9-2-2 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:

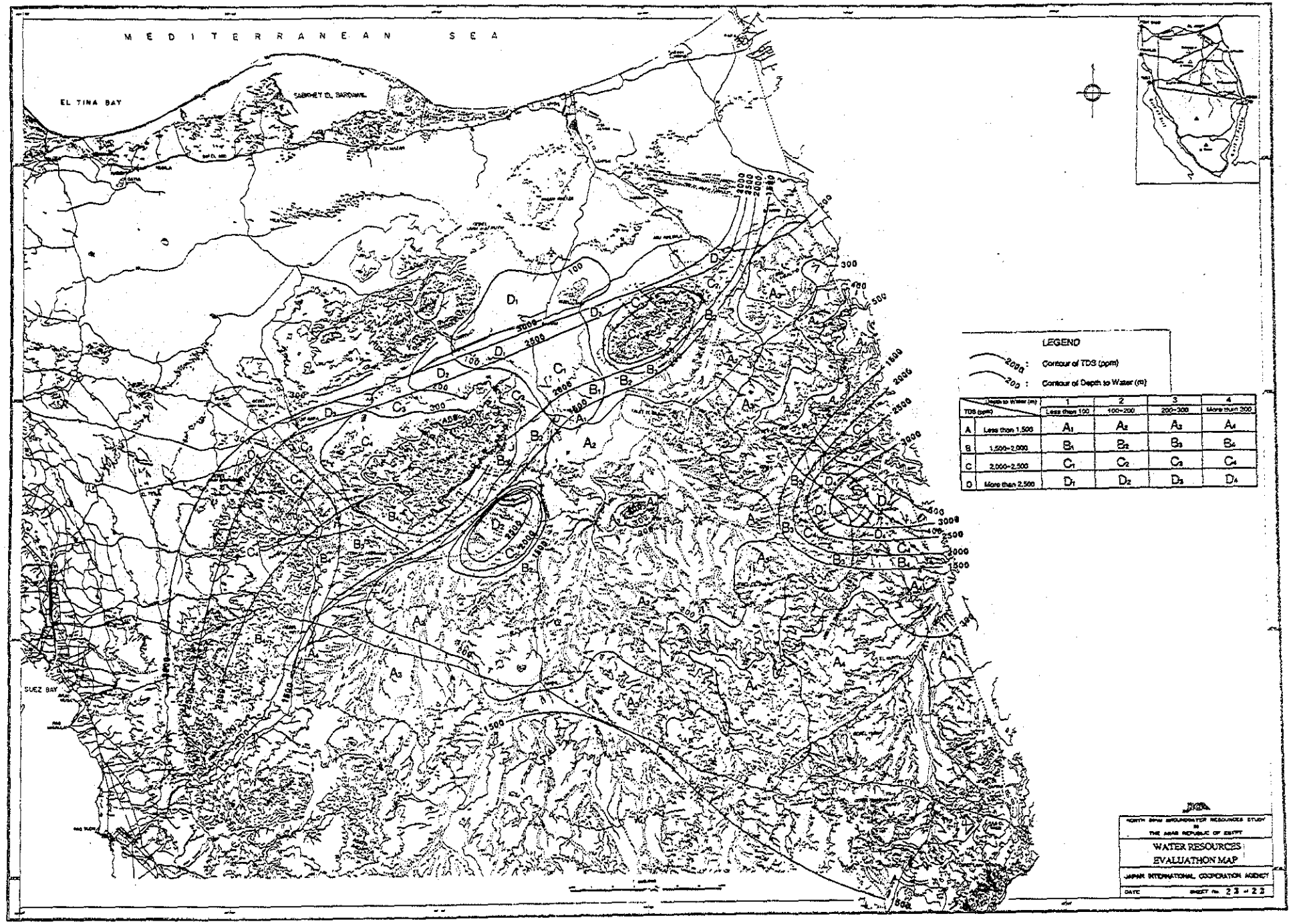
1) TDS is satisfactorily low,
2) Depth to the water is small,
3) Demand of the water is high, and
4) Easy access to the site.

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 (Fig.9-1).

9-3 Recommendation for Groundwater Development

9-3-1 Quaternary Aquifer

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.



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

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 the 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 TDS value and ion content.

(4) The groundwater recharge system should be investigated on the bases 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.

9-3-2 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 in stalled strictly in the sandstone of the Lower Cretaceous, because groundwater of other aquifers has 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.

9-4 Additional Studies Required

9-4-1 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 not negligible.

It is also urgent to confirm the limit of the above mentioned Quaternary in the west beyond of 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 behaviour 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 inflow of groundwater from the aquifer of the Pre-Quaternary into the Quaternary aquifer, location and its behaviour shall be identified especially in the area where 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 dimension 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.

9-4-2 Pre-Quaternary Aquifers

9-4-2-1 Tertiary Aquifer

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

As for the Eocene aquifer, additional data will be required to determine to properties, since the spring water of the Eocene aquifer at Quscima 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 and

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 Quascima. The plateau in the south of Nakhl would be very important since the Eocene bed in this area extends over broad area in the south.

9-4-2-2 Upper Cretaceous Aquifer

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 extremely high TDS in the northern part of Ragabet El Naam fault. However, TDS at well 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.

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. Evaluation of this type of aquifer is subject to 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.

9-4-2-3 Lower Cretaceous Aquifer

Information concerning the aquifer in this formation is the most advanced of all the aquifers in the study area as shown in the Hydrogeological Map and Portfolio. This is the most promising groundwater source in North Sinai. Practical development of this aquifer could commence at any time; however, it would be useful to undertake further investigations for the following purpose:

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 hydrogeological mechanism

Confirmation shall be made on the groundwater flow from the south to the north passing through the Ragabet El-Naam Fault. The major flow is assumed to pass through the area around Nakhl in relation to the aquifer system in the south of the fault.

9-4-2-4 Jurassic Aquifer

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

10. PROPOSED GROUNDWATER DEVELOPMENT AT NAQB AND THEMED

The entire study area is under a arid climatic condition. Except for large towns like El-Arish and Rafah, most villages and towns are suffering from an acute shortage of domestic water.

In order to solve this problem, a preliminary design of water supply facilities was made. The proposed water source will be the groundwater of which the availability and water quality were confirmed by the test well Sheira-2 recently drilled by RIWR.

The yield of this well is approximately 100 m^3/day which is more than sufficient for the water demand of Naqb and Themed towns by the year 2000. The quality of the water is acceptable as shown in Chapter 10, Main Report. Layout of the facilities are shown in Fig. 10-1 ~ 10-4.

Design conditions and water supply facilities are summarized below:

Design Conditions

	Themed	Naqb	Total
Design population	1000	600	1600
Daily consumption	30 l/cap/day	30 l/cap/day	-
Design capacity	30 m^3/day	18 m^3/day	48 m^3/day

Water Supply Facilities

Water source	Borehole	:	Turonian Aquifer
Pipelines	ø 50 mm	:	7,500 m
	ø 80 mm	:	64,600 m
Reservoirs	25 m^3	:	Themed
	16 m^3	:	Naqb
Distribution :	ø 80 mm 2,500 m	:	Themed
	ø 50 mm 6,750 m	:	Naqb

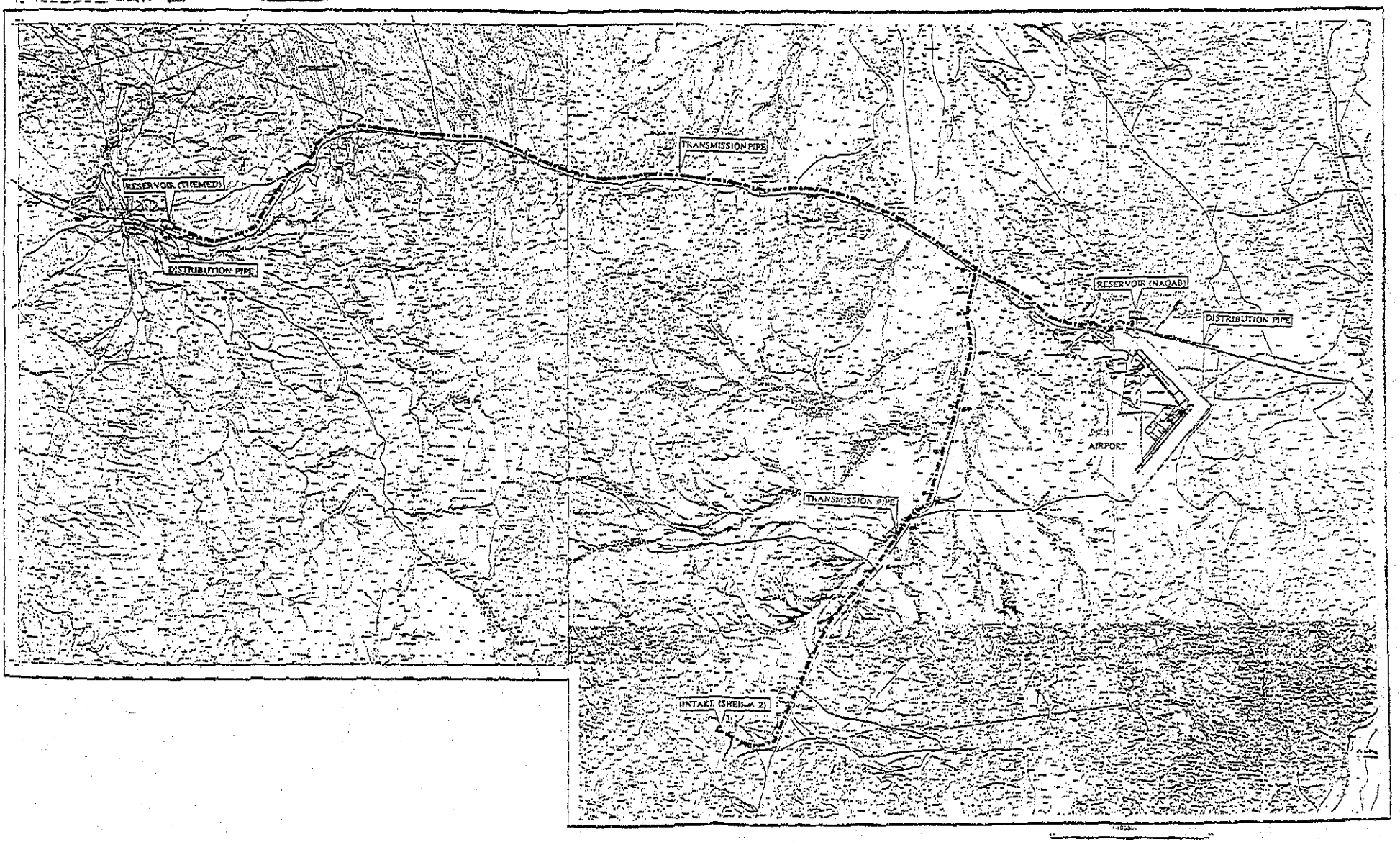


FIG 10-1 OUTLINE OF WATER SUPPLY FACILITIES

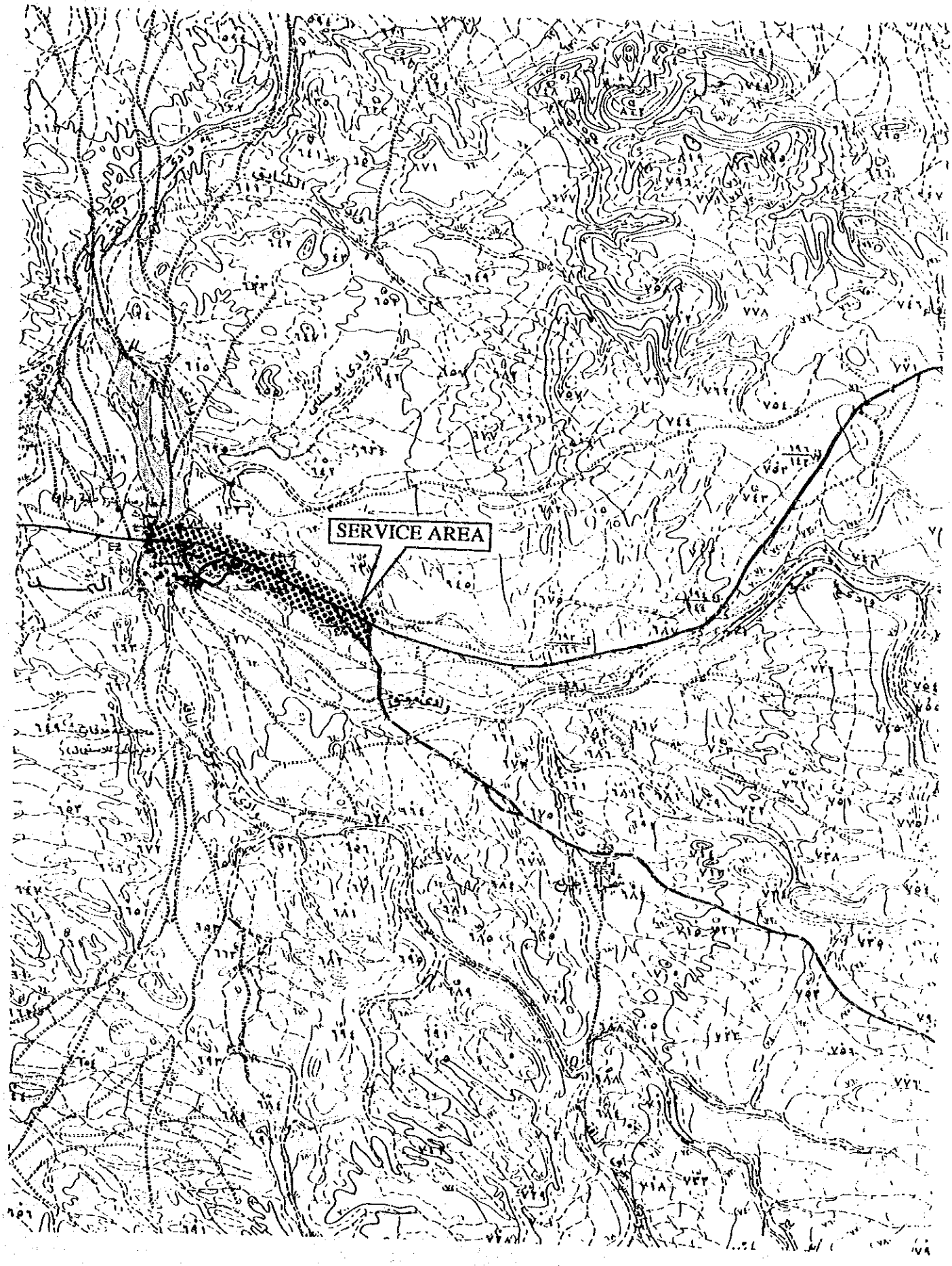


FIG 10-2 SERVICE AREA (THEMED) 1 : 50,000

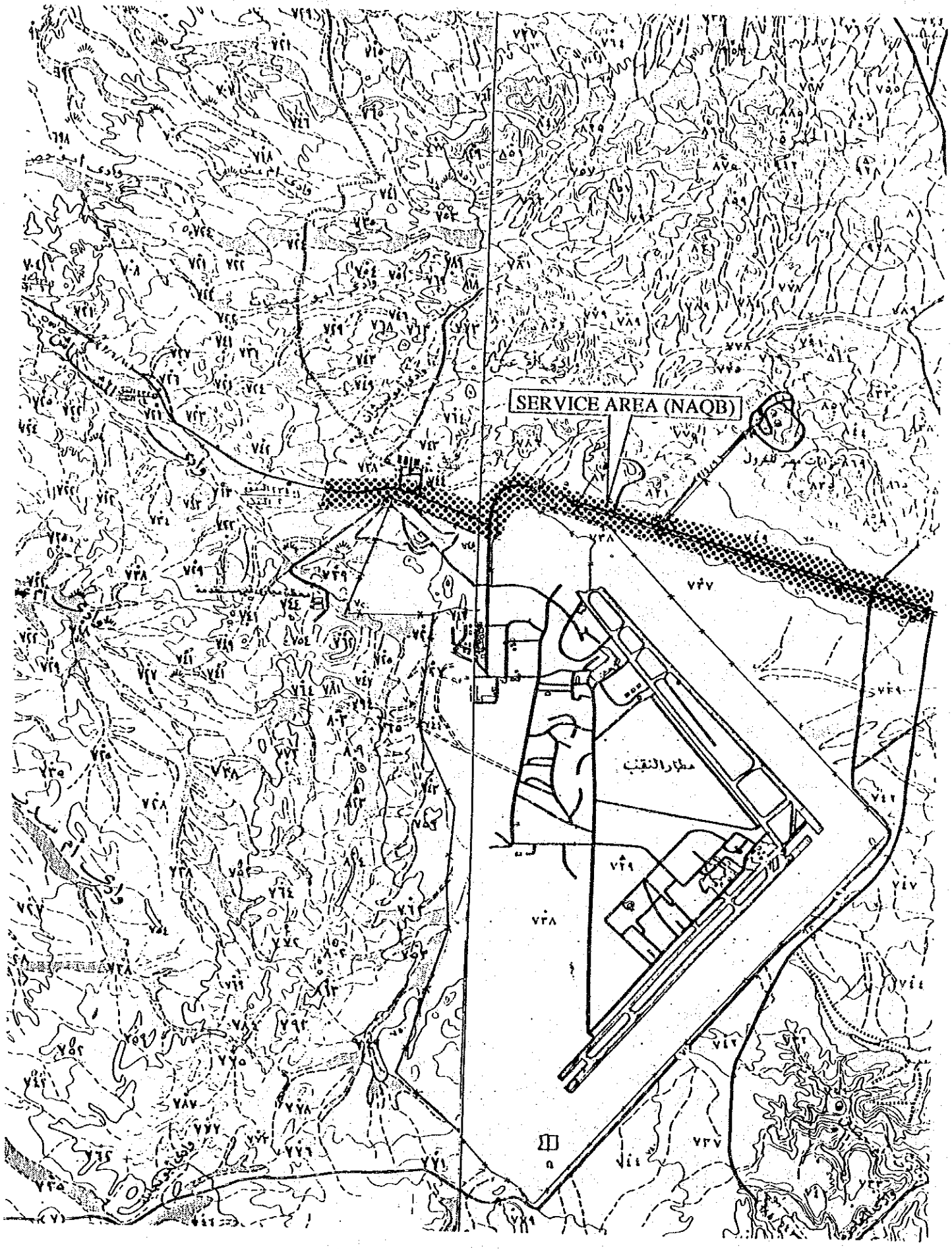


FIG 10-3 SERVICE AREA (NAQB) 1 : 50,000

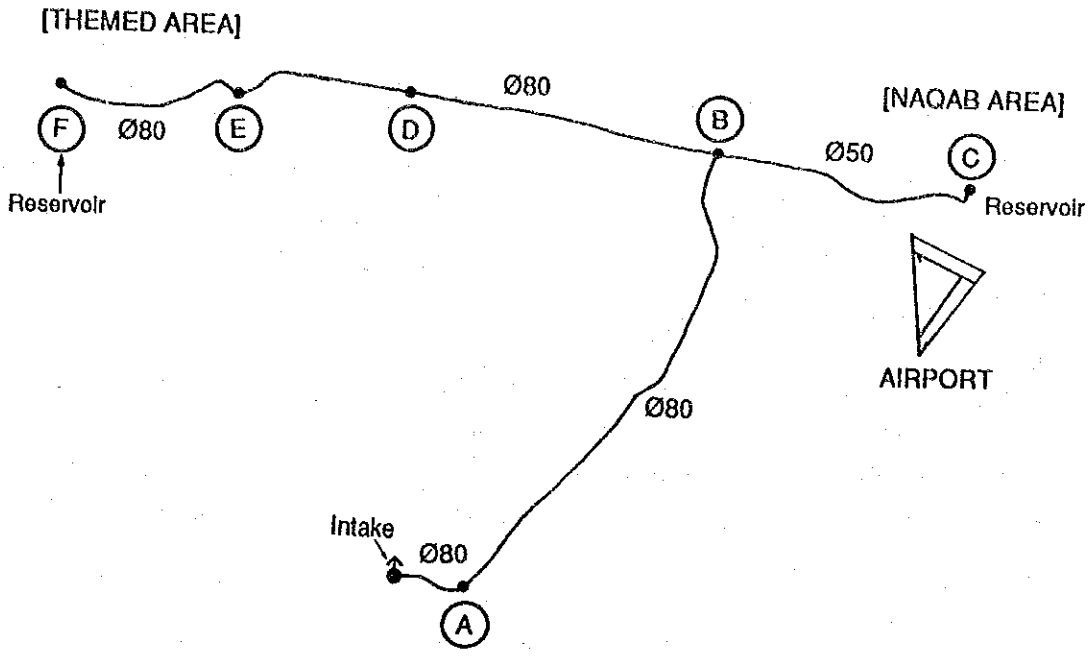


Fig.10-4 DISTRIBUTION SYSTEM

11. CONCLUSION AND RECOMMENDATION

11-1 Conclusion

11-1-1 Quaternary Aquifer

The thick Quaternary formation identified in the coastal plain from El-Arish to Rafah extends about 30 km long along the coast with widths varying from 10 km to 15 km. This formation is between 80 m and 100 m thick (Chapter 6).

The lowest part of the Quaternary in this area is kuakar, calcareous sandstone of shallow marine deposits. Kurkar 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 7-2).

The sand dunes distribute over the 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. 7-1).

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 (Technical Report I).

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

The TDS of the groundwater in a kurkar aquifer is high and ranges from 2,000 ppm to 5,000 ppm. With the commencement of pumpage by the modern boreholes in the area, there would be groundwater consisting mainly of fresh water lenses recharged, in part, by the current climatic conditions (Section 7-2-4, Main Report).

As pumpage continued, the fresh groundwater originated by the recharge under the current climatic conditions would have been exhausted since recharge was 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 reason why TDS of some wells has increased while at other wells the TDS remains at the same level when the pumpage commenced in spite of the 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 much lowered considerably. Due to the hydrogeological mechanism, this was not avoidable to a certain extent. Further recession of the water level may allow the seawater to easily intrude into the aquifer.

To prevent seawater intrusion, groundwater extraction must be strictly controlled. For this purpose, the safe yield to prevent water level recession has been estimated at some areas where appropriate data was available. It is urgently required that the safe yield shall be determined at all places in the well field (Section 8-2, Main Report).

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 limited compared with the available volume of the groundwater in the kurkar system. Detailed distribution of the aquifer shall be confirmed.
Under the circumstances, the control of the groundwater extraction in the present well field is a more urgent matter than further

development. In this respect, investigation and evaluation of the Quaternary aquifer in the coastal plain from El-Arish and Sheikh Zuwayied is urgently required since it is an area hardly developed as a well field.

11-1-2 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;

1) The aquifer in limestone of the Eocene of the Tertiary,

2) The aquifer in limestone of the Upper Cretaceous and

3) The aquifer in 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 (Gebel Risha in Quseima area, Gebel El Shara and the plateau to the south of Nakhl (Section 7-3, Main Report)).

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 southwest (Section 7-4, Main Report).

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

The most promising aquifer for immediate development is identified in the sandstone of the Lower Cretaceous (Section 7-5, Main Report).

This formation consists of porous quartzose sandstone, occasionally interbedded with shale. The contents of the shale is high in the north and 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, and 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.

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.

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 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 deep in the central part of the study area, but is 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. The deeper water level was observed at Quseima, Kuntilla and Sadr El Heitan. The water level is also deep at Sheira on the southern side of Ragabet El-Naam Fault.

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 was observed in the area near the domes. The higher value was observed in the area where there is no significant structural disturbance. The high value of the transmissivity is available in 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 Cetaceous is estimated at 30 x 10^9 m^3 under favourable conditions. The TDS is less than 1,500 ppm and the water level is within 300 m from the ground surface (Section 7-5, Main Report).

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. TDS determines the limit of the water use and the depth to the water determines the operation cost of the water source.

For this reason, 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 to the groundwater movement in 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, and the influence of the fault on the hydrogeological mechanism.

11-2 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 follow:

1) The assumptions derived from areas 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 unexploited 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 the 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.