3.7 Precambrian

Some springs are occurred in the Precambrian Basement Rocks in the areas such as St. Catherine, the Wadi Zalaga and the Wadi Watir areas. Their outlines are as follows.

Area	Name of Spring	TDS (mg/l)	Geological Situation
St. Catherine	El Rabba	160	Joints in the granite
Wadi Watir	Ain Furtaga	1088 - 1368	Fissures in the granite and contact zone with dorelite
Wadi Zaghara	Ain Umm Ahmed	5123	Contact zone between granite and dorelite

As shown above, groundwater springs out from the joints developed in the rocks and contact zone between granite and dolerite dykes. Dorelite dykes in the area are generally impervious, therefore, groundwater is dammed up by the dykes and springs out after reaching to the spring through the fissures and joints in the granitic basement rocks.

The spring, El Rabba is located in a church in St. Catherine. It springs from the joint of granite and its TDS is extremely low, 160 mg/l. Water type is classified as $MgSO_4$ type. On the other hand, Ain Umm Ahmed yields groundwater from the contact zone between granite and dorelite, however, TDS is high, 5,123 mg/l.

As mentioned in Chapter V, intensively developed lineament and dykes are observed in the Precambrian Rocks in several areas (Fig. 2.2-6).

(A) Ring structure

(B) Area, where minor lineaments are concentrated

(C) Area, where conjugate faults are well developed

Several springs and/or dug wells are distributed in/around these structures as shown in Fig. 3.7-1. They are as follows;

Structure		Area	Spring/Dug well
(A)	Ring structure	Ain Qaseby	Ain Qaseby, Ain El Malhah
(B)	Minor lineaments	G. Mikeimin/G. Mileihis	Ain Furtaga, Ain Umm Ahmed, Ain El Khudra, etc.
(C)	Conjugate faults	Oasis Feiran	A group of dug wells in Oasis Feiran and Tarfa

The Precambrian Rocks are impervious, however, groundwater will infiltrate to the fissures, joints and faults formed in the Rocks and flows down reaching to the Quaternary Wadi Deposits. Thus, the Precambrian rocks act like waterways for recharge to the Quaternary Aquifers.

Some springs and dug wells seem to be controlled by the existence of dykes; Dykes with open cracks will gather groundwater and dykes with no open cracks will act like a barrier against the groundwater flow in the rocks. The groundwater in the Precambrian Rocks, after all, discharges to the Quaternary aquifers in the wadis.

Basically it is almost impossible to develop groundwater directly from the Basement Rocks by wells. Springs are occurred in the Precambrian Basement Rock area. In most case of springs, its origin of groundwater is Precambrian Rocks and it is extracted from the Wadi Deposits. It is suggested that the Precambrian Basement Rocks act like conduit for groundwater to the Quaternary Aquifer. From this point of view, large scale of groundwater development in the Precambrian Rocks seems to be unrealistic.

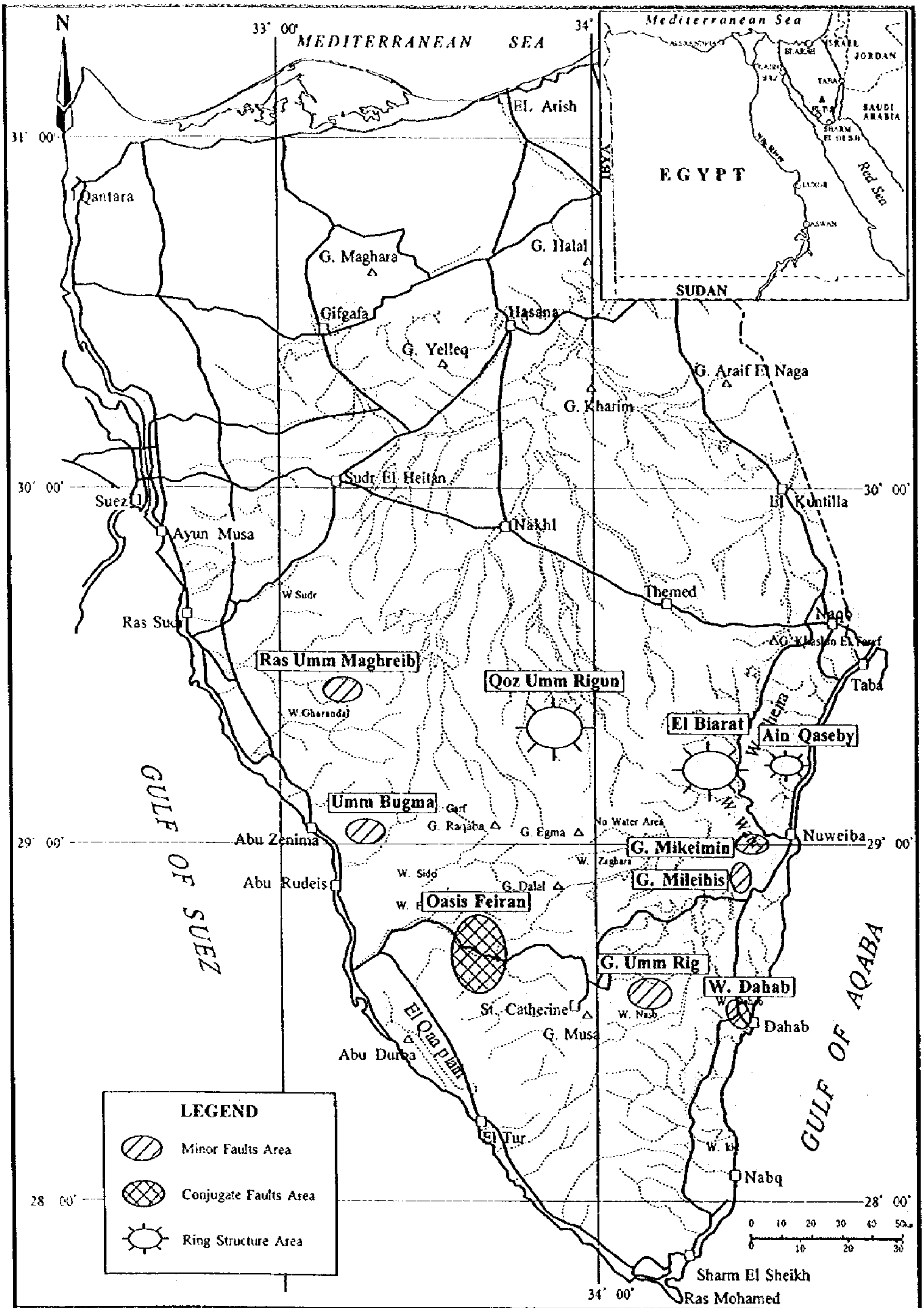

Fig. 3.7-1 Location of Typical Structures

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3.8 Type of Groundwater in South Sinai

A total of 56 chemical analysis data were classified into seven (7) water types: NaCl type, Na_2SO_4 type, $NaHCO_3$ type, $CaCl_2$ type, $CaSO_4$ type, $MgSO_4$ type and $MgCl_2$ type. Among them, the $MgCl_2$ type appeared only in winter season at Nuweiba. The result is shown in Table 3.8-1 and is drawn in Fig. 3.8-1.

3.8.1 Quaternary Aquifer

The major groundwater types of the Quaternary aquifer are $MgSO_4$ and NaCl. The groundwater type of $MgSO_4$ is distributed mainly in the inland of South Sinai such as St. Catherine, Tarfa, the Wadi. Feiran and several wadis in the east of the El Qaa Plain.

In the area where it covers St. Catherine to the Wadi Feiran, groundwater is recharged by the Precambrian distributed nearby. Five (5) wells, out of six (6) wells in the area, were classified as $MgSO_4$ type in winter. El Rabba spring has the lowest TDS of 160 mg/l and it belongs to this type. Same situation was found in the wadi areas in the El Qaa Plain, where groundwater in the three (3) wadis was also in this type except the Wadi Hibran.

On the other hand, the NaCl type is distributed mainly in the El Qaa Plain and Nuweiba Coastal Plain.

The most of $MgSO_4$ types in winter vary to $CaSO_4$ or $CaCl_2$ types in summer.

Considered the situation above, it seems that the $MgSO_4$ type represents the fresh water recharged from rainfall because most groundwater of low TDS belongs to this type and rainfall is concentrated in winter.

3.8.2 Upper Cretaceous Aquifer

Most groundwater belongs to the NaCl type. Only in El Malha area, groundwater type varies from $MgSO_4$ type in winter to NaCl type in summer. Groundwater in El Malha area receives recharge from the rainwater. This situation is same as the Quaternary Aquifer.

3.8.3 Lower Cretaceous Aquifer

A major groundwater type is NaCl followed by Na_2SO_4 and $CaSO_4$ type. The NaCl type is distributed mainly in Nakhl, Themed, a part of the Main Block and Wadi Feiran. Seasonal variation is not clear.

Table 3.8-1 List of Groundwater Types and TDS of Each Aquifer

<Quaternary Aquifer>

Well Identification						February-97		August-97	
No	Sr. No	Area	Code No.	Well Name (Spring)	Aquifer (lithology)	Water Type	TDS (mg/l)	Water Type	TDS (mg/l)
5	26	El Qaa	48BB-004	QAA15	Quaternary (S+G)	$CaCl_2$	420	$CaCl_2$	467
7	30	El Qaa	48BB-008	QAA21	Quaternary (S+G)	$CaCl_2$	490	NaCl	611
8	37	El Qaa	48-BB016	QAA29	Quaternary (S+G)	$CaCl_2$	425	$CaCl_2$	452
13	2	El Qaa	47EC-001	W. Hibran	Quaternary (S+G)	$CaCl_2$	900	$CaCl_2$	1424
14	3	El Qaa	47EC-002	W. Mir	Quaternary (S+G)	$MgSO_4$	685	$CaSO_4$	533
15	4	El Qaa	48CE-002	W. Thiman	Quaternary (S+G)	$MgSO_4$	834	dry	
16	5	El Qaa	48CE-001	W. Isra	Quaternary (S+G)	$MgSO_4$	765	NaCl	796
3	17	El Qaa	48AB-003	QAA8	Quaternary (S+G)	Na_2SO_4	1085	NaCl	1485
11	13	El Qaa	48AB-019	El Hag Sobahe	Quaternary (S+G)	Na_2SO_4	1250	$CaSO_4$	1643
1	2	El Qaa	37DE-001	PZ-8	Quaternary (S+G)	NaCl	4230	NaCl	4435
2	7	El Qaa	37EE-001	QAA10	Quaternary (S+G)	NaCl	1680	NaCl	2147
4	24	El Qaa	48BB-006	QAA12	Quaternary (S+G)	NaCl	588	NaCl	653
9	40	El Qaa	48CB-005	Abu Kalam	Quaternary (S+G)	NaCl	2124	NaCl	3899
10	26	El Qaa	48CB-012	M Abu Salem	Quaternary (S+G)	NaCl	3280	NaCl	2320
12	1	El Qaa	-	Hamam Musa	Quaternary (S+G)	NaCl	9378	NaCl	7572
6	28	El Qaa	48BB-007	QAA23	Quaternary (S+G)	$NaHCO_3$	448	$NaHCO_3$	483
17	27	Feiran	47CB-002	M. Salem 1	Quaternary (S+G)	$MgSO_4$	796	$CaCl_2$	666
18	48	Feiran	47CB-022	Refaay	Quaternary (S+G)	$MgSO_4$	694	$CaCl_2$	564
19	15	Talfa	47CE-005	Gomaa Khamis	Quaternary (S+G)	$MgSO_4$	590	$CaSO_4$	547
20	6	St Cat	47DE-002	Haroun Well	Quaternary (S+G)	$MgSO_4$	575	$CaSO_4$	646
21	7	St. Cat	57CA-004	Soyara 1	Quaternary (S+G)	$CaSO_4$	676	$CaCl_2$	628
22	23	St Cat	47DE-012	El Rabba Spring	Quaternary (S+G)	$MgSO_4$	194	$CaSO_4$	176
30	14	Sudr	25BC-009	A. K. Khamis	Quaternary (S+G)	$MgSO_4$	4360	NaCl	4565
26	5	Nuweiba	66DB-005	E. Hemyed	Quaternary (S+G)	$MgSO_4$	2092	$MgCl_2$	1950
27	21	Nuweiba	66EB-008	A. A. Hemad	Quaternary (S+G)	Na_2SO_4	3460	NaCl	3461
23	1	Watir	66DA-001	Furtaga-1	Quaternary (S+G)	$MgSO_4$	1368	$MgSO_4$	1361
24	16	Watir	66CE-001	Saleh Seleem	Quaternary (S+G)	$MgSO_4$	1802	$CaSO_4$	1325
25	2	Zalaga	-	Ainez Well	Quaternary (S+G)	$CaSO_4$	1796	$MgSO_4$	2087
28	1	Zaghara	57DC-001	Dug Well	Quaternary (S+G)	$CaSO_4$	880	NaCl	783
29		Dahab	-	Reservoir Tank	Quaternary (S+G)	$CaCl_2$	3972	NaCl	3170

<Upper Cretaceous Aquifer>

Well Identification						February-97		August-97	
No	Sr. No.	Area	Code No.	Well Name (Spring)	Aquifer (lithology)	Water Type	TDS (mg/l)	Water Type	TDS (mg/l)
1	40	Sudr	35AB-004	Ain Abou Ragem	Upper Cretaceous (LS)	NaCl	5650	NaCl	6419
2	2	Malha	45EA-001	A. A. Seleman Well (1)	Upper Cretaceous (LS)	$MgSO_4$	1648	NaCl	1700
3	3	Malha	45EA-002	A. A. Seleman Well (2)	Upper Cretaceous (LS)	$MgSO_4$	1572	NaCl	1657
4	2	El Tur	35BA-001	Hammam Faraoun	Upper Cretaceous (LS)	NaCl	12930	NaCl	14451
						As of Pumping Test			
5	13	Garandal	35ED-001	Gharandal-2	Upper Cretaceous (LS)	NaCl	1708		
6	43	El Tih	45CA-001	JICA-3	Upper Cretaceous (LS)	NaCl	6738		
7	46	El Tih	46AB-001	JICA-6	Upper Cretaceous (LS)	NaCl	2952		

<Lower Cretaceous Aquifer>

Well Identification						February-97		August-97	
No	Sr. No.	Area	Code No.	Well Name	Aquifer (lithology)	Water Type	TDS (mg/l)	Water Type	TDS (mg/l)
1	3	Sheira	65DA-001	Sheira-1	Lower Cretaceous (SS)	$CaSO_4$	1562	$CaCl_2$	1432
2	1	Ayun Musa	24EC-011	Ayun Musa	Lower Cretaceous (SS)	$MgSO_4$	2599	Na_2SO_4	3724
						As of Pumping Test			
3	41	El Tih	45BB-001	JICA-1	Lower Cretaceous (SS)	$CaSO_4$	1206		
4	42	El Tih	55CA-001	JICA-2	Lower Cretaceous (SS)	NaCl	1182		
5	43	El Tih	45CA-001	JICA-3	Lower Cretaceous (SS)	Na_2SO_4	470		
6	44	El Tih	55EA-001	JICA-4	Lower Cretaceous (SS)	Na_2SO_4	1047		
7	46	El Tih	46AB-001	JICA-6	Lower Cretaceous (SS)	NaCl	1520		
8	27	Nakhl	44ED-001	Nakhl-1	Lower Cretaceous (SS)	NaCl	1690		
9	28	Nakhl	44DC-001	Nakhl-2	Lower Cretaceous (SS)	$CaSO_4$	1630		
10	30	Nakhl	44DD-001	Nakhl-4	Lower Cretaceous (SS)	Na_2SO_4	1536		
11	31	Nakhl	44DD-002	Nakhl-5	Lower Cretaceous (SS)	NaCl	1614		
12	32	Nakhl	44DD-003	Nakhl-6	Lower Cretaceous (SS)	NaCl	1634		
13	33	Nakhl	44EC-001	Nakhl-7	Lower Cretaceous (SS)	NaCl	2210		
14	34	Nakhl	55BD-002	Nakhl-8	Lower Cretaceous (SS)	NaCl	1728		
15	9	W. Watir	56BE-001	Sheira-3	Lower Cretaceous (SS)	$CaSO_4$	1080		
16	10	W. Watir	56BE-002	Sheira-4	Lower Cretaceous (SS)	Na_2SO_4	1068		
17	14	W Feiran	37BE-001	Feiran-1	Lower Cretaceous (SS)	NaCl	784		
18	15	W Feiran	37BE-002	Feiran-2	Lower Cretaceous (SS)	NaCl	840		
19	34	Themed	55BD-002	Themed-1	Lower Cretaceous (SS)	NaCl	1728		

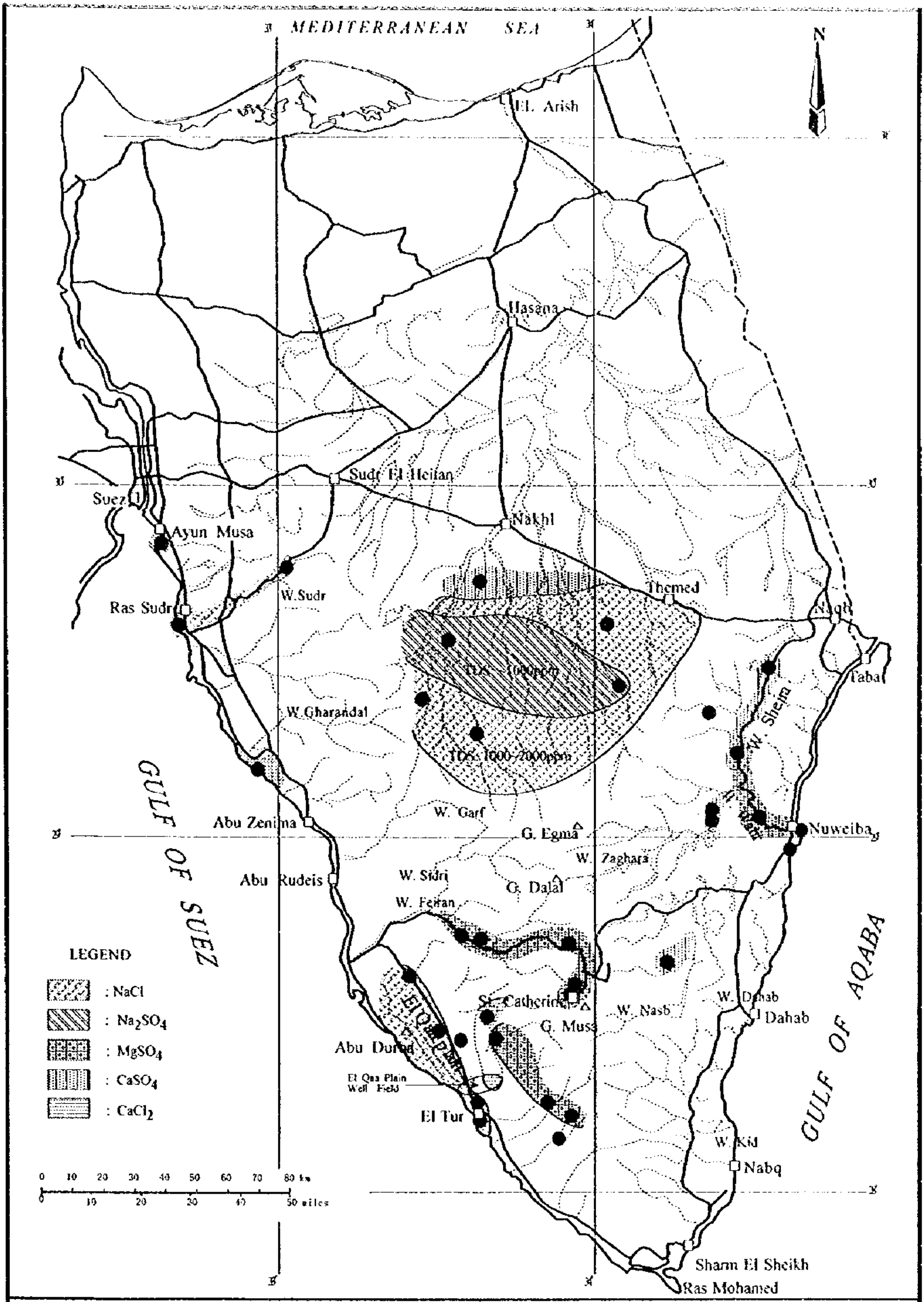

Fig.3.8-1 Distribution of Groundwater Type in South Sinai

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3.9 Isotope Analysis

Isotope analysis was conducted to grasp characteristic of groundwater, and the results are listed on Table 3.9-1. Isotope analysis is divided into radioactive isotopes and stable isotopes.

3.9.1 Radioactive Isotopes

Tritium, ^3H, is an unstable isotope of hydrogen with a half-life of 12.3 year. Prior to 1953, rainwater had less than 10 tritium units (TU: $^3H/\ ^2H = 10^{-18}$). For example, it was 5 TU at Rafaa in North Sinai in 1992. Tritium can be used in a qualitative manner to determine groundwater age in the sense that groundwater with less than 2 to 4 TU, is dated prior to 1953.

TU in the groundwater of the Lower Cretaceous is very low, therefore, it is considered that the Lower Cretaceous Aquifer received no or a limited groundwater recharge at least since 1953. On the other hand, it is considered that the groundwater in the El-Qaa Plain is recharged by recent precipitation.

According to the result of radiocarbon dating, the age of the groundwater in the Lower Cretaceous Aquifer ranges from 14,000± 2,000 Y.B.P to 27,000±2,000 Y.B.P. The age of them tends to be older from south to north in the study area. It becomes more older than 30,000 Y.B.P in North Sinai..

The age of groundwater in the Quaternary Aquifer is less than 1, 000 Y.B.P

3.9.2 Stable Isotopes

In general, five elements; hydrogen, oxygen, carbon, nitrogen and sulfur can be used to study geological process and surface water. Hydrogen and oxygen are selected in this study.

Results of stable-isotope studies are expressed as deviation (δ) in parts per thousand (‰) by the following formula.

$$\delta = \frac{R_{sample} - R_{standard}}{R_{standard}} \times 1000$$

If the value is positive, the sample is enriched with the heavy isotope relative to the standard. Negative means isotopically light.

Water (SMOW). The comparison is made by means of the parameter δ, which is defined as

$$\delta^{18}O(‰)=\left[\frac{(^{18}O/^{16}O)_{sample}}{(^{18}O/^{16}O)_{SMOW}}-1\right]\times10^3 \qquad \delta^2H(‰)=\left[\frac{(^2H/^1H)_{sample}}{(^2H/^1H)_{SMOW}}-1\right]\times10^3$$

When δ^2H is plotted as a function of $\delta^{18}O$ for water continental precipitation origin, an experimental linear relationship is found. It is described by the equation below (Yurtsever & Gat, 1981)

$$\delta^2H=8.2\delta^{18}O+10.8$$

This is known as the global meteoric water line. Continental precipitation samples will tend to group close to this line. Precipitation falling in areas with lower temperatures will tend to have lower δ^2H and $\delta^{18}O$ values.

Fig. 3.9-1 shows that A group is close to the global meteoric line but B group is somewhat away from the line. J-6 is located between A and B. A group consists of groundwater in the Lower Cretaceous Aquifer and B group includes the groundwater in the Quaternary Aquifer. Then, paleo- temperature of the groundwater in the Lower Cretaceous was cooler than that of B group. There is another evidence, which supports above as shown in Fig. 3.9-2. Relationship between Mean Annual Air Temperature and $\delta^{18}O$ is expressed as following formula.

$$\delta^{18}O = 0.3387\,T - 11.99$$

On the basis of the figure, Mean Annual Air Temperature of A and B groups ranges from 8.9°C to 12.5°C and from 16.7°C to 20.3°C respectively. The groundwater of A group's aquifers was recharged in about 8°C cooler environment than B group in the Würm glacial stage.

It is well known that the seawater level went down in glacial stage all over the world. Fluctuation of seawater level in the Würm glacial stage is shown in Fig. 3.9-3. The range of the groundwater age in the Lower Cretaceous Aquifer is shown in the figure. It indicates that the aquifer was recharged around the climax of the glacial stage.

Table 3.9-1 Results of Isotope Analysis

Group	Site	T (°C)	δ ^{18}O (SMOW)	T (°C)	δ ^{2}H (SMOW)	Nature	Aquifer	14C-Age(year)
A	Neckel-5	8.9	-8.99	10.7	-57.90	well	Low.Cretace	27000±2000
	Sadr Al-Hetan	10.5	-8.44	12.4	-53.00	well	Low.Cretace	26000±2000
	JICA-2	10.5	-8.43	11.0	-56.90	well	Low.Cretace	23200±2000
	JICA-1	10.6	-8.41	10.4	-58.61	well	Low.Cretace	20000±2000
	JICA-3	11.4	-8.12	11.7	-55.10	well	Low.Cretace	21500±2000
	Wadi Sheira	11.7	-8.04	11.9	-54.40	well	Low.Cretace	22000±2000
	JICA-4	12.5	-7.77	12.3	-53.39	well	Low.Cretace	18000±2000
B	Sahl El-Qaa 12	16.7	-6.33	20.1	-31.90	well	Quaternary	-
	JICA-6	17.1	-6.20	16.1	-42.77	well	Low.Cretace	14000±2000
	Sahl El-Qaa 8	17.4	-6.11	19.5	-33.50	well	Quaternary	-
	Saint Catherine	17.4	-6.11	22.7	-24.60	spring	Precambrian	-
	Ain Umm-Ahmed	19.9	-5.25	23.3	-23.00	spring	Wadi Deposit	-
	Ain Mir	20.3	-5.13	25.2	-17.70	spring	Wadi Deposit	-

A: Lower Cretaceous B: Quaternary or Spring

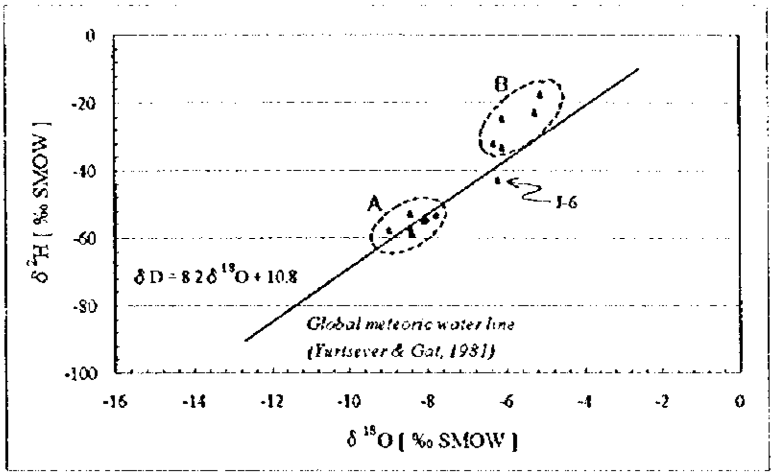

Fig. 3.9-1 Relationship between δ^2H and $\delta^{18}O$

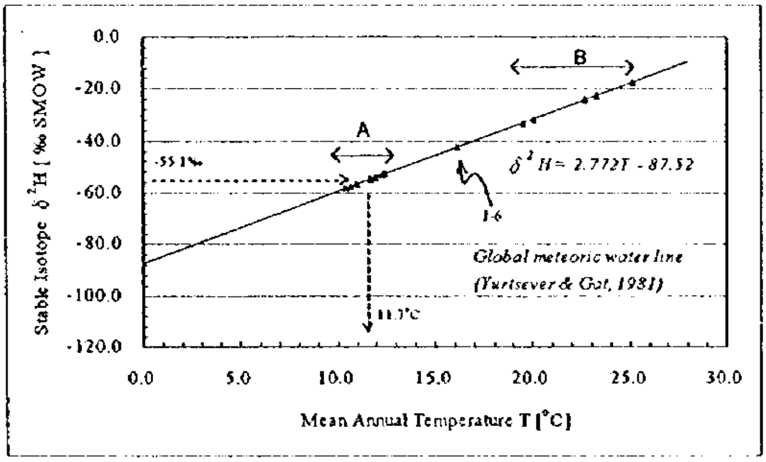

Fig. 3.9-2 Relationship between δ^2H and Mean Annual Temperature

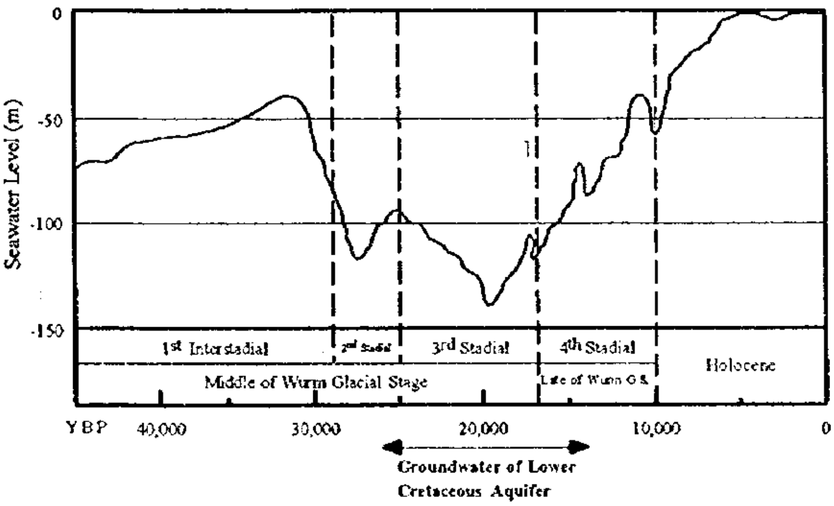

Fig. 3.9-3 Fluctuation of Seawater Level in the Würm Glacial Stage and Groundwater (Lower Cretaceous Aquifer)

CHAPTER IV GROUNDWATER POTENTIAL AND EVALUATION

4.1 Quaternary Aquifer in El Qaa Plain

4.1.1 Existing Water Balance

1) Recharge to El Qaa Plain

Sources of recharge to the El Qaa Plain are the Precambrian Basement Rocks, the Mesozoic Sedimentary Rocks and the Wadi Deposits that are distributed in the eastern side of the plain. Rain water precipitates mainly on the Precambrian Basement Rocks. Some amount of rainfall is lost as evaporation from the ground surface. Residual amount of rainwater infiltrates into underground through faults and fissures developed in the basement rocks. Some of fissure water reaches the El Qaa Plain and directly recharges the aquifer. A part of infiltrated rainwater recharges the Wadi Deposits. Groundwater in the Wadi Deposits reaches the El Qaa Plain.

The annual average flow rate was estimated as follows based on the estimation by BRGM/WRRI (1993b) and Hatem (1996).

Area	Wadi Name	Estimated Recharge (m^3/day)	Estimated Recharge (m^3/year)
Limestone Area			
	Abu Reymate	176.5	64,409
	El Rawd	273.2	99,709
	Thogra	105.6	38,540
	Umm Gurdy	133.7	48,801
	Abora	433.6	158,248
Sub-total		1,122.5	409,707
Basement Area-1			
	Gebaa	792.8	289,390
	Warka	578.5	211,153
Sub-total		1,371.4	500,543
Basement Area-2			
	Hibran	1,124.7	410,509
	Mir	2,255.3	823,196
	Mnhy	1,654.2	603,774
	Wargan	3,529.8	1,288,379
	Shadak	3,759.3	1,372,160
	Emlaha	1,357.9	495,635
Sub-total		13,681.2	4,993,653
Total		16,175.1	5,903,903

2) Outflow to Sea

No surface water directly flows out to the sea. Only groundwater discharges to the sea near El Tur. Its amount is estimated as 2.47 x 10^6 m^3/year.

3) Groundwater Consumption

The water resources in the El Qaa Plain is consumed for municipal water of El Tur and Sharm El Sheikh and irrigation water in the plain.

Groundwater extraction in the El Qaa Plain was more than 8,000 m^3/day (=2.92 x 10^6 m^3/year) since 1984. Extraction rate in 1997 was estimated to be 9,415 m^3/day (= 3.44 x 10^6 m^3/year) as shown below.

(unit: m^3/day)

Domestic water for El Tur	Domestic water for Sharm El Sheikh	Irrigation	Dug wells	Total	
				(m^3/day)	(m^3/year)
6,000	1,000	451	2,000	9,415	3.44 x 10^6

4) Water Balance

The existing water balance of the El Qaa Plain is calculated as follows.

	(x 10^6 m^3)
Recharge (m^3/year)	5.9
Extraction (m^3/year)	3.4
Outflow to Sea (m^3/year)	2.5
Balance	0.0

4.1.2 Groundwater Development Potential

As mentioned above, it is concluded that the groundwater in the El Qaa Plain is keeping balance between recharge amount and discharge amount. The result suggests that there is no surplus amount of groundwater for further development in terms of sustainable development.

On the other hand, more groundwater development will be required by increasing population in El Tur and future development in agricultural sector in the El Qaa Plain. Therefore, following countermeasures are examined to meet the increasing water demand.

(1) to allow a certain degree of decreasing in groundwater level

(2) to allow a certain degree of increase in TDS

(3) to prevent saline water intrusion to prospective aquifer area by constructing new wells

Increase of groundwater extraction may cause negative impacts in the area. Constraints on water balance, environment and economy are discussed base on the groundwater simulation.

4.1.3 Groundwater Simulation

(1) General Procedure of Groundwater Simulation

Based on hydrogeological investigation, northern part of the El Qaa plain was selected as simulation area. Prospective aquifer area is selected in the area in NNE direction from El Tur considering influence to the existing well field.

Groundwater simulation study is composed of aquifer model construction, calibration, prediction and evaluation. An aquifer model is constructed with field data manipulated for computer input. After calibrating the model with observed data, prediction of water level and quality is executed inputting future withdrawal plans. Predicting results are evaluated for development potential considering water balance, environmental impact and economics.

(2) Simulation Model and Boundary Conditions

The second and third aquifers were modeled in finite difference three-dimensional manner.

Basic equations applied to the simulation were as follows.

i) Basic Equation for Groundwater Flow

The unsteady-state, three-dimensional movement of groundwater through heterogeneous and anisotropic porous media is described by the following partial-differential equation.

$$\frac{\partial}{\partial x}\left(Kxx\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(Kyy\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(Kzz\frac{\partial h}{\partial z}\right)-W=Ss\frac{\partial h}{\partial t}$$

Where, Kxx, Kyy and Kzz: values of hydraulic conductivity along the x, y and z coordinate axes, h: the potentiometric head, W: a volumetric flux per unit volume and represents source and/or sink of water, Ss: the specific storage of the porous media, t: time.

ii) Basic Equation for Solute Transport

The basic equation governing three-dimensional solute transport in groundwater can be written as follows.

$$\frac{\partial}{\partial x_i}\left(D_{ij}\frac{\partial C}{\partial x_j}\right)-\frac{\partial}{\partial x_i}(v_iC)+\frac{q_s}{\theta}C_s+\sum R_k=\frac{\partial C}{\partial t}$$

Where, C: solute concentration, t: time, xi: distance along the respective Cartesian coordinate axis, D_{ij}: hydrodynamic dispersion coefficient, v_i: linear pore water velocity, q_s: volumetric flux of water per unit volume of aquifer representing sources (positive) and sinks (negative), C_s: concentration of the sources or sinks, θ : porosity of the porous medium, ΣR_k: chemical reaction term.

iii) Boundary Condition

Eastern boundary was constant flux and fixed concentration of recharge water. Northern and western boundary (mountains) were no flux. At western boundary (Gulf of Suez), constant head and constant concentration were employed. No flux boundary was adopted at the south.

iv) Input Data

Aquifer constant, pumpage, and recharge rate were inputted for each cell, manipulating from hydrological and hydrogeological studies. Groundwater pumpage in the El Qaa plain amounts to 9415 m^3/day (domestic: 6000 m^3/day, water to Sharm El Sheik: 1000 m^3/day, irrigation: 415 m^3/day, dug wells: 2000 m^3/day).

v) Calibration

No variation of water level has been observed since 1989, steady-state flow was calibrated with model. Salinity is major problem in the El Qaa plain, so then TDS was selected as water quality index. Average distribution of TDS was simulated by a solute transport model.

vi) Prediction

According to the future development plan, five (5) cases of groundwater extraction were predicted. Domestic use is assumed for cases 1 to 4, and 5 is assumed to develop for irrigation. Prediction period is 120 years (20 years for increasing extraction and 100 years for maintaining constant extraction).

Conditions of each Case are as follows.

Unit: 10^6 m^3/year

	R	S	Total	P1	P2	D	Total
Present	5.90	0.00	5.90	3.44	0.00	2.47	5.91
Case 1	5.90	3.36	9.26	7.30	3.86	2.10	9.40
Case 2	5.90	2.01	7.92	5.48	2.04	2.34	7.81
Case 3	5.90	1.01	7.01	4.56	1.12	2.49	7.05
Case 4	5.90	0.36	6.26	3.65	0.21	2.62	6.27
Case 5	5.90	2.09	7.99	5.48	2.04	2.42	7.89

R: Recharge, S: Decrease of Storage (Water released from groundwater storage due to drawdown), P1: Present Pumpage, P2: Increase of Pumpage, D: Flow out to Sea

In the above Case 1 to 5, groundwater for domestic water supply is planned to product in the prospective aquifer area. In case of Case 5, plan of irrigation water is added to the Case 2 for prevention of saline water intrusion to the prospective aquifer area from the north of the El Qaa Plain where saline water is widely distributed.

vii) Evaluation of Prediction Results

Evaluation criteria applied to the prediction results are as follows.

<Criteria for Water Balance Constraint>

Rank	Annual Residual Drawdown (m)	Description
A	0.00 - 0.02	Not surely safe, but allowable if there is no alternative plan
B	0.03 - 0.1	The aquifer storage will be possibly depleted in future
C	0.1 <	The aquifer storage will be probably depleted in near future

<Criteria for Environmental Constraint>

Rank	TDS	Description
A	< 1,000	Good : Good quality
B	1,000 -1,500	Allowable : Slightly poor quality, but not exceed drinking water quality standards
C	1,500 <	Not allowable : Exceed drinking water quality standards

<Criteria for Environmental Constraint>

Rank	Total Residual Drawdown (m)	Description
A	0.00 - 0.50	Allowable: No problems for practical use
B	0.51 - 2.00	Undesirable : Partly damaged
C	2.00 <	Not allowable : Damaged

Results of the model simulation of each case are summarized as bellow:

Case	Pumpage (m^3/day)	Add (m^3/day)	Water Balance	Water Quality	Environmental Impact	Economic
1	20000	10585	UD	A	NA	G
2	15000	5585	UD	G	NA	G
3	12500	3085	A	G	UD	G
4	10000	585	A	G	A	G
5	15000	5585	UD	G	NA	G

Remarks; G=Good, A=Allowable, UD=Undesirable, NA=Not Allowable
Pump: Total pumpage, Add: Additional pumpage

From the above results, both development plan of Case 3 and Case 4 are acceptable. In Case 3, additional groundwater abstraction amounts to about 3,000 m^3/day. This value will be a groundwater extraction potential in the El Qaa Plain. However, it can be expected that the development causes slight influence on the existing dug wells. Results of simulation on water level, drawdown and TDS in Case 3 and 4 are shown in Fig. 4.1-1 (1) and (2), respectively.

Comparing with Case 2, results of Case 5 indicate that extraction for irrigation at the north of domestic well field is effective to preserve the existing domestic wells.

4.2 Lower Cretaceous

4.2.1 Water Balance

Water balance of the Lower Cretaceous is estimated by following equations:

$$\Delta S = R - (Q + O_N) \quad (4.2.1\text{-}1)$$

where, ΔS: groundwater storage increment/deficit, R: recharge to the aquifer, Q: total extraction and O_N: outflow from South Sinai to North Sinai

As discussed in Chapter III, recharge to the Lower Cretaceous is negligibly small which is nearly equal to zero. R is, therefore, considered as zero.

1) Main Block

Present total extraction from the Main Block of the Lower Cretaceous is 760,000 m^3/year. O_N is estimated as 1.38×10^6 m^3/year using following equation.

$$O_{N,G} = L_{(\text{flow section})} \times b_{(\text{aquifer thickness})} \times K_{(\text{permeability})} \times (\Delta h/\Delta x)_{(\text{hydraulic gradient})}$$

where, L: 100 km, b: 240 m x 0.62 % = 149 m and $\Delta h/\Delta x$: 0.4/1000

Therefore, equation (4.2.1-1) is,

$$\Delta S = 0 - (760{,}000 + 1{,}380{,}000) = -2{,}140{,}000\ (m^3/\text{year})$$

The result shows that the Main Block decreases its volume a total of 2.14×10^6 m^3 every year.

2) Sheira Block

A total of 360,000 m^3/day of groundwater is extracted by four (4) wells. No periodical water level data is available. Therefore, water balance in this area is still unknown.

3) Feiran Body

In the Wadi Feiran area, six (6) wells are producing 720,000 m^3/day of groundwater. Furthermore, new production wells are under construction. However, periodical monitoring of groundwater level is not carried out. Only extraction data is available. Therefore, water balance in this area is still unknown.

4.2.2 Development Potential of Main Block

Storage of groundwater is estimated as 98×10^9 m^3. Present deficit of water balance is 2.38×10^6 m^3/year as discussed above. In order to evaluate the groundwater development potential of the Main Block, available volume of groundwater is estimated under the following conditions.

(1) Recharge to the aquifer is neglected considering the safety side.

(2) Outflow from South Sinai to North Sinai through the Ragabet El-Naam Fault is estimated as 1.38×10^6 m^3/year.

(3) Outflow to Gharandal Sub-Block is ignored to make estimation simplified.

(4) Groundwater will be developed in the area from Nakhl to its southern adjacent area.

(5) Groundwater table decreases keeping present gradient of water table.

(6) It is able to extract groundwater till water level becomes 400 mBGL at Nakhl considering the maximum ability of existing submersible pump.

For estimation above, a groundwater profile was prepared as Fig. 4.2-1. Present water level of the Well Nakhl-5 is 199 mBGL (190 mASL) and that of the southernmost fringe of groundwater is 275 mASL. When the condition 4) above is applied, allowable groundwater recession is 201 m. This recession causes migrations of water front about 9 km toward the north from the present location. Fig. 4.2-1 also shows the total storage of groundwater in the Main Block and exploitable volume against water level recession from the present water level.

Groundwater potential is a total volume which is stored in the aquifer between present water front and shifted water front (9 km north from the present water front). It is estimated as 13×10^9 m^3 which is 12 % of total storage of the Main Block.

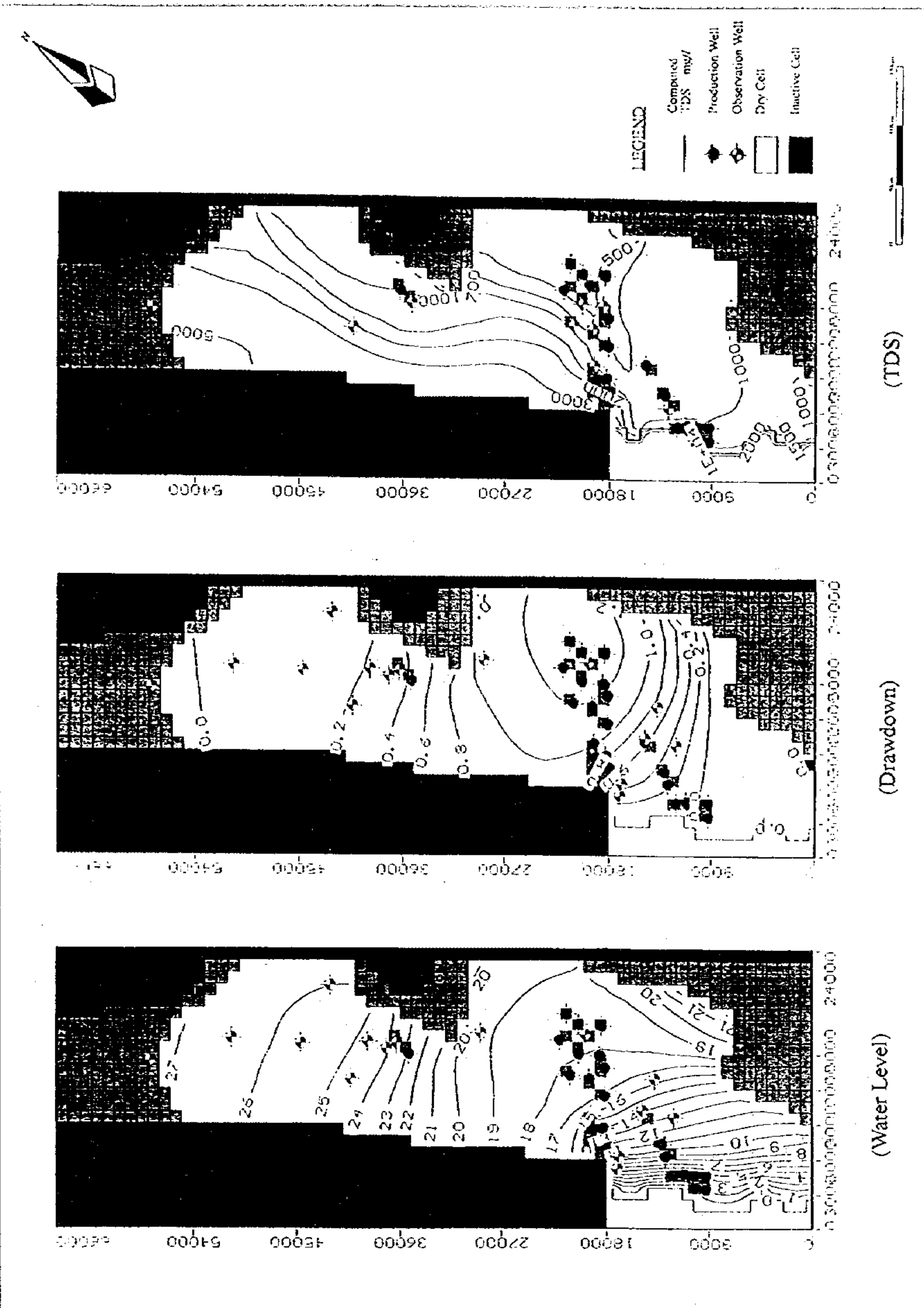

Fig. 4.1-1 (1) Groundwater Simulation Results after 120 Years in El Qaa Plain (Case 3)

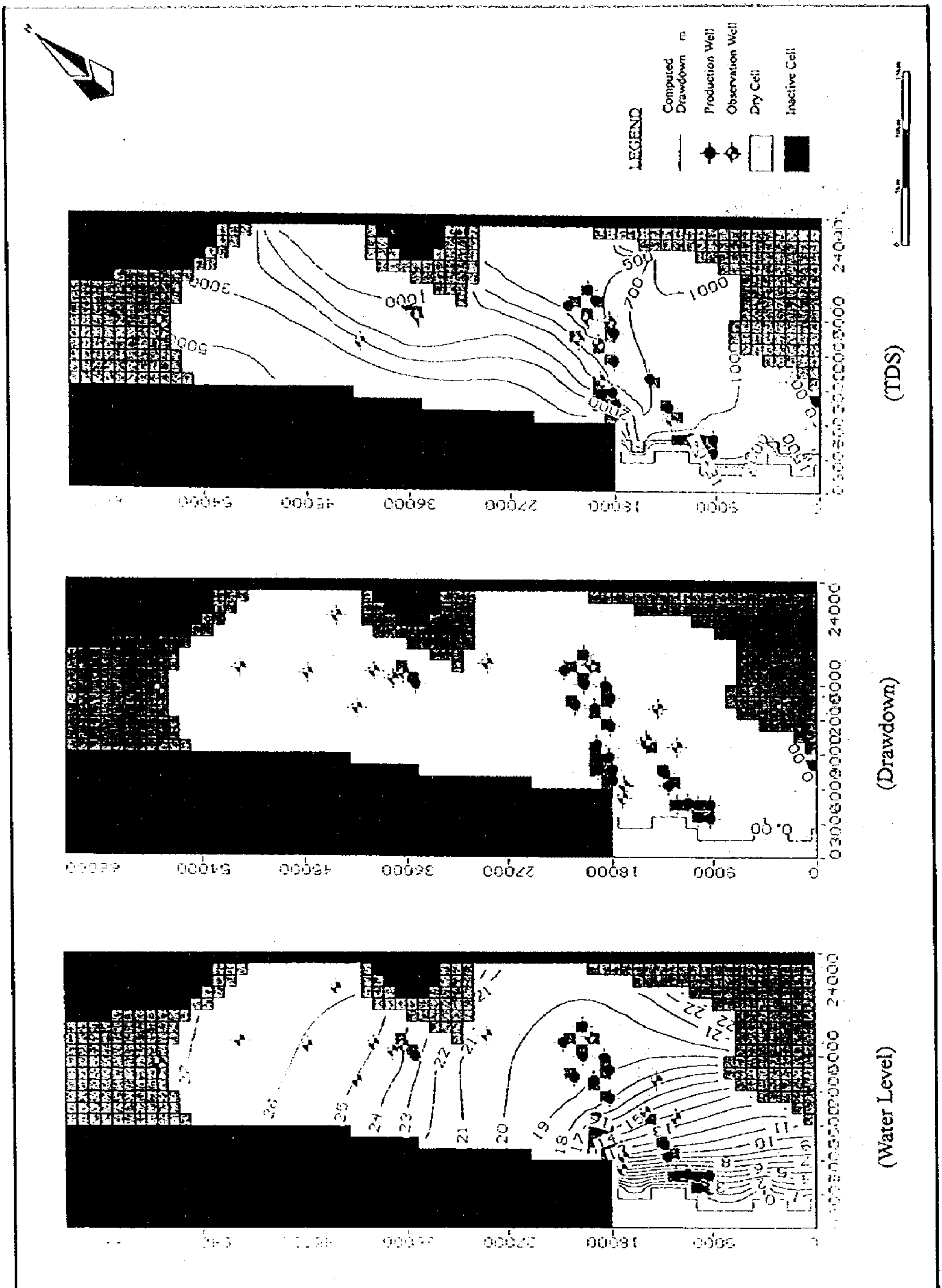

Fig. 4.1-1 (2) Groundwater Simulation Results after 120 Years in El Qaa Plain (Case 4)

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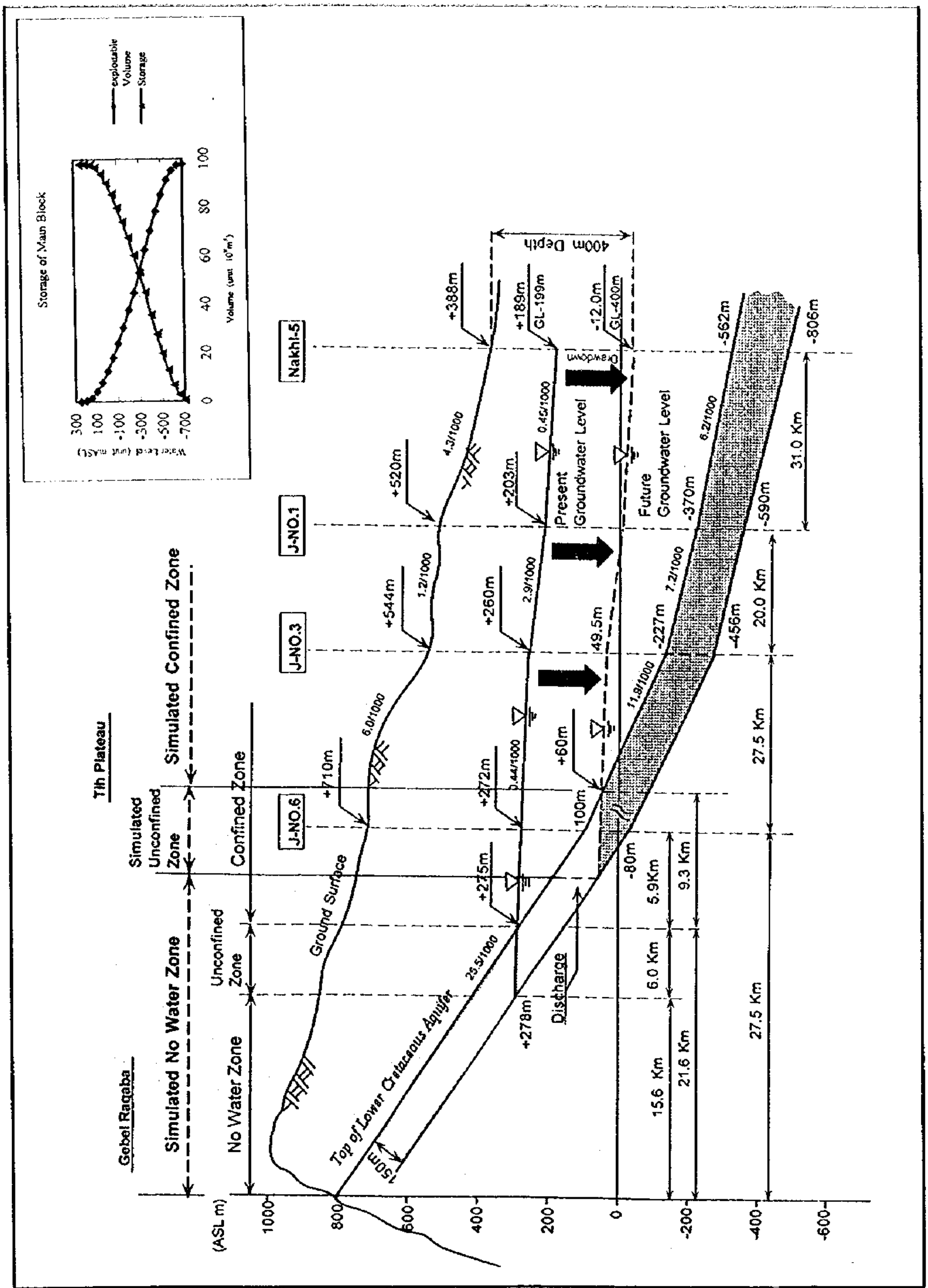


Fig. 4.2-1 Section of Simulated Groundwater Level and Storage (Lower Cretaceous)

CHAPTER V EXISTING WATER USE AND FUTURE WATER DEMAND

5.1 Existing Domestic Water Supply and Sewerage System

5.1.1 Water Supply System

1) Outline of Water Supply System

Domestic water is supplied in eight (8) cities in South Sinai, such as El Tur, Sharm El Sheikh, Dahab, Nuweiba, St. Catherine, Abu Rudeis, Abu Zenima and Ras Sudr. They are operated and maintained by Municipalities and New Communities, Housing and Public Utilities in the Ministry of Development (hereinafter referred to as MOD).

Sources of domestic water supply are divided into three (3) categories.

(1) Purified Nile water for Ras Sudr, Abu Zenima and Abu Rudeis

(2) Desalinated sea water for Sharm El Sheikh, Nuweiba and Dahab

(3) Groundwater for El Tur, St. Catherine, Nuweiba, Dahab and Bedouin communities

Among them, groundwater in El Tur and St. Catherine is suitable for potable water. However, that of Nuweiba and Dahab is saline so that it is used for domestic use except drinking.

Served area, population served, water sources are as follows.

City	Served Area (km^2)	Population		Water Source
		Resident (cap)	Tourists (cap/day)	
El Tur	13.0	16,055	188	groundwater
Sharm El Sheikh	1.3	8,163	15,056	sea water, groundwater
Dahab	10.5	4,262	1,813	sea water, groundwater
Nuweiba	8.5	6,416	3,204	groundwater, sea water
St. Catherine	3.1	4,785	1,058	groundwater
Abu Rudeis	5.9	8,436	0	Nile River
Abu Zenima	1.9	6,318	0	Nile River
Ras Sudr	4.2	7,374	1,673	Nile River
Total	48.4	61,809	22,992	

The water is transmitted to the distribution reservoir or elevated water tank from each source. Then, it is distributed by gravity.

Ras Sudr, Abu Zenima and Abu Rudeis are supplied water from the Nile River through the treatment plant in Suez. The main transmission pipeline to these cities is ductile cast iron pipe of 600 mm diameter. The pipeline has been extended to El Tur and will be extended to Sharm El Sheikh till 1998. Moreover, another main transmission pipeline for the Nile water is under planning from Suez to Abu Rudeis as a secondary pipeline.

In case of the rural communities of the Bedouin people, water supply is carried out in the following two (2) manners.

(1) Rural communities near the city area: supplied by water tank lorries
(Wadi Village, Abu Suweira, etc.)

(2) Other communities: supplied by dug wells constructed in and near the communities
(Wadi Saal, Wadi Nasb, Wadi Isla, Wadi Mir, Sheikh Attia, etc.)

2) Standard for Potable Water

Unit water demands are decided quoting a similar project "The Urgent Development Plan of the Suez Bay Coastal Area Development" by MOD.

Standard for potable water supply is Drinking Water Quality Standard in Egypt.

3) Water Production and Consumption

The quantity of water production, consumption by category and losses as unaccounted water in 1998 are summarized in the table below.

<Production and Consumption of Potable Water>

[Unit : m^3/day]

City Name	Water Source	Production Capacity	Water Demand in 1997					Surplus/ Deficit
			Residents	Tourist	Others*1	Loss	Total	
El Tur	Groundwater	6,000	4,014	120	1,498	240	5,872	128
Sharm El Sheikh		10,260	2,041	9,590	2,561	410	14,602	-4,342
	Groundwater	1,000						
	(from El Tur City)							
	Seawater	9,260						
Dahab		2,000	1,066	1,155	499	80	2,800	-800
	Groundwater*2	[500]	[500]				[500]	
	Seawater	2,000						
Nuweiba		3,560	1,604	2,041	639	102	4,386	-826
	Groundwater*2	[2,700]	[2,700]				[2,700]	
	Spring Water	2,560						
	Seawater	1,000						
St. Catherine	Groundwater	450	1,196	674	112	18	2,000	-1,550
Abu Rudeis	River Nile	2,750	2,109	0	661	110	2,880	-130
Abu Zenima	〃	2,700	1,580	0	424	68	2,072	628
Ras Sudr	〃	6,100	1,844	1,066	1,523	244	4,677	1,423
Total		33,820	15,454	14,646	7,917	1,272	39,289	-5,469

Note: 1) *1: Mainly for industrial, public office, shops, restaurants
2) *2: Brackish water

The water supply quantity compared with the present water demand is generally showing a tendency of shortage in supply. The total shortage amounts to about 5,500 m^3/day as of 1997. Therefore, a restriction on water consumption is carried out in Sharm El Sheikh and Nuweiba cities throughout the year.

In accordance with above table, the total water production capacity in the eight (8) cities is about 33,820 m^3/day and more than 97 percent of above capacity is accounted for urban area. The water losses, as unaccounted water indicated above, consist of physical leakage and commercial losses, including the unbilled water consumption occurring in the residential category as a result of meters in poor operating conditions.

4) Organization, Operation and Maintenance

(1) Organization

The management of the water supply system including the public sewerage system is under the responsibility of MOD. However, as a special measure, there are water supply facilities that are owned and managed by private firms, such as some desalination treatment plants and pipe distribution network for private hotels in Sharm El Sheikh city.

Concerning public water supply system, planning, design and construction of the major facilities are performed by MOD, while the construction of small water supply systems and operation and maintenance for all facilities are conducted by the respective Municipality, though there are some exceptions.

(2) Division of Responsibility for Water Supply System

The division of responsibility for water supply system is basically formulated according to the scale and/or degree of difficulty of planning, construction, operation and maintenance as well as ownership.

5) Water Tariff

(1) Water Tariff Structure

The water tariff in South Sinai is basically set by the South Sinai Governorate. Although the Municipalities have some authority to set their own tariff. In effect, a water tariff is set based on the following significant factors such as type of water source, water supply method, water supply capacity and distinction of consumers.

The water tariff structure contemplates imposing the following charge to the consumers:

(i) Fixed Charge for Water and Sewerage: This charge is independent of the water and sewerage service reception.

(ii) Fixed "Client Charge": This charge is to cover the expense incurred by Municipalities when attending a client like water meter reading, inspection, etc.,

(iii) Variable Charge: This charge is based on the amount of water consumption measured in cubic meters.

(2) Present Water Tariff

The unit water tariff of residents is fixed by the amount of water consumption, while a uniform charge is applied for other type of consumers like commerce, institution and industries.

5.1.2 Sewerage System

The sewerage system is working in four (4) cities, El Tur, Sharm El Sheikh, Dahab and Nuweiba. In Sharm El Sheikh, an expansion works of the sewerage system is under construction. Construction works are undergoing in other four (4) cities, St. Catherine, Abu Rudeis, Abu Zenima and Ras Sudr. No sewerage system is provided in the rural areas.

The sewerage system in South Sinai is basically classified into the three (3) cases mentioned below.

Case 1 : Collected wastewater is treated in wastewater treatment plant.

Case 2 : Collected wastewater is infiltrated into natural soil following primary treatment.

Case 3 : Collected wastewater is transported by lorries and disposed in the desert.

Oxidation pond system is the treatment method used in all the wastewater treatment plant except the irrigation use, which is the most appropriate in consideration to the availability of extensive land area in South Sinai and the simplicity of operation and maintenance requirement of the WWTP.

The treated wastewater is lost due both atmospheric evaporation and subsurface infiltration resulting in no discharge to sea, river or lake. The treated wastewater is reused for irrigation use although it supplies to the plantation of trees only.

5.2 Future Water Demand

5.2.1 Future Development Plan

The Sinai Peninsula is one of the strategically important places in terms of development. The Government of Egypt decided a strategic development plan, "National Project for the Development of Sinai" (NPDS) in 1994. The target year of the NPDS is 2017.

Future water demand was estimated regarding the NPDS as a given condition.

5.2.2 Estimation of Future Water Demand

1) Estimation of Development in Sectors

The water usage in South Sinai is divided into four categories: residential use, tourism use, industrial use and agricultural use. Future water demand was estimated based on the following three (3) conditions.

Case	Residential Use	Other Uses
1	As planned in NPDS	As planned in NPDS
2	60 % value of NPDS	As planned in NPDS
3	Estimation based on Census data in 1986 and 1996	As planned in NPDS

(1) Population Growth

As mentioned above, future population growth is estimated in three (3) cases mentioned above. Projection of population growth is shown in Fig. 5.2-1. The results are shown in the table below.

	City Name	1996	2017		
			Case 1	Case 2	Case 3
1	El Tur	14,155	110,023	66,014	72,227
	Urban / Rural	12,072 / 2,083	104,522 / 5,501	62,713 / 3,301	68,616 / 3,611
2	Sharm El Sheikh	7,197	131,846	79,108	179,426
	Urban / Rural	4,799 / 2,398	125,254 / 6,592	75,152 / 3,955	170,455 / 8,971
3	Dahab	3,758	90,143	54,086	22,765
	Urban / Rural	1,077 / 2,681	82,932 / 7,211	49,759 / 4,327	15,554 / 7,211
4	Nuweiba	5,657	113,969	68,381	33,841
	Urban / Rural	2,405 / 3,252	104,851 / 9,118	62,911 / 5,471	24,723 / 9,118
5	St. Catherine	4,219	17,378	12,165	6,324
	Urban / Rural	754 / 3,465	13,034 / 4,345	7,820 / 4,345	1,980 / 4,345
6	Abu Rudeis	7,438	10,043	10,043	16,217
	Urban / Rural	4,152 / 3,286	6,026 / 4,017	6,026 / 4,017	9,730 / 6,487
7	Abu Zenima	5,570	6,026	6,026	19,992
	Urban / Rural	2,645 / 2,925	2,832 / 3,194	2,832 / 3,194	9,796 / 10,196
8	Ras Sudr	6,501	219,776	131,866	9,626
	Urban / Rural	1,419 / 5,082	195,601 / 24,175	117,360 / 14,505	2,214 / 7,412
	Total	54,495	699,204	427,688	360,418
	Urban / Rural	29,323 / 25,172	635,051 / 64,153	384,574 / 43,114	303,067 / 57,351

(2) Tourism

The major tourist resort zones in South Sinai are located along the coast area of the Gulf of Aqaba and the Gulf the Suez, with an abundance of marine attractions. The most representative one is Sharm El Sheikh followed by Nuweiba and Dahab. In addition, Ras Sudr and its adjacent area recently show rapid growth in tourism. St. Catherine is another attraction area close to "Gebel Musa". Total tourist number in 1997 reached approximately 23,000 capita per day.

Its growth is estimated as the table below.

(Unit : capita/day)

City Name	1997	2002	2007	2012	2017
El Tur	188	451	556	661	713
Sharm El Sheikh	15,056	17,718	18,605	19,492	20,379
Dahab	1,813	4,737	6,687	8,636	9,611
Nuweiba	3,204	8,338	10,905	13,472	15,183
St. Catherine	1,058	1,544	1,739	1,933	2,030
Ras Sudr	1,673	4,142	6,611	9,079	11,548
Total	22,992	36,929	45,101	53,273	59,465

(3) Estimation of Industrial and Other Development

Present main industry in South Sinai is petroleum, mining, building material production, and mechanical and electrical appliance

According to the NPDS, development seems to be planned mainly in the field of mining, chemical and construction material. However, its figure is not clear.

Estimation of development area in the sector is estimated as follows.

(Unit : hectare)

City Name	1997	2002	2007	2012	2017
El Tur	10	12	15	18	21
Ras Sudr	10	12	15	18	21
Total	20	24	30	36	42

(4) Estimation of Agricultural Land Expansion

Existing agricultural lands are distributed in the El Qaa Plain, the Wadi Feiran, the Ras Sudr Coastal Plain and the Nuweiba Coastal Plain. Expansion of those agricultural land and development of new agricultural land are planned in the NPDS as shown below.

(Unit : hectare)

Area	1996	1997	2002	2007	2012	2017
El Qaa Plain	336	346	363	546	689	887
Wadi Feiran	84	87	88	93	98	103
Ras Sudr	63	65	157	214	264	300
Nuweiba	105	108	118	156	210	294
Abu Zenima	0	0	20	21	21	21
Wadi Gharandal	0	0	33	45	55	63
Ras Nasrani	0	0	55	75	92	105
Dahab	0	0	155	216	282	315
Wadi Watir	0	0	67	89	120	168
Malha 1	0	0	121	165	203	231
Malha 2	0	0	121	165	203	231
Malha 3	0	0	199	270	333	378
Themed	0	0	375	510	628	714
Sudr El Heitan	0	0	375	510	628	714
Total	588	606	2,249	3,074	3,826	4,524

2) Estimation of Future Water Demand

(1) Unit Water Demand

Unit water demands applied to the estimation are as follows.

Sector		Unit water demand
Potable water		
	Urban area	0.24 m^3/capita/day
	Rural area	0.12 m^3/capita/day
Tourism		0.40 m^3/capita/day
Industrial		107 m^3/ha/day
Agriculture		16.3 m^3/ha/day

(2) Future Water Demand

Future water demand in whole South Sinai in 2017 is estimated on the basis of the above unit water demands.

The results are 272,965 m^3/day for case 1, 205,307 m^3/day for case 2 and 186,558 m^3/day for case 3. These figures include 36,963 m^3/day of agricultural water demand in Central sinai.

The itemized results for each case are as follows.

<Estimated Water Demand of South Sinai in 2017>

(Unit: m³/day)

Case 1	Potable	Tourism	Industry	Others	Sub-total	Agriculture	Total
El Tur	25,745	285	2,247	1,414	29,691	14,464	44,155
Sharm El Sheikh	30,852	8,152	0	1,950	40,954	0	40,954
Dahab	20,769	3,844	0	1,231	25,844	5,135	30,979
Nuweiba	26,258	6,073	0	1,617	33,948	7,536	41,484
St. Catherine	3,649	812	0	223	4,684	0	4,684
Abu Rudeis	1,928	0	0	96	2,024	0	2,024
Abu Zenima	1,063	0	0	53	1,116	342	1,458
Ras Sudr	49,845	4,619	2,247	2,836	59,547	7,624	67,171
Taba	0	2,942	0	147	3,089	0	3,089
Total	160,111	26,728	4,494	9,567	200,897	35,101	235,998

Case 2	Potable	Tourism	Industry	Others	Sub-total	Agriculture	Total
El Tur	15,447	285	1,348	854	17,934	14,464	32,399
Sharm El Sheikh	18,512	8,152	0	1,333	27,997	0	27,996
Dahab	12,461	3,844	0	815	17,120	5,135	22,256
Nuweiba	15,755	6,073	0	1,091	22,919	7,536	30,456
St. Catherine	2,398	812	0	161	3,371	0	3,371
Abu Rudeis	1,928	0	0	96	2,024	0	3,699
Abu Zenima	1,063	0	0	53	1,116	342	1,458
Ras Sudr	29,907	4,619	1,348	1,794	37,668	7,624	45,292
Taba	0	2,942	0	147	3,089	0	3,089
Total	97,471	26,727	2,696	6,345	133,239	35,101	168,340

Case 3	Potable	Tourism	Industry	Others	Sub-total	Agriculture	Total
El Tur	16,901	285	1,348	927	19,461	14,464	33,925
Sharm El Sheikh	41,986	8,152	0	2,507	52,645	0	52,645
Dahab	4,598	3,844	0	422	8,864	5,135	13,999
Nuweiba	7,028	6,073	0	655	13,756	7,536	21,292
St. Catherine	996	812	0	90	1,898	0	1,898
Abu Rudeis	3,113	0	0	156	3,269	0	3,269
Abu Zenima	3,575	0	0	179	3,754	342	4,094
Ras Sudr	1,420	4,619	1,348	369	7,756	7,624	15,380
Taba	0	2,942	0	147	3,089	0	3,089
Total	79,6177	26,727	2,696	5,452	114,492	35,101	149,591

<Estimated Agricultural Water Demand in Central Sinai>

Unit: m³/day

Area	1996	1997	2002	2007	2012	2017
Malha 1	0	0	1,972	2,690	3,309	3,765
Malha 2	0	0	1,972	2,690	3,309	3,765
Malha 3	0	0	3,243	4,401	5,428	6,161
Sub-Total	0	0	7,178	9,781	12,046	13,691
Themed	0	0	6,112	8,313	10,236	11,638
Sudr El Heitan	0	0	6,112	8,313	10,236	11,638
Total	0	0	23,346	26,407	32,518	36,967

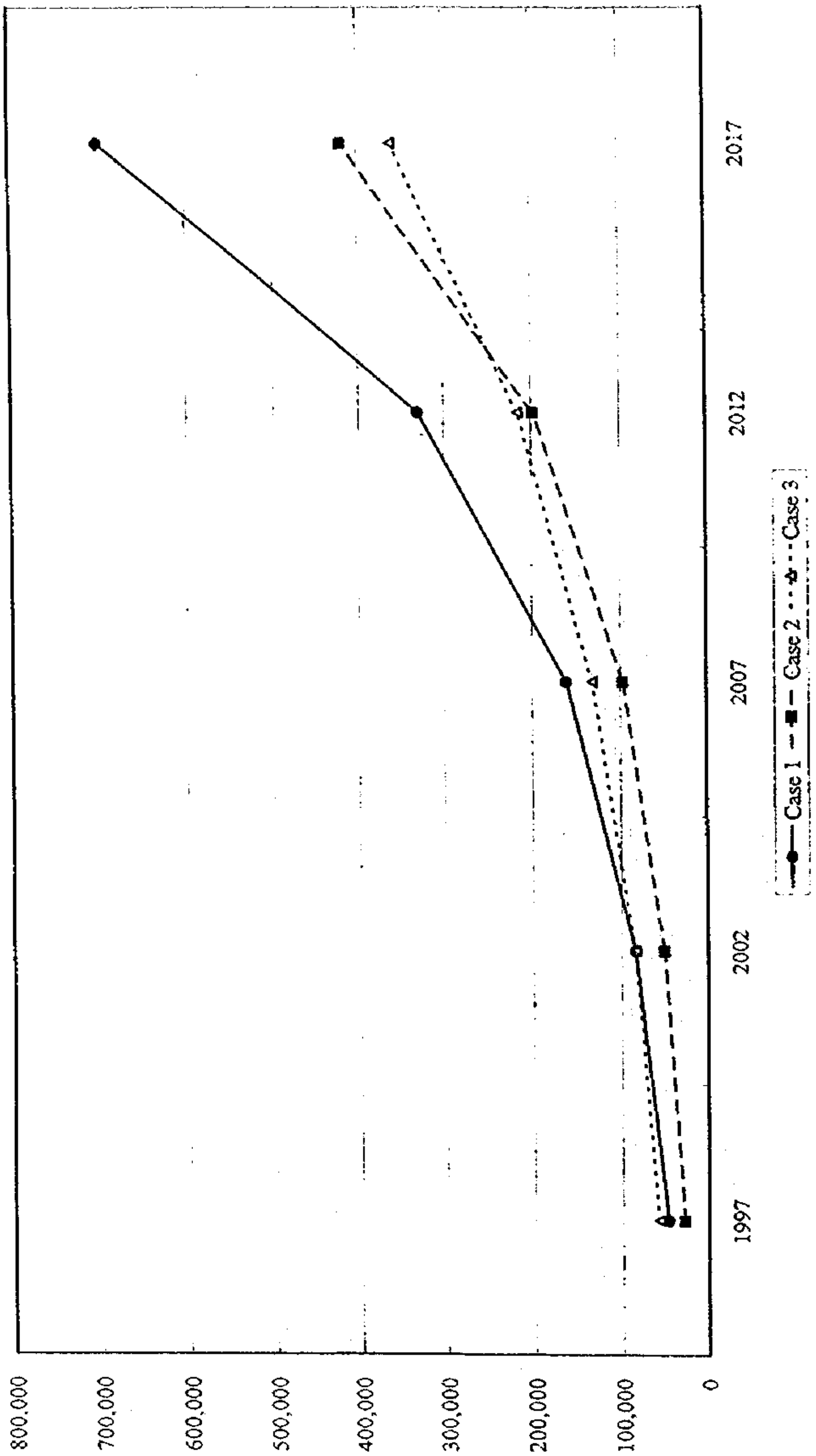


Fig. 5.2-1 Projection of Population Growth in South Sinai

CHAPTER VI GROUNDWATER DEVELOPMENT PLAN

6.1 Basic Concept of Groundwater Development

The water demand in South Sinai is estimated 39,289 m^3/day in 1997 except agricultural use. On the other hand, capacity of water supply facilities is 33,820 m^3/day which is a deficit of 5,469 m^3/day.

The NPDS intends to increase the total water demand up to 272,965 m^3/day in 2017 including agricultural use: 235,998 m^3/day for domestic and 36,967 m^3/day for agricultural use.

This increasing water demand will surge to the Nile River. However, according to M.B.A. Saad and M.S.M. Farid (1996), the water demand in Egypt will increase to 82 billion m^3 in 2027 while Egypt's share of the Nile water is fixed to 55.5 billion m^3/year. Although other water sources are considered, deficit of water source is estimated 1.7 billion m^3/year.

Therefore, it is essential to make groundwater development plan for decreasing the load to the Nile River as much as possible.

The plan is to cover the newly added water demand for 2017 to the existing water demand in 1997.

6.2 Groundwater Development Plan

6.2.1 Scope of Groundwater Development Plan

1) Prospective Aquifer Area

Considering the potential and water quality of aquifers, following prospective aquifer areas are selected based on the discussion in Chapter IV.

(1) The Main Block of the Lower Cretaceous Aquifer

(2) The Quaternary Aquifer in the El Qaa Plain

2) Service Area

In the Study, the main service areas are classified as follows.

(1) Domestic water supply to the western side of South Sinai (Ras Sudr, Abu Rudeis and Abu Zenima)

(2) Domestic water supply to the eastern side of South Sinai (Nuweiba)

(3) Domestic and irrigation water supply to El Qaa Plain (El Tur)

(4) Irrigation water supply to Sudr El Heitan, El Malha and Themed areas

(5) Domestic water supply to Bedouin communities

Service areas and water sources (development areas) are shown in Fig. 6.2-1 and 6.2-2.

3) Extraction Volume to be Developed

The estimated total water demand in 2017 is 272,965 m^3/day, while the present water supply capacity is 33,820 m^3/day. Therefore, necessary development volume is 239,145 m^3/day (=272,965 m^3/day - 33,820 m^3/day).

Considering the supply areas and necessary quantity of groundwater, amount to be developed is allocated each aquifer area as shown below.

Service Area	Development Area	Type of Aquifer	Extraction Rate (m^3/day)
Western side of South Sinai	Western side of the Main Block (southeast of Sudr El Heitan)	Lower Cretaceous	57,500
Eastern side of South Sinai	Eastern side of the Main Block (southeast of Nakhl)	Lower Cretaceous	35,000
El Qaa Plain	NNE of El Tur	Quaternary	5,300
Sudr El Heitan	In the service area	Lower Cretaceous	11,700
El Malha area	In the service area	Lower Cretaceous	13,700
Themed	In the service area	Lower Cretaceous	11,700

4) Water Quality Required

Required TDS is decided based on the Drinking Water Standard in Egypt.

For domestic water supply, it is 1500 mg/l. In case of irrigation water supply, it is generally 3000 mg/l, however, it is also decided as 1500 mg/l because this water is also supplied to farmers as potable water.

5) Water Conveyance Route

After exploiting from the production wells, groundwater is sent to each service areas. In this Study, the water conveyance routes are considered up to the distribution tanks and the study of distribution system is not included.

Following five (5) plans of conveyance routes are to be studied.

(1) Plan 1: From the Main Block (southeast of Sudr El Heitan) to western side of South Sinai (Ras Sudr)

(2) Plan 2: From the Main Block (southeast of Nakhl) to eastern side of South Sinai

(Nuweiba)

(3) Plan 3: From the El Qaa Plain to El Tur

(4) Plan 4 A, B, C: Within the project area

(5) Plan 5: Within the communities

Among the plans above, study of conveyance route is not necessary in Plan 4 and Plan 5 because water sources are developed within the service area. Therefore, remaining three (3) plans were studied.

(1) Plan 1

Ras Sudr has the largest water demand among the cities in the western side of South Sinai except Sharm El Sheikh. To meet its demand, groundwater from the Main Block shall be sent to Ras Sudr and be connected with the conveyance main of the Nile water. There are two (2) alternatives: (A) to run along the road from Sudr El Heitan to Ras Sudr and (B) to run along the Highway between Nakhl and Suez, then, reach the junction of Highways about 17 km north of Ayun Musa. Result of evaluation is as shown below.

Route	Distance (km)	Highest Point (mASL)	Necessary Head (m)	Access Road	Easiness of Laying Out
A	64	535	(gravity)	good	easy
B	94	630	80	good	easy

Based on the evaluation above, the conveyance route A was selected for the Plan 1.

(2) Plan 2

Nuweiba including Taba area has also large water demand in the eastern side of South Sinai. Especially, Taba area is expected to develop as tourists site as Sharm El Sheikh. The Plan 2 intends to develop groundwater at the south of Themed and convey water to Taba and Nuweiba through Naqb avoiding hazardous route of the Wadi Watir. After reaching to the coastline of the Gulf of Aqaba, water will be separated for use in Taba and in Nuweiba.

Route	Distance (km)	Highest Point (mASL)	Necessary Head (m)	Access Road	Easiness of Laying Out
A	181	780	300	easy	Partly difficult
B	189	782	302	easy	Difficult to protect against flood

Based on the evaluation above, the conveyance route A was selected for the Plan 2.

(3) Plan 3

Groundwater development area is located about 17 km NNE from El Tur. The conveyance route will be along the road to the Wadi Hibran. Total length of conveyance pipeline is 9 km.

6.2.2 Design Condition

1) Development Water Capacity

The development water capacity in the target year of 2017 for the facilities plans are shown in the following table.

Development Plan	Development Capacity (m^3/day)	Service Area	Main Purpose of Supply
Plan 1	57,500	Ras Sudr, Abu Zenima, Abu Rudeis	Residential use*1
Plan 2	35,000	Nuweiba (including Taba)	〃
Plan 3	5,300*2	El Tur	〃
Plan 4A	11,700	Sudr El Heitan	Agriculture use
Plan 4B	13,700	Malha	〃
Plan 4C	11,700	Themed	〃
Plan 5	5 / 25 / 50	Bedouin Community	Common use

Note:*1: Residential use is including the future water demand for tourism and industrial use.
*2: Capacity in the target year of 2007

2) Groundwater Development Facility

Outline of the development facilities is shown below.

Plans	Development Capacity (m^3/day)	Intake Facility			Conveyance Facility		
		Intake Well		Pipeline	P/S	Pipeline	Reservoir
		Nos	Depth(m)	Length (km)	Nos	Length(km)	Total Cap (m^3) x Nos
Plan 1	57,500	92	1,000	109	1	64	7,250 x 4
Plan 2	35,000	56	1,000	70	4	181	7,250 x 4
Plan 3	5,300	9	155	19	0	9	1,400 x 2
Plan 4A	11,700	19	1,000	7	0	0	360 x 19
Plan 4B	13,700	22	1,000	7	0	0	360 x 22
Plan 4C	11,700	19	1,000	7	0	0	360 x 19
Plan 5A	5	1	20	0.1	0	0	5 x 1
Plan 5B	25	1	20	0.1	0	0	25 x 1
Plan 5C	50	2	20	0.1	0	0	50 x 1

Purification facilities are not included because water sources are extracted from deep wells.

6.2.3 Design Criteria

Unit water demand and water quality are discussed in 5.2.2 of Chapter V and 6.2.1 of this Chapter, respectively.

Design standard applied to the Study are as follows.

a. The Egyptian Code of Practice for the Design and Construction of Pipelines for Water Supply and Sanitary Drainage Nets, MODANC 1990.

b. If the above code is not sufficient to do the designing, the criteria of Japan Water Works Association will be used as the reference materials.

c. WHO Guideline.

Other criteria for water works facilities are as follows.

Item	Criteria
Pipe materials(collection and conveyance pipeline)	steel pipe, polyvinyl chloride pipe (u-PVC) and ductile cast iron pipe
Connection methods	ductile cast iron pipe, u-PVC: socket type steel pipe: welding and flange type
Maximum inner pressure	p = less than 120 m
Minimum Soil cover depth	h = more than 120 cm
Interval of valve installation	L = less than 2 km
Capacity of the distribution water reservoir	V1 = more than 12 hr (for the urban area) V2 = more than 24 hr (for the rural area)

6.2.4 Planning of Water Development Facilities

1) Outline of Facilities

Outline of each facilities from Plan 1 to Plan 5 is summarized as the table below. Detailed study results such as hydraulic calculation, list of pipe materials are described in Chapter XIII of the Supporting Report.

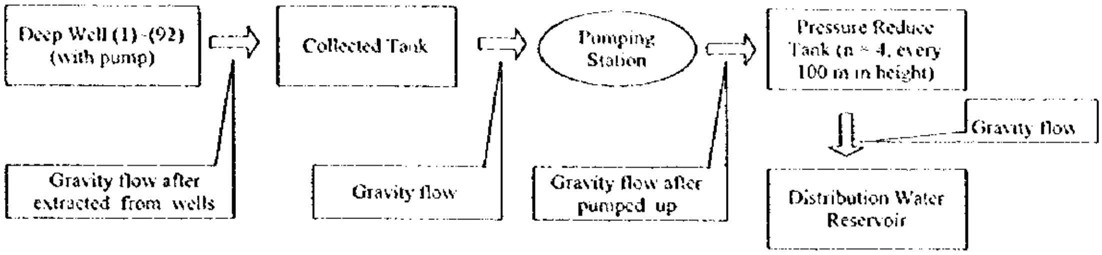
Item	Unit	Plan 1	Plan 2	Plan 3	Plan 4			Plan 5		
					4A	4B	4C	5A	5B	5C
Intake Facilities										
Wells (Total) :	nos	92	56	9	19	22	19	1	1	2
Production well	nos	80	48	7	16	19	16	1	1	2
Stand-by well	nos	12	8	2	3	3	3	0	0	0
Water capacity per a well	m³/day	720	720	720	720	720	720	5	25	25
	m³/hr	30	30	30	30	30	30	1	5	5
Well depth (Maximum)	GL-m	1,000	1,000	155	1,000	1,000	1,000	20	20	20
Collection pipeline (well to Collection Tank)										
Diameter	m φ	0.125 ~0.9	0.125 ~0.8	0.125 ~0.3	0.125	0.125	0.125	0.040	0.080	0.080
Conveyance Facilities										
No1 Pumping Station		1	4	0	-	-	-	-	-	-
Pressure reduce tank	nos	4	7	-	-	-	-	-	-	-
Conveyance pipeline (Collected tank to Reservoir)										
Diameter	m	0.6 ~ 0.9	0.6 ~ 1.2	0.45	-	-	-	-	-	-
Length	km	64	181	9	-	-	-	-	-	-
Distribution water reservoir	nos	4	2+2	2	16	19	16	1	1	2
Capacity	m³	7,250	7,900: 750	1,400	360	360	360	5	25	25

2) Description of Groundwater Development Facilities

(1) Plan 1: Water Supply to Western Side (Ras Sudr, Abu Rudeis and Abu Zenima)

The plan is to supply 57,500 m³/day of water to the western side of South Sinai. The intake points for the water sources are located in the southern area of Nakhl. The extracted water will be conveyed to the distribution water reservoir located in the suburb of Ras Sudr through the one (1) pumping station and four (4) pressure reduce tanks.

The water flow diagram is shown below.

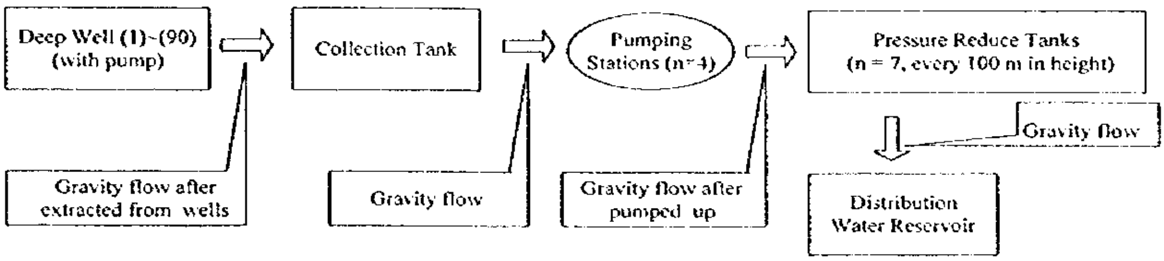


The longitudinal profile of conveyance pipeline is shown in Fig. 6.2-3.

(2) Plan 2: Water Supply to Eastern Side (Nuweiba including Taba)

The plan is to develop about 35,000 m^3/day of water for water demand in the eastern side of South Sinai. The intake points for the water sources are located in the southeastern area of Nakhl. The extracted water will be conveyed first to the distribution water reservoir located about 10 km southwest of Taba through the four (4) pumping station and seven (7) pressure reduce tanks. An amount of 2,940 m^3/day of water is led to Taba and remaining 31,520 m^3/day of water is conveyed to Nuweiba.

The water flow diagram is shown below.

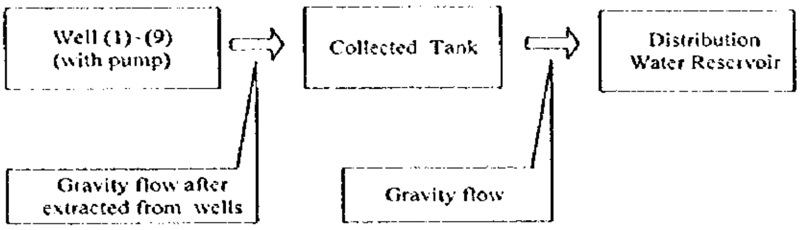


The longitudinal profile of conveyance pipeline is shown in Fig. 6.2-4.

(3) Plan 3: Water Supply to El Tur

The plan is to supply 5,300 m^3/day of water to El Tur. The intake points for the water sources are located about 17 km NNE from El Tur. The extracted water will be conveyed to the distribution water reservoir located about 8 km NNE of El Tur by gravity.

The water flow diagram is shown below.

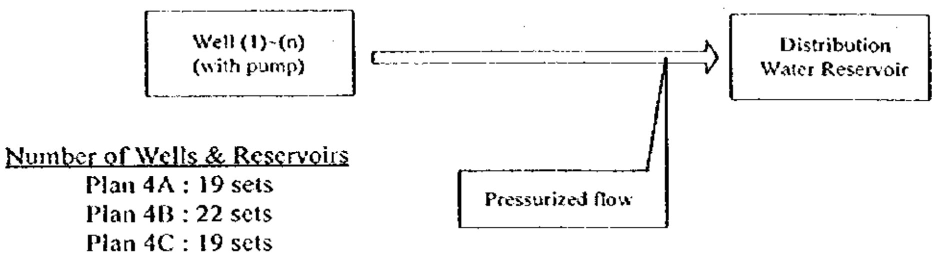


The longitudinal profile of conveyance pipeline is shown in Fig. 6.2-5.

(4) Plan 4: Water Supply to Agricultural Farms (Sudr El Heitan, El Malha and Themed)

The plan is to supply irrigation water and potable water to the project areas: 11,700 m^3/day to Sudr El Heitan, 13,700 m^3/day to El Malha areas and 11,700 m^3/day to Themed. Water intakes are located in each project area. Extracted groundwater is directly conveyed to the distribution reservoir.

The water flow diagram is shown below.



(5) Plan 5: Water Supply to Bedouin Communities

The plan is to supply water for residential and agricultural uses to Bedouin communities scattered in South Sinai. Groundwater is extracted by dug well and is led to the distribution tank near the well.

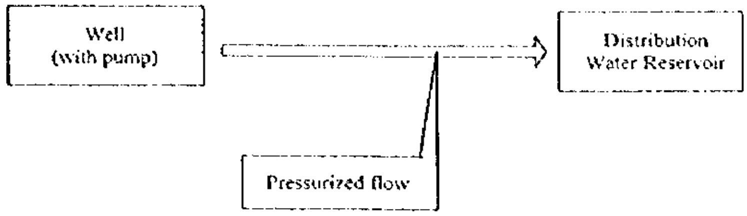
Considering the size of communities, following three plans were prepared:

Plan 5A: Water Demand 5 m^3/day

Plan 5B: Water Demand 25 m^3/day

Plan 5C: Water Demand 50 m^3/day

The water flow diagram is shown below.



6.3 Management, Operation and Maintenance Plan

6.3.1 Management Plan

The requirement of consumers on the water supply is that, it is satisfactory with regard to the water quantity, quality, and constant supply. In other way, the supplier has to supply consumers with stable and safe water. As water is one of the basic human needs which affects preservation and evolution of the society, it is not too much to say that the water supply project is very important for the social welfare. Moreover, the development and/or expansion of water sources which is in accord with the water supply planning for the future water demand, is an essential element for the administrative bodies. The establishment of an impartial water tariff system should be considered to reach early achievements from the above points of view.

From above things, administrative bodies for water works shall take into account that it is required for each service area to conduct operation and maintenance of the water works. Administration of these matters must consider the fairness for consumers and unification of the policy.

Important matters for the indices of water control are mentioned below, and establishment and execution of them are expressly matters of weight for South Sinai with insufficient water sources.

(1) Establishment of management organization for municipalities.

(2) Establishment of an impartial water tariff system

(3) Thorough review of the water quantity and quality control

(4) Diffusion of economization concept to increase water consumption awareness and improvement of the water implements

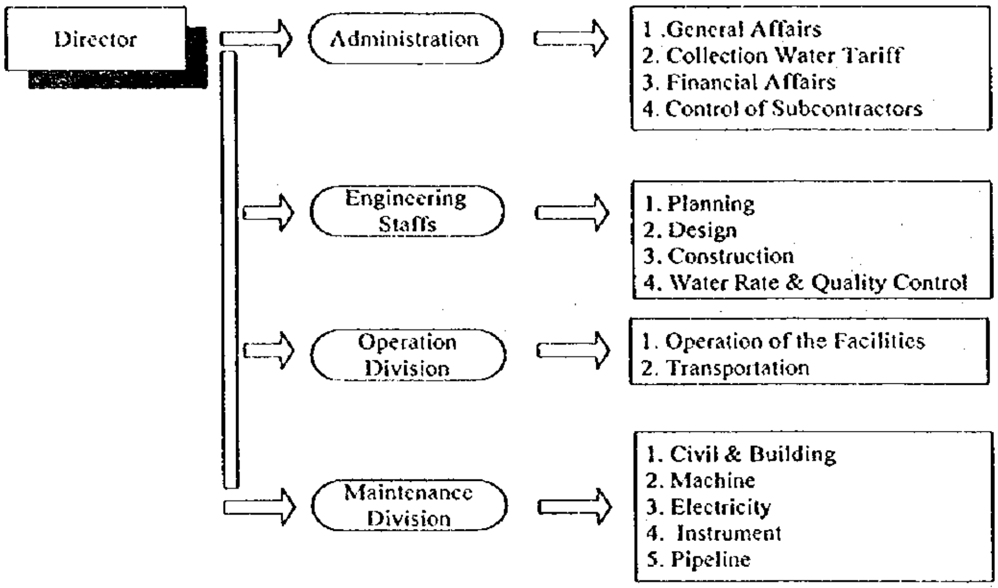
(5) Prevention of water sources pollution

6.3.2 Operation and Maintenance Plan

Proper operation and maintenance of water works might be difficult due to lack of water engineers, related facilities and budgets in respective municipalities. However, it is desirable in the future to be carried out by a unit organization with proper knowledge and experience of water works. Of course central administration such as Governorate and States, should actively participate. The required matters and the outline of an operation and maintenance are given below.

1) Organization and Personnel Plan

As an example, the organization for water control department is shown below. However, personnel required will depend on the scale and technical outline of the facilities. The personnel plan will also be related to the employment situation in the jurisdiction area.



2) Operation and Maintenance of Facilities

The operation of facilities is conducted for the whole water works from intake to distribution facilities. Facilities are usually operated 24 hours a day. Therefore, the working schedule of operation personnel for the water facilities will be considered in three or four shifts a day in addition to the workers in the daytime.

On the other hand, management of the maintenance system should be composed with personnel from each special field mentioned above. The working system of maintenance personnel is suitable for works in the daytime except the special case such as an emergency measures.

The important matters of daily works which are indispensable for the maintenance works and for which even greater efforts should be made, are ;

(1) detectors for water meter and automatic control system.

(2) disinfection facility for direct influence to human bodies

6.4 Implementation Plan and Cost Estimation

6.4.1 Implementation Plan

1) Organization for Project Implementation

South Sinai Development Authority is responsible for developing water supply system except developing wells for agriculture. This authority conducts design and construction of intake facility, conveyance/transmission pipeline, distribution reservoir and supply pipeline. In addition, conveyance/transmission system for water supply is operated and maintained by the authority.

On the other hand, General Directorate of Water Resources in South Sinai, MPWWR and WRRI basically are responsible for design and implementation of Water Resources Development Project for agricultural and rural water supply.

2) Implementation Plan

Implementation plans for the projects are proposed considering the balance of water demand and supply in the future. Also it is important to consider efficiency for water supply within each area. In addition, it is necessary to deliberate site conditions, availability of construction materials, equipment and machinery. Thus, proposed implementation plans are shown in Table 6.4-1.

6.4.2 Project Cost

1) General

The project cost should be estimated under the following conditions.

- The civil works are contracted on the contract basis. The machinery and equipment required for construction works will be provided by the contractors. Therefore, depreciation costs of machinery and equipment are included in the estimated construction cost.

- The exchange rates between Egyptian Pound and U.S. Dollar/Japanese Yen are adopted based on the average from October in 1997 to March in 1998.

  1 U.S.Dollar = 3.39 L.E = 133.3 Yen

- Land acquisition cost is not necessary because project sites belong to government.

2) Cost Estimation

Unit costs for various items of work should have been analyzed at the time of March in 1998 based on the unit costs of similar projects, quotations of contractors and current market prices. Construction costs are estimated by these unit costs for individual components. Costs of temporary and preparatory works for each component are assumed to be included within the costs of miscellaneous works. Project cost includes contingencies, engineering and administration cost. Engineering and administration costs are assumed as 5 % of the construction cost respectively. In addition, physical contingency is estimated at 15 % of capital cost. These percentages are adopted based on the other similar projects.

3) Operation and Maintenance Cost

Operation and maintenance cost consists of the annual salaries/wages of the staff for O/M, operation cost of pump, repairing/maintenance cost of facilities, depreciation and fuel cost for transportation, administration and general expenditure. These costs are calculated on the basis of the unit costs and information about O/M provided by SSDA, WRRI and MPWWR.

Summary of Project Costs and O/M Costs

Project	Project Cost (1,000 L.E.)	Construction Cost of Supply/Irrigation Pipeline (1,000 L.E.)	Total Project Cost (1,000 L.E.)	O/M Cost (1,000 L.E.)
Plan 1	461,500	208,200	669,700	11,600
Plan 2	535,800	137,600	673,400	15,100
Plan 3	17,000	65,000	82,000	400
Plan 4A	74,500	19,000	93,500	2,100
Plan 4B	86,300	22,400	108,700	2,500
Plan 4C	74,500	19,000	93,500	2,100
Plan 5A	159	-	159	9
Plan 5B	191	-	191	11
Plan 5C	496	-	496	15

Cost estimation for each plan is shown in Table 6.4-2 (1) to (5).

Table 6.4-1 Implementation Plan

Item		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015 ~2016
Plan 1	Intake Facilities	- - -	- - -	——	——	——	——			——	——				——	——		
	Conveyance Facilities	- - -	- - -	——	——	——												
Plan 2	Intake Facilities	- - -	- - -	- - -	——	——	——	——		——	——					——	——	
	Conveyance Facilities	- - -	- - -	——	——	——	——	——										
Plan 3	Intake Facilities	- - -	——			——												
	Conveyance Facilities	- - -	——															
Plan 4A	Intake Facilities	- - -	——					——					——					
	Conveyance Facilities	- - -	——															
Plan 4B	Intake Facilities	- - -	——	——					——					——				
	Conveyance Facilities	- - -	——															
Plan 4C	Intake Facilities	- - -	——					——					——					
	Conveyance Facilities	- - -	——															
Plan 5A	Intake Facilities	- - -	——															
	Conveyance Facilities	- - -	——															
Plan 5B	Intake Facilities	- - -	——															
	Conveyance Facilities	- - -	——															
Plan 5C	Intake Facilities	- - -	——															
	Conveyance Facilities	- - -	——															

Note) - - : Survey and Detail Design , —— : Construction

Table 6.4-2 (1) Cost Estimation for the Project of Plan 1

Item	Cost (LE)	Remarks
A Well (Number of Well: 92)	261,312,660	
B Collection Pipeline (Total Length: 109.2km)	23,186,093	
C Pumping Station (Collected Tank: 2, Booster Pump: 1)	7,065,738	
D Surge Tank (Number of Tank: 1)	26,659	
E Pessure Reduce Tank (Number of Tank: 4)	796,084	
F Conveyance Pipeline (Total Length: 64.0km)	66,860,562	
G Distribution Water Reservoir (Number of Reservoir: 4)	5,610,420	
H Total Construction Cost	364,858,216	
I Administration Cost	18,242,911	5% of Above H
J Engineering Cost	18,242,911	5% of Above H
K Physical Contingency	60,201,606	15% of Above H～J
Total	461,545,644	
Annual Operation and maintenance Cost	11,600,000	

Table 6.4-2 (2) Cost Estimation for the Project of Plan 2

Item	Cost (LE)	Remarks
A Well (Number of Well: 56)	159,059,880	
B Collection Pipeline (Total Length: 69.8km)	15,591,267	
C Pumping Station (Collected Tank: 8, Booster Pump: 4)	24,422,389	
D Surge Tank (Number of Tank: 4)	80,284	
E Pessure Reduce Tank (Number of Tank: 7)	1,209,600	
F Conveyance Pipeline (Total Length: 181.0km)	220,407,077	
G Distribution Water Reservoir (Taba: 2, Nuweiba 2)	2,788,446	
H Total Construction Cost	423,558,943	
I Administration Cost	21,177,947	5% of Above H
J Engineering Cost	21,177,947	5% of Above H
K Physical Contingency	69,887,226	15% of Above H～J
Total	535,802,063	
Annual Operation and maintenance Cost	15,059,900	

Table 6.4-2 (3) Cost Estimation for the Project of Plan 3

Item	Cost (LE)	Remarks
A Well (Number of Well: 9)	5,820,066	
B Collection Pipeline (Total Length: 18.6km)	2,535,799	
C Collected Tank (Number of Tank: 1)	90,092	
D Conveyance Pipeline (Total Length: 9.0km)	4,245,678	
E Distribution Water Reservoir (Number of Reservoir: 2)	771,654	
F Total Construction Cost	13,463,289	
G Administration Cost	673,164	5% of Above F
H Engineering Cost	673,164	5% of Above F
I Physical Contingency	2,221,443	15% of Above F～H
Total	17,031,060	
Annual Operation and maintenance Cost	411,100	

Table 6.4-2 (4) Cost Estimation for the Project of Plan 4

Cost Estimation for the Project of Plan 4A & 4C

Item	Cost (LE)	Remarks
A Well (Number of Well: 19)	53,966,745	
B Pipeline (Total Length: 6.7km)	1,256,103	
C Distribution Water Reservoir (Number of Tank: 19)	3,693,049	
D Total Construction Cost	58,915,897	
E Administration Cost	2,945,795	5% of Above D
F Engineering Cost	2,945,795	5% of Above D
G Physical Contingency	9,721,123	15% of Above D~F
Total	74,528,610	
Annual Operation and maintenance Cost	2,138,100	

Cost Estimation for the Project of Plan 4B

Item	Cost (LE)	Remarks
A Well (Number of Well: 22)	62,487,810	
B Pipeline (Total Length: 7.7km)	1,450,468	
C Distribution Water Reservoir (Number of Tank: 22)	4,276,162	
D Total Construction Cost	68,214,440	
E Administration Cost	3,410,722	5% of Above D
F Engineering Cost	3,410,722	5% of Above D
G Physical Contingency	11,255,383	15% of Above D~F
Total	86,291,267	
Annual Operation and maintenance Cost	2,529,100	

Table 6.4-2 (5) Cost Estimation for the Project of Plan 5

Cost Estimation for the Project of Plan 5A

Item	Cost (LE)	Remarks
A Dug Well (Depth: 20m Number of Well: 1)	109,410	
B Pipeline (Total Length: 75.0m)	4,150	
C Distribution Water Reservoir (Number of Tank: 1)	12,143	
D Total Construction Cost	125,703	
E Administration Cost	6,285	5% of Above D
F Engineering Cost	6,285	5% of Above D
G Physical Contingency	20,741	15% of Above D~F
Total	159,014	
Annual Operation and maintenance Cost	9,100	

Cost Estimation for the Project of Plan 5B

Item	Cost (LE)	Remarks
A Dug Well (Depth: 20m Number of Well: 1)	117,810	
B Pipeline (Total Length: 75.0m)	4,150	
C Distribution Water Reservoir (Number of Tank: 1)	28,925	
D Total Construction Cost	150,885	
E Administration Cost	7,544	5% of Above D
F Engineering Cost	7,544	5% of Above D
G Physical Contingency	24,896	15% of Above D~F
Total	190,869	
Annual Operation and maintenance Cost	11,100	

Cost Estimation for the Project of Plan 5C

Item	Cost (LE)	Remarks
A Dug Well (Depth: 20m Number of Well: 2)	235,620	
B Pipeline (Total Length: 150.0m)	8,300	
C Distribution Water Reservoir (Number of Tank: 2)	147,850	
D Total Construction Cost	391,770	
E Administration Cost	19,589	5% of Above D
F Engineering Cost	19,589	5% of Above D
G Physical Contingency	64,642	15% of Above D~F
Total	495,590	
Annual Operation and maintenance Cost	15,100	

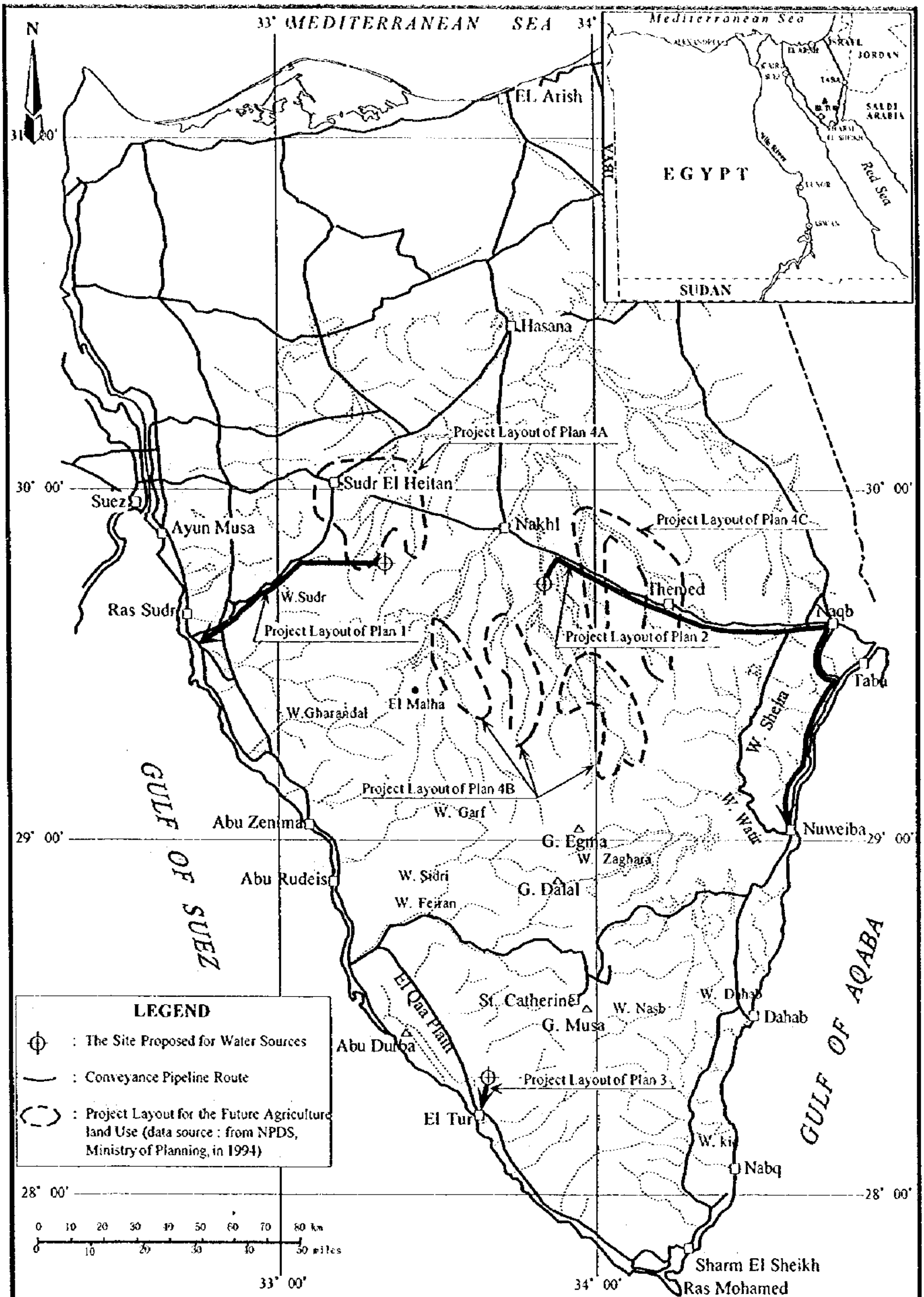


Fig. 6.2-1 Project Layout (Plan 1, 2 and 4)

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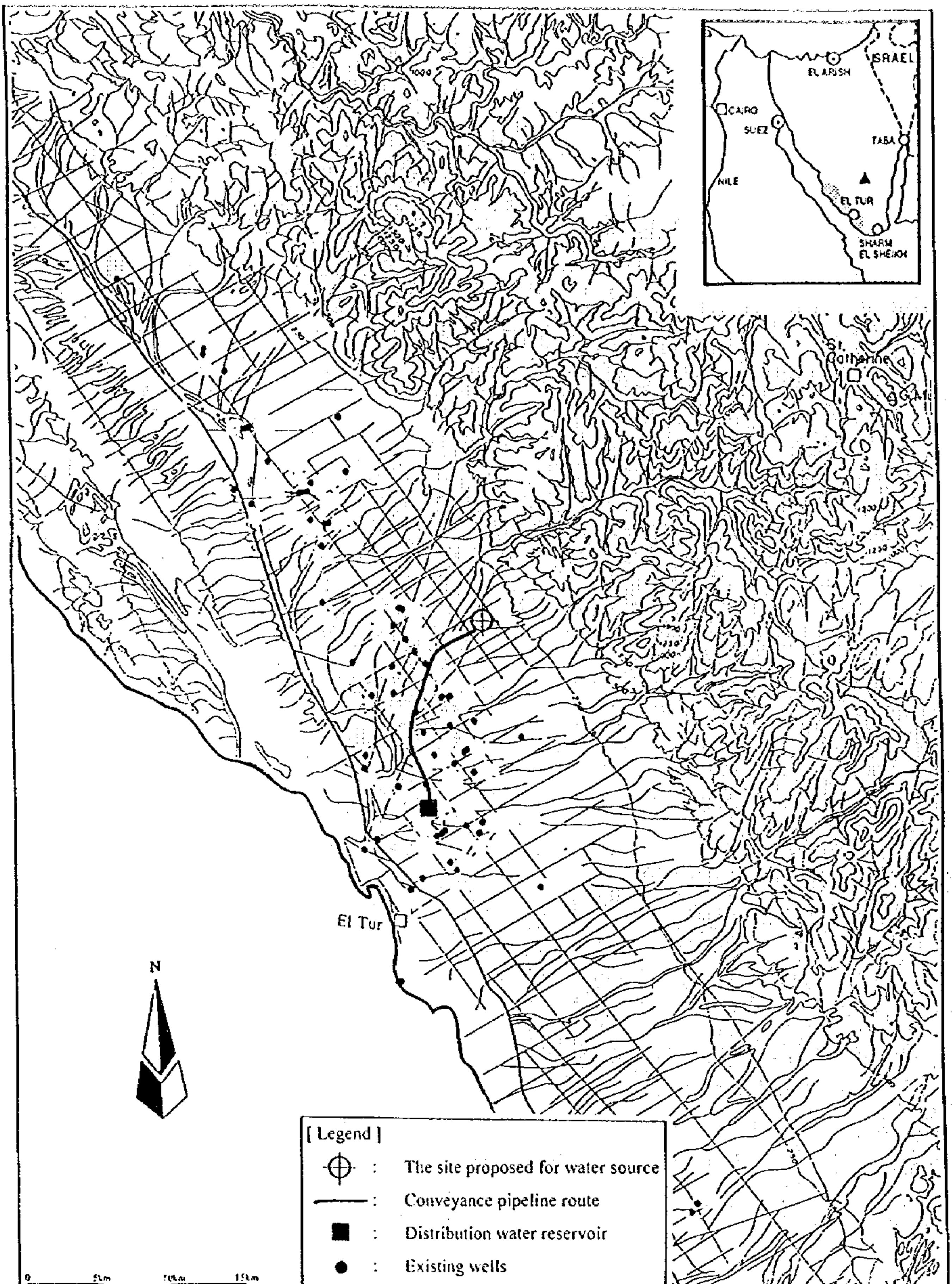

Fig. 6.2-2 Project Layout (Plan 3)

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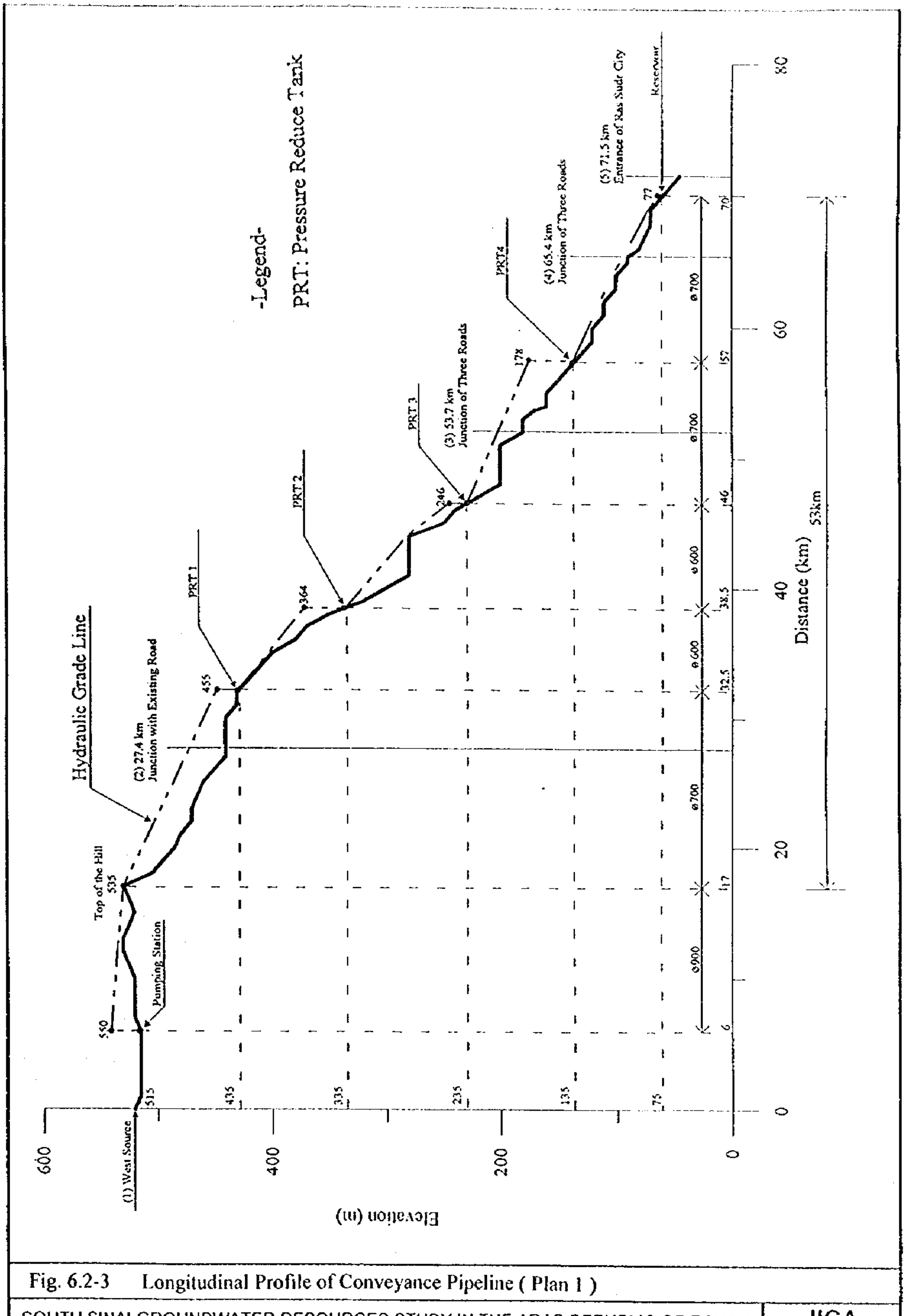

Fig. 6.2-3 Longitudinal Profile of Conveyance Pipeline (Plan 1)

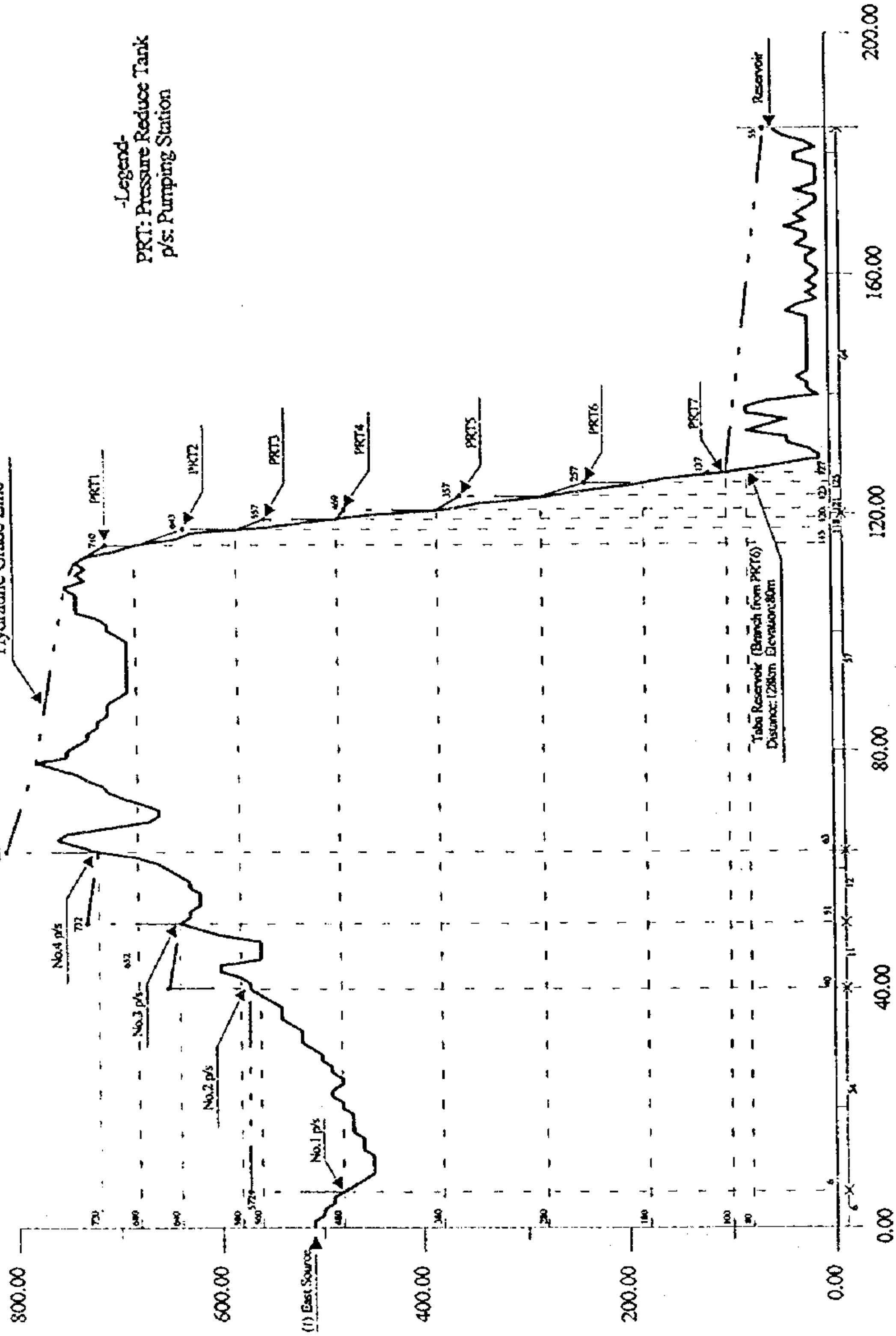

Fig. 6.2-4 Longitudinal Profile of Conveyance Pipeline (Plan 2)

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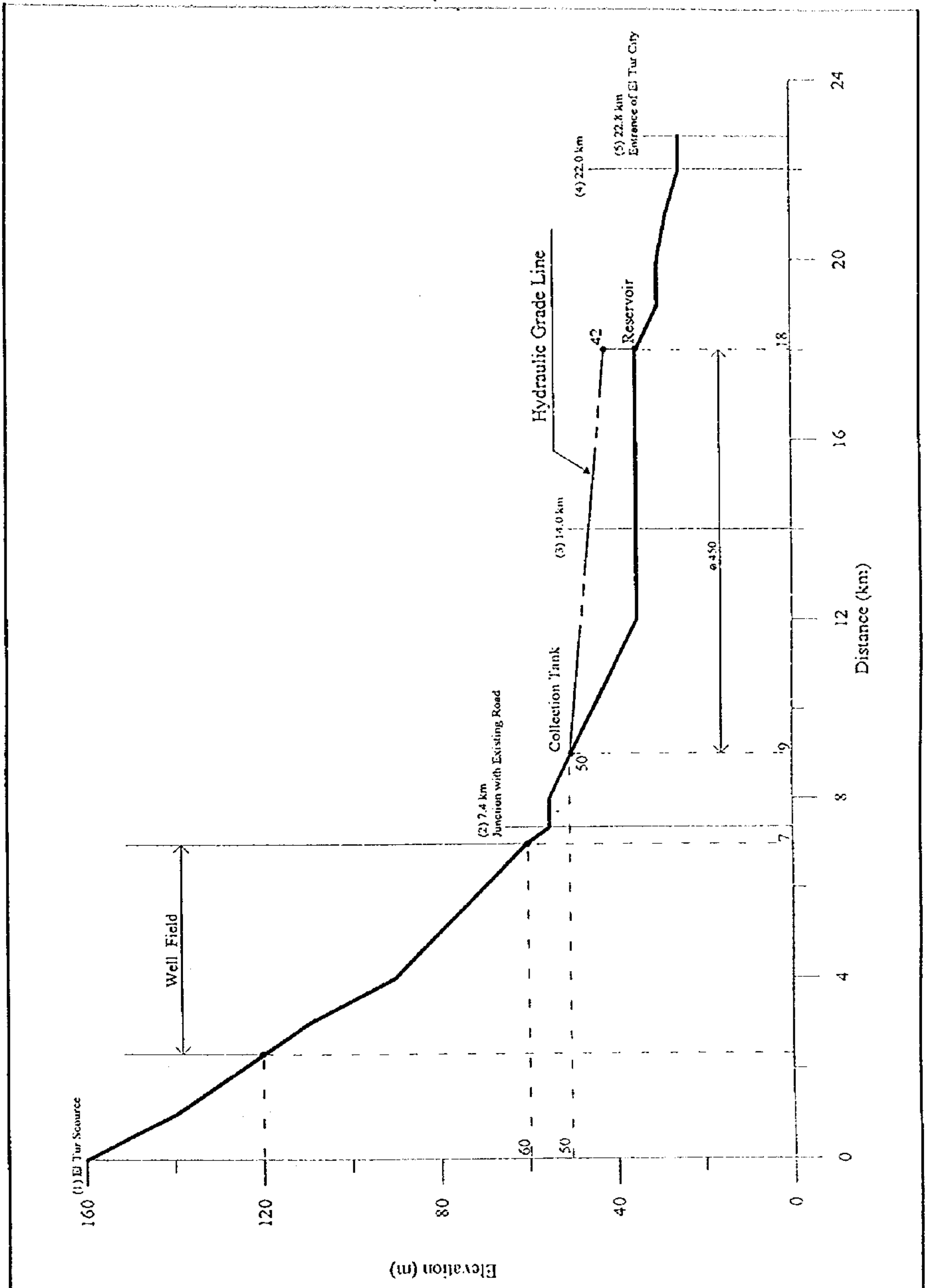

Fig. 6.2-5 Longitudinal Profile of Conveyance Pipeline (Plan 3)