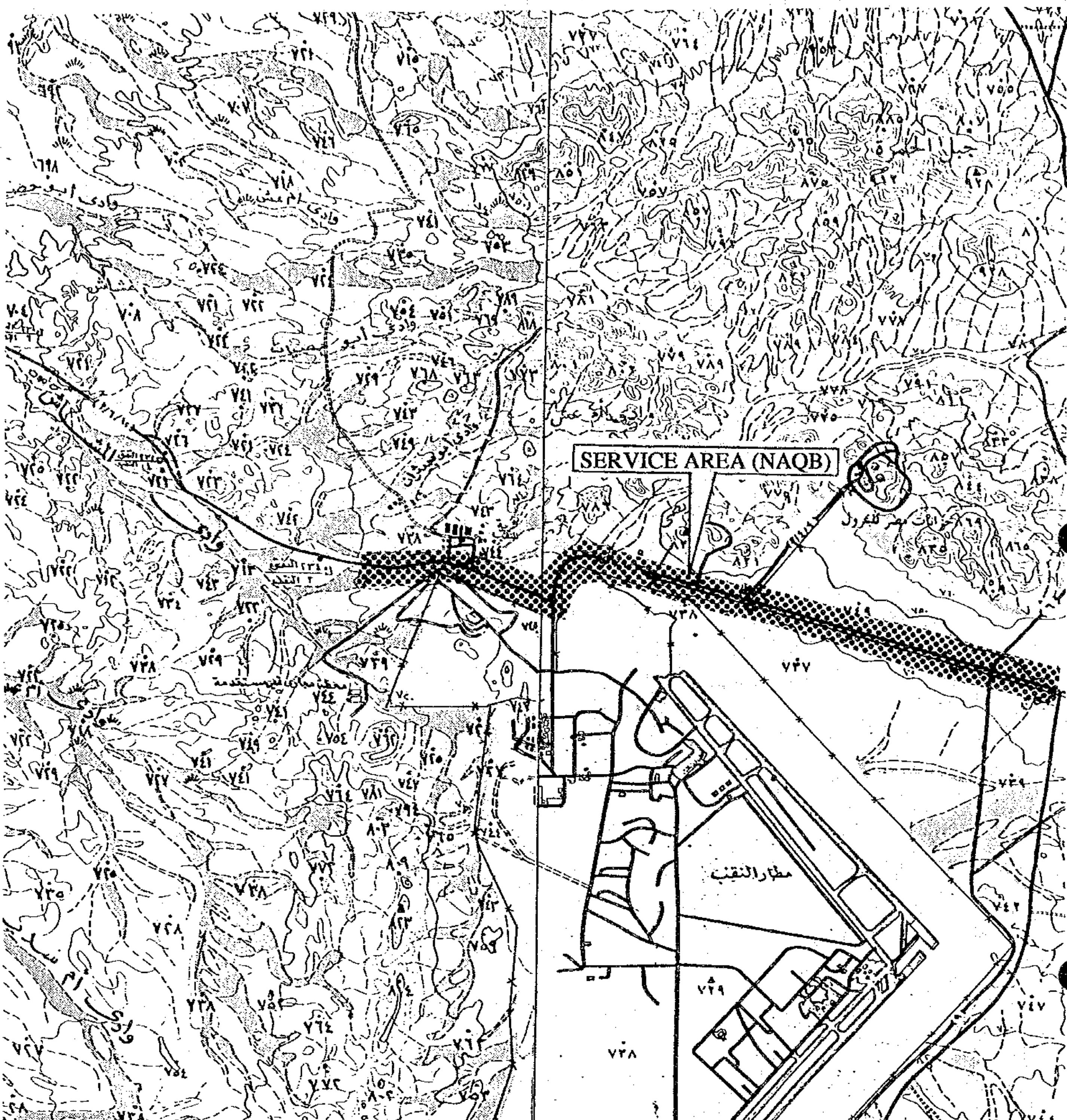


FIG. 11-5-3 SERVICE AREA (NAQB) 1 : 50,000

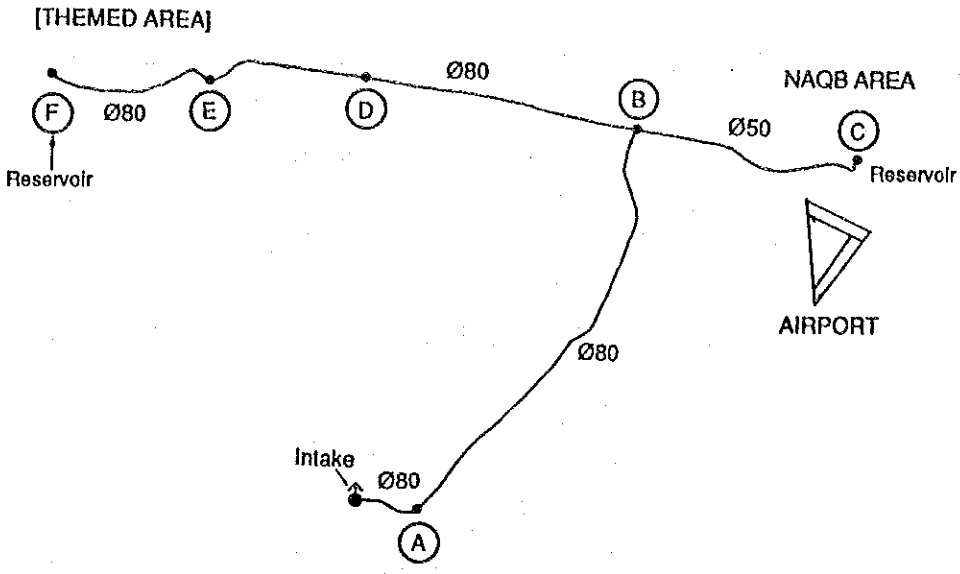


FIG 11-6-1 DISTRIBUTION SYSTEM

(2) Water Source Facility

1) Capacity : q

$$Q = WdMAX1 + WdMAX2 =$$
$$= 42.6 + 26.0 = 68.6\ m^3/day.$$

$$q = \frac{68.6}{24 \times 60} \times 10^3 \times 1.2$$
$$= 57.1 \Rightarrow 60\ l/min$$

2) Discharge Head : ΔP

ΔP_1 : Friction loss of pipelines
ΔP_2 : Actual head

[Unit : m]

Point	ΔP_1	ΔP_2	ΔP
Intake ~ A	1.6	Well + 110	
A ~ B	14.4	Actual + 15	
B ~ C	7.8		
B ~ D	5.5		
D ~ E	2.7		
E ~ F	2.1		
Total	34.1	125	159.1

Each friction loss is determined based on following calculation:

ΔP_1 : Friction loss of pipelines

$$\Delta P_1 = 10.666 \times C^{-1.85} \times d^{-4.87} \times Q^{1.85} \times 1.03\ l$$

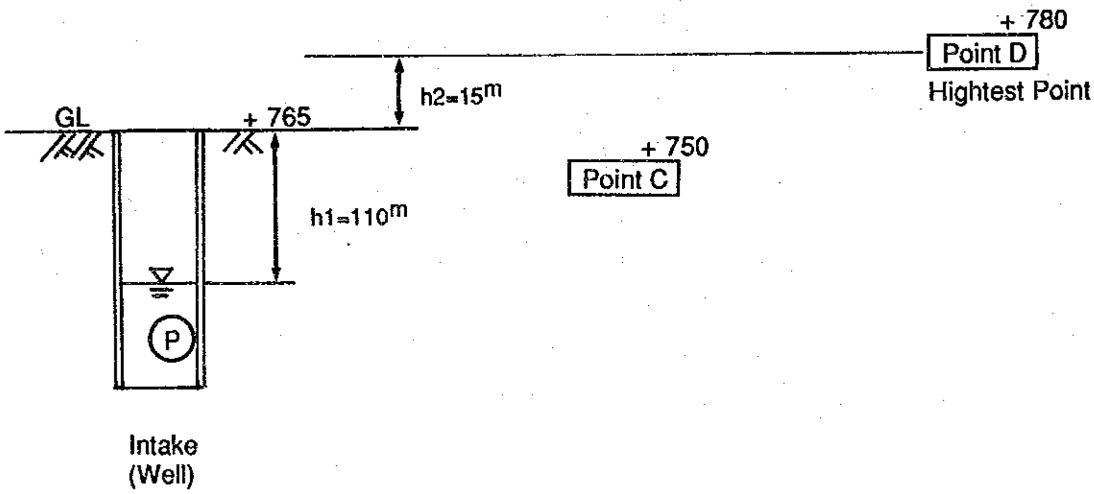
(by Hazen-Williams Formula)

$Q = WdMAX \times 1/(24 \times 60 \times 60)$ $\quad C = 120$

ΔP_2 : Actual head

$$\Delta P_2 = h_1 + h_2$$
$$= 110 + 15 = 125\text{m}$$

FIG. 11-6-2 ACTUAL HEAD



Therefore,

$$\Delta P = \Delta P_1 + \Delta P_2$$
$$= 34.1 + 125 = 159.1\ \text{m}$$

3) Motor capacity: kw

$$kw = \frac{r.Q.H}{6120} \times \frac{1}{\delta w} \times \delta p = \frac{1000 \times 0.06 \times 159.1}{6120} \times \frac{1}{0.3} \times 1.15$$
$$= 6.0 \Rightarrow 7.5\ \text{kw}$$

(3) Reservoir Tank

[THEMED]

$$VT = WdMAX1\ m^3/day \times \frac{14}{24}$$
$$= 42.6 \times \frac{14}{24} = 24.9 \Rightarrow 25\ m^3$$

[NAQB]

$$VN = WdMAX2\ m^3/day \times \frac{14}{24}$$
$$= 26.0 \times \frac{14}{24} = 15.2 \Rightarrow 16\ m^3$$

Each retention time is proposed for 14 hours considering conditions of the service areas.

(4) Distribution Pipe

The diameter and length of pipes were determined as follows:

Table 11-6-2 Diameter and Length

Area	Length	Diameter
THEMED	2,500 m	ø 80
NAQB	6,750	ø 80

ΔP : Friction loss of pipelines

$$\Delta P = 10.666 \times C^{-1.85} \times d^{-4.87} \times QHMAX^{1.85} \times 1.03\ l$$

by Hazen-Williams Formula

$$QHMAX = WdMAX \times 1/(24 \times 60 \times 60)$$

(5) Chlorination Facility

Chlorination equipment is to be installed. Drop type feeding equipment is to be installed at the top of the ground type reservoirs.

Chlorination equipment are as follows:

Table 11-6-3 Chlorination Equipment

Project area	Type	Dosing rate (mg/l)	Capacity of solution tank (l)	Dissolving tank (50l)	Storage chemical (kg/3 months)
THEMED	Gravity	5.0	20 l	1	32
NAQB	Gravity	5.0	20 l	1	20

Feeding rate was calculated as follows:

$$P = \frac{Q}{24} \times R \times \frac{1}{Sc \times Sd \times rd} \times 10^{-3} \qquad [Q = WdMAX]$$

P : feeding rate of 5% solution (l/hr)

W : daily maximum water demand (m^3/day)

R : dosing rate of hypochlorite : $NH_4 > 0.1$mg/l then 5mg/l

: $NH_4 \leq 0.1$mg/l then 3mg/l

Sc : effective density of hypochlorite 60%

Sd : density of solution 5%

γd : specific gravity of solution 1.05

Solution tank capacity was calculated as follow:

Ct = P x 24 x D

Ct : tank capacity

D : 3 (for 3 days)

In addition, a tank for preparing the hypochlorite solution must be made available.

A 3-month supply of hypochlorite is to be stored in a suitable place such as the pump house. The amount of reserve was calculated as follows:

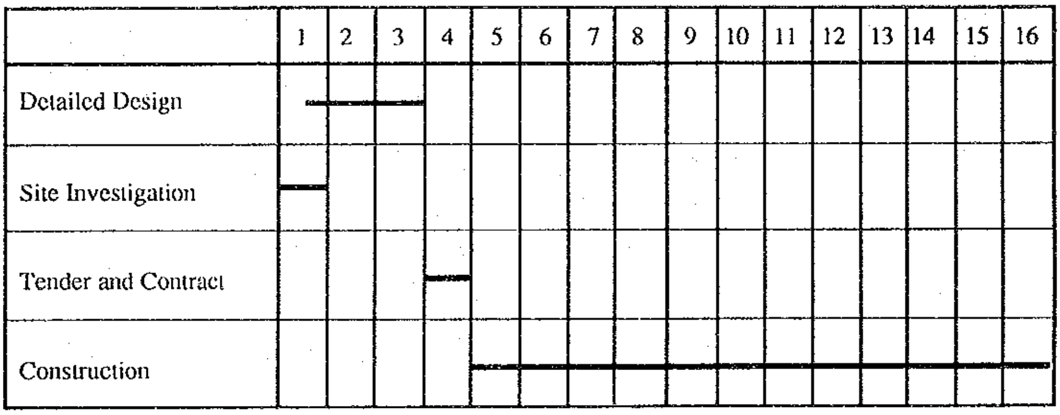
$$Cc = Q \cdot R \times \frac{1}{Sc} \times 90 \times 10^{-3}$$

Cd = amount of reserve (kg)

11-7 Construction Schedule

(1) Detailed Design

The detailed design of the project is to be prepared based on this report. Preparation of the detailed design will be carried out as follow:



(i) Updating of design conditions

(ii) Surveys of the number of residents and households who will receive water supplies (these figures are needed to determine the locations of public taps) and the preparation of public tap location maps.

(iii) Levelling surveys for the plans prepared for this report and for completing the plans. Installation of temporary bench marks in the site.

(iv) Confirmation of land acquisition for project construction sites. This must be completed at least one month prior to the commencement of project construction.

(2) Construction Schedule

The schedule is shown as follow:

12 CONCLUSION AND RECOMMENDATION

12-1 Conclusion

12-1-1 Quaternary Aquifer

The thick Quaternary formation identified in the coastal plain from El-Arish to Rafah extends for about 30 km long along the coast with width varying from 15 km to 20 km. This formation is between 80 m and 100 m thick (Chapter 7).

The lowest part of the Quaternary in this area is kurkar, the calcareous sandstone of shallow marine deposits which is mainly underlain by Pre-Quaternary shale and partly by sandstone and limestone. The thickness of kurkar varies from 10 m to 30 m although it is thinning out at certain places (Section 8-2).

The sand dunes distribute over most of this Quaternary formation underlain by the old beach sand overlaying kurkar. Gravel and clay are interbedded with these sandy beds in various thickness depending upon locality..

Where kurkar is overlain by clay, a confined aquifer is formed. Where a clayey bed is absent and the Quaternary deposits, other than kurkar, overlie kurkar, an unconfined aquifer is found. In this case there is hydraulic continuity between the kurkar aquifer and the overlaying aquifer of the Quaternary, other than kurkar. The water level is determined by the piezometric potential surface of the kurkar aquifer even in the unconfined aquifer (Fig. 8-2-13).

The major water source in the Quaternary aquifer is assumed to be kurkar. However, even the aquifer of kurkar is assumed to be supplied with groundwater by the other aquifer in the Pre-Quaternary formations, which is assumed by the preliminary water balance in the well field in El-Arish (Technical Report I).

Of course, there would be recharge of the fresh water to the Quaternary aquifer to a certain extent under the current climatological conditions. However, the present rate of extraction of the groundwater from the Quaternary aquifer obviously exceeds the total annual rainfall in some areas of the El-Arish well field.

The TDS of the groundwater in the kurkar aquifer is high; it ranges from 2,00 ppm to 5,000 ppm. With the commencement of pumpage in the area there would be groundwater consisting mainly of fresh water lenses recharged, in part, by the current climatic conditions and such fresh water might be mixed with the groundwater supplied by the kurkar (Section 8-2-4).

As pumpage continued, the fresh groundwater originated by the recharge under the current climatic condition would have been exhausted since the recharge is only limited. In such an aquifer the fresh water is replaced by the highly saline water of a kurkar aquifer.

This is assumed to be the reason why the TDS of some wells has increased while at other wells the TDS remains at the same level in spite of extraction of the groundwater for more than 20 years.

At present, extremely intensive groundwater extraction is observed at the well field of El-Arish and in the coastal plain from Sheikh Zuwayid to Rafah. The total volume of pumpage is estimated at 90,000 m^3/day at these well fields. As a result, the water level has lowered considerably since 1962. At some places the water level remains 1 to 2 m below the seawater level (Chapter 8, Technical Report I).

The increase in the TDS of groundwater in these well fields is unavoidable to a certain extent due to the hydrogeological mechanism. Further recession of the water level may easily allow seawater intrusion into the aquifer.

To prevent seawater intrusion groundwater extraction shall be strictly controlled. For this purpose, the safe yield for preventing water level recession was estimated at some areas where appropriate data was available. It is urgently required that the safe yield be determined at all places in the well field (Section 9-2).

The aquifer developed in the coastal sand dune is assumed to be the isolated aquifer from the kurkar system prevailing in the Quaternary formation. This is assumed to be recharged by the current climatic conditions. The TDS of the groundwater is very low, ranging from 300 ppm to 700 ppm, although its yield is assumed to be limited compared to the available volume of the groundwater in the kurkar system. The detailed mechanism of the aquifer system is still subject to further confirmation

Under the circumstances, the control of the groundwater extraction in the present well field is more urgent than its further development. In this respect, investigation and evaluation of the Quaternary aquifer in the coastal plain from El-Arish and Sheikh Zuwayid is urgently required since it is an area hardly developed as a well field.

12-1-2 Pre-Quaternary Aquifer

There are various types of aquifers developed in the Pre-Quaternary formations. Of these, the aquifers applicable for practical groundwater usage are:

The aquifer in limestone of the Eocene of the Tertiary,

The aquifer in limestone of the Turonian of the Upper Cretaceous and

The aquifer in the sandstone of the Lower Cretaceous.

The aquifer in limestone of the Eocene was observed at Quseima where the formation is located on a plateau. The groundwater occurs as a spring and yields approximately 1,500 m^3/day with a favorable TDS of 1,440 ppm. A similar geological setup in the limestone of the Eocene was observed on the plateau extending to the south from Gebel Risha in Quseima area, at Gebel El Shara and the plateau to the south of Nakhl (Section 8-3).

The aquifer developed in the limestone of the Turonian was observed at well Sheira-2. Its TDS is 1,100 ppm and the water level is 81 m from the ground surface. An aquifer of this type is assumed to extend further in a southwestern direction (Section 8-4).

Although favorable groundwater was found at these aquifers, its hydrogeological properties are subject to studies rather than objects of its immediate development.

The most promising aquifer for immediate development was identified in the sandstone of the Lower Cretaceous (Section 8-5).

This formation consists of porous quartzose sandstone, occasionally interbedded with shale. The contents of the shale is high in the north but almost absent in the south. The facies changes into limestone in the northern part of the study area.

The thickness of the formation varies from place to place. However, it ranges between 200 m and 300 m, in general; it is very thick at Halal (600 m). Excluding the thickness of the interbedded shale, the thickness of the aquifer of the Lower Cretaceous is estimated to be approximately 200 m.

The TDS of the groundwater of this type of aquifer is in a range between 1,200 ppm and 3,000 ppm. The high TDS value was observed at the limestone facies (Umm Shihan, and in the area near the dome structure where the geological structure is significantly disturbed). It is assumed that the movement of the groundwater is restricted by the disturbed structure.

The TDS of the groundwater in the Lower Cretaceous sandstone aquifer is in a range between 1,200 ppm and 1,500 ppm in the area where there is no significant disturbance of the geological structure. Groundwater of this type of aquifer is found in the large triangle area surrounded by Hasana, Nakhl and Kuntilla.

The depth to the aquifer ranges between 300 m and 1,000 m. It is deep in the central part of the study area, but is shallow in the area around dome.

The depth to the water level ranges between 161 m and 340 m. The shallower water level was observed at the central part of the study area. Deeper water levels were observed at Quseima, Kuntilla and Sadr El Heitan. The water level is also deep at Sheira on the southern side of the Ragabet El Naam Fault.

The transmissivity of the sandstone of the Lower Cretaceous ranges between 12 m^2/day and 400 m^2/day. The smaller value was observed in an area near the domes. The higher value was observed in an area where there is no significant structural disturbance which occupies a broad area in the central part of North Sinai (Chapter 5, Technical Report I).

The total amount of the storage in the aquifer of the sandstone of the Lower Cretaceous was estimated at 30 x 10^9 m^3 under favorable conditions. The TDS is less than 1,500 ppm within 300 m from the ground surface (Section 7-5).

From the viewpoint of water usage, important parameters for evaluating the aquifer of the sandstone in the Lower Cretaceous are the TDS and the depth to the water. The TDS determines the limit of the water use; the depth to the water determines the operation cost of the water source.

For this reason, the TDS and the depth to the water are taken as parameters for the evaluation of the groundwater of the Lower Cretaceous aquifer. It was found that a broad area surrounded by Hasana, Sadr El Heitan, Nakhl and Arif El Naga is a promising area for groundwater. The sandstone aquifer where the groundwater is obtainable is between 100 m and 200 m from the ground surface and has a TDS less than 1,500 ppm, except in the area around the domes.

Additionally, the sandstone of the Lower Cretaceous distributes over a broad area in the study area that is overlain by various formations. It extends beyond the Ragabet El-Naam Fault which is assumed to be a barrier of the groundwater movement of the sandstone of the Lower Cretaceous. The importance of the aquifer in the sandstone of the Lower Cretaceous in the southern side of the fault is that it is assumed to be the source of groundwater to the north. For this reason it is necessary to determine the function of the aquifer in the southern side of the fault that is in the aquifer system of the sandstone of the Lower Cretaceous.

12-2 Recommendations

Since the necessary data collection and studies to be undertaken for clarification of hydrogeological properties of the prospecting aquifers are summarized in Chapter 9, the most important recommendations are as follows:

1) The assumptions derived for area A1 and A2 of the sandstone aquifer of the Lower Cretaceous should be confirmed by test wells.

2) The safe yield for preventing further recession of the water level at the well field of El-Arish and the coastal plain from Sheikh Zuwayid to Rafah should be determined.

3) Hydrogeological investigation should be undertaken in the coastal plain between El-Arish and Sheikh Zuwayid to determine the productivity of the Quaternary aquifer.

4) The location and hydrogeological conditions of the aquifer of the Pre-Quaternary in the vicinity of the Quaternary aquifer in the coastal plain should be studied to determine their influence on the Quaternary aquifer.

5) The hydrogeological study should be undertaken to determine the extension and mechanism of the aquifer in the coastal sand dunes.

6) A monitoring network should be established, including the test wells drilled by RIWR and the study team during the study. Some test wells should be required in the area where the Quaternary formation is underlain by the Pre-Quaternary sandstone or limestone. These monitoring wells should be strictly for observation purposes only; no production wells should be included. Target aquifers of the monitoring network should be the Quaternary aquifer in the coastal plain, the aquifers in the coastal sand dunes and the aquifer in the sandstone of the Lower Cretaceous.

7) The initial task of groundwater management is to store precise and reliable data concerning the water level, the water quality and well data in a systematic data bank. As a matter of fact, during the study, RIWR made a great effort to improve the filing system. Further improvement of data processing and storing would yield greater benefits for groundwater study and management.

8) Since availability of the groundwater is confirmed, the most efficient usage of the groundwater should be carefully studied for practical development purposes.

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