No. 57

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

MINISTRY OF ELECTRICITY AND WATER
THE SULTANATE OF OMAN

# THE FEASIBILITY STUDY
# ON
# BARKA POWER AND DESALINATION PLANT PROJECT
# IN
# THE SULTANATE OF OMAN

## FINAL REPORT

SEPTEMBER 1994

PACIFIC CONSULTANTS INTERNATIONAL

MPN
CR (3)
94-119

JICA
THE FEASIBILITY STUDY ON BARKA POWER
AND DESALINATION PLANT PROJECT IN THE SULTANATE OF OMAN
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# PREFACE

In response to a request from the Government of the Sultanate of Oman, the Government of Japan decided to conduct a Feasibility Study of the Barka Power and Desalination Plant Project in the Sultanate of Oman and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent to the Sultanate of Oman a study team headed by Mr. Yukio Toyoshima of Pacific Consultants International, four times during the period from November 1993 to August 1994.

The team held discussions on the project with officials concerned of the Government of the Sultanate of Oman and conducted the survey. After the team returned to Japan, further studies were made and the present report was prepared.

I hope that this report will contribute to the promotion of the development program in the Sultanate of Oman and to the enhancement of friendly relations between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of the Sultanate of Oman for their close cooperation extended to the team.

September 1994

Kimio Fujita

Kimio Fujita
President
Japan International Cooperation Agency

September 1994

Mr. Kimio Fujita
President
Japan International Cooperation Agency
Tokyo, Japan

Dear Mr. Fujita

Letter of Transmittal

We are pleased to submit to you the feasibility report on the Barka Power and Desalination Plant Project of the Sultanate of Oman. The report contains the advice and suggestions of the authorities concerned of the Government of Japan and your Agency as well as the formulation of the above mentioned project. Also included are comments made by the Ministry of Electricity and Water of the Government of the Sultanate of Oman during technical discussions on the draft report which were held in the Sultanate of Oman.

This report presents a scheme for four stages of development for power and water in accordance with the demand forecast up to 2010. Upon completion of each stage of the Project, the shortage of power and water will be eliminated, thus greatly contributing to the improvement in living standards of the Sultanate of Oman.

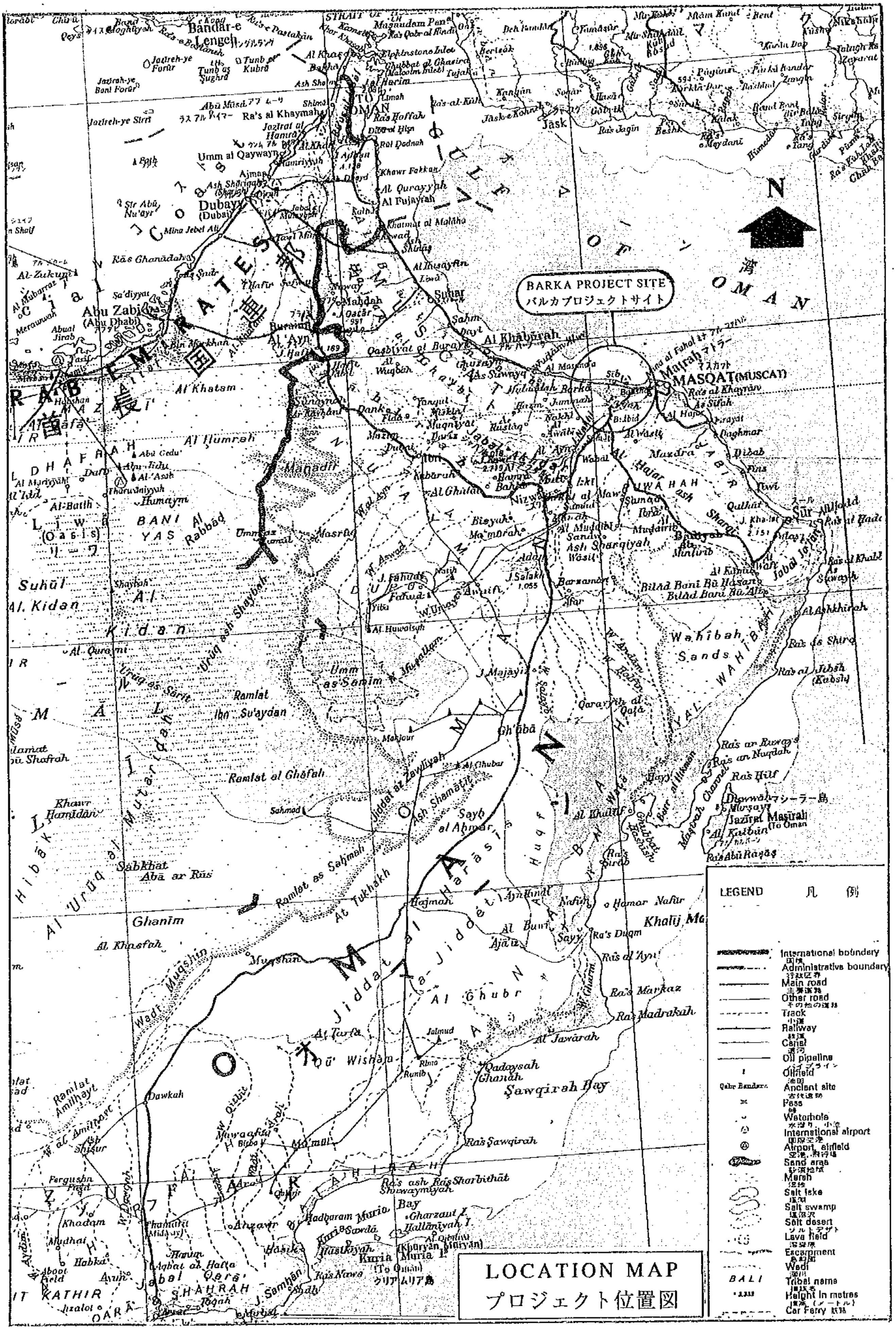
In view of the urgency of power and water development in the Sultanate of Oman and of the need for socio-economic development of the Sultanate of Oman as a whole, we recommend that the Government of the Sultanate of Oman implement this Project as a top priority.

We wish to take this opportunity to express our sincere gratitude to your Agency, the Ministry of Foreign Affairs, and the Ministry of International Trade and Industry. We also wish to express our deep gratitude to the Ministry of Electricity and Water and other authorities concerned of the Government of the Sultanate of Oman for the close cooperation and assistance extended to us during our investigations and study.

Very truly yours,

Y. Toyoshima

Yukio Toyoshima
Team Leader
Barka Power and Desalination Plant Project



LOCATION MAP
プロジェクト位置図

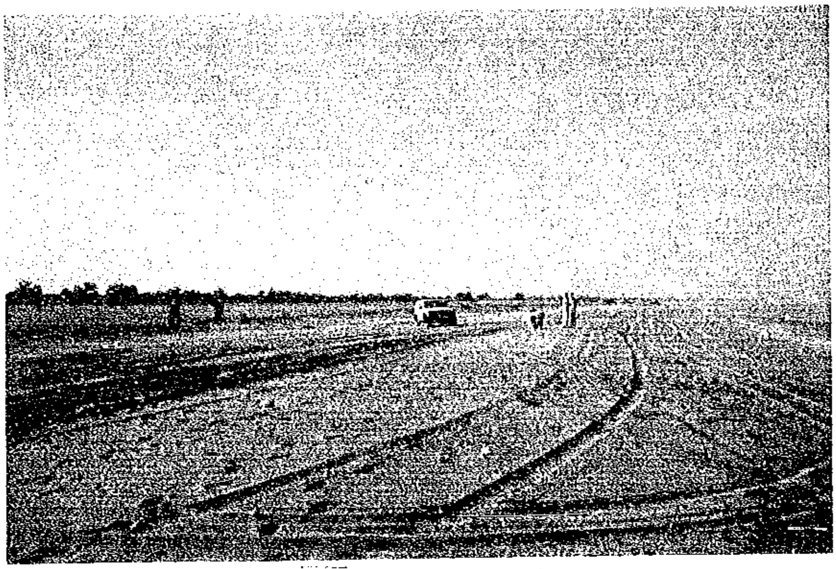


Photo 1 Barka Project Site

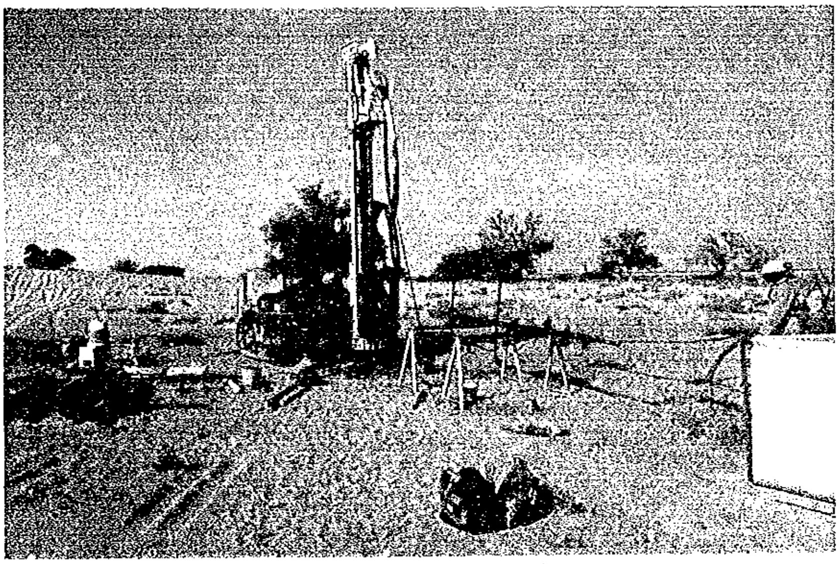


Photo 2 Boring on Land at the Site

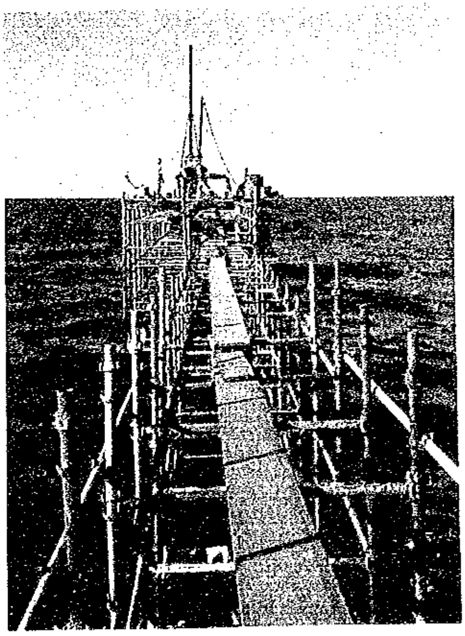


Photo 3 Offshore Boring at the Site

# ACRONYMS AND ABBREVIATIONS

## Organizations

| | |
|---|---|
| CBO | Central Bank of Oman |
| DGE | Directorate General of Electricity (MEW) |
| DGW | Directorate General of Water (MEW) |
| DPS | Department of Planning and Statistics |
| GPDP | Ghubrah Power and Desalination Plant |
| JICA | Japan International Cooperation Agency |
| MEW | Ministry of Electricity and Water |
| MAF | Ministry of Agriculture and Fisheries |
| MC | Ministry of Communication |
| MCI | Ministry of Commerce and Industry |
| MD | Ministry of Development |
| MNHC | Ministry of National Heritage and Culture |
| MRME | Ministry of Regional Municipalities and Environment |
| MH | Ministry of Housing |
| MWR | Ministry of Water Resources |
| OIFC | Oman Investment and Finance Company |
| QU | Qaboos University |
| RIE | Rusail Industrial Estate |
| RPS | Rusail Power Station |

## Others

| | |
|---|---|
| C.D. | Chart Datum |
| DCM | Document/Book/Map |
| EIA | Environmental Impact Assessment |
| F/S | Feasibility Study |
| FY | Fiscal Year |
| GDP | Gross Domestic Product |
| IEE | Initial Environmental Examination |
| M/M | Minutes of Meeting |
| Max. | Maximum |
| Min. | Minimum |
| RO | Rial Omani |
| S/W | Scope of Work |
| SPT | Standard Penetration Test |

# MEASUREMENT

Length

| | |
|---|---|
| mm | millimetre |
| cm | centimetre |
| m | metre |
| km | kilometre |

Area

| | |
|---|---|
| $cm^2$ | square centimetre |
| $m^2$ | square metre |
| $km^2$ | square kilometre |
| ha | hectare |

Volume

| | |
|---|---|
| l | litre |
| $m^3$ | cubic metre |
| $Nm^3$ | normal cubic metre |
| bal | 1 barrel = 36 U.K. gallons |
| gal | 1 U.K. gallon = 4.546 litres |
| mscf | million standard cubic feet<br>(one barrel of oil = 6 mscf of gas) |
| MGPD | million gallons per day |
| MG | million gallons |

Weight

| | |
|---|---|
| µg | microgram |
| mg | milligram |
| g | gram |
| kg | kilogram |
| ton | metric ton |

Others

| | |
|---|---|
| V | volt |
| KV | kilovolt |
| KVA | kilovolt ampere |
| W | watt |
| KW | kilowatt |
| MW | megawatt |
| KWh | kilowatt hour |
| MWh | megawatt hour |
| GWh | gigawatt hour |
| sec | second |
| min | minute |
| hr | hour |
| dB | decibel |
| ppm | parts per million |
| % | percent |
| µs | microsiemens |
| cal | calorie |

# ABBREVIATION OF MAJOR TECHNICAL TERMS

| | |
|---|---|
| GT | Gas Turbine |
| ST | Steam Turbine |
| HRSG | Heat Recovery Steam Generator |
| MSF | Multi-Stage Flush |
| RO | Reverse Osmosis |
| D | Desalination |
| C/C | Combined Cycle |
| P/D | Power/Desalination |
| BPST | Back Pressure Steam Turbine |
| G | Generator |
| T/L | Transmission Line |
| S/S | Sub Station |
| P/S | Power Station |
| SG | Steam Generator |

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# CHAPTER 1 INTRODUCTION

# CHAPTER 1 INTRODUCTION

## 1.1 Background and Objectives of the Study

### 1.1.1 Background of the Study

The Sultanate of Oman has achieved significant economic growth over the past 20 years, particularly since 1970 when oil revenues began to increase. Prosperity has brought with it a rapidly rising demand for power and water in the capital of Muscat and its surrounding areas. At the end of the 1980s, a shortage of power and water was forecast. In response to these demands, the government planned to build a power and desalination plant in the suburbs of Barka, located some 60 kilometers west of Muscat. This facility would meet the demand for power and water and, at the same time, promote the government's third five-year plan (1986 - 1990). At the request of the government of Oman, the Japanese Government sent a Japan International Cooperation Agency (JICA) team to conduct a feasibility study in 1985. However, because of the 1986 drop in oil prices, the government of Oman was not able to proceed with the project.

Under its fourth five-year plan, which began in 1991, the Sultanate of Oman is diversifying its manufacturing and other industries in order to create a national economy that is not dependent on oil. To achieve this goal, the government is attempting to attract small and medium-sized foreign companies that will bolster industry in Oman. Accordingly, demand for power and water is rising at an even faster pace.

In November 1992, the government of Oman again asked the Japanese government to carry out a feasibility study on the Barka Power and Desalination Plant Project. In response to the request, JICA sent a survey team in February 1993 to select and approve the project site. In June 1993, JICA dispatched a preliminary survey mission headed by Mr. Norio Shimomura. The group discussed the scope of the work (S/W) with the Ministry of Electricity and Water (MEW), the organization that had requested the study. Afterwards, both parties signed the S/W and the minutes of the meeting (M/M), and decided to proceed with the study.

### 1.1.2 Objectives of the Study

The purpose of this study is to draw up an optimum development plan for the Barka Power and Desalination Plant, taking into account the technology to be used, the surrounding environment, the economy and the financing for the project. JICA will determine the feasibility of the project, which is targeted for completion in the year 2010. Because of the pressing need for power and water, the study will examine the possibility of implementing the plan in phases.

## 1.2 Scope and Contents of the Study

For power supply, the study targets the Muscat System and the Wadi Jizzi and Manah Systems, which are linked to the Muscat System. For water supply, it proposes the Muscat district and South Batinah. These locations were chosen based on the S/W.

The study comprises of the following three stages:

### 1.2.1 First Stage

The first stage of the study focuses on data collection, on-site investigation, examination of power and water development, and drawing up of the development plan.

(1) Collection of data and review of existing data

(2) On-site investigation

1) Power and desalination plant site, including a geological studies (boring on land and at sea).
2) Fuel transportation routes and capacity
3) Routes of power transmission lines and water supply pipe lines.
4) Infrastructure, including ports, harbors and roads.
5) Environmental conditions (preliminary assessment of effects on environment).

(3) Examination of power and water development

1) Framework of existing systems, including control, operations and maintenance.
2) Existing and planned power and water supply systems.

3) Power and water consumption by sector, including billing systems.
4) Power and water demand forecasts.
5) Power supply and demand balance (plan to boost power supply, and assessment of effects on existing systems).

(4) Drawing up of development plan

1) Review of existing development plans.
2) Drawing up of alternative plans.
3) Analysis of alternative plans.
4) Selection of an optimum development plan.

### 1.2.2 Second Stage

(1) Conceptual design

1) Power and desalination plant.
2) Buildings, structures and civil-engineering works.
3) Power transmission lines and substations.
4) Water supply pipelines, pump stations, reservoirs and related facilities.

(2) Environmental Study

1) Assessment of effects on environment
2) Plans for environmental preservation

### 1.2.3 Third Stage

(1) Plan for implementation, and economic and financial analyses

1) Plans for staged implementation (construction plan, training plan, operation and maintenance plan, and environmental control plan).
2) Schedule of staged implementation.
3) Preparation of construction cost estimate.
4) Economic and financial analyses.

## 1.3 Execution of the Study

In order to carry out this study in the scopes described above, JICA dispatched a feasibility study team headed by Mr. Yukio Toyoshima to Oman during the following periods.

Schedule

First on-site study : December 1 - December 12, 1993
Second on-site study : January 26 - February 20, 1994
Third on-site study : June 15 - July 3, 1994
Fourth on-site study : August 10 - August 21, 1994

In addition to the studies on-site, the team carried out the follow-up work in Japan. The report was produced based on these studies.

### 1.3.1 On-Site Study

Groups specializing in different fields carried out a diverse range of studies on power, water, civil engineering, the environment and the economy. The team performed a large proportion of the tasks in Oman to promote technological transfer.

(1) Meetings with MEW and Data Collection

In addition to participating in meetings with MEW, the team collected the necessary materials and data from the ministry and from related organizations.

(2) Inspection of Related Facilities

The team visited the following facilities involved in the study, examined their current status and collected the necessary information.

- Power plants, substations, desalination plants, industrial complexes, ports, harbors and other facilities.

(3) Survey of Plant Site, and Geological and Other Surveys.

1) Rough topographical survey to determine the elevation of the site.
2) Boring on land and at sea, to obtain soil data needed for the design of the plant facilities, buildings, intake channel and outflow channel.
3) Rough sounding of sea bottom to obtain data for the design of the inflow channel and the outflow channel.
4) Measurement of sea water temperature and analysis of water quality, for use in the design of condensers for the power generation facilities and the desalination plant.
5) Study of maps indicating power transmission routes and substation locations, and on-site investigations.

6) Study of maps indicating water supply pipe routes and on-site investigations.

(4) Environmental Study

1) Identified items that affect nature and the social environment and produced a screening checklist and a scoping checklist.
2) Examined existing data, conducted on-site investigations and produced an environmental matrix, primarily based on interviews with relevant organizations, in order to identify additional items that should be included in the environmental impact assessment (EIA). An EIA must be conducted prior to the implementation of the project.
3) Forecast the spread of hot discharge water and of exhaust gas into the atmosphere, using a simplified program.

(5) Feasibility Design

1) Power/water demand forecast
2) Selection of power/desalination plant design and finalization of the plant size.
3) Conceptual design of power/desalination plant and related facilities
4) Construction schedule
5) Preparation of construction cost estimates
6) Economic/financial analyses

### 1.3.2 Studies Conducted in Japan

The part of the study carried out in Japan mainly comprised of the production of the following reports, which were submitted after conducting an on-site study.

(1) Inception Report
(2) Progress Reports
(3) Interim Report
(4) Draft Final Report
(5) Final Report

## 1.4 Acknowledgment

Sincere gratitude is expressed herewith for the unreserved cooperation and convenience extended by the following persons to the Study Team in carrying out the feasibility study and related activities.

HE. Abdullah Bin Alin Bin Dawood
Under Secretary, Ministry of Electricity and Water

HE. Jafar Al-Shakh
Director General Water, Ministry of Electricity and Water

Mr. Mohamed Redha Hassan Ali
Director General Electricity, Ministry of Electricity and Water

Mr. Mohamed Amin Mustafa
Director of Planning & Statistics, Ministry of Electricity and Water

The persons concerned in MEW and other organizations in Oman.

# CHAPTER 2 SUMMARY AND RECOMMENDATION

## A. SUMMARY

### 2.1 Background and Necessity of the Project

The social and economic development of the Sultanate of Oman has resulted in a rapidly rising demand for Power and Water in Muscat and its surrounding areas. This will lead to a shortage in supply capacities of the existing power plants and desalination plants in meeting the growing demands. To cope with this situation the Ministry of Electricity and Water (MEW) plans to build a power and desalination complex plant in the suburbs of Barka, located some 60 kilometers west of Muscat.

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

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

### 2.2 Proposed Project Site

#### 2.2.1 Surrounding Environment

The proposed site, which was selected by MEW, is located on the coast about 60 km westward from Muscat and about 5.5 km eastward from Barka. Its size is 610 x 1,000 m and satisfies the space requirement for the proposed plant facilities.

There are several towns and villages around the site - Romays, Haradi, Hayyasim, etc. - where the main economic activities are farming and fishing. Other notable communities, economic activities, facilities and sites of cultural heritage were not seen around the site. Furthermore, there are no reports or information announcing the existence of endangered fauna and flora around the site.

#### 2.2.2 Topographical and Geological Features

The land of the proposed site is generally flat and the ground height is approximately HAT + 0 ~ 1.8 m. It is necessary to raise the ground level of the site up to HAT + 4.0 m taking into consideration wave overtopping and wave run-up. The slope of the sea bed is about 1/100 ~ 1/200.

According to the results of the soil investigation, a firm strata with SPT values of more than 50 is founds at 5.0 ~ 11.0 m below the ground surface.

### 2.2.3 Temperature and Quality of Sea Water

The sea water temperature offshore from the site in December was about 26°C and there was no difference by depth. The sea water temperature at the surface in summer is estimated to be more than 30°C.

The quality of sea water is good.

### 2.2.4 Accessibility

The Batinah Highway (Route 1) runs along the coast, line to which the distance from the proposed site is about 3.7 km. A rural road branches from Route 1 and runs nearby the site and on to Barka. The surface conditions of these roads are quite good. However, the weight, width and height of cargo will be restricted since there are grade separations at several places in and near Muscat. It is necessary to consider the above in the design and transportation plan, and the costs relating to reinforcement of road (bridges) needs to be scheduled.

## 2.3 The Present State of the Power Utilities and the Electric Development Plan

### 2.3.1 Existing Power Supply Facilities

#### (1) Power Generation Facilities

Since 1976, the Sultanate of Oman has included the development of power supply sources and expansion of electric power distribution facilities in its five-year economic development plans. In the period between 1976 and 1993, installed generating capacity rose markedly, from 85 MW to 1,410 MW, as did the total amount of electricity generated, from 266.1 GWh to 5,832.2 GWh. The main networks linking the generating sources with consumers are the Muscat System and the Wadi Jizzi System, with installed capacities of 815 MW (63 % of total installed capacity) and 222 MW (16 %), respectively.

The Muscat System supplies power to the Muscat metropolitan area and the South Batinah region with power stations at Ghubrah and Rusail. The Ghubrah Power Station provides steam for a desalination plant, incorporating five steam turbines in addition to gas turbine generators, which are the main power source. Ghubrah has 11 such generators and Rusail, six. The Wadi Jizzi System supplies power to the North Batinah region from the Wadi Jizzi Power Station, at which nine gas turbine generators are in use.

### (2) Power Distribution Facilities

The Ghubrah and Rusail Power Stations are interconnected by two 132 KV transmission lines, and power flows through seven 132 KV/33 KV primary substations. The overhead transmission lines are 400 mm$^2$ all aluminum alloy conductor (AAAC) wires and 240 mm$^2$ aluminum clad steel reinforced (ACSR) wires, principally using the single-route, two-circuit method. The substations incorporate indoor-type, gas insulated switchgear (GIS) that take into account external appearance, while offering countermeasures against salt-dust damage and space savings. The substations are provided with oil-filled, air-cooled transformers with 135 MVA maximum capacity.

The Wadi Jizzi System incorporates seven 132 KV/33 KV primary substations that are connected by 132 KV overhead transmission lines. The Muscat and Wadi Jizzi Systems are not interconnected at present.

### 2.3.2 Operational Organization of the Power Utilities

The Ministry of Electricity and Water (MEW) is responsible for the electric power development plan and the electric power distribution facilities planing in Oman. The MEW manages power generation, transmission, transformation and distribution, with the Directorate General of Electricity (DGE) in charge of power generating plants, and the Directorate General of Water (DGW) in charge of desalination plants. Further, the Planning Department acts as coordinator. The MEW contracts operation and maintenance of the power supply facilities in Muscat System to a private-sector Omani firm, SOGEX.

### 2.3.3 Special Features of Load Fluctuations

As well as determining the component of the Muscat System's daily load curve that is to be allocated to this project's power generating plant, load fluctuation records have been studied in order to determine the annual power consumption balance. This study uncovered the following fluctuations in load:

(1) There are severe seasonal variations in the air temperature of the Muscat metropolitan area and the Batinah region, and the major cause of load fluctuations is air conditioning demand, which is directly linked to changes in air temperature.

(2) Power consumed on a minimum load day in winter was 36 % of the annual maximum for the daytime, and 17 % for night. The daily load curve for the maximum and minimum load days were very similar in 1984 and 1993. Similar trends in load fluctuations will probably continue.

(3) The load factor (average load/peak load) is at the 50 % level in the first half, and shows no marked fluctuations.

### 2.3.4 Electric Power System Planning

Electric power supply equipment should be reliable, with voltage, frequency and service interruptions regulated within an allowable level. Further, facilities must have a long service life because of the lengthy construction periods required to build them. Therefore, the equipment should provide not only a cost-effective initial investment, but also low costs over its entire life cycle, including fuel and other operating expenses.

For a power system to fulfill all of its requirements, a thorough system planning must be undertaken with the following procedures:

(1) Prepare a power supply plan based on projected demand, the power supply development plan, and the distribution facilities plan for the period from 1994 to 2010.

(2) In order to ensure that projected demand can be met, calculate the difference between supply capacity and power consumption, taking into account the reserve capacity.

(3) To determine capacity of the generating equipment, calculate station consumption factor, transmission loss factor, load factor and unscheduled plant shutdown rates.

### 2.3.5 Power Demand Forecasting

Historically, there has been a strong statistical association between electricity consumption and the country's production of crude oil, which is the primary source of the government's income. The increase in power demand has been a result of (1) the expansion of the power supply area due to the government's building of power transmission and distribution facilities, (2) the increasing public investment in industrial real estates, hospitals, schools, roads and so on, and (3) private investment in housing and the private consumption of electrical appliances, as a diffusion of public spending.

The energy consumption and the peak load for both Muscat and Wadi Jizzi Electric Systems are expected to increase steadily and rapidly. The total consumption of electricity of both systems is projected to rise from approximately 3,767 GWH in 1993 to 10,874 GWH in 2010. (These figures do not include the consumption at desalination plants.) The average annual rate of increase is calculated at 6.4 percent.

The composition of the electricity consumption is not expected to change significantly. The domestic consumption of the Muscat System will continue to account for nearly half of the total consumption. The number of household connections in the system is expected to rise at an annual rate of 3.5 percent, whereas the unit consumption (i.e., average consumption per connection) is projected to rise at a yearly rate of 3.5 percent between 1993 and 2000, 3.0 percent during the following five years, and 2.5 percent thereafter, until 2010. The current household electrification ratio in the Muscat System area is estimated at nearly 100 percent, and hence, the population growth will be the primary factor for increasing the number of domestic connections.

For both systems, the growing domestic unit consumption is attributed largely to the steadily increasing use of air conditioners. Nearly every household in the Muscat and Wadi Jizzi Systems' area has at least one air conditioner. This electrical appliance is one of the household needs in this country, where the temperature rises to over 40 degrees centigrade in the summer. Given the fact that the average family size is about 7 in the systems' area, the number of air conditioners that the average household use will continue to increase, thus pushing up the unit energy consumption. The future domestic unit consumption is projected as follows:

| Year | 1990 (actual) | 1993 (actual) | 2000 (projected) | 2010 (projected) |
|---|---|---|---|---|
| Muscat System (MWH) | 12.6 | 14.6 | 18.6 | 24.4 |
| Wadi Jizzi System (MWH) | 8.2 | 9.3 | 12.2 | 17.7 |

The medium spending on electricity among the connected households in the capital area is estimated at 160 R.O at present, as compared to the estimated medium household income of 2,500 R.O. a year in the area. It must be noted that the energy demand in the future will be materially affected by the growth of household income.

As far as the non-domestic electricity consumption is concerned, a marked change is anticipated in the government consumption for the Muscat System. The change is a substantial decrease in the percentage of that consumption to the total consumption, from approximately 20 percent in 1993 to 15 percent in 2010. This proportional decrease will be offset by an increase in commercial and industrial shares, presumably reflecting a progressive shift in the government's development role from direct involvement to indirect assistance to the private sector.

The total power requirement of the two systems (including the requirement for desalination plants) is expected to increase from approximately 1,000 MW to 2,900 MW during the intervening 17 years between 1993 and 2010. The average annual rate of increase is computed at 6.5 percent. With an assumption that the total installed capacity of the existing power stations will remain at 1288 MW after 1996, the power requirement for the proposed Barka power station is projected at 106 MW in 1998, 304 MW in 2000, and 1,640 MW in 2010.[1] (A power shortage is expected in 1997, before the first generating unit of the Project is commissioned.)

### 2.3.6 Power Supply Development Plan

#### (1) Type of Generating Capacity to be Ensured

Considering demand characteristics in the Sultanate of Oman, generating capacity for this project will be provided by a combined-cycle plant, through a combination of gas and steam turbines using natural gas as fuel. The portion of the daily load curve to be allocated to the project extends from the base load to the peak load, and the generating capacity must be able to handle wide load fluctuations.

#### (2) Forecasting Supply Capability

The present generating capacity of the Muscat and Wadi Jizzi Systems is 1,037 MW. With 276 MW (220 MW in the Muscat System and 56 MW in the Wadi Jizzi System) to come onstream by 1996, total capacity will rise to 1,313 MW. This figure will decrease due to plant shutdown and scrapping

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[1] The forecast was made by using the micro method and the macro trend extrapolation. The one made by the micro method was adopted as the final forecast. For the Project's desalination system, the RO process was assumed.

associated with the growing obsolescence of some generating equipment. With a service life of 20 years assumed for power generating equipment, it is estimated that generating capacity will drop rapidly, from a peak of 1,288 MW in 1996 to 304 MW in 2010 as power generating equipment are expected to reach the end of their service lives. However, the MEW has not released details of plans to retire and scrap the power plants, nor have they issued an electric power development plan to compensate for the reduction in supply capability.

### (3) Installed Capacity of Power Plant

Installed capacity of the power plant being developed for this project will consist of enough capacity to meet maximum power consumption projected for each year until 2010, plus a reserve margin (150 MW). Plant operations will start up in four stages:

| | | |
|---|---|---|
| Phase 1 | 1999 | 388 MW |
| Phase 2 | 2002 | 292 MW |
| Phase 3 | 2007 | 584 MW |
| Phase 4 | 2010 | 584 MW |
| Total | | 1,848 MW |

As decided through consultations with MEW, installed capacity will be maintained at the 1996 level of 1,288 MW until 2010. In a separate project, MEW is to successively replace existing power plants that have reached the end of their service lives, with more reliable and cost-effective equipment.

## 2.4 Power Plant

### 2.4.1 Fuel

MEW has determined that the fuel will be as follows:

| | | |
|---|---|---|
| (1) | Main fuel | Natural gas (lower heating value 35,800 KJ/kg) |
| (2) | Emergency fuel | Distillate oil (lower heating value 42,915 KJ/kg) |

### 2.4.2 Selection of Unit Generating Capacity

The greater the unit capacity of a power plant, the lower the construction, operating and maintenance costs per unit. The disadvantage is that breakdowns have more wide-ranging effects. After determining that the unit capacity for this project would be in the range of 60 MW to 120 MW, the optimum capacity had to determine, taking into account economic issues as well as reliability and stability. Our study revealed that 100 MW units would be optimal. The maximum capacity of existing power plants is 83 MW at the Rusail Power Plant, and since MEW has adequate experience in the operation, maintenance and management of units of this capacity, the transition to 100 MW units should be smooth.

### 2.4.3 Selection of Type of Power Plant

#### (1) Type of Power Plant to Be Selected

The selection of a type of power plant must take into account reliability, stability and economy in combining a power plant with a desalination plant. For this project, we selected the multi-stage flush (MSF) and reverse osmosis (RO) methods were selected, which are typically used in desalination plants. The type of power plant capable of coping with fluctuations in power demand (mid-range load and peak load) was considered.

#### (2) Power Plant Suited to the MSF Process

The amount of steam required by a desalination plant using the MSF process is relatively stable because seasonal and daily fluctuations in water demand are stable. Accordingly, the power plant must have good follow-up characteristics for load fluctuations, as well as a high thermal efficiency, and the power plant and desalination plant should have excellent overall operational reliability and stability. The method that best satisfies these conditions is the co-generation system, which will supply steam needed by the desalination plant using the exhaust of a back-pressure turbine, and at the same time generating electricity, for which it will be allocated the base load component on the daily load curve.

To guarantee the required volume of steam and reliability and stability of the electric power supply, the optimum unit capacity of the power plant will be 60 MW. Four units (total output: 240 MW) will enable the plant to generate the annual base load of 350 MW by adding 110 MW generated from an independent power supply system.

#### (3) Power Plant Suited to the RO Process

When a power plant is used in combination with a desalination plant employing the RO process, there is only a 100 % electric power load and no steam load. Because this power load becomes the base load of the power plant, a power plant that is capable of maintaining high heat efficiency is crucial. Accordingly, a combined-cycle plant that achieves thermal efficiency of 48 % or greater (lower heating value LHV base, 50°C) at the generating end is optimal.

(4) The Optimum Power Plant When Used in Combination with a Desalination Plant

Two options in terms of thermal efficiency, operational reliability and stability, operability and maintainability, construction period, construction cost and fuel consumption were compared.

Option A: A co-generation plant employing a back-pressure turbine combined with an MSF-process desalination plant.

Option B: A combined-cycle power plant combined with an RO-process desalination plant.

With Option B, not only do the excellent load follow-up characteristics of gas turbines match the distinctive load fluctuations in Oman, but the power plant also enjoys lower construction and running costs. Overall, therefore, we conclude that Option B is superior to Option A.

(5) Power Plant for Independent Use

Independent power plants are designed to allocate the intermediate and peak load components of the daily load curve in order to absorb seasonal and daily fluctuations in power demand. Accordingly, this type of plant requires a power plant that is capable of frequent start-ups, wide-ranging load adjustment capability, and maintenance of a high thermal efficiency, even at partial load. Since the combined-cycle plant satisfies these requirements, it can be used in independent power plants.

### 2.4.4 Basic Configuration of the Power Plant

Since the combined-cycle plant is advantageous when used with an RO-process desalination plant, and is also superior when used as an independent power plant, it has been decided that the basic configuration of the power plant will be as follows:

(1) A combined-cycle plant comprising two gas turbines (96 MW x 2), two heat recovery steam generators (HRSG), and one steam turbine (100 MW x 1) in one block. The total output of one block is 292 MW.

(2) The required installed capacity of 1,848 MW by the year 2010, the final year of the project, will be composed of six blocks of combined cycle plant and one open cycle gas turbine.

### 2.4.5 Features of Combined-Cycle Power Plants

Combined-cycle power plants combine a gas turbine based on Brayton Cycle and a steam turbine based on Rankine Cycle, thereby improving overall thermal efficiency. Their features are as follows:

(1) Thermal efficiency is extremely high - 48 % (the figure planned for this project is 48 %).
(2) The rated thermal efficiency can be maintained even under partial load.
(3) Start-up and shutdown times are short.
(4) Maximum output increases as air temperature decreases.
(5) The volume of hot water discharge is low.
(6) There are very few atmospheric pollutants because natural gas is used.

## 2.5 Power Transmission and Transformation Facilities

### 2.5.1 Power Transmission Plan

The majority of power generated at the Barka Power Station, which has a planned installed capacity of 1,848 MW, is transmitted to the Muscat metropolitan area via the Bait Barka and Madinat Qaboos substations. So that the power transmission line does not impede land development in the districts over which it passes, the mountainside route of the existing 132 KV power transmission lines was selected was selected.

### 2.5.2 Power System Analysis

A power system analysis of the Barka Power Station, focusing on the following points was performed:

(1) The power flow and voltage drops in the power transmission lines and substations.
(2) Higher transmission voltage.
(3) Capacity of interconnected transformers.
(4) Stability, frequency drop and system operation.
(5) Short-circuit capacity of transmission system.

The results of the sample systems analysis were presented to MEW, using a computer simulation focusing on power flow and stability.

### 2.5.3 Selecting Higher Transmission Voltage

For transmission lines interconnecting the Barka Power Station and the Bait Barka and Madinat Qaboos substations, transmitting 1,200 MW of electric power to the Muscat System over a distance of 60 km would require multiple lines at the existing voltage of 132 KV, which is not realistic from a technical standpoint. A higher voltage is therefore necessary. Three nominal voltages of 220 KV, 275 KV and 400 KV were investigated. After performing technical and economic comparisons, it was concluded that a 220 KV line would be best, taking into consideration its adaptability for future expansion of the system.

### 2.5.4 Power Transmission Lines

Power transmission lines comprise two vertically arranged circuits suspended on steel towers, constructed of structural steel. The lines themselves will use AAAC wires, and by calculating the size from stable limit transmission capacity, taking future demand into consideration, the size of each line has been set at 400 $mm^2$ x 4 conductor/phase.

### 2.5.5 Substations

Taking into consideration the convenience of system management, operability during inspection or when faults occur, and reliability, the double bus 4 bus tie system will be used. Substations will incorporate gas-insulated switchgear (GIS), which comprise integrated equipment such as $SF_6$ (sulfur hexafluoride) circuit breakers and isolators. The GIS units will be useful in combating salt-dust damage, harmonizing with the environment and saving space.

In a system that incorporates direct neutral grounding for both the primary and secondary sides, the use of auto-transformers in the Y-Y windings of the transformers for the Y-Y-D connections is advantageous, not only in terms of reliability, but also from an economic point of view. Therefore, the auto-transformers have been adopted for the transformers with 220 KV/132 KV interconnections.

## 2.6 Present State of Water Resources and Development Plan

### 2.6.1 Existing Water Supply Utilities

#### (1) Water Resources

Compared with the other Gulf Coast Countries, Oman has mountains in the central part of the country providing comparatively large amounts of rainfall, and there are many wellfields for natural water supply from ancient times.

In the Muscat area, however, water demand has increased in recent years to be ensured along with the area modernization, and the Ghubrah Desalination Plant is now operating with 132,000 m$^3$/d (29 MGPD) water production in a total of 5 units which were constructed from 1976. Well water is restricted to 20,000 m$^3$/d for resources conservation.

The existing water supply capacity (since 1993) is therefore a total of 153,000 m$^3$/d including a desalination plant of oil refinery, and also the Ghubrah Plant is expected to have an additional No. 6 unit in service with 27,300 m$^3$/d water production in 1996. Water production costs for the desalination plant are about 600 baiza/m$^3$. In the South Batinah area, there are no desalination plants and the inhabitants are obliged to depend on well water.

#### (2) Water Supply Facilities

Water supply in the Muscat area is routed as follows:

Water Source → Water Reservoir → Consumer
(Pump station)
Main water transmission pipeline
Water distribution network

As the water sources, there are the Ghubrah Pump Station, Eastern area wellfields, Central area wellfields and Western area wellfields.

Main water transmission pipelines of 1,000 mm dia are laid out for a total of 41 km from the Ghubrah Pump Station to both, the east and west. Also from Mowallah, at the west end of the system, a pipeline of 600 mm dia is connected to the Seeb water reservoir.

There are 12 service area reservoirs in total, of various scale, which are provided to cover daily consumption of each contract areas.

Producted water from the MSF process plant is supplied, after post-treatment by mixing well water and the addition with alkaline substances, fluoride, etc., to improve its quality for drinking purpose.

Water is provided at a rate of 2 baiza/gallon (440 baiza/$m^3$) for general use, and 3 baiza/gallon (660 baiza/$m^3$) to industries.

### 2.6.2 Organization of Water Supply System

All the water supply in the Muscat area is managed by MEW.

The Desalination Plant is handled by DGE, through construction, operation and maintenance, and is trusted to the charge of SOGEX Co. together with the Power Station.

The downstream water supply system with water transmission piping is in the charge of DGW, and in the Muscat area is operated and maintained by the Directory of Muscat Water of DGW.

### 2.6.3 Fluctuation Character on Demand and Supply of Water

Water demand in Muscat area is steadily increasing. Although it varies with a pattern of increase in summer and decrease in winter, the difference is not so much that the most of it, in June, is 11 % over the average. Daily fluctuation is also 30 % over the annual average even at the maximum record. Therefore, there is sufficient water supply for the water demand including such seasonal and daily fluctuation together with water reservoir and wellfieldes if necessary.

### 2.6.4 Water Demand Forecasting

Similar to the case for electricity consumption, water consumption has a strong statistical association with the country's production of crude oil. It is presumed that an increase in water consumption is largely subject to the level of the public investment in the water transmission and distribution facilities, which in turn is affected by the government's revenue from crude oil production.

Water consumption has been suppressed almost chronically, due to the insufficient capacity of water production facilities. It is estimated, more importantly, that only 45 percent of all the households of the Muscat Governorate were connected to the piped water system in 1993. Conversely, when the Project is realized, a sufficient water production capacity will become available, and if the piped water system is (or can be) expanded geographically at a rapid rate, water consumption will increase substantially. The potential demand for water is believed to be high, which means that people will consume more water, if sufficient water is available to them (through the piped system).

The Project intends to supply water to the existing Muscat water system as well as to six wilayats (districts) in South Batinah, including Barka, where it will be located. The total water consumption is projected to be approximately 150,000 cubic meters per day ($m^3/d$) in 2000 and 283,000 $m^3/d$ in 2010, as compared to the actual figure of 99,000 $m^3/d$ for 1993. The average annual rate of increase between 1993 and 2010 is calculated at 6.4 percent. For comparison, the rate of increase between 1981, when the total consumption was approximately 20,000 $m^3/d$, and 1993 was 14.3 percent on average.

The water consumption in South Batinah alone is estimated at 5,000 $m^3/d$ in 2000 and 32,000 $m^3/d$ in 2010. The unit consumption (i.e., average consumption per connection) in the region, where piped water is not yet available, is expected to be much lower than that in the capital area. For example, the domestic unit consumption will be approximately 0.5 $m^3/d$ in 2000, and 0.75 $m^3/d$ in 2010. The corresponding figures for the Muscat area are 1.1 $m^3/d$ and 1.4 $m^3/d$, respectively.

Consumption by domestic consumers in the Muscat area is expected to account for approximately 50 percent of the total in 2010, up from 41 percent in 1993. The average annual increase in the number of household connections in the area is assumed at 2,000 between 1994 and 1996, 3,500 in 1997 and 1998, 4,250 for the subsequent 5 years, and 3,850 thereafter, until 2010. The corresponding figure for the last three years between 1990 and 1993 is estimated at 2,000 per year. The above projected figures reflect the government's stated policy to expand the supply area in a positive manner. As the piped water distribution network is expanded into remote areas, the per-connection cost for the provision of transmission and distribution facilities will become higher. Therefore, if the capital investment in the distribution network remains at the same level, the annual increase in the number of connections will decrease. If the connections are increased in number as projected, the household service ratio in the Muscat Governorate will rise to approximately 62 percent.

The domestic unit consumption in the Muscat area in 1993 was 0.98 $m^3$/day or 216 gallon/day. This level of consumption is equivalent to the spending of approximately 13 R.O. a month, at the existing tariff of 2 baiza per gallon. While the medium spending on supply water is not known, it is safe to assume that the medium spending is smaller than the mean. Nevertheless, the cost for supply water is not small for the medium income families, in considering that the estimated medium monthly income is 200 R.O. in the area. The average annual increase in the domestic unit consumption is projected at 2 percent until 2010.

While the domestic water consumption of the Muscat Water System is expected to increase 3.5 times during the 17 years between 1993 and 2010, the increase in government consumption will be less than twice. The reason is that the number of potential government customers outside the capital area is limited. Commercial consumption, which includes consumption by industrial establishments, is projected to increase by 3.6 times during the same period. Although the unit consumption will not rise at more than 2 percent annually, the number of commercial consumers is expected to increase at more than 5 percent annually. This high rate of increase can be explained, to some extent, by the government's continuous efforts for the industrialization and economic development of the nation. New connections for commercial uses occur in the areas already served, as well as in newly expanded areas. It is anticipated that commercial consumption will exceed government consumption by the year 2010.

### 2.6.5 New Desalination Plant Development Plan

#### (1) Relation to Current development plan

In MEW's Muscat Water Supply Master Plan developed in 1993 (hereinafter referred to as "Master Plan"), it has been concluded such that, through feasibility study of four plans: underground water, surface water, extension of the Ghubrah Desalination Plant, and new Barka Power Generation and Desalination Plant, these plans except for the water dependent on wellfields are applicable.

This feasibility study is, however, focuses on the Barka Plant expecting the water production to be reasonably sufficient to cover the increasing water demand in Muscat and South Batinah area in 2010, independently without consideration to any other plan.

(2) Forecasting of existing water supply facilities capacity

Water production capacity of the existing facilities of MEW will be at 180,000 $m^3/d$ in 1998, just before Barka plant first started commercial operation.

On other hand, the existing plant would also be able to remain in service as long as within economical balance, though the legal depreciation period provided is 20 years. In this view point, the Ghubrah Plant would mostly be available in 2010, while the No. 1 and No. 2 Unit should be renewed because they are not economical due to single purpose MSF unit with high fuel cost and would also be elapsed into 34 years and 27 years of service respectively by 2010.

On such partial renewal of the Ghubrah Plant, the Barka Plant could fill up the shortage of Ghubrah with allowance of its water production capacity.

(3) Unit capacity

In case MSF process, the unit is desirable to be made larger in capacity for economy in service, while it has a trend disadvantage for maintenance work as its scale, paradoxically.

In the Ghubrah Desalination Plant, unit capacity is uniformly 6 MGPD except for the No. 1 unit.. For Barka Plant, the unit capacity adopted will be 7 MGPD, and built with 2 units as a set at the same time considering combination with the power generation plant.

(4) Required capacity of water production in 2010

Required capacity of Barka water production in 2010 is given as follows:

- Water demand of Muscat and South Batinah area in 2010 : 282,809 $m^3/d$
- Required design capacity ((282,809 ÷ 0.85) x 1.2)* : 399,260 $m^3/d$
- Existing facilities capacity : 180,230 $m^3/d$
- Required capacity of Barka Desalination Plant : 219,030 $m^3/d$

Therefore, the Barka Plant capacity should be as total 254,000 $m^3/d$, based on each capacity 7 MGPD (31,800 $m^3/d$) of 8 units.

* 0.85 : Revenue ratio - See § 5.3.2 (1)
1.2 : Design capacity ratio - See § 5.3.2 (3)

(5) Construction schedule

The construction schedule shall be provided with four stages as water demand estimation.

| | | | |
|---|---|---|---|
| The First Stage | : | Commissioning in 1999, | 63,600 m³/d |
| The Second Stage | : | Commissioning in 2002, | 63,600 m³/d |
| The Third Stage | : | Commissioning in 2006, | 63,600 m³/d |
| The Fourth Stage | : | Commissioning in 2009, | 63,600 m³/d |

## 2.7 Sea Water Desalination Plant

### 2.7.1 Design Criteria

(1) Product Water quality

It shall conform with Omanian Standard No. 8 Drinking Water.

(2) Sea Water condition

Sea water conditions are applied the data from the Ghubrah Plant, including temperature.

- Salinity (TDS) : 39,500 ppm
- Temperature : 24 -35 °C

### 2.7.2 Selection of Desalination Process

(1) Desalination process

While there are several desalination processes, both MSF and RO processes are currently leading, and they have a share of 71.7 % and 19.4 %, respectively, for more than 4,000 m³/d of unit capacity at the end of 1993.

In case of sea water desalination MSF and RO have share of 79 % and 16 % respectively among the recent large sea water desalination plants more than 4,000 m³/d capacities, at order base from 1990 to 1993.

Total record of RO process sea water desalination plants up-to-date more than 4,000 m³/d in capacity are also 31 plants with about 700,000 m³/d, including constructed and contracted ones, and half of them have been contracted since 1990.

It seems that the RO process plants will steadily be increased further as well as enlargement of the unit scale, from now on.

Comparison of both processes, MSF and RO, are described in the followings.

(2) Technical evaluation

The MSF process established around 1960 is matured and stable in technology and have high reliability at present, but is unexpectable for further technical advancement.

Although the principle of the RO process was discovered by Sourirajan, Loeb et al. during the 1950s and quickly progressed, application to sea water desalination was late and the first large RO process plant was established in 1984 in Bahrain, with a capacity of 45,000 $m^3/d$. And, now, it is still under developing stage.

Major differences between both processes in application, MSF and RO, are energy consumption rate and membrane replacement cost.

In case of MSF process, it requires considerable steam and electricity in consumption which is primarily incorporated with electric power generation as dual-purpose use of the steam before desalination stage in order to improve the thermal efficiency. The MSF process is not economical as it requires much steam consumption in itself, comparing to RO process.

In the RO process, it needs often to replace RO element due to degradation of RO membrane, and it is normally impossible to extend its service life without replacement.

Cause of degradation is normally classified into four categories; mechanical, biological, physical and chemical causes.

For such causes of degradation, it has had resolution in the progress of preventive technics using pre-treatment processes. Especially risky problems are membrane oxidization by $Cl_2$ can be prevented by use of chlorine-resistive material and reducing agent injection.

Durability of membrane can surely be extended to make the average service life longer, through investigation of the cause and by pre-treatment of the raw sea water. At present, it is insured for the membrane element to have 5-years service life with 12 - 20 % of annual replacement ratio, assumed by appropriate pre-treatment, taking place for previous condition of the service life as 3 years, so that RO plant has become available depending on its reliability.

In other points, advantages of MSF process are described for the superiority of product water quality, and less chemicals required for pre-treatment of raw sea water quality due to its easy treatment conditions.

While, the advantages of RO process are that there is no necessity of blending, simple post-treatment because of enough salinity of product water, less intake quantity of raw sea water, easy operation and simple maintenance, and less delivery time of 6 month than MSF for construction.

However, the major points in comparison will be focused to their economy, without regard to the above-mentioned matters.

(3) Economic comparison of both systems

The economic comparison of both systems are conducted under the following conditions:

a) Ghubrah No. 5 Unit's 1993 operation record is used as typical MSF plant. There are applied actual data such as operation hours, power generation, exported electricity, water transmitted, and operation cost etc.

b) The Ghubrah No. 5 Unit figures are also used for the RO plant's ones for power generation and water production, based on assumption of the same conditions of comparison.

For the power station, it is applied in combined cycle. The operation cost etc. are also calculated from the relevant documents.

Case 1: Ghubrah No. 5 Unit water production costs are calculated with expected electricity unit price 14 RO/MWh.

Case 2: Water production costs are calculated, using purchased electricity unit price, independently of the RO process plant.

Case 3: Water production costs are developed from an expected combined system loading with the same output as Case 1.

The result of the calculations is given in the following:

| | |
|---|---|
| Case 1: | 640 baiza/m$^3$ |
| Case 2: | 515 baiza/m$^3$ |
| Case 3: | 430 baiza/m$^3$ |

These values would be keep the position relative to each other due to adequate comparative condition, even when the absolute quantity vary a little within an extent from variation of the assumption.

(4) Overall conclusion from the comparisons

MSF plant is superior in reliability due to the many operating plants while it is not so economical and takes a longer delivery time.

In case of the RO plant, the adoption would depend finally on the economical difference to MSF plant, because of RO's applicability is steadily higher with its reliability, also for this project.

Therefore, we decided to evaluate further in detail (as shown in Table 9.2.9) the difference between them in economics estimated for 2010 at Barka Power Station. Also a conceptual design was conducted to evaluate both process plants.

### 2.7.3 Conceptual Design of Desalination Plant

For both, MSF and RO processes, the conceptual design are conducted as follow:

(1) MSF process

To be composed of 60 MW back-pressure turbines and two trains of 31,800 m$^3$/d (7 MGPD) desalination units.

(2) RO process

To be based on the same capacity as MSF, 31,800 m$^3$/d (7 MGPD) x 2 units, per set.

### 2.7.4 Conceptual Design of MSF Plant

Principal particulars are as follows:

| | |
|---|---|
| Type | Cross tube type multi-stage flush type |
| Total Production Capacity | 254,000 $m^3/d$ |
| No. of Units | 31,800 $m^3/d$ x 2 unit x 4 set |
| Scale prevention | Anti scale agent injection and ball cleaning |
| Evaporator stage number | Heat Recovery Section 20 stages<br>Heat Rejection Section 3 stages<br>Total 23 stages |
| Performance | 8.0 lb/1,000 Btu |
| Brine top temperature | 107 °C |
| Post treatment | $CO_2$ + Limestone treatment<br>Chlorination |

### 2.7.5 Conceptual Design of RO plant

Principal particulars are as follows:

| | |
|---|---|
| Type | Reverse Osmosis Process Type |
| Total Production Capacity | 254,000 $m^3/d$ |
| No. of Units | 63,600 $m^3/d$ x 4 unit |
| Pre-treatment | Chlorination<br>gravity filtration (coagulant filter)<br>pH adjustment<br>Dechlorination<br>safety filter (cartridge filter) |
| High Pressure Pump (per Unit) | 950 $m^3/h$ x 8 pumps with energy recovery turbine 8 trains |

| | |
|---|---|
| • RO module | |
| • Post treatment | pH adjustment with $Ca(OH)_2$<br>Chlorination |

Operation condition:

| | |
|---|---|
| • Chlorine Injection | 1 - 2 ppm as $Cl_2$ |
| • Recovery Rate | 40 % |
| • Power Consumption | less than 7.2 KWh/$m^3$ |

## 2.8 Water Transmission Facilities

### 2.8.1 Water Transmission Plan

(1) Scope of conceptual design

The conceptual design for the facilities (water reservoir and pump station) within the Barka Plant Site and the main water transmission pipeline to service area reservoir are included.

(2) Water transmission plan

On completion of the Barka plant in 2010, the product water 254,000 $m^3$/d from Barka will be distributed by rough estimation as follow:

| | | | | |
|---|---|---|---|---|
| Product water<br>254,000 $m^3$/d | → | 200,000 $m^3$/d | : | Muscat area |
| | → | 45,000 $m^3$/d | : | South Batinah area |
| | → | 9,000 $m^3$/d | : | On-site and its surroundings |

(3) Planning of transmission pipelines

The diameter and examined the pressure loss using Hazan-Williams Formula is determined for each pipeline.

## 2.8.2 Water Transmission Facilities

### (1) Water reservoir

The capacity of water reservoir facilities at the Barka Site will be sufficient to accommodate the daily production output of the desalination plant, as 32,000 m$^3$ x 2 reservoir x 4 set, according to the Guidelines of MEW.

### (2) Water pump

| | |
|---|---|
| Number of Pumps | 10 sets (including standby 2 set) |
| Type | Single stage centrifugal pump |
| Capacity | 1,460 m$^3$/h |
| Head | 100 m |
| Motor output | 640 KV |

### (3) Transmission pipeline to Muscat area

For the pipeline, it will be made of cement lining ductile iron pipe with the following sizes:

| Origin | | Destination | Distance | Pipe bore |
|---|---|---|---|---|
| Barka | → | Seeb Reservoir | 30 km | 1,400 mm |

Eastward water transmission further than Mowallah is to be through the existing pipeline and also pipelines from Seeb reservoir will be installed by MEW before the Barka project starts.

## 2.8.3 Water Transmission to South Batinah

### (1) Proposed service area and pipeline route

The service area and pipeline will be proposed as follows:

Route A: Barka Plant → Barka → Point "A" → Nakhl

Route B: Point "A" → Point "B" → Al Musannah
→ A'Rustaq → Al Awabi

(2) Water transmission facilities

As the pipeline to the district to be served is at a high elevation from sea level, each pump station with a small buffer reservoir should be installed at the level of approximately 100 m above each other

### 2.8.4 Water Transmission Cost

Water transmission costs are shown in the following table:

| Walayat | | Barka | Nakhl | Al Musannah | A'Rustaq | Al Awabi | Total |
|---|---|---|---|---|---|---|---|
| Population in Dec. 1993 | | 61,164 | 12,570 | 45,414 | 59,379 | 8,488 | 187,015 |
| Approximate Design Demand at 2010 | $m^3/d$ | 15,000 | 3,000 | 11,000 | 14,000 | 2,000 | 45,000 |
| Estimated Construction Cost | Million R.O. | 0.42 | 3.41 | 2.69 | 7.41 | 2.36 | 16.30 |
| Transmission Cost Total | $Baiza/m^3$ | 6.8 | 99.9 | 25.6 | 84.2 | 131.9 | |

## 2.9 Civil and Architectural Facilities

### 2.9.1 Design Conditions

(1) Concrete : Ordinary Portland Cement Concrete

(2) Significant Wave Height : $H_{1/3} = 3.7$ m

(3) Design Wind Speed : V = 80 knots (approx. 40 m/s)

(4) Horizontal Seismic Coefficient : $Kh = 0.02$

### 2.9.2 Foundations

In accordance with the results of the soil investigation, a soil strata with SPT - value ≥ 20 exists at a depth of more than 3.0 ~ 8.0 m from the existing ground surface, but more than 5.0 ~ 12.0 m from the finished ground level (HAT + 4.0 m). It is not feasible to adopt direct foundations. Therefore, pile foundations (driven cast-in-situ piles) which reach a firm strata with SPT - value ≥ 50 are to be adopted to support the main facilities.

Pile diameter : d = 500 mm

Allowable axial bearing capacity : qa = 90 T

### 2.9.3 Finished Ground Level of Site

It is necessary to raise the ground level of the site to secure the safe operation of proposed plant, considering the high water level and wave height. According to the study on wave overtopping and wave run-up, the finished ground level of the site is determined as HAT + 4.0 m. As a result, the present ground level will be raised about 2.2 ~ 4.0 m.

### 2.9.4 Water Intake System

Three types of water intake facilities were studied.

- Open channel type
- Buried pipeline type
- Jetty type

Considering the experience in Ghubrah Power and Desalination Plant, the possibility of oil leakage in the Gulf region, impacts to the environment and so forth, it is concluded that a water intake system with buried pipelines is to be adopted.

## 2.10 Operation and Maintenance Plan

So that the power and desalination plant can be operated and maintained safely and economically, an operation and maintenance plan specifies the management structure and other requirements for plant operation and maintenance, and details of the operating organization and staff are needed.

The following can be cited as operation and maintenance management items: operations management, daily inspections, routine inspections, repairs and retrofitting, and equipment history management. The organizational structure required to perform these duties will comprise an Operation Department, Maintenance Department and Administration Department. A plant manager and a deputy plant manager will direct operations. Personnel estimated for this project will total 445. These staff will fall into the following categories:

| | | |
|---|---|---|
| (1) | Office of the Plant Manager and Deputy Manager: | 4 |
| (2) | Operations Department (four shifts): | 184 |
| (3) | Maintenance Department: | 210 |
| (4) | Administration Department: | 47 |
| | Total | 445 |

These personnel must meet educational qualifications and have adequate experience corresponding to their occupational category. They will be employed as the completion of each construction phase requires, and after receiving on-the-job training and other instruction, will take part in plant operation, maintenance and management.

## 2.11 Environmental Study

### 2.11.1 Natural Environment

The area around the proposed project site is not developed and its natural environment is well preserved. Furthermore, the coastal area including the proposed site is designated as a "Coastal Reserved Area".

There are several kinds of trees, shrubs and other plants in and around the site. Activities of some animals and birds have also been seen. However, it appears that no endangered species of fauna and flora exist in this area.

### 2.11.2 Social Environment

There are several towns or villages such as Haradi, Hayyasim, etc. around the proposed site, where the major economic activities are fishing and farming. Other notable economic activities were not seen and there are no sources of pollution.

The seaside is used for recreation such as swimming and boating by some people.

There are no reports or information indicating the existence of any sites of cultural heritage.

### 2.11.3 Major Study Items

It was found, as a result of the environmental examination, that the following are the major study items which are expected to give a certain impact to the surrounding environment.

(1) Type of Water Intake Facility

Construction of a water intake facility protruding far from the shore may cause some impact to the natural environment such as a change of landscape and a change of shoreline features. From the aspect of the environmental protection, a water intake facility with a buried pipeline is the most recommendable option.

(2) Hot Water Discharge

It is considered that there is no serious impact to aquatic biota and fishing due to the hot water discharge from the following points of view:

1) A similar marine environment exists in a wide area along the coast.

2) No mangroves and coral reefs exist around the site.

3) The main fisheries are in the area around the islands which are located about 15 km offshore.

It is, however, to be noted that an outfall needs to be designed to minimize the impact area.

(3) Waste Water Discharge

Waste water from the plant needs to be discharged outside the plant after treatment to the allowable levels.

(4) Air Pollution

It is expected that the exhaust gas from the plant will not cause a serious impact to the surrounding environment since natural gas is the main fuel.

(5) Noise and Contamination of Seawater during Construction

It is anticipated that the impact to the economic activities and the environment in the surrounding area is not serious. However, it is necessary to explain to the local inhabitants the necessity and advantages of the project as well as to select adequate construction methods for minimizing the impact.

### 2.11.4 Environmental Protection Measures

Prior to the implementation of the project, it is necessary to carry out detailed investigations on the natural and social environment and prepare a supplementary EIA report. It is important that, based on the above, environment protection measures are adequately planned in the detailed design stage.

## 2.12 Implementation Plan

Today, power and water demand in the Muscat district exceeds the supply capacity, and this demand will rapidly increase in the future. The meet this demand, a power facility of at least 150 MW must commence operations in early 1998. Furthermore, a desalination facility must come on-line as soon as technically possible, with another one capable of a 63,000 m³ daily output necessary to start operations by mid 1998. To accomplish this, the engineering works that are required before the construction of plant facilities must be carried out on schedule.

- Completion of the bidding documents - September 1995
- Signing of the contract and commencement of the construction - May 1996

When construction begins according to the above schedule, annual capacity of the power and desalination plants made available for commercial operation is as follows;

| Year<br>Description | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Power Plant (MW) | | | | | | | | | | | | | |
| Installed Capacity | 192 | 196 | 96 | 96 | 100 | 96 | 196 | 96 | 96 | 196 | 96 | 196 | 196 |
| Cumulative Total | 192 | 388 | 484 | 580 | 680 | 776 | 972 | 1,068 | 1,164 | 1,360 | 1,456 | 1,652 | 1,848 |
| Desalination Plant (x $10^3 m^3/d$) | | | | | | | | | | | | | |
| Installed Capacity | 63.6 | | | 63.6 | | | | 63.6 | | | 63.6 | | |
| Cumulative Total | 63.6 | | | 127.2 | | | | 190.8 | | | 254.4 | | |

## 2.13 Construction Cost Estimate

The construction costs were estimated at 1994 prices. These construction costs include physical contingencies for the civil works and electrical/mechanical equipment of 10 % of their respective base direct cost, MEW's administration expenses of 0.5 % of the base direct construction cost annually and engineering fee of 1.5 % of the base direct construction cost.

The following foreign exchange rate is applied in the study;

US$1.00 = 0.3845 Rial Omani (R.O.)

The total construction costs of the project at 1994 prices based on the above conditions is as follows:

(1) Alternative A (Desalination : MSF Process)

1) Electric Power Portion : 563.90 million R.O.
2) Desalination Portion : 332.26 million R.O.
Total 896.16 million R.O.

(2) Alternative B (Desalination : R.O. Process)

1) Electric Power Portion : 564.18 million R.O.
2) Desalination Portion : 262.02 million R.O.
Total 826.20 million R.O.

The breakdown of construction costs is as follows:

(1) Alternative A (Desalination: MSF Process)

(Million R.O.)

| Category | Item | Foreign Currency | | Local Currency | Total |
|---|---|---|---|---|---|
| | | | (Million US$) | | |
| Electric Power Portion | Power Plant Facilities | 421.47 | (1,096.15) | 29.56 | 451.03 |
| | Power Transmission Facilities | 40.91 | (106.40) | 11.53 | 52.44 |
| | Sub-Total (Base Direct Cost) | 462.38 | (1,202.56) | 41.09 | 503.47 |
| | Contingencies, MEW Admi. Expense, Engineering Fee | 53.79 | (139.90) | 6.63 | 60.42 |
| | Total (1994 Prices) | 516.17 | (1,342.45) | 47.72 | 563.89 |
| Desalination Portion | Desalination Facilities | 199.78 | (519.59) | 50.94 | 250.72 |
| | Water Transmission Facilities | 32.60 | (84.79) | 13.34 | 45.94 |
| | Sub-Total (Base Direct Cost) | 232.38 | (804.37) | 64.28 | 296.66 |
| | Contingencies, MEW Adm. Expense, Engineering Fee | 27.69 | (72.01) | 7.91 | 35.60 |
| | Total (1994 Prices) | 260.07 | (676.38) | 72.19 | 332.26 |
| Grand Total | 1994 Prices | 776.24 | (2,018.83) | 119.92 | 896.16 |

(2) Alternative B (Desalination: R.O. Process)

(Million R.O.)

| Category | Item | Foreign Currency | | Local Currency | Total |
|---|---|---|---|---|---|
| | | | (Million US$) | | |
| Electric Power Portion | Power Plant Facilities | 427.33 | (1,111.39) | 23.96 | 451.28 |
| | Power Transmission Facilities | 40.91 | (106.40) | 11.54 | 52.45 |
| | Sub-Total (Base Direct Cost) | 468.24 | (1,217.80) | 35.50 | 503.73 |
| | Contingencies, MEW Admi. Expense, Engineering Fee | 54.38 | (141.43) | 6.07 | 60.45 |
| | Total (1994 Prices) | 522.62 | (1,359.23) | 41.57 | 564.18 |
| Desalination Portion | Desalination Facilities | 141.83 | (368.93) | 46.17 | 188.00 |
| | Water Transmission Facilities | 32.60 | (84.79) | 13.34 | 45.94 |
| | Sub-Total (Base Direct Cost) | 174.43 | (453.71) | 59.51 | 233.94 |
| | Contingencies, MEW Adm. Expense, Engineering Fee | 20.96 | (54.50) | 7.12 | 28.08 |
| | Total (1994 Prices) | 195.39 | (508.21) | 66.63 | 262.02 |
| Grand Total | 1994 Prices | 718.01 | (1,867.44) | 108.20 | 826.20 |

(3) Estimated Stage Construction Cost

The estimated cost of each stage for the best alternative, namely Alternative B, is as follows (1994 Prices):

1) First Stage Construction (May 1996 ~ Dec. 1998)

| | | |
|---|---|---|
| Electric Power Portion | : | 145.10 million R.O. |
| Desalination Portion | : | 113.19 million R.O. |
| Total | : | 258.29 million R.O. |

2) Second Stage Construction (May 1998 ~ Dec. 2001)

| | | |
|---|---|---|
| Electric Power Portion | : | 101.29 million R.O. |
| Desalination Portion | : | 49.61 million R.O. |
| Total | : | 150.90 million R.O. |

3) Third Stage Construction (May 2001 ~ Dec. 2006)

| | | |
|---|---|---|
| Electric Power Portion | : | 157.17 million R.O. |

Desalination Portion : 49.61 million R.O.
Total : 206.78 million R.O.

4) Fourth Stage Construction (May 2006 ~ Dec, 2009)

Electric Power Portion : 160.62 million R.O.
Desalination Portion : 49.61 million R.O.
Total : 210.23 million R.O.

## 2.14 Economic Evaluation

The economic evaluation of this feasibility study has four primary objectives: (1) to select the least cost development program among the four alternatives developed, (2) to determine the prices (or charges) of the Project's outputs, (3) to assess the financial viability of the Project from the lenders' or investors' viewpoint, and (4) to assess the efficiency of investing in the Project for the society as a whole. The least cost alternative is identified on the basis of the lowest present value of the discounted capital and operating costs. The benefit of the Project's outputs is expressed in terms of both capacity and energy (or "production") charges. These charges are determined based on the concept of the Long Run Marginal Cost (LRMC), which measures the full cost to supply utilities. The financial and economic viabilities of the Project are tested only for the least-cost alternative; and the feasibility assessment is made as to whether the financial or economic rate of return exceeds (or is equivalent to) the discount factor (or the opportunity cost of capital) of 8 % assumed for the Project.

### 2.14.1 Least cost development program

Among the four alternatives developed, Alternative 2 was found to be the least cost solution in both financial and economic terms, as shown below. Instead of 8 %, discount factors of 7 %, 9 % and 10 % were applied, to test for any change in the order of the total costs among the four alternatives. No changes were observed. For Alternative 2 (hereinafter referred to as "the Project"), the financial and economic rates of return were computed.

(million R.O.)

| Description | Capital cost | Operating cost | Not-shadow priced, total (financial cost) | Shadow priced, total (economic cost) |
|---|---|---|---|---|
| Alternative 1 (MSF, 4 stages) | 520.28 | 199.78 | 720.05 | 693.72 |
| Alternative 2 (RO, 4 stages) | 471.97 | 181.41 | 653.38 | 630.71 |
| Alternative 3 (MSF, 2 stages) | 536.02 | 199.83 | 735.84 | 709.67 |
| Alternative 4 (RO, 2 stages) | 478.65 | 181.41 | 660.06 | 637.74 |

### 2.14.2 Prices of the Project's outputs (long-run marginal cost)

Existing tariff levels are not high enough to cover the full cost to supply power and water. Approximately one-third of the total cost required for the services for those utilities was subsidized by the Government in 1993. The appropriate levels of charges (or prices) for power and water that the Project generates or produces, were set by employing the concept of Long Run Marginal Cost (LRMC), as shown below. Since the Project includes facilities for power generation/water production and transmission but not for distribution, the charges are those at the transmission-end and not at the consumer-end.

| | |
|---|---|
| Electricity: | |
| Capacity charge | 34.63 R.O./KW/year |
| Energy charge | 11.45 x $10^{-3}$ R.O./KWH |
| Water: | |
| Capacity charge | 219.34 R.O./$m^3$/d/year |
| Energy (or production) charge | 4.43 x $10^{-3}$ R.O./$m^3$ |

### 2.14.3 Financial rate of return

Two kinds of financial rate of return assessment were made. The first one was concerned with the rate of return of the Project, given no considerations to debt services and inflation so that the fundamental soundness of the Project can be evaluated. Regarding the power load factor, a constant factor of 52 %, which was projected for the system as a whole, was applied for the entire project life. Similarly, for the peak power load and the water requirement, the projected and limited demand for the Barka plant, which is equal to the difference between the total system demand and the existing capacity, was assumed until 2010. The other kind of assessment was concerned with the rate of return on the equity invested at the first stage of the Project, under more realistic circumstances. Cash flow tables were prepared in nominal prices, taking also into account the debt financing elements. Because of the higher cost efficiency of its operation, the proposed Barka plant in practice will have priority over the other plants as to operating hours. Hence, under this scenario, an average load factor of 70 %, a power requirement at the maximum available capacity of 92 %, and operation of the desalination plant at 95 % of its available capacity were assumed.

(1) Rate of return of the Project

The (internal) financial rate of return (FRR) of the Project was computed at 13 %. The FRR of the power division alone was 10 %, and that of the water division alone, 17 %.

(2) Rate of return on the equity invested in the first stage of the Project

It has been decided that the Project will be implemented by the BOO or BOOT method. The following assumptions were used for this rate of return analysis.

1) Equity-loan ratio: 1 : 1

(Some portion of the equity capital required may be raised by the sale of shares of the project company.)

2) Loan (non-recourse commercial bank loan):

| | |
|---|---|
| Interest rate: | 8 % |
| Amortization: | Approximately 10 years |

(Assume a fixed rate, while the rate actually adopted will be a floating rate.)

3) Concessions

a) Tax: Exempted from all the applicable taxes including income tax during the entire project period.

b) Power (and water) purchase on a "Take or Pay" basis.

(Operation at 70 % available capacity of the power plant, and at 95 % available capacity of the desalination plant)

c) Concession period: Life expectancies (20 years) for all the generation/ desalination equipment

d) Guaranteed supply of natural gas during the entire concession period, at the price of 0.0283 R.O. per cubic meter as of 1994 (annual 3 % increase).

4) Inflation: 3 %

The result of the analysis is summarized below. The debt service coverage is expected to be at 1.12 for the first year of the loan repayment. The ratio will rise steadily and quickly, to 1.51 for the fifth year.

| Summary of analysis | |
|---|---|
| Financial requirement | |
| Power plant: | US$324.39 million |
| Desalination plant: | US$180.55 million |
| Total: | US$504.94 million (194.15 million R.O.) |
| Finance | |
| Equity : | US$252.47 million |
| Loan: | US$252.47 million |
| After-debt service cash flow (1998-2018) | US$1,863 million (716.32 million R.O.) |
| Rate of return on equity: | 22 % |

A sensitivity test was performed regarding the power load factor assumed. As exhibited below, the FRR will be little affected at lower load factors.

| Sensitivity analysis | | | | |
|---|---|---|---|---|
| Load factor | 55 % | 60 % | 65 % | (70 %) |
| Net operating income (Thousand R.O.) | 976,756 | 1,001,668 | 1,026,580 | (1,051,492) |
| FRR on equity | 21 % | 22 % | 22 % | (22 %) |

### 2.14.4 Economic rate of return

The economic rate of return analysis was made by two approaches: a revenue-based one and one that estimated the cost saved by carrying out the Project instead of its alternatives based on different development schemes.

The economic rate of return computed by the revenue-based method was 13 %.

In the analysis by the so-called comparative method, in which only the cost of an alternative to a project is compared with the cost of the project, the cost saved by not adopting the alternative is treated as the net benefit generated by the project.

The alternative scheme to the proposed power plant is represented by the oil-fired plant type. The estimated capacity and energy costs at the transmission-end under this scheme are estimated at 41.75 R.O./KW/year and 3.30 x $10^{-2}$ R.O./KWH, respectively. The internal economic rate of return was computed at 29 %.

One of the alternatives to the proposed Barka desalination plant is to construct small desalination plants similar to the one built in Sur in 1993 at the cost of US$12 million. With the assumption that the operating cost to produce one unit of water at the alternative plants, which also run on the RO system, is the same as that at the proposed Barka plant, the economic rate of return of the Project can be estimated by comparing only the initial investment cost for this alternative scheme and that for the Project. To meet the projected demand, the construction of 48 plants would be required by 2010. The economic rate of return is calculated at 41 %.

Based on the discussion above, it is safe to conclude that the Project is viable from both financial and economic points of view. The internal rates of return of the Project obtained all exceeded the assumed discount rate of 8 %. Because the Project is intended to be implemented by the BOO or BOOT method, the analysis of "the rate of return on equity invested" may have found to be of most interest. The charges assumed in the analysis should be considered to be justifiable, because the unit operating costs applied were actual costs, and because the discount factor of 8 %, which was used in computing the capacity costs, was reasonable. The rate of return obtained was 22 %. This rate should be high enough to make the Project feasible.

## B. RECOMMENDATIONS

(1) To meet the projected power and water demands, a power plant with a minimum capacity of 200 MW and a desalination plant with a first-stage capacity of 63,000 $m^3/d$ (14 MGPD) will have to be commissioned in early 1998 and mid 1998, respectively. To accomplish this urgent task, it is essential that the required pre-construction engineering work be implemented according to the following schedule:

- Completion of bidding documents - September 1995
- Conclusion of contract and commencement of construction - May 1996

(2) The following items, which this feasibility study was not concerned with, need to be implemented in line with the progress of the Project.

- Construction of off-site fuel supply facilities.
- Securing operation and maintenance staff for the proposed plant.

(3) In line with the Omanization policy, it is important to train Omaninationals through actual involvement in the entire process of the project.

(4) Transmission power loss and water distribution leakage are significant in the existing facilities, wasting valuable resources for development. Along with this project, measures must be taken to reduce these loss and leakage.

(5) The planned privatization of the electricity and water supply service is regarded as an appropriate measure to introduce private fund for the development of the country. It is urgent that laws and regulations concerned with the privatization of public utilities service be instituted.

# CHAPTER 3 OUTLINE OF THE SULTANATE OF OMAN

# CHAPTER 3 OUTLINE OF THE SULTANATE OF OMAN

## 3.1 Location and Geographical Features

The Sultanate of Oman is located at the southeastern end of the Arabian Peninsula, at a latitude of 16° - 26° N. and a longitude of 52° - 60° E. The country faces the Arabian Sea and the Gulf of Oman, and borders the United Arab Emirates, Saudi Arabia and Yemen. The country covers an area of approximately 300,000 square kilometers, and is about three fourths the size of Japan. The country boasts the largest national land area, after Saudi Arabia and Yemen, on the Arabian Peninsula. The country also has a detached area on the Musandam Peninsula located in the Strait of Hormuz.

## 3.2 Climate

The weather in the north of Oman is hot and humid, with a maximum temperature of 45 °C between June and August. Batinah Plain in particular experiences high humidity. However, during the winter (November - February), the region enjoys comfortable weather and the temperature does not drop below 10 °C. Large rainfalls sometimes occur in the north. The central region, on the other hand, has a typical desert climate, except for the hot, humid coastal area along the Arabian Sea. Salalah Plain in the south is located in the subtropical region that receives monsoons from the Arabian Sea. This region experiences annual rainfall of over 500 mm. A maximum temperature of 30 °C in the summer makes the region a superb summer resort.

## 3.3 Population and Manpower

The nationwide census carried out in December 1993 revealed that the population of Oman was approximately 2,020,000 and that the number of Omanis and foreigners was 1,480,000 (74 %) and 537,000 (26 %), respectively. The country sees an annual average population increase of 3.5 %. About 3 % of the population lives in the Muscat metropolitan area, while another 27 % lives in the Batinah coastal region. About half of the population lives inland.

One of the most striking characteristics of the Omani population is the large number of foreigners, including Indians, Bangladeshis, Pakistanis and Sri Lankans. Foreigners make up 26 % of Oman's total population and 47 % of the population in the Muscat metropolitan area. This suggests that Oman's workforce is very dependent on foreigners. However, in recent years, a trend to replace foreigners with native Omani workers has gained strength in many sectors.

## 3.4 Characteristics of Economic Structure and Economic Development

### (1) Outline

The Sultanate of Oman has achieved significant economic growth as Sultan Qabus, who assumed control in 1970, invested a large portion of the country's oil income into the improvement of the country's infrastructure. He also promoted development based on five-year plans, beginning in 1976. The fourth five year plan, which began in 1991, was drafted before the breakout of the gulf crisis, and therefore, focused on economic development of the private sector. The plan's main points were: to boost investment in mining, agriculture and fishing, in order to lessen dependence on oil income; to improve the standard of living in rural regions; to secure water resources; and to increase the ratio of Omanis in the workforce.

### (2) Financial Status after the Gulf Crisis

The eruption of the gulf crisis did not seriously affect the Omani economy. The country actually experienced an increase in oil income as a result of the jump in crude oil prices. However, the average annual price of crude oil in 1991 fell to US$17.44/barrel, far below the government's estimated price of US$19/barrel. In response, Oman took out a US$300 million syndicated loan and issued government bonds. The government continued its five-year economic plan to supplement these measures. The fiscal 1992 budget was prepared based on an average annual crude oil price of US$15.5/barrel. However, the average price from January to September was US$18.09/barrel.

### (3) Revenues and Expenditures

#### 1) Heavy Dependence on Oil Income:

Income from non-oil sectors is gradually increasing as a result of the government's policy to lessen the country's dependence on oil. However, the proportion of oil income to total revenues remains high, standing at 77.1 % in 1992. Therefore, Oman's economy is seriously affected by fluctuations in crude oil prices. The drop in prices that began in 1982 caused a significant shortage in revenues, resulting in delays in development projects and forcing the government to take out syndicated loans.

The project, which was based on a 1985 feasibility study, was intended to be implemented under the forth five-year plan. However, the project was postponed because of the shortfall in revenues.

2) High National Defense Expenditures

The Sultanate of Oman was forced to spend large amounts (30 - 40 % of total revenues) on national defense because of the disturbance in the Dhufar region during the 1970s and on defense of the Strait of Hormoz during the Iran-Iraq war in the 1980s.

3) Revenue Deficit

Since 1982, there has been a chronic deficit in revenues. From 1985, when the average annual price of crude oil was US$27/barrel, until 1986, when it dropped to US$13.5/barrel, the country recorded a deficit of RO 66 million. The deficit in 1991 was RO 283 million.

4) Accumulation of National General Savings Fund

This fund was established in 1980 and had accumulated 15 % of each year's oil income until 1985. The country planned to save 5 % a year beginning in 1986. However, the drop in crude oil prices forestalled this plan. Savings finally resumed in 1989.

(4) Trade Structure

Oil's proportion of total exports has been steadily decreasing. Yet, the amount still hovers near 90 %. Japan is Oman's largest purchaser of oil. In 1990, 39.2 % of Oman's oil was exported to Japan.

Oman's primary imports include machinery (including automobiles), industrial products, food and livestock. The United Arab Emirates is Oman's largest trading partner. Imports from U.A.E. were 23.2 % of the total in 1990. A considerable amount of Japanese products also flow into Oman through U.A.E. Therefore, in real economic terms Japan is Oman's largest trade partner, both in imports and exports.

Oman's trade balance remains in the black.

## (5) Natural Resources

### 1) Oil

Oman's first commercial oil field was discovered in 1964 and exports started in 1967. Today, Petroleum Development of Oman (PDO) produces 700,000 barrels of oil per day, and three companies (French Elf Aquitaine, U.S. Occidental and Japanese JAPEC) combined produce 50,000 barrels per day, bringing the total daily oil production to 750,000 barrels. Estimated recoverable deposits stand at 5 billion barrels, which should last about 20 years. Although Oman does not belong to OPEC, its sales prices reflect international spot prices and are considered very reasonable. The average price between January and November 1992 was US$17.64/barrel.

### 2) Natural Gas

A gigantic gas field with an estimated deposit of about 17 trillion cubic feet was discovered in 1991. This figure is expected to double in the future. Although at present natural gas production is limited to enough for domestic consumption, Oman will be able to produce 5 million tons of LNG a day by 1999, if production stays on schedule. Oman will be able to export this excess LNG and earn more foreign currency.

### 3) Mineral Resources

Oman has, from ancient times, been a renowned copper producer. The electric smelting plant of Oman Mining Company (OMCO), located in Sohar produces about 15,000 tons of copper annually.

Furthermore, there is an estimated 2 million tons of chrome deposits in Sohar and Izuki. Oman Chrome Company, established in 1991, set its annual production target at 12,000 tons.

## (6) Industry

### 1) Manufacturing Industry

Oman's industrial policies focus on nurturing medium- and small-sized companies in the private sectors of food processing, construction materials and housing. These policies will continue to be implemented over the next 20 years.

In 1983, a model industrial complex was established in Rusail, a Muscat suburb, in order to attract companies. In 1992, similar industrial complexes were completed in Sohar and South **Raisute**. The country declared 1991 and 1992 years for industry, and concentrated on promoting various sectors.

2) Agriculture

The area of arable land is about 40,000 ha (1/700 of the total national land), with Batinah, in north Oman, accounting for about 20,000 ha. A large number of the farmers own tiny plots of about 1 ha, and agricultural productivity is low.

Principal products are dates, limes, watermelons, French beans, okra and cabbage. In 1981, the Public Authority for Marketing Agricultural Produce (PAMAP) was established to promote sales and boost distribution efficiency of agricultural products.

3) Fishing

Oman's 1,700-kilometer-long coast line makes developing marine resources an important part of the government's policy to lessen the country's dependence on oil. The coastal area on the Arabian Sea yields several types of premium fish. Oman exports US$665 million annually (1990) in tuna, lobster and cuttlefish to GCC and EU countries. The country also exports US$13.71 million (1991) in marine products, mostly prawn, to Japan.

# CHAPTER 4 PRESENT STATE OF POWER UTILITIES AND POWER DEVELOPMENT PLAN

# CHAPTER 4 PRESENT STATE OF POWER UTILITIES AND POWER DEVELOPMENT PLAN

## 4.1 General Overview of the Power Utilities

### 4.1.1 General Development

When the Sultan Qaboos came to power in 1970, he instituted a policy of investing oil profits back to improving the society and upgrading basic industries. The Sultan launched a five year development program, which featured the establishment of in program to develop, generate, transmit and distribute power. This program resulted in spectacular growth in total installed capacity, which rose from 85 MW in 1976 to 1,410 MW in 1993 as shown in Figure 4.1.1. Generated power also posted substantial growth over the same period, rising from 266.1 GWH to 5,832.2 GWH.

Steady growth in demand for electricity was accompanied with an increase in power generation facilities in districts where there was demand for electricity. Table 4.1.1 and Figure 4.1.3 show the growth in power generation capacity in 1993 by region. Table 4.1.2 and Figure 4.1.3 show changes in power generation capacity, maximum electricity, and generated power. These diagrams reveal the following characteristics of power development in Oman:

(1) Generated power grew at a rate of 28.4 % in the decade between 1976 to 1985, and at 10.8 % between 1986 to 1993. While it is true the rate has declined in recent years, the pace of growth is still impressive. The generated power in 1993 recorded an increase of 14 % over the previous year, presumably resulting from a 8.5 % increase in the installed capacity. In other words, an increase in the capacity of power supply inevitably induced a demand for additional power.

(2) The percentage of total generated power for the system in the Northern sector in 1993 was the highest for the Muscat system at 73.0 %, followed by the Wadi Jizzi system at 16.5 %. The systems combined comprise 89.5 % of the total power demand, and form the core of power supply and demand in Oman. The Wadi Jizzi system boasts the highest rate of increase in generated power for all areas, recording an increase by 4.9 times during the period between 1984 and 1993 vis-a-vis 2.5 times for the Muscat system.

(3) Oman generally used diesel engine-driven generators which are excellent in the delivery and efficiency. Recently however, these have been phased out, and

replaced by gas-turbine generators, which are proving more economical. As of 1992, gas turbine generators accounted for 66.2 % of all generators. Rusail Power Plant now has six 83 MW gas turbines for power generation, and these are now the principal type of generators in the Muscat System. Steam turbines are used not only to generate power but also to produce steam for the desalination plant and are only found at the Ghubrah Plant.

| Year | Installed Capacity | | | | | Generated Power | |
|---|---|---|---|---|---|---|---|
| | Steam Turbines | Gas Turbines | Diesel Engines | Total | Percent Increase | Million KWH | Percent Increase |
| 1976 | 26 | | 59 | 85 | | 266.1 | |
| 1977 | 76 | | 59 | 135 | 58.8% | 404.2 | 51.9% |
| 1978 | 76 | 52 | 73 | 201 | 48.9% | 463.1 | 14.6% |
| 1979 | 76 | 157 | 107 | 340 | 69.2% | 575.0 | 24.2% |
| 1980 | 76 | 157 | 142 | 375 | 10.3% | 787.2 | 36.9% |
| 1981 | 76 | 157 | 142 | 375 | 0.0% | 1,043.5 | 32.6% |
| 1982 | 76 | 211 | 185 | 472 | 25.9% | 1,314.4 | 26.0% |
| 1983 | 76 | 265 | 221 | 562 | 19.1% | 1,712.4 | 30.3% |
| 1984 | 76 | 431 | 273 | 780 | 38.8% | 2,241.2 | 30.9% |
| 1985 | 76 | 571 | 293 | 940 | 20.5% | 2,743.8 | 22.4% |
| 1986 | 76 | 627 | 334 | 1,037 | 10.3% | 3,152.8 | 14.9% |
| 1987 | 76 | 877 | 272 | 1,225 | 18.1% | 3,393.3 | 7.6% |
| 1988 | 76 | 877 | 307 | 1,260 | 2.9% | 3,772.8 | 11.2% |
| 1989 | 76 | 877 | 306 | 1,259 | -0.1% | 3,926.8 | 4.1% |
| 1990 | 76 | 905 | 318 | 1,299 | 3.2% | 4,501.0 | 14.6% |
| 1991 | 76 | 905 | 318 | 1,299 | 0.0% | 4,627.8 | 2.8% |
| 1992 | 76 | 905 | 318 | 1,299 | 0.0% | 5,116.9 | 10.6% |
| 1993 | 105 | 934 | 371 | 1,410 | 8.5% | 5,832.2 | 14.0% |

Source : MEW Statistical Year Book 1992
MEW Annual Report 1993

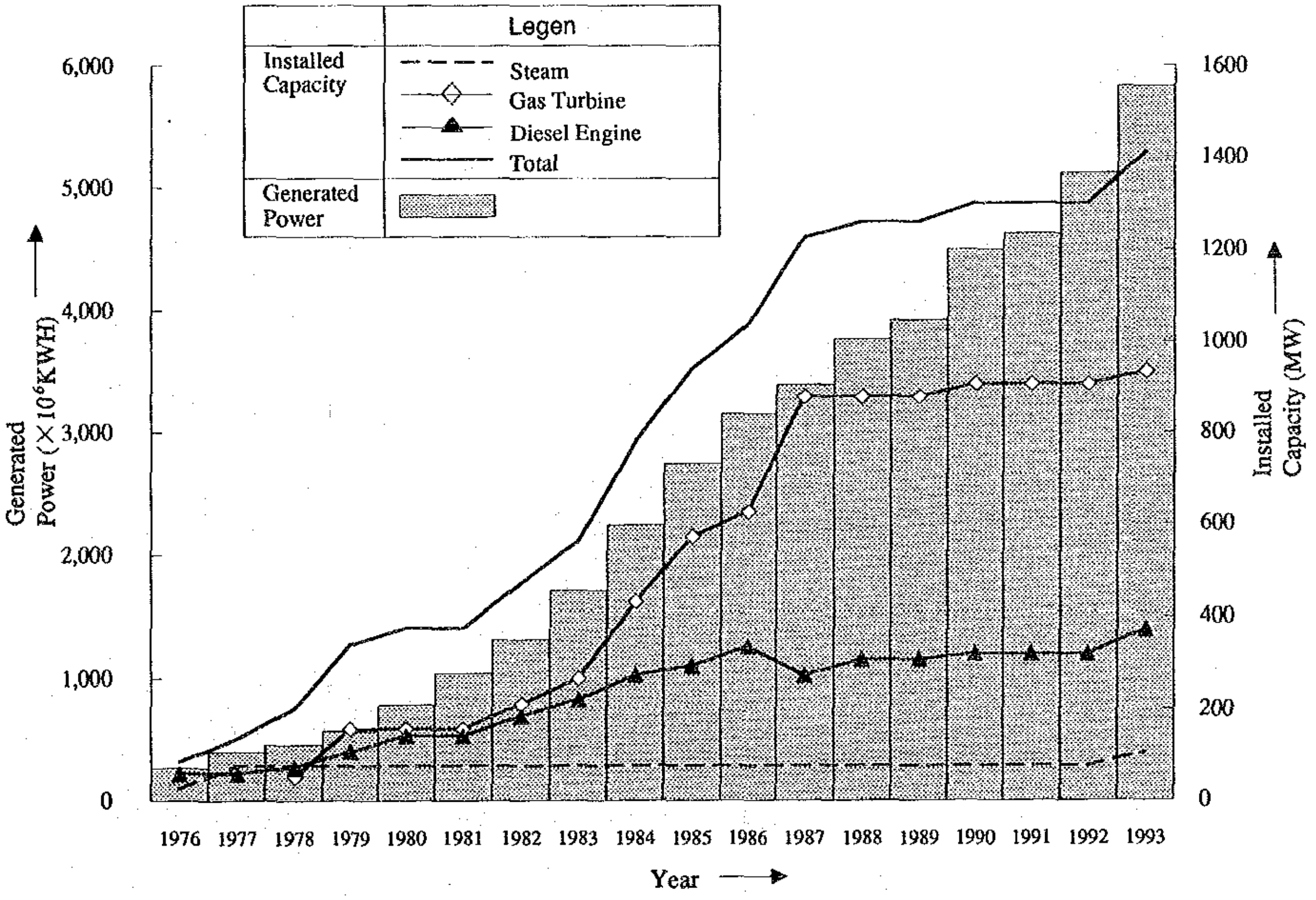


Figure 4.1.1 Changes in Installed Capacity and Generated Power

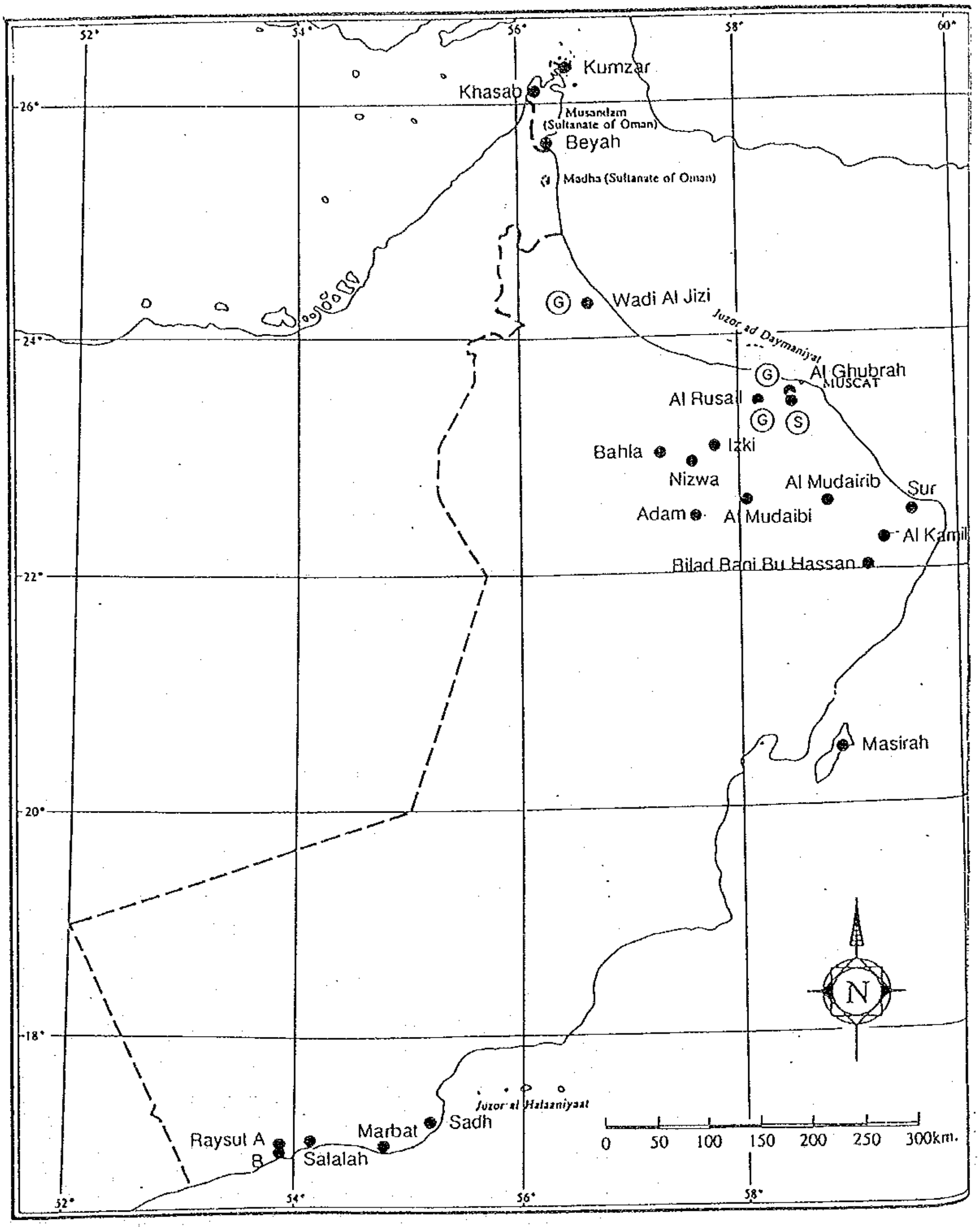
Table 4.1.1 Existing Power Station (Northern & Sourthern Sectors)

| Region | Power Station | Installed Capacity MW as of 1993 | No. of machines as of 1993 | Year of Commissioning |
|---|---|---|---|---|
| Muscat | Al Ghubrah | 317.000 | 16 | 1976 |
| | Al Rusail | 498.000 | 6 | 1984 |
| Wadi Jizzi | Wadi Al jizzi | 222.000 | 8 | 1982 |
| Dakhliya | Adam | 7.435 | 10 | 1980 |
| | Bahla | 23.152 | 8 | 1980 |
| | Izki | 8.867 | 7 | 1980 |
| | Nizwa | 37.676 | 10 | 1978 |
| Sharqiyah | Sur | 37.244 | 11 | 1979 |
| | Al Mudaibi | 18.638 | 7 | 1980 |
| | Al Mudairib | 28.202 | 10 | 1980 |
| | BBB Hassan | 36.468 | 10 | 1980 |
| | Al Kamil | 5.630 | 5 | 1980 |
| | Masirah | 5.461 | 7 | 1976 |
| Musandam | Khasab | 17.000 | 6 | 1982 |
| | Beyah | 8.430 | 5 | 1978 |
| | Mudha | 2.380 | 4 | 1982 |
| | Kumzar | 1.198 | 4 | 1984 |
| | Sheesa | 0.956 | 4 | 1984 |
| Dhahirah | Al Fayya | 0.731 | 4 | 1988 |
| Dhofar | Salalah | 42.381 | 8 | 1971 |
| | Raysut A | 37.920 | 6 | 1983 |
| | Raysut B | 42.206 | 6 | 1988 |
| | Marbat | 3.205 | 7 | 1975 |
| | Sadh | 1.930 | 5 | 1974 |
| | Al Halanyat | 0.544 | 4 | 1987 |
| | Rakhyut | 0.480 | 3 | – |
| | Thumrayt | 1.860 | 4 | 1993 |
| | Dalkut | 0.480 | 3 | – |
| | Hasik | 0.264 | 2 | – |
| TOTAL | | 1,409.738 | 190 | |

Source : MEW Annual Report 1993

SULTANATE OF OMAN

LOCATION OF POWER STATIONS



Produced by Ministry of Electricity & Water in September 1993.
Based on National Survey Authority OR 3, edition 1, dated April 1993.
This map is not an authority on International Boundaries.

Source: MEW Statistical Year Book 1992

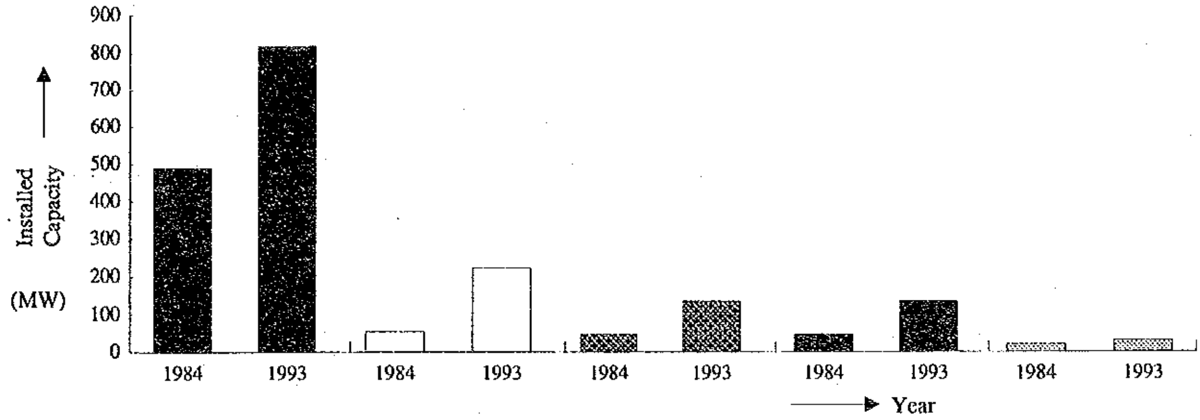
- - - International Boundary
● Gas Turbine Station Ⓖ
● Steam Turbine Station Ⓢ
● Diesel Engine Station

Figure 4.1.2 Location of Existing Power Stations

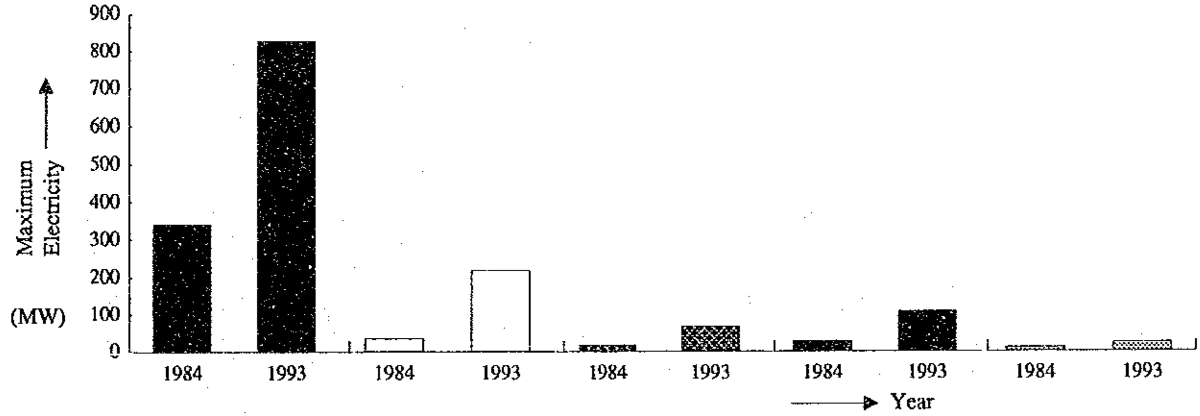
## Table 4.1.2 Change in Installed Capacity by System or Region (Northern Sector)

| Syetem or Region | | Year | Installed Capacity (MW) | Maximum Electricity (MW) | Generated Power (GWH) |
|---|---|---|---|---|---|
| Muscat | | 1984 | 489.0 | 340.0 | 1516.6 |
| | | 1993 | 815.0 | 826.0 | 3,862.5 |
| Wadi Jizzi | | 1984 | 54.0 | 34.0 | 178.1 |
| | | 1993 | 222.0 | 218.0 | 870.8 |
| Dakhliya | Adam | 1984 | 2.3 | 2.1 | 4.7 |
| | | 1993 | 7.4 | 5.4 | 16.0 |
| | Bahla | 1984 | 4.1 | 4.0 | 11.6 |
| | | 1993 | 23.2 | 20.9 | 56.1 |
| | Izki | 1984 | 2.6 | 2.2 | 7.1 |
| | | 1993 | 8.9 | 11.2 | 28.3 |
| | Nizwa | 1984 | 12.3 | 7.6 | 29.9 |
| | | 1993 | 37.7 | 29.5 | 93.2 |
| | Total | 1984 | 27.7 | 15.9 | 53.3 |
| | | 1993 | 77.2 | 67.0 | 193.6 |
| Sharqiyah | Sur | 1984 | 17.3 | 11.0 | 32.0 |
| | | 1993 | 37.2 | 25.1 | 85.5 |
| | Al Mudaibi | 1984 | 7.6 | 3.7 | 8.9 |
| | | 1993 | 18.6 | 16.1 | 42.5 |
| | Al Muderib | 1984 | 7.6 | 5.4 | 15.7 |
| | | 1993 | 28.2 | 26.7 | 80.2 |
| | BBB Hassan | 1984 | 5.4 | 2.8 | 6.6 |
| | | 1993 | 36.5 | 28.1 | 58.9 |
| | Al Kamil | 1984 | 4.4 | 2.7 | 4.9 |
| | | 1993 | 5.6 | 8.9 | 9.9 |
| | Masirah | 1984 | 4.5 | 1.2 | 7.8 |
| | | 1993 | 8.4 | 2.5 | 12.9 |
| | Total | 1984 | 46.8 | 26.8 | 75.9 |
| | | 1993 | 134.5 | 107.4 | 289.9 |
| Musandam | Khasab | 1984 | 10.0 | 6.7 | 22.3 |
| | | 1993 | 17.0 | 16.1 | 53.8 |
| | Beya | 1984 | 5.9 | 2.5 | 7.5 |
| | | 1993 | 8.4 | 4.1 | 14.8 |
| | Mudha | 1984 | 2.4 | - | 1.9 |
| | | 1993 | 2.4 | 1.5 | 5.2 |
| | Kumzar | 1984 | 1.1 | - | 0.0 |
| | | 1993 | 1.2 | 0.5 | 1.0 |
| | Sheesa | 1984 | 0.1 | 0.0 | - |
| | | 1993 | 1.0 | 0.1 | 0.2 |
| | Al Faya | 1986 | 0.1 | - | - |
| | | 1993 | 0.7 | 0.3 | 0.7 |
| | Total | 1984 | 19.6 | 9.2 | 29.8 |
| | | 1993 | 30.7 | 22.6 | 75.7 |

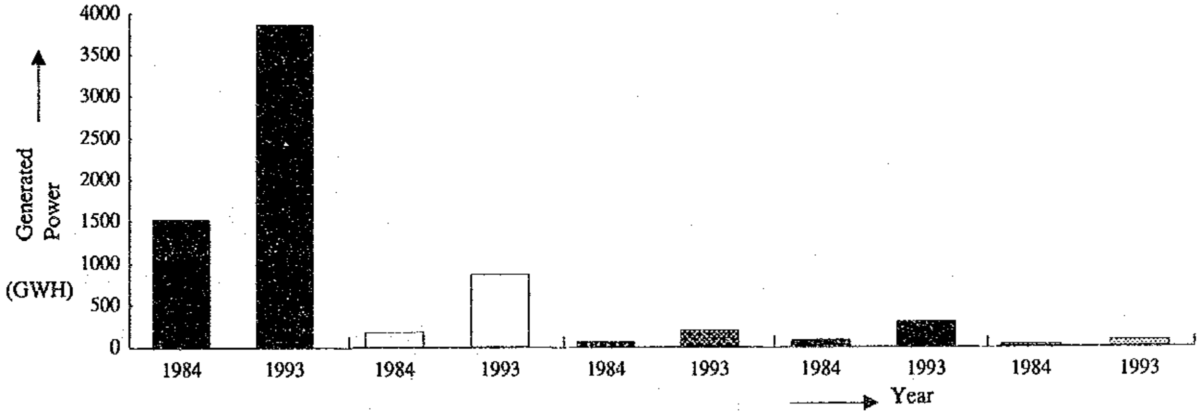
Soruce : MEW Annual Report 1993



(a) Installed Capacity



(b) Maximum Electricity



(c) Generated Power

■ Muscat

□ Wadi Jizzi

▩ Dakhliya

■ Sharqiyah

▨ Musandam

Figure 4.1.3 Changes in Installed Capacity, Maximum Electricity and Generated Power (Northern Sector)

### 4.1.2 Power Supply Facilities

Power supply facilities have the function of supplying electricity to the consumer by transmitting, transforming and distributing power generated by the power plants. Table 4.1.3 describes the kind and number of power supply facilities of the Muscat and Wadi Jizzi systems.

Power transformation is carried out by 223 transformers with a total capacity of 5,795 MVA. The two systems have 488 km of power transmission lines and 1,568 km of power distribution lines, which have been installed so as not to disrupt the surrounding environment. To avoid detracting from the urban environment, 9.2 % of the distribution lines have been laid underground.

Table 4.1.3 Power Supply Facilities

| System | Transformation Facilities | Transmission and Distribution Facilities |
|---|---|---|
| Muscat | (a) Station transformers<br>2 locations, 22 transformers, 1,535.2 MVA | (a) 132 KV transmission lines<br>Overhead 196 km |
| | (b) Primary substation transformers<br>(132KV/33KV)<br>7 locations, 14 transformers, 1,521 MVA | (b) 33KV distribution lines<br>Overhead 649 km<br>Underground 137 km |
| | (c) Distribution substation transformers<br>(33KV/11KV)<br>106 transformers, 1,470 MVA | (c) |
| Wadi Jizzi | (a) Station transformers<br>1 location, 11 transformers, 372 MVA | (a) 132 KV transmission lines<br>Overhead 292 km |
| | (b) Primary substation transformers<br>(132KV/33KV, 66KV/33KV)<br>7 locations, 10 transformers, 482 MVA | (b) 66KV distribution lines<br>Overhead 23km |
| | (c) Distribution substation transformers<br>(33KV/11KV)<br>7 locations, 60 transformers, 414.5 MVA | (c) 33KV distribution lines<br>Overhead 752 Km<br>Underground 7 km |

Source: MEW Statistical Year Book 1992

### 4.1.3 Consumers

Figure 4.1.4 shows changes in the number of consumers (No. of accounts) by system and area in the Northern Sector. In 1993, the Muscat system served 54.3 % of all consumers, while Wadi Jizzi accounted for 21.5 %. These two systems combined accounted for by far the largest portion of consumers in Oman. The rate of increase in the number of consumers in the Muscat System was 5.7 %, and in the Wadi Jizzi System 9.7 %. The rate of growth for all the systems in Oman was 7.7 %.

Consumers can be classified into four groups by category: domestic, government, industrial, and commercial. Tables 4.1.4 and 4.1.5 show the number of consumers and power consumed. Domestic and government consumers combined account for more than 90 %, while industrial and commercial consumers are minimal.

Unit: No. of accounts

| System/Year | 1991 | 1992 | 1993 | % Increase |
|---|---|---|---|---|
| Muscat | 128,702 | 135,240 | 143,658 | 6.2 % |
| Wadi Jizzi | 47,400 | 52,606 | 56,981 | 8.3 % |
| Sharqiya | 27,867 | 31,569 | 34,951 | 10.7 % |
| Dakhliya | 18,850 | 20,479 | 23,215 | 13.4 % |
| Musandam | 5,146 | 5,451 | 5,780 | 6.0 % |
| Total | 227,965 | 245,345 | 264,585 | 7.8 % |

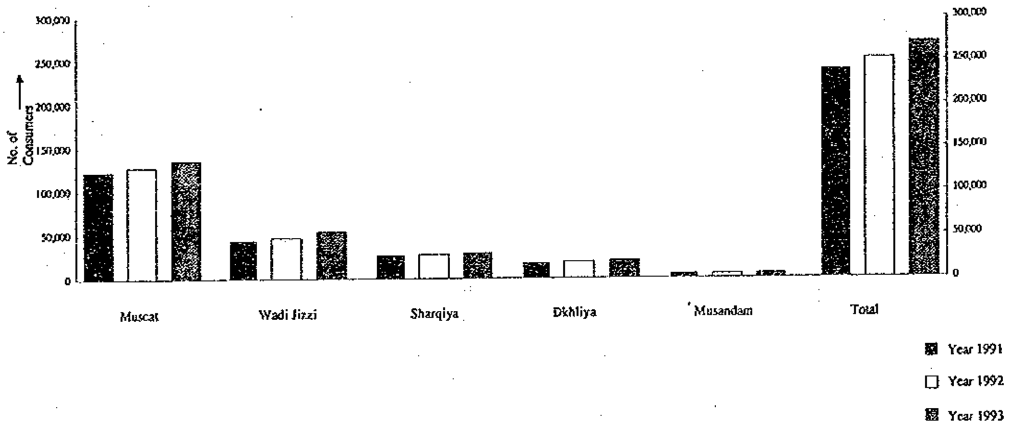


Figure 4.1.4 Change in No. of Consumers by System

Table 4.1.4 Change in No. of Consumers by Category

Unit: No. of accounts

| Category/Year | 1991 | 1992 | 1993 | Percent of Total 1993 |
|---|---|---|---|---|
| Domestic | 201,280 | 215,458 | 232,324 | 87.7 % |
| Government | 12,314 | 13,699 | 14,971 | 5.8 % |
| Industrial (Private) | 67 | 72 | 79 | 0.0 % |
| Commercial | 14,304 | 16,116 | 17,211 | 6.5 % |
| Total | 227,965 | 245,345 | 264,585 | 100.0 % |

Table 4.1.5 Change in Consumed Power by Category

Unit: GWH

| Category/Year | 1991 | 1992 | 1993 | Percent of Total 1993 |
|---|---|---|---|---|
| Domestic | 2,017.3 | 2,302.1 | 2,651.0 | 64.9 % |
| Government | 896.3 | 945.0 | 1,047.9 | 25.7 % |
| Industrial (Private) | 60.3 | 73.3 | 93.5 | 2.3 % |
| Commercial | 230.2 | 238.3 | 291.6 | 7.1 % |
| Total | 3,204.1 | 355.7 | 4,084.0 | 100.0 % |

### 4.1.4 Electricity Rates

Table 4.1.6 shows the electricity rate by category. Most of monthly domestic usage appears to be less than 3,000 KWH, at a rate of 10 Baiza/KWH. This is assumed to account for more than 70 % of total consumers. Government accounts for about 25.7 % of total consumption, and so is considered to have a major influence on the accounting of power utilities.