THE FEASIBILITY STUDY
FOR
THE POWER AND DESALINATION
COMPLEX PLANT PROJECT
IN
THE SULTANATE OF OMAN

(SUMMARY)

AUGUST 1985

JAPAN INTERNATIONAL COOPERATION AGENCY

CONTENTS

A. SUMMARY

1. BACKGROUND AND NECESSITY OF THE PROJECT

In the Sultanate of Oman the demands for electric power and water have grown rapidly and are still growing at very high pace with the social and economic development of the country and the rise of standard of living of the people. This will lead to the shortage in supply capabilities of the existing power plants and water supply facilities to meet the growing demands. To cope with this situation the Ministry of Electricity and Water (MEW) plans to construct a large scale power and desalination complex plant near Barka town.

Japan International Cooperation Agency (JICA), in response to the request of the Government of Oman, has conducted feasibility study on the above project and compiled the results of studies in this report.

This project is very important for the country, and also it should be completed early as possible when considering demand and supply condition. Therefore, it is suggested that the construction work be started in the immediate future.

2. PRESENT CONDITIONS OF ELECTRIC POWER SUPPLY AND DESALINATION

2.1 Existing power facilities

(1) Power facilities in the Capital area

a) Power stations

There are three power stations in the Capital area, and their total installed capacity as of the end of January 1985 is 566.1 MW as shown below:

Power station	Type of plant	Installed capacity (MW)
Ghubrah	Steam	72.5
Ghubrah	Gas turbine	212.5
Sub-total		285.0
Rusail	Gas turbine	249.0
Riyam	Diesel	32.1
Total		566.1

MEW has a plan to shift diesel units of Riyam power station to rural areas in the coming one or two years, and to install at Rusail gas turbine power station No. 4 and No. 5 units of each 83.0 MW in 1986 and No. 6 unit of 83.0 MW in 1987.

Power consumption for station service is estimated at 10.4 MW for Ghubrah power and desalination complex plant and 0.65% of installed capacity for Rusail gas turbine power station. Therefore, the total installed capacity and sending-end capacity in the Capital area excluding Riyam power station for 1986 and 1987 will be as follows:

(MW)

Power station	1986			1987		
	Installed capacity	Station service	Sending-end cap.	Installed capacity	Station service	Sending-end cap.
Ghubrah	285.0	10.4	274.6	285.0	10.4	274.6
Rusail	415.0	2.6	412.4	498.0	3.2	494.8
Total	700.0	13.0	687.0	783.0	13.6	769.4

b) Transmission lines

Two double circuit 132 kV transmission lines run from Ghubrah power station, the one to Wadi Adai substation and the other to Al Falaj substation. Another two double circuit 132 kV lines run from Rusail power station. They are to Seeb and Ghubrah substations.

The construction of three double circuit 132 kV transmission lines are scheduled to be started in June 1985. They are:

- From Rusail power station to Wadi Adai substation
- From Rusail power station to Barka substation
- From Wadi Adai substation to Wadi Kabir substation

In addition, tender call for the construciton of double circuit 132 kV line between Barka substation and Musanna substation is scheduled to be made by the end of 1985.

33 kV and 11 kV lines are used for power distribution. The public supply is carried out at 200/240 V, 50 Hz.

c) Substations

There are five 132/33 kV substations of Al Falaj (250 MVA), Wadi Adai (250 MVA), Rusail (150 MVA), Ghubrah (84 MVA) and Seeb (126 MVA).

Barka, Wadi Kabir and Musanna substations of each 250 MVA are under planning.

d) Interconnection of Musanna, Suwaiq, Rustaq and Mabellah

Plan is on-going to supply electricity by 33 kV lines from planned Musanna substation to three towns of Musanna, Suwaiq and Rustaq. These towns are now fed by diesel power stations. The interconnection of these towns and Mabellah with power system of the Capital area is scheduled to be commissioned in 1986.

(2) *Power facilities in the Batinah coast*

a) Power stations

In Musanna, Suwaiq and Rustaq there are diesel power stations of 7.4 MW, 6.9 MW and 7.2 MW, respectively. However, MEW plans to supply electricity to these towns from the Capital area by interconnected transmission line from 1986 as described before.

In the Batinah coast excluding the above towns, there are three power stations of the total installed capacity of 65.8 MW as shown below:

Location	Type of plant	Installed capacity (MW)
Copper mine	Gas turbine	51.0
Shinas	Diesel	3.9
Khabourah	Diesel	10.9
Total		65.8

Power station at copper mine is equipped with three gas turbine-generators of each 17.0 MW. Of these three units, one unit is of MEW, one unit of Oman Mining Company and the remaining one unit is operated for common use by MEW and Oman Mining Company. It is planned that two units of each 27.0 MW gas turbine-generator (MEW) be added to this power station in 1985 and two units of each 30.0 MW gas turbine-generator (Rural Development Committee) be added in 1986. Therefore, the total installed capacity at copper mine will increase to 105.0 MW in 1985 and 165.0 MW in 1986.

b) Transmission lines and substations

Energy generated by gas turbine power station at copper mine is transmitted from Magan substation (66/33 kV) to three substations of Sohar, Saham and Majis (each 33/11 kV).

Power transmission to the Inland area such as Buraimi, Ibri and surrounding villages is planned to be started in 1986.

2.2 Existing water supply system

The planned water supply district covered by this Project is the Batinah coastal area of 70 km from Muscat to Barka.

Up to the year 1976, the water supply to the Capital Area had been dependent on pumping up of underground water only. To meet the rapid growth of water demand, the first desalination plant was constructed in Ghubrah and entered service in 1977. In 1983, the No.2 plant was put into parallel operation with the above No.1 plant. The present water production capacity of the desalination plants is 47,730 m^3/day.

Name of Plant	Water Production Capacity	Commissioning year
Existing	MIGPD m^3/d	
No.1 MSF Plant	5 (22,730)	1977
No.2 MSF Plant	5.5 (25,000)	1983
Sub-total	10.5 (47,730)	
Under construction		
No.3 MSF Plant	5.5 (25,000)	1986
No.4 MSF Plant	5.5 (25,000)	1986
Sub-Total	11 (50,000)	
Total	21.5 (97,730)	

Note: Water production capacity in the table is the average of capacity at high temperature operation and capacity at low temperature operation.

MIGPD = Million Imperial Gallon/day
1 Imperial gallon = 0.004546 m^3

At present, two more plants of No.3 and No.4, each with the same capacity (25,000 m^3/day), are being constructed in Ghubrah and scheduled to be put into commercial operation in March 1986. Consequently, by March 1986, the total production capacity of all desalination plants will reach 97,730 m^3/day.

Most of wells in the Capital Area are located at five ground water regions of Wadi Adai, Wadi Hatat, Seeb, Mawallaa, and Al Khawd. The ground water pumping quantity increased to 23,000 m^3/day in 1982. But in order to prevent the ground water from contamination by sea water penetrating into the ground due to excessive pumping, MEW has a policy to maintain the average ground water pumping quantity of 22,000 m^3/day as shown in the following table.

Ground Water Pumping Plan after 1985

District	Max. pumping rate (m^3/d)	Average pumping rate (m^3/d)	No. of wells
Wadi Adai	50,000	10,000	approx. 30
Mawallaa	2,000	1,000	3
Seeb	18,000	10,000	12
Al-Khawd Dam Well Field	22,000		14
Old Government Well Field	10,000		20
Rusail	1,000	1,000	2
Total	103,000	22,000	approx. 80

3. DEMAND FORECAST FOR ELECTRIC POWER AND WATER

For both electric power and water, demand forecasts for the period from 1985 through 1990 have been established by the MEW. Demand forecast for electricity covers the Capital area and the Batinah coast including Inland area, while demand forecast for water is for the Capital area only. These forecasts have been reviewed and extended up to 1995 by JICA study team. Results of study are summarized as follows:

3.1 Demand forecast for electricity and scale of development of the proposed Barka power plant

In the Capital area, peak load grew from 46.6 MW in 1976 to 135.5 MW in 1980 and 340.3 MW in 1984, representing an average growth rate of 30.6% per annum for the period from 1976 to 1980 and 25.9% per annum for the last 4 years from 1980 to 1984. This high-paced growth in power demand is due partly to the construction of various kinds of infrastructure and partly to the rapid growth in population.

For the coming several years, the following new loads are anticipated in addition to the natural growth of the existing lighting load:

- Growth in industrial load at cement factory, oil refinery and Rusail industrial estate, etc.

- New bulk load which will be produced with the completion of Qaboos university and its hospital, Ghubrah hospital, etc.

- New residential load which will be produced with the completion of community projects.

- Loads in Musanna, Suwaiq, Rustaq and Mabellah in the Batinah coast which are scheduled to be connected to the Capital area through expansion of transmission line.

In the northern half of the Batinah coast there are load centers of Khabourah, Saham, Sohar, Liwa, Shinas, etc.

Power demand and supply balance for the period up to 1995 in the integrated power system including the Capital area and the Batinah coast is forecasted as follows:

(MW)

Item	1987	1988	1990	1991	1992	1995
Peak load						
Capital area	703	840	1,068	1,180	1,270	1,527
Batinah coast	-	191	258	288	329	468
Total (A)	703	1,031	1,326	1,468	1,599	1,995
Reserve capacity						
Capital area	82	82	82	82	82	82
Batinah (copper mine's power plant)	-	30	30	30	30	30
Total (B)	82	112	112	112	112	112
Required capacity						
(A) + (B) = (C)	785	1,143	1,438	1,580	1,711	2,107
Supply capacity (Existing and under planning)						
Capital area	769	769	769	769	769	769
Batinah (copper mine's power plant)	-	225	225	225	225	225
Total (D)	769	994	994	994	994	994
Demand & supply balance (D) - (C)	-16	-149	-444	-586	-717	-1,113

Note: 1. Supply capacity in the Capital area does not include capacity of the proposed Barka power station.

2. Peak load of the Capital area includes loads of Musanna, Suwaiq, Rustaq and Mabellah.

3. Load of Khabourah is included in the load of Batinah coast.

4. Expansion of copper mine's power plant for the period up to 1986 is already authorized. However, it is suggested that additional two units of each 30 MW gas turbine-generator be installed in 1986/87 near Sohar town to secure demand and supply balance in the Batinah coast before commissioning of the proposed Barka power station.

From the above table, it is suggested that the proposed Barka power station be developed with a capacity of more than 150 MW by 1988 and more than 700 MW by 1991.

3.2 Demand forecast for water and scale of development of the proposed Barka desalination plant

The demand for water in the Capital area has also grown rapidly in the recent years with the economic development and the growth in population. The water production increased from 4,555,000 m^3 (12,400 m^3/day) in 1977 when the first desalination plant was commissioned at Ghubrah to 11,177,000 m^3 (30,600 m^3/day) in 1980 and 23,488,000 m^3 (64,400 m^3/day) in 1984. This represents an average growth rate of 34.8% per annum for the period from 1977 to 1980 and 20.4% for the period from 1980 to 1984. Of the total water production in 1984, 82% was produced by desalination plant and the remaining 18% by wells.

In addition to the natural growth of the existing demands, the following new demands are anticipated:

- Bulk demands of the Rusail industrial estate, cement factory, sports-stadium, Qaboos university and its hospital, etc.
- New residential water demand which will be produced with the completion of community projects at Azaiba, Ghala, Bosher, Lansab, etc.
- Growth in demand by use of landscaping and by extension of service area.

Based on the existing and under construction facilities, the water demand and supply balance for the period up to 1995 in the Capital area is forecasted as follows:

(m^3/day)

Item	1985	1987	1988	1990	1991	1995
Required water production (Average)	99,274	136,958	155,088	193,596	206,877	260,000
Peak demand in the summer season (A)	114,165	157,500	178,350	222,635	237,908	299,000
Reserve capacity (B)	30,000	30,000	30,000	30,000	30,000	30,000
Required supply capacity (A) + (B) = (C)	144,165	187,500	208,350	252,635	267,908	329,000
Water Supply Capacity						
Wells	22,000	22,000	22,000	22,000	22,000	22,000
Ghubrah desalination plant	47,730	97,750	97,750	97,750	97,750	97,750
Total (D)	69,730	119,750	119,750	119,750	119,750	119,750
Demand & supply balance (D) - (C)	-74,435	-67,750	-88,600	-132,885	-148,158	-209,250

In the Capital area there is no large dam and reservoir, and the supply of water depends mainly on the desalination plant. Therefore, in order to secure stable supply of water it is necessary for desalination plant to have additional one unit at least (30,000 m^3/day) as the reserve capacity, taking into account the lowering of supply capability due to accidents or scheduled maintenance.

To meet the growing demand for water, Barka desalination plant should be commissioned with the shortest construction period technically possible. If construction works are started in May 1986, Barka desalination plant will be able to enter service around the end of 1988 with a capacity of 90,000 m^3/day including reserve capacity of 30,000 m^3/day. This capacity should be increased to 150,000 m^3/day including reserve capacity in 1991 to cover shortage in supply capability of 148,000 m^3/day in the same year. However, when considering the shortage in supply capability of 209,000 m^3/day in 1995, it will be appropriate for Barka desalination plant to be developed up to the ultimate capacity of 180,000 m^3/day by the end of 1990 in accordance with commissioning date of the power plant from viewpoint of economy and stability of supply.

4. SELECTION OF UNIT SIZE

4.1 Power plant

In general, the larger the unit size of the power plant the less the construction cost per kW installed. Therefore, it is appropriate to select unit size as large as possible in the standardized size. However, the selection of unit size of power plant has a close relation with operation of power system. Taking these into account, the optimization study on the unit size of power plant was carried from two positions.

Position 1: Selection of unit size made by attaching the most importance to the economy of Barka power plant which works as the main power source in the power system.

Position 2: Selection of unit size made by attaching the most importance to the reliability of power system including Barka and other power plants.

The results of study show that when economy must be respected the most the selection of a unit capacity of 120 MW is suitable, but if reliability of power system must be respected by all means it is appropriate to select a unit capacity of 60 MW.

As described later, the total costs (present worth) of the plant adopting a unit capacity of 120 MW will be about 5% less than those of the plant adopting a unit capacity of 60 MW.

However, influence exerted on the power system by adopting a unit capacity of 120 MW is larger than that exerted by adopting a unit capacity of 60 MW, i.e. the frequency drop of the power system caused by fault of a turbine-generator in the low load period of January and February in 1991 will be 48.75 to 47.50 Hz for the 120 MW unit and 49.17 to 48.33 Hz for the 60 MW unit.

The frequency drop risks to give a grave effect to turbine-generator. In general, the allowable limit of operation frequency in the 50 Hz power system is 48.5 Hz, and frequency drop to 47.5 Hz will require immediate shutdown of operation. Therefore, when fault occurs on the 120 MW unit it will be necessary to execute load shedding in order to prevent overall failure of the power system. This means that when reliability and stability of power system should be secured by all means it is suitable to adopt a unit capacity of 60 MW.

4.2 Desalination plant

For desalination plant also, it is more economic to select unit size as large as possible. At present, the largest unit size having performance record of long-run commercial operation is around 36,000 m^3/day.

Desalination plant must be operated to cope with seasonal variation of water demand and scheduled maintenance. In the Capital area, seasonal variation of demand for water is about ±15% of the average demand. The demand variation in 1995 is forecasted to be 260,000 m^3/day x 0.3 = 78,000 m^3/day. Therefore, if unit size of 30,000 m^3 is adopted, it will be possible to shut down two units for maintenance in the winter season every year. Taking these into account, it will be appropriate to select a unit size of 30,000 m^3/day.

5. SELECTION OF TYPE OF PLANT

5.1 Desalination plant

For desalination plant, comparative study was carried out on the multi-stage flush evaporation (MSF) process and reverse osmosis (RO) process, mainly from the following viewpoints:

- a) *Actual results of commercial operation*
- b) Adaptability to large scale plant
- c) Adaptability to dual purpose plant
- d) Operation and maintenance
- e) Length of construction period
- f) Economy

The results of study show that the both processes have merits and demerits, i.e. MSF process is superior to RO process in actual results of commercial operation, adaptability to large scale plant and also adaptability to dual purpose plant, while RO process is superior to MSF process in operation and maintenance, construction period and economy. However, MSF process is predominant for desalination plants in commercial operation and especially for large scale plant such as the proposed plant. Therefore, it is considered suitable to adopt MSF process from viewpoint of reliability.

For MSF process, the performance ratio 8 was judged the most economical both in the extraction turbine alternative and in the back pressure turbine alternative. Consequently, it is suggested that MSF process of a performance ratio 8 be adopted for the desalination plant to be jointly operated with the proposed power plant.

5.2 Power plant

The proposed power plant should be capable to correspond to daily and seasonal large variation of load on one hand and supply continuously steam in a given quantity to the desalination plant on the other hand. Taking these into account, comparative study was carried out on the 6 combinations of power plant and desalination plant, i.e. Type-A, Type-B, Type-C, Type-D, Type-E and Type-F. Turbine-generators of the power plant in each type of combination are as follows:

Type-A

- Gas/steam combined cycle power plant: 360 MW (Power generation)

    3 units of each 80 MW gas turbine-generator
    1 unit of 120 MW steam turbine-generator

- Steam power plant: 360 MW (Power generation and desalination)

    3 units of each 120 MW steam turbine-generator

Type-B

- Gas/steam combined cycle power plant: 720 MW (Power generation and desalination)

    7 units of each 80 MW gas turbine-generator
    2 units of each 80 MW steam turbine-generator

Type-C

- Gas/steam combined cycle power plant: 360 MW (Power generation
- Steam power plant: 360 MW and desalination)

Same constitution as Type-A power plant.
Steam feed pipes of both plants are connected
to supply steam to desalination plant

Type-D

- Gas/steam combined cycle power plant: 360 MW (Power generation)

3 units of each 80 MW gas turbine-generator
1 unit of 120 MW steam turbine-generator

- Gas turbine power plant: 400 MW (Power generation and desalination)

5 units of each 80 MW gas turbine-generator
with heat recovery steam generator for
desalination plant

Type-E

- Steam power plant: 160 MW (Power generation and desalination)

2 units of each 80 MW back pressure steam turbine

- Gas/steam combined cycle power plant: 560 MW (Power generation)

5 units of each 80 MW gas turbine-generator
2 units of each 80 MW steam turbine-generator

Type-F

- Steam power plant: 180 MW (Power generation and desalination)

3 units of each 60 MW back pressure steam turbine

- Gas/steam combined cycle power plant: 560 MW (Power generation)

5 units of each 80 MW gas turbine-generator
2 units of each 80 MW steam turbine-generator

5.3 Economic evaluation

For each type of combination of power plant and desalination plant (types A, B, C, D, E and F), the total costs (construction cost, operation and maintenance costs, administration expenses, fuel cost, etc.) incurred from the beginning of the construction works to the end of service life of the plant were converted to the present worth as of the beginning of 1986 to calculate the following ratio and rate:

Benefit/cost ratio (B/C ratio)
Economic internal rate of return (EIRR)

In principle, the purpose of feasibility study is to formulate the most economical project. Therefore, the project which meets the least cost solution is recommended as the optimum project.

However, when equipment considered has not enough operation record or there is a special condition in demand pattern, these conditions should be taken into account.

In spite of the fact that in the desalination sector RO process is more economical than MSF process, MSF process was recommended in this study, considering that MSF process is predominant for large scale desalination plant in commercial operation while RO process has almost no performance record for power and desalination dual purpose plant. Also in the desalination sector it was planned to adopt the performance ratio 8 because this ratio is the most economical both in the extraction turbine alternative and in the back pressure turbine alternative.

The special condition in the demand pattern is for power generation sector, and this problem has a close relation with stability of electricity supply and reliability of plant operation.

The overall evaluation of the project including considerations on the economy and on the reliability of supply is described below.

(1) Benefit/cost ratio and economic internal rate of return

The present worth of the total costs of each type of combination (combination of power plant and desalination plant), as well as, the benefit/cost ratio (B/C ratio) of Type-F combination are as follows:

Present Worth of the Total Costs and Costs Economized against Type-F Combination

	Discount rate 8%		Discount rate 10%	
	Present worth of the total costs	Costs economized against Type-F combination	Present worth of the total costs	Costs economized against Type-F combination
Type-A	756.0	40.6	634.9	34.7
Type-B	758.9	37.7	636.6	33.0
Type-C	756.6	40.0	635.7	33.9
Type-D	758.1	38.5	633.1	36.5
Type-E	789.3	7.3	662.3	7.3
Type-F	796.6		669.6	

B/C ratio of Type-F combination

	Discount rate 8%	Discount rate 10%
Against Type-A	0.949	0.948
Against Type-B	0.953	0.951
Against Type-C	0.950	0.949
Against Type-D	0.952	0.945
Against Type-E	0.991	0.989

Note: C: Cost of Type-F combination

B: Cost of other type of combination. This cost is regarded as the benefit of Type-F combination because it is the expenditure to be saved by the execution of Type-F combination.

As shown in the above table, the most economical solution is Type-A combination when using a discount rate of 8%. The economic ranking of projects can be clarified by the economic internal rate of return (EIRR) which is the discount rate equalizing present worths of the total costs of two projects. When taking Type-A combination as the basis, the EIRR of this alternative is calculated as follows:

Against Type-B combination: 11.5%
Against Type-D combination: 8.9%

Against Type-E combination: Meaningless to calculate because
Against Type-F combination: EIRR will be more than 30%

Seen from economic viewpoint, the least advantageous solution is Type-F combination. This alternative costs higher than Type-A combination by more than 5% (41 million R.O. in the present worth calculated at the discount rate of 8%).

(2) Consideration on the stability of supply

Type-A combination is the most economical. However, in Type-A combination, when fault occurs on the 120 MW turbine-generator supplying base load at the minimum load time in January and February it is necessary to execute partial load shedding in order to prevent overall failure of the power system. Such a counter-measure is needed for only several years after commissioning of the power plant, and probability of occurrence of fault at the minimum load time in the winter season is extremely low. Therefore, when the most importance is attached to the long-term economy, it is suggested that Type-A combination be adopted as the optimum solution.

However, stability of electricity supply is the most important for electric utility. Since Barka power plant is planned to play as the main power source in the integrated grid system covering the Capital area and the Batinah coast, the safety and reliability of operation are especially required for this power station. When standing on this viewpoint, any type of power plant giving fears of load shedding is not desirable, and it is rather suitable to adopt a power plant which is more reliable in operation and supply, though it may be less economic. Type-F power plant is the most suitable to meet requirements of stability of supply and reliability of operation.

5.4 Conclusion

As stated before, detailed comparative study was carried out on the six types of combination of power plant and desalination plant.

Of these six types of combination, Type-A has a defect that the influence exerted on the power system is large when fault occurs on its steam turbine-generator in the minimum load time in the winter season, but has a merit in its high economic performance. Therefore, seen from long-term economic viewpoint, Type-A combination is considered recommendable.

On the other hand, the cost of Type-F combination is higher than Type-A combination by around 5%, but the influence on the power system caused by fault of its steam turbine-generator is the least. This means that this type has a high reliability in operation.

The merit of high reliability of Type-F combination, though impossible to express in a quantitative manner, would be by no means so small. On the other hand, when considering economic conditions of Oman at present and for the future up to the end of service life of the plant, the above excess cost of 5% would be by no means decisively large amount.

Taking account of the above conditions and the present situation of Oman, Type-F combination, though less economic, is judged more recommendable than Type-A combination.

6. CONSTRUCTION SITE OF POWER AND DESALINATION COMPLEX PLANT

6.1 Topography, geology and foundation treatment

The site for power and desalination complex plant, designated by MEW, is located about 9 km east of Barka town. The land is large enough to obtain required area (1,000 m x 1,000 m) for the complex plant.

The elevation of the ground is approximately 1 meter above H.H.W.L. (highest predicted tide at port Qaboos), so that an area of approximately 660,000 sq meters for plant related facilities is to be raised at least 1 meter from the original height, taking into consideration the discharge plans for waste water from the plant and high waves due to monsoons.

Seen from results of borings at Ghubrah desalination plant and borings executed near Barka town for the prospection of subterranean water, the value N of the standard penetration test is estimated to be more than 20 at 5 to 6 meters depth from the ground surface. Therefore, reinforced concrete double slab and mat, and reinforced concrete mat are considered suitable for foundation of civil structures, heavy equipment, buildings, etc.

However, at the stage of definite study, it is necessary for detailed geological investigations to be executed to determine finally the structure of foundation.

6.2 Sea water depth and temperature of sea water

The sea is shallow. The results of sounding of the sea water depth show that gradient of the sea bottom is from 1/110 to 1/280.

The sea water temperature was around 24°C disregarding depth and distance from sea-shore. This is because measurement of the sea water temperature was carried out in the winter season of this country (average ambient temperature: 24°C). According to data, temperature of the sea water at the surface in the summer season reaches above 30°C. Therefore, at the stage of definite study, it is necessary to carry out measurement of sea water temperature in the summer season in order to determine finally sea water intake system, taking into account gentle slope of the sea bottom and temperature distribution of the sea water.

7. TRANSMISSION LINES AND SUBSTATIONS

7.1 275 kV transmission line from Barka power station to Khuwair interconnection substation (60 km)

According to power demand forecast, the peak load in the Capital area in 1988-1991, when Barka power station is planned to enter service by stage, is considered to be about 90% of the integrated system peak load including the Capital area and the Batinah coast. The site for substation where transmission line from Barka power station is connected to the existing system of the Capital area should be near load centers and favorable for interconnection. Taking into account these conditions and also results obtained from power system analysis, it is suggested that an interconnection substation (Khuwair interconnection substation) be constructed on a flat area at the foot of mountain about 3 km south of Ghubrah power station.

To transmit a bulk power of 740 MW of Barka power station for a distance of 60 km at 132 kV several circuits are required. Therefore, from economic and technical viewpoint, this transmission voltage is not suitable, and higher voltage should be selected.

Comparative study was carried out on the three transmission voltages of 220 kV, 275 kV and 330 kV. As the result of study, 275 kV line was selected taking into consideration the adaptability to the future extension of the power system.

The proposed line route is as follows:

Starting from Barka switchyard, the line takes a course southward, across the highway and then turns to the east to reach Barka substation which is under planning. Power for Batinah coast is stepped down to 132 kV here and transmitted by 132 kV line. After branching at Barka substation, the 275 kV line crosses over 132 kV Barka-Musanna line, then takes a course for Rusail and bypasses Rusail power station on the south. Then it takes course to the east and reaches Khuwair interconnection substation. At this substation 275 kV line from Barka is interconnected with two 132 kV lines from Ghubrah to Wadi Adai, and from Rusail to Wadi Adai.

7.2 132 kV transmission line from Musanna substation to Sohar substation (125 km)

To meet the growing demand for electric power in the northern half of the Batinah coast (Khabourah, Saham, Sohar, Liwa, Shinas, etc.) and in the Inland area (Buraimi, Ibri and other small towns and villages), MEW plans to increase generating capacity of copper mine power station located about 20 km south of Sohar from the present 51 MW to 165 MW by the end of 1986. However, as described in paragraph 2.3.1, additional two units of each 30 MW gas turbine-generator are necessary to be installed in 1987/1988. By this expansion program, power demand and supply balance in these areas can be secured up to 1988, but in 1989 shortage in supply capacity will be produced.

In the Capital area, on the other hand, construction program of 132 kV line from Rusail power station to Musanna is now on-going. This line, together with Musanna substation, is scheduled to enter service in 1986. In consideration of this situation, it is suggested to extend the 132 kV transmission line from Musanna substation to Sohar substation. For this purpose, construction of Khabourah substation and expansion of Sohar substation are suggested.

In this connection, it is to be noted that, apart from the proposed project, another 132 kV line must be constructed between copper mine power station and Sohar substation by the end of 1986, because the existing lines (single circuit 66 kV line between copper mine power station and Magan substation and double circuit 33 kV line between Magan substation and Sohar substation) are already over-loaded.

7.3 Substations

General characteristics of substations to be constructed together with transmission lines are as follows:

. Khuwair interconnection substation	275/132 kV, 3 units of transformers, each 250 MVA 132/ 33 kV, 2 units of transformers, each 125 MVA
. Khabourah substation	132/ 33 kV, 2 units of transformers, each 45 MVA
. Barka substation	275/132 kV, 2 units of transformers, each 250 MVA (Extension)

8. PRODUCT WATER DISTRIBUTION FACILITIES

8.1 Product water reservoir

It is planned to construct a product water reservoir in the plant site. Taking into account the capacity of desalination plant (180,000 m^3/day) and the maximum quantity of well water for blending (36,000 m^3/day), the reservoir is designed to have a total capacity of 216,000 m^3. With this capacity, the reservoir can regulate supply quantity of product water.

The product water reservoir is divided into four tanks of each 54,000 m^3.

8.2 Product water pumps

In consideration of variation of supply quantity of product water and stoppage of pumps for periodic inspection and maintenance, seven units of product water pump including one unit for reserve are planned to be installed. General characteristics of each pumps are as follows:

- Capacity	27.5 m^3/min
- Head	100.0 m
- Revolution	980 rpm
- Motive power	750 kW electric motor

8.3 Water conduit pipes

The following two water conduit pipes are planned to be installed along the highway between Muscat and Sohar.

Section	Capacity (m^3/day)	Pipe diameter (mm)
(1) Line-A conduit pipe		
Barka plant - Ghubrah reservoir	108,000	1,200 (35 km) 1,000 (25 km)
(2) Line-B conduit pipe		
Barka plant - Seeb town branch valve	108,000	1,200
Seeb town branch valve - Airport branch valve	70,000	900
Airport branch valve - Azaiba branch valve	38,000	700

9. OPERATION AND MAINTENANCE STAFF

The estimated required total number of operation and maintenance staff is about 350 persons. Classification of the staff is as follows:

		Number
Common department		6
Plant Manager		1
Deputy Plant Manager		2
Others		3
Administrative department		36
Operation department		175
Chief		1
Operator (Power plant)		106
Operator (Desalination plant)		68
Maintenance department		131
	Total	348

Practical training of staff should be executed under the direction of guarantee enginer from 6 months prior to the test operation of the plant to the end of guarantee period, and using operation and maintenance manuals.

10. CONSTRUCTION SCHEDULE

To meet the growing demand for electricity, it is necessary for generating capacity of at least 160 MW to enter service by the middle of 1988. In the desalination sector, even when No. 3 and No. 4 units are installed at Ghubrah desalination plant, the shortage in water supply capability will still continue. Therefore, it is necessary for Barka desalination plant to be commissioned as early as possible. Taking these conditions into account, the works should be started in the following conditions:

- Definite study and preparation of tender documents:	Completion by the beginning of 1986
- Award of contract and start of works:	May 1986

If works are started in the above conditions, the increase in capacities of power plant and desalination plant will be as follows:

Item	1988	1989	1990	1991
Power plant (MW)				
Commissioning	160	160	280	140
Accumulated total	160	320	600	740
Desalination plant (1,000 m^3/d)				
Commissioning	60	30	90	-
Accumulated total	60	90	180	180

11. CONSTRUCTION COST ESTIMATE

The construction costs were estimated at 1985 prices, and both the foreign currency portion and local currency portion were escalated at the rate of 3% per annum. These construction costs include physical contingencies (10%), MEW's administration expenses (3%) and engineering fee (2.5%). According to construction price indices for the period from 1980 to 1985 in Japan and those for the period from 1978 to 1983 in Oman, the compounded price rise was calculated at about 2.5% per annum, but in this project 3% per annum was adopted including margin.

Thus, the total construction costs of the project at 1985 prices were estimated at 343.28 million R.O. of which 241.60 million R.O. is for electric power sector and 101.68 million R.O. for desalination sector. When applying the price escalation rate of 3% per annum, the construction costs for electric power sector will increse to 264.12 million R.O. and those for desalination sector to 109.85 million R.O., totalling 373.97 million R.O. of which 320.24 R.O. (US$936.37 million) is foreign currency portion and 53.73 million R.O. local currency portion as shown below (Cost of power and desalination complex plant is of Type-F):

Construction Cost of Type-F

(Million R.O.)

Sector	Item	Foreign Currency		Local currency	Total
			(Million US$)		
Electric power	Generating facilities	160.33	(468.79)	10.79	171.12
	Transmission facilities	10.86	(31.75)	4.35	15.21
	Substation facilities	19.22	(56.20)	3.64	22.86
	Sub-total (Base direct cost)	190.41	556.74	18.78	209.19
	Physical contingencies, administration expenses, engineering fee	24.27	70.96	8.14	32.41
	Total (1985 prices)	214.68	627.70	26.92	241.60
	Escalated prices	235.41	688.33	28.71	264.12
Desalination	Processing facilities	51.52	(150.64)	9.16	60.68
	Product water distribution facilities	17.88	(52.28)	9.48	27.36
	Sub-total (Base direct cost)	69.40	(202.92)	18.64	88.04
	Physical contingencies administration expenses, engineering fee	9.14	(26.72)	4.50	13.64
	Table (1985 prices)	78.54	(229.64)	23.14	101.68
	Escalated prices	84.83	248.04	25.02	109.85
Grand total	1985 prices	293.22	(857.34)	50.06	343.28
	Escalated prices	320.24	(936.37)	53.73	373.97

12. FINANCIAL ANALYSIS

12.1 Conditions for analysis

In this analysis Type-F combination was adopted for power and desalination complex plant. The conditions for analysis are as follows:

a) Conditions for funds procurement

Taking into account the terms of loans generally adopted by the export and import banks of industrial countries and some examples of government loan given to Oman, the following conditions were assumed for the procurement of construction costs in foreign currency:

Interest rate:	7.3% (compounded rate)
Repayment period:	15 years after commissioning

It is assumed that the local currency portion of the construction costs will be financed by the budget of the government, so there will be no interest charged on the project. But, in order to calculate adequate prices on the cost basis for electricity and water, the following loan conditions of Oman Development Bank was used in the project:

Interest rate:	8.0%
Repayment period:	10 years after commissioning

b) Loss factors in supply of electricity and water

The power transmission and distribution loss factor was estimated at 15% based on data in 1983.

For product water, the loss factor due to leakage and other reasons was estimated at 20% including un-metered consumption.

c) Prices of electricity and water

The prices of electricity and water used for estimating operating revenues were calculated on the cost basis.

12.2 Results of analysis

Calculations for financial analysis were made over the period up to 2010 as in the case of economic evaluation. Results of analysis made on the abovementioned loan conditions and assumed tariffs for electricity and water are as follows:

a) Profit and loss calculation and cash-flow

The annual balance will show a slight deficit up to 1994 and keep black every year after 1995, and accumulated net income will amount to 279.57 million R.O. by 2010.

Due to interest during construction, deficit in the accumulated cash balance will continue up to 1999 and turn to black in 2000.

b) Rate of return

The rate of return, that is the ratio of operating income to the fixed assets in operation is as follows:

- For the first 10 years after completion of the project:	6.1%
- Over the whole service life:	11.7%

c) Rate of net income

The rate of net income, that is the ratio of net income to the fixed assets in operation is as follows:

- For the first 10 years after completion of the project:	0.75%
- Over the whole service life:	6.2%

C. GENERAL CHARACTERISTICS OF FACILITIES

Facilities	General characteristics
(A) Power and Desalination Complex Plant	
1. Civil works	
(1) Water intake channel:	
Intake quantity:	40 m^3/sec
Structure:	Open channel with dredged waterway and dykes
Waterway:	Length: 850 m, Width: 65 m
Dyke:	Length: 2 x 850 m + 210 m = 1,910 m (Max. height: 11.5 m)
(2) Seawater Intake Facility:	Intake and Pump Pit
Structure:	Reinforced concrete open channel, curtain-wall type
Length:	60.00 m
Width:	73.00 m
Height:	13.20 m
(3) Water Discharge Facilities:	Discharge Pit and Discharge Channel
Structure:	Reinforced concrete open channel
Length:	130.00 m
Width:	8.00 - 21.00 m
Height:	2.80 - 8.50 m
(4) Product Water Reservoir:	
Capacity:	54,000 m^3 x 4 Units
Structure:	Reinforced concrete mat, including soil stabilization

Facilities	General characteristics
2. **Buildings**	
(1) Power Plant Main Building (for Steam Turbine Generator)	
Foundation:	Reinforced concrete double slab and mat
Structure:	Steel construction, 3 stories
Scale:	Building area 17,341 m^2 Building volume 138,000 m^3
(2) Administration Building (Common Use Building)	
Foundation:	Reinforced concrete mat, including soil stabilization
Structure:	Reinforced concrete construction, 2 stories
Floor area:	2,940 m^2
(3) Power Plant Control Building	
Foundation:	Reinforced concrete mat, including soil stabilization
Structure:	Reinforced concrete construction, 2 stories, partially with mezzanine floor
Floor area:	8,183 m^2
(4) Desalination Plant Control Building	
Foundation:	Reinforced concrete mat, including soil stabilization
Structure:	Reinforced concrete construction, one story
Floor area:	540 m^2
(5) Other Buildings (Chemical injection building, product water treatment building, common use building)	

Facilities	General characteristics
(6) Self-standing stack (3 units)	
Foundation:	Reinforced concrete mat, including soil stabilization
Structure:	Steel construction
Height:	80 m
Top diameter:	2.4 m
3. Power Plant (Type F)	
3.1 Steam turbine-generators	
(1) Steam generator (3 units)	
Type:	Natural circulation module type finned water tube
Evaporation:	ca.400 t/h
Steam pressure:	ca.80 kg/cm^2
Main fuel:	Natural gas
(2) Steam turbine (3 units)	
Type:	Impulse type
Rated capacity:	60 MW
Inlet steam pressure:	ca.80 kg/cm^2
Speed:	3,000 rpm
(3) Generator (3 units)	
Rated capacity:	75 MVA
Power factor:	0.8
Short circuit ratio:	About 0.5

Facilities	General characteristics
3.2 Gas turbine-generator	
(1) Turbine (5 units)	
Type:	Heavy duty industrial type
Rated capacity:	84 MW (50°C), 109 MW (15°C)
Speed:	3,000 rpm
(2) Generator (5 units)	
Rated capacity:	140 MVA
Power factor:	0.8
Short circuit ratio:	About 0.5
3.3 Steam turbine-generator for gas/steam combined cycle	
(1) Heat recovery steam generator (4 units)	
Type:	Natural circulation module type finned water tube
Evaporation:	ca.160 t/h
Outlet steam pressure:	ca.60 kg/cm^2
(2) Steam turbine (2 units)	
Type:	Impulse type
Rated capacity:	80 MW (50°C), 85 MW (15°C)
Inlet:	ca.60 kg/cm^2
Speed:	3,000 rpm
(3) Generator (2 units)	
Rated capacity:	110 MVA
Power factor:	0.8
Short circuit ratio:	About 0.5

Facilities	General characteristics
4. Desalination plant (6 units)	
(1) Evaporator	
Type:	Cross tube rectangular type
Stage No.	Heat recovery 20 stages Heat rejection 3 stages Total 23 stages
(2) Brine heater	
Type:	Horizontal shell and tube type
(3) Deaerator	
Type:	Vacuum packed tower type
Performance:	Dissolved oxygen, Max. 20 ppb
(4) Venting equipment (per 1 unit)	
Steam ejector:	Twin 3 stages type
Vent condenser (1 unit):	Horizontal shell and tube type
Ejector condenser (1 unit):	Horizontal shell and tube type
(5) Main process pump (per 1 unit)	
Brine recycle pump (1 unit)	Cap. 13,150 m^3/h, Total head 50 m
Brine blow down pump (1 unit)	Cap. 1,812 m^3/h, Total head 20 m
Distillate pump (2 units)	Cap. 1,500 m^3/h, Total head 20 m
Condensate pump (2 units)	Cap. 198 m^3/h, Total head 35 m

Facilities	General characteristics
(6) Product water treatment equipment (Total 1 unit)	
Type:	Lime stone filter type using the exhaust gas from the evaporator
Treatment capacity:	Total 180,000 m^3/day
Total hardness of treated water:	60 ± 10 mg/l (as $CaCO_3$)
(7) Auxiliary steam generator (Total 2 units)	
Type:	Water tube outdoor service
Evaporation:	300 Tons/h (per 1 unit)
Steam pressure:	10 kg/cm^2G
Steam temperature:	183°C
Fuel:	Natural gas (Heavy oil for stand-by)

Facilities	General characteristics	
(B) Transmission Facilities		
1. Barka - Khuwair line		
(1) Section and length		
Barka PS - Barka SS	13 km	
Barka SS - Khuwair SS	47 km	
(2) Voltage:	275 kV	
(3) Number of circuit:	2	
(4) Conductor	AAAC 400 mm^2 x 4	
(5) Supporting facility:	Double circuit angle steel tower	
2. Musanna - Khabourah - Sohar line		
(1) Section and length		
Musanna SS - Khabourah SS	60 km	
Khabourah SS - Sohar SS	65 km	
(2) Voltage:	132 kV	
(3) Number of circuit:	2	
(4) Conductor:	AAAC 400 mm^2 x 2	
(5) Supporting facility:	Double circuit angle steel tower	
(C) Substation Facilities		
1. Kuwair interconnection substation		
(1) Transformer capacity	250 MVA	125 MVA
(2) Voltage	275/132 kV	132/33 kV
(3) Number of unit	3	2

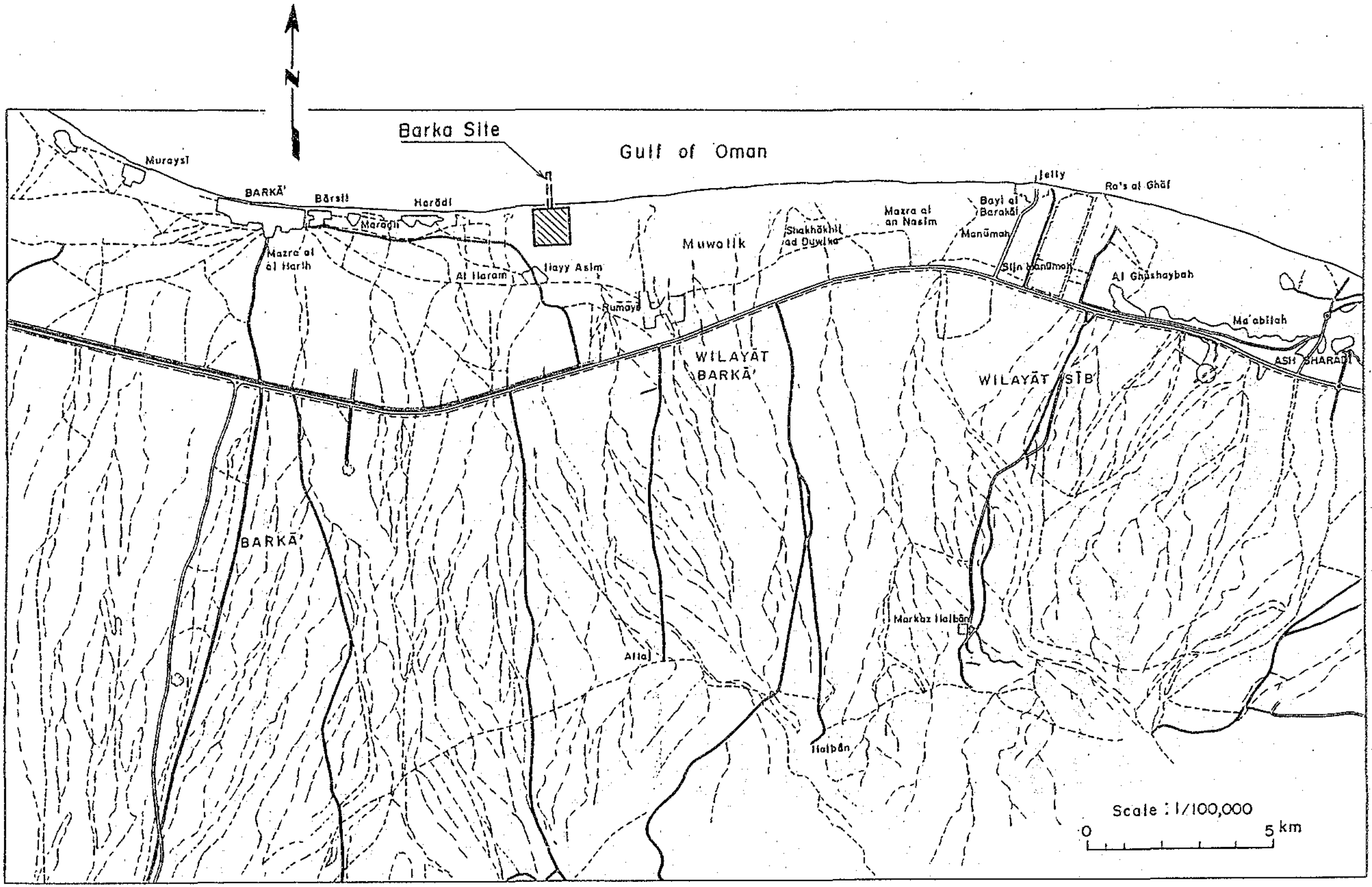
Facilities	General characteristics	
2. Khabourah substation		
(1) Transformer capacity	45 MVA	
(2) Voltage	132/33 kV	
(3) Number of unit	2	
3. Barka substation (Extension)		
(1) Transformer capacity	250 MVA	
(2) Voltage	275/132 kV	
(3) Number of unit	2	
(D) Product Water Distribution Facilities		
1. Product water reservoir (Refer to (A) 1.(4))		
2. Product water transfer pump		
(1) Number of unit	7 (6 Units: Working, 1 Unit: Stand-by)	
(2) Capacity	27.5 m^3/min	
(3) Head	100 m	
(4) Revolution	980 rpm	
(5) Driver	750 kW electric motor	
3. Water conduit pipe		
	Capacity (m^3/day)	Pipe diameter (mm)
(1) Line-A conduit pipe		
Barka plant - Ghubrah reservoir	108,000	1,200 (35 km) and 1,000 (25 km)

Facilities	General characteristics	
(2) Line-B conduit pipe		
Barka plant - Seeb town branch valve	108,000	1,200
Seeb town branch value - Airport branch valve	70,000	900
Airport branch valve - Azaiba branch valve	38,000	700

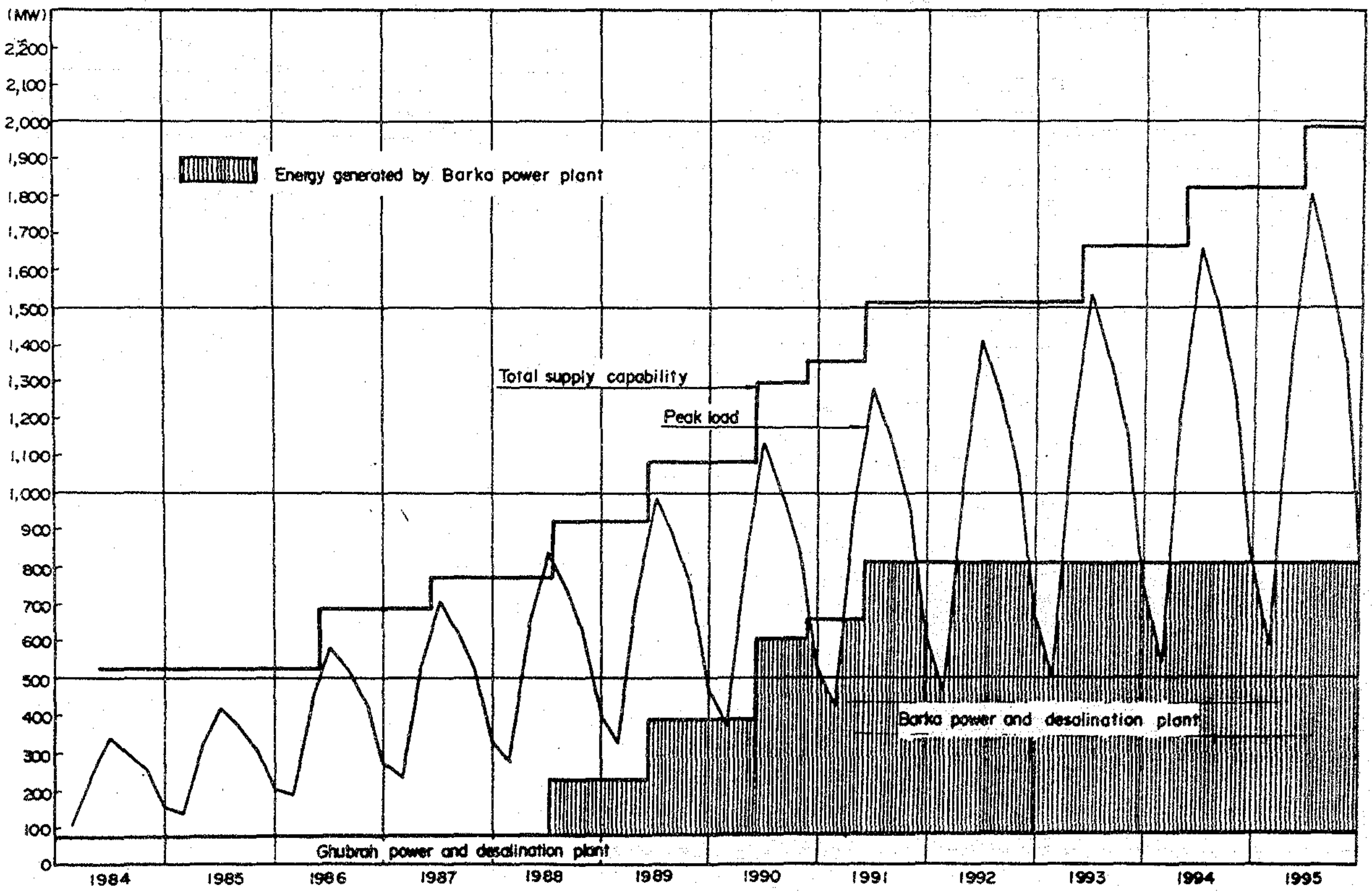
ATTACHED FIGURE

- LOCATION OF BARKA SITE
- LOAD FORECAST AND POWER DEVELOPMENT PROGRAM
- WATER DEMAND AND SUPPLY BALANCE AND DESALINATION PLANT CONSTRUCTION PROGRAM
- PLOT PLAN
- SYSTEM DIAGRAM OF POWER AND DESALINATION COMPLEX PLANT (TYPE-F)
- PROPOSED TRANSMISSION LINE ROUTE
- ELECTRIC POWER SYSTEM
- WATER SUPPLY DISTRICT PLANNED FOR CAPITAL AREA
- WATER CONDUIT PIPE ROUTE
- CONSTRUCTION SCHEDULE FOR POWER AND DESALINATION COMPLEX PLANT

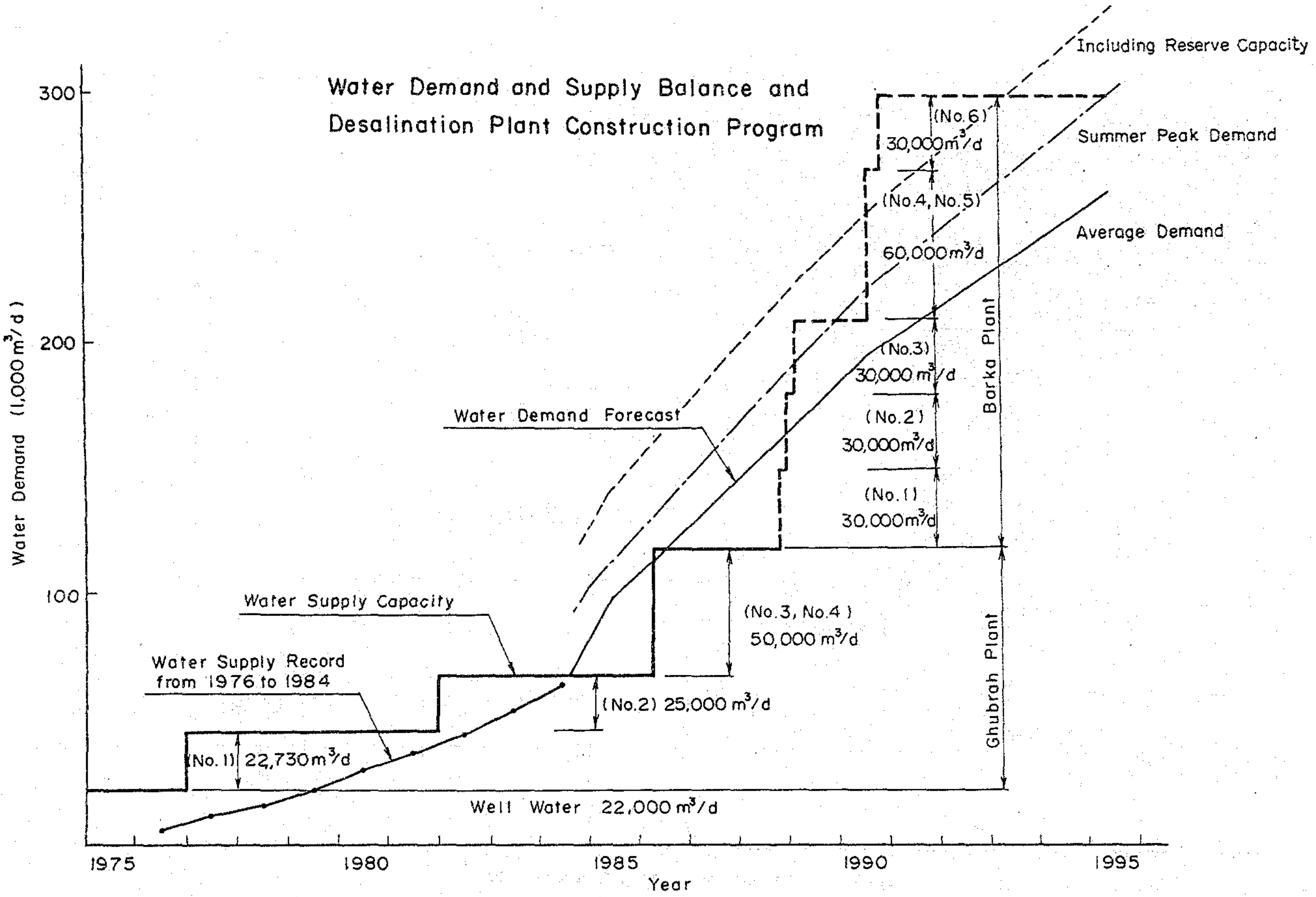
LOCATION OF BARKA SITE

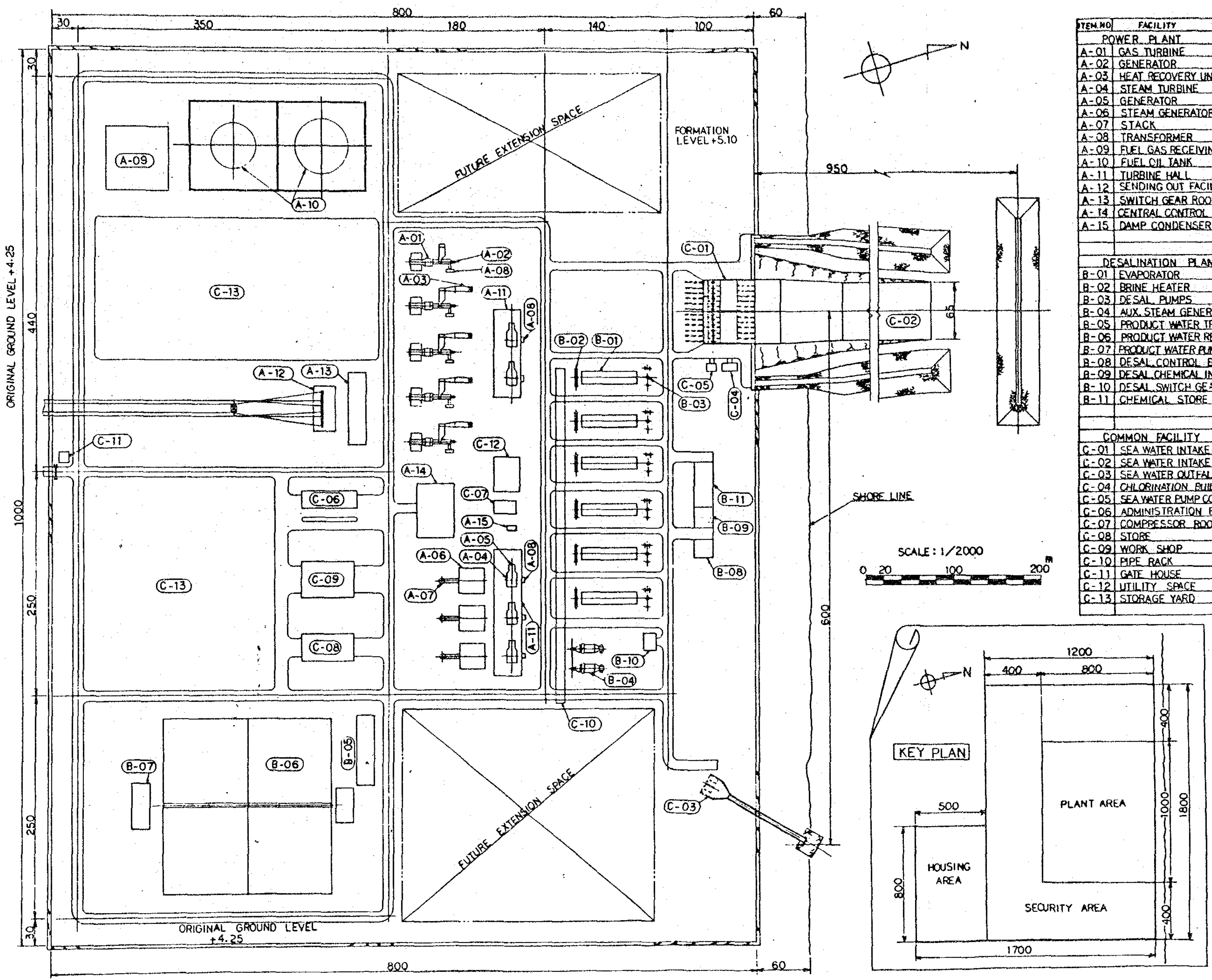


Load forecast and power development program



Water Demand and Supply Balance and Desalination Plant Construction Program





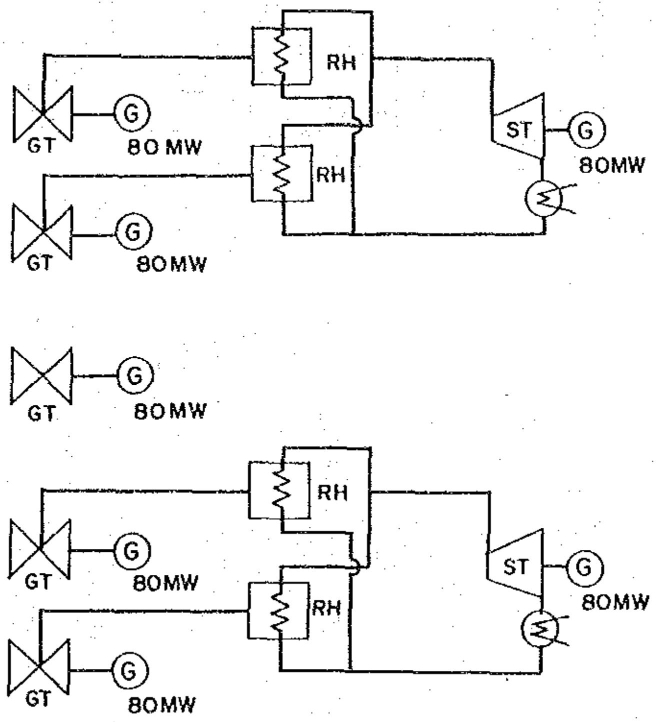
ITEM NO	FACILITY	REMARKS
POWER PLANT		
A-01	GAS TURBINE	
A-02	GENERATOR	
A-03	HEAT RECOVERY UNIT	
A-04	STEAM TURBINE	
A-05	GENERATOR	
A-06	STEAM GENERATOR	
A-07	STACK	
A-08	TRANSFORMER	
A-09	FUEL GAS RECEIVING UNIT	
A-10	FUEL OIL TANK	
A-11	TURBINE HALL	
A-12	SENDING OUT FACILITY	
A-13	SWITCH GEAR ROOM	
A-14	CENTRAL CONTROL BUILDING	
A-15	DAMP CONDENSER	
DESALINATION PLANT		
B-01	EVAPORATOR	
B-02	BRINE HEATER	
B-03	DESAL. PUMPS	
B-04	AUX. STEAM GENERATOR	
B-05	PRODUCT WATER TREATMENT	
B-06	PRODUCT WATER RESERVOIR	
B-07	PRODUCT WATER PUMPING STATION	
B-08	DESAL. CONTROL BUILDING	
B-09	DESAL. CHEMICAL INJECT. BUILDING	
B-10	DESAL. SWITCH GEAR BUILDING	
B-11	CHEMICAL STORE HOUSE	
COMMON FACILITY		
C-01	SEA WATER INTAKE & PUMP PIT	
C-02	SEA WATER INTAKE CHANNEL	
C-03	SEA WATER OUTFALL	
C-04	CHLORINATION BUILDING	
C-05	SEA WATER PUMP CONTROL ROOM	
C-06	ADMINISTRATION BUILDING	
C-07	COMPRESSOR ROOM	
C-08	STORE	
C-09	WORK SHOP	
C-10	PIPE RACK	
C-11	GATE HOUSE	
C-12	UTILITY SPACE	
C-13	STORAGE YARD	

PLOT PLAN

SYSTEM DIAGRAM OF POWER AND DESALINATION COMPLEX PLANT (TYPE-F)

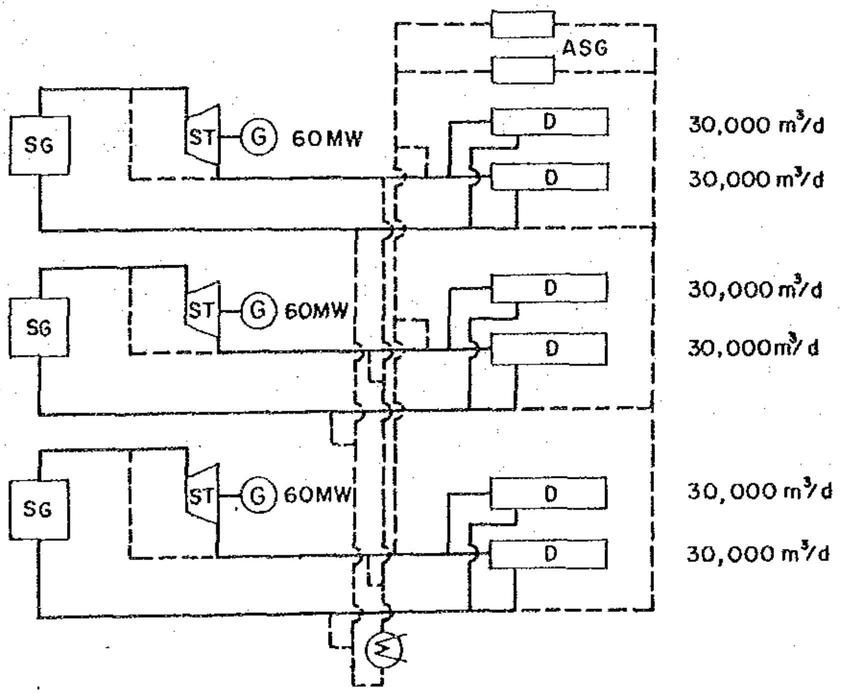
TOTAL OUTPUT
- POWER PLANT
  - GAS TURBINE 80MW x 5 = 400MW
  - COMBINED STEAM TURBINE 80MW x 2 = 160MW
  - BACK PRESSURE TURBINE 60MW x 3 = 180MW
  - (total) 740MW
- DESALINATION PLANT 30,000m³/d x 6 = 180,000m³/d

(1) GAS-STEAM COMBINED CYCLE GENERATOR

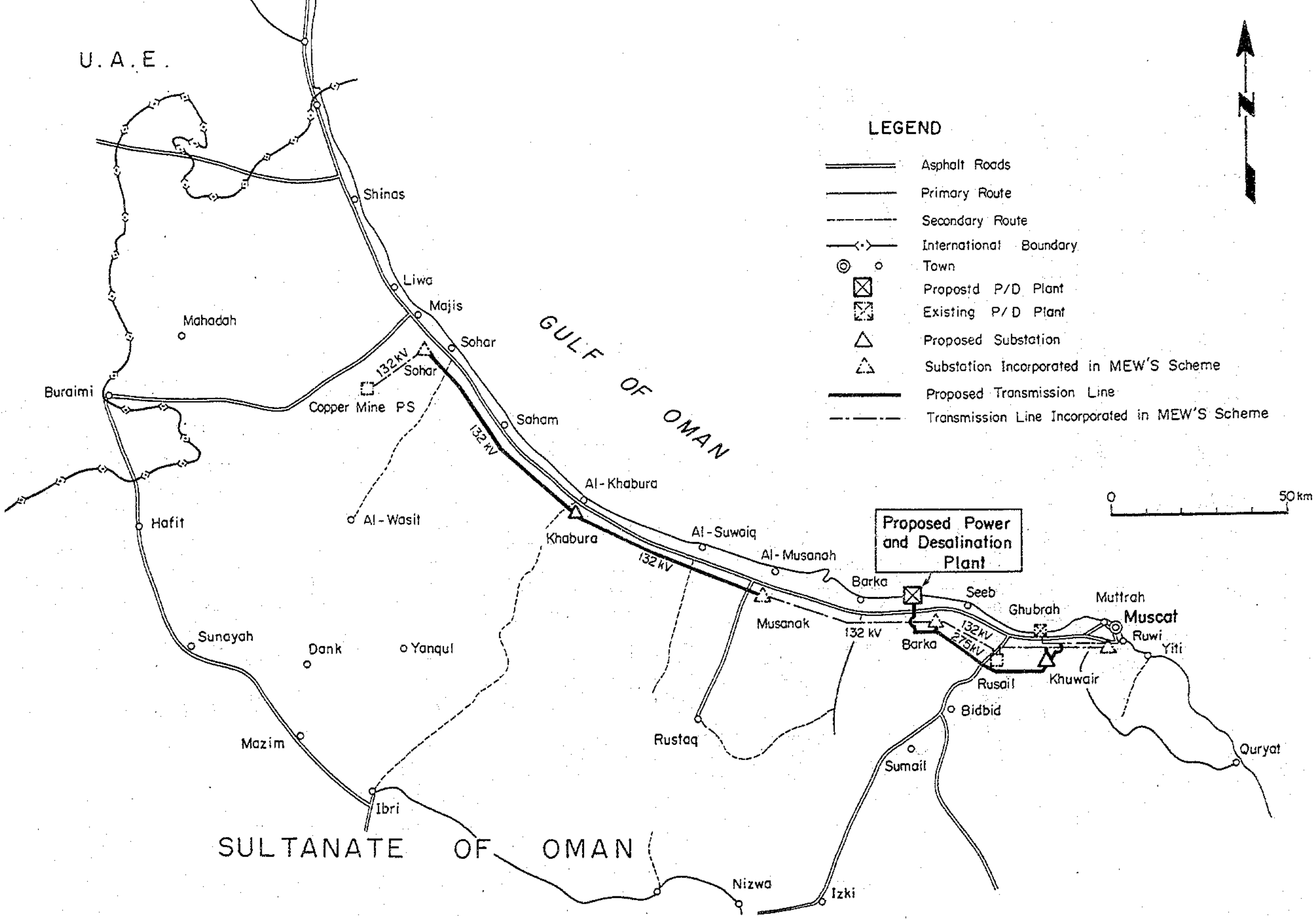


GT : Gas Turbine
ST : Steam Turbine
RH : Recovery Heat Steam Generator
G : Electric Generator
SG : Steam Generator
ASG : Aux. Steam Generator
D : Desalination Plant

(2) BACK PRESSURE STEAM TURBINE CYCLE GENERATOR AND DESALINATION PLANT

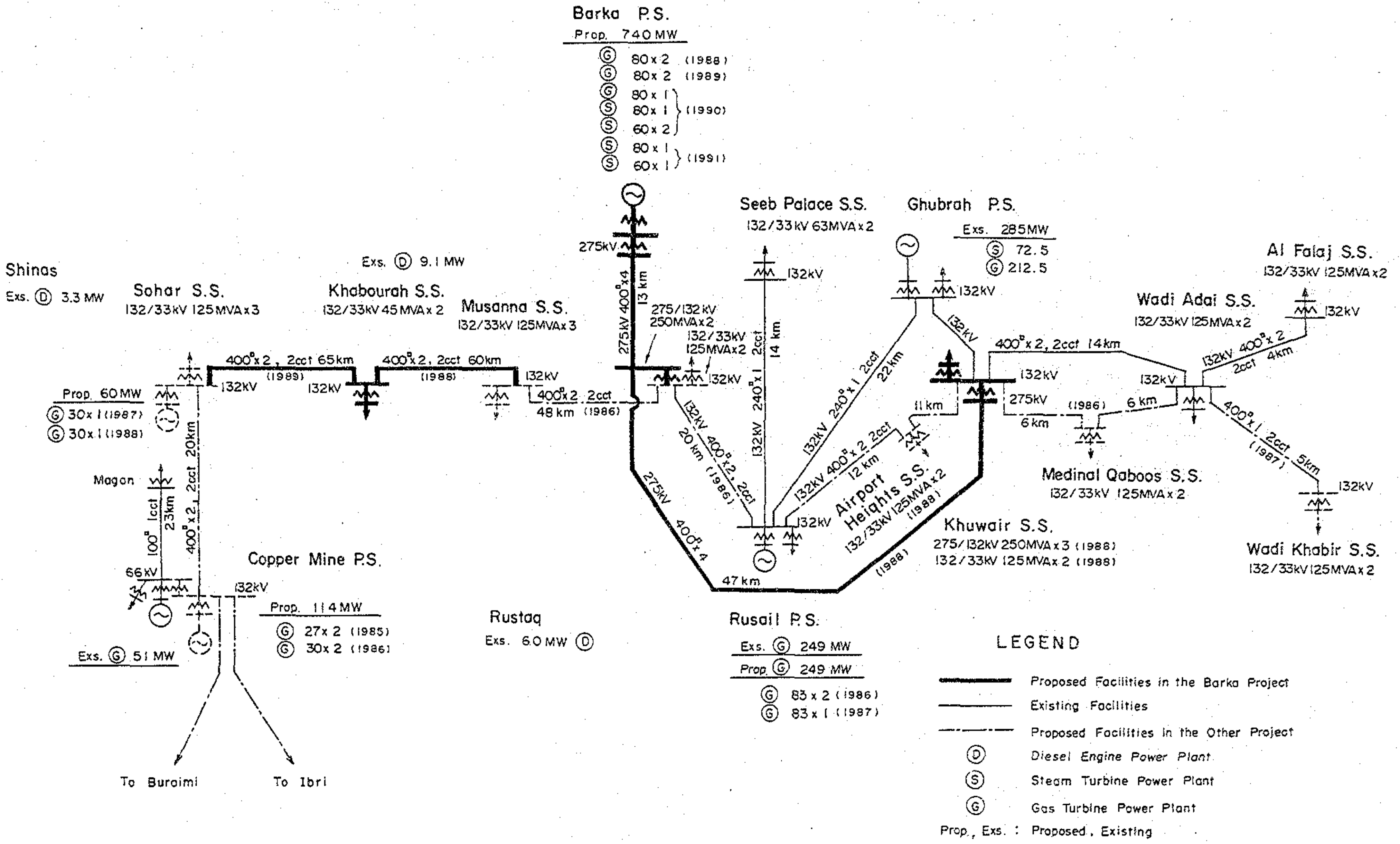


Proposed Transmission Line Route

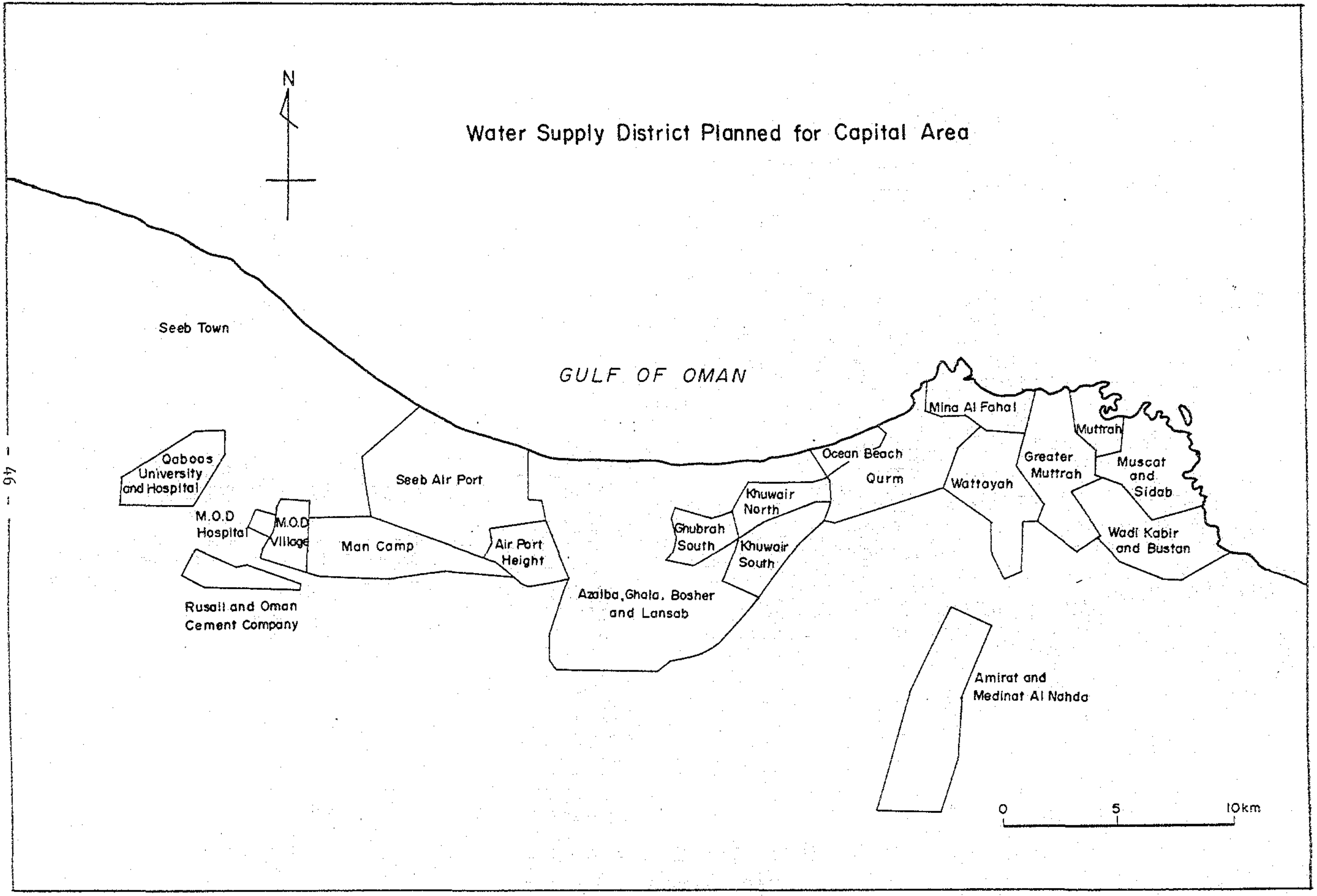


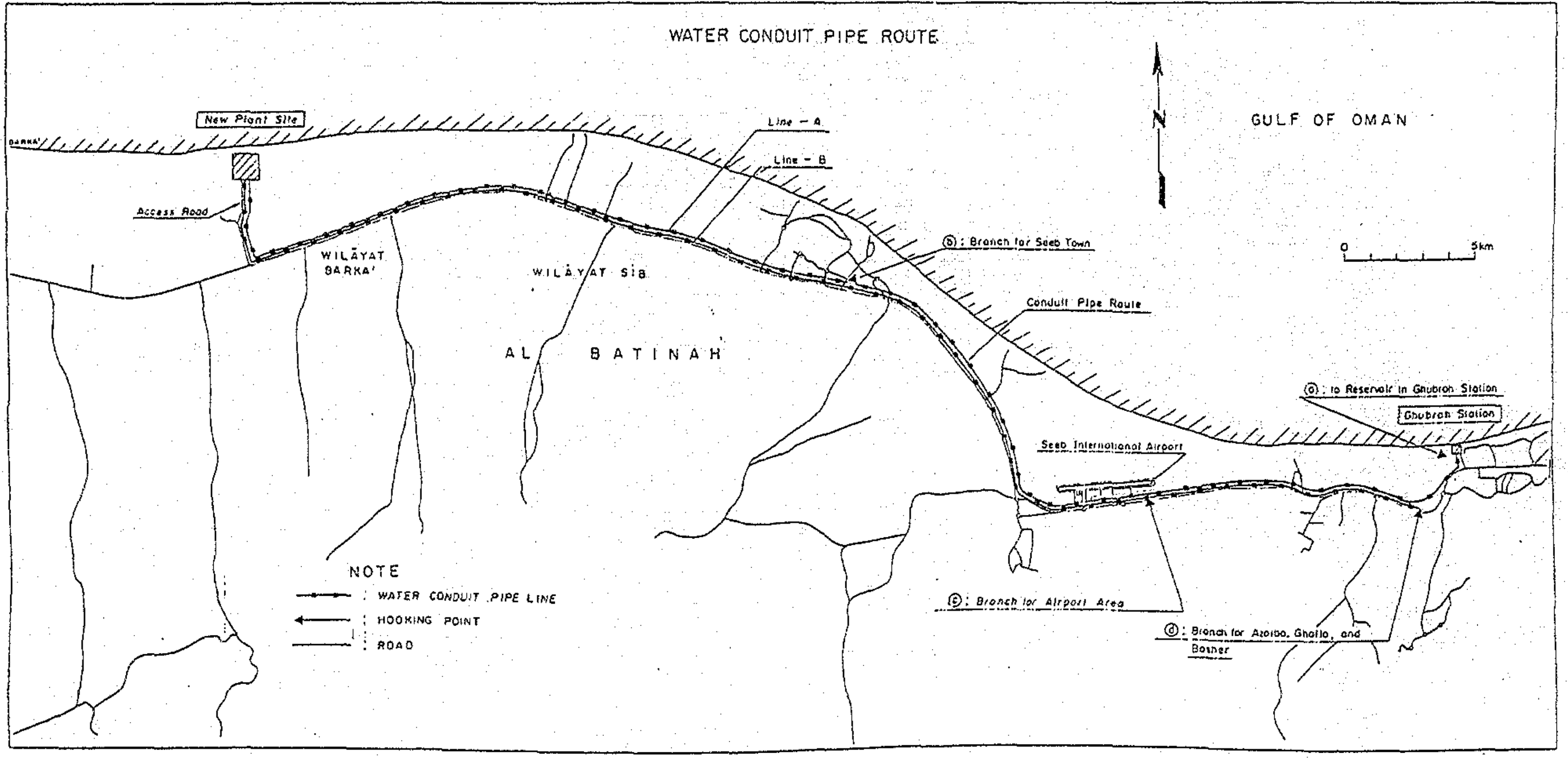
ELECTRIC POWER SYSTEM

(Capital and Batinah Areas)



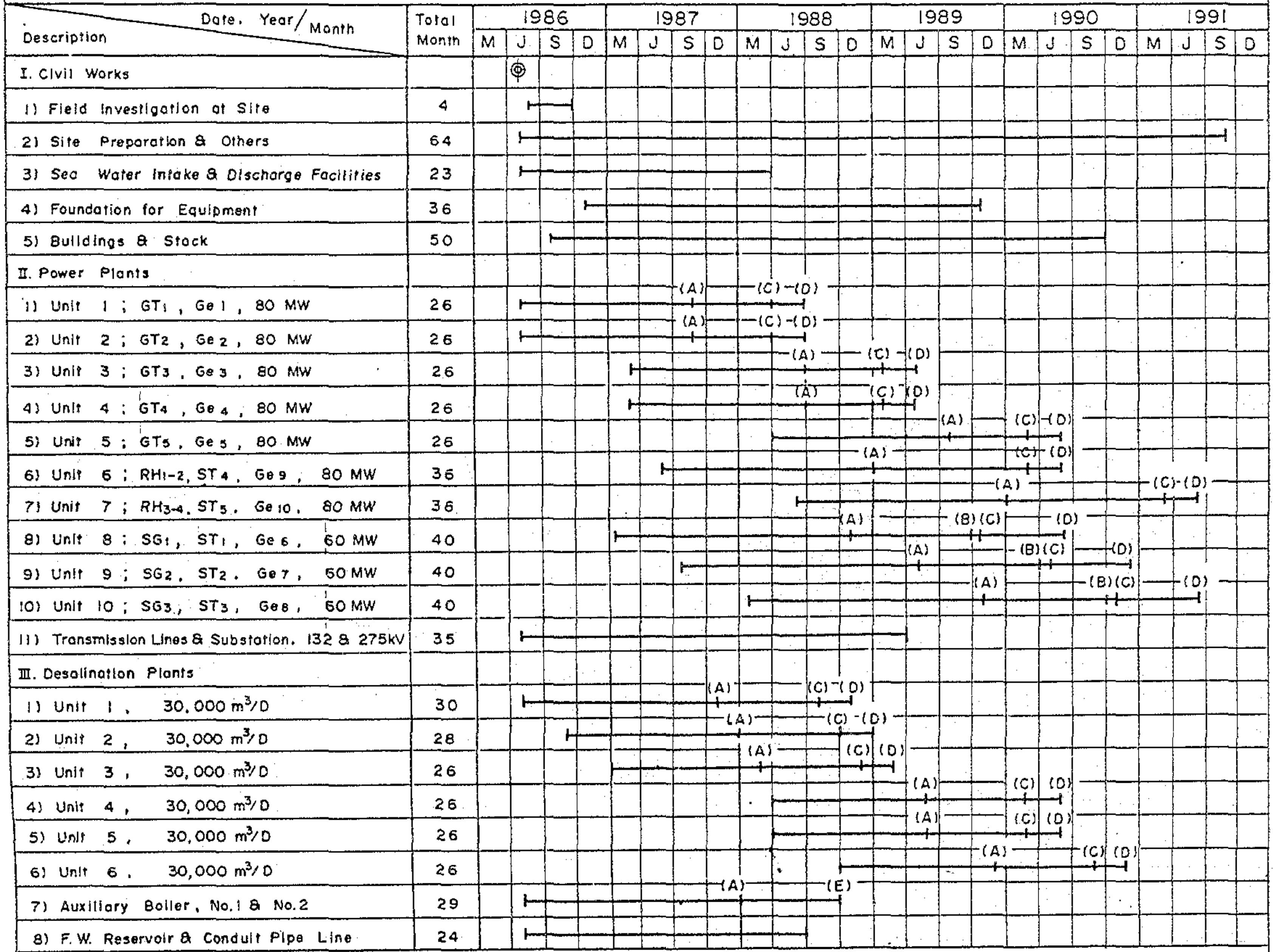
Water Supply District Planned for Capital Area





WATER CONDUIT PIPE ROUTE

Construction Schedule for Power and Desalination Complex Plant.



Description	Total Month
I. Civil Works	
1) Field Investigation at Site	4
2) Site Preparation & Others	64
3) Sea Water Intake & Discharge Facilities	23
4) Foundation for Equipment	36
5) Buildings & Stack	50
II. Power Plants	
1) Unit 1 ; GT1 , Ge 1 , 80 MW	26
2) Unit 2 ; GT2 , Ge 2 , 80 MW	26
3) Unit 3 ; GT3 , Ge 3 , 80 MW	26
4) Unit 4 ; GT4 , Ge 4 , 80 MW	26
5) Unit 5 ; GT5 , Ge 5 , 80 MW	26
6) Unit 6 ; RH1-2, ST4 , Ge 9 , 80 MW	36
7) Unit 7 ; RH3-4, ST5 , Ge 10 , 80 MW	36
8) Unit 8 ; SG1 , ST1 , Ge 6 , 60 MW	40
9) Unit 9 ; SG2 , ST2 , Ge 7 , 60 MW	40
10) Unit 10 ; SG3 , ST3 , Ge 8 , 60 MW	40
11) Transmission Lines & Substation, 132 & 275kV	35
III. Desalination Plants	
1) Unit 1 , 30,000 m³/D	30
2) Unit 2 , 30,000 m³/D	28
3) Unit 3 , 30,000 m³/D	26
4) Unit 4 , 30,000 m³/D	26
5) Unit 5 , 30,000 m³/D	26
6) Unit 6 , 30,000 m³/D	26
7) Auxiliary Boiler, No.1 & No.2	29
8) F.W. Reservoir & Conduit Pipe Line	24

Note: ◎ : Contract, May 1, 1986 (A) : Commencement of Erection (B) : Hydraulic Test : (C) : Test (D) : Completion of Erection or Commissioning

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