3. Study on Desalination Technology

3.1 Current Desalination Technology

3.1.1 Development of Desalination Technology

The installations of seawater and brackish water desalination for domestic and industrial water production have increased rapidly since 1970s with a remarkable development of desalination technology and an increasing demand for water supply in the Middle East and some other areas where water shortage has become increasingly severe and fresh water resources are insufficient. As is shown in Table II-3.1.1, the gross capacity of the installed desalination plants in the world exceeded 16,000,000 m^3/day by the end of 1991. The growth in desalination capacity from 1980 to 1991 is shown in Fig. II-3.1.1.

Table II-3.1.1 Installation of Desalination Plants in the World

	Water Production Capacity 1000 m^3/day	Percentage %
Middle East	8,913	54.9
USA	2,372	14.6
Europe	1,460	9.0
Asia	1,282	7.9
Africa	1,062	6.5
Others	1,147	7.1
Total	16,236	100

Source: Water Reuse Promotion Center (Japan)

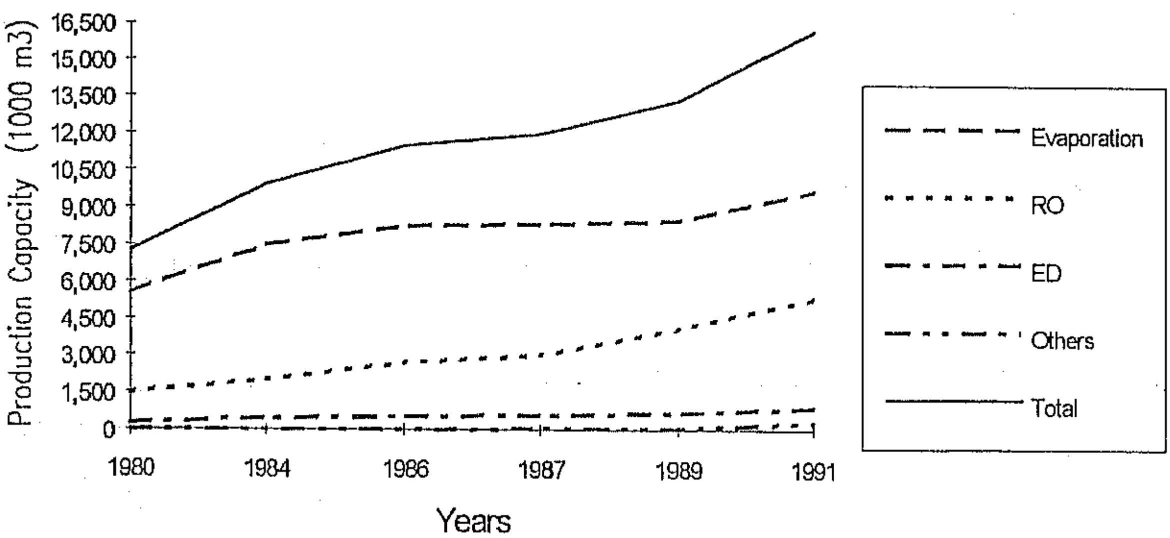


Fig. II-3.1.1 Production Capacity of Desalination Plants
(Source: Water Reuse Promotion Center, Japan)

According to the principle applied, the methods of desalination can be classified in the way shown in Fig. II-3.1.2. The processes accompanying phase change are the Evaporation Process (Liquid - Gas - Liquid) and Crystallization Process (Liquid - Solid - Liquid), and those without phase change are the Membrane Process, Solvent Extract Process and Ion Exchange Process. Among them, evaporation (especially MSF) and membrane processes (reverse osmosis and electrodialysis) are the main processes used in domestic and industrial water production.

In the early 1970s, the evaporation process was dominant in seawater desalination with large scale installations. The multi-stage flash (MSF), multi effect evaporation (ME) and vapor compression processes (VC) were employed. However, from the middle 1980s, following a remarkable development in membrane manufacturing technology, the utilization of electrodialysis (ED) and reverse osmosis (RO) increased rapidly because of their features of energy saving and high efficiency.

Table II-3.1.2 shows the total installations of desalination plant throughout the world in 1980 and 1991 utilizing evaporation, ED and RO. It can be seen that ED and RO installations increased faster than the evaporation installations.

Besides their applications in domestic and industrial water production, RO and ED are also applied nowadays in many other fields such as ultra pure water production, waste water reuse and so on.

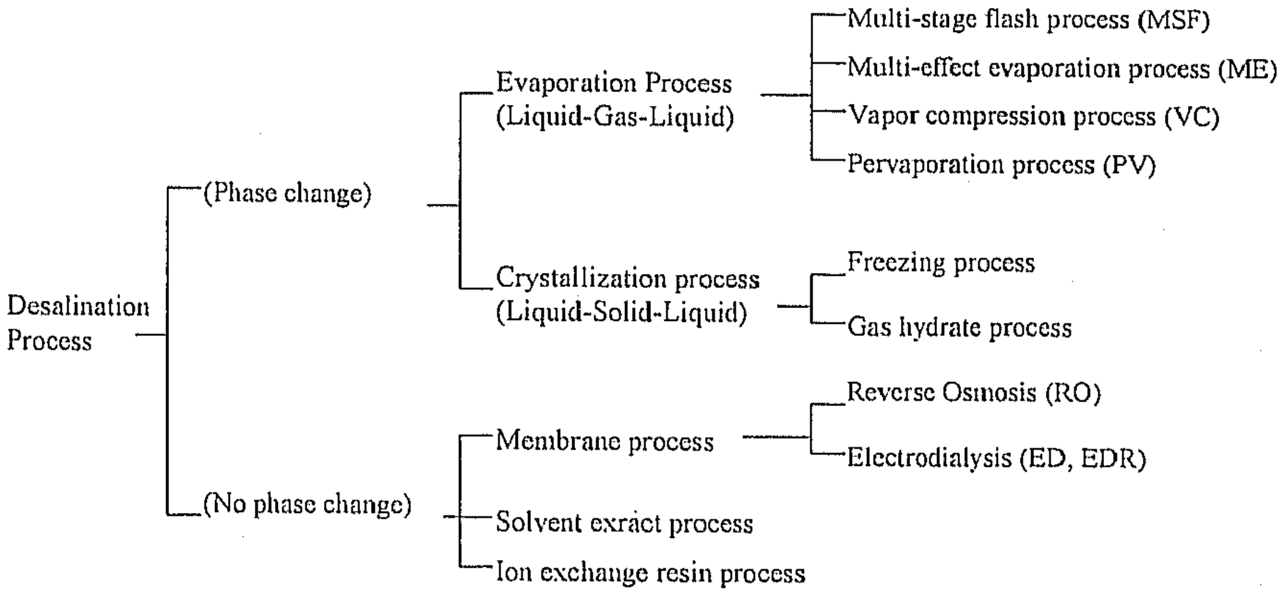


Fig. II-3.1.2 Desalination Processes

(Source: Takaharu Yamada, Trends in Saltwater Desalination Technology)

Table II-3.1.2 Installed Production Capacities by Process

Method	1980		1991		Increase in 11 years
	1000 m^3/day	%	1000 m^3/day	%	%
Evaporation	5,526	75.9	9,693	59.7	75.4
RO	1,478	20.3	5,339	32.9	261.2
ED	274	3.8	898	5.5	227.7
Others	-	-	306	1.9	-
Total	7,278	100.0	16,236	100.0	123.1

Source: Water Reuse Promotion Center (Japan)

3.1.2 Characteristics of Evaporation, ED and RO Processes

(1) Evaporation Process

The evaporation process utilizes the very basic principle of impurity separation by phase change. When water is boiled, water vapor and other volatile matters are released to the atmosphere above the boiling liquid, while the dissolved solids remain in the liquid. Distilled water is then obtained when the water vapor is condensed.

The typical evaporation process is the multi-stage flash process (MSF) which utilizes the method of "flash evaporation" rather than "boiling water". In the flash process, the saline water that is to be distilled is pumped through a pipe bundle in an evaporator, heated outside, and pumped in again at the bottom of the evaporator. With a higher temperature than the saturation temperature under the pressure acting in the evaporator, the heated water flashes and is self-evaporated on entering the evaporator. A desalination plant that uses this method is designed so that the incoming feed water is heated through its entire temperature range under pressure conditions that do not permit the formation of vapor during the heating process. After the maximum required temperature has been reached, the pressure on the liquid is reduced in successive stages. At each stage in the reduction of pressure, there is an accompanying formation of vapor by flashing. The condensation of all these increments of water constitutes the water output of the plant. According to the water flow system, the process is either the through-flow type or the brine circulating type MSF process.

Fig. II-3.1.3 shows a typical schematic diagram of the brine circulating type MSF process applied in many desalination plants.

The main features of the evaporation process can be generalized as follows.

a) Since water is treated by distillation, very high quality water with a TDS less than 10 mg/L can be obtained;

b) Energy consumption is usually high and independent of raw water quality. Therefore, the process is suitable for seawater desalination and for use in countries and areas where a cheap heat source or other energy source is available. Application of high efficiency heat-exchanging machines and utilization of the residual heat energy are the main ways to reduce energy cost.

c) Construction cost is usually high especially for small and medium scale plants. Unit cost can be reduced by building large scale plants.

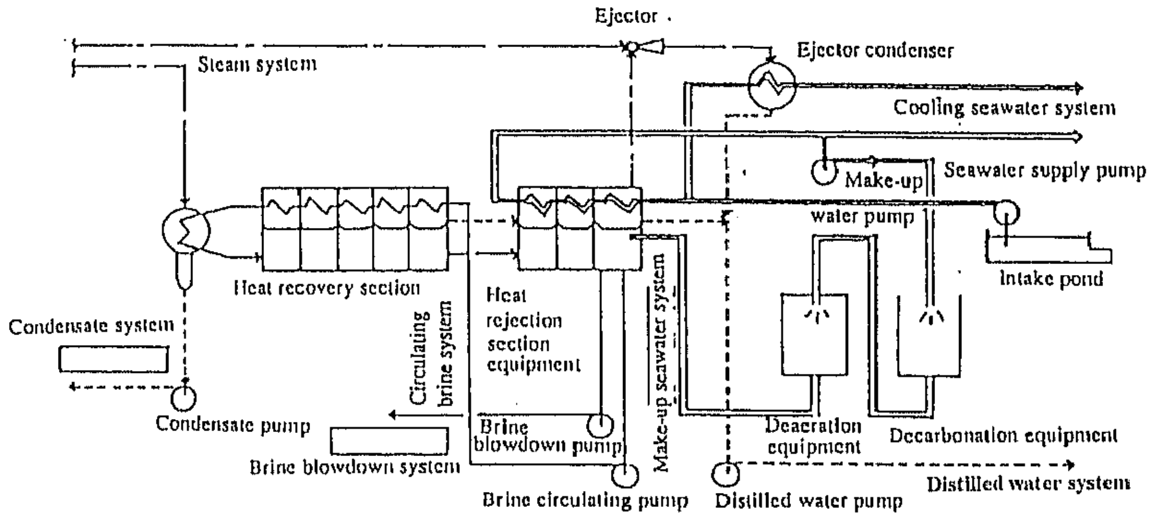


Fig. II-3.1.3 Schematic Diagram of a Brine Circulating Type Multi-Stage Flash Evaporation Process

(2) Electrodialysis Process

Electrodialysis involves electrochemical separation using two part membranes; one part selects cations and the other selects anions. The membranes are placed alternately so as to form compartments. A direct current is placed across the resulting compartments. As saline feed water is introduced into the compartment, the cations travel to the cathode and the anions travel to the anode.

As shown in Fig. II-3.1.4, the cation-permeable membrane permits positive ions, e. g. Na, to pass through, while it repels negative ions, e. g. Cl. In a similar way, the anion-permeable membrane allows negative ions to pass through, but repels positive ones. The membranes act as one-way check valves by preventing the re-entry of the ions that they let through. Hence the stream between the membrane is desalted while the streams on the electrode sides have a concentration of penetrating ions.

In a practical ED desalination plant, multiple pairs of membranes are used between a single pair of electrodes forming many compartments, as is illustrated in Fig. II-3.1.5. Since the alternating membranes select either anions or cations, every other compartment has a concentration of ions, while alternate compartments are depleted, which results in the production of desalinated water.

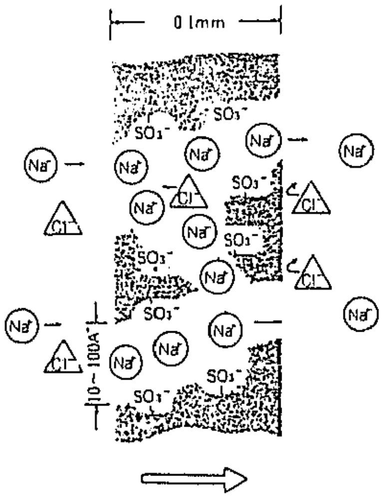


Fig. II-3.1.4 Conceptual Structure of an Anion Selective Membrane

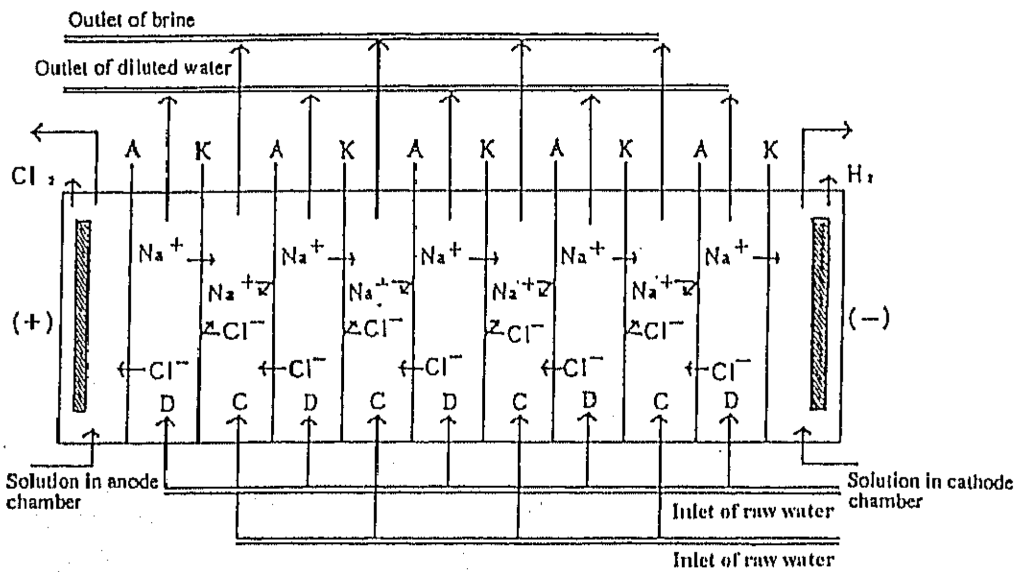


Fig. II-3.1.5 Schematic Diagram of ED Desalination Process

In Japan, the ED process is applied in many seawater concentrating plants to produce salts. In the United States and some other countries, ED is used in some of the brackish water desalination plants for potable water production. There are very few examples of ED plants for seawater desalination.

The main features of ED process are as follows.

a) The required electric current for ED operation varies proportionally to the amount of dissolved solids to be removed. Desalination of more highly mineralized water needs higher electrical energy. As long as a high electric current can be applied, ED can even be used for concentrating very dense brine, regardless of its high cost.

b) Since EC uses only flat membranes, a large space is needed for installation. Therefore, construction of large scale plant is usually difficult.

c) Nonionic substances in the water can not be removed by the ED process.

An improvement on the ED process was realized by using the electrodialysis reversal (EDR) principle. In EDR, the polarity of the direct current is reversed two to four times per hour, and the membranes periodically clean themselves without the use of chemicals. This widens the application range of the ED process.

(3) Reverse Osmosis Process

Reverse osmosis can be viewed as a filtering process at the molecular-ionic level. A semi-permeable membrane is used, i.e. the membrane allows the passage of the solvent in either direction, but prevents the passage of the solution. The principle can be illustrated by the three diagrams in Fig. II-3.1.6. The first diagram shows normal osmosis, the natural process by which water flows through such a membrane from pure water, or from a diluted to a more concentrated solution. Every solution has a specific osmotic pressure, determined by the identities and concentrations of the dissolved materials. As is shown in the second diagram, this flow continues until the resulting osmotic head equals the pressure of the solution. At this point, osmotic equilibrium exists, and the net flow of the water across the membrane is zero. If the solution compartment is then enclosed, and a pressure higher than the natural osmotic pressure of the solution is applied, the direction of water flow is reversed, as is indicated in the third diagram. The solution becomes more concentrated, and purified water is obtained on the other side of the membrane.

In practical utilization of reverse osmosis, semi-permeable membranes are assembled in compact modules. There are various types such as tubular, flat plate, hollow fiber and spiral-wound modules. The later two are widely used in many plants for seawater and brackish water desalination.

Fig. II-3.1.7 shows the schematic diagram of a desalination plant using the reverse osmosis process.

The main features of the RO process are as follows.

a) The required pressure can be simply exerted to the feed water by high pressure pumps.

b) Energy consumption is relatively low.

c) A wide range of application can be readily realized by selecting suitable membranes. The remarkable development in membrane manufacturing technology has made this possible.

d) The membrane area can be increased easily within a limited space by using the compact spiral-wound and hollow fiber modules.

e) Pretreatment is necessary to remove fouling and scaling matters from the feed water to the RO units.

f) Both ionic and nonionic substances can be removed at the molecular scale level.

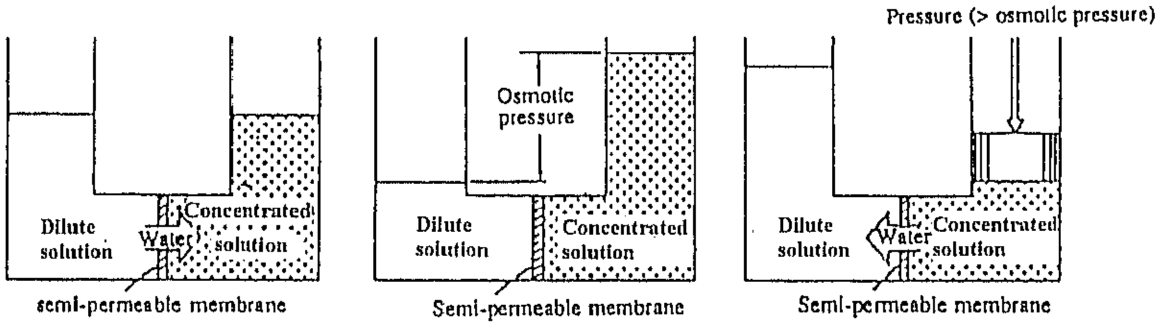


Fig. II-3.1.6 Principle of Reverse Osmosis

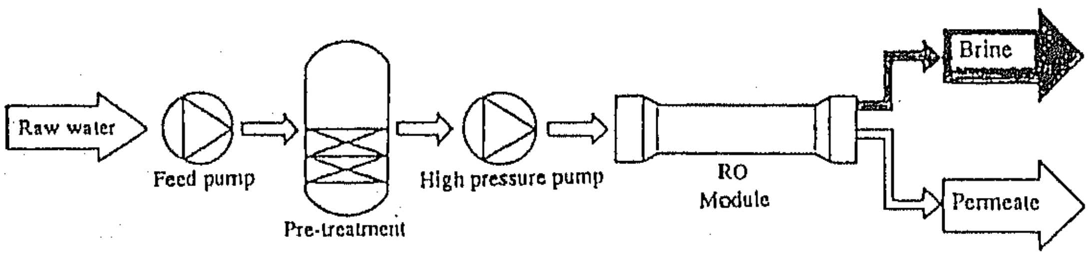


Fig. II-3.1.7 Schematic Diagram of Reverse Osmosis Process

3.1.3 Comparison of Evaporation, ED and RO Processes

(1) Separation Performance

The separation performance of the evaporation process is excellent and high quality treated water with a TDS less than 10 mg/L can be obtained. With the RO process, the treated water may have a TDS ranging from 10 to 500 mg/L depending on raw water salinity and membrane property. For ED, as well as EDR, a TDS of 100 mg/L is considered the attainable limit from an economic view point, because the electrical resistance of water with a lower TDS becomes very high and electrical efficiency drops drastically.

Nonionic organic substances can be removed by the evaporation and RO processes, but not by the ED process.

Bacteria and viruses are nonionic organisms with molecular scales. Therefore they can be removed by RO but not by ED. Because evaporation, especially MSF, usually operates under a reduced pressure with a low temperature (40 ~ 45 °C), it can not perform sterilization effectively.

(2) Energy Consumption

Energy consumption by the three processes is compared in Table II-3.1.5 for three cases, i.e. seawater with a TDS of 35000 mg/L, brackish water with a TDS of 5000 mg/L and 2000 mg/L. Considering the application range of each process, MSF and RO are compared for seawater desalination and RO and ED are compared for brackish water desalination.

For seawater desalination, MSF needs about three times as much energy as that required by RO (heat energy is converted to the equivalent electric power in the table). For brackish water desalination, ED and RO need about the same amount of energy in the case of 2000 mg/L, and RO consumes less energy than ED in the case of higher TDS of 5000 mg/L.

(3) Construction cost and water cost.

In Table II-3.1.3, the costs for desalination plant construction and water production are listed regarding raw water salinity and applied desalination process. The plant capacity is assumed to be 10,000 ~ 50,000 m3/day. For a desalination plant of much larger capacity, water production cost becomes lower.

Table II-3.1.3 Energy Consumption

Process	Raw Water	KWH/m^3 Production
MSF	Sea water TDS=35,000 mg/L	25.0
RO	Sea water TDS=35,000 mg/L	7.0
ED	Brackish water TDS = 5,000 mg/L	2.5
RO	Brackish water TDS = 5,000 mg/L	1.6
ED	Brackish water TDS = 2,000 mg/L	1.2
RO	Brackish waer TDS = 2,000 mg/L	1.1

Source: JICA Study Team

Table II-3.1.4 Costs of Desalination by Raw water Quality

Process	Raw water Quality	Capital Cost $/m^3.day	Water cost $/m^3
MSF	Sea water TDS 35,000 mg/L	1600 ~ 3000	1.25 ~ 2.6
RO	Sea water TDS 35,000 mg/L	1300 ~ 2400	1.1 ~ 1.6
ED	Brackish water TDS 5,000 mg/L	1500 ~ 2000	0.8 ~ 1.2
RO	Brackish water TDS 5,000 mg/L	900 ~ 1500	0.4 ~ 1.0
ED	Brackish water TDS 1,600 mg/L	600 ~ 1200	0.3 ~ 0.6
RO	Brackish water TDS 1,600 mg/L	600 ~ 1200	0.3 ~ 0.6

a Source: IDA report and JICA Study Team

b. Desalination for domestic water supply

c. Production Capacity = 10,000 ~ 50,000 m^3/day
Stream $ 1.39 /Mb tu
Electric power $ 0.07 ~ 0.1 /KWH
Fixed Charge (7% 20 year)
Membrane Replacement 3 ~ 6 years

d. The costs of product water storage, distribution and administration are not included.

(4) Summary

The results of the above comparison are summarized in Table II-3.1.5 with a consideration of the other items relating to process design, operation and maintenance.

Table II-3.1.5 General Comparison of Desalination Processes

Item	Evaporation	ED	RO
Quality of treated water	3	2	2
Construction Cost	1	2	3
Operation Cost	2	3	3
Number of Installations	3	2	3
Operation & Maintenance	2	2	3
Reliability	3	3	3
Pre-treatment	3	2	2
Safety of treated water	2	1	3

3: excellent 2: good 1: poor

Generally speaking, the evaporation process with its longer history of application and numerous installations has the advantages of high quality treated water and high reliability in operation. However, its construction cost and energy consumption are high, and a large quantity of cooling water is required for plant operation. For these reasons, most of the large installations are in gulf areas where cheap energy is available and cooling water is collected from the sea.

The application of the ED process is limited to brackish water desalination because electric energy consumption becomes very high with a high salinity water.

The application range of the RO process is broader; it can be used for both seawater and brackish water desalination. However, RO membranes are sensitive to raw water quality and pre-treatment is usually required.

3.2 Quality of Brackish Groundwater in the Study Area and Desalination System to be Applied

3.2.1 Water Quality of Zerqa Aquifer in the Study Area

(1) Water quality of Zerqa aquifer in the North area

The water quality of the Zerqa aquifer in the North of the Study Area near Deir Alla is shown in Table II-3.2.1. The table includes the water quality analyses data of Test Well No. 1 (TW 1) and the existing Abu Zeigan No. 1 Well (AZ 1).

Table II-3.2.1 Water Quality of Zerqa Aquifer in the North Area

Well	TDS (mg/L)	Temp (°C)	pH	Ca (meq/L)	Mg (meq/L)	Na (meq/L)	K (meq/L)	Cl (meq/L)	SO_4 (meq/L)	HCO_3 (meq/L)	NO_3 (mg/L)	TH (mg/L)	Fe (mg/L)	SiO_2 (mg/L)
TW 1	7262	36.3	6.38	37.15	10.40	51.40	4.20	50.00	34.30	17.16	8.72	2378	10.7	22.1
AZ 1[a]	8707	35.5	6.6	42.40	9.43	87.87	5.90	78.98	38.63	29.44	< 0.1	2592	179	13.7
AZ 1[b]	7622	35.0	6.28	42.20	11.50	79.80	4.60	76.92	36.76	23.63	1.99	2685	100.5	17.3

1) Source: water quality analyses results by JICA Study Team
2) TH (total hardness) as $CaCO_3$
3) a- analyses in winter season; b- analyses in summer season

The salinity of the water is around 7000-8000 mg/L as TDS with a temperature of 35-36 oC. NaCl is the main component of salt in the water (3000 mg/L or more). Besides, the cations of Ca, Mg and the anions of SO4 and HCO3 that are considered to be scaling substances exist in relatively high concentrations, and the calculated total hardness is about 2500 mg/L as CaCO3. Fe in the water of Abu Zeigan No. 1 well is much higher than that of Test Well No. 1. This is believed to be caused by rust from the well casing, not from the aquifer. Because this artesian well is not being used, when it was opened for sampling, the accumulated rust was washed out and affected the analysis results. Therefore, Fe concentration of Test Well No. 1 is representative for the water in the aquifer. As for SiO2 which is a fouling substance for membranes, its concentration is about 20 mg/L.

(2) Water Quality of Zerqa Aquifer in the Middle Area

In the middle region of the Study Area, there are no existing wells tapped to the Zerqa Aquifer. Water quality analyses results of the two test wells drilled by the JICA Study Team in this area are shown in Table II-3.2.2.

The data show that the salinity of water in this area is higher than those in both the North area and the South area (see next section) and exceeds 9500 mg/L in TDS. Water temperature is relatively low (less than 32 oC). NaCl concentration is 5000-6000 mg/L as the main component of salt in the water and the calculated total hardness is about 3000 mg/L. The Fe concentration of 10-15 mg/L and SiO2 of 13.18 mg/L are similar to the values in the North area.

Table II-3.2.2 Water Quality of Zerqa Aquifer in the Middle Area

Well	TDS (mg/L)	Temp (°C)	pH	Ca (meq/L)	Mg (meq/L)	Na (meq/L)	K (meq/L)	Cl (meq/L)	SO_4 (meq/L)	HCO_3 (meq/L)	NO_3 (mg/L)	TH (mg/L)	Fe (mg/L)	SiO_2 (mg/L)
TW 2	9724	31.9	6.74	46.69	16.6	108	6.5	116.7	36.34	26.62	3.94	3165	10.8	13.7
TW 4	9526	31.7	6.62	44.86	12.8	96.5	5.5	88.7	46.69	24.38	4.43	2883	15.8	17.9

1) Source: water quality analyses results by JICA Study Team
2) TH (total hardness) as $CaCO_3$

(3) Water Quality of Zerqa Aquifer in the South Area

Table II-3.2.3 shows the water quality analyses results of Test Well No. 5 (TW 5) and Test Well No. 6 (TW 6) in comparison with the existing Hisban No. 2 (H 2) and Kaffrein No. 7 (K 7) wells which, according to the hydrogeological evidence, are believed to be Zerqa Aquifer wells.

Table II-3.2.3 Water Quality of Zerqa Aquifer in the South Area

Well	TDS (mg/L)	Temp. (°C)	pH	Ca (meq/L)	Mg (meq/L)	Na (meq/L)	K (meq/L)	Cl (meq/L)	SO_4 (meq/L)	HCO_3 (meq/L)	NO_3 (mg/L)	TH (mg/L)	Fe (mg/L)	SiO_2 (mg/L)
TW 5	5204	35.3	6.12	22.94	11.98	57.75	4.5	64	11.17	20.72	0.79	1746	1.72	5
TW 6	5540	31.5	6.16	21.72	10.25	52.1	4.1	56.4	11.87	19.16	7.22	1599	-	10.2
H 2[a]	4055	37.0	6.7	16.6	8.85	34.61	3.28	40.93	10.35	15.77	<0.1	1273	2.12	11.4
H 2[b]	4121	36.5	6.44	16.6	9.0	38.75	2.75	40.9	10.2	15.27	1.59	1280	0.8	15.5
K 7[a]	5508	32.5	6.4	19.8	13.03	50.61	5.49	59.92	10.5	23.03	<0.1	1642	6.4	14.4
K 7[b]	5590	31.5	6.92	15.34	15.9	59.5	4.25	61.98	12.44	19.78	2.34	1562	5	20.24

1) Source: water quality analyses results by JICA Study Team
2) TH (total hardness) as $CaCO_3$
3) a- analyses in winter season; b- analyses in summer season

The TDS values of both TW 5 and TW 6 are about 5000 mg/L but a difference is noted in their temperatures (35.3 and 31.5 oC). NaCl concentration is estimated as 3000 mg/L - about the same as that in the North area. The concentrations of scaling substances are lower in this area, which can be seen from the concentrations of Ca, Mg, SO4, HCO3, and from the calculated total hardness (about 1500 mg/L). Fe concentration is less than 5 mg/L and SiO2 is about 10 mg/L.

The lower salinity of the water from H 2 well is believed to have resulted from a mixing of the less salty water from the Kurnub aquifer that overlies the Zerqa Aquifer, because the well was not completely isolated from the upper aquifer when it was drilled.

3.2.2 Desalination System to be Applied

As discussed in section 3.1, evaporation (MSF or others), electrodialysis (ED or EDR) and reverse osmosis (RO) are the main processes currently applied for sea water and brackish water desalination. Each process has its own features and applicable conditions from the standpoints of energy consumption, construction cost, operation and maintenance and so on. The desalination system to be applied in this project should be selected from a consideration of brackish water quality and project site conditions in the Study Area.

(1) Evaporation process

The evaporation process will not be considered for this project for the following two reasons:

- Its energy consumption is too high for brackish water desalination.
- It is not suitable for inland installation because of the difficulty in supplying a sufficient volume of the cooling water that is indispensable for vapor condensation.

(2) Electrodialysis and Reverse Osmosis processes

Generally speaking, both ED and RO processes are applicable to brackish water desalination. The technologies of both have already been well established and many plants have been installed throughout the world. However, their costs vary with water quality and need to be compared.

The relationship between energy consumption and water salinity for ED and RO is shown in Fig. II-3.2.1; with a brackish water of TDS less than 1500 mg/L, less energy is required for ED; with a TDS from 1500 to 2500 mg/L, almost the same amount of energy is required for both and with a TDS higher than 2500 mg/L, RO needs less energy than ED.

The cost of desalination for a brackish water with a TDS of 5000 mg/L is evaluated for ED and RO in Table II-3.2.4. The table shows that both capital cost and water cost for ED are higher than those for RO. If the TDS is higher, the difference in costs between the two processes is even larger.

For the above mentioned reasons, the ED (or EDR) process is mostly applied to the desalination of brackish water with a TDS less than 3000 mg/L, but RO can be applied to the desalination of brackish water and sea water over a wide range of salinities.

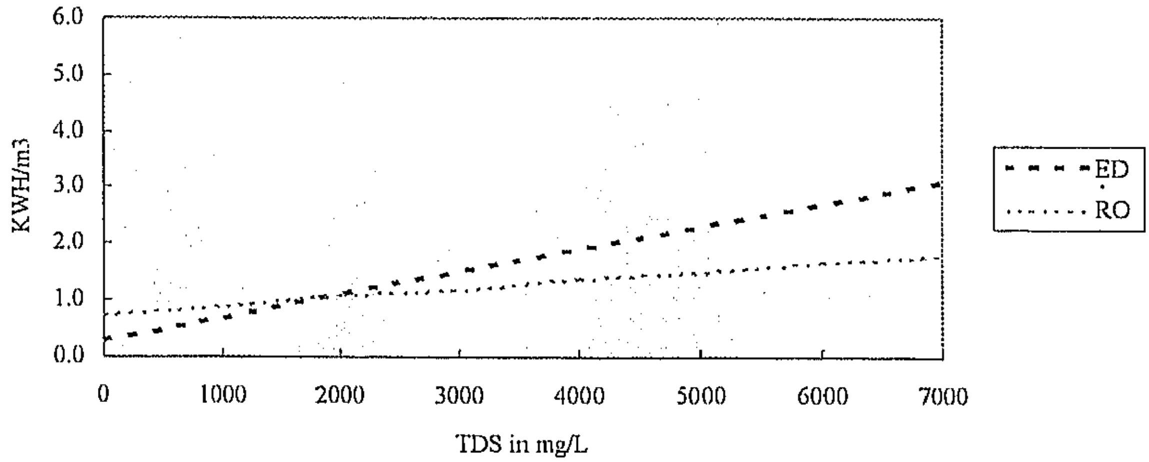


Fig. II-3.2.1 Energy Consumption of ED and RO
(Source: calculation by JICA Study Team
based on desalination plant experiences)

Table II-3.2.4 Cost Comparison of ED and RO

Item	Unit	ED	RO
Capital Cost	$\$/m^3$ day	1500 - 2000	900 - 1500
Energy Consumption	KWH/day	2.5 - 3.0	1.2 - 1.6
Water Cost	$\$/m^3$	0.5 - 0.7	0.2 - 0.5

Source: calculation by JICA Study Team based on desalination plant experiences
Assumption: Raw water TDS = 5000 mg/L
Recovery ratio = 80 - 85%
Electric power cost = $ 0.1/KWH
Load factor = 90%

The brackish water from the Zerqa Aquifer in the North of the Study Area is about 7500 mg/L and that in the South is about 5000 mg/L in TDS. For the desalination of this type of water, RO is considered to be the most suitable process to be applied.

3.3 Quality of the Treated Water

The objective quality of the treated water after desalination should be decided by consideration of (i) Jordanian drinking water quality standards and internationally commonly acceptable TDS, (ii) attainable water quality by RO treatment and (iii) the possibility of blending the desalinated water with the water supplied from other water sources to improve drinking water quality in the water supply area where high TDS is a common problem.

In Jordanian Drinking Water Quality Standards, TDS is set at two levels, the permissible value of 500 mg/L and the maximum allowable value of 1500 mg/L. The WHO guideline for TDS is 1000 mg/L. However, in many countries as well as in Japan, 500 mg/L is set as the maximum allowable TDS value. TDS higher than 500 mg/L is only recommended for countries or areas where fresh water resources are insufficient. Because dissolved solids can not by removed by conventional water treatment processes, and a strict TDS standard may require high cost water purification treatment by RO or other processes that is not really necessary from the view point of a minimum requirement for human health, the WHO guideline for the whole world can not be set too strictly. For these reasons, the objective TDS of treated water should at least be less than 500 mg/L to meet the commonly acceptable level and the permissible value in Jordanian Standards.

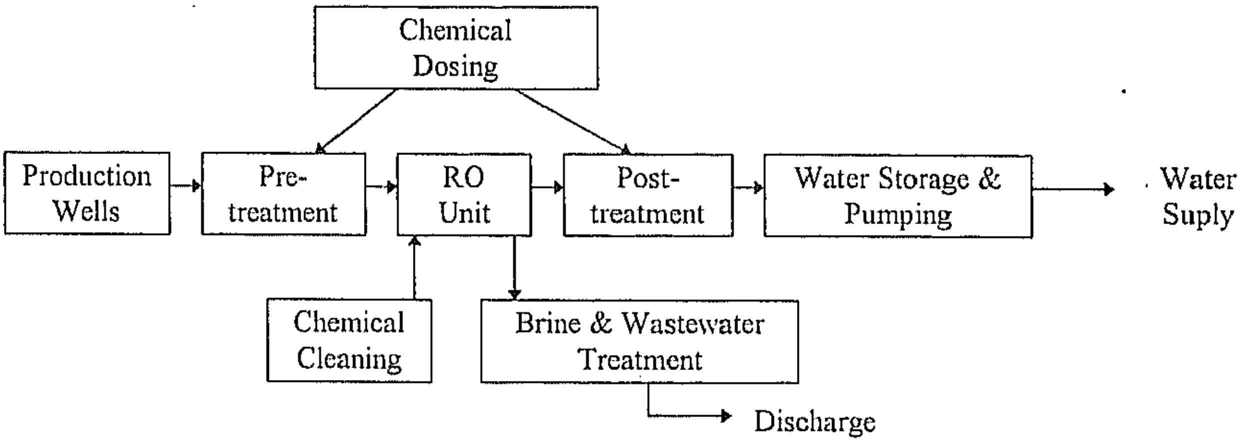
On the other hand, RO is a process that can produce very high quality water, and the treated water from most of the RO plants in the world has a TDS less than 200-300 mg/L. With the brackish water in the Study Area having a TDS of 5000 (South) to 7500 mg/L (North), a treated water with a TDS of less than 300 mg/L needs a salt rejection higher than 94-96% which is common for RO operation. Therefore, it is reasonable to set the objective TDS of the treated water as 300 mg/L.

With high quality desalinated water, there is a possibility that desalinated water could be blended with the water from other sources in some areas to improve water quality for water supply. However, pumping of groundwater beyond the safe yield is one of the reasons for the increase in groundwater salinity in both the Amman and Jordan Valley areas and one of the objectives of brackish groundwater desalination is to reduce water abstraction from shallow aquifers and to gain a recovery in the water table and water quality. Hence blending of desalinated water with the water from other sources should be restricted so as not to cause over-abstraction of the other groundwater resources.

3.4 Reverse Osmosis System

3.4.1 System Configuration

The basic configuration of a RO plant for brackish groundwater desalination shall be as follows.



The brackish groundwater from the production wells flows first to the pre-treatment unit where turbid matters and other fouling substances which may damage RO membranes are removed or controlled by physiochemical treating or chemical conditioning. Then the water is fed to the RO unit where salts are rejected and concentrated in the brine and fresh water is obtained through the semi-permeable membranes. The post-treatment often includes pH adjusting and disinfection of the desalted water as the final treatment process to produce drinking water. Beside the main flow of the above mentioned water treatment process, there are water storage and pumping facilities for water supply, chemical cleaning facilities for regular cleaning of RO membranes and waste water treatment facilities for neutralization and biological treatment of the chemical wastes which are finally mixed with the brine and discharged out of the plant.

3.4.2 RO Membrane Modules

(1) Membrane material

There are two principal materials used for RO membranes: cellulose acetate (CA) and polyamide (PA).

a) CA membrane

Cellulose acetate has been used as membrane material since the early days of RO application. The main characteristics of CA membranes are as follows.

- Operation pH range 4 ~ 6.
- Sensitive to biological fouling and continuous sterilization by chlorine is required.
- Resistant to residual chlorine.
- Middle or high pressure is required to keep high flux

b) PA membrane

Polyamide membrane is newly developed and it has dominated the market recently due to its high performance. Its main characteristics are as follows.

- Operation pH range 3~ 9
- High flux can be kept under a low pressure.
- High salt rejection.
- Resistant to bacteria
- Sensitive to residual chlorine

PA membrane is replacing CA membrane in many plant installations because of its higher salt rejection and lower operation pressure. However, CA membrane is still used in some cases because it is resistant to higher residual chlorine.

(2) Membrane module

There are four types of RO membrane modules, flat plate, tubular, hollow fiber and spiral wound. Because flat plate and tubular membrane modules need a large space for installation, their usage is limited to some special cases. The membrane modules widely used for water desalination are hollow fiber (HF) and spiral wound (SW) modules.

a) HF module

A hollow fiber membrane module bundles a large numbers of fibers in one container. Fig. II-3.4.1 shows the structure of a single hollow fiber and that of the module. The element fiber has a diameter about 90 μm with a hollow hole (about 40 μm diameter) at its center so that the surface area per unit volume is very large. HF membrane modules are sensitive to turbid matters and fouling substances, and need a thorough pretreatment of the feed water. The silt density index (SDI) of the water is required to be less than 3.0.

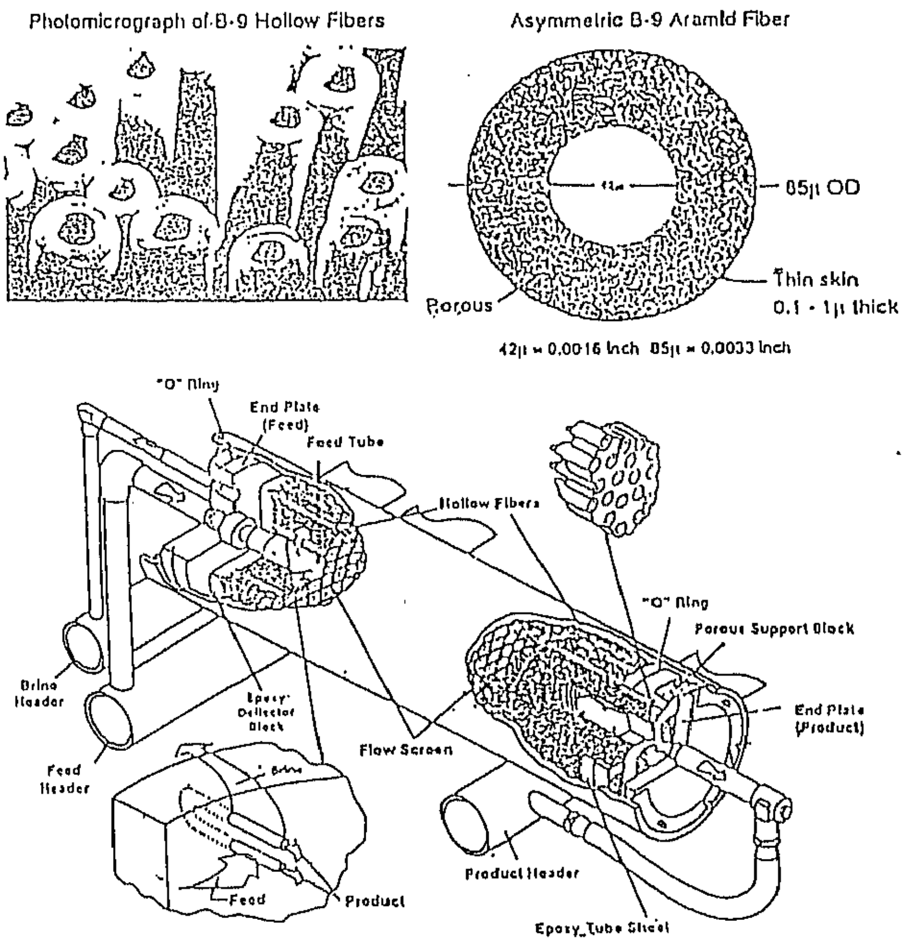


Fig. II-3.4.1 Hollow Fiber (HF) Membrane Module

b) SW module

As is shown in Fig. II-3.4.2, a spiral wound membrane module has a center tube with element membranes around it in a spiral form. Each two membrane elements have a mesh spacer in between them forming a space for carrying feed water to the membrane surface. The permeate carrier inside the membrane element carries the product water to the center tube. The membrane area per unit volume in the SW module is smaller than the HF module.

SW modules are less sensitive to fouling matters than HF modules and the required raw water quality is SDI < 4.0.

SW membrane modules are widely used for seawater and brackish water desalination, ultra-pure water production and waste water reuse.

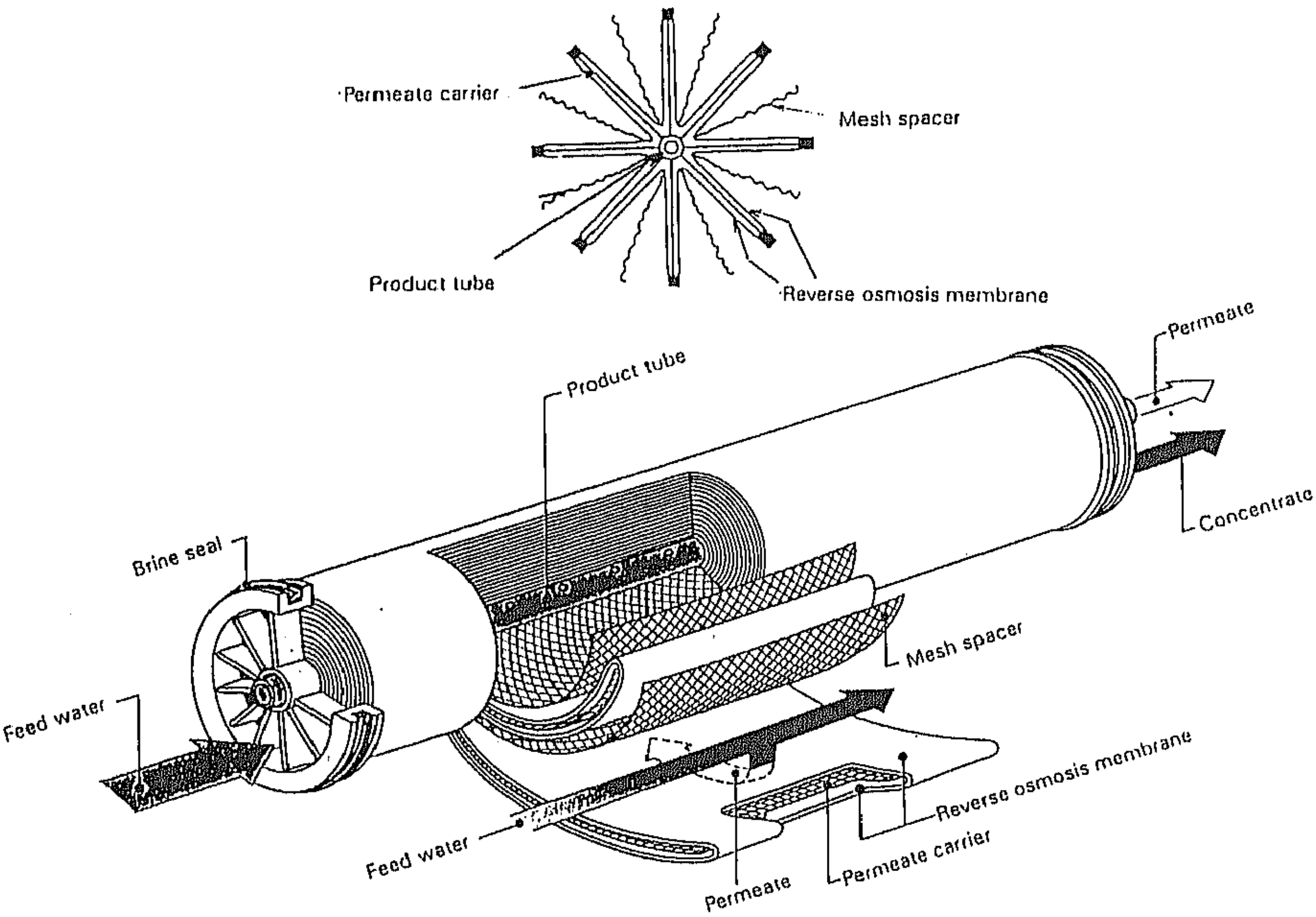


Fig. II-3.4.2 Spiral Wound (SW) Membrane Module

(3) Applied pressure

According to the required operation pressure, RO membranes are further classified to three types.

a) High pressure (50 Kg/cm^2 ~ 70 Kg/cm^2)

High pressure membranes are mainly applied to seawater desalination with a salt rejection higher than 99% (NaCl concentration 35000 mg/L).

b) Middle pressure (around 30 Kg/cm^2)

Middle pressure membranes are used for brackish water desalination and industrial water production. At a NaCl concentration of 2000 mg/L, a salt rejection of 90 ~ 99% can be achieved.

c) Low pressure (below 20 Kg/cm^2)

Low pressure membrane is a new product with a high performance. It is widely used in water treatment, brackish water desalination, ultra-pure water production, waste water re-use and so on. At a NaCl concentration of 2000 mg/L, a salt rejection of 90 ~ 99.5% is achievable.

Recently, a new RO membrane which enables a high flux at an operation pressure below 10 Kg/cm^2 has been manufactured. This has made the application range of RO process broader.

(4) RO membrane to be used for this project

The specifications of the RO membrane to be used are considered as follows.

- Membrane material	Polyamide or cellulose acetate
- Membrane module type	Spiral wound or hollow fiber
- Salt rejection*	> 98%
- Flux per module**	> 20 m /day
- Operation pressure	25 ~ 40 kg/cm^2
- Feed water temperature	32 ~ 36°C
- Recovery ratio	80 ~ 85 %
- pH range	3 ~ 9
- Brine flow rate per module	40 ~ 200 l/min

Note : * under the standard condition of 1500 mg/L as NaCl, 15°C and 15 kg/cm^2

** 8 inch module

3.4.3 Consideration of Water Quality

(1) Raw water quality

Based on the water quality analyses results of the test wells and the existing wells in the Study Area, the design TDS for the brackish groundwater is considered as follows:

- North area : 7500 mg/L
- South area : 5000 mg/L

The concentrations of the component ions are shown in Table II-3.4.1.

(2) Treated water quality

The expected quality of the treated water from RO desalination plants are also shown in Table II-3.4.1. The objective water quality described in section 3.3, i.e. a TDS less than 300 mg/L will be achieved. The values of the other water quality items will be far below those prescribed in Jordanian Drinking Water Quality Standards and WHO Drinking Water Quality Guidelines.

(3) Brine quality

With a recovery ratio of 80 ~ 85%, the concentration of the brine discharged from a RO plant will be 5 ~ 7 times of that of the raw water. Therefore, the TDS of the brine is estimated to be 25000 ~ 37500 mg/L. The concentrations of the component ions will be concentrated as well.

Table II-3.4.1 Qualities of Raw Water, Treated Water and Brine

Item	Unit	North area			South area		
		Raw water	Treated water	Brine	Raw water	Treated water	Brine
pH	-	6.2 ~ 6.5	5.8 ~ 8.6	5.8 ~ 8.6	6.1 ~ 6.4	5.8 ~ 8.6	5.8 ~ 8.6
TDS	mg/L	7500	75 ~ 300	37,500	5000	50 ~ 220	25000 ~ 33500
SDI	-	5 ~ 6	< 3	-	4 ~ 5	< 3	-
Ca	mg/L	700 ~ 900	7 ~ 30	3500 ~ 4500	400 ~ 500	5 ~ 20	2000 ~ 3350
Mg	mg/L	100 ~ 150	1 ~ 5	500 ~ 750	100 ~ 150	1 ~ 7	500 ~ 1000
Na	mg/L	1100 ~ 1300	12 ~ 50	5500 ~ 6500	1000 ~ 1200	13 ~ 58	5000 ~ 8100
K	mg/L	100 ~ 200	1 ~ 6	500 ~ 1000	100 ~ 200	1 ~ 8	500 ~ 1400
Cl	mg/L	1700 ~ 2000	17 ~ 70	2500 ~134000	1500 ~ 1700	23 ~ 100	7500 ~ 11400
SO_4	mg/L	1600 ~ 1800	16 ~ 65	8000 ~ 9000	400 ~ 600	6 ~ 24	2000 ~ 4000
HCO_3	mg/L	1000 ~ 1200	5 ~ 20	5000 ~ 6000	1000 ~ 1200	. 7 ~ 30	5000 ~ 8000
Fe	mg/L	8 ~ 12	< 0.01	40 ~ 60	< 1	< 0.01	10 ~ 20
Mn	mg/L	< 0.5	< 0.01	< 2.5	< 0.1	< 0.01	< 0.7
SiO_2	mg/L	15 ~ 25	0.4 ~ 1.8	75 ~ 125	5 ~ 15	0.1 ~ 0.4	25 ~ 100
SS	mg/L	<10	-	<100	<10	-	<100

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4. Alternative Development Plans

4.1 Alternative Plans

Based on the previous Hydrogeological Analysis, Water Demand Analysis, Study on the existing Water Supply System and other studies in Phases I and II, a considerable number of development plans can be formulated for the potential development of brackish groundwater in the Study area.

The study methodology that has been applied to formulate a comprehensive strategy for developing the brackish groundwater, was to select alternative development plans, each of which had a clear frame work. Each alternative was examined technically, institutionally, economically and financially. For the selection of alternatives, the following common components were considered and separately examined for each development plan:

- Supply areas and Quantity
- Development area and quantity
- Desalination process and Quality of treated water
- Distribution/transfer of product water
- Disposal of concentrated brine
- Electricity supply

As a result, five (5) alternative plans combining these components have been formulated.

4.1.1 Supply Areas and Quantity

The demand projection analysis and study on the current water supply system situation can be summarized in the following sections.

(1) Study Area

The present water supply is less than the Jordanian government's target per capita supply. Demand and water balance in the Study area are summarized in the Table II-4.1.1. In the target year of the Development Strategy, 2010, they are 608.5 MCM/year and 428 MCM/year respectively.

The present water resources considered by the existing development plans and by the Peace Treaty will not be able to satisfy future demand .

Table II-4.1.1 Summary of Domestic and Industrial Water Demand in the Uplands (MCM)

Year	Population	Domestic Water Demand		Industrial Water Demand	Water Supply*	Balance
		Low	High			
1995	4,065	285	342	23.3	181	-127 to -184
2000	4,856	340	408	36.4	181	-195 to -263
2005	5,697	398	477	43.4	181	-260 to -339
2010	6,622	461	553	55.5	181	-336 to -428

Source: JICA Study Team.
Note*: Water supply of 181 MCM includes 28.3 MCM of treated water through the Deir Alla/ Amman pipeline.
Population includes foreign workers in Jordan Valley.

(2) Northern Part of Jordan (Uplands)

Production and supply in the study area (Table II-4.1.2 and Fig.II-4.1.1) shows that Amman Governorate imports and consumes a considerable part of total production in the area within the inter-governorate water conveyance network. In Zarqa, Irbid and Balqa governorates water supply are balancing production volume and Mafraq governorate is forced to export more than 60% of production volume while all the governorate wishes to increase supply.

Table II-4.1.2 Summary of Conveyance between Governorates

	Production	Import	Export	Supply	Net Import
Amman	54.6	46.7	0.2	101.1	46.4
Zarqa	29.4	15.2	19.4	25.2	-4.2
Irbid	30.8	3.6	0.0	34.4	3.6
Mafraq	35.5	0.0	22.2	13.3	-22.2
Balqa	17.1	1.3	0.5	18.0	0.8
Total	167.7	67.0	42.5	192.2	24.5

Source: WAJ, Information Dept., 1994

Development of the maximum potential of the brackish groundwater must be considered for alleviating the future water shortage in these governorates.

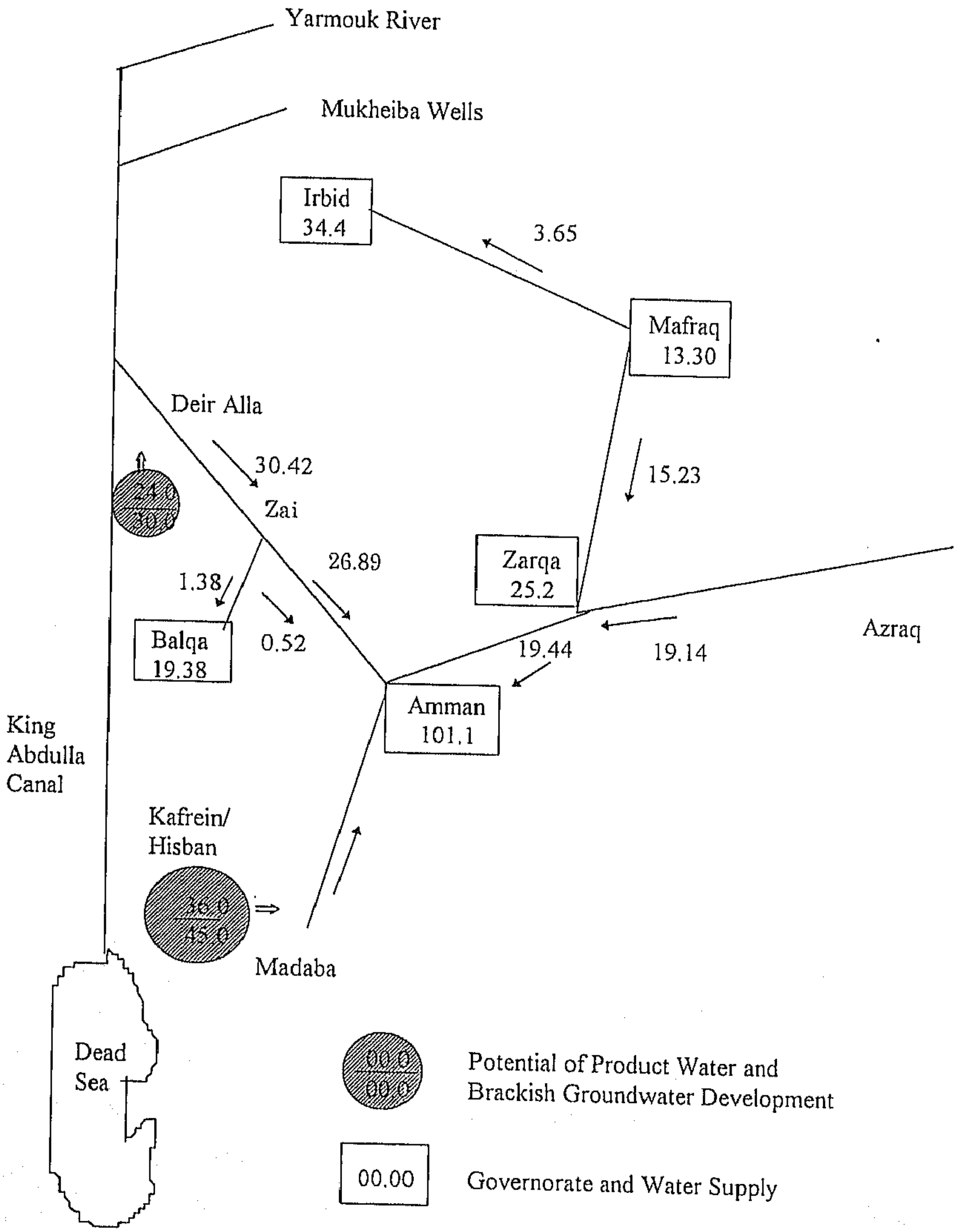


Fig. II-4.1.1 Inter Governorate Water Conveyance in the Study area in 1993
(Unit = MCM/year)

(3) Jordan Valley

Domestic and industrial water in Jordan Valley are supplied by groundwater. The salinity of the water has increased in recent years, and fresh groundwater development is reaching its limit.

If the surface water supplied through the King Abdulla Canal is used, water treatment facilities will be required.

Jordan Valley is one of the highest priority areas in the National Development Plan.

Demand and water balance until the year of 2010 are shown in Table II-4.1.3 and it shows the serious shortage in the near future but;

- There is not any more fresh groundwater resource in the Jordan Valley and
- Salinity in the supplied groundwater is becoming high due to the over pumping.

And therefore a certain emergency measure is required to increase the domestic water supply in this area. There are some optional systems considered other than the desalination of the brackish groundwater.

- Fresh water pipe line from Taibelias Lake
- Water treatment facility using King Abudulla Canal water

Table II-4.1.3 Summary of Domestic and Industrial Water Balance in the Jordan Valley

(MCM)

Year	Gross Water Demand in the Valley: Domestic	Industry	Tourism	Total	Water Supply	Water Balance
1995	12.54	0.98	-	13.52	10.13	-3.39
2000	15.28	1.22	0.3[*1]	16.84	10.13	-6.71
2005	18.68	1.51	-	20.19	10.13	-10.06
2010	22.90	2.32	1.3[*1]	26.54	10.13	-16.41

*1 : under study in Japan and tentative figures.

In this context, the following two (2) alternative proposal have been considered:

- Emergency development of a 5 MCM/year desalination plant for supplying the increasing demand in the Jordan Valley toward the year of 1998.
- Maximum development for Jordan Valley and Northern Jordan (Uplands) considering the absolute increase in demand toward the year of 2010.

4.1.2 Development Area and Quantity

According to the Hydrogeological analysis, two areas for development of brackish groundwater were identified, i.e. Deir Alla and Kafrein. The locations are shown in Fig. II-4.1.5 "Brackish Groundwater Desalination Project Location". Their potentials for safe development are 30 MCM/year and 45 MCM/year respectively.

Alternative quantities to be developed have been selected as follows:

- 6 MCM/year development in Deir Alla, to satisfy the 5 MCM/year production required in 1998.
- 6 MCM/year development in Kafrein, to satisfy the 5 MCM/year production required in 1998.
- Maximum development in Deir Alla area of 30 MCM/year.
- Maximum development in Kafrein area of 45 MCM/year.

4.1.3 Desalination Process and Quality of Treated water.

As discussed and reported in Section 3, Study on Desalination Technology, a review of desalination processes lead to a comparison of the Electrodialysis Reversal (EDR) and Reverse Osmosis (RO) processes, with RO being selected as the most suitable process in this project. The objective quality of the treated water is 300 mg/L in TDS. To achieve this objective, given the particular characteristics of the brackish groundwater in the Study area identified by the water quality analysis carried out in the field, no other alternative can be considered.

The process flow of the RO system desalination facilities under consideration is shown on Fig. II-4.1.8 and consists of the following equipment:

- Degasifier
- Coagulation
- Pretreatment by dual media filter
- Adsorption columns
- RO unit
- Waste water treatment
- Chlorination

Typical layout plans and sections for the alternative desalination plant are as shown on Fig. II-4.1.11, through Fig. II-4.1.15.

4.1.4 Transfer of Product Water

(1) Uplands

For the supply of product water to the Uplands, two alternative proposals have been considered:

- Utilization of the existing Deir Alla - Zai transfer pipeline connected to Dabuq reservoir in Amman City.

  This transfer system was constructed for the purpose of pumping up the surface water to Amman through King Abdulla Canal, and therefore when the international allocation from the Yarmouk River will be fulfilled, existing room of the capacity may not be used.

  Construction of a new transfer pipeline from Kafrein to the existing National Park Pump Station.

- In the brackish groundwater development in Kafrein/Hisban, a new transfer pipeline is required in order to supply to Amman City. A high lift pumping system with four stage pump stations is considered.

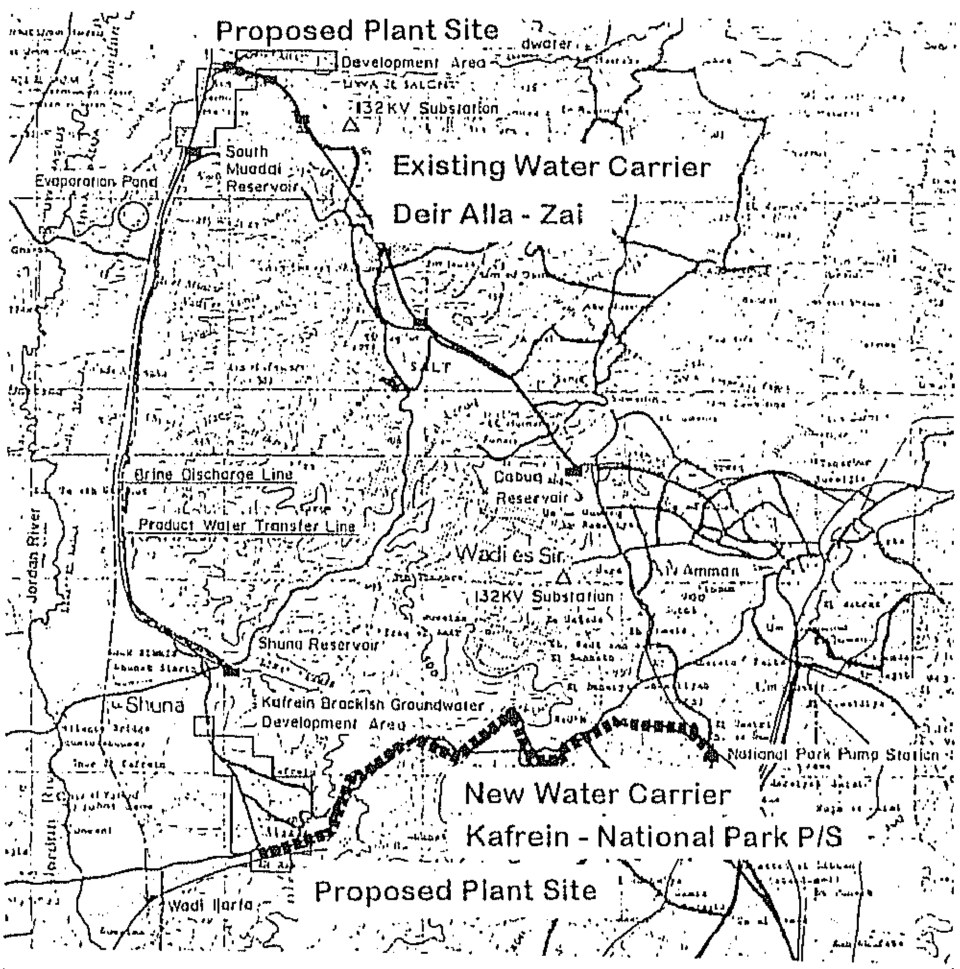


Fig. II-4.1.2 Water Carriers between Jordan Valley and Amman City

The National Park Pump Station and reservoir are newly constructed. The reservoir is a key reservoir in the main Amman network connecting Walah/Madaba well field, Abu Alanda reservoir and Dabuq reservoir as shown on Fig. II-4.1.3.

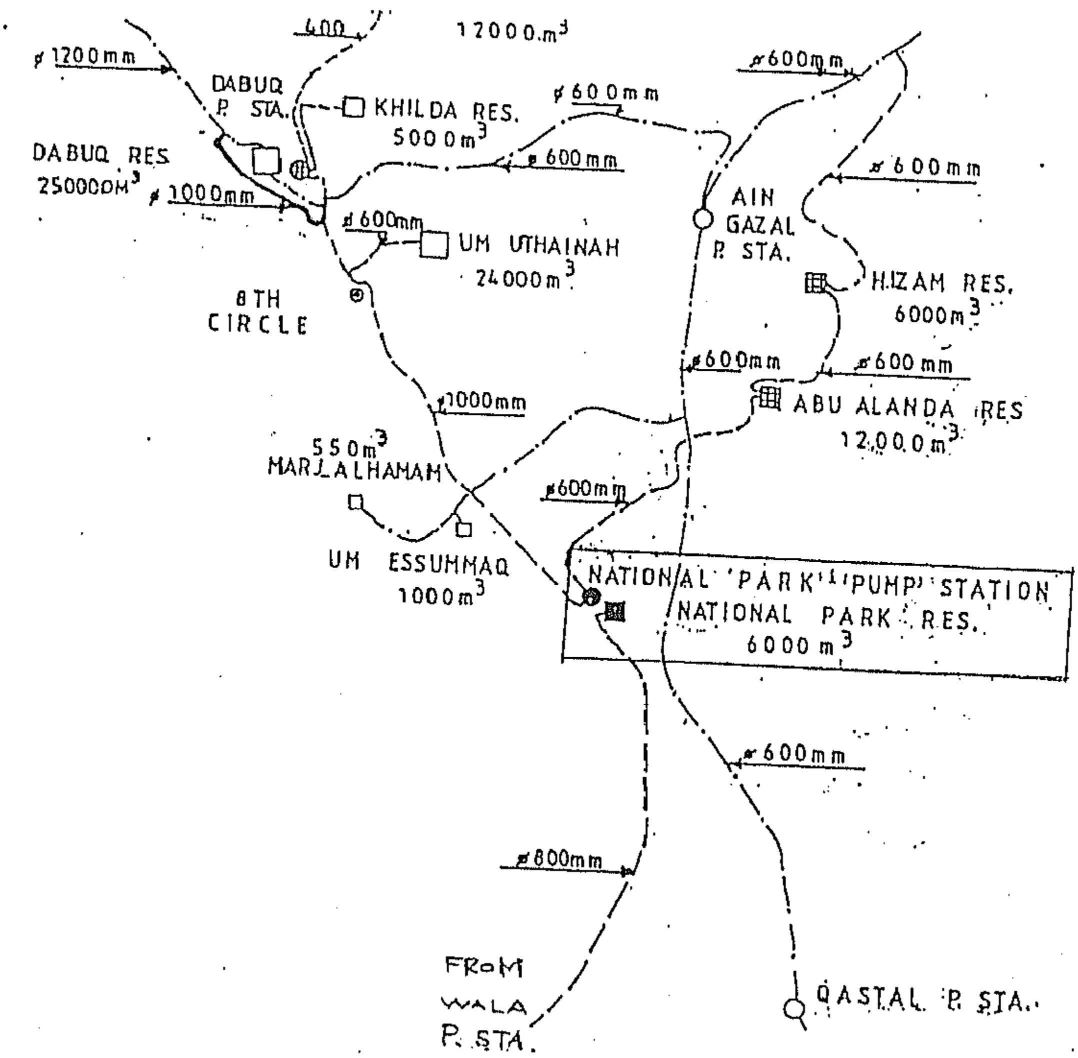


Fig. II-4.1.3 Connection to Existing Distribution Network in Amman

(2) Jordan Valley

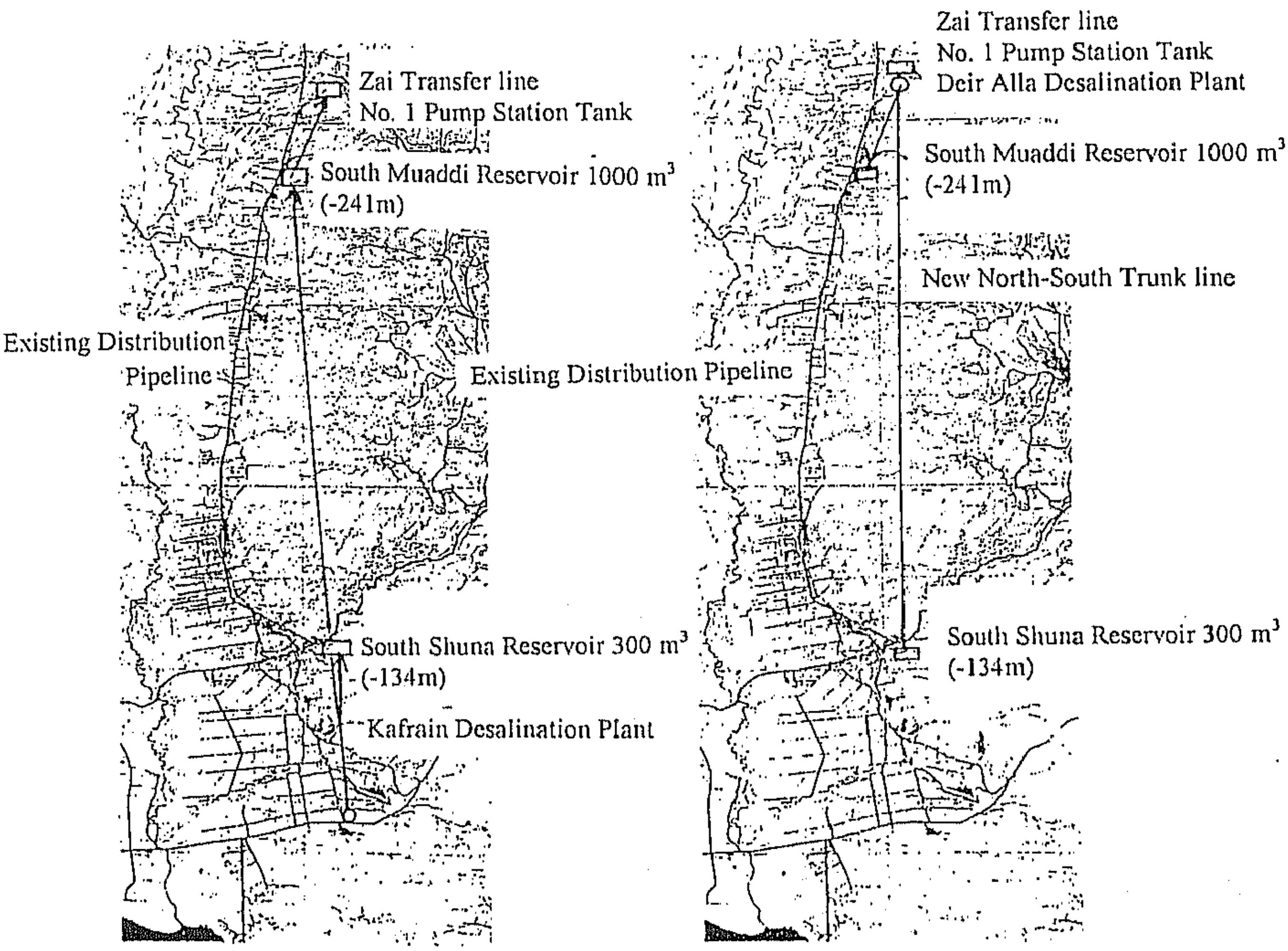
Demand in Jordan Valley stretches from North Shuna to the Dead Sea East Coast Tourism Area and is increasing dramatically. The capacity of the existing distribution network is insufficient for the deployment of the proposed desalination plant and a new North-South trunk line must therefore be considered. The new line needs a capacity of 3 MCM/year according to the water balance shown in Table II-4.1.4.

Table II-4.1.4 Demand-Supply Balance at each district in Jordan Valley

Unit = MCM/year

	North Shuna	Deir Alla	South Shuna	Total
1998	-3.0	-2.0	-0.2	-5.2
2010	-7.7	-5.5	-3.2	-16.4

Source: JICA Study Team



Desalination at Kafrain

Desalination Plant at Deir Alla

Fig. II-4.1.4 Connection to Existing Distribution Network in the Jordan Valley

4.1.5 Disposal of Concentrated Brine

Disposal of concentrated brine is an essential component of the application of the desalination process for domestic and industrial water supply, both from the environmental point of view as well as the desalination process itself.

Alternative proposals for this component are as follows:

- Common Discharge Facility in Jordan River Valley.

  There are much brackish groundwater and springs resources available along the Jordan River, not only in east bank but in west bank also. When considering the water quality conservation of Jordan River, a common brine discharge facility must be facilitated for the desalination development and will alleviate the construction and operation cost.

- Discharge Facilities from Deir Alla to Dead Sea.

  Independent brine discharge pipeline carrying the concentrated brine by 30 MCM/year development from Deir Alla to Dead Sea.

- Discharge Facilities from Kafrein to Dead Sea.

  Discharge facility from Kafrein plant site will be a direct discharge to Wadi Ijarfa in case of small development and a discharge pipeline system to Dead Sea in case of large development.

- Evaporation pond for 5 MCM/year plan.

  However, the evaporation pond proposal is quite obviously impractical as examined in Supporting Report and therefore will not be studied further.

4.1.6 Electricity Supply

The required electricity supply depends on the development quantity and ranges from approx. 1,700 kw for a 5 MCM/year production plant to more than 12,000 kw for a 36 MCM/year production plant. Electricity systems to be considered for alternative plans in Jordan Valley are as follows:

- Receiving from the existing 33 kv transmission line available in Jordan Valley near the proposed plant sites.
- Future extension of 132 kv trunk line from Al-Subeih Substation to the desalination plant in Deir Alla.
- Construction of Own Power Generation System in the desalination plant in Kafrein and connecting to the existing 33 kv transmission line.

Skeleton diagrams of the electricity supply to the desalination facilities under consideration are shown on Drawings for Alternative Plans in Data and Drawings for Plan A, Plan B & D, Plan C and New Transfer Pump Line from Kafrein to National Park Pump Station respectively.

4.1.7 Alternative Plans

By combining the above alternative components, alternative plans to be studied in the formulation of a comprehensive development strategy for brackish groundwater have been determined and are listed on Table II-4.7.1 below.

- Plan A: Maximum development in Deir Alla area of 30 MCM/year alleviating the shortage in the Northern part of Jordan including Amman.
- Plan B: 6 MCM/year development in Deir Alla area, to satisfy the 5 MCM/year production required in the Jordan Valley in 1998.
- Plan C: Maximum development in Kafrein area of 45 MCM/year alleviating the shortage in the Northern part of Jordan including Amman.
- Plan D: 6 MCM/year development in Kafrein area, to satisfy the 5 MCM/year production required in the Jordan Valley in 1998.
- Plan E: Maximum development in Deir Alla and Kafrein area, a total of 75 MCM/year, alleviating the shortage in the Northern part of Jordan including Amman.

The locations and the alternative components are shown in the drawings listed in Table II-4.1.5.

Table II-4.1.5 Drawings for Alternative Plans

Fig. No.	Title
Fig. II-4.1.5	Project Location 1/20000
Fig. II-4.1.6	Project Location Map (Deir Alla Area)
Fig. II-4.1.7	Project Location Map (Kafrein Area)
Fig. II-4.1.8	Basic Flow of Desalination Plant
Fig. II-4.1.9	Common Brine Discharge Line
Fig. II-4.1.10	Profile of Common Brine Discharge Line
Fig. II-4.1.11	Layout of Desalination Plant (Plan A)
Fig. II-4.1.12	Flow Diagram of the Project (Plan A)
Fig. II-4.1.13	Layout of Desalination Plant (Plan B/D)
Fig. II-4.1.14	Flow Diagram of the Project (Plan B/D)
Fig. II-4.1.15	Layout of Desalination Plant (Plan C)
Fig. II-4.1.16	Flow Diagram of the Project (Plan C)

More detail drawings are available in "Data and Drawings".

Table II-4.1.6 Proposed Alternative Plans

Component \ Plan	Plan A	Plan B	Plan C	Plan D	Plan E
Development Area of Brackish Groundwater	Deir Alla	Deir Alla	Kafrein	Kafrein	Deir Alla/Kafrein
Development Volume	30 MCM/year	6 MCM/year	45 MCM/year	6 MCM/year	75 MCM/year
Quality of Brackish Groundwater	TDS 7,500 mg/L	TDS 7,500 mg/L	TDS 5,000 mg/L	TDS 5,000 mg/L	TDS 7,500/5,000 mg/L
Desalination Process	Reverse Osmosis (RO)	Reverse Osmosis (RO)	Reverse Osmosis (RO)	Reverse Osmosis (RO)	Reverse Osmosis (RO)
Product Water Supply Area	Amman Jordan Valley	Amman Jordan Valley	Amman Jordan Valley East bank of Dead Sea	Jordan Valley East bank of Dead Sea	Amman Jordan Valley East bank of Dead Sea
Supply Volume	24 MCM/year	5 MCM/year	36 MCM/year	5 MCM/year	60 MCM/year
Product Water Quality	TDS 300 mg/L	TDS 300 mg/L	TDS 300 mg/L	TDS 300 mg/L	TDS 300 mg/L
Water Distribution / Conveyance	Existing Network New North-South Line Existing Zai Transfer Line	Existing Network New North-South Line Existing Zai Transfer Line	New Transfer Line to Amman	Existing Network New North-South Line	New Transfer Line to Amman Existing Network New North-South Line Existing Zai Transfer
Electricity Supply by Power Generation	no	no	12,000 KW	no	12,000 KW
Connection to the Transmission Line	132 KV	33 KV	33 KV	33 KV	132 / 33 KV
Brine Disposal	Common Discharge Facility to Dead Sea	Common Discharge Facility to Dead Sea	Discharge Facility to Dead Sea	Wadi Ijarfa	Common Discharge Facility to Dead Sea
	Independent Discharge Facility to Dead Sea	Evaporation Pond			

Notes: 1) As an alternative plan to B and D, surface water purification from K.A.C. shall be examined.
2) As an alternative plan to E, Disi water conveyance scheme shall be examined.

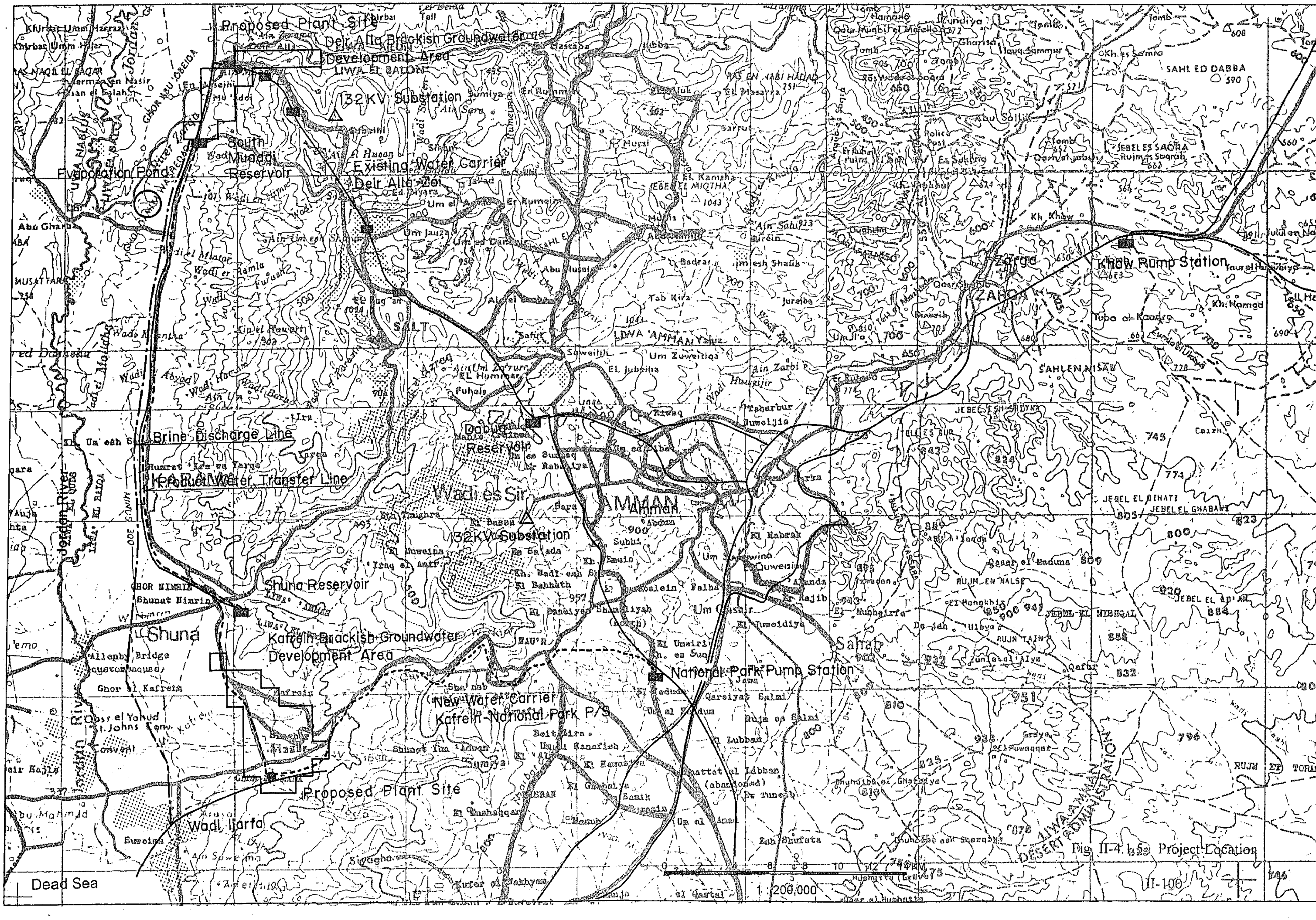


Fig. II-4.1.5a Project Location

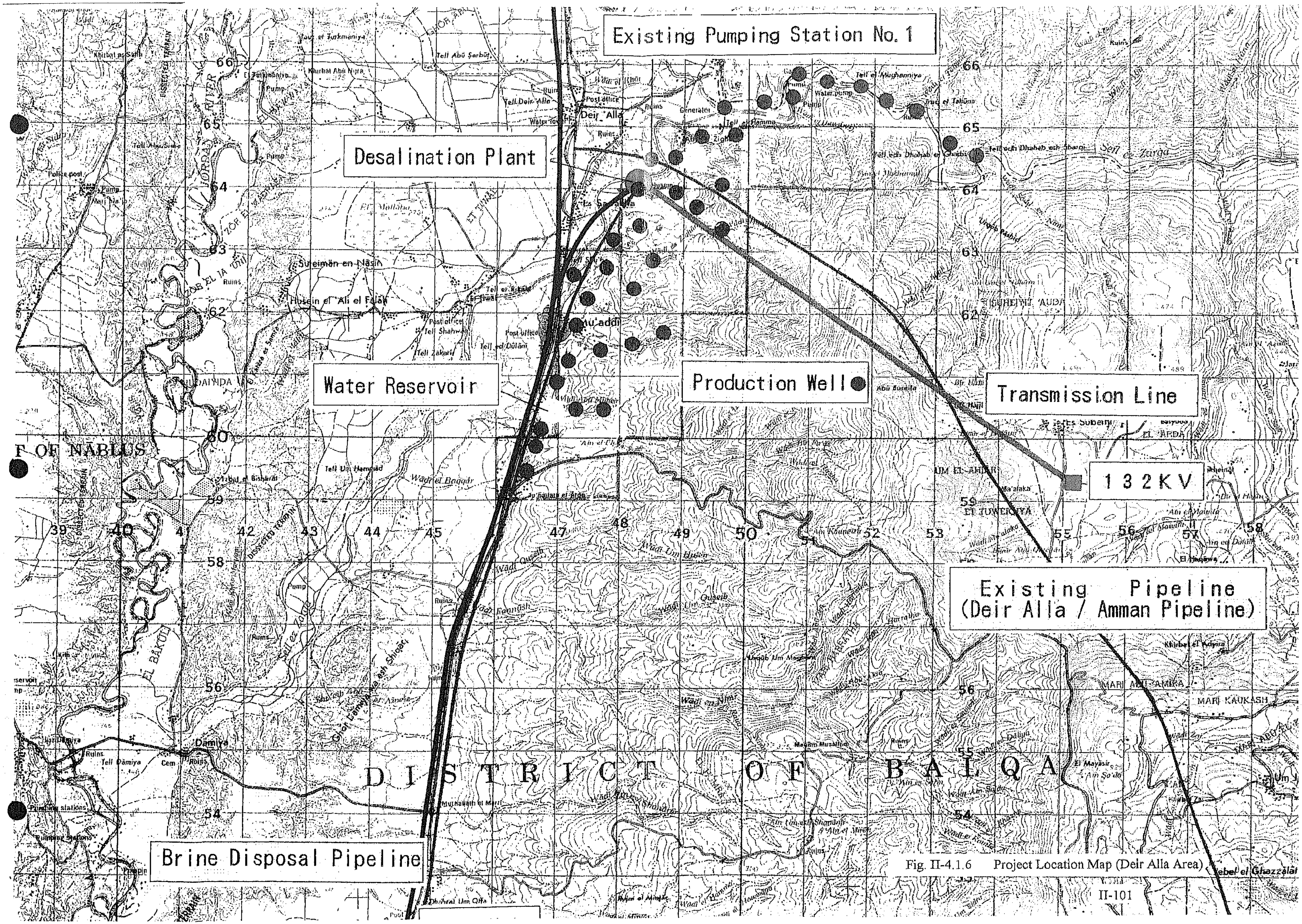


Fig. II-4.1.6 Project Location Map (Deir Alla Area)

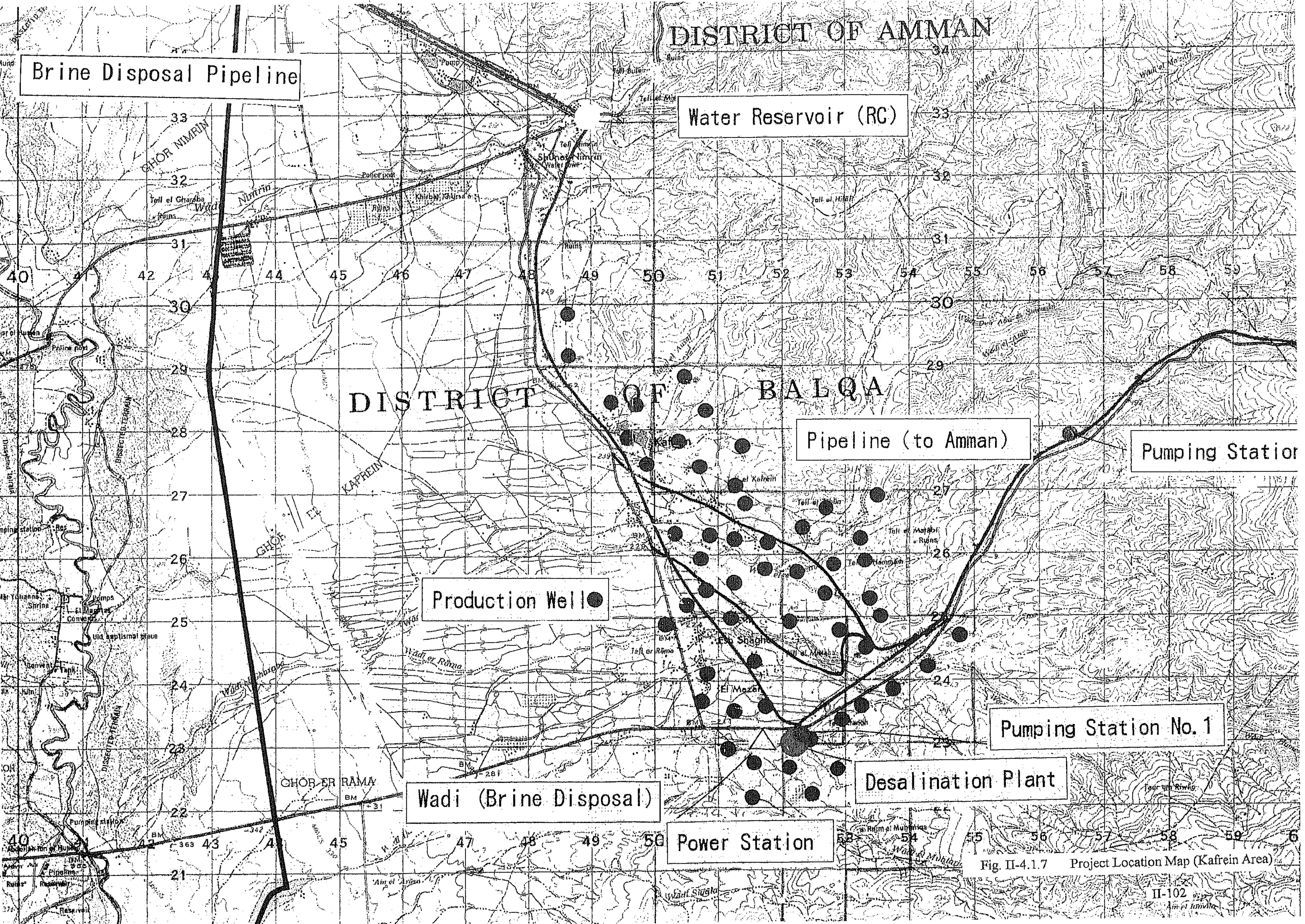
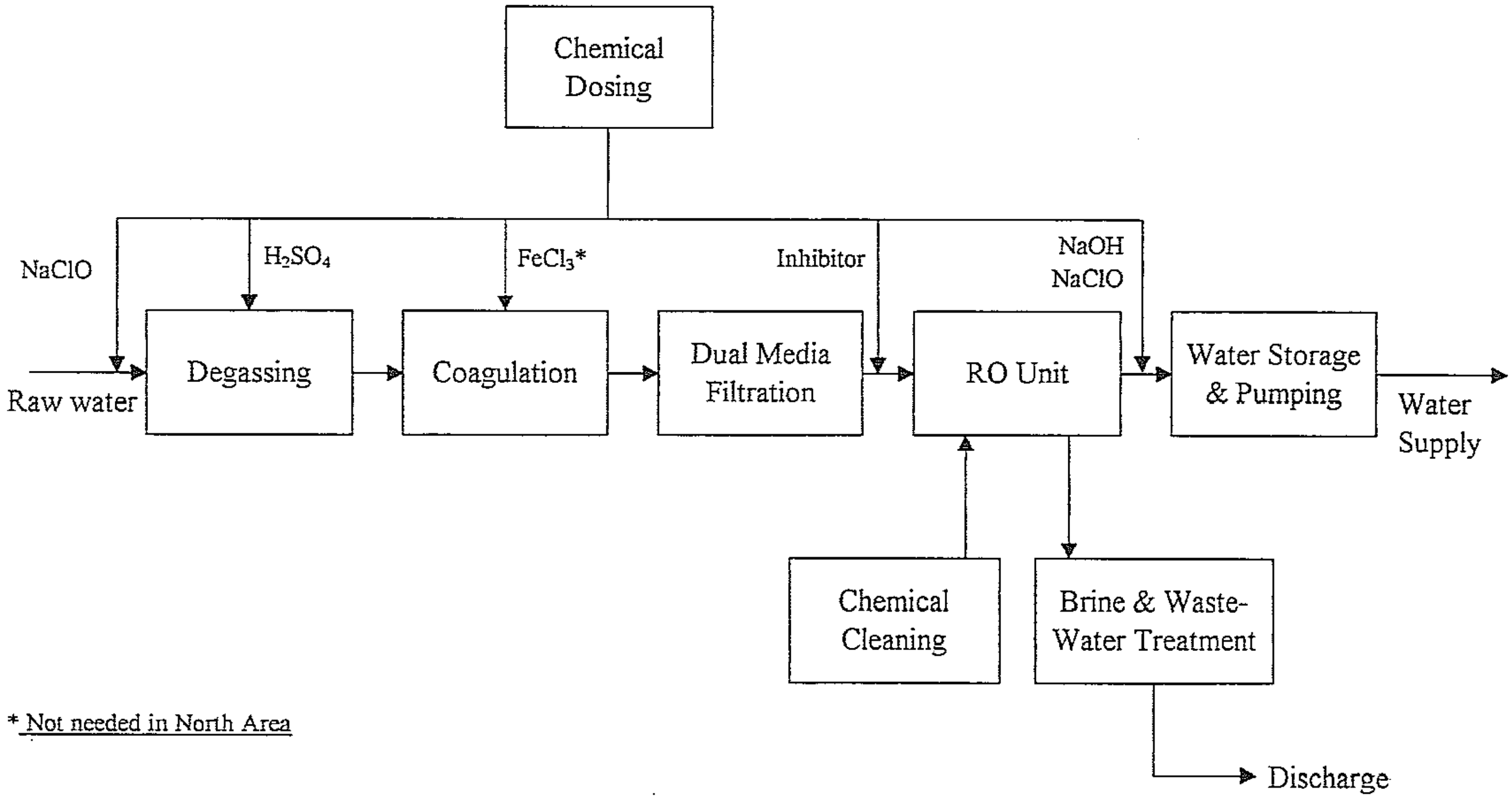


Fig. II-4.1.7 Project Location Map (Kafrein Area)



* Not needed in North Area

Fig. II-4.1.8 Basic Flow of Desalination Plant

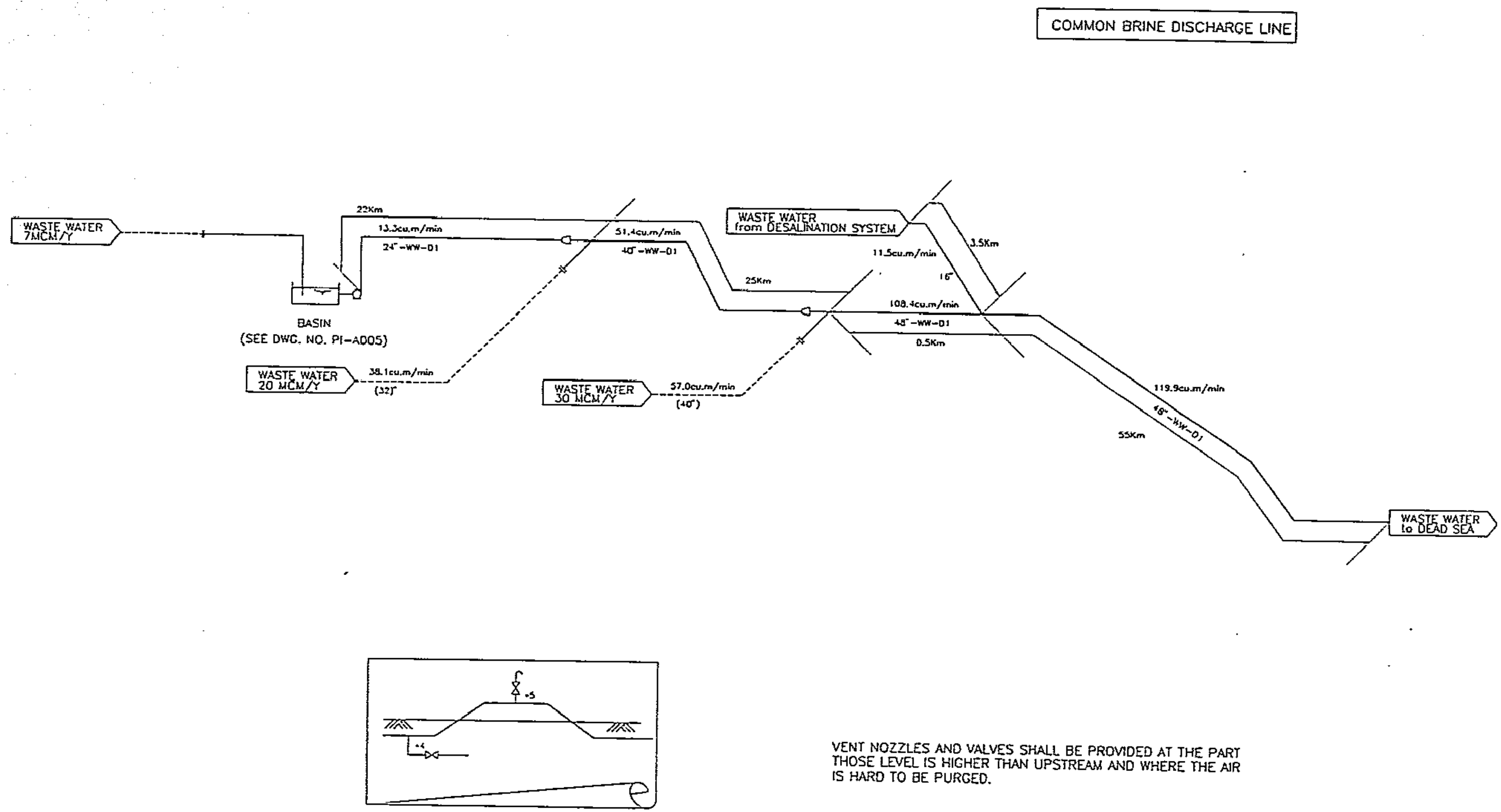


Fig. II-4.1.9 Common Brine Discharge Line

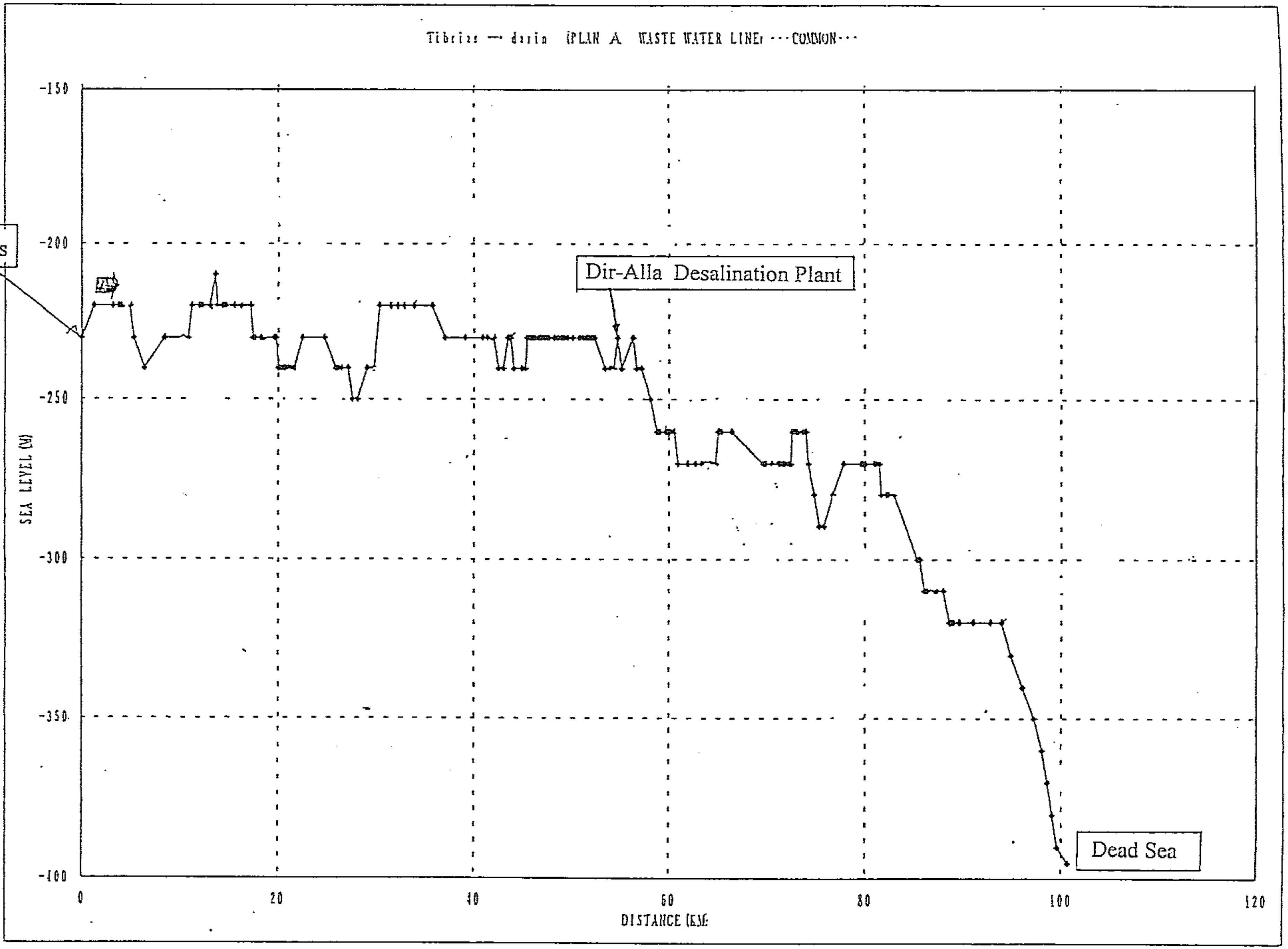


Fig. II-4.1.10 Profile of Common Brine Discharge Line

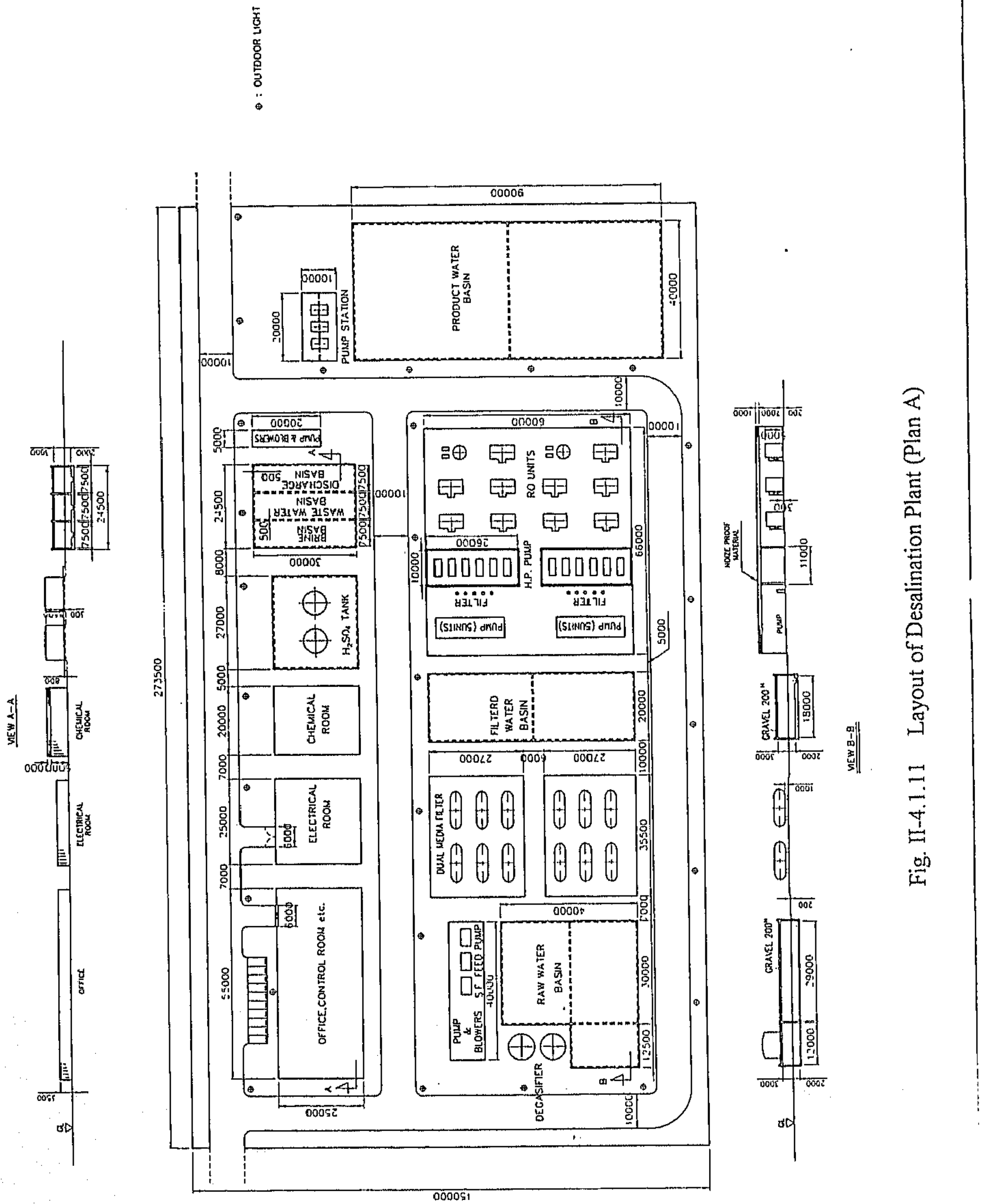


Fig. II-4.1.11 Layout of Desalination Plant (Plan A)

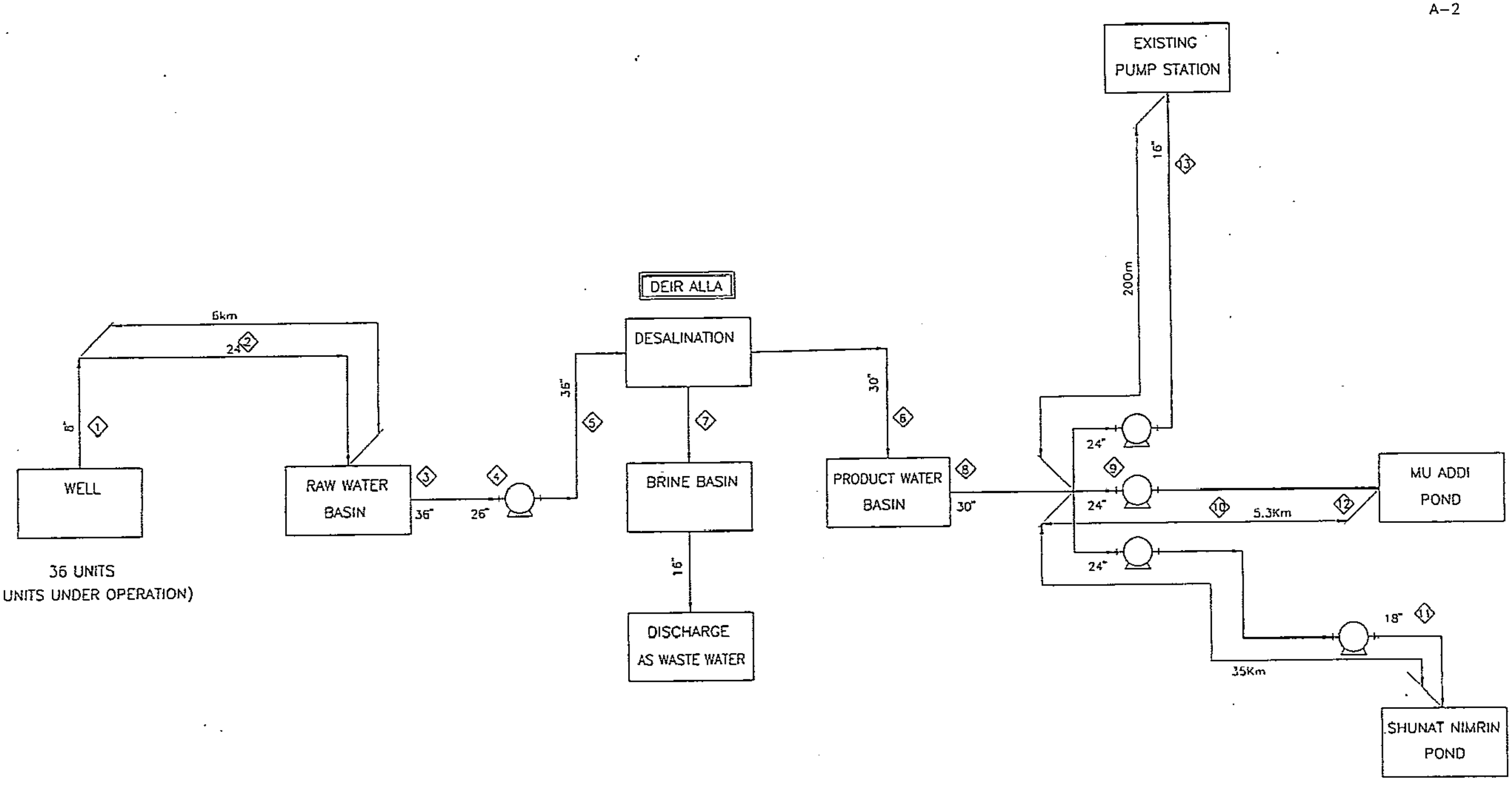


Fig. II-4.1.12 Flow Diagram of the Project (Plan A)

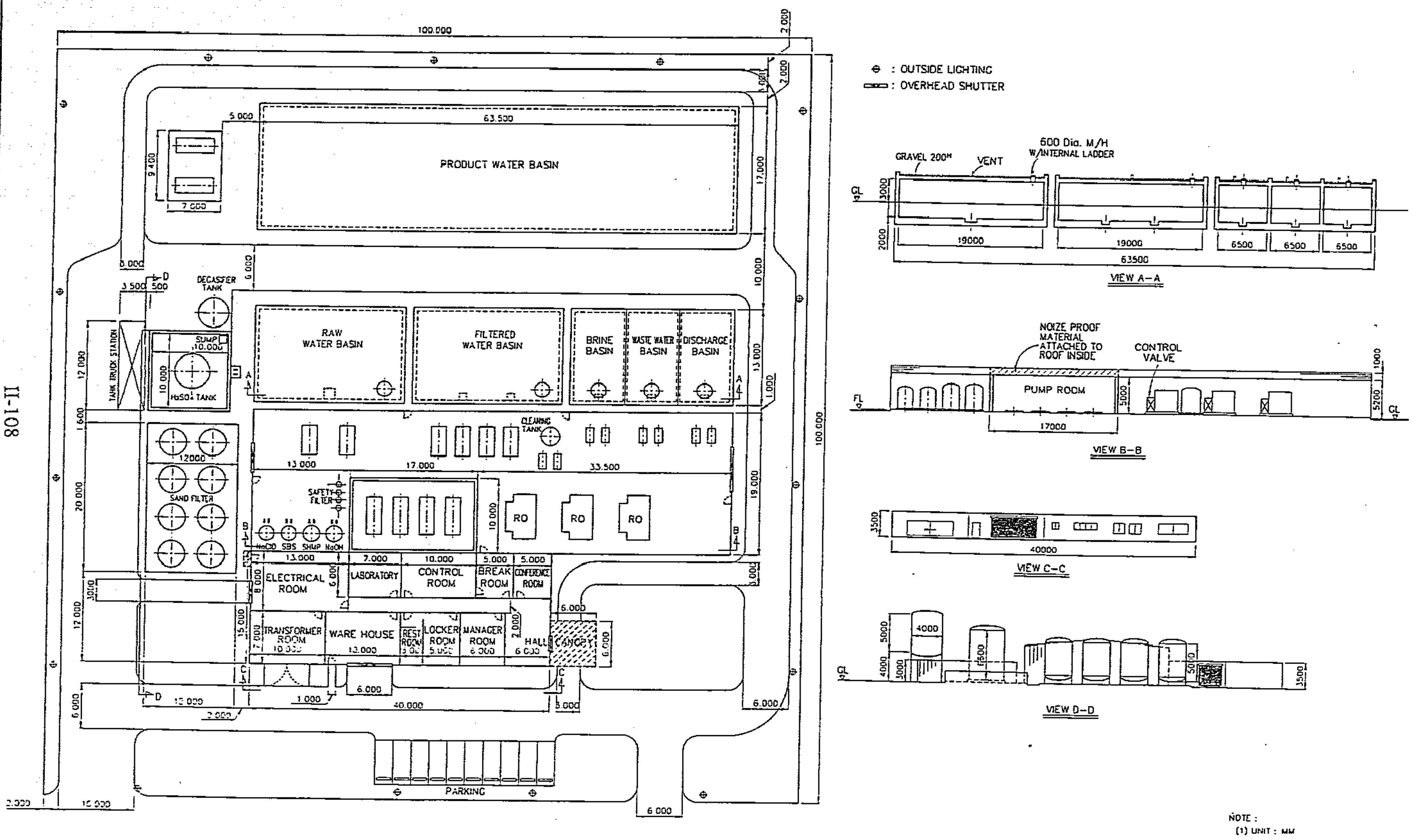


Fig. II-4.1.13 Layout of Desalination Plant (Plan B/D)

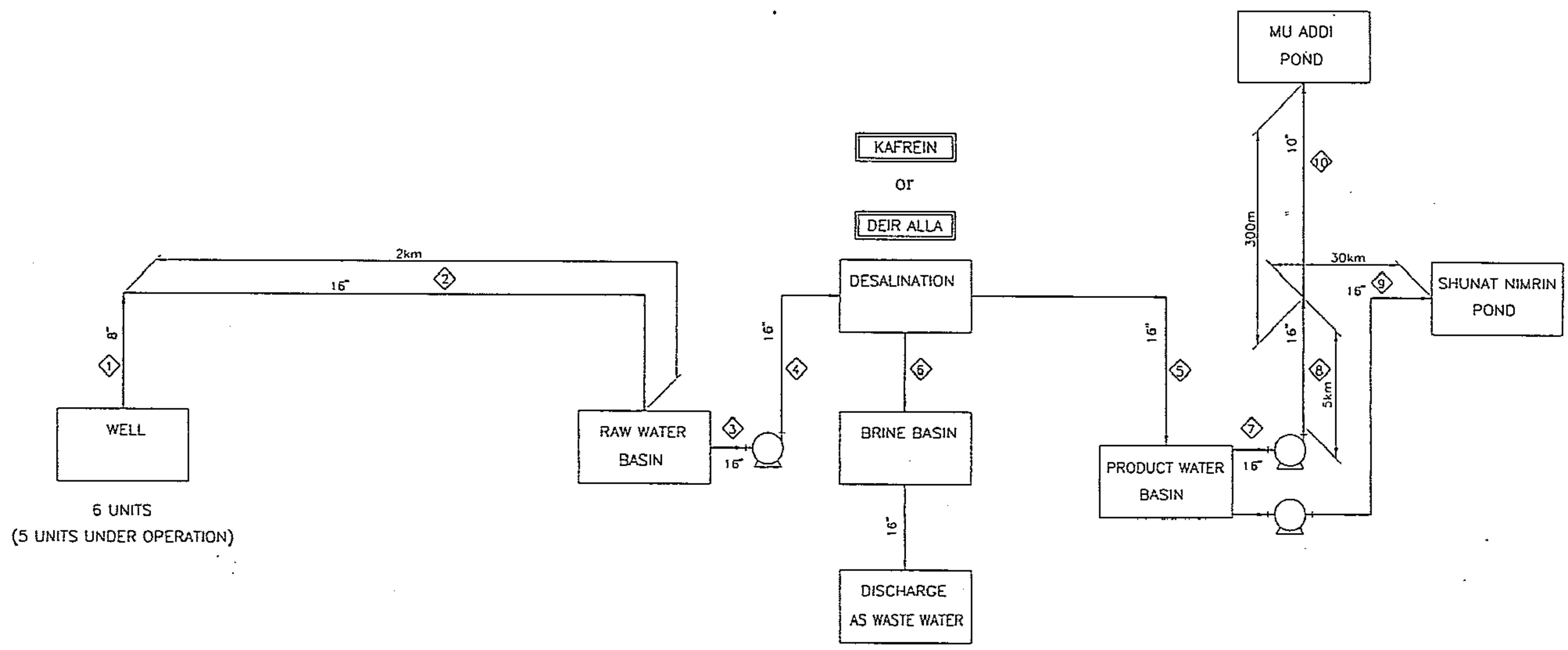


Fig. II-4.1.14 Flow Diagram of the Project (Plan B/D)

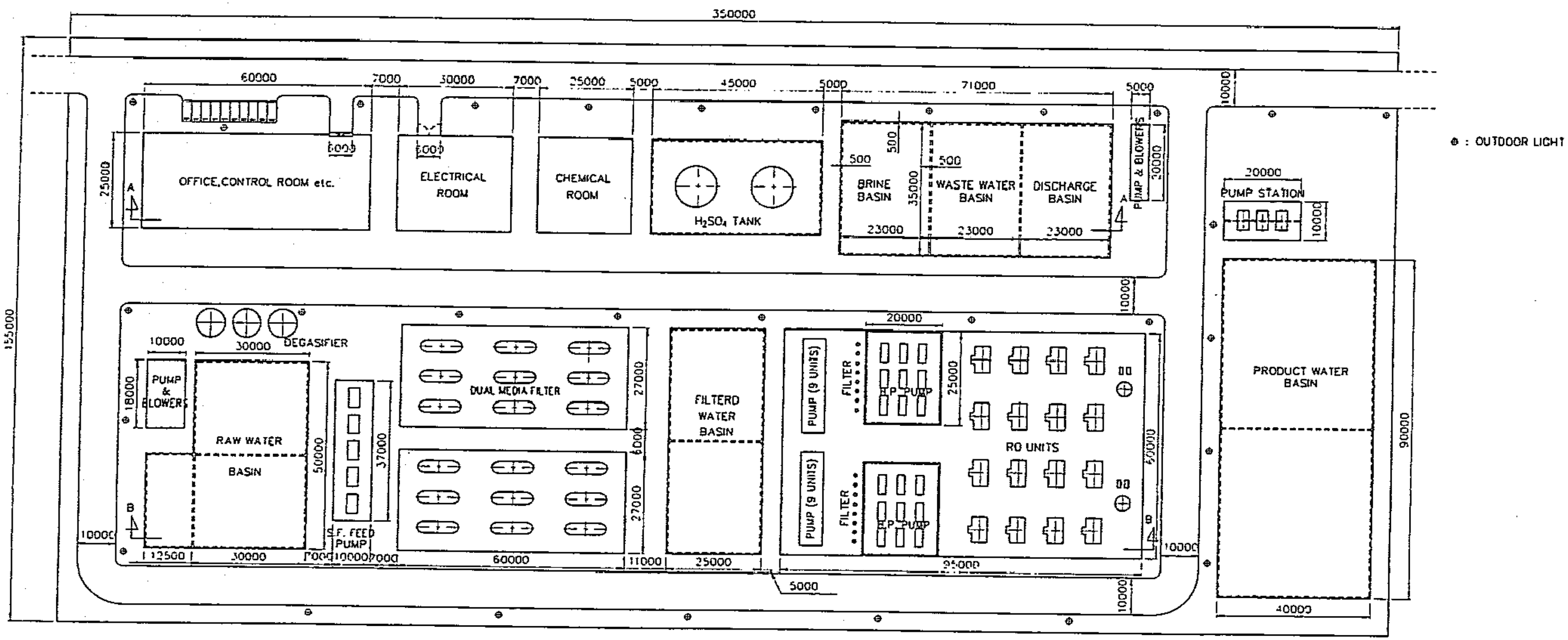
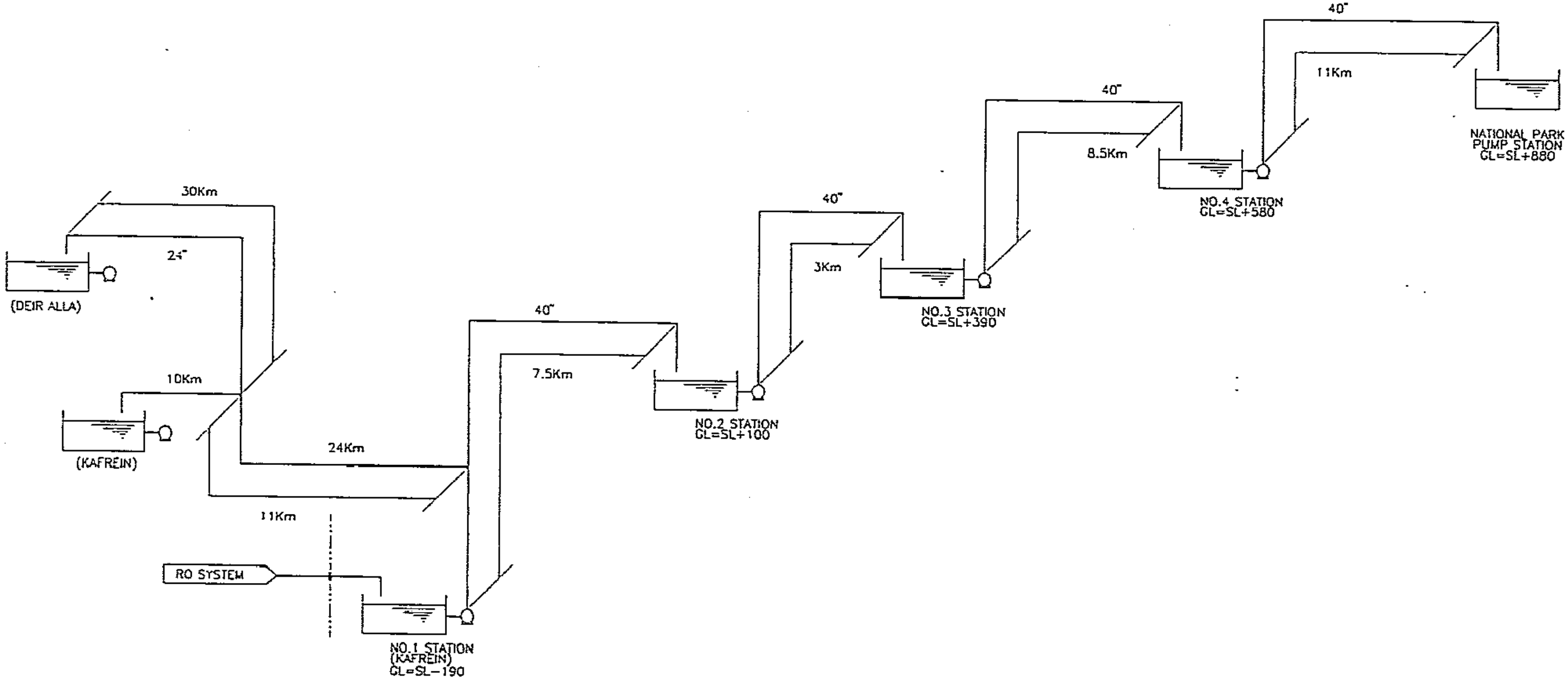


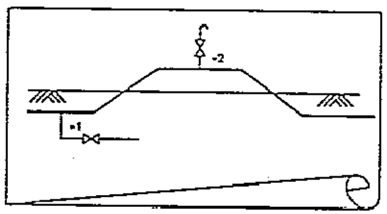
Fig. II-4.1 15 Layout of Desalination Plant (Plan C)

C-2



NOTE•1: DRAIN NOZZLES AND VALVES SHALL BE FURNISHED TO THE DEAD SPACE WHERE THE WATER CAN BE ACCUMULATED.

NOTE•2: VENT NOZZLES AND VALVES SHALL BE PROVIDED AT THE PART THOSE LEVEL IS HIGHER THAN UPSTREAM AND WHERE THE AIR IS HARD TO BE PURGED.



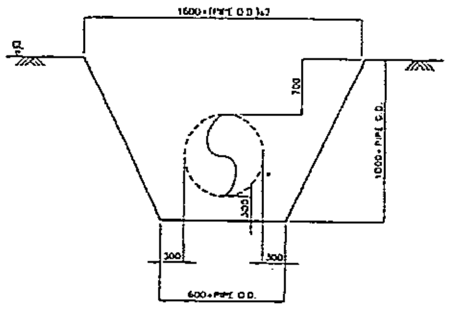


Fig. II-4.1.16 Flow Diagram of the Project (Plan C)