CHAPTER IX EXISTING WATER SUPPLY SYSTEM AND SEWERAGE SYSTEM

9.1 Existing Water Supply System

The existing water supply systems in eight (8) cities of South Sinai were studied and illustrated in this chapter. The eight (8) cities are El Tur, Sharm EL Sheikh, Dahab, Nuweiba, St. Catherine, Abu Rudeis, Abu Zenima and Ras Sudr.

9.1.1 Outline of the System

The major existing water supply systems in South Sinai, operated and maintained by Municipalities, Communities, Private Firms and Ministry of Development, New Communities, Housing and Public Utilities (referred to as "MOD") according to water source and water supply system is shown below.

Groundwater → (Transmission Pipeline) → Distribution Reservoir → (Supply Pipeline) → Consumers

Groundwater → (Aqueduct) → Water Treatment Plant → (Transmission Pipeline) → Distribution Reservoir → (Supply Pipeline) → Consumers

Sea Water → (Aqueduct) → Water Treatment Plant → (Transmission Pipeline) → Distribution Reservoir → (Supply Pipeline) → Consumers

The Nile River → (Valve Chamber) → Elevated Water Tank → (Supply Pipeline) → Consumers

A lot of groundwater is extracted from shallow wells, located in the El Tur, Dahab, Nuweiba and St. Catherine cities and rural communities, by submersible or volute horizontal pumps installed in each well.

The water extracted from the wells is first transmitted through the transmission pipeline to the distribution reservoir located in a hilly place in the service area. The water flows by gravity through the distribution system (the pipe networks) to the consumers in the city.

On the other hand, the extracted groundwater that could not be used directly as potable water is conveyed to the water treatment plant (WTP) through aqueduct. In the WTP, the water is disinfected by using chlorine gas, which is either injected to the inlet pipeline or to the outlet pipeline of the storage.

The chlorinated water is delivered to the distribution tank located in a hilly place in the service area. The method of water supply from distribution reservoir to the consumers is through gravity.

Seawater is used as water sources, for the water supply system of Sharm El Sheikh, Dahab and Nuweiba cities in East Sinai along the Gulf of Aqaba. Seawater following desalination in WTP is conveyed to distribution reservoir located in a hilly area. The method of water supply from distribution reservoir to the consumers is through gravity. The desalination method applied is either an evaporation system, an electric dialysis or a reverse osmosis system.

The cities served with Nile River water are Abu-Zenima, Abu-Rudeis and Ras-Sudr in West Sinai all along the Gulf of Suez. A branch main from the main transmission pipeline is used to transmit the water to an elevated water tank. The water in the elevated tank is distributed through gravity to the consumers in the city.

The main transmission pipeline of River Nile Water, a ductile cast iron pipe of 600mm diameter, runs from Suez city to near the El Tul city at present. The pipeline is to be extended up to Sharm El Sheikh city in near future and is under construction at present. It will be completed within 1998.

Moreover, another main transmission pipeline of River Nile Water is under planning from Suez city to Abu Rudeis city as a secondary pipeline.

The above transmission main has several boosters pumping stations for supply the required quantity of water with the required water pressure to the service area.

9.1.2 Area and Population Served

The existing water supply system covers a total of about 50 km^2 in the eight (8) cities of South Sinai except the rural area. Almost the entire city populations are served with potable water.

The service area and the total population served including tourists in the eight (8) cities are shown in Table 9.1.2-1. The total number of residents and tourists are approximately 62,000 persons and 23,000 persons per day as of 1997.

9.1.3 Standard for Potable Water

Unit water demands and water quality standards for potable water are shown in Table 9.1.3-1 and 9.1.3-2. The coefficient number of daily maximum and peak hourly water demands are quoted from a similar project, "The Urgent Development Plan of the Suez Bay Coastal Area Development" of November, 1993 to be carried out by "Ministry of

Development, New Communities, Housing and Public Utilities (MOD). The latter water quality standard is quoted from Egyptian Law and World Health Organization (WHO) standards.

9.1.4 Water Production and Consumption

The quantity of water production, consumption by category and losses as unaccounted water in 1998 are summarized in Table 9.1.4-1.

In accordance with the Table 9.1.4-1, the total water production capacity in the eight cities in South Sinai is about 33,820 m3/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.

Thus, the actual unit water consumption of residents including rural area in 1998 is estimated as 250 liter/capita/day from Table 9.1.4-2. But these unit consumption are described as 240 liter/capita/day for the urban area's residents and 120 liter/capita/day for the rural area's residents in National Project for the Development of Sinai (NPDS).

On the other hand, unit water consumption of the tourists is 640 liter/capita/day from Table 9.1.4-2. This is also clearly shown on NPDS as 400 liter/capita/day.

Therefore, the actual unit water consumption for the residents and tourists are more than the number that to be described in NPDS.

9.1.5 Water Supply Facilities

1) El Tur city

(1) Urban Area

The potable water for this city is abstracted from eight (8) wells in the suburbs located at about 10 km from city area and conveyed to water treatment plant (referred to as "WTP") by the pumps (type of pump: submerged or horizontal volute pumps). The production capacity from the wells is approximately 6,000 m3/day in accordance with the statistical data book of South Sinai Governorate as of January 1998.

In the WTP, chlorine gas is injected into the water as disinfectant. Then the chlorinated water is distributed through the reservoirs on the hummock and pipe net work as potable water in city area.

Potable water is supplied to consumer such as residents, shops, restaurants, hotels and industries through the pipe network in the city. Supplied water quantity is just sufficient to meet the water demand at present.

An outline of water supply system in El Tur city is shown in Fig.9.1.5-1.

The water quality of extracted water from wells is good and meets the standards for potable water. The results of latest water quality analysis are shown in Table 9.1.5-1. The total resolved solids (TDS) of drew up water from wells are within the limit of 500 to 800 mg/l from results of water quality analysis.

(2) Rural Area

The water use condition of rural area in this city was studied and illustrated for four (4) big rural communities in which resident population is more than about two hundreds (200). Water supply to three communities of them (Wadi Village, El-Gedal and Ras-Raia) are conveyed from WTP by pipeline same as urban area. Potable water for the remaining Mier community is obtained from two own wells.

Most of the agriculture activity is in the rural area located in the suburbs of the urban area. The water for such use is generally abstracted from the private shallow wells in the farms. However, in most of cases the water abstracted is slightly brackish which is unsuitable for potable use.

2) Sharm El Sheikh city

The main consumer of water supply are tourists / hotels and industries. The water sources are desalinated seawater and groundwater. The desalinated water account for approximately 9,300 m3/day and groundwater for 1,000 m3/day. Groundwater is extracted from wells in El Tur city and conveyed by pipeline and water tank lorries.

The water for most of hotels and private buildings is supplied by private water production company such as South Sinai Water Corporation through private pipe network system. A part of this desalinated water has also been supplied to other small consumers with water tank lorries.

On the other hand, the water for public use such as residents and other consumers in the urban area is supplied both by desalination plants for public use and groundwater, through distribution reservoir and pipe networks.

An outline of water supply system in Sharm El Sheikh city is shown in Fig.9.1.5-2.

The supply capacity for residents is insufficient in summer season although the water supply for tourist is sufficient throughout in a year. Water supply to residents is limited to about two hours a day in summer season. However, new water treatment plant for public use is under constructed, the construction works will be completed up to March 1998. Accordingly, service works for public use will be done drastic improvement.

The desalinated water lacks in mineral salt contents, a public health concern especially for children.

The groundwater extracted from wells is of good quality for potable uses same as El Tur city. The results of latest water quality analysis are shown in Table 9.1.5-1.

The existing main water supply facilities are shown in Table 9.1.5-3.

The technical problems with the present water supply system are summarized below.

- Water Supply Capacity

Due to the shortage of water, water supply to residents is limited to about two hours a day in summer season. Hence existing water supply capacity is insufficient.

- Water Source

The future water demands will inevitably increase according to the growth of the population and tourists with the development of the city. In order to meet the future demand, new water sources need to be developed immediately such as new desalination system, River Nile water transmission system and new groundwater sources.

- Water Treatment Plant

The major desalination water treatment plant for public use has become superannuated and its energy efficiency is low. Some of its equipment were provided by Israel for which spare parts are not readily available. This leads to problems of operation and maintenance.

- Water Quality

Lack of mineral contents in desalinated water and its potential health effects especially on children is an important water quality concern. Accordingly blending of desalinated water with other water like groundwater needs to be given due to consideration.

3) Dahab city

(1) Urban Area

The main consumers of water supply are hotels and commercial establishments.

The water sources are desalinated water for potable use and groundwater (brackish water) for nonpotable use. The former desalinated water, obtained from seawater in the desalination plants, has a capacity of 2,000 m3/day. The capacity of groundwater is about 500 m3/day, which is extracted from intake wells, there are about five (5) kilometer distance from sea.

The production capacity of desalination plant has expanded to 4,000 m3/day in 1997 by MOD.

The desalinated potable water has been conveyed to consumers by pipe network through the distribution reservoir and water tank lorries, brackish water is conveyed by pipeline after being pretreated in the water treatment plant at present.

An outline of water supply system in Dahab city is shown in Fig.9.1.5-3.

The lack of mineral content in desalinated water is a public health concern, same as that of Sharm El Sheikh city.

The results of latest water quality analysis of non-potable groundwater (brackish water), which is used for just washing, is shown in Table 9.1.5-1. The total resolved solids (TDS) of drew up water from wells are within the limit of 2,500 to 3,000 mg/l from results of water quality analysis.

The existing main water supply facilities of Dahab city is shown in Table 9.1.5-4

The technical problems in the present water supply are summarized below.

- Water Quality

Lack of mineral contents, and the potential health problems, especially to children, of desalinated potable water is a significant issue. As a mitigation measure, blending of desalinated water with other water like groundwater needs to be given due to consideration.

(2) Rural Area

The water use condition of rural area in this city was studied and illustrated for Seal

Community in which resident population is more than about two hundreds (200).

The water supply to this community, both for potable and agriculture used is abstracted from twenty (20) wells located in the rural area.

4) Nuweiba city

(1) Urban Area

The water sources for city area are desalinated seawater and spring water for potable water and brackish groundwater for non-potable use. The production capacity of desalinated water is 400 m3/day for public use and 600 m3/day for private use such as hotels, spring water is approximately 2,600 m3/day and non-potable groundwater is 2,700 m3/day.

The potable water is produced in the desalination plant using seawater at present. Regarding the potable water supply, consumers in the port area are served through distribution reservoir and pipe network while those in the city area are served by the water tank lorries. Although the distribution pipe network in the city area has already constructed, these line does not using yet since the development of new spring water source is not completed.

On the other hand, groundwater (brackish water) is abstracted from the suburbs of city area, and it is being conveyed for non-potable use in households and the port area through distribution reservoir and pipe network. Also small quantity of brackish water is conveyed to the desalination plant for, and desalinated potable water is supplied for institutional use by the water tank lorries.

The supply capacity of desalinated potable water is insufficient throughout the year. The potable water is supplied for only about four (4) hours a day in the port area.

In order to alleviate the shortage the potable water, a new spring water source and transmission pipe laying works to the city are under construction at present.

An outline of water supply system in Nuweiba city is shown in Fig.9.1.5-4.

Concerning the water quality, low mineral content of potable desalinated water is a public health concern, similar of Sharm El Sheikh and Dahab cities. The results of latest water quality analysis of non-potable groundwater (brackish water), which is used for just washing, is shown in Table 9.1.5-1.

The existing main water supply facilities of Nuweiba city is shown in Table 9.1.5-5.

The technical problems in the present water supply system are summarized below.

- Water Supply Capacity

At present, the water supply of potable water is limited to about four (4) hours a day throughout the year. The capacity shortage has reached more than 1,100 m3/day. Therefore, prompt completion of the water supply system from the spring is required.

- Water Quality

Lack of mineral content of desalinated potable water is the major concern. In order to alleviate this problem blending of desalinated water with other potable water of groundwater and/or spring water is required.

- The method of water distribution system

The potable desalinated water is supplied to the consumers by the water tank lorries except for the port area where piped water is supplied. Therefore, it is necessary to expand the piped potable water supply system from the viewpoint of public health aspect.

(2) Rural Area

The water use condition of rural area in this city was studied and illustrated for three big rural communities mentioned below in which resident population is more than about two hundreds (200) persons. They are El-Shikh Atiya, Wasit and Nu-Magena communities.

Two rural communities, Wasit and Nu-Magena, receive their potable water conveyed by water tank lorries from the desalination plant mentioned above. The other rural community of El-Shikh Atiya has separate wells for potable use and nonpotable agricultural use. Water for agricultural use makes use of brackish water obtained from wells.

The quality brackish groundwater used for agriculture contains more than 2,000 mg/l of TDS (Total Dissolved Solids).

5) St. Catherine city

(1) Urban Area

The potable water is extracted from three shallow wells located at about 1.5 to 16 km away from the city area. The production capacity is 450 m3/day from the statistical data book of South Sinai Governorate as of January 1998.

Water from the well located nearest to the city is conveyed by pump to a portion of the city residents directly through the distribution reservoir and pipe network. Water from the other two wells are distributed to public water tanks in the city and to some rural communities also by the water tank lorries. However, all other residents have to obtain their potable water from public water tanks in the city area and carry by themselves. This potable water service is labor intensive and inconvenient.

An outline of water supply system in St. Catherine city is shown in Fig.9.1.5-5.

The groundwater extracted is of good quality for potable use. The result of latest water quality analysis is shown in Table 9.1.5-1.

The existing main water supply facilities are shown in Table 9.1.5-6.

The technical problems in the present water supply are summarized below.

- Water Supply Capacity

The supply of potable water is limited throughout the year. The shortage of water has reached to about 1,500 m3/day at present. Therefore, development of new groundwater sources is necessary.

- Water Quality

Gradual deterioration of groundwater quality is under way, it is presumed from the results of interview survey that was carried out by the Study Team. Lack of sewerage system in the city could be the major cause of water quality deterioration.

For the protection of groundwater and improvement of the environmental condition, sewerage system for the city is under construction at present. It will be completed by the year 1998.

(2) Rural Area

The water use condition of rural area in this city was studied and illustrated for two big rural communities mentioned below in which resident population is more than about two hundreds (200) persons. They are El-Talfa Village and Wade Feiran.

The potable water sources of them are groundwater, both through their own village wells.

6) Abu Rudeis city

(1) Urban Area

Nile River Water treated to potable quality water in the water treatment plant in Suez city is being used as potable water for the city. This is the most important potable water source for all cities in the West Sinai region such as Ras Sudr, Abu Zenima, El Tur and Sharm El Sheikh in addition to Abu Rudeis city.

The treated water from Suez city is conveyed by transmission main of ductile cast iron pipe. Several booster pumping stations are installed along the transmission main to supply the required quantity of water with adequate pressure.

A branch main from the transmission pipeline is used to transmit the water to an elevated water tank located in the city area. The water in the elevated water tank is distributed through gravity. The water supply capacity is 2,750 m3/day in accordance with the statistical data book of South Sinai Governorate as of January 1998. However, supply capacity of the potable water is insufficient especially in summer season.

An outline of water supply system in Abu Rudeis city is shown in Fig.9.1.5-6.

The treated water from Nile River meets the standards for potable use.

The existing main water supply facilities are shown in Table 9.1.5-7.

The technical problems in the present water supply are summarized below.

- Water Supply Capacity

The supply of potable water is limited throughout the year. The water shortage is about 150 m3/day at present. Therefore, development of new groundwater sources and increased intake from the main pipeline of River Nile Water needs to be considered.

- Administration of the Water Supply Quantity

The quantity of supplied water is not measured at present since no water meters are installed either in the pipe network or households. Thus the actual consumption and deficit to meet the required water demand is not known clearly.

(2) Rural Area

The water use condition of rural area in this city was studied and illustrated for eight (8) big rural communities in which resident population is more than two hundreds (200) persons and other two small rural communities.

Water supply to rural communities is mentioned below:

Potable water to most rural communities is conveyed by the water tank lorries from wells.

7) Abu Zenima city

(1) Urban Area

The potable water for the city area is River Nile Water treated in Suez city, same as for Abu Rudeis city. In fact the entire water supply system is same as that of Abu Rudeis city.

The water supply capacity is about 2,700 m3/day in accordance with the statistical data book of South Sinai Governorate as of January 1998. The supply capacity of the potable water is sufficient in throughout the year.

An outline of water supply system in Abu Zenima city is shown in Fig.9.1.5-7.

The existing main water supply facilities are shown in Table 9.1.5-8.

The technical problems in the present water supply are summarized below.

- Administration of the Water Supply Rate

The quantity of supplied water is not measured at present since no water meters are installed either in the pipe network or households. Thus the actual consumption and deficit to meet the required water demand is not known clearly.

(2) Rural Area

The water use condition of rural area in this city was studied and illustrated for nine (9) big rural communities in which resident population is more than two hundreds (200) persons.

Potable water supply to rural communities is mentioned below:

Most of these villages receive their potable water conveyed by the water tank lorries from wells located in nearby area. However, El-Samra receives Nile River water as its potable water, same as that of city area.

8) Ras Sudr city

(1) Urban Area

The potable water of the city area is River Nile Water treated in Suez city, same as for Abu Rudeis and Abu Zenima.

The water supply system is also basically similar for all these three (3) cities. However, three (3) branch lines from the main transmission pipeline is used to convey the required water to the city.

The total water supply capacity is about 6,100 m3/day in accordance with the statistical data book of South Sinai Governorate as of January 1998, although the results of interview survey that conducted by the Study Team, the total water consumption is about 2,000 m3/day. However, the total water capacity to be consumed in this report will be applied the data from South Sinai Governorate.

An outline of water supply system in Ras Sudr city is shown in Fig.9.1.5-8.

The quality of supplied water and treated water from Nile River is sufficiency.

The existing main water supply facilities are shown in Table 9.1.5-9.

The technical problems in the present water supply are summarized below.

- Administration of the Water Supply Quantity

The quantity of supplied water is not measured. Because water meters are installed neither in the pipe network nor households. The actual water consumption is unknown.

(2) Rural Area

The water use condition of rural area in this city was studied and illustrated for five (5) big rural communities in which resident population is more than about two hundreds (200) and four (4) other rural communities.

Potable water supply to rural communities is mentioned below:

Most of these rural communities are served by water tank lorries from nearby wells. Wadi Sudr and Abu-Suira communities are served with Nile River water, similar to that of city area.

9.1.6 Organization, Operation and Maintenance

1) Organization

The management of the water supply system including the public sewerage system is under the responsibility of Municipalities, and/or Ministry of Development, New Communities, Housing and Public Utilities.

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. Typical organization of water supply management is shown below in Table 9.1.6-1.

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. The existing condition of organization for water supply works is illustrated below in Table 9.1.6-2.

9.1.7 Water Tariff

1) Water Tariff Structure

The water tariff in the South Sinai is basically set by the South Sinai Gonernorate. Although the Municipalities have some authority to set their own tariff. In effect, a water tariff is set based on the following significant factors.

- Type of water source

- Water supply method

- Water supply capacity

- Distinction of consumers

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

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

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

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

2) Present Water Tariff

The present lists of water tariff applied by each Municipality are shown in Table 9.1.7-1.

Accordance to Table 9.1.7-1, 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.

9.2 Existing Sewerage System

9.2.1 Outline of the System

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

The treated wastewater from wastewater treatment plant (WWTP) in the cities is being reused for irrigation uses although it supplies to the plantation of trees only.

Case 1: Collected wastewater is treated in WWTP.

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 WWTP except the irrigation use, which is 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 surface water bodies such as sea, river or lake. On the other hand, treated wastewater is being reused to above plantation.

9.2.2 Service Area and Population

The sewerage system is provided basically in city areas only. Rural areas are not provided with sewerage facilities. However, in the four cities of St. Catherine, Abu Rudeis, Abu Zenima and Ras Sudr the sewerage systems are under construction only, and hence the services are not yet available. Also in Sharm El Sheikh, an expansion works of the sewerage system is under construction.

9.2.3 Wastewater Facilities

The sewerage system of each eight (8) cities is shown in Fig 9.1.5-1 to 9.1.5-8 and existing main facilities are shown in Table 9.2.3-1.

Table 9.1.2-1 Served Area and Population (in 1998)

	City Name	Served Area		Population			
		Served Area (km2)	City Area (km2)	Residents			Tourists (Person/day)
				City (Person)	Rural (Person)	Sub-total (Person)	
1	El Tur	13.0	21.0	13,692	2,363	16,055	188
2	Sharm El Sheikh	1.3	1.8	5,443	2,720	8,163	15,056
3	Dahab	10.5	15.4	1,222	3,040	4,262	1,813
4	Nuweiba	8.5	29.5	2,728	3,688	6,416	3,204
5	St.Catherine	3.1	3.4	855	3,930	4,785	1,058
6	Abu Rudeis	5.9	10.2	4,709	3,727	8,436	0
7	Abu Zenima	1.9	21.1	3,000	3,318	6,318	0
8	Ras Sudr	4.2	16.8	1,609	5,765	7,374	1,673
	Total	48.4	119.2	33,259	28,550	61,809	22,992

Note :

1) Data Source is as follows.

* Area : Statistical Data Book (from table on page22), Jan 1996,South Sinai Governorate
* Tourist Number : Statistical Data Book (from table on page33), Jan 1998,South Sinai Governorate
* Population : Statistical Data Book (from table on page33), Jan 1998,South Sinai Governorate

Above population number is assumed that increase rate is 6.5 % every year from censuss data in 1

2) Population number of residents includes the rural area.

Table 9.1.3-1 Unit Water Demand

	Unit	Daily Average	Daily Maximum	Peak Hourly
Residential Use				
* Urban Area	m^3/Capita/day	q_{11} = 0.24	$q_{12} = q_{11} \times 1.3$	$q_{13} = q_{11} \times 2.0$
* Rural Area	〃	q_{21} = 0.12	$q_{22} = q_{21} \times 1.3$	$q_{23} = q_{21} \times 2.0$
Tourist	〃	q_{31} = 0.40	$q_{32} = q_{31} \times 1.3$	$q_{33} = q_{31} \times 2.0$
Industrial Use	m^3/ha/day	q_{41} = 107	$q_{42} = q_{41} \times 1.2$	$q_{43} = q_{41} \times 2.0$
Agriculture Use	〃	q_{51} = 16.3	$q_{52} = q_{51} \times 1.5$	---

Note :

Data Source is as follows :

* Residential Use of Daily Average : National Plan for Development of Sinai (NPDS), Sept 1994, Ministry of Planning.
* Industrial Use : Standard Unit of Industrial Productoin by Medium Classification in Japan, 1986, MITI. Futher details refer to Chapter 10.2.2.
* Tourists Use of Daily Average : National Plan for Development of Sinai (NPDS), Sept 1994, Ministry of Planning.
* Coefficient number of water demands for daily maximum, peak hourly, Industrial Use.
: Similar Project of Ministry of Development, New Communities, Housing and Public Utilities in Suez City.
* Required water quantity for Agriculture Use : Results of discussion with WRRI (Feb 1, 1998) and "data of required water for agriculture use" from Water Distribution Resources Institute, Egypt.

Table 9.1.3-2 Potable Water Quality Standards

Item	Symbol	Unit	Egyptian Standards	WHO Standards
Color (Platinum-Cobalt units)	-	TCU	50	15
Turbidity (NTU)	-	NTU	5	5
Taste	-	-	should be acceptable	should be acceptable
Odor	-	-	should be acceptable	should be acceptable
Lead	Pb	mg/l	0.1	0.01
Arsenic	As	mg/l	0.05	0.01
Cyanide	CN	mg/l	0.05	0.07
Cadmium	Cd	mg/l	0.01	0.003
Selenium	Se	mg/l	0.01	0.01
Mercury	Hg	mg/l	0.001	0.001
Barium	Ba	mg/l	should be acceptable	0.7
Chromium	Cr	mg/l	should be acceptable	0.05
Fluoride	F	mg/l	0.8	1.5
Nitrate	NO_3^-	mg/l	45	50
Nitrite	NO_2^-	mg/l	-	3
Total Dissolved Solids	TDS	mg/l	1,500	1,000
Iron	Fe	mg/l	1	0.3
Manganese	Mn	mg/l	0.5	0.5
Copper	Cu	mg/l	1.5	2
Zinc	Zn	mg/l	15	3
Calcium	Ca	mg/l	200	-
Magnesium	Mg	mg/l	150	-
Total Hardness as CaCO3	T-H	mg/l	500	-
Chloride	Cl^-	mg/l	600	250
Sulfate	SO_4^-	mg/l	400	250
Phenol	Phenol	mg/l	0.002	-
pH	pH	-	6.5 ~ 9.2	-
Mineral Oil		mg/l	shall not be included	-
Hydrogen Sulfide		mg/l	shall not be included	0.05
Anionic Detergents/Forming Agents		mg/l	shall not be included	-
Gross alpha activity (pCi/l)		pCi/l	3	-
Gross beta activity (pCi/l)		pCi/l	30	-

Note :

1) Data Source : Egyptian Standards for Potable Water and Guidelines for Drinking Water Quality of WHO.

2) TCU : True Color Unit

3) NTU : Nephelometric Tubidity Unit

Table 9.1.4-1 Water Production and Consumption of Potable Water

[Unit : m^3/day]

	City Name	Water Source	Production Capacity	Water Demand in 1997 Residents	Tourist	Others*1	Loss	Total	Surplus /Deficit
1	El Tur	Groundwater	6,000	4,014	120	1,498	240	5,872	128
2	Sharm El Sheikh		10,260	2,041	9,590	2,561	410	14,602	-4,342
		Groundwater (from El Tur City)	1,000						
		Seawater	9,260						
3	Dahab		2,000	1,066	1,155	499	80	2,800	-800
		Groundwater*2	[500]	[500]				[500]	
		Seawater	2,000						
4	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						
5	St.Catherine	Groundwater	450	1,196	674	112	18	2,000	-1,550
6	Abu Rudeis	River Nile	2,750	2,109	0	661	110	2,880	-130
7	Abu Zenima	"	2,700	1,580	0	424	68	2,072	628
8	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) Data Source : Statistical Data Book (from tables on page33), Jan 1998, South Sinai Governorate

2) *1 : Mainly for industrial, public offices, shops, restaulants

3) *2 : Brackish water

Table 9.1.4-2 Unit Water Consumption of Residents and Tourists as of 1998

	City Name	Residents Served Population (Person)	Residents Water Demand (m^3/day)	Residents Unit Water Consumption m^3/Capita/day	Tourists Served Population (Person)	Tourists Water Demand (m^3/day)	Tourists Unit Water Consumption m^3/Capita/day
1	El Tur	16,055	4,014	0.25	188	120	0.64
2	Sharm El Sheikh	8,163	2,041	0.25	15,056	9,590	0.64
3	Dahab	4,262	1,066	0.25	1,813	1,155	0.64
4	Nuweiba	6,416	1,604	0.25	3,204	2,041	0.64
5	St.Catherine	4,785	1,196	0.25	1,058	674	0.64
6	Abu Rudeis	8,436	2,109	0.25	0	0	---
7	Abu Zenima	6,318	1,580	0.25	0	0	---
8	Ras Sudr	7,374	1,844	0.25	1,673	1,066	0.64
	Total/Average	61,809	15,454	0.25	22,992	14,646	0.64

Note :

1) Data Source : Statistical Data Book (from table on page 33) , Jan 1998, South Sinai Governorate

Table 9.1.5-1 Results of the Latest Water Quality Analysis for Supply Water (in 1994 to 1996)

Well Name	Date d/m/y	pH	E.C mmh/cm	TDS mg/l	Cations K mg/l	Na mg/l	Mg mg/l	Ca mg/l	Anions SO4 mg/l	Cl mg/l	HCO3 mg/l	CO3 mg/l
Egyptian Standard (Potable)		6.5 ~ 9.2	---	1,500	---	---	150.00	200.00	400.00	600.00	---	---
1) El Tur City												
Qaa12	0/3/96	7.70	0.73	492	2.70	80.50	2.40	72.80	11.00	176.40	178.10	0.00
Qaa15	0/3/96	7.80	0.73	481	2.70	80.50	3.50	65.00	84.00	127.80	139.70	0.00
Qaa23	0/3/96	7.80	0.74	468	2.30	100.10	25.60	52.00	12.00	149.10	146.40	0.00
Qaa20	0/3/96	7.40	0.86	516	2.70	115.00	1.20	52.00	20.20	174.00	149.50	0.00
Qaa21	0/3/96	7.90	0.99	646	2.70	130.00	7.10	66.40	28.80	117.20	207.40	0.00
Qaa29	0/3/96	7.50	0.77	504	3.50	87.90	5.90	62.40	13.00	154.40	175.70	0.00
Qaa28	0/3/96	7.90	0.97	654	3.50	115.00	7.80	82.00	29.80	205.50	147.00	0.00
Qaa26	0/3/96	7.50	1.37	79(	2.70	151.80	5.50	101.40	29.30	282.60	219.60	0.00
2)Sharm El Sheikh City												
T-1 (in El Tur)	0/3/96	7.70	0.96	570	2.30	121.90	3.70	61.20	9.10	209.10	161.00	0.00
T-2 (in El Tur)	0/3/96	7.90	0.77	581	2.30	115.00	1.20	12.00	24.00	154.10	184.20	0.00
3)Dahab City												
Wadi Dahab-2				2,500								
Wadi Dahab-4				2,500								
Wadi Dahab-5				2,500								
Wadi Dahab-6				3,000								
Wadi Dahab-7				2,500								
Wadi Dahab-8				3,000								
4)Nuweiba City												
Regwa 1	24/8/94	6.90	6.90	4,105	18.10	747.50	316.59	252.00	792.00	1,931.91	32.94	0.00
Regwa 2	24/8/94	7.10	2.91	1,789	13.48	254.15	99.06	208.00	513.60	666.34	29.28	0.00
Regwa 5	24/8/94	6.90	10.49	6,931	27.34	1,380.00	528.50	194.40	2,803.20	1,948.95	29.28	0.00
Regwa 8	24/8/94	7.10	2.81	1,964	61.60	254.15	115.41	194.80	734.40	570.49	28.67	0.00
5)St. Catherine City												
Ramadan Gabaly	0/1/95	7.70	1.08	693	1.54	55.66	9.76	149.60	329.28	124.96	21.96	0.00
Haron	0/1/95	8.00	0.67	435	0.77	28.52	15.01	85.80	212.64	70.29	22.57	0.00
Saleh Mahmoud Farag	0/1/95	8.00	0.43	290	1.16	19.78	14.27	48.40	144.00	39.05	23.18	0.00
Mohamed Farag2	0/1/95	7.80	1.22	709	0.77	50.83	1.95	171.60	330.72	134.55	17.69	0.00
Ismaeil Ibrahim	0/1/95	8.00	1.01	689	1.54	63.02	9.27	143.00	309.12	134.55	28.06	0.00
Mohamed Mansour2	0/1/95	8.00	0.49	356	0.77	34.50	15.86	55.00	170.88	60.71	18.30	0.00
Ahamed Mausour	0/1/95	8.80	0.25	132	3.47	27.60	2.07	13.20	22.56	48.99	10.98	0.00

Table 9.1.5-2 Existing Water Supply Facilities of El Tur City

Name	Numbers		Type	Description
Intake Well	8	pcs	Shallow well	Depth 30 ~ 50 m (static water level)
Aqueduct	1	set	Steel Pipe	
Water Treatment Plant	1	set		
1)Receiving Reservoir	1	pc	Rectangular Tank	Cap 2,500 m^3
2)Distribution Pump	3	pcs	Volute pumps	7.2 m^3/min x 87 kw
3)Disinfectant	1	set	Chlorine Gas	
Transmission Pipeline	1	set		
Distribution Reservoir	2	pcs	Under Construction	Cap 1,200 & 600 m^3
Pipe Network	1	set		
Water Tank Lorry	1	set		

1) Data Source : Interview survey by the Study Team in Sep 1996 and Feb 1998.

Table 9.1.5-3 Existing Water Supply Facilities of Sharm El Sheikh City

Name	Numbers		Type	Description
Intake Well (El Tur City)	2	pcs	Shallow well	Depth 30 ~ 50 m (static water level)
Aqueduct	1	set	Steel Pipe	El Tur ~ Sharm El Sheikh
Water Treatment Plant	1	set	Desalination Plant	
1)SES No1 Station	1	pc	Evaporation	Cap 190m^3 /d (Max 450)
2)SES No2 Station	1	pc	Evaporation	Cap 170m^3 /d(Max 400)
3)El Fayrouz Village	1	pc		Cap 250m^3 /d(Max 600)
4)Movimepek Hotel	1	pc		Cap 400m^3 /d(Max 400)
5)Residence Hotel	1	pc		Cap 100m^3 /d(Max100)
6)Aqua Malina Hotel	1	pc		Cap 250m^3 /d(Max 250)
7)Ras Nsrany	1	pc		Cap 400m^3 /d(Max 500)
8)Aida Village	1	pc		Cap 200m^3 /d(Max 200)
9)El Sheikh Coast	1	pc		Cap 400m^3 /d(Max 400)
10)Sonesta (Hilton)	1	pc		Cap 400m^3 /d(Max 400)
11)South Sinai Co.,Ltd.	1	pc	Reverse Osmosis	Cap 3,000m^3 /d(Max 6,000)
12)City Sharm	1	pc	Evaporation	Cap 200m^3 /d(Max 200)
13)South Sinai Dev Authority	1	pc	Reverse Osmosis	Cap 4,000m^3 /d(under construct)
Transmission Pipeline	1	set		
Distribution Reservoir	1	pcs		Cap 5,000 m^3 (for public use)
Pipe Network	2	set		for Public & Private
Water Tank Lorry	1	set		for Public & Private

1) Data Source is as follows :

* Water Treatment Plant : Statistical Data Book (from table on page 31), Jan 1996, South Sinai Governorate

* Others : Interview survey by the Study Team in Sep 1996 and Feb 1998.

Table 9.1.5-4 Existing Water Supply Facilities of Dahab City

Name	Numbers		Type	Description
Intake Well (Brackish)	4	pcs	Shallow well	Depth 50 ~ 60 m
Aqueduct	1	set	Steel & PVC Pipe	
Pre-Treatment Plant	1	set		
Water Treatment Plant			Desalination Plant	
1)Existing	1	pc	Reverse Osmosis	Cap 900m^3 /d (Max 2,000)
2)Under Construction	1	pc	Reverse Osmosis	Cap 2,000m^3 /d (Max 2,000)
3)Storage Reservoir	2	pc	Under Construcftio	Cap 3,000 m^3
Transmission Pipeline	1	set		
Distribution Reservoir	1	pcs		Cap 1,250 m^3
Pipe Network	2	set		for Potable & Brackish Water
Water Tank Lorry	1	set		

1) Data Source : Interview survey by the Study Team in Sep 1996 and Feb 1998.

Table 9.1.5-5 Existing Water Supply Facilities of Nuweiba City

Name	Numbers		Type	Description
Intake Well (Brackish)	6	pcs	Shallow well	Depth 30 ~ 60 m
Aqueduct	1	set	Steel & PVC Pipe	including Asbestos pipe
Water Treatment Plant	1	set	Desalination Plant	
1)for Public Use	1	pc	Evaporation	Cap 400m^3 /d (Max 2,000)
2)for Official Use	1	pc	Electric Dialysis	Cap 5m^3 /d(Max 300)
3)Disinfectant	1	set	Disinfectant:NaHcl	for Public Use
Transmission Pipeline	2	set	Potale & Brackish	
Distribution Reservoir	3	pcs	Potale & Brackish	Cap 1,000 x 2, & 500 m^3
Pipe Network	1	set		Port Area & City Area (not working)
Water Tank Lorry	1	set		

1) Data Source : Interview survey by the Study Team in Sep 1996 and Feb 1998.

Table 9.1.5-6 Existing Water Supply Facilities of St. Catherine City

Name	Numbers		Type	Description
Intake Well	3	pcs	Shallow well	Depth 50 m
No1 Well	1	pcs	Supply by Pipeline	Distance from city : 1.5 km
No2 Well	1	pcs	Supply by Lorries	Distance from city : 6.5 km
No3 Well	1	pcs	Supply by Lorries	Distance from city : 16 km
New Well (under construct)	3	pcs	Supply by Pipeline	Distance from city : 4.5 ~ 16 km (will be completed within 1998)
Transmission Pipeline	1	set	Steel &PVC Pipe	dia 100 mm
〃	1	set	Steel	New pipeline : under construction
Distribution Reservoir	1	pcs		Cap 33 m^3
〃	3	pcs	under construction	Cap 500 x 2, & 1,000 m3
Pipe Network	1	set		under expansion works
Water Tank Lorry	1	set		

1) Data Source : Interview survey by the Study Team in Sep 1996 and Feb 1998.

Table 9.1.5-7 Existing Water Supply Facilities of Abu Rudeis City

Name	Numbers		Type	Description
Valve Chamber	1	pcs	Underground	Gate Valve, Flow Meter etc.,
Transmission Pipeline	1	set	Steel Pipe	dia 300 mm
Distribution Reservoir	1	pcs	Elevated Water Tar	Cap 1,000, 35 m High
Pipe Network	1	set		under expansion works

1) Data Source : Interview survey by the Study Team in 1996.

Table 9.1.5-8 Existing Water Supply Facilities of Abu Zenima City

Name	Numbers		Type	Description
Valve Chamber	1	pcs	Underground	Gate Valve, Flow Meter etc.,
Transmission Pipeline	1	set	Steel Pipe	dia 300 mm
Distribution Reservoir	1	pcs	Elevated Water Tar	Cap 1,000, 35 m High
Pipe Network	1	set	Steel/Asbestos/UPV	under expansion works

1) Data Source : Interview survey by the Study Team in Sep 1996 and Feb 1998.

Table 9.1.5-9 Existing Water Supply Facilities of Ras Sudr City

Name	Numbers		Type	Description
Valve Chamber	3	pcs	Underground	Gate Valve, Flow Meter etc.,
Transmission Pipeline	3	set	Steel Pipe	dia 200 mm
Distribution Reservoir	1	pcs	Elevated Water Tar	Cap 1,000, 35 m High
〃	2	pcs	Elevated Water Tar	Cap 500, 35 m High
Pipe Network	3	set	Steel/Asbestos/UPV	under expansion works

1) Data Source : Interview survey by the Study Team in Sep 1996 and Feb 1998.

Table 9.1.6-1 Typical Organization of Water Supply Management

Working Item	Working Organization		
	MOD	Municipality	Private Firm
Planning			O
1) Main Facilities*1	O		
2) Other Facilities*2		O	
Construction			O
1) Main Facilities	O		
2) Other Facilities		O	
Operation			O
1) Main Facilities	O	O	
2) Other Facilities		O	
Maintenance			O
1) Main Facilities	O	O	
2) Other Facilities		O	
Management		O	O

Note :

*1 Main Facilities : Main pipeline of River Nile Water, WTP, Elevated Water Tanks

*2 Other Facilities : Pipe Network, etc.,

Table 9.1.6-2 Present Conditions of Organization, Operation and Maintenance

City Name	Facilities	Water Works			
		Plann-ing	Const-ruction	Mainte-nance	Operation
1) El Tur	Intake Well	MOD	MOD	Muni	Muni
	Aqueduct	〃	〃	〃	〃
	Water Treatment Plant	〃	〃	〃	〃
	Transmission Pipeline	〃	〃	〃	〃
	Distribution Reservoir	〃	〃	〃	〃
	Pipe Network	〃	〃	〃	〃
	Water Tank Lorry	〃	〃	〃	〃
2) Sharm El Sheikh	Intake Well (El Tur City)	MOD	MOD	Muni	Muni
	Aqueduct	〃	〃	〃	〃
	Water Treatment Plant	〃	〃	〃	〃
	Transmission Pipeline	〃	〃	〃	〃
	Distribution Reservoir	〃	〃	〃	〃
	Pipe Network	〃	〃	〃	〃
	Water Tank Lorry	〃	〃	〃	〃
	Private Supply System	Pr-Firm	Pr-Firm	Pr-Firm	Pr-Firm
3) Dahab	Intake Well (Brackish)	MOD	MOD	Muni	Muni
	Aqueduct	〃	〃	〃	〃
	Pre-Treatment Plant	〃	〃	〃	〃
	Water Treatment Plant	〃	〃	MOD	MOD
	Transmission Pipeline	〃	〃	Muni	Muni
	Distribution Reservoir	〃	〃	〃	〃
	Pipe Network	〃	〃	〃	〃
	Water Tank Lorry	〃	〃	〃	〃
4) Nuweiba	Intake Well (Brackish)	MOD	MOD	Muni	Muni
	Aqueduct	〃	〃	〃	〃
	Water Treatment Plant	〃	〃	〃	〃
	Transmission Pipeline	〃	〃	〃	〃
	Distribution Reservoir	〃	〃	〃	〃
	Pipe Network	〃	〃	〃	〃
	Water Tank Lorry	〃	〃	〃	〃
5) St.Catherine	Intake Well	MOD	MOD	Muni	Muni
	Transmission Pipeline	〃	〃	〃	〃
	Distribution Reservoir	〃	〃	〃	〃
	Pipe Network	〃	〃	〃	〃
	Water Tank Lorry	〃	〃	〃	〃

City Name	Facilities	Water Works			
		Plann-ing	Const-ruction	Mainte-nance	Operation
6) Abu Rudeis	Valve Chamber	MOD	MOD	Muni	Muni
	Transmission Pipeline	〃	〃	〃	〃
	Distribution Reservoir	〃	〃	MOD	MOD
	Pipe Network	〃	〃	Muni	Muni
7) Abu Zenima	Valve Chamber	MOD	MOD	Muni	Muni
	Transmission Pipeline	〃	〃	〃	〃
	Distribution Reservoir	〃	〃	MOD	MOD
	Pipe Network	〃	〃	Muni	Muni
8) Ras Sudr	Valve Chamber	MOD	MOD	Muni	Muni
	Transmission Pipeline	〃	〃	〃	〃
	Distribution Reservoir	〃	〃	MOD	MOD
	Pipe Network	〃	〃	Muni	Muni

Note :

MOD : Ministry of Development, New Communities, Housing and Public Utilities.

Muni : Municipality

Pr-Firm : Private Firm

Table 9.1.7-1 Present Public Water Tariff

[Unit : LE/m^3]

City Name	Consumers						
	Residents			Comme-rcial	Hotels	Indust-ries	Rural Commu
	~ 30 m^3	31 ~ 50 m^3	51 m^3 ~				
1) El Tur	0.18	0.25	1.00	1.00	6.00	1.00	0.18
2) Sharm El Sheikh	0.18	0.25	1.00	1.00	6.00	1.00	---
3) Dahab		1.00		6.00	6.00	---	Free
4) Nuweiba (Potable)		1.00		6.00	6.00	---	0.18~2.9
(Brackish)	10 LE/Month/Home			---	---	---	---
5) St.Catherine	4 LE/Month/Home			4.00	6.00	---	1.25
6) Abu Rudeis	0.18	0.25	1.00	1.00	6.00	1.00	0.18~0.7
7) Abu Zenima	0.18	0.25	1.00	1.00	6.00	3.00	1.00
8) Ras Sudr	0.18	0.25	1.00	1.00	6.00	1.00	0.18

1) Data Source : Interview survey to each Municipality by the Study Team in Sep 1996 and Feb 1998.

Table 9.2.3-1 Wastewater Facilities in Eight Cities

Data Source : Interview survey to each Municipality by the Study Team in Sep 1996 and Feb 1998.

1) El Tur City

Name	Numbers		Type	Description
Collection Pipeline	1	set	Concrete pipe	
Sewage Pumping Station	4	sets	Underground	Submersible pump
Main Pumping Station	1	set	Underground	Wastewater Rate: 3,000 m^3/day
1)Main Pump	3	pcs	Horizontal Volute	1.5 m^3/min x 43m x 45 kw
WWTP			(using the treated wastewater for irrigation use)	
1)Primary Treatment	2	pcs	Oxidation Ponds	Wastewater Rate: 3,000 m^3/day Area: about 10,000 m^2
2)Secondary Treatment	1	pcs	Activated Sludge	Wastewater: 1,000 m^3/day

2) Sharm El Sheikh City

Name	Numbers		Type	Description
Collection Pipeline	1	set	Concrete pipe	
Sewage Pumping Station	6	sets	Underground	Submersible pump
WWTP			(using the treated wastewater for irrigation use)	
1)Ponds	4	pcs	Oxidation Ponds	Wastewater: 3,500 ~5,000 m3/day Area: about 15,000 m^2
2)New WWTP	1	set	Oxidation Ponds	Under Construction (will be completed within 1998)

3) Dahab City

Name	Numbers		Type	Description
Collection Pipeline	1	set	Concrete pipe	
Sewage Pumping Station	5	sets	Underground	Submersible pump
WWTP	2	sets	(using the treated wastewater for irrigation use)	
1)Ponds (per WWTP)	3	pcs	Oxidation Ponds	Wastewater: 1,120 m^3/day Area: about 7,500 m^2

4) Nuweiba City

Name	Numbers		Type	Description
Collection Pipeline	1	set	Concrete pipe	
Sewage Pumping Station	--	sets	Underground	Submersible pump
WWTP	2	sets	(using the treated wastewater for irrigation use)	
1)Ponds (per WWTP)	5	pcs	Oxidation Ponds	Wastewater: 1,800 m^3/day Area: about 19,000 m^2

5) St.Catherine

Name	Numbers		Type	Description
Collection Pipeline	1	set	Concrete pipe	Completion the construction works
Sewage Pumping Station	non	sets	---	no need
WWTP			(Treated wastewater will be used for irrigation use)	
1)Primary Treatment	2	pcs	Activated Sludge	Wastewater: 2,000 m^3/day (will be completed within 1998)

Note : commencement of sewerage works is scheduled for March 1999.

6) Abu Rudeis City : Under construction

Name	Numbers		Type	Description
Collection Pipeline	1	set	Concrete pipe	
Wastewater Pit	lot	set	Underground	
Sewage Pumping Station	--	sets	Underground	Submersible pump
WWTP	1	set	Oxidation Ponds	Wastewater: --- m^3/day
1)Ponds	--	pcs	per a WWTP	Area: about --- m^2

Note : commencement of sewerage works is scheduled for March 1999.

7) Abu Zenima City : Under construction

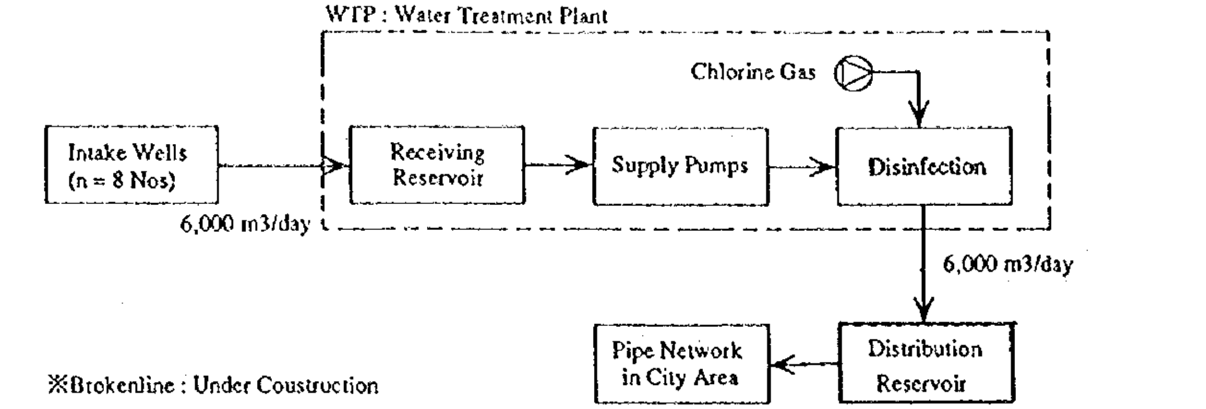
Name	Numbers		Type	Description
Collection Pipeline	1	set	Concrete pipe	
Wastewater Pit	10	set	Underground	
Sewage Pumping Station	--	sets	Underground	Submersible pump
WWTP	1	set	Oxidation Ponds	Wastewater: --- m^3/day
1)Ponds	--	pcs	per a WWTP	Area: about --- m^2

Note : commencement of sewerage works is scheduled for March 1999.

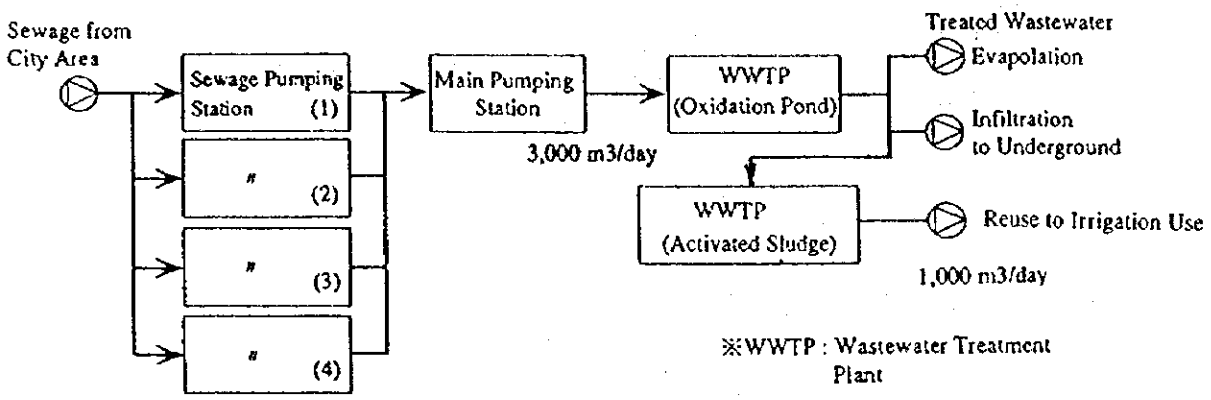
8) Ras Sudr City : Under construction at present

Name	Numbers		Type	Description
Collection Pipeline	1	set	Concrete pipe	
Wastewater Pit	lot	set	Underground	
Sewage Pumping Station	--	sets	Underground	Submersible pump
WWTP	1	set	Oxidation Ponds	Wastewater: --- m^3/day
1)Ponds	--	pcs	per a WWTP	Area: about --- m^2

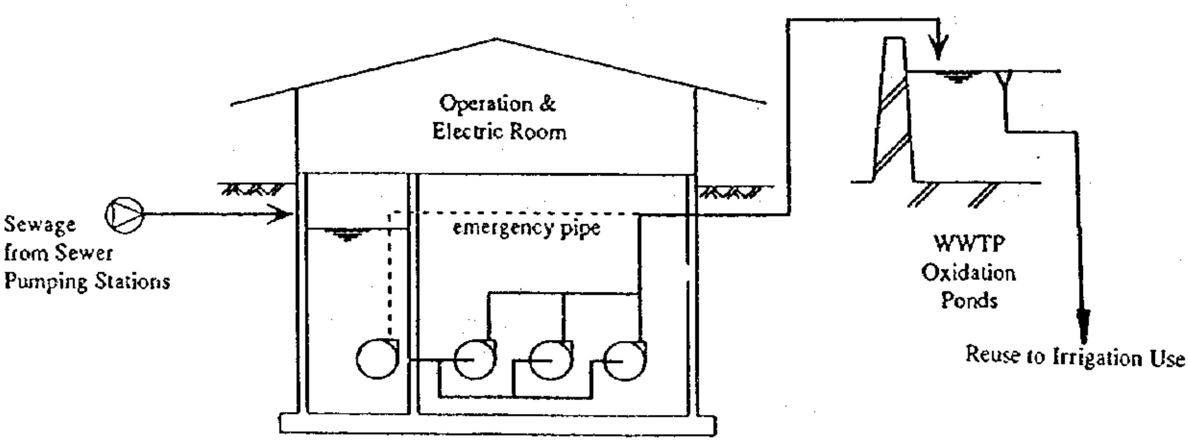
Note : commencement of sewerage works is scheduled for 1998.



Outline of the Water Supply System

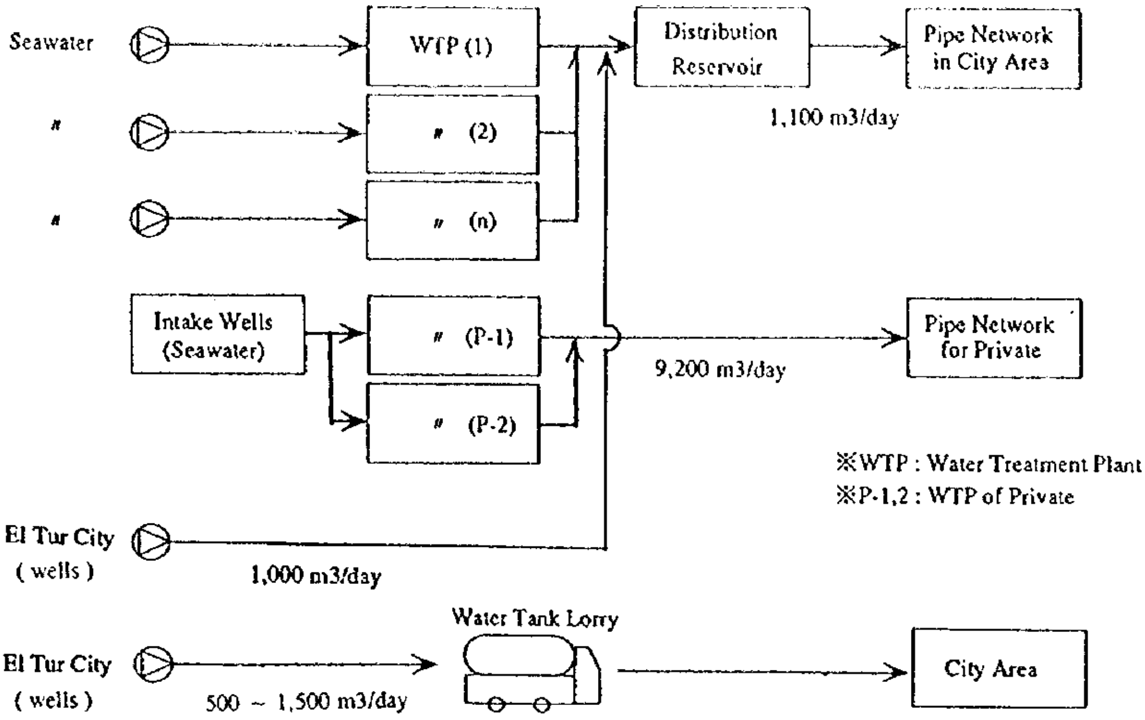


Outline of the Sewerage System

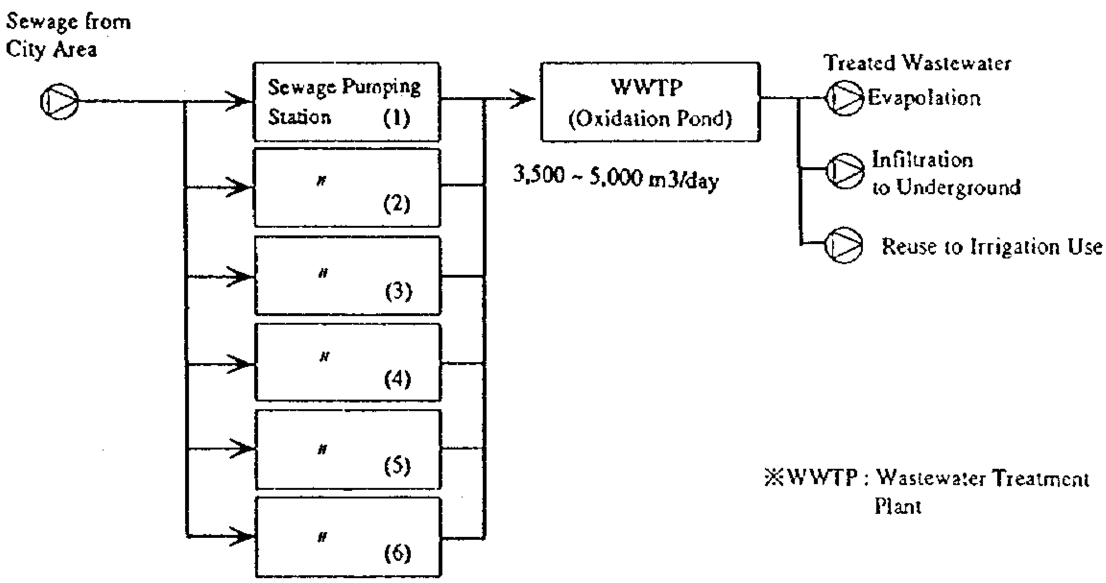


Main Pumping Station of Sewerage System

Fig. 9.1.5-1 Outline of the Water Supply and Sewerage System in El Tur City

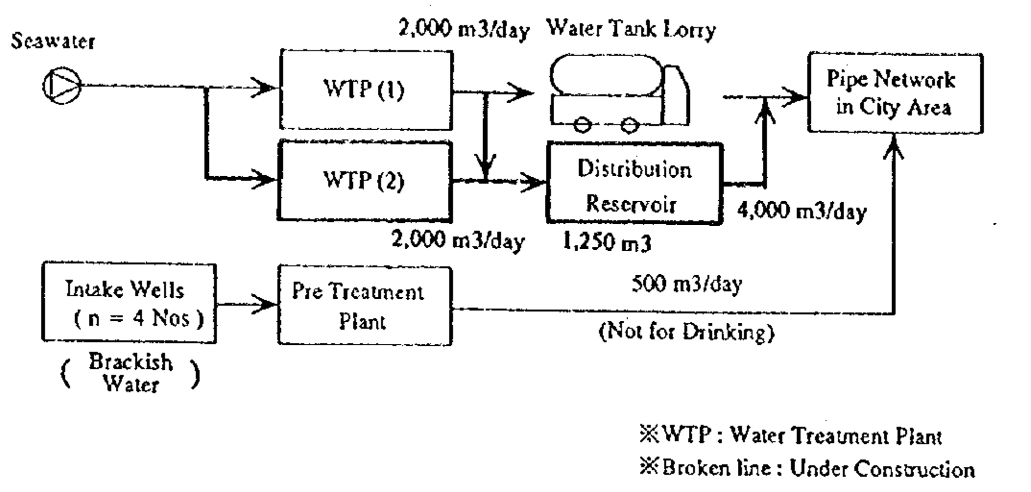


Outline of the Water Supply System

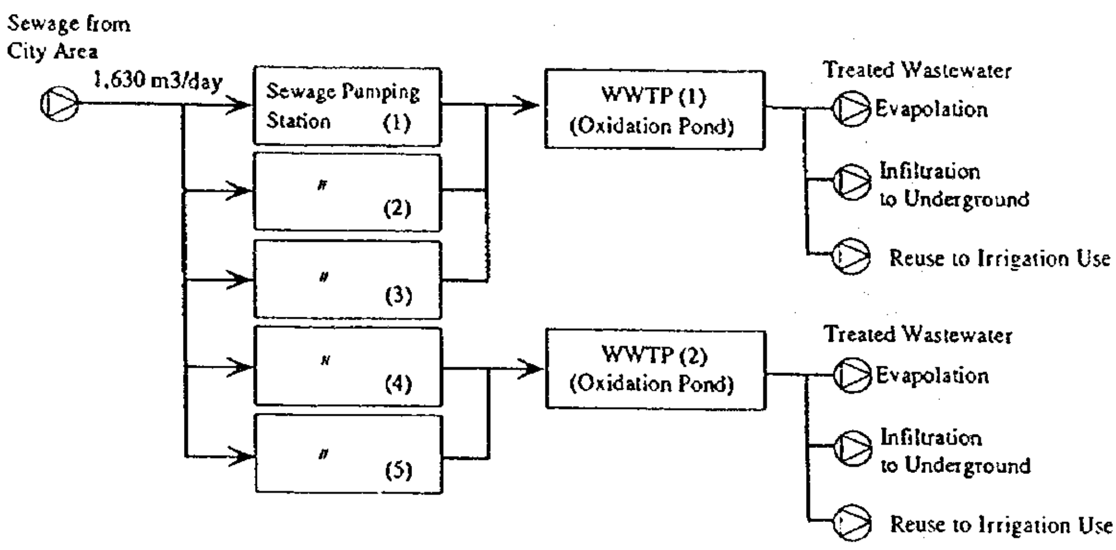


Outline of the Sewerage System

Fig. 9.1.5-2 Outline of the Water Supply and Sewerage System in Sharm El Sheikh City

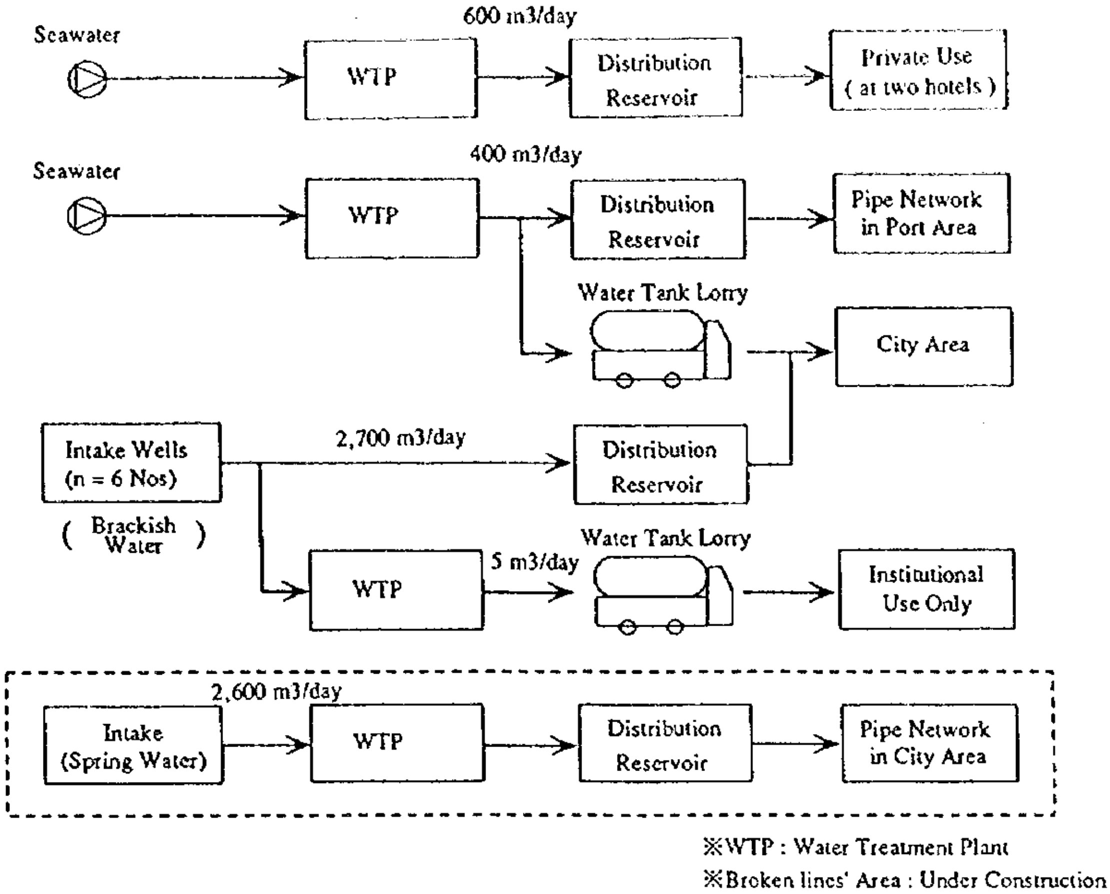


Outline of the Water Supply System

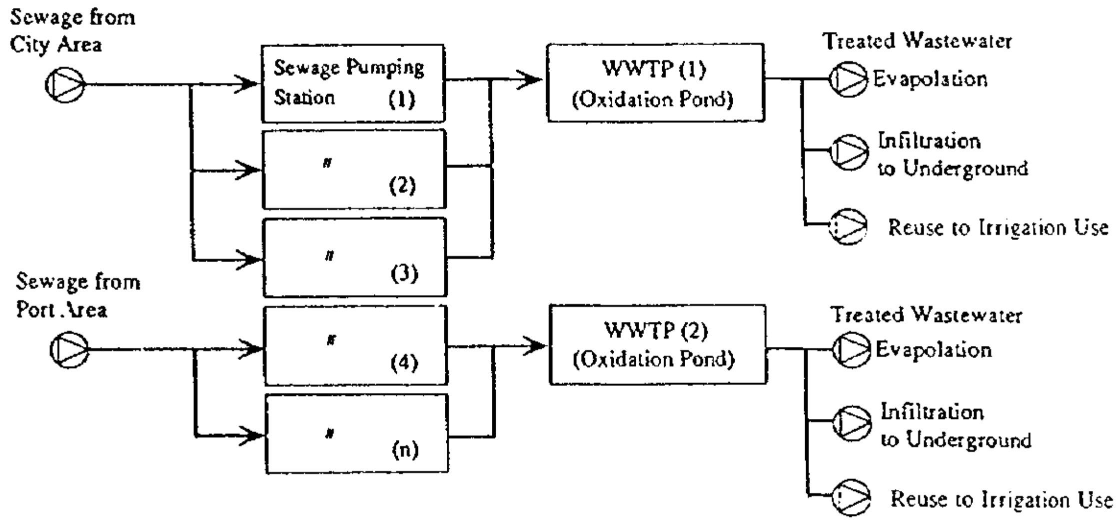


Outline of the Sewerage System

Fig. 9.1.5-3 Outline of the Water Supply and Sewerage System in Dahab City

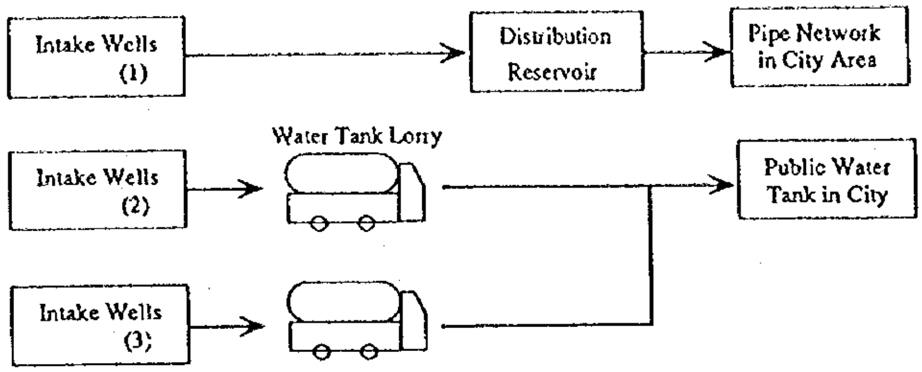


Outline of the Water Supply System

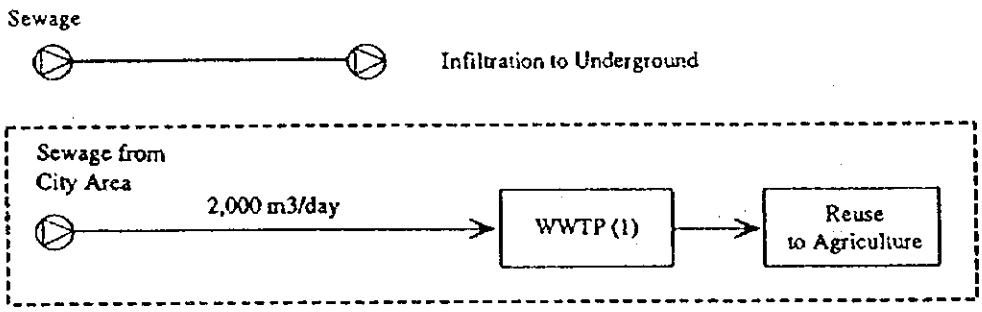


Outline of the Sewerage System

Fig. 9.1.5-4 Outline of the Water Supply and Sewerage System in Nuweiba City



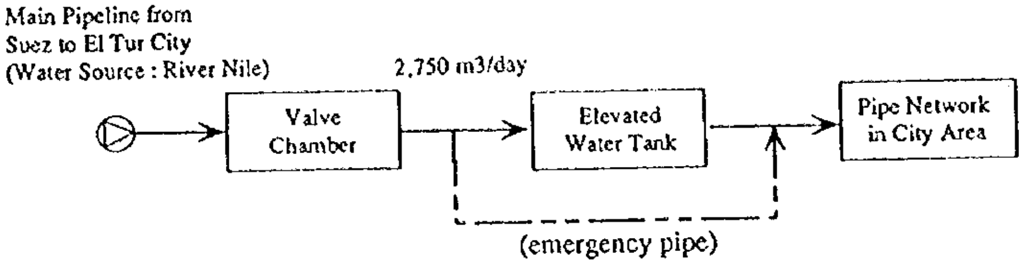
Outline of the Water Supply System



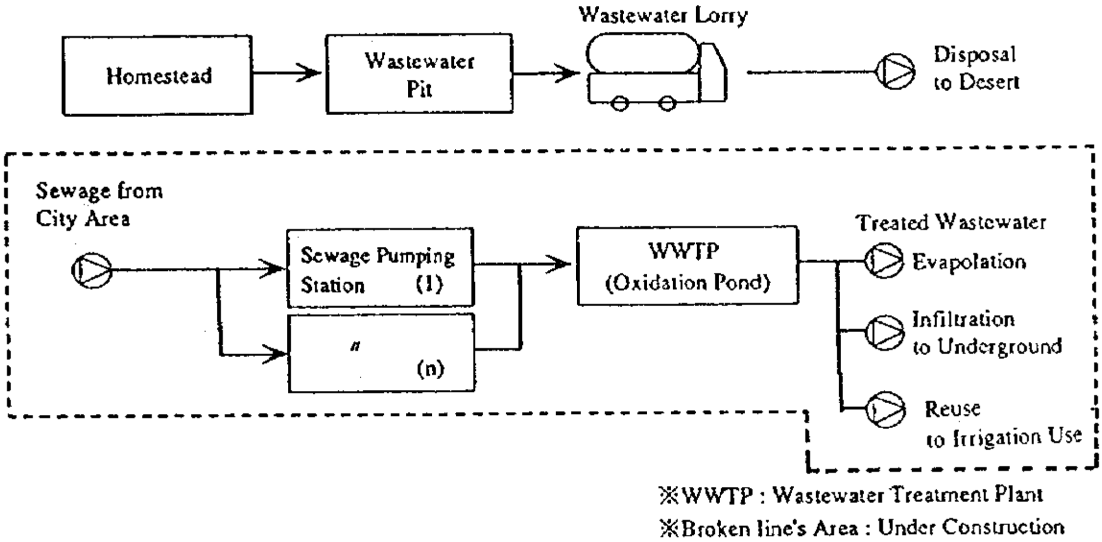
※WWTP : Wastewater Treatment Plant
※Broken lines' Area : Under Construction

Outline of the Sewerage System

Fig. 9.1.5-5 Outline of the Water Supply and Sewerage System in St.Catherine City

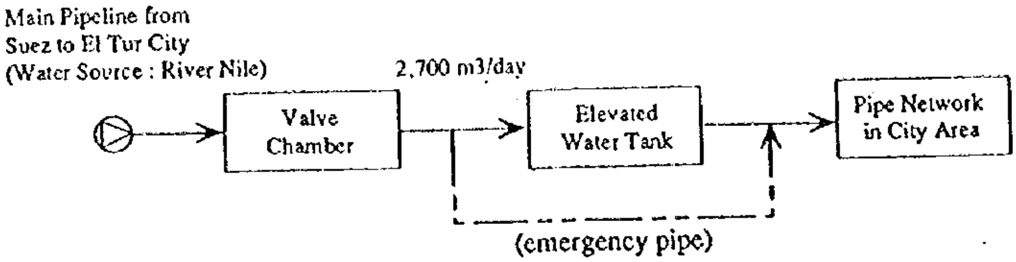


Outline of the Water Supply System

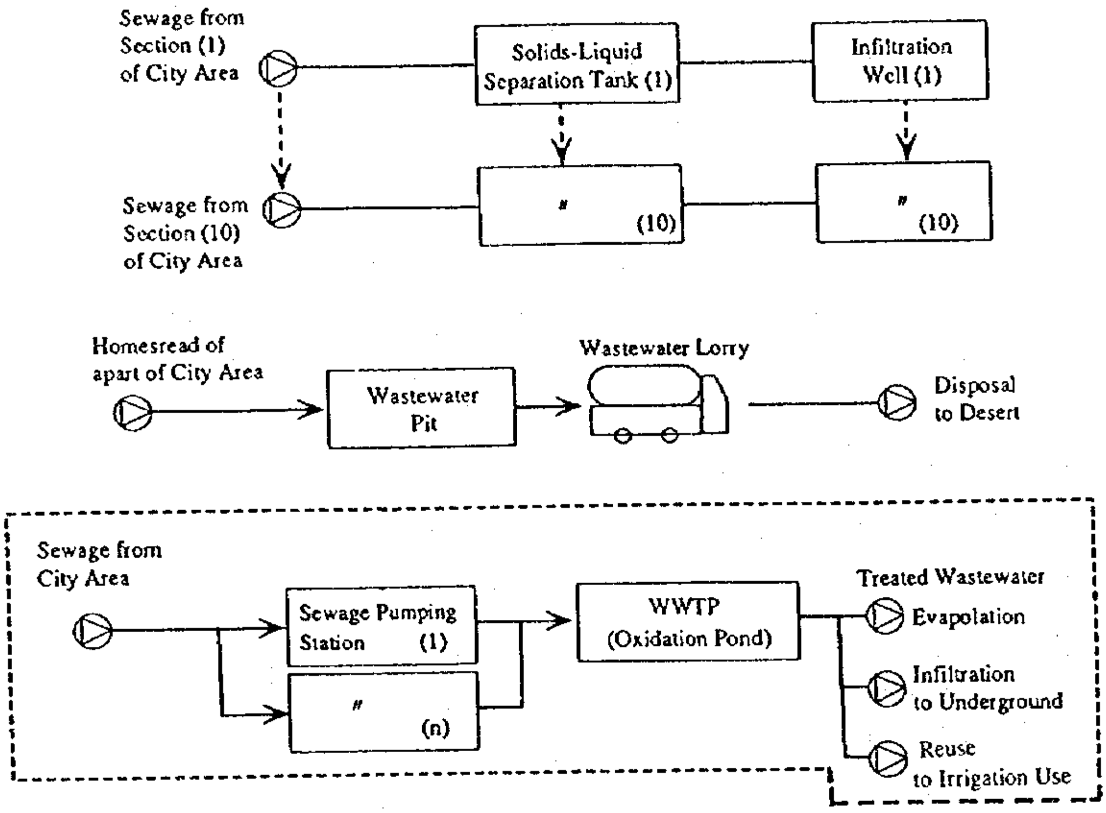


Outline of the Sewerage System

Fig. 9.1.5-6 Outline of the Water Supply and Sewerage System in Abu Rudeis City



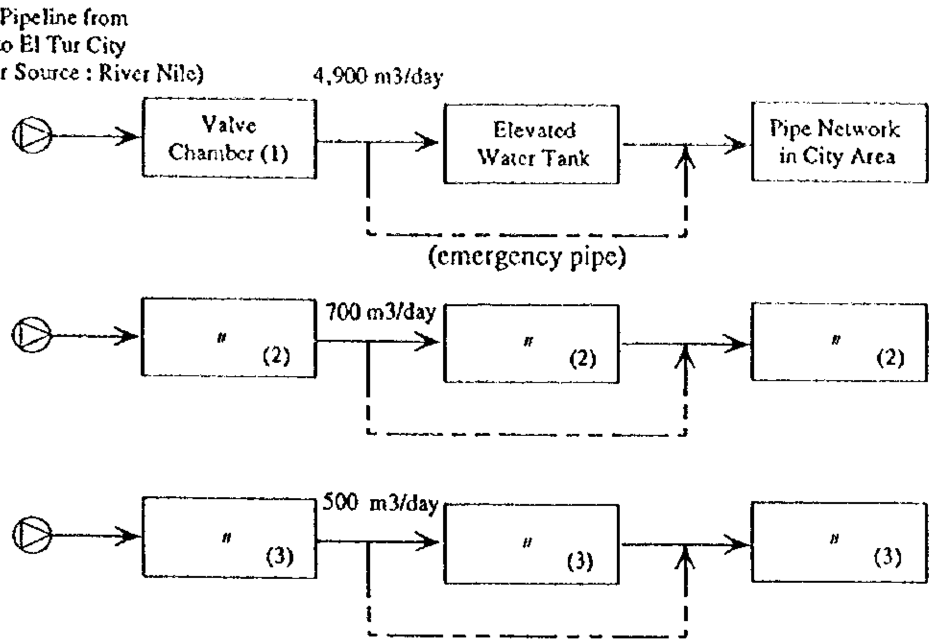
Outline of the Water Supply System



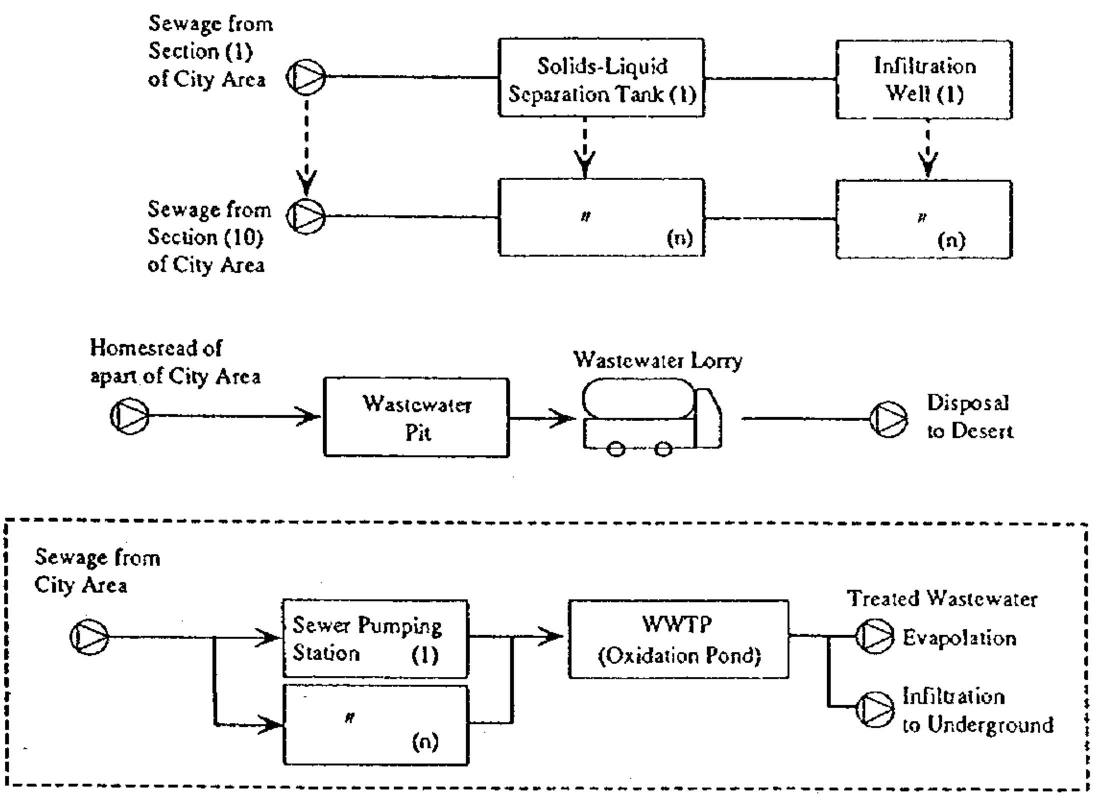
※WWTP : Wastewater Treatment Plant
※Broken line's Area : Under Construction

Outline of the Sewerage System

Fig. 9.1.5-7 Outline of the Water Supply and Sewerage System in Abu Zenima City



Outline of the Water Supply System



※WWTP : Wastewater Treatment Plant
※Broken line's Area : Under Construction

Outline of the Sewerage System

Fig. 9.1.5-8 Outline of the Water Supply and Sewerage System in Ras Sudr City

CHAPTER X EXISTING WATER USE AND FUTURE WATER DEMAND

10.1 Existing Water Use

Water in South Sinai is being utilized for residential, tourism, commercial, and industrial use, and for agricultural use such as crops, plantation of trees. The sources of water for daily use are classified into groundwater, river Nile water, seawater and treated wastewater from the sewerage system (wastewater treatment plant). Although the selection of these water sources is determined by the geographical and social conditions of a location in the served area, the cities on the west side of South Sinai except El Tur city, are using river Nile water as a water source. On the other hand, the cities on the east side (including Sharm El Sheikh city) are using desalinated water which is treated from seawater. The existing water uses in line with the purpose are mentioned below.

10.1.1 Resident Use

In accordance with the census data in 1996, the population in the urban and rural areas in South Sinai is approximately 29,500 and 25,000 persons respectively. The supply method for potable water to urban areas is generally distribute by pipeline to each household, while distribution to rural areas transport from the water sources by the water tank lorries.

In Nuweiba and Dahab cities, where capacity of potable water sources is insufficient, the brackish water from shallow wells is distributed as part of domestic water such as for washing and sprinkle water to the gardens. This water is supplied to consumers by the independent distribution pipe network.

The water supply quantity compared with the present water demand is generally showing a tendency of shortage in supply. The total shortage in South Sinai amount to about five thousands (5,500) m^3/day as of 1997. Therefore, restrictions on water consumption is carried out from place to place such as Sharm El Sheikh and Nuweiba cities throughout the year.

10.1.2 Tourism Use

The major marine resort zones in South Sinai are located along the coastal area of the Gulf of Aqaba and the Gulf of Suez. And further, St. Catherine city close to Mt. Sinai (be called "Gebel Musa" in Arabic) is also one of the major tourist attraction in South Sinai. According to the statistical data book established Jan 1998 by the South Sinai Governorate, the total tourist number in 1997 reached the approximately 23,000 per day.

In Taba, Nuweiba and Dahab cities which are located along the coastal area of the Gulf of Aqaba, the development for tourism, like tourist hotels, are proceeding quickly, in addition to the existing amenities for tourists. Almost all water sources are for tourism use in these hotels, and generally they have individual water supply system such as desalination plant. The total water demand for tourism use in the coast area of the Gulf Aqaba as of 1997 is approximately 3,200 m^3/day.

Furthermore, in Ras Sudr, El Tur and Sharm El Sheikh cities at the coastal area of the Gulf of Suez, large-scale developments for tourism are proceeding. The water source for tourism use in Ras Sudr city, is the Nile River Water which is purified in the water treatment plant in Suez city. In El Tur city, groundwater extracted from wells, as public water to the city area at present. For the reason of shortage of water, Municipality of Sharm El Sheikh city can not distribute the water to all hotels. Thus, some hotels have individual water supply systems, others are supplied the water from private water production companies. A total capacity of the desalination plants is more than 4000m^3/day. The total tourism water consumption in the coast area of the Gulf Suez as of 1997 is approximately 11,000 m^3/day.

Also, in St. Catherine city located in the middle of South Sinai, the tourism development with resort hotels are under construction at present, although the development scale may be smaller than other tourism zones. The total water consumption for tourism use in this area as of 1997 is approximately 200 m^3/day.

10.1.3 Industrial and Other Use

Other large water consumers are industries, public offices such as municipality, schools, police stations and commercial use. Water for the industrial use is same as that for residential use. However, the actual condition of each type of water consumer is not clear at present. An outline of industrial water use is given below.

- Number of production factory: 60 (in 1996),
  12 (more than 100 employee)
- Type of industry: Petroleum industry,
  Building material production,
  Mechanical and electrical appliance production
- Water source: Same water as residential use

10.1.4 Agricultural Use

Agriculture in South Sinai is mainly carried out in the rural areas of the inland provinces. Major agricultural land use is shown in the table below. The main products are fruits (such as olive, orange, banana), vegetables (such as tomato, zucchini, cucumber, eggplant) and grains (such as wheat and barley).

Existing Major Agriculture Land Use

	Agriculture Land	Administrative Body	Area (unit : Feddan)
1	El Qaa Plain	El Tur	800
2	Wadi Feiran	Abu Rudeis	200
3	Ras Sudr	Ras Sudr	150
4	Nuweiba	Nuweiba	250
	Total		1,400

Note : 1 Feddan = 4,200 m^2

Data Source : NPDS in 1994

The water source for agricultural use is generally extracted from shallow wells which are developed near the cultivation land. However, cultivated land area and products are restricted from quantity and the quality of the intake water.

Furthermore, the treated wastewater from wastewater treatment plant has been reused as one of the water source for the plantation of trees. The reused water is only used for plantation of trees in areas adjoining the wastewater treatment plant. This water source is not applicable to good crops such as fruits, vegetables and grains, because it is not evident that the water quality is safe enough at present. However, the reuse of treated wastewater is carried out at all (eight) cities.

10.2 Water Demand Forecasting in Future

10.2.1 Future Development Plan

The groundwater sources to be developed and/or confirmed, as a result of the Study will form a base for the development plan from the point of view of groundwater use. It will be used aggressively to South Sinai Area, which is one of the most important and strategic places for the national development plan in Egypt. The project policies and target year will be coordinated with a national project which is called National Project for the Development in Sinai (1994), Ministry of Planning, Egypt. The target year of the Project is planned as 2017 in the same way as NPDS.

The development plan in the study would not the existing and/or planned the projects that have executed by the government of Egypt.

Expectations that the intake loading from the Nile River water and production costs of the water will be decreased, will be evaluated and justified. In this chapter, the water demand forecasting in future for development in South Sinai will be presented. The plan of water facilities for the groundwater development will be given in chapter 13.

10.2.2 Estimation of Future Water Demand

1) Condition of Future Water Demand Estimation

The water usage in South Sinai is divided into four categories as mentioned before. The water qualities to be required for them are basically divided into two kinds: potable water (for residents, hotels and industries) and agricultural water. Regarding the future water demand forecasting of each category detailed account is given below.

(1) Residential Use

The water demand of residential use would be determined based on population forecast up to 2017, which is the target year of the Project. The populations of urban and rural areas up to 2017 in eight cities are estimated by using census data in 1986 and 1996. This forecast includes the population of rural areas such as Bedouin.

The future population is estimated in accordance with two basic materials that are the data from South Sinai Governorate (NPDS) and the above census data. Results are shown in Table 10.2.2-1 to 4

(2) Tourism Use

The tourist number for the future water demand forecasting will be used of the statistics data received from South Sinai Governorate in Jan, 1996 and Feb, 1998.

An actual tourist number as of 1997 is presented in Table 9.1.4-2. However, it has already decreased to a half compared with the tourist number forecasting in the above statistics data. Therefore, tourist number up to 2017 is revised as the same rate with an actual number in 1997. The tourist forecast after revision is described below.

Tourist Forecast After Revision

(Unit: Persons/day)

	City Name	1997 *-1	2002 *-2	2007 *-2	2012 *-2	2017 *-2
1	El Tur	188	451	556	661	713
2	Sharm El Sheikh	15,056	17,718	18,605	19,492	20,379
3	Dahab	1,813	4,737	6,687	8,636	9,611
4	Nuweiba	3,204	8,338	10,905	13,472	15,183
5	St.Catherine	1,058	1,544	1,739	1,933	2,030
6	Abu Rudeis	0	0	0	0	0
7	Abu Zenima	0	0	0	0	0
8	Ras Sudr	1,673	4,142	6,611	9,079	11,548
	Total	22,992	36,929	45,101	53,273	59,465

Note :

1) Data Sources is as follows.

*-1 Tourist number as of 1997 in Table of after the revision : Statistical Data Book (from table on page33, Feb 1998), South Sinai Governorate

2) Estimation of Tourist Number from 2002 to 2017 in Table of after revision

*-2 Tourist number = (nos of 1997 in after revision / nos of 1997 in before revision) x (nos of before revision)

(3) Industrial and Other Use

The future water demand of industries as of 2017 will be estimated from the development area in accordance with the NPDS. Therefore, the development areas of the industry are assumed to increase gradually from 1997 to 2017. The development area forecast is shown in the Table blow.

(Unit: hectare)

	City Name	1997	2002	2007	2012	2017
1	El Tur	10	12	15	18	21
2	Sharm El Sheikh	0	0	0	0	0
3	Dahab	0	0	0	0	0
4	Nuweiba	0	0	0	0	0
5	St.Catherine	0	0	0	0	0
6	Abu Rudeis	0	0	0	0	0
7	Abu Zenima	0	0	0	0	0
8	Ras Sudr	10	12	15	18	21
	Total	20	24	30	36	42

Note :

1) Data Sources is as follows.

The development area for industrial use as of year 2017 is quoted from Article 3.2.3 of NPDS in 1994.

The unit water demand for industrial use to be used in this study is described in Table 9.1.3-1. It is estimated as 107 m^3/day per hectare which is about a half (1/2) of similar type of industry in Japan from the point of view of land use efficiency. The type of industries which go into the industrial zone and the unit water demand of them are shown in the Table below.

The water loss will be assumed as 5 % of total water flow rate for potable water.

Unit Water Demand for Industrial Use

Industrial Type	Unit Water Demand (m^3/ha/day)
1. Food Industry	174
2. Wood & Wooden Products	15
3. Chemical Producgts	261
4. Products of Petroleum & Coal	69
5. Tanneries & Leather Products	78
6. Non-metalic Mineral Products	44
7. Basic Metal Industry	105
Simple Average	107

Source: Standard Unit of Industrial Production by Medium Classification in Japan, 1986, Ministry of International Trade and Industry (MITI)

(4) Agricultural Use

The future water demand for the agricultural use will be estimated from the development area in accordance with the NPDS. Existing agricultural land area as of 1997 is described. And future development area as of 2017 is indicated under the condition that the development area for the agricultural use is assumed to go on increasing gradually with the same population rate in rural area from 1997 to 2017.

The development area forecast is shown in Table blow. The unit water demand for agriculture use to be used in this study is described in Table 9.1.3-1. It is estimated as 16.3 m^3/day per hectare.

Development Area Forecast for Agriculturel Land Use

(Unit : hectare)

	Agriculture Land	Jurisdiction	1996	1997	2002	2007	2012	2017
	[Existing]							
1	El Qaa Plain	El Tur	336	346	363	546	689	887
2	Wadi Feiran	Abu Rudeis	84	87	88	93	98	103
3	Ras Sudr	Ras Sudr	63	65	157	214	264	300
4	Nuweiba	Nuweiba	105	108	118	156	210	294
	Sub-Total (1)		588	606	726	1,008	1,260	1,584
	[Future Development Plan]							
5	Abu Zenima	Abu Zenima	0	0	20	21	21	21
6	Wadi Gharandal	Ras Sudr	0	0	33	45	55	63
7	Ras Nasrani	Ras Sudr	0	0	55	75	92	105
8	Dahab	Dahab	0	0	155	216	282	315
9	Wadi Watir	Nuweiba	0	0	67	89	120	168
10	Malha 1	Ras Sudr	0	0	121	165	203	231
11	Malha 2	Ras Sudr	0	0	121	165	203	231
12	Malha 3	Ras Sudr	0	0	199	270	333	378
13	Themed	Ras Sudr	0	0	375	510	628	714
14	Sudr El Heitan	Ras Sudr	0	0	375	510	628	714
	Sub-Total (2)		0	0	1,522	2,066	2,566	2,940
	Total		588	606	2,249	3,074	3,826	4,524

Note :

1) Data Source is as follows.

* Agriculture use area in the future development plan as of year 2017 is quoted from Article 3.2.3 of NPDS.

* NPDS : National Project for the Development of Sinai in 1994, Ministry of Planning.

2) Result of Estimation

The future water demand forecasting in South Sinai includes a study about water of two purposes (potable water and agricultural water).

The population forecasting of former will be executed based on the three cases mentioned below. Then the future water demand for tourism and industrial uses are the case from NPDS. The conditions of case studies are as follows.

Case 1 : Data from South Sinai Governorate (same as NPDS)

Case 2 : 60 % value of Data from South Sinai Governorate (same as NPDS)

Case 3 : Census data in 1986 and 1996 based

Results are described in Table 10.2.2-5,6,7. From the table, the quantity of future water demand in 2017 is approximately; case 1: 200,000 m^3/day, case 2: 130,000 m^3/day, case 3: 110,000 m^3/day.

On the other hand, the future water demand forecasting for agriculture use will be estimated as one case from NPDS. The water demand forecasting with the future development for an agriculture land use is shown in the Table blow. From this table, it can be seen that the quantity of future water demand in 2017 is approximately 74,000 m^3/day.

Future Water Demand Forecast for Agriculture Use

(Unit : m^3/day)

	Agriculture Land	1996	1997	2002	2007	2012	2017
	[Existing]						
1	El Qaa Plain	5,477	5,641	5,924	8,901	11,232	14,464
2	Wadi Feiran	1,369	1,410	1,432	1,509	1,590	1,674
3	Ras Sudr	1,027	1,058	2,566	3,491	4,299	4,885
4	Nuweiba	1,712	1,763	1,919	2,535	3,418	4,798
	Sub-Total (1)	9,584	9,872	11,841	16,436	20,538	25,821
	[Future Development Plan]						
5	Abu Zenima	0	0	332	336	339	342
6	Wadi Gharandal	0	0	539	734	904	1,027
7	Ras Nasrant	0	0	899	1,223	1,506	1,712
8	Dahab	0	0	2,532	3,520	4,590	5,135
9	Wadi Watir	0	0	1,095	1,447	1,950	2,738
10	Malha 1	0	0	1,978	2,691	3,313	3,765
11	Malha 2	0	0	1,978	2,691	3,313	3,765
12	Malha 3	0	0	3,236	4,403	5,422	6,161
13	Themed	0	0	6,113	8,317	10,241	11,638
14	Sudr El Heitan	0	0	6,113	8,317	10,241	11,638
	Sub-Total (1)	0	0	24,814	33,678	41,819	47,922
	Total	9,584	9,872	36,655	50,114	62,357	73,743

Note :

1) Data Source is as follows.

* Development area as of year 2017 has quoted from Article 3.2.3 of NPDS.
* NPDS: National Project for the Development of Sinai in 1994, Ministry of Planning.
* Unit Water Demand: Refer to Table 9.1.3-1"Unit Water demand".

2) The calculation method of water demand is as follows.

* Agriculture: Q = [Agriculture use Area (hectare)] x 16.3 m^3/ha/day.
  This unit water demand is equivalent to about 2,500 m^3/feddan/year.
* 1 feddan = 4,200 m^2 = 0.42 ha
* Expansion of agriculture land area up to 2017: Same as increase rate of residents in rural area.

The differences in these future water demand forecasting is not small, considering that water demand of case 1 is 100 %, case 2 and 3 are 65 %, 55 % respectively. However, the future water demand to be used in the development plan will be reflected the results of case 1 since South Sinai is one of the most important and strategic development areas for the Government of Egypt and the project policies will consider coordination with national projects.

Table 10.2.2-1 Population Ratio in Urban Area Forecasting Compared with Total Populatoin

Case 1 : Forecast by the data from South Sinai Governorate Based

	City Name	Year						
		1986	1996	1997	2002	2007	2012	2017
1	El Tur	0.67	0.85	0.85	0.88	0.90	0.93	0.95
2	Sharm El Sheikh	0.56	0.67	0.67	0.71	0.83	0.92	0.95
3	Dahab	0.18	0.29	0.29	0.47	0.69	0.83	0.92
4	Nuweiba	0.36	0.43	0.43	0.50	0.78	0.87	0.92
5	St.Catherine	0.10	0.18	0.18	0.37	0.57	0.67	0.75
6	Abu Rudeis	0.49	0.56	0.56	0.57	0.58	0.59	0.60
7	Abu Zenima	0.29	0.47	0.47	0.47	0.47	0.47	0.47
8	Ras Sudr	0.25	0.22	0.22	0.41	0.63	0.79	0.89
	Total	0.39	0.54	---	---	---	---	---

Case 2 : Forecast by 60 % Value of the data from South Sinai Governorate Based

	City Name	Year						
		1986	1996	1997	2002	2007	2012	2017
1	El Tur	0.67	0.85	0.85	0.87	0.88	0.93	0.95
2	Sharm El Sheikh	0.56	0.67	0.67	0.68	0.76	0.89	0.95
3	Dahab	0.18	0.29	0.29	0.35	0.74	0.87	0.92
4	Nuweiba	0.36	0.43	0.43	0.50	0.74	0.87	0.92
5	St.Catherine	0.10	0.18	0.18	0.26	0.44	0.55	0.64
6	Abu Rudeis	0.49	0.56	0.56	0.57	0.58	0.59	0.60
7	Abu Zenima	0.29	0.47	0.47	0.47	0.47	0.47	0.47
8	Ras Sudr	0.25	0.22	0.22	0.41	0.63	0.79	0.89
	Total	0.39	0.54	---	---	---	---	---

Case 3 : Forecase by the Census Data Based in 1986 and 1996

	City Name	Year						
		1986	1996	1997	2002	2007	2012	2017
1	El Tur	0.67	0.85	0.86	0.88	0.90	0.93	0.95
2	Sharm El Sheikh	0.56	0.67	0.68	0.77	0.86	0.92	0.95
3	Dahab	0.18	0.29	0.30	0.41	0.50	0.58	0.68
4	Nuweiba	0.36	0.43	0.44	0.60	0.67	0.72	0.73
5	St.Catherine	0.10	0.18	0.20	0.23	0.27	0.29	0.31
6	Abu Rudeis	0.49	0.56	0.56	0.57	0.58	0.59	0.60
7	Abu Zenima	0.29	0.47	0.49	0.49	0.49	0.49	0.49
8	Ras Sudr	0.25	0.22	0.23	0.23	0.23	0.23	0.23
	Total	0.39	0.54	---	---	---	---	---

Note

* Ratio in 1986 and 1996 are actual number in Census data
* Other figure (1997 to 2017) are estimated from recent census data trend.

Table 10.2.2-2 Population Forecast in South Sinai

Case 1 : Forecast by the the data from South Sinai Governorate Based

(Unit : Persons)

	City Name	1986	1996	1997	2002	2007	2012	2017
1	El Tur	6,483	14,155	15,075	20,654	33,852	61,028	110,023
	Urban area	4,338	12,072	12,857	18,176	30,467	56,756	104,522
	Rural area	2,145	2,083	2,218	2,478	3,385	4,272	5,501
2	Sharm El Sheikh	1,556	7,197	7,665	10,501	20,775	52,336	131,846
	Urban area	869	4,799	5,111	7,459	17,161	48,149	125,254
	Rural area	687	2,398	2,554	3,042	3,614	4,187	6,592
3	Dahab	1,584	3,758	4,002	5,483	15,950	37,918	90,143
	Urban area	281	1,077	1,147	2,577	11,006	31,472	82,932
	Rural area	1,303	2,681	2,855	2,906	4,945	6,446	7,211
4	Nuweiba	2,399	5,657	6,025	8,254	21,894	49,953	113,969
	Urban area	861	2,405	2,561	4,127	17,077	43,459	104,851
	Rural area	1,538	3,252	3,463	4,127	4,817	6,494	9,118
5	St.Catherine	3,363	4,219	4,493	6,106	9,151	12,611	17,378
	Urban area	347	754	803	2,259	5,216	8,449	13,034
	Rural area	3,016	3,465	3,690	3,847	3,935	4,162	4,345
6	Abu Rudeis	5,129	7,438	7,921	8,273	8,625	9,307	10,043
	Urban area	2,515	4,152	4,422	4,716	5,003	5,491	6,026
	Rural area	2,614	3,286	3,500	3,557	3,623	3,816	4,017
7	Abu Zenima	3,023	5,570	5,932	5,956	5,980	6,002	6,026
	Urban area	883	2,645	2,817	2,799	2,811	2,821	2,832
	Rural area	2,140	2,925	3,115	3,157	3,169	3,181	3,194
8	Ras Sudr	5,392	6,501	6,924	9,486	46,692	101,300	219,776
	Urban area	1,329	1,419	1,511	3,889	29,416	80,027	195,601
	Rural area	4,063	5,082	5,412	5,597	17,276	21,273	24,175
	Grand Total	28,929	54,495	58,037	74,713	162,919	330,455	699,204
	Sub Total (Urban)	11,423	29,323	31,229	46,002	118,156	276,625	635,051
	Sub Total (Rural)	17,506	25,172	26,808	28,711	44,763	53,830	64,153

Note :

1) Data Sources is as follows.

* Population (Residents) in 1997, 2002 : Statistical Data Book (page35), Feb 1998,

* Population (Residents) in 2007 to 2017 : Statistical Data Book (page15), Feb 1998, South Sinai Governorate

Table 10.2.2-3 Population Forecast in South Sinai

Case 2 : Forecast by 60 % Value of the the data from South Sinai Governorate Based

(Unit : Persons)

	City Name	1986	1996	1997	2002	2007	2012	2017
1	El Tur	6,483	14,155	15,075	17,642	20,704	36,617	66,014
	Urban area	4,338	12,072	12,857	15,357	18,280	34,054	62,713
	Rural area	2,145	2,083	2,218	2,285	2,424	2,563	3,301
2	Sharm El Sheikh	1,556	7,197	7,665	8,993	13,552	32,494	79,108
	Urban area	869	4,799	5,111	6,088	10,297	28,889	75,152
	Rural area	687	2,398	2,554	2,905	3,255	3,605	3,955
3	Dahab	1,584	3,758	4,002	4,410	9,570	22,751	54,086
	Urban area	281	1,077	1,147	1,546	6,603	18,883	49,759
	Rural area	1,303	2,681	2,855	2,864	2,967	3,868	4,327
4	Nuweiba	2,399	5,657	6,025	8,254	13,817	29,972	68,381
	Urban area	861	2,405	2,561	4,127	10,246	26,075	62,911
	Rural area	1,538	3,252	3,463	4,127	3,571	3,896	5,471
5	St.Catherine	3,363	4,219	4,493	5,202	7,065	9,231	12,165
	Urban area	347	754	803	1,356	3,130	5,070	7,820
	Rural area	3,016	3,465	3,690	3,847	3,935	4,162	4,345
6	Abu Rudeis	5,129	7,438	7,921	8,273	8,625	9,307	10,043
	Urban area	2,515	4,152	4,422	4,716	5,003	5,491	6,026
	Rural area	2,614	3,286	3,500	3,557	3,623	3,816	4,017
7	Abu Zenima	3,023	5,570	5,932	5,956	5,980	6,002	6,026
	Urban area	883	2,645	2,817	2,799	2,811	2,821	2,832
	Rural area	2,140	2,925	3,115	3,157	3,169	3,181	3,194
8	Ras Sudr	5,392	6,501	6,924	5,692	28,015	60,780	131,866
	Urban area	1,329	1,419	1,511	2,334	17,650	48,016	117,360
	Rural area	4,063	5,082	5,412	3,358	10,366	12,764	14,505
	Grand Total	28,929	54,495	58,037	64,422	107,328	207,154	427,688
	Sub Total (Urban)	11,423	29,323	31,229	38,322	74,019	169,300	384,574
	Sub Total (Rural)	17,506	25,172	26,808	26,100	33,309	37,855	43,114

Note :

1) Data Sources is as follows.

* Population (Residents) in 1997, 2002 : Statistical Data Book (page35), Feb 1998,

* Population (Residents) in 2007 to 2017 : 60 % value of Statistical Data Book based (page15), Feb 1998, South Sinai Governorate except Abu Rudeis and Abu Zenima cities.

Table 10.2.2-4 Population Forecast in South Sinai

Case 3 : Forecast by the Census Data Based in 1986 and 1996

(Unit : Persons)

	City Name	1986	1996	1997	2002	2007	2012	2017
1	El Tur	6,483	14,155	14,938	21,826	33,671	50,471	72,227
	Urban area	4,338	12,072	12,847	19,207	30,304	46,938	68,616
	Rural area	2,145	2,083	2,091	2,619	3,367	3,533	3,611
2	Sharm El Sheikh	1,556	7,197	8,388	18,039	38,794	83,431	179,426
	Urban area	869	4,799	5,704	13,915	33,238	76,757	170,455
	Rural area	687	2,398	2,684	4,124	5,556	6,674	8,971
3	Dahab	1,584	3,758	3,955	6,003	9,821	15,408	22,765
	Urban area	281	1,077	1,194	2,447	4,877	8,962	15,554
	Rural area	1,303	2,681	2,761	3,556	4,945	6,446	7,211
4	Nuweiba	2,399	5,657	5,956	9,014	14,682	22,957	33,841
	Urban area	861	2,405	2,606	5,368	9,865	16,463	24,723
	Rural area	1,538	3,252	3,350	3,646	4,817	6,494	9,118
5	St.Catherine	3,363	4,219	4,449	4,918	5,387	5,855	6,324
	Urban area	347	754	880	1,133	1,452	1,693	1,980
	Rural area	3,016	3,465	3,569	3,785	3,935	4,162	4,345
6	Abu Rudeis	5,129	7,438	7,704	9,266	11,206	13,523	16,217
	Urban area	2,515	4,152	4,314	5,282	6,499	7,979	9,730
	Rural area	2,614	3,286	3,390	3,984	4,707	5,544	6,487
7	Abu Zenima	3,023	5,570	5,861	7,911	10,950	14,977	19,992
	Urban area	883	2,645	2,872	3,876	5,366	7,339	9,796
	Rural area	2,140	2,925	2,989	4,035	5,585	7,638	10,196
8	Ras Sudr	5,392	6,501	6,622	7,270	7,987	8,772	9,626
	Urban area	1,329	1,419	1,523	1,672	1,837	2,018	2,214
	Rural area	4,063	5,082	5,099	5,598	6,150	6,754	7,412
	Grand Total	28,929	54,495	57,873	84,247	132,498	215,394	360,418
	Sub Total (Urban)	11,423	29,323	31,940	52,899	93,438	168,148	303,067
	Sub Total (Rural)	17,506	25,172	25,933	31,348	39,060	47,246	57,351

Note :

1) Data Sources is as follows.

* Population (Residents) in 1996 : Census Data in 1986 and 1996, Egypt.

* Population (Residents) in 1997 to 2017 : Estimation from the above Census Data

Table 10.2.2-5 Future Water Demand Forecast for Residents, Tourists and Industries.
Case 1: Data Source from South Sinai Governorate based (same as NPDS)

(Unit : m^3/day)

	City Name	Consumers	1997	2002	2007	2012	2017
1	El Tur	1) Residents	3,352	4,659	7,718	14,134	25,745
		(Urban Area)	3,086	4,362	7,312	13,621	25,085
		(Rural Area)	266	297	406	513	660
		2) Tourists (Hotels)	75	180	222	264	285
		3) Industries	1,070	1,284	1,605	1,926	2,247
		4) Others (loss, etc)	225	306	477	816	1,414
		Sub-Total	4,722	6,429	10,022	17,140	29,691
2	Sharm El Sheikh	1) Residents	1,533	2,155	4,553	12,058	30,852
		(Urban Area)	1,227	1,790	4,119	11,556	30,061
		(Rural Area)	306	365	434	502	791
		2) Tourists (Hotels)	6,022	7,087	7,442	7,797	8,152
		3) Industries	0	0	0	0	0
		4) Others (loss, etc)	378	462	600	993	1,950
		Sub-Total	7,933	9,704	12,595	20,848	40,954
3	Dahab	1) Residents	618	967	3,234	8,327	20,769
		(Urban Area)	275	618	2,641	7,553	19,904
		(Rural Area)	343	349	593	774	865
		2) Tourists (Hotels)	725	1,895	2,675	3,454	3,844
		3) Industries	0	0	0	0	0
		4) Others (loss, etc)	67	143	295	589	1,231
		Sub-Total	1,410	3,005	6,204	12,370	25,844
4	Nuweiba	1) Residents	1,031	1,485	4,677	11,209	26,258
		(Urban Area)	615	990	4,099	10,430	25,164
		(Rural Area)	416	495	578	779	1,094
		2) Tourists (Hotels)	1,282	3,335	4,362	5,389	6,073
		3) Industries	0	0	0	0	0
		4) Others (loss, etc)	116	241	452	830	1,617
		Sub-Total	2,429	5,061	9,491	17,428	33,948
5	St.Catherine	1) Residents	636	1,004	1,724	2,527	3,649
		(Urban Area)	193	542	1,252	2,028	3,128
		(Rural Area)	443	462	472	499	521
		2) Tourists (Hotels)	423	618	695	773	812
		3) Industries	0	0	0	0	0
		4) Others (loss, etc)	53	81	121	165	223
		Sub-Total	1,112	1,703	2,540	3,465	4,684
6	Abu Rudeis	1) Residents	1,481	1,559	1,636	1,776	1,928
		(Urban Area)	1,061	1,132	1,201	1,318	1,446
		(Rural Area)	420	427	435	458	482
		2) Tourists (Hotels)	0	0	0	0	0
		3) Industries	0	0	0	0	0
		4) Others (loss, etc)	74	78	82	89	96
		Sub-Total	1,555	1,637	1,718	1,865	2,024
7	Abu Zenima	1) Residents	1,050	1,051	1,055	1,059	1,063
		(Urban Area)	676	672	675	677	680
		(Rural Area)	374	379	380	382	383
		2) Tourists (Hotels)	0	0	0	0	0
		3) Industries	0	0	0	0	0
		4) Others (loss, etc)	53	53	53	53	53
		Sub-Total	1,103	1,104	1,108	1,112	1,116

	City Name	Consumers	1997	2002	2007	2012	2017
8	Ras Sudr	1) Residents	1,012	1,605	9,133	21,759	49,845
		(Urban Area)	363	933	7,060	19,206	46,944
		(Rural Area)	649	672	2,073	2,553	2,901
		2) Tourists (Hotels)	669	1,657	2,644	3,632	4,619
		3) Industries	1,070	1,284	1,605	1,926	2,247
		4) Others (loss, etc)	138	227	669	1,366	2,836
		Sub-Total	2,889	4,773	14,051	28,683	59,547
9	Taba	1) Residents	0	0	0	0	0
		(Urban Area)	0	0	0	0	0
		(Rural Area)	0	0	0	0	0
		2) Tourists (Hotels)	142	1,262	1,822	2,382	2,942
		3) Industries	0	0	0	0	0
		4) Others (loss, etc)	7	63	91	119	147
		Sub-Total	149	1,325	1,913	2,501	3,089
	Total	1) Residents	23,302	14,485	33,730	72,849	160,109
		(Urban Area)	7,496	11,039	28,359	66,389	152,412
		(Rural Area)	3,217	3,446	5,371	6,460	7,697
		2) Tourists (Hotels)	9,196	14,772	18,040	21,309	23,785
		3) Industries	2,140	2,568	3,210	3,852	4,494
		4) Others (loss, etc)	1,732	1,591	2,749	4,901	9,419
		Grand-Total	36,370	33,416	57,729	102,911	197,807

Note :

1) Data Source is as follows.

- * Population (Residents) in 1997, 2002 : Statistical Data Book (page35), Feb 1998, South Sinai Governorate
- * Population (Residents) in 2007 to 2017 : Statistical Data Book (page15), Feb 1998, South Sinai Governorate
- * Population Ratio : Refer to Table 10.2.2 "Population Ratio in Urvan Area Forecasting"
- * Number of Tourists : See Table 10.2.4
- * NPDS : National Project for the Development of Sinai in 1994, Ministry of Planning.
- * Unit Water Demand : Refer to Table 9.1.3-1"Unit Water demand".
- * Industries : Industrial development area as of year 2017 has quoted from Article 3.2.3 of NPDS.

2) The calculation method of water demand is as follows.

- * Reditents (Urban Area) : Q_1 = [Population] x 0.24 m^3/capita/day
- * Reditents (Rural Area) : Q_2 = [Population] x 0.12 m^3/capita/day
- * Tourist : Q_3 = [Population] x 0.40 m^3/capita/day
- * Industries : Q_4 = [Industrial Area (hectare)] x 107 m^3/ha/day,
- * Others (loss, etc.) : Q_6 = 5 % of water demands.

Table 10.2.2-6 Future Water Demand Forecast for Residents, Tourists and Industries.
Case 2 : Data Source from 60 % Value of South Sinai Governorate based (same as NPDS)

(Unit : m^3/day)

	City Name	Consumers	1997	2002	2007	2012	2017
1	El Tur	1) Residents	3,352	3,960	4,678	8,480	15,447
		(Urban Area)	3,086	3,686	4,387	8,173	15,051
		(Rural Area)	266	274	291	308	396
		2) Tourists (Hotels)	75	180	222	264	285
		3) Industries	642	770	963	1,156	1,348
		4) Others (loss, etc)	203	246	293	495	854
		Sub-Total	4,272	5,156	6,157	10,395	17,935
2	Sharm El Sheikh	1) Residents	1,533	1,810	2,862	7,366	18,511
		(Urban Area)	1,227	1,461	2,471	6,933	18,037
		(Rural Area)	306	349	391	433	475
		2) Tourists (Hotels)	6,022	7,087	7,442	7,797	8,152
		3) Industries	0	0	0	0	0
		4) Others (loss, etc)	378	445	515	758	1,333
		Sub-Total	7,933	9,342	10,819	15,921	27,996
3	Dahab	1) Residents	618	715	1,941	4,996	12,461
		(Urban Area)	275	371	1,585	4,532	11,942
		(Rural Area)	343	344	356	464	519
		2) Tourists (Hotels)	725	1,895	2,675	3,454	3,844
		3) Industries	0	0	0	0	0
		4) Others (loss, etc)	67	130	231	423	815
		Sub-Total	1,410	2,740	4,846	8,873	17,121
4	Nuweiba	1) Residents	1,030	1,486	2,888	6,726	15,755
		(Urban Area)	615	990	2,459	6,258	15,099
		(Rural Area)	416	495	429	468	656
		2) Tourists (Hotels)	1,282	3,335	4,362	5,389	6,073
		3) Industries	0	0	0	0	0
		4) Others (loss, etc)	116	241	362	606	1,091
		Sub-Total	2,428	5,062	7,612	12,720	22,920
5	St.Catherine	1) Residents	636	787	1,223	1,716	2,398
		(Urban Area)	193	325	751	1,217	1,877
		(Rural Area)	443	462	472	499	521
		2) Tourists (Hotels)	423	618	695	773	812
		3) Industries	0	0	0	0	0
		4) Others (loss, etc)	53	70	96	124	161
		Sub-Total	1,112	1,475	2,015	2,614	3,371
6	Abu Rudeis	1) Residents	1,481	1,559	1,635	1,776	1,928
		(Urban Area)	1,061	1,132	1,201	1,318	1,446
		(Rural Area)	420	427	435	458	482
		2) Tourists (Hotels)	0	0	0	0	0
		3) Industries	0	0	0	0	0
		4) Others (loss, etc)	74	78	82	89	96
		Sub-Total	1,555	1,637	1,717	1,865	2,025
7	Abu Zenima	1) Residents	1,050	1,051	1,055	1,059	1,063
		(Urban Area)	676	672	675	677	680
		(Rural Area)	374	379	380	382	383
		2) Tourists (Hotels)	0	0	0	0	0
		3) Industries	0	0	0	0	0
		4) Others (loss, etc)	52	53	53	53	53
		Sub-Total	1,102	1,103	1,108	1,112	1,116

	City Name	Consumers	1997	2002	2007	2012	2017
8	Ras Sudr	1) Residents	1,012	963	5,480	13,056	29,907
		(Urban Area)	363	560	4,236	11,524	28,166
		(Rural Area)	649	403	1,244	1,532	1,741
		2) Tourists (Hotels)	669	1,657	2,644	3,632	4,619
		3) Industries	642	770	963	1,156	1,348
		4) Others (loss, etc)	116	170	454	892	1,794
		Sub-Total	2,440	3,560	9,541	18,735	37,668
9	Taba	1) Residents	0	0	0	0	0
		(Urban Area)	0	0	0	0	0
		(Rural Area)	0	0	0	0	0
		2) Tourists (Hotels)	142	1,262	1,822	2,382	2,942
		3) Industries	0	0	0	0	0
		4) Others (loss, etc)	7	63	91	119	147
		Sub-Total	149	1,325	1,913	2,501	3,089
	Total	1) Residents	10,712	12,329	21,762	45,174	97,471
		(Urban Area)	7,495	9,197	17,764	40,632	92,298
		(Rural Area)	3,217	3,132	3,997	4,543	5,174
		2) Tourists (Hotels)	9,197	14,772	18,041	21,309	23,786
		3) Industries	1,284	1,541	1,926	2,311	2,696
		4) Others (loss, etc)	1,060	1,432	2,086	3,440	6,198
		Grand-Total	22,401	31,399	45,727	74,736	133,240

Note :

1) Data Source is as follows.

- Population (Residents) in 1997, 2002 : Statistical Data Book (page35), Feb 1998, South Sinai Governorate
- Population (Residents) in 2007 to 2017 : Statistical Data Book (page15), Feb 1998, South Sinai Governorate
- Population Ratio : Refer to Table 10.2.2 "Population Ratio in Urvan Area Forecasting"
- Number of Tourists : See Table 10.2.4
- NPDS : National Project for the Development of Sinai in 1994, Ministry of Planning.
- Unit Water Demand : Refer to Table 9.1.3-1"Unit Water demand".
- Industries : Industrial development area as of year 2017 has quoted from Article 3.2.3 of NPDS.

2) The calculation method of water demand is as follows.

- Reditents (Urban Area) : Q_1 = [Population] x 0.24 m^3/capita/day
- Reditents (Rural Area) : Q_2 = [Population] x 0.12 m^3/capita/day
- Tourist : Q_3 = [Population] x 0.40 m^3/capita/day
- Industries : Q_4 = [Industrial Area (hectare)] x 107 m^3/ha/day,
- Others (loss, etc.,) : Q_6 = 5 % of water demands.

Table 10.2.2-7 Future Water Demand Forecast for Residents, Tourists and Industries.
Case 3: Data Source from Census Data in 1986 and 1996 based

(Unit : m³/day)

	City Name	Consumers	1997	2002	2007	2012	2017
1	El Tur	1) Residents	3,334	4,924	7,677	11,689	16,901
		(Urban Area)	3,083	4,610	7,273	11,265	16,468
		(Rural Area)	251	314	404	424	433
		2) Tourists (Hotels)	75	180	222	264	285
		3) Industries	642	770	963	1,156	1,348
		4) Others (loss, etc)	203	294	443	655	927
		Sub-Total	4,254	6,168	9,306	13,765	19,461
2	Sharm El Sheikh	1) Residents	1,691	3,834	8,644	19,223	41,986
		(Urban Area)	1,369	3,340	7,977	18,422	40,909
		(Rural Area)	322	495	667	801	1,077
		2) Tourists (Hotels)	6,022	7,087	7,442	7,797	8,152
		3) Industries	0	0	0	0	0
		4) Others (loss, etc)	386	546	804	1,351	2,507
		Sub-Total	8,099	11,468	16,890	28,370	52,644
3	Dahab	1) Residents	618	1,014	1,764	2,924	4,598
		(Urban Area)	286	587	1,170	2,151	3,733
		(Rural Area)	331	427	593	774	865
		2) Tourists (Hotels)	725	1,895	2,675	3,454	3,844
		3) Industries	0	0	0	0	0
		4) Others (loss, etc)	67	145	222	319	422
		Sub-Total	1,410	3,054	4,660	6,698	8,865
4	Nuweiba	1) Residents	1,027	1,726	2,946	4,730	7,028
		(Urban Area)	626	1,288	2,368	3,951	5,934
		(Rural Area)	402	438	578	779	1,094
		2) Tourists (Hotels)	1,282	3,335	4,362	5,389	6,073
		3) Industries	0	0	0	0	0
		4) Others (loss, etc)	115	253	365	506	655
		Sub-Total	2,425	5,314	7,673	10,625	13,756
5	St.Catherine	1) Residents	639	726	821	906	996
		(Urban Area)	211	272	348	406	475
		(Rural Area)	428	454	472	499	521
		2) Tourists (Hotels)	423	618	695	773	812
		3) Industries	0	0	0	0	0
		4) Others (loss, etc)	53	67	76	84	90
		Sub-Total	1,116	1,411	1,592	1,763	1,899
6	Abu Rudeis	1) Residents	1,442	1,746	2,125	2,580	3,114
		(Urban Area)	1,035	1,268	1,560	1,915	2,335
		(Rural Area)	407	478	565	665	778
		2) Tourists (Hotels)	0	0	0	0	0
		3) Industries	0	0	0	0	0
		4) Others (loss, etc)	72	87	106	129	156
		Sub-Total	1,514	1,833	2,231	2,709	3,269
7	Abu Zenima	1) Residents	1,048	1,414	1,958	2,678	3,575
		(Urban Area)	689	930	1,288	1,761	2,351
		(Rural Area)	359	484	670	917	1,224
		2) Tourists (Hotels)	0	0	0	0	0
		3) Industries	0	0	0	0	0
		4) Others (loss, etc)	52	71	98	134	179
		Sub-Total	1,100	1,485	2,056	2,812	3,753

	City Name	Consumers	1997	2002	2007	2012	2017
8	Ras Sudr	1) Residents	977	1,073	1,179	1,295	1,421
		(Urban Area)	366	401	441	484	531
		(Rural Area)	612	672	738	811	889
		2) Tourists (Hotels)	669	1,657	2,644	3,632	4,619
		3) Industries	642	770	963	1,156	1,348
		4) Others (loss, etc)	114	175	239	304	369
		Sub-Total	2,403	3,675	5,025	6,386	7,758
9	Taba	1) Residents	0	0	0	0	0
		(Urban Area)	0	0	0	0	0
		(Rural Area)	0	0	0	0	0
		2) Tourists (Hotels)	142	1,262	1,822	2,382	2,942
		3) Industries	0	0	0	0	0
		4) Others (loss, etc)	7	63	91	119	147
		Sub-Total	149	1,325	1,913	2,501	3,089
	Total	1) Residents	10,778	16,458	27,112	46,025	79,618
		(Urban Area)	7,666	12,696	22,425	40,355	72,736
		(Rural Area)	3,112	3,762	4,687	5,670	6,882
		2) Tourists (Hotels)	9,197	14,772	18,041	21,309	23,786
		3) Industries	1,284	1,541	1,926	2,311	2,696
		4) Others (loss, etc)	1,063	1,639	2,354	3,482	5,305
		Grand-Total	22,470	35,734	51,346	75,629	114,494

Note :

1) Data Source is as follows.

- Population (Residents) from 2002 to 2017 : Trend from Census Data in 1986 and 1996.
- Population Ratio : Refer to Table 10.2.2 "Population Ratio in Urvan Area Forecasting"
- Number of Tourists : See Table 10.2.4
- NPDS : National Project for the Development of Sinai in 1994, Ministry of Planning.
- Unit Water Demand : Refer to Table 9.1.3-1"Unit Water demand".
- Industries : Industrial development area as of year 2017 has quoted from Article 3.2.3 of NPDS.

2) The calculation method of water demand is as follows.

- Reditents (Urban Area) : Q_1 = [Population] x 0.24 m^3/capita/day
- Reditents (Rural Area) : Q_2 = [Population] x 0.12 m^3/capita/day
- Tourist : Q_3 = [Population] x 0.40 m^3/capita/day
- Industries : Q_4 = [Industrial Area (hectare)] x 107 m^3/ha/day,
- Others (loss, etc.) : Q_6 = 5 % of water demands.

CHAPTER XI WATER BALANCE AND GROUNDWATER DEVELOPMENT POTENTIAL

11.1 Quaternary Aquifer in El Qaa Plain

11.1.1 Water Balance

As described in Chapter III, some studies had tried to estimate the hydrologic budget, or water balance, for El Qaa Plain. However, these attempts were based on few data and some assumptions. Consequently, the estimated recharge to El Qaa Plain ranged from 17,000 m^3/day to 66,000 m^3/day. After hydrological consideration for the South Sinai, the Study Team calculated that the precipitation volume to the catchment area of W. El Awag and W. Emlaha where are included in the north El Qaa Plain is 27,738,000 m^3/year. The total runoff from the area is 3,744,900 m^3/year, and the recharge of the area is 13,143,100 m^3/year (36,008 m^3/day). It is considered that the volume of water infiltrate mostly into the mountainous ground surface in the area and is stored in fractures and cracks of the Basement rocks. Some of them continue to percolate into the Basement rocks more deeply, others reach the Quaternary Deposits in El Qaa Plain through the Basement rocks and recharge aquifers occurring in it. The Quaternary Deposits have a thickness of more than 1,000 meters. It is not probable that all the estimated volume that infiltrates widely into the large area recharges only the main aquifer in El Qaa Plain.

According to the result of the isotope study carried out in the past, water in the main aquifer in El Qaa Plain was indicated to be a mixture of recent and older water. (Sinai Water Resources Study Phase II, Environmental Isotope Study of Sinai Groundwater, May 1993) The system of the recharge in El Qaa Plain may be considerably complex and has not been clarified entirely.

The Study Team estimated the recharge volume of the main aquifer by computer simulation although there is a difficulty of lack of data. As a result the recharge volume of the main aquifer is estimated at 16,175 m3/day (5.9×10^6 m^3/year). Although this is the most reliable figure for the present, the precision of the estimation should be improved in order to manage the groundwater properly in the future. For that purpose, it is necessary to prepare the construction of the hydrological observation network, the continuous observation of water level, the recorded discharge rate of the production wells and so forth.

11.1.2 Groundwater Development Potential

1) Groundwater Evaluation of the Main Aquifer

The state of the main aquifer in El Qaa Plain is summarized as follows;

It was revealed that the aquifer that has been called the first aquifer is the part of the second aquifer. The hydrogeological parameters of the third aquifer show that it has less availability than the second aquifer. The second aquifer is the main aquifer that is exploited for domestic water mostly in El Qaa Plain. Although the main aquifer appears widely in the north El Qaa Plain, the isopach map of this aquifer shows that it has actually two sub-basins. Most probably the north sub-basin is recharged by groundwater through the northern mountains consist of Pre-Quaternary sedimentary rocks. And the southern sub-basin is recharged through the Precambrian Basement rocks of the eastern mountains as indicated by the flow lines map and the water quality map.

The water quality map shows that the groundwater quality of the south sub-basin is better than that of the north sub-basin. Generally the quality of the water becomes poorer as the water comes nearer the coastal line.

The values of Transmissivity and Specific Capacity that can indicate an availability of groundwater become larger from west to east and distribute parallel to the mountain foot on the east. The lines of depth to water show the similar tendency. The depth to water is an important factor concerning the cost of groundwater exploitation.

The evaluation map of groundwater resources in El Qaa Plain (Fig. 8.2.1-25) was drawn by combining the contour lines of the depth to water and the water quality distribution. The areas were classified and evaluated on the basis of the tables below.

Classification Matrix for Groundwater Resources Evaluation of the Main Aquifer in El Qaa Plain

	Ranking / Allotment	i / 9	ii / 7	iii / 5	iv / 3
	Depth (m)	< 30	30-50	50-70	70 <
Ranking /Allotment	TDS (mg/l)				
S / 15	< 1000	**Si (24)**	**Sii (22)**	**Siii (20)**	**Siv (18)**
A / 12	1000-1500	**Ai (21)**	**Aii (19)**	**Aiii (17)**	**Aiv (15)**
B / 9	1500-2000	**Bi (18)**	**Bii (16)**	**Biii (14)**	**Biv (12)**
C / 6	2000-3000	**Ci (15)**	**Cii (13)**	**Ciii (11)**	**Civ (9)**
D / 3	3000 <	**Di (12)**	**Dii (10)**	**Diii (8)**	**Div (6)**

Evaluation	Points	Classification Type of Aquifer
Excellent	22-24	Si, Sii
Very good	19-21	Siii , Ai, Aii
Good	16-18	Siv, Aiii, Bi, Bii
Fair	13-15	Aiv, Biii, Ci, Cii
Moderately Fair	10-12	Biv, Ciii, Di, Dii
Poor	6-9	Civ, Diii, Div

2) Groundwater Development Area

The suitable area to develop groundwater from the hydrogeological point of view is naturally the area evaluated as the excellent and very good in the evaluation map of groundwater resources. The existing production wells for domestic water have been constructed in the area suggested by the map. In addition, a couple of production wells for future use have been completed by WRRI in a part of the area recently. The area will be mainly exploited when the new groundwater development plan will be implemented in future.

3) Groundwater Development Potential

The following simple equation is representing flow through an aquifer;

Recharge to the aquifer – Discharge to the aquifer = Change in groundwater storage

If discharge exceeds recharge, the amount of water stored is reduced and the water level falls. It continues until the storage becomes exhausted.

Therefore, the groundwater development potential in an area will be evaluated on the basis of the storage of the aquifer and the natural recharge to the aquifer.

The volume of groundwater storage in the main aquifer in El Qaa Plain is estimated as follows;

Based on the Isopach Map of the Main Aquifer (Fig. 8.2.1-9), the areas of the aquifer with the thickness of 20, 40, 60, and 80 were obtained with a planimeter as shown in the table below.

The area of the aquifer;

A thickness	0	20	40	60	80	(meters)
The area	678	576	476	342	131	(km^2)

The volume of the whole aquifer is roughly integrated by the following simplified expression;

$$678 \times 10^6 \times 10 + (576+476+342+131) \times 10^6 \times 20 = 37.28 \times 10^9 \ (m^3)$$

Effective porosity of the aquifer material is estimated at 0.15;

Then, the groundwater volume stored is;

$$37.28 \times 10^9 \times 0.15 = 5.6 \times 10^9 \ (m^3)$$

This stored volume can be pumped up with the discharge rate of 20,000 m^3/day for more than 700 years continuously. However, as revealed by the simulation work, Chapter XII, continuous extraction may cause the reduction in groundwater level and the deterioration in water quality. The appropriate pumping rate should be considered and estimated to make this kind of effect minimize. This consideration has been done with a computer model in Chapter XII.

11.2 Lower Cretaceous Aquifer

11.2.1 Water Balance

1) Main Block

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

$$\Delta S = R - (Q + O_N) \quad (8.3.2\text{-}1)$$

where,

ΔS: groundwater storage increment/deficit

R: recharge to the aquifer

Q: total extraction

O_N: outflow from South Sinai to North Sinai

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

Total extraction from the Main Block of the Lower Cretaceous is 780,000 m^3/year (Refer to 9) of Chapter VIII).

O_N is estimated as 1.38×10^6 m^3/year using following equation.

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

L: 100 km,

b: 240 m x 0.62 = 149 m

0.62 is average ratio of effective aquifer thickness establishing from screen length ratio to the whole Lower Cretaceous aquifer thickness.

$\Delta h/\Delta x$: 0.3/1000

K: 1.0×10^{-3} cm/sec

Permeability of the Lower cretaceous aquifer is established based on the results of pumping test, grain size analysis and so forth. Every test values of permeability vary each other, however, it is considered that its permeability as the representative of the whole aquifer is proper value from the synthetic point of view.

Therefore, equation (8.3.2-1) is,

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

The result shows that the Main Block of the Lower Cretaceous Aquifer decreases its volume a total of $2.14 \times 10^6\ m^3$ every year.

2) Sheira Block

Wadi Sheira area is in the same situation as Wadi Feiran area. A total of 360,000 m^3/day of groundwater is extracted by four (4) wells. No periodical water level data is available because it is difficult to measure by a sounder due to installed submersible pumps in the wells. Therefore, Water balance in this area is still unknown.

3) Feiran Body

In 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 in the area. It is hard to estimate groundwater recharge to the Feiran Block of the Lower Cretaceous from the Precambrian Basement Rocks.

11.2.2 Development Potential of Main Block

1) Development Potential

Discussion of groundwater development potential is made on only Main Block of the Lower Cretaceous Aquifer because water balance data of other area is not available.

Storage of groundwater is estimated as 98 x 10^9 m^3. Present deficit of water balance is 2.64 x 10^6 m^3/year. .

According to the development plans, the development groundwater volumes from the lower Cretaceous Aquifer are tabulated below.

	Item	Volume
i)	Available groundwater volume	13.9 x 10^9 m^3
ii)	Groundwater flow rate to North Sinai:	1.38 x 10^6 m^3 /year
iii)	Existing groundwater extraction:	0.76 x 10^6 m^3 /year
iv)	New development volume for part 1:	20.99 x 10^6 m^3 /year
v)	New development volume for part 2:	12.78 x 10^6 m^3 /year
vi)	New development volume for part 4:	13.54 x 10^6 m^3 /year

If all the development plans 1, 2 and 4 will be attained, total water demand will become 49.45 x 10^6 m^3 /year. Therefore, life of available groundwater storage is calculated as shown below.

$$13.9 \times 10^9 \, m^3 / 49.45 \times 10^6 \, m^3 /year = 281(year)$$

This calculation means that the life of Main Block of the Lower Cretaceous Aquifer is about 281 years, provided that development plans 1, 2 and 4 are carried out.

On the other hand, according to the NPDS, agricultural development in the Central Sinai area (Malha, Sudr El Heitan and Themed) intends to use flood water or the Wadi El Arish instead of groundwater. If this idea will be applied, the life of available groundwater storage is,

$$13.9 \times 10^9 \, m^3 / 35.91 \times 10^6 \, m^3/year = 387 \text{ (years)}$$

2) Consideration on the development of fossil groundwater

Groundwater in the Lower Cretaceous Aquifer is so called Fossil Water because it is never recharged by present surface water. Therefore it is not sustainable. There are many discussions on the development of fossil water. Situation of fossil water is same as that of petroleum. Although petroleum must run out sooner or later, it is consumed so far.

In Sinai, many people lives there and is facing a lack of enough water sources. Population in the area has been increased as development in many sector is going on.

Taking this circumstance into consideration, development of groundwater in the Lower Cretaceous Aquifer should be carefully carried out under the proper control.

Life of the aquifer should be maintained as long as possible. It is estimated considering following conditions.

i) Not fully consume whole volume of groundwater in the aquifer.

ii) Life of aquifer is as long as possible for enough period to develop new technology in the field of water sources.

Result of evaluation is as follows;

i) Estimated possible volume of development of groundwater is about 14 % of the total volume of the Lower Cretaceous Aquifer.

ii) Life of the aquifer is estimated as 281 years if the water development volume of the plan 1, 2 and 4 in South Sinai depends on groundwater source.

iii) Life of the aquifer is estimated as 387 years if the plan 4 (irrigation) use surface water like as NPDS.

iv) Life of aquifer becomes more longer if submersible pump is developed, which is capable to extract groundwater from the depth more than 400 m.

11.3 Groundwater Monitoring

Groundwater in the Lower Cretaceous Aquifer is considered as unsustainable fossil water. Therefore, development of this groundwater shall be done carefully under proper control. In order to realize this control, groundwater level shall be monitored.

In order to achieve above purpose, following matter shall be monitored periodically;

- Groundwater Level Monitoring
- Extraction Rate Monitoring

11.3.1 Groundwater Level Monitoring

The Quaternary Aquifer in El Qaa Plain is the property of El Tur because it is only one (1) proper water source to supply all the domestic water from the Plain. Then groundwater level monitoring is very important to make the groundwater basin management.

As for the Lower Cretaceous Aquifer, from the same point of view, five (5) automatic water level recorder were installed in the JICA Wells, J-1, J-2, J-3, J-4 and J-6. However, there is no monitoring well in other blocks, Sheira Block, Feiran Block and Gharandal Sub Block.

It is recommended to construct monitoring well with automatic water level recorder for the Lower Cretaceous Aquifer in Sheira Block, Feiran Block and Gharandal Block because the groundwater development is actually going on in these areas.

Table 11.1.1-1 Variation of Groundwater Levels of Observation Wells (in meters)

Well No.			Sep-94	Dec-94	Mar-95	Jun-95	Sep-95	Dec-95	Mar-96	May-96	Feb-97	Sep-97
3	37DA-002	RIWR6	27.28	28.00	28.00	28.10	28.05	28.00	28.05			
				0.72	0.00	0.10	-0.05	-0.05	0.05			
11	37EA-003	QAA5/1	29.00	29.10	29.00	29.00	29.40	29.40	29.00	29.99	28.98	28.83
				0.10	-0.10	0.00	0.40	0.00	-0.40	0.99	-1.01	-0.15
13	37EA-007	QAA2/2	24.13	24.11	24.11	24.11	24.21		24.11	24.13	24.26	24.15
				-0.02	0.00	0.00	0.10		-0.10	0.02	0.13	-0.11
15	37EB-001	RIWR7	25.42	25.38	25.29	25.44	25.44	25.29	25.29	25.76	25.17	25.29
				-0.04	-0.09	0.15	0.00	-0.15	0.00	0.47	-0.59	0.12
21	48AB-002	QAA25/1	23.15	23.15	23.65	23.70	22.75	23.58	23.65		23.68	23.69
				0.00	0.50	0.05	-0.95	0.83	0.07		0.03	0.01
43	48CB-001	RIWR1	1.78	1.98	1.78	2.08	2.08	1.78	1.78	2.08	1.65	1.84
				0.20	-0.20	0.30	0.00	-0.30	0.00	0.30	-0.43	0.19
44	48CB-002	RIWR2	8.32	8.61	8.41	8.61	8.61	8.41	8.41	8.31	8.29	8.10
				0.29	-0.20	0.20	0.00	-0.20	0.00	-0.10	-0.02	-0.19
46	48CB-008	T-1/2		16.48	16.50	16.53		16.78	16.50	15.56	15.84	
					0.02	0.03		0.25	-0.28	-0.94	0.28	
50	48CC-003	T-7	14.34	14.34	14.34	14.39	14.24	14.31	14.33	14.38	14.27	14.26
				0.00	0.00	0.05	-0.15	0.07	0.02	0.05	-0.11	-0.01
52	48CC-005	RIWR1B	18.61	18.7	18.7	18.75	18.65	18.55	18.7	20.12	18.47	18.45
				0.09	0.00	0.05	-0.10	-0.10	0.15	1.42	-1.65	-0.02
Average of water level change				0.22	-0.05	0.08	0.06	-0.08	-0.05	0.96	-1.08	-0.02

Upper Column; Observed water level in m ASL
Bottom Column; Difference from the previous observation.

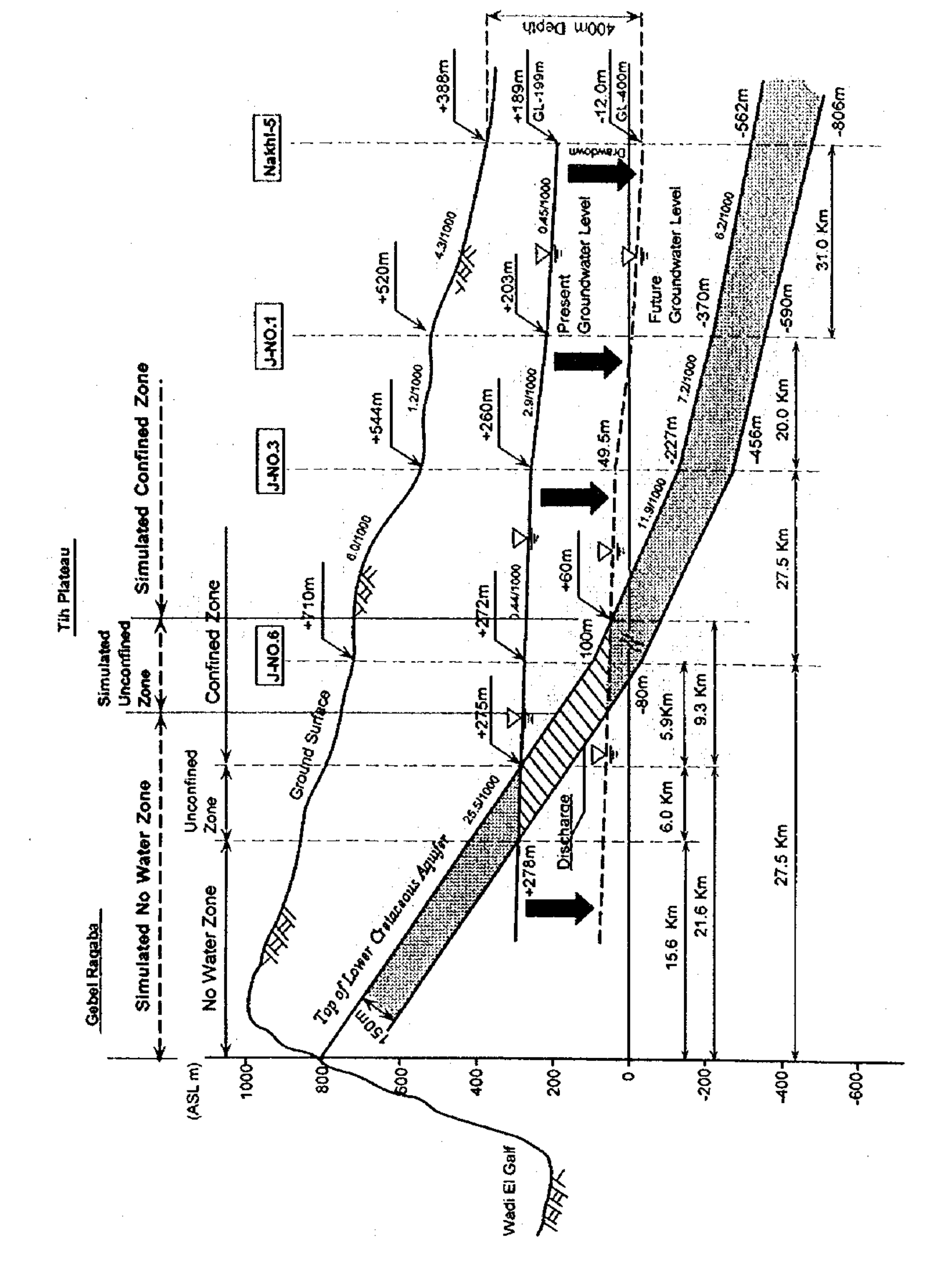


Fig. 11.2.2-1 Section of Simulated Groundwater Table (Lower Cretaceous)

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CHAPTERXII GROUNDWATER SIMULATION

12.1 Basic Concept of Groundwater Simulation

12.1.1 General Procedure of Groundwater Simulation

Groundwater simulation study is composed of aquifer model construction, calibration, prediction and evaluation as shown in Fig.12.1.1-1. 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.

1) Aquifer Modeling

Aquifer modeling is carried out by numerical groundwater model using digital computer. A three-dimensional aquifer model was adapted for study area, as discussed in the following section. The aquifer model simulates three-dimensional groundwater flow and solute transport in the phreatic or confined aquifer.

The aquifer model is constructed by mainly topography, aquifer distribution, hydraulic characteristics, groundwater discharge and recharge, and groundwater quality. The study area is horizontally discretized by grid with 1-Km width. Node of grid represents aquifer characteristics of the area where each node is centered.

2) Data Manipulation

Groundwater model study uses various kinds of input data such as aquifer characteristics, water levels, pumpage, recharge, etc. These data, most of which are collected in the field, are first placed in primary data files. They are then processed in various ways such as sorting, interpolation and aggregation, before being placed in secondary data files for model inputs.

(1) Hydrogeological data

Hydrogeological data consists of general geological data including geological and topographical maps, geophysical survey results, composite loggings of test wells and aquifer testing. Based on these data, contour maps on the surface of aquifer, aquitard and hydrogeological basement were prepared. The contour maps including ground elevation were converted into computer codes.

(2) Water level

Water levels measured in field were modified to water table elevation based on the ground height of observed points. Then contour maps were converted into computer codes.

(3) Groundwater quality

Salinity in groundwater is main problem in El Qaa plain. Therefore total dissolved solid (TDS) is used for groundwater quality index in the modeling study. Based on groundwater quality (TDS) measured in field, contour maps were drawn and converted into computer codes.

(4) Groundwater use and Recharge

Results of the investigation on well inventory were converted into computer codes. From rainfall data, groundwater recharge was estimated using recharge equations.

3) Calibration of Model

The model is test-operated inputting recharge and pumpage data and outputting the calculated head in each node. The output will be compared with observed water level records, then the model will be modified/adjusted until final agreement between the calculated and the observed water level is achieved. Using calibrated groundwater level, concentration of TDS is calculated by solute transport model. The model output will be compared with observed TDS, and adjusted until agreement between the calculated and the observed TDS is obtained. Thus the model is calibrated and ready to predict water level and quality (TDS) under various development situation.

4) Model Prediction and Evaluation

On the basis of future groundwater development plan, a tentative proposal for groundwater abstraction plan is prepared. Then the plan is inputted into the calibrated model. Response of the model is evaluated by the following criteria:

Evaluation Factor	Criteria
1. Water Balance	Abstraction should be less than the recharge
2. Environmental Impact	Salinity should be less than the criterion
	Influence to dug wells should be allowable
3. Economics	Total pumping head should be less than criterion

If the model response is not allowable even for one criterion, the development plan should be modified in terms of withdrawal, pumping pattern and well location. The model is operated until the final agreement with all the criteria is achieved. With the above steps of aquifer modeling, the optimum development plan is fixed and further examined in its financial and economic feasibility.

12.1.2 Description of Numerical Model

1) Introduction

It is considered that a model is a tool designed to represent a simplified version of reality, and properly constructed groundwater models, as they are also representations of reality, can be valuable predictive tools for groundwater resources management. Of groundwater models, a mathematical model is commonly used to study groundwater system.

A mathematical model consists of a set of differential equations that describe groundwater flow. Since the assumptions necessary to solve a mathematical model analytically are fairly restrictive, numerical techniques are generally required to solve the mathematical model approximately under realistic situations.

There are many numerical techniques to solve differential equations. Among them, finite difference and finite element methods are representative (Fig.12.1.2-1). The finite difference method is superior in less computer memory requirement and simplicity of data manipulation. The finite element method has excellence in flexibility of mesh formation. In practical aspect of groundwater flow simulation, there is little distinction between both methods. The finite difference method is applied for the proposed groundwater potential evaluation of the study area, in consideration of data availability and accuracy of aquifer parameters.

Solute transport in groundwater systems is described by the advective-dispersive equation. This equation is difficult to solve by both finite difference and finite element methods causing numerical dispersion and oscillation. To minimize such errors, small grid spacing and time steps are required.

To avoid the numerical problems solving advective-dispersive equation by finite difference and finite element methods, particle tracking method is introduced. Particle tracking method is used to solve advection combining with a finite difference solution of the dispersion portion of the advective-dispersive equation.

2) Groundwater Flow Model

(1) Basic Equation of Groundwater Flow

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

$$\frac{\partial}{\partial x}\left(Kxx\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(Kyy\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(Kzz\frac{\partial h}{\partial z}\right)-W=Ss\frac{\partial h}{\partial t} \qquad (12.1.2-1)$$

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.

Equation (12.1.1-1), together with specified flow and/or head conditions at the boundaries of an aquifer system and specified initial-head conditions, constitutes a mathematical representation of a groundwater flow system. Numerical method, such as the finite difference method, is usually applied to solve equation (12.1.2-1).

(2) Derivation of the Finite Difference Equation (McDonald and Harbaugh, 1988)

An aquifer system is discretized with a mesh of blocks called "cells" as illustrated in Fig.12.1.2-1, the location of which are referenced with a row(i), column(j) and layer(k) coordinate system parallel to the x, y and z directions, respectively. The width of cells in the row direction, at a given column j, is defined Δr_j; the width of cells in the column direction at a given row i, is defined Δc_i; and the thickness of cells in a given layer k, is defined Δv_k. At center of each cell, there is a point called a "node" at which head is to be calculated.

From the application of the continuity condition, the sum of all flows into and out of the cell is equal to the rate of change in storage within the cell, expressing as follows.

$$\sum Q_i = \Delta S \qquad (12.1.2-2)$$

Where, Q_i: flow rate into the cell, ΔS: storage change within the cell over a time interval Δt. For convenience flow entering cell is defined positive and outflow is defined negative.

A cell i,j,k and six adjacent cells are illustrated in Fig.12.1.2-3. Applying finite difference method, groundwater flow is approximated by the node-to-node flow. Flow into cell i,j,k in the row direction from cell i,j-1,k(Fig.12.1.2-4) is given by Darcy's law as

$$Q_{i,j-1/2,k} = KR_{i,j-1/2,k}\Delta c_j \Delta v_k \frac{h_{i,j-1,k} - h_{i,j,k}}{\Delta r_{j-1/2}} \qquad (12.1.2-3)$$

Where, $Q_{i,j-1/2,k}$: volumetric fluid discharge through the face between cells i,j,k and i,j-1,k, $h_{i,j,k}$: head at node i,j,k, $h_{i,j-1,k}$: head at node i,j-1,k, $KR_{i,j-1/2,k}$: hydraulic conductivity along the row between nodes i,j,k and i,j-1,k, $\Delta c_j \Delta v_k$: area of the cell faces normal to the row direction, $\Delta r_{j-1/2}$: distance between nodes i,j,k and i,j-1,k. The hydraulic conductivity between the nodes is normally calculated as a harmonic mean.

$$KR_{i,j-1/2,k} = \frac{2KR_{i,j-1,k}KR_{i,j,k}}{KR_{i,j-1,k} + KR_{i,j,k}} \qquad (12.1.2-4)$$

Similar expressions can be written approximating the flow into the cell through the remaining five faces. Flow in row direction through the face between cells i,j,k and i,j+1,k is expressed as

$$Q_{i,j+1/2,k} = KR_{i,j+1/2,k}\Delta c_j \Delta v_k \frac{h_{i,j+1,k} - h_{i,j,k}}{\Delta r_{j+1/2}} \qquad (12.1.2-5)$$

While for the column direction, flow into the cell through the forward face is

$$Q_{i+1/2,j,k} = KC_{i+1/2,j,k}\Delta r_j \Delta v_k \frac{h_{i+1,j,k} - h_{i,j,k}}{\Delta c_{i+1/2}} \qquad (12.1.2-6)$$

and flow into the cell through the rear face is

$$Q_{i-1/2,j,k} = KC_{i-1/2,j,k}\Delta r_j \Delta v_k \frac{h_{i-1,j,k} - h_{i,j,k}}{\Delta c_{i-1/2}} \qquad (12.1.2-7)$$

For the vertical direction, inflow through the bottom face is

$$Q_{i,j,k+1/2} = KV_{i,j,k+1/2}\Delta r_j \Delta c_i \frac{h_{i,j,k+1} - h_{i,j,k}}{\Delta v_{k+1/2}} \qquad (12.1.2-8)$$

while inflow through the upper face is given by

$$Q_{i,j,k-1/2} = KV_{i,j-1/2,k}\Delta r_j \Delta c_i \frac{h_{i,j,k-1} - h_{i,j,k}}{\Delta v_{k-1/2}} \qquad (12.1.2-9)$$

The notation can be simplified by combining grid dimensions and hydraulic conductivity into a single constant ("hydraulic conductance"). Hydraulic conductance between nodes i,j-1,k and i,j,k can be written as

$$CR_{i,j-1/2,k} = KR_{i,j-1/2,k}\Delta c_j \Delta v_k / \Delta r_{j-1/2} \qquad (12.1.2-10)$$

Storage change within the cell over a time interval Δt is expressed as follows.

$$\Delta S = Ss_{i,j,k}\frac{\Delta h_{i,j,k}}{\Delta t}\Delta r_j \Delta c_i \Delta v_k \qquad (12.1.2-11)$$

Where, $Ss_{i,j,k}$: specific storage of cell i,j,k, $\Delta h_{i,j,k}$: head change over a time interval Δt, $\Delta r_j \Delta c_i \Delta v_k$: volume of cell i,j,k. Assuming $\Delta t = t_m - t_{m-1}$, an approximation to the time derivative of head at time t_m can be written as

$$\left(\frac{\Delta h_{i,j,k}}{\Delta t}\right)_m = \frac{h^m{}_{i,j,k} - h^{m-1}{}_{i,j,k}}{t_m - t_{m-1}} \qquad (12.1.2-12)$$

Where, $h^m{}_{i,j,k}$: head of cell i,j,k at time t_m, $h^{m-1}{}_{i,j,k}$: head of cell i,j,k at time t_{m-1} which precedes t_m.

Substituting equation (12.1.2-3), equations (12.1.2-5) through (12.1.2-9), and equations (12.1.2-11) and (12.1.2-12) into equation (12.1.2-2), and applying relationship in equation (12.1.2-10), finite difference approximation for cell i,j,k can be obtained as

$$\begin{aligned}
&CR_{i,j-1/2,k}(h^m{}_{i,j-1,k} - h^m{}_{i,j,k}) + CR_{i,j+1/2,k}(h^m{}_{i,j+1,k} - h^m{}_{i,j,k}) \\
&+ CC_{i-1/2,j,k}(h^m{}_{i-1,j,k} - h^m{}_{i,j,k}) + CC_{i+1/2,j,k}(h^m{}_{i+1,j,k} - h^m{}_{i,j,k}) \\
&+ CV_{i,j,k-1/2}(h^m{}_{i,j,k-1} - h^m{}_{i,j,k}) + CV_{i,j,k+1/2}(h^m{}_{i,j,k+1} - h^m{}_{i,j,k}) + QS_{i,j,k} \\
&= Ss_{i,j,k}(\Delta r_j \Delta c_i \Delta v_k)\frac{h^m{}_{i,j,k} - h^{m-1}{}_{i,j,k}}{t_m - t_{m-1}} \qquad (12.1.2-13)
\end{aligned}$$

Where, $QS_{i,j,k}$: source or sink term of cell i,j,k.

An equation of this form is written for every cell in the calculation domain, and the system of equations is solved simultaneously for the heads at time t_m. Solving techniques of simultaneous equations are classified into direct and iterative methods. Finite difference approximation of three-dimensional groundwater flow produces a large system of simultaneous equations. Iterative method is superior to direct method in requirement of computer memory, and is usually used to solve such large system. Strongly Implicit Procedure method (SIP), Slice Successive Overrelaxation method (SSOR), and Preconditioned Conjugate Gradient method (PCG) are typical of iterative method. Precise explanation of solving techniques should be referred to McDonald and

Harbaugh (1988), and Hill (1990).

(3) MODFLOW

MODFLOW (Modular Finite-Difference Ground-Water Flow Model) developed by U.S. Geological Survey (McDonald and Harbaugh, 1988; Harbaugh and McDonald, 1996), is widely used numerical model which can simulate groundwater flow in a three-dimensional heterogeneous and anisotropic medium. As mentioned following section, MODFLOW was applied to simulate groundwater flow systems in El Qaa plain.

In a three-dimensional finite difference model, vertical discretization can be seen as a sequence of horizontal layers. In complicated hydrogeological condition, this grid system causes a cell contain material from different stratigraphic units (Fig.12.1.2-5(b)). In MODFLOW, vertical discretization can be viewed as an effort to represent individual aquifers or permeable zones by individual layers of the model (Fig.12.1.2-5(c)). This distortion can be generated by giving the elevation of the top and bottom of the layer. It allows flexibility in discretizing, however, introduces small error into the finite difference approximation.

3) Solute Transport Model

(1) Basic Equation of Solute Transport

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

$$\frac{\partial}{\partial x_i}\left(D_{ij}\frac{\partial C}{\partial x_j}\right)-\frac{\partial}{\partial x_i}\left(v_i C\right)+\frac{q_s}{\theta}C_s+\sum R_k=\frac{\partial C}{\partial t} \qquad (12.1.2-14)$$

Where, C: solute concentration, t: time, x_i: 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.

Assuming that equilibrium-controlled linear or non-linear sorption and first-order irreversible rate reactions are involved in the chemical reactions, the chemical reaction term in equation (12.1.2-14) can be expressed as (Grove and Stollenwerk, 1984),

$$\sum R_k=\frac{\rho b}{\theta}\frac{\partial C^*}{\partial t}-\lambda\left(C+\frac{\rho b}{\theta}C^*\right) \qquad (12.1.2-15)$$

Where, ρ_b: bulk density of the porous medium, C*: concentration of solute sorbed on the porous medium, λ: rate constant of the first-order rate reactions.

The linear pore water velocity in equation (12.1.2-14) can be calculated by the Darcy's Low.

$$v_i = \frac{K_{ii}}{\theta}\frac{\partial h}{\partial x_i} \qquad (12.1.2-16)$$

The potentiometric head in equation (12.1.2-16) is obtained from the solution of the three-dimensional groundwater flow equation (12.1.2-1), and the solute transport equation is linked to the flow equation through this relationship.

The second term on the left-hand side of equation (12.1.2-14), $\partial(v_iC)/\partial x_i$, is referred to as the advection term. The advection term describes the transport of solute at the same velocity as the groundwater (Fig.12.1.2-6).

The first term on the left-hand side of equation (12.1.2-14), $\partial[D_{ij}\partial C/\partial x_j]/\partial x_i$, represents a dispersion term. The dispersion term refers to the spreading of solute over a greater region than the process of advection only (Fig.12.1.2-6). The hydrodynamic dispersion coefficient is calculated from following equation (Bear, 1979).

$$D_{ij} = \alpha_T v\delta_{ij} + (\alpha_L - \alpha_T)v_iv_j/v + D_d \qquad (12.1.2-17)$$

Where, α_L: longitudinal dispersivity, α_T: transverse dispersivity, $v=(v_x^2 + v_y^2 + v_z^2)^{1/2}$, δ_{ij}: Kronecker's delta $(=1(i=j);\ =0(i \neq j))$, D_d: coefficient of molecular diffusion. Diffusion is generally secondary process in field solute transport.

(2) Numerical Approximation by Method of Characteristics (Zheng, 1990)

i) Classification of solution methods

Numerical methods for solving the advective-dispersive equation can be classified as Eulerian, Lagrangian or mixed Eulerian-Lagrangian (Neuman, 1984). In Eulerian approach, the transport equation is solved with a fixed grid method such as finite difference method. The Eulerian approach provides advantage of fixed grid. For advection dominated situation, however, an Eulerian method is susceptible to excessive numerical dispersion or oscillation, and limited by small grid spacing and time steps.

In the Lagrangian approach, the transport equation is solved in either a deforming grid or deforming coordinate in a fixed grid. The Lagrangian approach provides an accurate solution to advection dominated problems, however, leads to computational difficulties in nonuniform media with multiple sinks/sources and complex boundary conditions (Yeh, 1990).

The mixed Eulerian-Lagrangian approach attempts to combine the advantages of both the Eulerian and the Lagrangian approaches by solving the advection term with a Lagrangian method and the dispersion term with an Eulerian method. The Lagrangian part of the method for solving the advection term, generally employs the forward tracking method of characteristics (MOC), the backward tracking modified method of characteristics (MMOC), or a hybrid of these two methods. The Eulerian part of the method for solving the dispersion term, applies a finite difference method, when a transport model is combined with a finite difference flow model.

ii) Method of Characteristics

Equation (12.1.2-14) is an Eulerian expression in which the partial derivative, ($\partial C/\partial t$), indicates the rate of change in solute concentration (C) at a fixed point in space. Equation (12.1.2-14) can also be expressed in the Lagrangian form as

$$\frac{DC}{Dt} = \frac{\partial}{\partial x_i}\left(D_{ij}\frac{\partial C}{\partial x_j}\right) - \frac{q_s}{\theta}\left(C - C_s\right) - \lambda\left(C + \frac{\rho_b}{\theta}C^*\right) \qquad (12.1.2-18)$$

Where the substantial derivative, $DC/Dt = \partial C/\partial t + v_i^* \partial C/\partial x_i$, indicates the rate of change in solute concentration (C) along the pathline of a contaminant particle.

The substantial derivative in equation (12.1.2-18) can be approximated as

$$\frac{DC}{Dt} = \frac{C^{n+1}{}_m - C^{n^*}{}_m}{\Delta t} \qquad (12.1.2-19)$$

Then equation (12.1.2-18) becomes

$$C^{n+1}{}_m = C^{n^*}{}_m + \Delta t RHS \qquad (12.1.2-20)$$

Where, $C^{n+1}{}_m$: average solute concentration for cell m at the new time level ($n+1$), $C^{n^*}{}_m$: average solute concentration for cell m at the new time level ($n+1$) due to advection alone, also referred to as the intermediate time level (n^*), Δt: time increment between the old time level (n) and the new time level ($n+1$), RHS: finite difference approximation to the terms on the right-hand side of equation (12.1.2-18).

The method of characteristics, MOC (Garder er. al., 1964; Konikow and Bredehoeft, 1978), uses a conventional particle tracking technique for solving the advection term. At the beginning of the simulation, a set of moving particles is distributed in the flow field. A concentration and a position in the Cartesian coordinate system are associated with each of these particles. Particles are tracked forward through the flow field using a small time increment. At the end of each time increment, the average concentration at cell *m* owing to advection alone (C^{n*}_m) is calculated from the concentrations of moving particles located within cell *m* as follows (Fig.12.1.2-7).

$$C^{n*}_m = \frac{1}{NP}\sum_{l=1}^{NP} C^n{}_l \qquad (12.1.2-21)$$

Where, NP: number of particles within cell *m*, C^n_l: concentration of the l^{th} particle at time level *n*.

Substituting C^{n*}_m into equation (12.1.2-20), the changes in concentration owing to dispersion can be calculated. The concentration for cell *m* at the new time level *(n+1)* is then obtained as the sum of the concentration due to advection alone and the concentration due to dispersion. Precise explanation of solving techniques should be referred to Konikow and Bredehoeft (1978) and Zheng (1990).

iii) Numerical Criteria

A time stepsize (Δt) is calculated from the minimum of the following three numerical criteria. This reads frequently to small time steps in field situations. When the cells are small, or the velocities are large, the minimum time step becomes small.

The Courant condition:

$$|\Delta t| \le \gamma_c Min\left(\frac{\Delta x}{vx}, \frac{\Delta y}{vy}, \frac{\Delta z}{vz}\right) \qquad (12.1.2-22)$$

Numerical stability for dispersion:

$$\Delta t \le 0.5 \Big/ \left(\frac{D_{xx}}{\Delta x^2}, \frac{D_{yy}}{\Delta y^2}, \frac{D_{zz}}{\Delta z^2}\right) \qquad (12.1.2-23)$$

Numerical stability for source and sink terms:

$$\Delta t \le \left|\frac{\theta_{i,j,k}}{q_s{}^n{}_{i,j,k}}\right| \qquad (12.1.2-24)$$

where, γ_c: Couran number, representing the number of cells a particle will be allowed to move in any direction in one transport step.

(3) MT3D

The MT3D (Zheng, 1990) is a model for simulation of advection, dispersion and chemical reactions of contaminants in groundwater flow systems in either two or three dimensions. The model uses a mixed Eulerian-Lagrangian approach to the solution of the advective-dipersive equation, based on the method of characteristics for advective term, and finite difference method for dispersive term. The model program uses a modular structure similar to that implemented in the MODFLOW. Therefore, it can simulate solute transport, using result of flow simulation by the MODFLOW. The MT3D was applied to analyze the salinity migration of groundwater in El Qaa plain as shown in following section.

The MODFLOW and the MT3D assume that density of groundwater is constant. This assumption is valid for water with low salinity. High salinity in groundwater causes density-dependent flow. Then, neglecting the effect of density change introduces some error in groundwater simulation with high salinity content.

4) Visual MODFLOW

Visual MODFLOW (Waterloo Hydrogeologic Inc.®) is an integrated package combining MODFLOW, MODPATH (Pollock, 1989), and MT3D with graphical interface. It provides easy-to-use modeling environment for practical applications in three-dimensional groundwater flow and contaminant transport simulations. The model grid, input parameters and simulation results can be visualized in cross-section or plan view. It is able to use on personal computer with WINDOWS or DOS systems. Considering convenience of simple use and ease of technical transfer, visual MODFOW was selected to use in this project.