AND ZONE WATER RESOURCES PLANNING STUDY WITH APPLICATIONS OF NON-CONVENTIONAL ALTERNATIVES

流域圏における水資源計画に関する研究

December 1991

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村 上 雅 博

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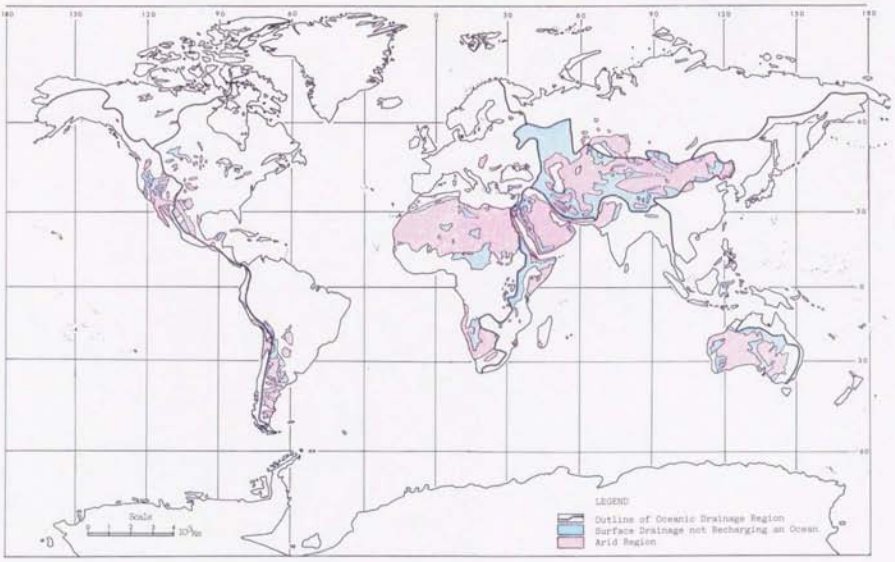
LIST OF VOLUMES



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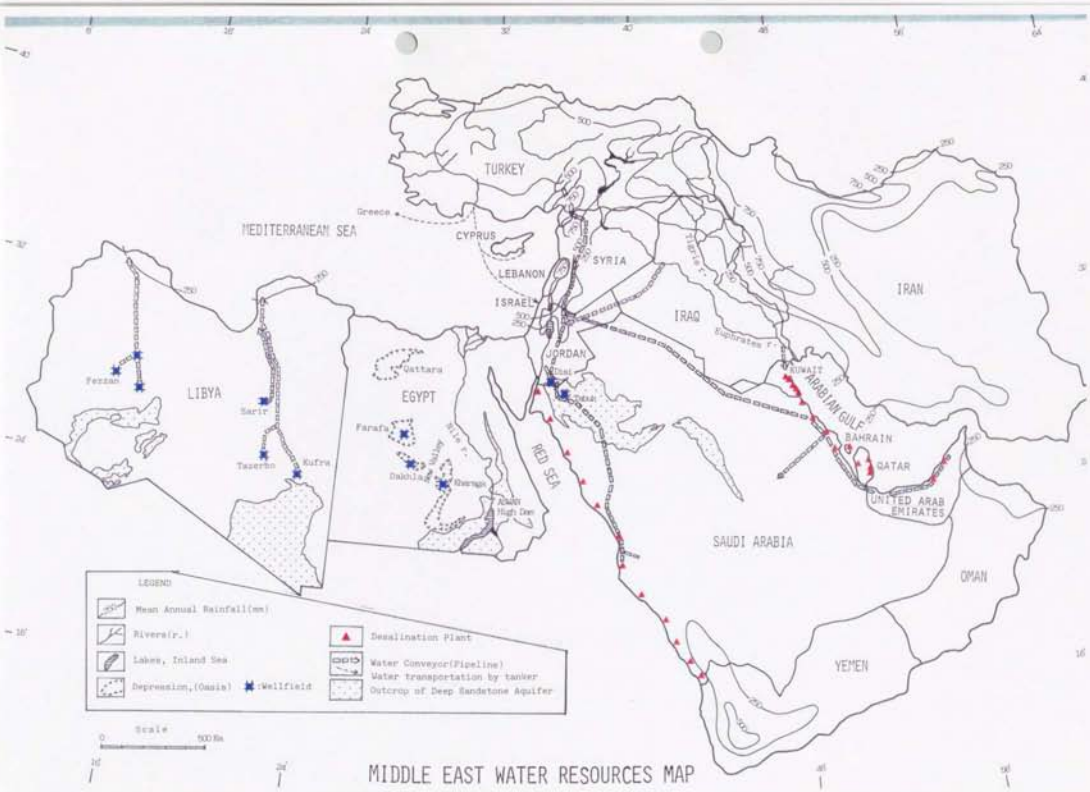
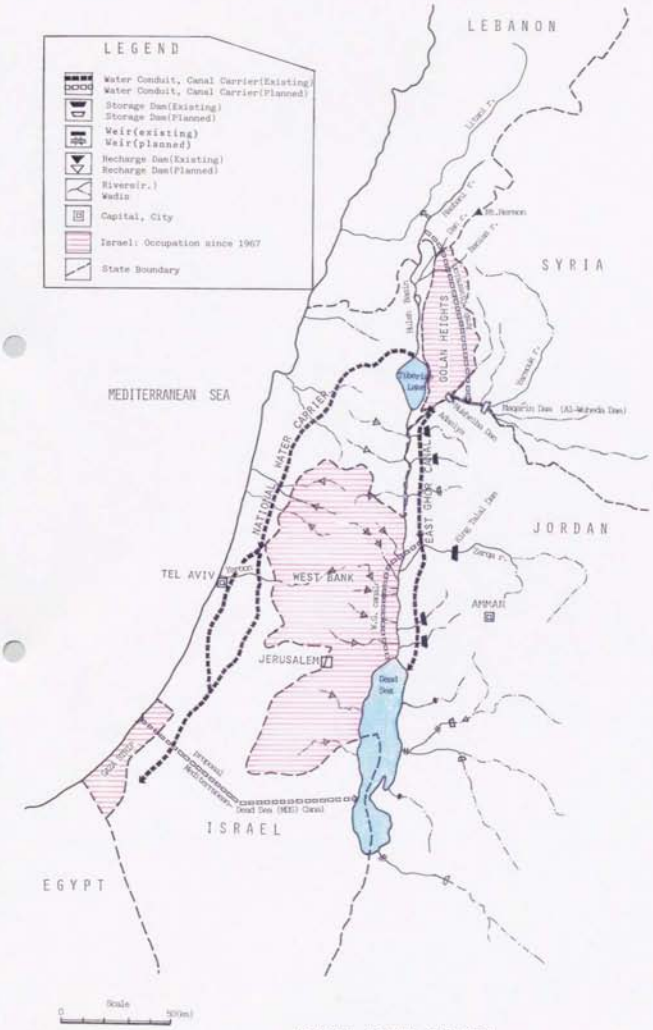


MIDDLE EAST WATER RESOURCES MAP



JORDAN RIVER SYSTEM

SUMMARY

A. Background

The arid zone covers one-third of the world's land surface, and has a unique nature of climate, hydrology, hydrogeology, and water resources. Concern is growing that the Middle East is on the verge of a resources crisis as indicated by the 1991 Persian Gulf war, whether it is linked with the Israel-Arab issue or not. Although the region possesses natural assets in abundance, with an estimated two-thirds of the world's proven oil reserves, it is deficient in the most strategic and valuable of all natural resources --- "water". By the year 2000, "water --- not oil" will be the dominant resources issue of the Middle East.

The demand for water to serve expanding third world populations continues to increase, while fresh water supplies are finite, and are becoming more and more difficult to develop on a renewable basis in their own territory. By the early decades of the twenty-first century almost all the states of the arid zone will be forced to solve severe water shortages problems especially in the urban centers as populations continues to grow.

Almost all the fresh and renewable waters such as river streams, lake water, and groundwater, which are termed as "conventional water " or "traditional water", will have already been exploited or are going to be fully developed in many of the Middle East countries by the end of this century or the beginning of the twenty-first century. The main efforts of governments will therefore be shifted to making more efficient use of available supplies than increasing the capacity of conventional hydraulic structures. Water conservation will be the key concept of sustaining water resources development in the arid zone. Marginal waters of the non-conventional water resources, which comprise brackish groundwater, seawater and reclaimed treated waste-water, are becoming increasingly important factors and will be a key element in water resources planning in the Middle East.

Since the Iraqi invasion to Kuwait in August 1990, there have been several changes in the Middle East political situation, which may facilitate a comprehensive resolution of the Israel-Palestine-Arab problem, whether it is politically linked or not. Resolution of the water resources problems including inter-state riparian issues, will be a good start to creating the foundations for a peace settlement following the end of the Persian

Gulf war. Indeed no peace settlement is conceived without resolution of the water issues. This will require undoubtedly integrated development plan for the Jordan river system that will be not only technically and economically feasible but also politically desirable and urgent, as shown by the case studies in this study.

B. Water Resources Development and Management; Present Status, Problems and Constraints to be Encountered

Many countries in the Middle East have experienced serious water supply problems since the 1950s, corresponding with the rapid increase in water demand. The potential for renewable water resources development is limited, owing to the sparse rainfall and the very high potential evaporation.

Multi-National River Development: There are two major water resources issues in the world's large river developments in the arid region: the quantity issue in inter-state water allocation and the quality issue of salinity problems. Various and serious salinity problems have been major issues in the basin management of large rivers since the mid twenty-century, including Indus river in Southwest Asia, the Tigris-Euphrates and Jordan rivers in the Middle East, the Nile river in the North Africa, and the Colorado river in the southwestern Arizona of the United States of America.

Riparian Issues: River waters in the Middle East are a conflict-laden determinant of both the domestic and external policies of the region's principal actors. All the countries of the Middle East, except for those in the Arabian peninsula and Libya, depend on three major river basins; the Tigris-Euphrates, the Nile and the Jordan. Given that these rivers do not respect national boundaries and that those states located upstream have obvious advantages both political and economic over those downstream, the potential for conflict over water is great.

Israel and Jordan - until Israel's invasion of Lebanon and her troublesome stand on clearing out obstructions to the intake of Jordan's East Ghor canal - have more or less informally agreed to share the Jordan River system within the framework of the "Johnston Plan :1953-1955". By the end of 1990s, however, Israel, Jordan and the West Bank or Palestine will have depleted virtually all of their renewable sources of fresh water if current patterns of consumption are not quickly and radically altered. In

the circumstances, the Jordan river system, which includes the Al-Wuheda dam scheme on the Yarmouk river, unquestionably holds the greatest potential for either conflict or compromise.

Non-Renewable Groundwater Resources Development: A vast amount of the non-renewable or fossil groundwater is tapped in the Paleozoic to Mesozoic-Neogen (Nubian) sandstones which underlie wide areas of the Arabian peninsula and the eastern Sahara desert including Saudi Arabia, Jordan, Egypt and Libya. The dominance and importance of the non-renewable groundwater reserves in national water resources planning became clear in the 1980s, such as with the "Man-Made River" project in Libya and "New Valley" project in Egypt. In Saudi Arabia, a total increase of 89 % was made in the national water supply during the Fourth Plan period (1985-1990). Many of the traditional and conventional uses of non-renewable or fossil water developments which have been practiced in the arid countries including Egypt, Libya, Saudi Arabia, Kuwait, Qatar, and Bahrain, have been suffered from the depletion of these valuable resources or deterioration in quality of their water. Taking into account the nation's needs for the water conservation and the dominant use of fossil groundwater in the agriculture sector of about 90 % of the Kingdom's water supply, the government of Saudi Arabia suggested the first reduction program including 8 % cut of total water supply, from $16.2 \times 10^9 m^3$ per annum in 1990 to $14.9 \times 10^9 m^3$ per annum in 1995 in the Fifth Plan period (1990-1995).

Desalination of Seawater: The oceans hold $1,338 \times 10^6 km^3$ of seawater, which accounts 96.5 % of the total water reserves of the earth of $1,386 \times 10^6 km^3$. In some of the more dry parts of the Middle East, in particular the Arabian Gulf states, where conventional good quality waters are not available and/or extremely limited, desalination of seawater has been commonly used to solve the water supply problems for the increasing demand in the municipal and industry (M&I) uses. The cost of the seawater desalination is invariably high, however, and is influenced by petroleum prices, that have enabled the oil-rich states of the Middle East to finance the buying of massive quantities of desalting equipment. Two-thirds of the world installations of the desalination plant are located in the oil-rich states in the Middle East, especially in the Gulf states.

Solar-Hydro Development: The solar-hydro scheme of the Mediterranean-Dead Sea (MDS) Canal was proposed by Israel in 1980. The scheme which has multiple socio-economic and political ramifications was intended to convey water from the Mediterranean Sea to the Dead Sea via canals and tunnels utilizing the height difference of close to 400 m to generate electricity

of totaling 600 MW. However, there has been no presentation of the concept of sharing resources and no effort at joint development. The MDS project was put aside, owing to the strong opposition of the Arab states and others and with the confusions and in the world oil market price in 1984. In recent days, however, talk of the much-discussed Mediterranean-Dead Sea (MDS) Canal has again been revived with worldwide attentions of using clean energy for sustaining global environment.

C. Objective and Concepts of the Study

This study attempts to evaluate some new non-conventional approaches to water resources which need to be taken into account in building the new peace in the Middle East. These new approach offer the opportunity to introduce new applications of well-tried technology to solve long-standing water problems which are at the center of many of the potential sources conflict.

This planning study introduces following five concepts:

1) **Integration of development alternatives in the context of a water master plan**, including non-conventional water resources applications in the arid region.
2) **Co-generation for clean energy and water**, including solar-hydro, groundwater-hydro and hydro-powered reverse osmosis desalination.
3) **Strategic use of non-conventional water resources for sustainable development**, including brackish water, seawater and reclaimed waste-water.
4) **Joint development with sharing of resources for multi-national basin development** of the Jordan river and Dead Sea.
5) **Water resources planning for a peace foundation settlement**, including Israel-Palestine-Arab issues.

D. The Study

The study has been initiated to review problems and constraints of the water resources development and management in the arid zone including non-conventional water resources development alternatives. The study introduces following five key subjects;

Review Studies

- Arid Zone Hydrology and Global Water Balance; reviews causation and definition of arid zone in a context of global water cycle and balance.
- Multi-National River Development; reviews the hydrology, water resources development, salinity problems and riparian issues, including the major rivers in the arid zone such as the Tigris-Euphrates, the Indus, the Nile, the Jordan and the Colorado.
- Desalination Practice in the Middle East; reviews the recent practice in the the Arabian Gulf countries.
- Non-renewable Groundwater Development; reviews world's largest fossil groundwater development in Saudi Arabia, and "Great Man-Made River Project" in Libya, and the "New Valley Development Project" in Egypt.
- Groundwater-hydro, Solar-hydro and Seawater Pumped-storage Development; reviews the non-conventional energy-water development alternatives.

Application Studies

This study attempts to conceive a sustainable water resources development plan including the non-conventional applications. The application studies have been carried out including Kuwait, Jordan, Palestine and Israel.

Desalination of brackish groundwater and seawater is the topic of this study, taking into account of energy saving made possible by recent innovations in reverse osmosis (RO) membrane technology. A new co-generation approach is proposed to demonstrate a way that potential energy can be used in developing on water resources system, including groundwater and seawater, which has not before been utilized in the context of conventional water resources development. This approach aims to coordinate 1) groundwater-hydro, ii) solar-hydro, and iii) hydro-powered reverse osmosis (RO) desalination in an integrated development context.

The study aims to cope with water resources planning for a peace foundation settlement with the concept of shared resources and their joint development between Israel-Palestine-Jordan, by taking into account the various recent changes in the political situation in the Middle East since 1990's Gulf war.

Kuwait has a hyper-arid climate with no conventional water resources.

Desalination is a key application to sustain the development of the country.

Jordan, neighbor country to Israel, will be exploiting almost all its renewable waters by the mid 1990s when the ongoing Al-Wuheda dam project on the Yarmouk river is completed. The Yarmouk is the largest tributary not yet fully developed in the Jordan river system. After completion of the diversion tunnel by the end of 1989, however, the project was stopped owing to the strong opposition of the Israeli government which is the administrator of occupied Palestine or the West Bank.

Israel has an arid to semi-arid climate with a variable source of water with a number of development alternatives, but has found it to be extremely difficult to make any extra water supplies available since the late 1960s. By the mid 1980s, Israel had exploited as much as 95 % of the total renewable water sources available in its territory, and has been forced to decrease the national water supply since 1987. Almost one-half of Israel's total water supply is, however, dependent on the water that has been diverted or pre-empted from Arab sources located outside the pre-1967 boundaries. The main effort had to be shifted to making more efficient use of the available supply than increasing the capacity of hydraulic structures.

Hydro-powered Reverse Osmosis (RO) Desalination in Kuwait: A low cost desalination method with a low energy requirement for seawater and brackish groundwater is one main approach to sustainable water resources development in the state where neither fresh groundwater nor surface water are available. Application of hydro-powered reverse osmosis (RO) desalination for brackish groundwater resources development is studied to examine the cost-effectiveness of the hybrid desalination and co-generation.

Application of Hydro-powered Reverse Osmosis (RO) Desalination in the Non-conventional Water Resources Development Plan in Jordan: The potential contribution of non-conventional water resources development is examined in the context of making strategies for national water master plans for the twenty-first century, which is urgently need in all countries of the Middle East, but especially in a non-oil producing country such as Jordan.

Co-generation of brackish groundwater reverse osmosis (RO) desalination with groundwater-hydro is a key concept examined in this study with the

aim of reducing abstraction of non-renewable groundwater from Disi sandstone aquifer. The potential contribution of non-conventional waters to meet the anticipated water demand is also studied here to provide a framework for a national water master plan for Jordan for the twenty-first century

Integrated Joint Jordan River Development Plan: Israel, a neighbor country of Jordan, and administrator of the West Bank or Palestine since 1967 performs the most comprehensive schemes for water resources management in the Middle East. Comparative studies are made of hydrology and water resources development and management between the two states (see Chapters IV &V) to identify the strategic dimensions of the water problems, including:

- Hydrology, water resources, water demand and the present approach to almost complete utilization of renewable water resources.
- Development history of the Jordan river and its complexities, commonalties, and conflicts (see Annex-II).
- Integrated national water resources development scheme; Israel National Water System (INWS).
- Potential contribution of marginal waters to the water master plan of Israel.
- Solar-hydro potential of the Mediterranean-Dead Sea (MDS) Canal, and its application to co-generation with hydro-powered reverse osmosis (RO) desalination.
- Joint Israel/Jordan Mediterranean-Dead Sea conduit scheme, which is based on the concept of integrated basin development including the linkage of Al-Wuheda dam project on the Yarmouk tributary river of the Jordan river system and side-wadi dam schemes in both West Bank and East Bank.

The strategic dimensions of the water problems in the Israel-Palestine-Jordan and the Arab worlds and their implications for the future are discussed to conclude the study on the multi-national water master planning in one of the world's driest region where the peace of the world has been at risk for more than forty years.

E. Conclusions

- Most of the flows in the major rivers in the Middle East have fully been developed in the 1960s-1980s with increasingly salinity problems

and riparian issues such as inter-state water allocation problems. Salinity control of the rivers is needed not only to protect the quality environment of river system but also to manage the desirable quantity of water to be re-used for the downstream irrigation or other water supply. Reverse osmosis (RO) application for the brackish water desalination in line with sustainable basin management will be a key application of controlling the salinity problems of the twenty-first century.

- Non-renewable or fossil groundwater resources should be regarded as a strategic reserves except for a emergency or short-term use.

- In the Arabian Gulf countries, where the conventional water resources such as renewable groundwater and surface water are not available, water conservation and low cost desalination are still needed to sustain economic development. The prevailing multi-stage flash (MSF) desalination is going to be replaced by steps to develop more low capital and operating cost process such as low pressure type of the reverse osmosis (RO) membrane. The role of the ocean, which is the largest water reserves on the earth, will be important to sustain water resources development in the twenty-first century.

- Non-conventional hydro-power schemes such as the Mediterranean-Qattara and the Mediterranean-Dead Sea hydro-solar developments have been revived to take into account worldwide attention to the global energy-environment and the move to increase the share of hydro-electric potential. Applications of the groundwater-hydro and the solar-hydro in non-conventional water resources development in the arid regions, which are typical clean energy developments in the non-conventional water resources development context, are likely to be a strategic priority to save the fossil energy and the global environment with economic feasibility.

- From the case study on the non-conventional water resources development in Kuwait, the unit cost of brackish groundwater reverse osmosis (RO) desalination for "with" and "without" application of the hydro-potential energy in the water pipeline system (200 m of differential head of water) was estimated to be US$0.4/$m^3$ and US$0.6/$m^3$, respectively, in which the hydro-powered brackish groundwater reverse osmosis cost is estimated to be as low as one-sixth to one-fourth of the conventional seawater desalination either by MSF (US$2.7/$m^3$) or RO (US$1.7/m^3).

- Potential of brackish waters including both groundwater and surface water, which have been neglected in the water resources study, has to be evaluated, taking into account the prevailing water quality in the arid zone aquifers and the promising progress in the reverse osmosis(RO) desalination technologies with economic feasibility.

- From the case study of Jordan, two schemes of the "Al-Wuheda" dam and the "Disi" groundwater development are identified, which are the key applications to sustain the national water resources development in the 1990s. After completing the Al-Wuheda dam on the Yarmouk river by the mid or end of the 1990s, which is the last major renewable water not fully utilized, the non-conventional water resources development including brackish groundwater and re-use of treated sewage water will become the key applications to formulate future national water master plans of Jordan.

- The proposed co-generation approach of brackish groundwater development with hydro-powered reverse osmosis (RO) desalination in the existing Aqaba water supply system minimizes both the cost and energy for the operation, providing $14.6 \times 10^6 m^3$ per annum of fresh water with potential hydro-power generation at 15.9×10^6kwh per annum. The sustainable management or conservation of the non-renewable fresh groundwater in the Disi aquifer is possible by developing the brackish groundwater in the Kurnub aquifer which has never been tapped.

- The water conservation and sustainable water resources management are the key measures to sustain the economic development of the arid regions, which may even includes the cutting of a part of national water supply from non-renewable sources. The conservation approach has to be performed in line with developing non-conventional water resources, by taking into account the new developments in the technology of desalination, waste water treatment and water saving techniques.

- Water resources planning study in the arid regions, especially developing countries in the Middle East, must be based on water conservation including the following strategic development alternatives:

  1) Water conservation including the diversion of existing water system from one use to another.

2) Strategic reserves of the fossil or non-renewable groundwater resources, with the exception of emergency or short-time use for specified purposes.
3) Non-conventional water resources development including desalination and re-use of treated sewage.
4) Inter-state water transfer or importation.

- The priority will, however, have to be given to domestic water resources development management and conservation including non-conventional measures rather than that of introducing water importation from outside countries. Inter-state riparian issues of water allocation have to be resolved.

- The proposed co-generation system which combines solar-hydro with hydro-powered reverse osmosis (RO) desalination on the Mediterranean-Dead Sea conduit scheme could produce $100x10^6m^3$ per annum of fresh water and 500 MW of electricity which is 12 % of the Israel's national grid's capacity of 4,060 MW. The unit water cost of the hydro-powered seawater reverse osmosis desalination is estimated to be US$0.68/$m^3$. The generated electricity would be shared by the Israel-Palestine-Jordan to supply their peak demands, while the product of fresh water of $100x10^6m^3$ per annum would be used exclusively for the water supply in the central Ghor (Jordan Valley).

- Al-Wuheda dam project, which enhances the hydro-solar potential of the Dead Sea, is to be linked with the Mediterranean-Dead Sea conduit scheme, to share the valuable inter-state resources and benefits in a context of the integrated joint development plan, not threatening new political conflicts but rather promoting peace and economic development for the Jordan, Palestine and Israel.

- The proposed integrated planning concept to form the framework of comprehensive development of the Jordan river system is based on the changes in the Israel-Arab situation since the 1990's Persian Gulf crisis. It is now possible to conceive a comprehensive joint development plan which is not only technically-economically feasible but also politically desirable and urgent.

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LIST OF ABBREVIATIONS (1/3)

International Organization

UN	= United Nations
UNRWA	= United Nations Relief and Works Agency for Palestine Refugees in the Near East
UNDP	= United Nations Development Program
UNEP	= United Nations Environmental Program
UNESCO	= United Nations Education Science Culture Organization
WHO	= World Health Organization
WMO	= World Meteorological Organization
FAO	= United Nations Food and Agriculture Organization

Government and Organization

U.S.A./U.S./ US	= United States of America
U.K./UK	= United Kingdom of England
U.A.E.	= United Arab Emirates
PLO	= Palestine Liberation Organization
MEW	= Ministry of Electricity and Water
MOAW	= Ministry of Agriculture and Water
KISR	= Kuwait Institute for Scientific Research
MOEW	= Ministry of Electricity and Water
MOWPW	= Ministry of Works, Power and Water
MOWI	= Ministry of Water and Irrigation
MOP	= Ministry of Planning
WAJ	= Water Authority of Jordan
JVA	= Jordan Valley Authority
MOA	= Ministry of Agriculture
NRA	= Natural Resources of Authority
RSS	= Royal Scientific Society
JNGC	= Jordan National Geographic Center
JEC	= Jordan Electricity Authority
JEPCO	= Jordan Electric Power Company

LIST OF ABBREVIATIONS (2/3)

Study

M/P	= Master Plan
Pre-F/S	= Pre-feasibility Study
F/S	= Feasibility Study
D/D	= Detailed Design

Project

MDS	= Mediterranean-Dead Sea Canal
INWC	= Israel National Water Carrier
EGC / EGMC	= East Ghor (Main) Canal
PG	= Palestine Grid

Desalination

ED	= Electrodialysis
FREEZ	= Freezing
HYBRI	= Hybrid Process
ME	= Multieffect Evaporation
MSF	= Multi Stage Flash Evaporation
RO	= Reverse Osmosis
VC	= Vapour Compression
CA	= Cellulose Acetate

LIST OF ABBREVIATIONS (3/3)

KV	= Kilo Voltage
KW	= Kilo Watt
KVA	= Kilo Voltage Ampere
hr/hrs	= Hour/Hours
km^2	= Square Kilometer
ha	= Hectare
l/s	= Liter per Second
m^3/h	= Cubic Meters per Hour
m^3/s	= Cubic Meters per Second
m^3/d	= Cubic Meters per Day
bs/ft	= Pound per Foot
MCM	= Million Cubic Meters
MCM/y	= Million Cubic Meters per Year
MCM/m	= Million Cubic Meters per Month
ppm	= Parts per Million
mg/l	= Milligram per Liter
E.L/G.L	= Ground Elevation
S.W.L	= Static Water Level
T.D.S(TDS)	= Total Dissolved Solids
E.C(EC)	= Electric Conductivity
VLF	= Very Low Frequency
Al/Bslt	= Alluvium/Basalt
O & M	= Operation and Maintenance
M & I	= Municipal and Industrial
API	= American Petroleum Industry
FEM	= Finite Element Method
FDM	= Finite Difference Method
Fig.(s)	= Figure(s)
Tab.(s)	= Table(s)
Ref.(s)	= Reference(s)

CONVERSION TABLES (1/2)

LENGTH

m	in	ft
1	39.37	3.281
0.0254	1	0.08333
0.3048	12	1
0.303	11.93	0.9942

AREA

m^2	in^2	ft^2
1	1550	10.764
0.0006452	1	0.006944
0.0929	144	1
3.3058	5124	35.58

VOLUME

m^3	in^3	ft^3	U.S. gallons	Imperial gallons
1	61024	35.31	264.2	220.0
0.00001639	1	0.0005787	0.004329	0.003604
0.02832	1728	1	7.481	6.228
0.003785	231	0.1337	1	0.8325
0.004547	277.5	0.1606	1.201	1
0.1804	11008	6.371	47.66	39.68

Note: 1 acre-feet = 1,223 m^3

FLOW RATE

m^3/min.	m^3/hour	l/sec.	U.S. gallon/min.	Imperial gallon/min.	ft^3/min.
1	60	16.67	264.2	222.0	35.31
0.01667	1	0.2778	4.403	3.666	0.5881
0.06	3.6	1	15.85	13.2	2.119
0.1804	10.82	3.007	47.66	39.68	6.371
0.003782	0.2271	0.0631	1	0.8235	0.1337
0.004547	0.2728	0.0578	1.201	1	0.1605
0.0283	1.699	0.472	7.481	6.229	1

CONVERSION TABLES (2/2)

PRESSURE

kg/cm^2	lb/in^2	Standard atomospheric pressure	Mercury column (m)	Water column (m)	Water column (ft)
1	14.22	0.9678	0.7355	10	0.1757
0.07031	1	0.0680	0.0517	0.7031	0.1782
1.0332	14.7	1	0.76	10.33	0.2389
1.359	19.34	1.3158	1	13.6	0.002343
0.1	1.422	0.09678	0.07355	1	0.0003239
0.03048	0.4335	0.0295	0.0224	0.3048	1

POWER

French horse power (P.S.)	British horse power (H.P.)	Kilowatt (KW)	Kg-m/sec.	ft-lb/sec.	kcal/sec.
1	0.9859	0.7055	75	542.5	0.1757
1.0143	1	0.746	76.07	550.2	0.1782
1.3596	1.3405	1	101.97	737.6	0.2389
0.01333	0.01315	0.009807	1	7.233	0.002343
0.001843	0.001817	0.001356	0.1383	1	0.0003239
5.691	5.611	4.186	426.9	3087	1

SI Unit Conversion Table

Unit	Symbol	SI Unit	
Newton	N	J/m	$m.kg.s^{-2}$
Pascal	Pa	N/m^2	$m^{-1}.kg.s^{-2}$
Joule	J	N.m	$m^2.kg.s^{-2}$
Watt	W	J/s	$m2.kg.s^{-3}$

Item	Symbol/Unit	Conversion to Other Unit
Length	m	angstrom,A=0.1nm
Area	m^2	hectare,ha=10^4m^2
Volume	m^3	litre,l=$10^{-3}m^3$
Weight	kg	tonne,t=1,000kg
Density	kg/m^3	
Time	s	minute,min=60s; hour,h=3,600s; day,d=86,400s
Velocity	m/s	
Pressure	N/m^2	$1kgf/cm^2$ =$1kp/cm^2$=98066.5Pa

I. INTRODUCTION

1.1 Background of the Study

Limitations on water, one of scarcest resources in the arid region, are likely to have a significant impact on the economic development of all countries of the Middle East. Middle East water resources issues in the aftermath of the Persian Gulf war are also likely to have a significant impact on the future political framework. The scarcity and the high cost of its development have long been recognized in arid regions, especially in the Arabian Gulf countries where neither surface water nor renewable fresh groundwater are available. The demand for water, however, to serve the expanding third world population continues to increase, while fresh water supplies are finite, and it is becoming more and more difficult to develop them on a renewable basis. Almost all fresh and renewable waters such as river streams, lake water, and groundwater, which are termed "conventional water " or "traditional water", have already been exploited or are going to be fully developed in the countries of Middle East and North Africa by the end of this century.

Few regions of the planet offer a more varied physiography or a richer mix of ethnicities, religions, languages, societies, cultures and politics than the Middle East. At the same time, no segment of the globe presents its diverse aspects in such an amalgam of conflicts and complexities. Out of this compound, one issue emerges as the most conspicuous, trans-boundary, and problematic --- water ---in which its scarcity and rapid diminution in some of the driest sectors of an area where there also happen to exist some of the fiercest national animosities. River waters in the Middle East are a conflict-laden determinant of both the domestic and external policies of the region's principal actors. However, as one of the leaders of the PLO recently stated: "water is more important than oil or politic", so politics may not remain a constraint to water development much longer.

As water shortages occur and full utilization is reached, policies tend to be framed more and more in zero-sum terms, adding to the probability of discord and it would seem to be unavoidable that the severity of Middle Eastern water problems will continue to increase significantly. In the already over-heated atmosphere of political hostility, insufficient water to satisfy burgeoning human, developmental, and security needs among all

nations of the Middle East has heightened ambient tensions. By the end of the 1990s, Israel, Jordan and the West Bank or Palestine will have lost virtually all of their renewable sources of fresh water if current patterns of consumption are not quickly and radically altered. In these circumstance, the Jordan River system, which includes the Al-Wuheda dam scheme on a major tributary of the Yarmouk river, unquestionable holds the greatest potential for conflict.

Despite of the many political complications in the Middle East, there is a recent history of tacit, although limited, cooperation over multi-national river development even among the bitterest opponents on the rivers of Nile, Euphrates and Jordan:

- Egypt and the Sudan have created a model of cooperation in "1959 Nile Waters Agreement", which not only governs the sharing of the Nile's waters but contains an instrument for settling controversies by negotiation. This could serve as a model for other river systems in the application of technology to alleviate water problems.

- Turkey has continually threatened to cut the flow of the Euphrates. Iraq and Syria could arrive at an arrangement over the Tabqa dam operation in 1975. Turkey agreed with Syria on the operation of the Ataturk dam in 1987, by releasing 500 m^3/sec ($15.8 \times 10^9 m^3$ per annum) water to the Syrian border. However, the water was used as a political weapon to forth Syria to curtail its support for Kurdish activists in southeast Anatolia.

- Israel and Jordan - until Israel's invasion of Lebanon and her troublesome stand on clearing out obstructions to the intake of Jordan's East Ghor canal - have more or less informally agreed to share the Jordan River system within the framework of the "Johnston Plan : 1955". (Ref.1.1-1)

Multi-national river development has been a keen concern of water resources planners throughout the world, especially in the developing countries in the arid region. Turkey's ambitious proposal for the "Peace Pipeline" project in 1987, to transfer water from Seyhan-Ceyhan river systems in southeastern Turkey to the Euphrates basin and other downstream countries by constructing a series of dams, water tunnels, and world longest international water pipeline system with a total length of about 6,550 km^2 and a capacity of 6 million cubic meters a day (Ref.1.1-2), has been shown to technically though not yet economically feasible. The

project would involve the crossing of several political boundaries, however, and is likely to be postponed until some of the most pressing political issues of the Arab world, including the international water rights problems between Turkey, Syria and Iraq have been solved. Trans-boundary river development may not take place this century, but planning and the easing of water disputes will certainly form an important part in political discussions which will determine the future pattern of boundaries to be re-drawn in any future peace settlements.

In the arid region, the potential of fresh and/or good quality of water is limited, because of the extremely limited amount of rainfall and the very high potential evaporation which exceeds ten times or more potential rainfall. Salinity pollution from irrigated agriculture is not a recent phenomenon, but an age-old problem. An important indirect water quality effect of irrigated agriculture is becoming increasingly apparent.

Soviet scientists report that the Caspian and Aral Seas are in retreat because excessive irrigation withdrawals are reducing inflow from their catchments. The Aral Sea has already shrunk dramatically in size; the water level has dropped by 3 m since 1960, reducing its size by some 18,000 km^2. In the mean time reduced inflow from the two major rivers of "Sir Darya" and "Amu Darya", with enhanced salinity from irrigation returns, has already increased the salinity of the Aral Sea up to 1,000 ppm of total dissolved solids. (Ref.1.1-3)

Basin irrigation has been practiced on the flood plain of the Tigris-Euphrates rivers since 4000 B.C.. Lack of drainage has repeatedly caused the build up of salts in soil and water that has inhibited food production and indeed contributed to the decline of Sumerian culture. More recently modern development of irrigation in arid regions have suffered from a variety of salinity pollution problems since. Problem areas have been included the Indus river in Southwest Asia, the Tigris-Euphrates rivers in the Middle East, the Nile river in the North Africa, the Murray river in Australia, and the Colorado river in southwestern Arizona. (Ref.1.1-4)

Since the 1950s in the southwestern Arizona the Colorado river has been seriously contaminated by irrigation return flows and highly saline pumped drainage water from the Wellton-Mohawk irrigation project. By 1961 the salinity of the Colorado river had reached a level that was unacceptable to the Government of Mexico. In 1973, Minute No.242 of the International Boundary and Water Commission (IBWC) became effective, which aims to

improve, enhance, and protect the quality of water available in the Colorado river for use in the United States and Mexico. The agreed-upon salinity level in the Colorado river can only be attained by either bypassing saline drainage or desalting this brackish water before it returns to the Colorado river. Since water is a precious resources in the semi-arid areas in the southern Arizona, a decision was made to reclaim a major portion of the Wellton-Mohawk drainage with a desalination plant which is the world largest reverse osmosis (RO) desalting facility with an installed capacity of 72.4 mgd (280,000 m^3/day). (Ref.1.1-5)

In some of the more arid parts of the Middle East, in particular the Gulf states, where no good quality water is available or is extremely limited, desalination of seawater has been commonly used to solve the problems of water supply for municipal and industrial (M&I) uses. Owing to the rapid increase in demand for water supply in the Arabian Gulf countries, namely Saudi Arabia, Kuwait, United Arab Emirate (UAE), Qatar, Bahrain, and Oman, where the potential for development of conventional water resources such as fresh surface water and renewable groundwater is extremely limited, other alternatives such as waste-water reclamation and desalination processes have been developed since the 1960s. Countries such as Saudi Arabia, Kuwait, Qatar, and Bahrain are using non-renewable groundwater resources in large quantities, causing depletion of these valuable resources. Although conventional water resources such as renewable groundwater and surface runoff are available in countries like Oman, the United Arab Emirates and Saudi Arabia, these resources have yet to be sustainably developed in an integrated water resources planning context.

A huge amount of non-renewable or fossil fresh groundwater is stored in the Paleozoic to Mesozoic-Neogen (Nubian) sandstones which underlie wide areas in the Arabian peninsula in Saudi Arabia and Jordan and in the eastern Sahara desert in Egypt and Libya. The dominance and importance of the non-renewable groundwater reserves in national water planning is confirmed by the 1985-90 development plans of Saudi Arabia and Libya.

Saudi Arabia is one of the world's leaders in production of wheat for self-sufficiency in food, but is heavily dependent on use of non-renewable groundwater. According to the "Fourth Development Plan (1985-1990); Ministry of Agriculture and Water", agricultural water demand in Saudi Arabia in 1985 amounted to 8,000 $x10^6m^3$/y, whereas water demand for urban, rural and industrial (M&I) use was 1,600 $x10^6m^3$/y. It was estimated that total water demand will be increased to 16,500 $x10^6m^3$/y by the year of 2000, being 14,000 $x10^6m^3$/y for agriculture and 2,500 $x10^6m^3$/y for M&I.

The huge amount of water demand for agriculture is based on the Kingdom's policy of self-sufficiency in food and on use of non-renewable groundwater for growing grain which generally requires 2,000 to 3,000 tons of water per ton of grain (Refs.1.1-6,7).

Groundwater development and/or mining in the Nubian sandstones of the inland desert depressions of Libya, "Great Man-Made River (GMR) Project", will be a key application of the Libya's development strategy for the twenty-first century. The Libyan government commenced construction in 1984-1986 (1st-2nd phase), with aim of abstracting groundwater in the inland desert at a rate of $2x10^9$ m^3 per annum (66 m^3/sec) in total. The water would be conveyed over 600 km north to farms on the Mediterranean coast, by installing the world's largest water pipeline system with a total length of 4,000 km (Ref.1.1-8). The life of the Nubian sandstone aquifer can only be estimated to be 20 to 200 years, owing to the lack of data for estimating groundwater recharge through wadi beds and/or depressions during occasional and temporary flash floods. The total pipeline system is therefore designed on the assumption of an aquifer life of 50 years.

The Egyptian government commenced non-renewable groundwater development in the Nubian sandstone aquifer in the inland Sahara desert in the mid 1950s, by the New Valley project which aims to expand the cultivated area in the Kharga and Dakhla oases. The construction of deep production wells in Dakhla oasis was completed by 1966, which increased the combined installed capacity of shallow and deep systems up to $190x10^6m^3$ per annum, but the yield had decreased to a level of $159x10^6m^3$ per annum by the end of 1969. The Egyptian authorities are planning to augment the extraction till it reaches $2,400x10^6m^3$/year by the year 2000. (Ref.1.1-9) The extraction of the target volume will lead to further decline of the piezometric head and cessation of the artesian flow. Another problem of the development project is the human problem in that many of the managerial staff do not like living in such isolated areas.

Desalination of brackish water and seawater is a key application of the non-conventional water resources development. The ocean holds $1,338x10^6km^3$ of seawater, which accounts 96.5 % of the total water reserves of the earth of $1,386x10^6km^3$. In some of the more dry parts of the Middle East, in particular the Arabian Gulf states, where conventional good quality of waters are not available and-or extremely limited, desalination of seawater has been commonly used to solve the water supply

problems for the increasing demand in the municipal and industrial (M&I) uses. The cost of the brackish groundwater desalination is competitive, while the seawater desalination is invariably high. The cost is largely influenced by petroleum prices. Two-third of the world installations of the desalting plant are located in the oil-rich states in the Middle East which could purchase massive quantities of desalting equipment.

A solar-hydro scheme by a Mediterranean-Dead Sea (MDS) Canal was proposed by Israel in 1980. The scheme which has multiple socio-economic and political ramifications was intended to convey water from the Mediterranean Sea to the Dead Sea via canals and tunnels utilizing the height difference of close to 400 m to generate 600 MW of electricity. In addition, proposals were made to use the water for cooling nuclear power stations rated at 1,800 MW, and to investigate the feasibility of generating 1,500 MW from Dead Sea as a solar pond (Ref.1.1-1). There has been no presentation of the concept of sharing resources with other countries and no effort at joint development. The MDS project was soon put aside, owing to the strong opposition from Arab states and others with the confusion and drop of the world oil market price in 1984. In recent days, however, talk of the much-discussed Mediterranean-Dead Sea (MDS) Canal has again been revived by worldwide attention to use of clean energy and safe guarding the global environment.

Israel has experienced much difficulty in making additional water supplies available since the late 1960s, when it was using as much as 95 % of the total renewable water sources available in its territory (Ref.1.1-8). Almost one-half of Israel's total water supply is dependent on the water that has been diverted or pre-empted from Arab sources located outside the pre-1967 boundaries (Ref.1.1-1). The main effort had to be shifted to making more efficient use of available supplies rather than increasing the capacity of hydraulic structures. In neighboring Jordan, almost all the renewable waters are going to be fully exploited by the mid to end 1990s when the on-going Al-Wuheda dam project on the Yarmouk river is completed. This is the largest tributary not yet fully developed in the Jordan river system. After constructing the diversion tunnel in late 1989, the project was stopped owing to strong opposition from the Israeli government which is the administrator of occupied Palestine or the West Bank.

Priority in water resources development in each state is still based on development of the nation's own water resources including not only the conventional fresh water resources such as renewable groundwater and the

surface water but also non-conventional water resources such as fossil groundwater, brackish groundwater, seawater, saline drainage water and re-use of treated sewage effluents. The potential contribution of the marginal waters to meet the anticipated water demand in Israel and Jordan will be a unique initiative. Another option will be diversion of the existing water system from one use to another; from agriculture to municipal and industry, as has happened in large population centers in Arizona in U.S.A.

Non-conventional water resources need to be developed properly in an integrated planning context such as a national water master plan. However, by the first decades of the twenty-first century almost all states in the arid region will be facing severe water shortages in urban centers as populations continue to grow. Water resources planning for the twenty-first century in the arid region may therefore comprise following alternatives;

a) Water conservation and diversion of existing water systems from one use to another.
b) Non-conventional water resources development including desalination and re-use of treated sewage.
c) Multi-national fresh water transfer or importation by pipeline, tanker or barge, including;
   - Ceyhan-Seyhan-Middle East Peace Pipeline
   - Euphrates diversion from Iraq to North Jordan
   - Shatt El-Arab diversion from Iraq to Kuwait
   - Manavgat-Mediterranean Medusa Bag Carrier (Ref.1.1-10)
d) Other marginal non-conventional measures including weather modification, dual (distribution) system, and rain harvesting.

There are now several changes in the political situation since the Iraq invasion to Kuwait in 1990, that may form part of a comprehensive resolution of the Israel-Arab problem. This may make integrated development concept not only technically and economically feasible but politically desirable and urgent.

1.2 Objectives, Concepts and Scope of the Study

This study attempts to evaluate some new non-conventional approaches to water resources which need to be taken into account in building the new peace in the Middle East. These new approach offer the opportunity to

introduce new applications of well-tried technology to solve long-standing water problems which are at the center of many of the potential sources conflicts.

This planning study introduces following five concepts:

1) **Integration of development alternatives in the context of a water master plan**, including non-conventional water resources applications in the arid region.
2) **Co-generation for clean energy and water**, including solar-hydro, groundwater-hydro and hydro-powered reverse osmosis desalination.
3) **Strategic use of non-conventional water resources for sustainable development**, including brackish water, seawater and reclaimed waste-water.
4) **Joint development with sharing of resources for multi-national basin development** of the Jordan river and Dead Sea.
5) **Water resources planning for a peace foundation settlement**, including Israel-Palestine-Arab issues.

The arid zone occupies about one-third of the land area of the earth, and includes both some advanced countries and many developing countries in North and South America, North and Southwest Africa, the Middle East, Central Asia, West Asia and Australia. This study is not a worldwide review of arid zone hydrology and water resources development but a case study on water resources planning in the developing countries of the Middle East. In this study, the Middle East includes the whole geographical region including Kuwait, Jordan, Palestine and Israel where the peace of the world is at risk.

1.3 Organization of the Thesis

This thesis consists of six chapters with two annexes, **Chapter-I** being this introduction.

Chapter-II has been initiated to review arid zone hydrology and problems and constraints of water resources development and management in the arid zone including non-conventional water resources development alternatives.

Section 2.1 reviews the causation, definition of arid zone in a context of global water cycle and balance. Sections 2.2 to 2.5 describe the

nature of the hydrology and riparian issues of major multi-national rivers in the Middle East such as rivers of Tigris-Euphrates, Indus, Nile and Jordan. Section 2.6 examines the world's first major challenge to control river salinity problems by installing the world's largest reverse osmosis (RO) desalinating plant at Yuma on the lower reaches of Colorado river. Section 2.7 describes large scale non-renewable or fossil groundwater development projects which are being carried out in Saudi Arabia, Egypt (New Valley project) and Libya (Great Man-made River project). Sections 2.8-2.9 describe desalination practices in the Arabian peninsula including brackish groundwater desalination by reverse osmosis (RO) in Bahrain and seawater distillation in the Arabian Gulf countries. Section 2.10 describes pioneer groundwater-hydro projects in Chile and Libya. Section 2.11 describes the world's first solar-hydro and seawater pumped-storage schemes in Egypt. Section 2.12 summarizes the review studies in Chapter II and suggests the implications of marginal waters as non-conventional water resources development in the arid region.

Chapters III to V are the application studies which attempt to conceive a sustainable water resources development plan including the non-conventional alternatives. The application studies have been carried out including Kuwait, Jordan, Palestine and Israel where the peace of the world is at a risk.

Desalination of brackish groundwater and seawater is the topic of this study, taking into account of energy saving made possible by recent innovations in reverse osmosis (RO) membrane technology. A new co-generation approach is proposed to demonstrate a way that potential energy can be used in developing on water resources system, including groundwater and seawater, which has not before been utilized in the context of conventional water resources development. This approach aims to coordinate 1) groundwater-hydro, ii) solar-hydro, and iii) hydro-powered reverse osmosis (RO) desalination in an integrated development context.

The study aims to cope with water resources planning for a peace foundation settlement with the concept of shared resources and their joint development between Israel-Palestine-Jordan, by taking into account the various recent changes in the political situation in the Middle East since 1990-91 Gulf war.

Chapter-III considers the application of hydro-powered reverse osmosis (RO) desalination to marginal water resources development in Kuwait and a

case study on the brackish groundwater development with hybrid RO. The unit water costs have been estimated to compare the cost effectiveness of various desalination methods including conventional thermal (MSF) process and membrane process with hydro-powered RO application.

Sections 3.1-3.3 describe the physiography, hydrology and water resources of Kuwait. Sections 3.4-3.5 describe the experimental reverse osmosis desalination projects which have been undertaken in Kuwait since 1985 on both seawater and brackish groundwater. Section 3.6 sets out a proposal for applying hydro-powered reverse osmosis desalination to brackish groundwater development in the southwestern part of Kuwait. Section 3.7 presents a water master plan study for the marginal water resources development in Kuwait.

Chapter-IV considers the application of non-conventional water resources development to a national water master plan for Jordan. Jordan has a limited potential for renewable water resources development and this will be exhausted by the mid to end 1990s. There are, however, various development alternatives for both conventional waters such as surface water and groundwater, and non-conventional waters including brackish waters, seawater and urban waste water.

Sections 4.1-4.3 describe the background and water resources development and management of Jordan. Section 4.4 provides an inventory of potential non-conventional water resources in Jordan. Section 4.5 describes a key proposal for co-generation by brackish groundwater reverse osmosis (RO) desalination and groundwater-hydro to sustain the non-renewable and renewable water resources system in the south Jordan. Section 4.6 presents a master plan study on non-conventional water use in the extent of a national water master plan for Jordan.

Chapter-V describes the integrated water resources development and management of the Jordan river system, with the aim of mitigating the historical complexities, commonalties and conflicts between Israel and the Arab states, is shown to provide an opportunity for sharing resources and joint development between Israel and Jordan.

Sections 5.1-5.2 describe the background and water resources of Israel. Section 5.3 is a review of Jordan river development and Israel's water resources development and management. Section 5.4 provides a case study on the joint Israel/Jordan Mediterranean-Dead Sea conduit scheme, which is a key proposal in the new co-generation system coupling reverse osmosis (RO)

seawater desalination with solar-hydro. Section 5.5 is a master plan study on multi-national water resources development, management including importation options among Israel and Middle East states.

Chapter-VI contains the concluding remarks and recommendations for the further study.

Annex-I describe the world state of the art in reverse osmosis (RO) desalination, which has important implications for water resources planning in the twenty-first century.

Annex-II gives physiography of Jordan and Israel and a historical review of multi-national river development of the Jordan river system including notes on negotiations over water allocation problems between Israel and other riparian states from 1948 to 1967. Some recommendations for the future plan of the joint development and management of the Jordan river system are given in the supplement of Annex-II.

REFERENCES (1.1-1.4)

Ref.1.1-1
Thomas Naff and Ruth C.Matson, 1984, "Water in the Middle East; Conflict or Cooperation ?", Westview Press / Boulder and London, pp.1-62.

Ref.1.1-2
David Gould, 1988, "The Selling of the Peace Pipeline", MEED, 26 March 1988, pp.10.

Ref.1.1-3
Michel Meybeck, Deborah Chapman and Richard Helmer, 1990, "Global Freshwater Qauality; A First Assessment", WHO/UNEP, pp.155-156.

Ref.1.1-4
Michel Meybeck, Deborah Chapman and Richard Helmer, 1990, "Global Freshwater Quality; A First Assessment", WHO/UNEP, pp.139-156.

Ref.1.1-5
Robert Applegate, 1986, "World Largest RO Desalting Facility to Salvage 72.4 mgd", WaterWorld News May/June 1986, pp.17-19.

Ref.1.1-6
Adnan A.Akkad, 1990, "Conservation in the Arabian Gulf Countries", Journal AWWA, Management and Operations, pp.40-50.

Ref.1.1-7
SWCC, 1988, "Kingdom of Saudi Arabia, Saline Water Conversion Corporation", Developing World Water, Grosvenor Press International, pp.198-199.

Ref.1.1-8
Peter Breaumont, Gerald H.Blake, and J.Malcolm Wafstaff, 1988, "The Middle East; A Geographical Study, 2nd Edition", David Fulton Publishers. pp.412-422.

Ref.1.1-9
Mamdouh Shahin, 1987, "Groundwater Resources in Egypt: Potentials and Limitations", IAHS, Proceedings of Roma Symposium: Hydrology in Perspective - Water in the Future, Publ.no.164, pp.179-192.

Ref.1.1-10
Christopher Savage, 1990, "Middle East Water"-lecture given to the Royal Society for Asian Affairs on 20 March 1990, London, Journal of the Royal Society for Asian Affairs.

II. REVIEW STUDIES ON ARID ZONE HYDROLOGY AND WATER RESOURCES DEVELOPMENT AND MANAGEMENT

2.1 Arid Zone in Global Atmospheric Circulation and Water Resources

Concern over global climatic changes caused by growing atmospheric concentrations of carbon dioxide and other trace gases has increased in recent years. Recent symptomatic global climatic changes such as El-Nino and Sahel drought and/or desertification have improved our understanding of atmospheric dynamics and global climate systems. One of the most important consequences of future changes in climate will be alterations in regional hydrological cycles and subsequent effects on the quality and quantity of regional water resources. Yet these consequences are poorly understood. Recent hydrological research strongly suggests that it is plausible that climatic changes caused by increases in atmospheric trace gas concentrations will i) alter the timing and magnitude of runoff and soil moisture, ii) change in lake levels and groundwater availability, and iii) affect water quality. Such a scenario raises the possibility of dramatic environmental and socio-economic dislocations and has widespread implications for future water resources planning and management.

By looking at the variations of climate and hydrologic conditions in geological time, we can simulate the analogues of the future greenhouse conditions which may cause significant changes in water availability. Nicolson and Flohn (1980, Ref.2.1-1) explored water availability in Africa using a variety of paleoclimatic records. They suggested that parts of the Sahel region which were drier 18,000 years before present (B.P.), became more moist in the period 10,000-4,500 years B.P., and then became drier up to the present. These changes can then be related to possible driving forces in global atmospheric circulation, which may explain the huge amount of fossil groundwater resources stored in the extensive Nubian sandstones of the Sahara desert during the late Pleistocene age.

Water differs markedly from most other natural resources by its remarkable property of continuous renewal in the water cycle, the main link in which is water exchange between oceans and the land. The world ocean is a giantic evaporator which, in this natural cycle, is the main source of fresh water. The fresh water falls as atmospheric precipitation and is the source of all water flows and water accumulation on land. The greater part of the water on the earth, approximately 97.5 %, is salt water and

water that is mineralized.

The volume of fresh water amounts to 35,029,000 km^3, or 2.52 % of the total amount of water reserved on the earth. Rivers and streams account for 0.006 %, fresh water lakes for 0.26 % and water contained in the atmosphere for 0.001 % of the total quantity of fresh water. The rest fresh water component includes soil moisture, permanent snow cover, marsh, active groundwater . (Ref.2.1-2) From the end of the 19th century onwards, the attention of many scientists has been directed to the problem of the connection between atmospheric precipitation, runoff and evaporation in river basins. Water resources development in the 20th century has been directed to exploiting river streams, lake water and groundwater of which the qualities have had to be exclusively fresh. Saline waters such as seawater and brackish water, of which storage potential is estimated to be as much as 97.5 % of the water on the earth (Ref.2.1-2), may suggest their increasingly important roles in water resources planning of arid countries in the 21st century.

2.1.1 Causation of arid zone

On a world scale there is a sharp fall in rainfall near 30° latitude (horse latitude) in both hemispheres (Fig.2.1.1-1), and in places, notably in west coastal Chile and Peru, rainfall is almost unknown and/or zero record (Fig.2.1.1-2). Since this aridity affects oceans as well as continents, it is apparent that there must be exist some process whereby rainfall is suppressed, for there is no shortage of water for evaporation. We shall look for this process among the dynamic factors associated with the general circulation of the atmosphere.

The immediate causes of this aridity can be listed as follows; the first is the tendency towards divergent wind-flow at low levels, especially in the pole-ward parts of the trade winds (Fig.2.1.1-3). This divergence causes general subsidence of the air column throughout the low troposphere where the water vapor is concentrated. Dynamic warming associated with this subsidence tends to lower the relative humidity and disperse cloud; it also create an impressive degree of hydrostatic stability, so that convection currents and shower-type precipitation are inhibited. At sea the trade winds have a shallow, moist layer of moving air capped by a stable or inversion layer, above which the air is very dry. Over land, as in the Sahara, in northern Mexico, Australia and much of the Middle East (in summer) the dryness may extend to ground level. Hence surface divergence, general subsidence, low humidities and an absence of deep

convection form a causally connected sequence over much (but not all) of the subtropical world. The second cause of aridity, not truly independent of the first, is the existence of high pressure zones near the latitudes of 30 degrees north and south (Fig.2.1.1-4). Over the ocean, this high pressure is recorded at sea level, but inland it may be necessary to ascend to levels of 2-3 km before experiencing the propagation of disturbances, and the subtropical high pressure belt which is continuous in both hemispheres, though considerably modified in form over southern Asia in summer. The sub-tropical high pressure belts also separate the circumpolar westerlies from the tropical easterlies. As is well known, both westerlies and easterlies are affected by traveling wave-perturbations, which account for a good part of the precipitation in both regimes. The amplitude of both sets of waves is at a minimum near the axis of the subtropical highs; hence the subtropics are least likely to be affected by rain-bearing disturbances. This constitutes the second cause of widespread aridity.

In general it should be stressed that low humidities throughout a deep layer in the lower troposphere invariably lead to aridity, while very dry climates may also occur in areas of high atmospheric humidity. Thus parts of the arid southwestern United States of America are dry, not because of low humidities, but because of the ineffectiveness of rain-making disturbances (Ref.2.1.1-1).

A further point is that remoteness from the sea is not a guarantee of drought; high moisture contents occur deep in the interior of Amazonia, more than 2,000 km from the ocean along any possible direct streamline, and rainfall is heavy. Yet extremely low rainfalls occur in many areas along oceanic coasts, as in Chile, Peru, Morocco and South-West Africa (see Figs.2.1.1-1&2). The point is, of course, that local sources of evaporation play a very small role in precipitation, which tends in most instances to fall from moist air-streams of which the humidity has been derived from very remote surfaces.

The aridity of the subtropics thus emerges as an aspect of world climate dependent on deep-seated features of the earth's general atmospheric circulation. It does not arise from local or man-made circumstances, but from natural causes involving exceedingly large energy transformations and momentum transports. It has not been conceived that the regime can be significantly altered by human intervention. Present discussion in the early 1990s, however, is based on the worldwide concern with global climatic changes, which may be due to the substantial increases of carbon

dioxide caused by the industrialization since World War II.

It is equally unlikely that any past climatic epoch can have experienced a complete absence of subtropical aridity. As we have seen, the maintenance of the mid-latitude westerlies absolutely requires the existence of compensating easterlies in the tropics. Similarly the transfer of momentum and heat northward in the tropics requires the existence of a Hadley cell (Figs.2.1.1-3&4), with subsidence (and hence low humidity and drought) at some subtropical latitude. Hence it seems likely that the arid zone can have been no more than constricted in extent and driven a few degrees equator-ward at the height of recent glacial development; it can hardly have been eliminated altogether (Ref.2.1.1-2).

2.1.2 Definition and classification of arid zone

Deserts have been mapped in regions as diverse such as low and high latitude zones, inland continents, and coastal zones. Cold deserts, which are situated in high mountain ranges or high latitude zones, are not included in this study. This study deals warm deserts which are situated in the zones between the tropics and the temperate zones.

One of the simplest classification of dry climates states simply that 10 in.(250 mm) is the dividing line between arid and semi-arid and 20 in.(500 mm) between semi-arid and humid (refer to Fig.2.1.1-1). Although these criteria are scorned by many scientific geographers and climatologists, it is actually not bad for the standard climatic classifications.

Most classifications today use combinations of temperature and precipitation, in order to make some allowance for the increasing evaporation with higher temperatures. De Martonne (1926&1942; Ref.2.1.2-1&2) and Koppen (1923; Ref.2.1.2-3) both used figures of mean annual precipitation (P) and temperature (T). The basic de Martonne formula (2.1.2-1) gives an index of aridity (I) which is a true sliding scale without artificial break points.

$$I \text{ (Index of aridity)} = \frac{P}{T + 10} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots (2.1.2\text{-}1)$$

Koppen's formula has rigid break points, but at least these are varied according to the season of maximum rainfall. The margin between arid and semi-arid would be ' R (Rainfall) = T + 11 '. Koppen's formulas were an attempt to assign climatic values to the limits of the main vegetation

types of the world.

Another philosopher analyses the temperature and precipitation ratios of individual months. The monthly indices, including mean monthly precipitation (Pm) and temperature (Pt), are then summarized into an annual figure. Thus, de Martonne's index becomes the total of twelve monthly indices each of which is calculated as ' 12*Pm/(Tm+10) '.

Thornthwaite's (1948; Ref.2.1.2-4) basic system is more complex, but uses only mean monthly temperature and precipitation to arrive at a figure for estimated potential evapotranspiration (PEt). An aridity index (AI) was proposed to classify the arid regions, which assumes; i) AI=0 for P=PEt, ii) AI=-100 for P=0, iii) AI=+100 for P is much greater than PEt. Following ranges of the aridity index (AI) were used;

Zone Classification	Aridity Index (AI)
Semi temperate	0 - -10
Semi-arid	-20 - -40
Arid	<-40

Thornswaite's method has been widely used by climatologists owing to its simple methodology. For the irrigation engineer, however, the method of estimating the parameters for potential evapotranspiration was found to be not accurate enough to be used for design purpose. He has introduced factors of soil to the point where his latest indices can no longer be considered purely climatic (Thornthwaite and Mather, 1957; Ref.2.1.2-5).

An early version of the concept of evaporation balance was devised by Albrecht Penck (1910; Ref.2.1.2-6), who used the geomorphic factor of hydrographic balance for a broad climatic classification. De Martonne (1942; Ref.2.1.2-2) drew a world map upon such a basis.

Emberger (1955; Ref.2.1.2.7) uses mean annual precipitation (P), mean daily maximum temperature of the warmest month (M), and mean daily minimum temperature of the coldest month (m), all combined into a single 'moisture quotient' (Q) using following formula:

$$Q = \frac{2P}{(M+m)(M-m)} \times 1000 \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (2.1.2\text{-}2)$$

Unlike the formulae of Koppen, Thornthwaite, or de Martonne, the moisture quotient of Emberger cannot be used by itself to make a valid climatic

map. His maps appear to be based upon his profound knowledge of vegetation, not upon the mapping of climatic data. After mapping the vegetation zones, he determines the associated moisture quotients and other climatic values within the zones. Thus, the northern limit of his arid zone in north-west Africa varies from a moisture quotient of 16 to one of 40. In characterizing the climate of his stations, he uses the actual mean daily minimum temperature of the coldest month, as well as the moisture quotient. His maps for north-west Africa, which he calls bioclimatic zone maps, are of fundamental value for all geographers and climatologists. Because of the accuracy and detail of his mapping, the maps form a valuable test of the vegetation validity of any climatic system. A simple check shows, for example, that de Maronne's index of 10 would serve fairly well as the northern limit of Emberger's Mediterranean arid bioclimatic zone.

Meigs, who was a chairman of Arid Zone Commission of the International Geographical Union, made a global arid zone map in 1951 (Fig.2.1.2-1), of which the zonal classifications have been widely used in arid zone research since World War II. Meigs classification is based on regional temperatures (mean monthly maximum and minimum) and the duration of dry periods. His arid index map has the following three sub-regions: 1) extremely-arid region, 2) arid region, and 3) semi-arid region. The extremely-arid region includes annual sum of zero record of rainfall for twelve months continuous observation, which occupies about 4 % of land area of the earth. The arid region comprises that with a minimum of one month of rainy season, which covers about 15 % of the land area of the earth. The semi-arid region includes a rainy season with an rainfall amount of 100-200 mm, which occupies about 14.6 % of the land area of the earth. (Ref.2.1.2-8)

2.1.3 Global atmospheric circulation and climatic changes in the arid zone

In the last couple of decades low Sahel rainfall, possibly related to climatic changes, has reduced water availability in North Africa. Folland and Palmer (1986; Ref.2.1.3-1) noted that there is a strong inverse relationship between worldwide Sea Surface Temperature (SST) and Sahelian rainfall. The SST has been rising since the late 1960s, which period corresponds with decreasing of rainfall in the Sahelian region. The present increase in SST is considered likely to be linked with global climatic change, which suggests the warming up of the climate by the

greenhouse effect. However, the rising SST may also be linked to El Nino Southern Oscillations (ENSO).

The El Nino events have occurred in 1972-73, 1976-77 and 1982-83 resulting in drought in the Sahel. Failure or weakening of the Guinea monsoon seriously reduced the rainfall on the Ethiopian Highlands. Most of the major rivers of North Africa originate in the Central African Uplands, Atlas Ranges and Ethiopian Highlands (see Section 2.2.4). More than 80% of the Nile's water originates in the Ethiopian Highlands. The reservoir level in Lake Nasser has fallen by more than 18 meters in the last seven years owing to the African drought. (Ref.2.1.3-2) As a result usable effective storages are only one fifth (20×10^9 m^3) of the 1979 level.

The increasing albedo is another climatic factor that affects water resources. Desertification has increased the albedo level in the catchment area of Northern Africa rivers. The net effect of high albedo level is that the sun's energy is reflected to the atmosphere to heat the air, causing increased evaporation and transpiration, resulting a decrease in the potential water resources.

2.1.4 Paleo-climatology and water resources planning

About 10,000 years B.P., the global climate was moist and cooler indicating atmospheric carbon dioxide concentrations between 260 and 290 mg/l. The earth was covered with 6.2 billion hectares of forest as compared to 4.1 billion hectares today at the end of the last (4th) glacial age. (Ref.2.1.4-1)

Nicholson and Flohn (1980: Ref.2.1.4-2) explored water availability in Africa using a variety of paleoclimatic records. The suggest that parts of the Sahel region were drier 18,000 years before present (B.P.), became more moist and cooler with frequent rains in the period 10,000-4,500 years B.P., and then became drier up to the present. Similarly, Goodfriend et al. (1986: Ref.2.1.4-3) explored the paleoclimatic evidence for climatic changes in the area of Jordan River Basin and Dead Sea. They identified large fluctuations in the level of terminal lake of Dead Sea in the late Pleistocene period up through 4,300 years B.P..

Reconstructions record back several centuries can provide valuable information on both past climatic conditions and the vulnerability of our water resources system to the future change. In a striking example, Stockton and Jacoby (1976: Ref.2.1.4-4) used tree rings to extend the

runoff record in the Colorado river basin back more than 400 years (Fig.2.1.4-1). ^{13}C isotope of the tree rings was used for the environment tracer. This kind of study has direct water management and policy implications. For example, the original 1922 Colorado river water allocation was based on the hydrologic record available at the time: about 30 years from the late 1890s to the early 1920s. In 1976, when the historical record was reconstructed back to the middle 1500s, the period from 1890 to 1920s stood out as a time of abnormally high runoff (Fig.2.1.4-1). The 400-year record now shows that more water was allocated to users than is likely to be available on a long-term average basis. If the long-term record had been available in 1922, the over-allocation might not have occurred. These changes can then be related to possible driving forces in the global atmospheric circulation.

Paleo-Carbon Dioxide and Greenhouse Effect

The atmospheric carbon dioxide (CO_2) concentrations in air particles trapped in the 2,200 meter Vostock ice cores have been analyzed to examine the historical changes of the climate since 160,000 years B.P (Ref.2.1.4-5). These Antarctic ice cores also provided temperature information for the same period based on oxygen isotope (^{18}O) ratio. The derived temperature changes, closely match changes in carbon dioxide concentrations (Fig.2.1.4-2).

Gammon et al. (1985: Ref.2.1.4-6) reviewed the history of atmospheric CO_2 from 10^8 years ago to the present. During Cretaceous (100,000,000 years B.P) age the carbon dioxide level was perhaps as high as several thousand parts per million, and then dropped to 200-300 mg/l during the glacial-inter-glacial cycles of the past few million years through 10,000 years B.P.. Since 19 century, the carbon dioxide level increased to about 350 mg/l, which could owing to the accelerated burning of fossil fuels as an energy source. (Fig.2.1.4-3) North America, Western Europe and the USSR and the Soviet block countries emit 67.4 I of the carbon dioxide to sustain the industrial activities. (Ref.2.1.4-7)

COMPAC and GCMs

The scientists of the Cooperative Holocene Mapping Project (COHMAP) have assembled a global array of well-documented paleoclimatic data and general circulation models (GCMs). The GCMs model was developed to look at soil moisture in the mid continental region of the United States of America and concluded that significant drying may occur if the concentration of carbon

dioxide (CO_2) in the Earth's atmosphere is doubled (Ref.2.1.4-8). The GCMs-generated hydrologic data suffer from two major limitations; namely i) the spatial resolution of GCMs is too coarse to provide hydrologic information on a scale typically of interest to hydrologist, and ii) hydrologic parameterizations in GCMs are very simple and often do not provide the detailed information necessary for water resources planning (Ref.2.1.4-9). The hybrid (COHMAP-GCM) model simulates the historical worldwide climatic changes in the atmosphere, geosphere, and biosphere that accompanied the transition from glacial to inter-glacial conditions during the past 18,000 years with geologic and paleo-ecologic evidence (Ref.2.1.4-10), of which the results are to be used not for predicting the changes in water resources systems in future but for understanding the change in global climate in a time of geological scale.

To assess the implications of greenhouse effect for water resources in the arid to semi-arid regions, regional-scale details of future changes are needed for temperature, precipitation, evaporation, soil moisture, and other hydro-climatological variables. It is simply assumed that the more increasing concentrations of greenhouse gases will give an adverse effect on the water resources in the tropic-temperate arid zones.

2.1.5 Nature of hydrological cycle and global water balance

Hydrology is concerned with the occurrence and movement of the water on the earth. Water is one of the commonest substances in nature. It occurs in chemically combined forms, free states, and biosphere. The free states include groundwater and soil moisture in the upper layer of the lithosphere and in the soil cover, and water in oceans, seas, lakes, rivers, glaciers, and permanent snow covers. A small amount of water occurs in the atmosphere as water vapor, water drops, and ice crystals. Unlike other natural resources, water is continually moving and changing from one form to another. The movement is a characteristic of all forms of water. The movements of ocean currents, rivers, groundwater runoff, humid air over oceans and continents, and transpiration, which are links in the inter-connected water cycle of nature.

Hydrologic cycle

General concept of the global hydrological cycle is illustrated in Fig.2.1.5-1. The rectangles of the figure denote various forms of water storage: in the atmosphere, on the surface of the ground, in the unsaturated soil moisture zone, in the groundwater reservoir below the

water table, in the channel network draining the basin, or in the oceans. The arrows in the diagram denote the various hydrological processes responsible for the transfer of water from one form of storage to another.

Thus the precipitable water (W) in the atmosphere may be transformed by precipitation (P) to water stored on the surface of the ground. In the reverse direction water may be transferred from the surface of the ground by evaporation (E) or from the unsaturated soil by transpiration through vegetation and subsequent evaporation from the leaf surface (ET).

Some of the water on the surface of the ground will infiltrate through the surface into the unsaturated soil (F) but some of its may find its way as overland flow (Qo) into the channel network. During precipitation, if the field moisture deficit of the soil which has arisen since the previous precipitation is substantially satisfied then there will be either recharge (R) to the groundwater or else lateral interflow (Qi) through the saturated soil into the channel network.

The groundwater storage is depleted by groundwater outflow (Qg) which enters the channel network and supplies the streamflow during dry periods. During prolonged droughts, soil moisture may be replenished by capillary rise (C) from groundwater to the unsaturated zone and subsequent loss to the atmosphere by evapotranspiration.

Overland flow (Qo), lateral interflow (Qi) and groundwater outflow (Qg) are all combined and modified in the channel network to form the runoff (Ro) from the area for which the balance is being calculated. These various hydrological processes form the subject matter of physical hydrology.

Global water balance

The quantities of water in the ocean, atmosphere, ice masses, lakes and rivers may be evaluated not so much difficult. It is more difficult to determine the amount contained in living organisms, and in the lithosphere. The figure of greatest uncertainty is that for inactive groundwater. A general idea of the world water reserves is shown in Tab.2.1.5-1. The total reserves of water is preliminarily estimated to be about $1.386 \times 10^9 km^3$. The breakdown of the volume of each form of water is shown below; (Ref.2.1.5-1)

Ocean and sea

The volume of water in the ocean is estimated to be $1,338 \times 10^6 km^3$ by assuming the area of ocean covers of $361.3 \times 10^6 km^2$ and its average depth of about 3.7 km, which represents about 96.5 % of the total water reserves of the earth.

Glaciers and permanent snow cover

The amounts of water in the ice of polar regions and in the glaciers of mountainous regions are estimated to be about $24 \times 10^6 km^3$, which account 68.7 % of the earth's total resources of fresh water.

Inactive groundwater

Substantial amounts of water are stored in the lithosphere. The amount of gravity water contained in the pores and cracks of saturated strata, which is an inactive groundwater in the earth's crust, is estimated to be $23.4 \times 10^6 km^3$, by assuming the effective porosity of 5 to 15 % and a maximum depth of 2,000 m.

Active groundwater

The depths of fresh-water accumulations vary, depending on local geological characteristics. By assuming an effective depth of aquifer between 200 and 600 m, the volume of active groundwater is preliminarily estimated to be $10.53 \times 10^6 km^3$, which is 30 % of the total volume of fresh water.

Soil moisture

Soil moisture is more closely related to weather conditions than is groundwater. During the wet seasons moisture is stored in the soil, while is is removed by evaporation and transpiration in the dry seasons. The storage of moisture in the soil is estimated to be $0.016 \times 10^6 km^3$, by assuming a soil layer of 2 m thick with 10% of moisture in average.

Lakes and reservoirs

There are a numerous lakes in the world. Large lakes with an area of more than 100 km^2 may store 95 % of the total reserves in all lakes in the world. The total water volume in the world's 145 large lakes amounts to

$0.168 \times 10^6 km^3$, which is 95 % of the world's total of $0.176 \times 10^6 km^3$. Of this, $0.091 \times 10^6 km^3$ is a fresh-water lakes, while approximately half the water in lakes ($0.085 \times 10^6 km^3$) is salty. Most of the salty lake water is concentrated in the large lakes without outlet such as Dead Sea and Caspian Sea.

The intensive construction of large dams has been carried out especially since World War II, which created a large reservoirs in the course of the major river. The total capacity of the 10,000 reservoirs of the world amounts to about $0.005 \times 10^6 km^3$ with a net capacity of about $0.002 \times 10^6 km^3$, which controls approximately 14 % of the total annual river runoff of $0.445 \times 10^6 km^3$.

Swamps

Marshes occur in many areas of the earth. These are mostly of peat marshes in countries with temperate climates and their equivalents in tropical and equatorial areas. The total amount of marsh water in the world is preliminarily estimated to be $0.011 \times 10^6 km^3$.

River channels

The total water storage in river channels of the world at a given moment is estimated at $0.002 \times 10^6 km^3$, which accounts only 0.006 % of all fresh water, however, it is of great importance to development as a continually renewed water supply.

Atmosphere

Water is contained in the atmosphere in the form of water vapor, water drops and ice crystals. The total quantity of moisture in the atmosphere amounts to about $0.012 \times 10^6 km^3$, which is equivalent to 25 mm of water if spread over the whole surface of the globe.

2.1.6 Remarks on global water reserves and water resources

The total amount of water in the hydrological cycle is constant and can neither be increased nor diminished. From the global scale water budget study outlined above, it looks as though there is more than enough fresh water to meet the demands of human survival both now and in the foreseeable future. However, water is often available in the wrong place, at the wrong time, or in the wrong quality. This uneven distribution is

highlighted in the arid region. In many of the countries in the Middle East, the hydrological cycle is being disturbed by over-exploitation either depleting or causing deterioration of the fresh water system including both rivers and groundwater aquifers.

The salt waters including seawater and brackish waters in the rivers and aquifers have been conceived as either useless or harmless, and outside the scope of the water resources planning except where neither conventional river water nor groundwater of good quality could exist. The volume of conventional fresh water reserves on the earth are, however, estimated to be minimal compared with other forms of water such as seawater which accounts for 96.5 % of the total water on the earth. Potential groundwater reserves are estimated to be as high as 30 % of the total fresh water reserves. However, brackish water is predominant in the major aquifers of the arid region owing to the minimal rainfall and hence minimal groundwater recharge.

Most of the known conventional water resources such as river water and groundwater of good quality or low salinity have already been developed or are going to be fully exploited in most countries of the Middle East. Non-conventional waters such as seawater and brackish waters including both surface and groundwater, therefore, seem likely to play an increasingly important role in water resources planning of the arid region for the twenty-first century, by taking into account the advances and innovations of desalting technologies including reverse osmosis applications to save energy and cost.

REFERENCES (2.1)

Ref.2.1-1
Nicholson,S.E. and H.Flohn, 1980, "African Environmental and Climatic Changes and the General Atmospheric Circulation in Late Pleistocene and Holocene, Climatic Change, no.2, pp.313-348.

Ref.2.1-2
UNESCO, 1976, "World Water Balance and Water Resources of the Earth", UNESCO-USSR Committee for the International Hydrological Decade (IHD), ISBN-92-3-101497-8, pp.17-56.

Ref.2.1.1-1
Benton,G. Estoque,M.A.,1954, "Water Vapor Transfer Over the North American Continent", Journal of Meteorology, vol.11, pp.462-477.

Ref.2.1.1-2
F.Kenneth Hare, 1964, "The Causation of the Arid Zone", UNESCO, pp.25-30.

Ref.2.1.2-1
Martonne, E. de., 1926, " Areisme et indice d'aridite.C.R.", Acad. Sci..Paris,vol.182,no.23.pp.1395-1396.

Ref.2.1.2-2
Martonne, E. de., 1942, " Nouvelle carte mondiale de l'indice d'aridite", Ann. Geogr.,vol.,51,no.288,pp.242-250.

Ref.2.1.2-3
Koppen,W.,1923, "Die Klimate der Erde", Berlin, Leipzig, de Gruyters.

Ref.2.1.2-4
Thornthwaite, CW, 1948, "An approach toward a rational classification of climate, Geogr.Rev., vol.39,no.1,pp.55-94.

Ref.2.1.2-5
Thornthwaite, CW, and Mather, J.R.,1957, "Instructions and Tables for Computing Potential Evapotranspiration and the water balance: Centerton N.J.,Laboratory of Climatology", Climatology, vol.10,no.3.

Ref.2.1.2-6
Penck, A., 1910, "Versuch einer Klilaklassifikation auf physiographischer Grundlage", K. Preussische Akademie der Wissenshaften,vol.1.pp.236-246.

Ref.2.1.2-7
Emberger,L., 1955, "Afrique du nord-ouest. In: Plant ecology. Review of Research", Arid Zone Research,VI, Paris UNESCO, pp.219-249.

Ref.2.1.2-8
Andrew Goudie and John Wilkinson, 1977, "The Warm Desert Environment", Cambridge University Press

Ref.2.1.3-1
Folland,C.K., and Palmer T., 1986, "Sahel Rainfall and Worldwide Sea Temperature 1901-1985", Nature, vol.320, no.6063, pp.602-607.

Ref.2.1.3-2
WPDC, WorldNews, 1988, "Egypt Moves to Avert Nile Crisis", Water Power & Dam Construction", Feb.1988, pp.3.

Ref.2.1.4-1
Matthews, E, 1983, "Global Vegetation and Land Use: New High-Resolution Data Base for Climate Studies", Journal of Climate and Applied Meteorology, Vol.22, pp.474-487.

Ref.2.1.4-2
Nicholson, S.E.,and H.Flohn, 1980, "African Environmental and Climatic Changes and the General Atmospheric Circulation in the Late Pleistocene and Holocene", Clim. Change, Vol.2, pp.313-348.

Ref.2.1.4-3
Good friend, G.A.,M.Mafarits, and I.CCarmi, 1986, " A High Stand of the Dead Sea at the End of the Neolithic Period: Paleoclimatic and Archaeological Implications", Clim. Change, Vol.9, pp.349-356.

Ref.2.1.4-4
Stockton,C.W., and G.C.Jacoby,Jr., 1976, "Long-term Surface-water Supply and Streamflow Trends in the Upper Colorado River Basin Based on Tree-ring Analyses", Lake Powell Res. Proj. Bull.18, Univ.of Ariz.,Tucson, 70pp.

Ref.2.1.4-5
Loruis,C.,et al., 1988, "Antarctic Ice Core: CO_2 and Climate Change Over the Last Climatic Cycle", EOS, June,1988, pp.681.

Ref.2.1.4-6
Gammon, R.H.,et al., 1985, "History of Carbon Dioxide in the Atmosphere", Atmospheric Carbon Dioxide and the Global Carbon Cycle, DOE/ER-0239, US. Department of Energy, Washington, D.C.,pp.23-62.

Ref.2.1.4-7
Rotty,R.M.,and C.D.Masters, 1985, "Carbon Dioxide from Fossil Fuel Combustion: Trends, Resources, and Technological Implications", Atmosphere", Atmospheric Carbon Dioxide and the Global Carbon Cycle, DOE/ER-0239, US. Department of Energy, Washington, D.C.,pp.63-80.

Ref.2.1.4-8
Manabe,S.,R.T.Wetherald, 1986, "Reduction in Summer Soil Wetness Induced by an Increase in Atmospheric Carbon Dioxide, Science, Vol.232, pp.626-628.

Ref.2.1.4-9
WMO, 1987, "Water Resources and Climatic Change: Sensitivity of Water Resources System to Climatic Change and Variability", Rep. WCAP-4, WMO/TD 247, p.50.

Ref.2.1.4-10
COHMAP Members, 1988, "Climatic Changes of the Last 18,000 years: Observations and Model Simulations", Science, Vol.241,pp.1043-1052.

Ref.2.5.1-1
UNESCO, 1978, "World Water Balance and Water Resources of the Earth", UNESCO-USSR Committee for the International Hydrological Decade (IHD), ISBN 92-3-101497-8, pp.17-56.

Table 2.1.5-1 World Water Reserves

Form of water	Volume (km^3)	Share of world reserves of total water reserves (%)	Share of world reserves of reserves of fresh water (%)	Remarks
Atmospheric water	12,900	0.001	0.01	
Glaciers and permanent snow cover	24,064,000	1.74	68.7	
Ground ice in zones of permafrost strata	300,000	0.022	0.86	
Water in rivers	2,120	0.0002	0.006	
Water in lakes	176,400	0.013	0.26	Fresh water; 91,000
Water in marshes	11,470	0.0008	0.03	
Soil moisture	16,500	0.001	0.05	
Active groundwater (in aquifer)	10,530,000	0.76	30.1	Including brackish and fossil
Inactive groundwater (in lithosphere)	23,400,000	1.7	-	
World ocean	1,338,000,000	96.5	-	

(Source; UNESCO, 1978)

2.2 The Tigris-Euphrates River

Despite the great size of the Middle East, there are only three rivers, the Nile, the Euphrates and the Tigris, which can be classified as large rivers by world standards. The watersheds of the both Euphrates and Tigris are situated within the Middle East, dominantly in the countries of Turkey, Syria and Iraq. (Fig.2.2-1)

The Euphrates river, which is the longest inter-state river in the Western Asia, has been developed since 4000 B.C. Several ancient civilizations in Mesopotamia were supported by basin irrigation from the Tigris-Euphrates river. Owing to the extremely arid climate, however, the farm lands on the Mesopotamian alluvials have been suffered from salt accumulation and water-logging problems since 2400 B.C. of the Sumerian age. The ancient civilization disappeared in accordance with the abandonment of irrigation-canal systems. It would be obvious that the washing down of the accumulated salts, or leaching as it is called, can be carried out only in an efficient drain area, which requires careful water management to sustain the irrigation system.

Before Turkey began building large dams on the Euphrates, the river's average annual flow at the Turkish-Syrian border was about $30x10^9m^3$. To this, a further $1.8x10^9m^3$ is added in Syria from the Khabour river, a major tributary. On several occasions in recent years, low water levels in the Lake Assad reservoir, behind the Tabqa dam have restricted the hydro-power output (with installed capacity at 800 MW) and irrigation development. In the longer term, however, a reduction of the Euphrates water entering the country could be a major constraint on Syrian power generation and agriculture. Iraq could receive $33x10^9m^3$ per annum of river water at Hit, 200 km downstream from the Syrian border before 1970s when both Turkey and Syria built a series of large dams on the Euphrates river. By the end of 1980s, the flow discharge decreased to as little as $8x10^9m^3$ per annum at Hit. In 1989, eighty per-cent (80%) of the natural runoff of the Euphrates river has just been developed by adding third large dam of 'Ataturk', which is the biggest dam in the Turkey with a gross reservoir storage volume of $48.7x10^9m^3$ (effective volume at $19.3x10^9m^3$).

The Euphrates river development, which comprise the problems of not only quantity issue but quality issue such as increasing river salinity in the downstream delta, are examined to distinguish the complexities,

commonalties, and conflict of riparian issues of the Middle East, where the peace of the world is at risk.

Historically the river development was limited to the lower reaches of the Tigris-Euphrates in the semi-arid and arid zones. The valleys of the Euphrates and the Tigris encompass the northern portion of the famous "Fertile Crescent", the birth place of the Mesopotamian civilizations. Owing to salt accumulation, water-logging, and poor management of the canal system, the irrigated lands were progressively abandoned and the old civilizations declined (Sumerian culture: 2400 B.C.).

The water resources of the Euphrates river have been almost fully developed since the 1970's by constructing a series of large dams at Keban, Karakaya, Karababa/Ataturk, and Tabqa on the upper to middle reaches of the main stream river. Eighty per-cent (80%) of the natural flow of the Euphrates river has just been developed by adding the Ataturk dam in 1989. The inter-basin-multi-national transfer project called the "Peace Pipeline" has been studied by Turkey since 1988. This aims to supply fresh water of $6x10^6$ m^3/day by constructing 6,550 km of the world's largest pipeline system for the supply water to various countries of the Middle East. The project includes the inter-basin transfer from Seyhan and Ceyhan rivers in Turkish territory. Fresh water supplies are finite, however, and it is becoming more and more difficult to undertake projects that include the shifting of available water supplies to new areas of demand, specially if the project involves crossing political boundaries.

2.2.1 The river basin

The Tigris-Euphrates basin is shared by major three countries such as Turkey, Syria, and Iraq (Fig.2.2-1). Both the Tigris and Euphrates rivers rise in the mountains of southern Turkey and flow southeastwards into Iraq. The main stream of the Euphrates in the Turkey is named as Firat which has four major tributaries of Karasu, Murat, Munzur and Peri. After crossing the border between Turkey and Syria, the Euphrates possesses only one large tributary, the Khabur, which joins the mainstream in Syria. While in contrast, the Tigris has four main tributaries, all of which unite with the mainstream in Iraq. The largest of these, the Great Zab, has its source in Turkey, while the lesser Zab and the Diyala rise in Iran. All of the catchment of the Adhaim, which is the smallest stream, is situated in Iraq. In southern Iraq the Tigris and the Euphrates unite to form the Shatt el Arab, which in turn flows into the Arabian Gulf.

The length of the main streams are 2,330 km for Euphrates, 1,718 km for Tigris, and 190 km for Shatt-el-Arab. The Euphrates crosses Turkey, Syria and Iraq in a general southeastern direction and is finally joined by the Tigris, thereafter flowing down to the Arabian Gulf in the river Shatt-el-Arab.

The hydrographic and hydrological characteristics vary greatly over the basin. Rainfalls in the headwaters area are abundant, but is seasonal. On the other hand, from about 37^0N the river runs through arid countries such as Syria and Iraq.

The catchment area of the Tigris-Euphrates is 423,800 km^2, of which 233,000 km^2 is of the Euphrates, 171,800 km^2 is of the Tigris, and 19,000 km^2 is of the Shatt-el-Arab (Ref.2.2.1-1).

2.2.2 Hydrology

The main sources of the Euphrates river flows in Turkey are found in the four tributaries, the Karasu, Murat, Munzur and Peri, all of which rise at altitudes of about 3,000 m or more in the mountainous areas of eastern Turkey. Hydrological study was initiated in 1927-1929 by installing the first pluviometric stations in the Firat basin which is the upper most part of the Euphrates river. The long-term records indicate an average annual precipitation of about 625 mm in the Keban basin, decreasing to approximately 415 mm in the lower Firat basin.

The upper part of the Euphrates basin has a catchment area of 63,874 km^2 at the confluence of the Firat and the Murat near the Keban, which produces 80 % of the total annual flow at Karababa/Ataturk (Fig.2.2.2-1). Average flow over the 31 years (1936-1967) of records at Keban station is 646 m^3/sec, including the lowest flow of 136 m^3/sec in September,1961 and maximum flood of 6,600 m^3/sec in May,1944. The long-term annual average flow discharge at the Karababa/Ataturk damsite is estimated to be 830 m^3/sec. (Ref.2.2.2-1)

The Firat has a relatively regular regime which is characterized by two months of very high average flow in April and May, and a period of eight dry months from July to February. The annual flow varies considerably from year to year, including the extremely low flow records between July,1957 and January,1963, during which the average flow decreased to only 83 % of the long-term average. The average winter flows, varying

between 200 and 300 m^3/sec, are first increased in February by early spring rains at lower elevations. The increase continues during March when the melting snow begins, and in April and May monthly average flows of 2,000 m^3/sec and more are reached with maximum floods occurring between mid-April and early May under the combined effect of snow melting and rains. The flow rapidly diminishes after June, reaching its minimum values in September and sometimes October.

The river flows of the Tigris-Euphrates in the Iraq are largely dependent on the discharges in the Turkey. Much of the discharge of the Tigris results from the melting snow accumulated during the winter season in Turkey. However, winter rains, which are common in late winter and early spring, falling on a ripe snowpack in the highlands, can greatly augment the flow of the mainstream and its tributaries, giving rise to the violent floods for which the river Tigris is notorious. The period of greatest discharge on the Tigris system as a whole occurs during March, April and May, and accounts for 53 % of the mean annual flow. The highest mean monthly discharge takes place during April. Minimum flow conditions are experienced in August, September and October and make up 7 % of the annual discharge. The mean annual flow of the Tigris is 48.7×10^9 m^3 in total at the confluence with the Euphrates river, which includes major tributaries such as "The Greater Zab" of 13.2×10^9 m^3, "The Lesser Zab" of 7.2×10^9 m^3, and "Diyala" of 5.7×10^9 m^3, while the Euphrates river has a mean annual runoff of $35.2 \times 10^9 m^3$. (Refs.2.2.1-1 and 2.2.2-2)

The total flow of the Euphrates is not as great as that of the Tigris, although the river regimes are similar. It, too, rises in the highlands of Turkey and is fed by melting snows, to an even greater extent than the Tigris, but lacks the major tributaries which the Tigris possesses. In Iraq, the period of maximum flow on the Euphrates is shorter and later than that of the Tigris, and is usually confined to the months of April and May. Discharge during the two months accounts for 42 % of the annual total. Minimum flows occur in August, September and October and contribute only 8.5 % of the total discharge. The mean annual runoff of the Euphrates is 35.2×10^9 m^3 at the confluence of the Tigris river. (Refs.2.2.1-1 and 2.2.2-2) These mean values, however, conceal the fluctuations in discharge which can occur from year to year, for it must be remembered that floods, as well as drought, are themselves of variable magnitude. Schematic regime hydrographs of the rivers Tigris and Euphrates are shown in Fig.2.2.2-2.

2.2.3 Euphrates river development and salinity problems

The Euphrates river, which is the longest multi-national river in the Western Asia, has been under developed since 4000 B.C. Several ancient civilizations in Mesopotamia were supported by basin irrigation from the Tigris-Euphrates river. Owing to the extremely arid climate, however, the farm lands on the Mesopotamian alluvials have been suffering from salt accumulation and water-logging problems since Sumerian times. These ancient civilizations disappeared with the abandonment of irrigation-canal systems.

One of the major reasons for the success of this complex irrigation network was the establishment of an efficient system of drainage, which prevented water-logging of the soil and consequent salination of the land. Throughout the lowland as a whole, the drainage was achieved by supplying irrigation water from the Euphrates in the west, and the Nahrawan canal in the east. (Fig.2.2-1) This permitted the river Tigris, which was situated between the two, to function as a drain, and to collect water from the adjacent agricultural lands. So efficient was this system, that it supported widespread cultivation of the land in the region for many years without a serious decline in land quality. The maximum limits of agricultural expansion in the Diyala Plains seem to have been attained during the Sassanian period (AD 226-637). With the collapse of Sassanian rule, a marked deterioration in agricultural conditions occurred, which continued almost unchecked for centuries. The reasons for the agricultural decline are complex, but the major one was probably the decreasing effectiveness of the central government, which meant the necessary reconstruction and maintenance of the irrigation networks tended to lapse. Progressive siltation of the major canals occurred, reducing the efficiency of water transmission, and the irrigation control works fell into dis-repaired. By the time of the Mongol invasions of the twelfth and thirteenth centuries AD, the abandonment of the once fertile land was almost complete.

The term 'hydraulic civilization' has been used to describe societies similar to those which existed in the alluvial lowlands of Iraq, and which required large scale management of water supplies by the bureaucracies of central governments for widespread agriculture to be feasible.

Although the agricultural recovery of the Tigris-Euphrates lowlands began during the late nineteenth century, with the cleaning of a number of the ancient canals, it was not until the early part of the twentieth century

that the first modern river control work, the Al Hindiyah barrage (1909-1913) was constructed on the river Euphrates. Its original function was to divert water into the Al Hillah channel, which was running dry, but later, following reconstruction in the 1920s, it was also used to supply other canals. Between the two World Wars, considerable attention was given to the Euphrates canal system, and many new channels were constructed and new control works established. On the river Tigris, development work tended to come later. The building of the Al Kut barrage commenced in 1934, but was not completed until 1943, while on the Diyala, a tributary of the Tigris, a weir was constructed in 1927-1928 to replace a temporary earth dam which had to be rebuilt each year following the winter flood. The weir allowed six canals to be supplied with water throughout the year.

Following the Second World War, river control schemes tended to concentrate on the problems of flood control. Two of the earliest projects, completed in the mid-1950s, were situated towards the upper part of the alluvial valley. The Samarra barrage was constructed on the Tigris river with the objective of diverting flood waters into the Tharthar depression to provide a storage capacity of $30x10^9m^3$. A similar scheme was also built on the river Euphrates, where the Al Ramadi barrage diverted flood waters into the Habbaniyah reservoir and the Abu Dibis depression. It had been hoped that the stored water from these two projects might be used for irrigation during the summer months, but it was discovered that the very large evaporation losses, together with the dissolution of salts from the soils of the depressions, seriously diminished water quality and rendered it unsuitable for irrigation purposes. In conjunction with the barrages on the mainstreams themselves, two major dams were constructed on tributaries of the Tigris. The Dukan dam, with a reservoir storage capacity of $6.3x10^9m^3$, was completed on the Lesser Zab river in 1959, while further south, on the Diyala river, the Darbandikhan dam with $3.25x10^9m^3$ of storage was opened in 1961.

The Tigris and Euphrates rivers are the main sources of water in Iraq. Due to flood irrigation, 1,598,000 hectares of land have been affected by salinity and the government is trying to reclaim this land (Fig.2.2.3-1). Iraq used to receive $33x10^9m^3$/year of river water at Hit, 200 km downstream from the Syrian border before the 1970s when both Turkey and Syria built a series of large dams on the Euphrates river. By the end of the 1980s, the flow discharge had decreased to as little as $8x10^9m^3$/year at Hit (Ref.2.2.3-1).

Before Turkey began building large dams on the Euphrates, the river's average annual flow at the Turkish-Syrian border was about $30x10^9m^3$. To this, a further $1.8x10^9m^3$ is added in Syria from the Khabur river, a major tributary (Ref.2.2.3-2). On several occasions in recent years, low water levels in the Lake Assad reservoir (Fig.2.2-1), behind the Tabqa dam have restricted the hydro-power output (with installed capacity at 800 MW) and irrigation development. In the 1970s, the Syria were planning to reclaim 640,000 ha or more in the Euphrates basin. However, progress has been slow, and only about 61,000 ha of new land has either been brought into cultivation or will be in the near future. The water requirement for this area is minimal, and can at present easily be supplied from the $12x10^9m^3$ in the Lake Assad reservoir, or from the river's flow. In the longer term, however, a reduction of the Euphrates water entering the country could be a major constraint on Syrian power generation and agriculture.

In 1989, eighty per-cent (80%) of the natural runoff of the Euphrates river was developed by closing the "Ataturk" dam, which is the biggest dam in the Turkey with a gross reservoir storage volume of $48.7x10^9m^3$ (effective volume at $19.3x10^9m^3$) as shown in Fig.2.2.2-1.

2.2.4 Inter-basin development plan in "Peace Pipeline" project

An inter-basin development plan was studied in the context of Turkey's ambitious "Peace Pipeline" project in 1987, which would include basin-transfer of Seyhan-Ceyhan-Euphrates rivers by constructing a series of dams and diversion tunnels. The "Peace Pipeline" would have a total length of about 6,550 km and a capacity of $6x10^6m^3$/day, with aim to supply fresh water to the countries in the Arabian Peninsula, including Syria, Jordan, Saudi Arabia, Kuwait, Bahrain, Qatar, United Arab Emirates and Oman. (Fig.2.2.4-1)

The unit cost of water pumped along the Peace Pipeline has preliminarily been estimated at 0.84 to 1.07 US$/$m^3$ (Ref.2.2.4-1). The economic viability of the project was assessed by comparing the other alternative cost by conventional seawater desalination. The unit water cost of the seawater desalination was simply estimated at 5US$/$m^3$ (Ref.2.2.4-1), however, it is not likely to represent the actual desalination cost. The desalination cost has to be reviewed by taking into account recent advances in membrane technologies for desalination such as reverse osmosis (RO). (see Sections 2.8 and 2.9)

2.2.5 Political constraints and feasibility

Fresh water supplies are finite, and it is becoming more and more difficult to undertake projects that includes the shifting of available water supplies to new areas of demand, especially if the project involves crossing political boundaries. The "Peace Pipeline" will probably not be a key application for each state but an option in water resources planning at a multi-national level. (Fig.2.2.4-1)

The total project cost of the Peace Pipeline was estimated at US$ $21x10^9$ (1990 price; Ref.2.2.5-1), which is one of the biggest global supper trans-boundary project in the world as compared below;

Project Name	Peace pipeline	Euro tunnel	Itaipu dam	MDS solar-hydro
Cost (US$)	$21x10^9$	$15x10^9$	$9x10^9$	$2x10^9$

No commitment with political feasibility, however, was given to the global supper trans-boundary project of the Peace Pipeline. The water politics will be a key issue of the trans-boundary river development in the Middle East with aim of settling regional peace of the Arab World after the Gulf War in 1991.

REFERENCES (2.2)

Ref.2.2.1-1
Mamdouh Shahin, 1989, "Review and Assessment of Water Resources in the Arab Region", Water International, vol.14, pp.206-219.

Ref.2.2.2-1
Kutlu Doluca, and Wolfgang Pircher, 1971, "Development of the Euphrates River Basin in Turkey", Water Power and Dam Construction, Feb.1971, pp.47-55.

Ref.2.2.2-2
Peter Beaumont, Gerald H.Blake, J.Malcolm Wafstaff, 1988, "The Middle East: A Geographical Study", David Fulton Publishers, London, pp.349-369.

Ref.2.2.3-1
World News, 1987, Turkey-Syria Water Accord Signed", Water Power and Dam Construction, September, 1987, p.3.

Ref.2.2.4-1
David Gould, 1988, "The Selling of the Peace Pipeline", MEED, 26 March,1988, p.10.

Ref.2.2.5-1
The Economist, 1990, "Survey of the Arab World", The Economist, 12 May 1990, p.12.

2.3 The Indus River

The Indus river is the second longest river in the West Asia and has a mean annual discharge of $207,500 \times 10^6$ m^3 (Ref.2.3-1). In terms of volume of river flow, the Indus river system is ten times greater than the Colorado river in U.S.A. and Mexico, and more than three times as large as the Nile river.

Alluvial plains in the middle to lower reaches of the Indus river system have been developed to form the largest irrigation scheme in the world. Approximately 16,000 km of canals have been constructed to irrigate over 9,000,000 hectares (Ref.2.3-1). This irrigation project covers the greater part of a vast plain covered with fine textured alluvial soil overlying coarser sediments extending deeply (ten to hundred meters) downward to the bedrock of an ancient valley.

The development of the irrigation project was mostly carried out since 1850s ancient but elements of flood irrigation channel can still be found. Most of the canals were excavated through the surface soil to the more pervious underlying fine sand, so that a large proportion of the surface water diverted through these canals seeped underground. The sediment, which forms an extensive aquifer, was continuously recharged by the leaking irrigation canals, so that the groundwater table rose al the regime. In many areas, this rise was estimated to be approximately 30 cm per year. The result was that in much of the Indus plain the groundwater elevation was near the soil surface where arid climatic condition prevails. Proper aeration of soil does not take place and the capillary action and evapo-transpiration moves salts from the sub-surface up to the root zone of crops and to the land surface, thus once fertile lands have so deteriorated that crops can no longer be grown. In 1950s-1960s, salinity and water-logging problems became so serious that an intensive research work was carried out by international agencies headed by the Harvard University Water Resources Group. The hydrogeological studies are focused on the aquifer utilization and management, including mining of groundwater.

During the successive stages of development of the irrigation systems in the Indus valley, little care was taken in the issue of land drainage, and emphasis was put on maximizing the area of extending irrigated land. Salinity control by integrated management of the underlying aquifer system in line with the surface-subsurface drainage could successfully reclaim

the irrigated land.

2.3.1 The river basin

The Indus river, one of the mightiest rivers of the world, rise in Tibet in the snow-clad Kailas range of the Himalayas, at a height of about 5,5000 m above mean sea level. The catchment extends over the four countries such as China, India, Pakistan, and Afghanistan. The basin area in Pakistan accounts for more than 50 % of the total drainage area. The Indus basin lies in the subtropical zone; the tropic of cancer passing through the southernmost part of the basin, whereas the northern edge of the basin reaches the latitude 37°N. (Fig.2.3.1-1)

The Indus cuts through mountain rages forming narrow gorge and deep channel from the headwaters until an important tributary, the Kabul river, joins it from the west near Attock. A few kilometers above the town of Mithankot, the Indus is joined by its most important tributary, the Panjnad river, which carries the waters of the five main tributaries namely; the Jhelum, Chenab, Ravi, Beas and Sutlej (Fig.2.3.1-1). The river slope from the headwaters to Attock is approximately 1/300, from Attock to Mithankot 1/4,000 and from Mithankot to the sea averages about 1/7,000. The total length of the Indus is about 2,900 km. The drainage area of the whole system is approximately 970,000 km^2.

The northern region of the Indus basin, where the Indus and its main tributaries, Jhelum, Chenab, Ravi, Beas and Sutlej are originated, is fully covered with rugged sky-high mountains, comprising a large area of about 452,000 km^2. Because of the steep and barren slopes of these mountains, the erosion is very excessive ranging from about 400 tons per km^2 to over 4,000 tons per km^2 annually according to localities, with an average of about 1,500 tons per km^2. Lower down, the basin comprises the vast plains formed and separated from each other by its five main tributaries. Further down from Mithankot, the Indus valley is covered with alluvium built up by the deposition of silt carried down by the Indus. The delta begins at from Kotri, about 185 km from the sea, where the land is almost level but the soil is generally infertile. Closer to the sea is marshy land which is generally flooded during high tides.

2.3.2 Hydrology

The Indus basin lies in the subtropical zone. In the plains, the average temperature during winter is about 21°C in Karachi and about 15°C in

Lahore. Summer, hottest season, is from May to August, and average temperature ranges from about 29°C in May to about 34°C towards the end of June or early July, when the maximum temperature often rise above 27.7°C. Despite the mighty Indus, the Indus plain is semi-arid. There significant extremes of rainfall in the basin. The area from Sukkur and Mithankot receives only about 100 mm of rain per annum, while, at Murree, a hill station at elevation 2,280 m, the annual precipitation is about 1,270 mm. The precipitation inclusive of snow, is many times heavier in the hilly region than in the plains. The mid-hill area with an elevation from about 1,200 m to 2,500 m, where the southwest monsoon generally strikes the mountain mass, gives the heaviest rainfall averaging about 1,250 mm to 1,500 mm per annum. Higher up or lower down in elevation, the air is more dry and clear to follow the rapid decrease in rainfall The rainfall further decreases rapidly from north to south in the plains; about 550 mm of annual rainfall in the foot hills to only about 100 mm at Mithankot and Sukkur. Further down from Sukkur, the rainfall increases a little owing to the maritime air; from 100 mm to about 200 mm along the sea coast. Mean annual rainfall over the Indus plains is less than 250 mm. (Fig.2.3.1-1)

Due to the uneven distribution of precipitation over the basin, the Indus and its tributaries receive most of their flows from the mountains. The flows are subject to extreme variations; the maximum summer discharge is over 100 times the winter minimum. During July and August, all the rivers attains their peaks, discharging considerable volume of water to the sea.

Mean annual runoff of the Indus is 207,000 $x10^6m^3$, which includes yearly maximum of 264,000 $x10^6m^3$ and minimum of 171,000 $x10^6m^3$. The Indus main stream carries about 110,300 $x10^6m^3$ per annum of flow, while major tributaries of the Jhelum, Chenab, Beas, Sutlej, Ravi bring 27,850 $x10^6m^3$, 29,000 $x10^6m^3$, 15,650 $x10^6m^3$, 16,800 $x10^6m^3$, and 7,900 $x10^6m^3$, respectively. Thus the main stream of Indus alone carries a little more than one-half of the total discharge of the system. When combined with the Jhelum and Chenab, it carries a little more than fourth-fifths of the over-all total. The three rivers, the Ravi, Beas and Sutlej together deliver a little less than one-fifth of the total flow of the system. The runoff coefficients are as high as 58 % to 82 %. (Ref.2.3-1)

2.3.3 Water resources development

As rainfall is scarce in the plains where the cultivable area lie, the

agriculture in the Indus plains has to depend almost exclusively on an irrigation system which utilize the river flows. In most of the areas of the Indus plains, irrigation is an inevitable measures to sustain the agriculture of the semi-arid lands.

From the middle of the 19th century onwards, a large number of weir and canal system were constructed on the Indus and its tributaries. The first of these was the Upper Bari Doab canal, of which the construction was started in 1850 and completed in 1859, to bring water from the Ravi river to the upper half of the doab from Mandhopur to Lahore. Up to the time when India and Pakistan became two independent countries in 1947, the Indus water system had already been developed to provide irrigation to about 10.9×10^6 hectares. It is remarkable by that time that no single storage reservoir had been constructed on the Indus river system which served the world's largest irrigation area. A number of huge hydraulic structures had been constructed on the Indus river system before 1947 (Fig.2.3-3-1):

Indus	: Paharpur canal, Sukkur barrage (N.W.,D Unhar, Begari, Ghoti canals)
Jhelum	: Upper Jhelum canal (Rasul barrage)
Chenab	: Upper Chenab canal (Merala barrage), Lower Chenab canal (Khanki barrage)
Jhelum-Chenab	: Trimmu barrage, Rangpur canal, Haveli-Sidhnai canal Panjnad barrage and canal, Abasia canal
Ravi	: Madhopur barrage (Upper-Central Bari Doab canals), Balloki barrage (Lower Bari Doab canal)
Sutlej-Beas	: Ferozepore barrage (eastern-Bikaner canals), Suleimanki barrage (Pakpattan-Fordwah-E.Sadifia canals), Islam barrage (Mailsi-Qaimpur-Bahawal canals)
Swat	: Upper-Lower Swat canals
Kabul	: Kabul river canal

Because the new international boundary cut across the common canal system of the Punjab, leaving one part in India and the other in Pakistan, controversy on the use of the canal waters arose soon after the partition. It took twelve years of patient negotiation before the controversy was settled in the form of "The Indus Waters Treaty" in 1960. Before this, intensive river development have been carried out since 1947 including the following.(Fig.2.3-3-1):

Indus	: Thal canals, Taunsa barrage (Dera Ghazi Khan-Muzaffargarh canals), Gudu barrage (Desert, D Unhar, Begari, Ghoti canals), Kotri barrage (Fuleli-Pinyari canals)
Jhelum	: Lower Jhelum canal (Rasul barrage)
Ravi	: Upper Bari Doab canals - extension
Beas	: Shah Nehar - Hoshiarpur canals
Sutlej-Beas	: Rajasthan canal
Kabul	: Warsak dam
Kurram	: Kurram Garhi weir

The following major works were undertaken throughout the Indus Basin Development Fund (IBDF) and its follow-on the Tarbela Development Fund:

Jhelum	: Mangla dam
Jhelum/Chenab/Ravi/Sutlej	: the Trimu-Sidhnai-Mailsi-Bahawal link canal system the Rasul-Qadirabad-Balloki-Suleimanki link canal system
Indus/Jhelum	: the Chashma barrage and Chashma-Jhelum link canal
Indus/Chenab	: the Taunsa-Panjnad link canal
Indus	: the Tarbel dam

The IBDF was originally intended to finance tubewell drainage works to compensate for leakage from the link canal systems, but at the choice of the Pakistan government the tubewell program was financed by other means and the savings to the IBDF were put forwards construction of the Tarbela dam.

2.3.4 Salinity and water-logging problems

During the successive stages of development of the irrigation systems in the Indus valley, little care was taken in the issue of land drainage, and emphasis was put on maximizing the area of extending irrigated land. In the Indus valley, as in all other flat valleys in the world, the natural surface and the sub-surface drainage is poor. Since there were not enough drainage channels, most of the rain water and canal seepage percolated down to lower depths. As time passed, the groundwater table got higher and higher by steps, and finally, in the 1950s-1960s it came close to the ground surface and has thus caused water-logging in many large areas. Proper aeration of soil could not take place and the capillary action and evapo-transpiration move salts from the sub-surface up to the root zone of

the crops and to the land surface, thus once fertile lands had so deteriorated that crops could no longer be grown.

In the former Pumjab area in West Pakistan, out of 5,000,000 hectares have already gone out of cultivation due to salinity caused by water-logging, 690,000 hectares are in an advanced stage of deterioration and 2,000,000 hectares are affected to a lesser degree. (Fig.2.3.1-1) Since 1954, extensive groundwater and salinity investigations were undertaken. As a result of these investigations, recommendations were made to install a great number of deep wells to lower the groundwater level, and to use the pumped water for flushing the salts from the ground-surface down to the drains provided as well as to the lower layer of soil. Moreover, the pumped water is used to supplement the existing canal supplies for irrigation.

In 1959, the Water and Power Development Authority (WAPDA), established in 1958 to take charge of all water and power development in Pakistan, launched its first reclamation project, called Project No.1, in Rechna Doab in the districts of Gujarawala, Sheikhupura, and Lyallpur. The Project No.1 comprised about 1,800 tubewells in a gross commanded area of 480,000 hectares. The average pumpage of groundwater was about 1,850 $x10^6m^3$ per annum. In 1961, WAPDA launched Project No.2 in Chai Doab, including 3,300 tubewells in a gross commanded area of 920,000 hectares with an average pumping amount of about 2,500 $x10^6m^3$ per annum. WAPDA extended this salinity control and reclamation work to maintain water management until the catastrophic threat to the well-being of the people of Pakistan was overcome.

Schematic diagram of salinity controlling land reclamation scheme in the lower Indus valley, of which method is largely dependent on the conjunctive aquifer management with surface and sub-surface drainage measures, is illustrated in Fig.2.3.4-1.

REFERENCES (2.3)

Ref.2.3-1
ECAFE, 1966, "A Compendium of Major International Rivers in the ECAFE Region", United Nations, Water Resources Series No.29, p.48-64.

Ref.2.3-2
Nathan Buras, 1967, "Modern Aquifer Management", IASH, Symposium of Haifa, Pub.No.72, pp.469-471.

2.4 The Nile River

Despite the great size of the Middle East, there are only three rivers, the Nile, Euphrates and Tigris, which can be classified as large rivers by the world standards. Of these, the Nile is the world's longest river which receives most of its discharge from precipitation falling well outside the Middle East on the Upland plateau of East Africa and highlands of Ethiopia.(Fig.2.4-1)

The Nile is the whole life of the Egypt. Egypt owes its existence to the Nile, which provides water for agriculture, industry and domestic use. Cultivation is dependent on irrigation from the Nile. The power house at Aswan on the Nile accounts for 40 per-cent of the national power supply.

The proposal to built a single large dam at Aswan for multi-objectives including i) flood control, ii) inter-annual water storage and hydro-power generation was put forward by Adrein Danionson in 1949 as an alternative to the Century Storage Scheme. Construction of the High Dam started in 1960 and completed in 1970. Before building and operating the High Dam, the Nile flood brought silt containing potassium and phosphorous and could leach away any accumulated salts. The fine-grained alluvial soils of the Nile Valley do not drain easily and need artificial drainage. Due to the hot arid climate, irrigation water evaporates quickly, leaving behind its salt causing salinization. In 1982 almost all the irrigated area in Egypt was potentially affected by salt. At least half of the area (12,000 km^2) was more or less affected at present. About 400 km^2 are provided with drainage systems each year at a cost of US$200 per hectare. Nevertheless, this is not sufficient to stop salinization. Farmers are unwilling to make this investment and the government authorities have difficulty in keeping open the drainage channels which are essential for proper functioning of the tile drainage underneath the farm lands. By regulating flows of the Nile River by High Aswan dam, costs of agriculture for the irrigated lands on the Nile delta have immensely increased by adding artificial fertilization, drainage system and water lifting. On the other hand, however, some costs were reduced such as those for clearing the irrigation channels of silt.

Water levels in the Nile, however, have been falling for nine years since the early 1980s. In 1985-86 there was a 3 m drop in the level of Lake Nasser the reservoir behind Aswan High dam, and in 1986-87 it fell from 195.6 m to 184.7 m (Ref.2.4-1). Egypt is attempting to avert a national

crisis by three strategies: 1) rationalization, 2) river development, and 3) groundwater development.

2.4.1 The river basin

The Nile basin, which covers approximately one-tenth of the African continent has a catchment of 3,007,000 km^2, which is shared by nine countries: Egypt, Sudan, Ethiopia, Uganda, Kenya, Tanzania, Ruwanda, and Zaire (Fig.2.4-1). The river length is 6,690 km, which is the world's longest. It flows from south to north over 35 degrees of latitude. All along the Nile's 6,690 km from its most remote source the Kagera river (in central Africa) to the Mediterranean, people are affected to some extent by the river or by its water. The main sources of the Nile are found in Ethiopia and the countries around Lake Victoria. With a few exceptions, the water resources in the headwater areas of the Nile system are not yet much developed. The main developments have taken place in the countries situated in the semi-arid and arid zones such as Sudan and Egypt. The upstream countries are, however, now considering Nile resources development projects in their territories.

The hydrographic and hydrological characteristics vary greatly over the basin. Rainfall in the headwater areas, although abundant, is seasonal. On the other hand, from about 14°N the river runs through arid country.

The river system has two main sources of water: the Ethiopian highlands and the equatorial region around Lake Victoria. More than 60 % of the river flow arriving in Egypt originates in the Ethiopian highlands by way of the Sobat, Blue Nile, and Atbara rivers. The bulk of this water comes down during the summer. The remainder of the flow arrives by way of the White Nile, which has its most remote source in Burundi. This source is a tributary of the Kagera, which enters Lake Victoria near the border between Uganda and Tanzania. In the equatorial region, the Nile system consists of a number of great lakes, connected either by rocky sections or swamps. The White Nile, called Bahr el Jabel after leaving the lake area, enters the Sudan through rocky gorges and then flows through a large swamp area (the Sudd region) in the southern Sudan where it is joined by the Sobat from the east and the Bahr el Ghazal which occasionally receives water from Lake Chad from the west. In the Sudd region a huge quantity of water is evaporated or transpired from aquatic vegetation. Only a small part of the Bahr el Ghazal flow ever reaches the Bahr el Jebel, and practically all of its water disappears in the swamps. Although the contribution of the White Nile to the total flow at Aswan is only 30 %, it

is most important because of its timing; during the dry season from February to June its flow is large compared with that of the Blue Nile.

2.4.2 Hydrology

The Nile flows for half of its course through country with no effective rainfall. The rainfall of the Nile basin indeed is scanty compared with other major rivers in Africa such as the Zaire, Niger, and Orange rivers. For the size of the Nile basin with its catchment area 3,007,000 km^2, the annual discharge is as small as $99.5x10^9m^3$, which is equivalent to 4.3 % of the annual runoff. Rainfall is rich in the headwater areas. The annual average rainfall in the Lake Plateau Basin is about 750 mm (30 inches). The heaviest rainfall occurs at Kalungala on the island of Bugola, where it averages 2,250 mm (90 inches) per annum. Other places of high rainfall are Bukoba on Lake Victoria and Gore in Ethiopia, where the average is about 2,000 mm (80 inches) per annum. The distribution of rainfall is shown on the map of Fig.2.4-1.

The dependence of Egypt on the Nile has led to intensive studies of quantities of water carried by the main stream and its tributaries throughout the year. Long term records of the annual average flow discharge at Aswan from 1871 to 1965 is shown in Fig.2.4.2-1. The annual average of the 95-years is estimated to be $91.2x10^9m^3$, which was the basis of design for over year storage at Aswan High dam. The changes in the Main Nile flows between Aswan and Rosetta before and after the construction of Aswan High Dam are also indicated in the Fig.2.4.2-1. Fig.2.4.2-2 shows the average discharge of the Main Nile at Aswan unaffected by reservoirs (Ref.2.4.2-1). The upper line shows the discharge of the main river at any time, and other lines the component discharges. The peak discharge of $712x10^6m^3$/day which was recorded on September 8th was made up as follows:

Rivers	Flow Discharge	Per-cent
White Nile	$70x10^6m^3$/day	10%
Blue Nile	$485x10^6m^3$/day	68%
Atbara	$157x10^6m^3$/day	22%
Main Nile (Total)	$712x10^6m^3$/day	100%

The minimum discharge of about $45x10^6m^3$/day which occurred on May 10th was made up as below:

Rivers	Flow Discharge	Per-cent
White Nile	$37.5x10^6m^3$/day	83%
Blue Nile	$7.5x10^6m^3$/day	17%
Atbara	nil	0%
Main Nile (Total)	$45.0x10^6m^3$/day	100%

The largest proportion of the flows is contributed by the Blue Nile, and the least by the Atbara during the high flow stage from July to January, while the White Nile is the more important source of supply during the low flow stage from February to June. The Atbara carries much less water than the Blue Nile, but the effect of a peak may be considerable, owing to the shorter journey with very little damping. The Atbara contributes nothing from January to June.

The average discharge of the Main Nile at Khartoum, and the portions contributed by the Blue and White Niles is shown in Fig.2.4.2-2. On the average of 84 % of the water of the Main Nile comes from Ethiopia and 16 % from the Lake Plateau of Central Africa. An interesting point is seen at the confluence of the Blue and While Niles. To make this clear a dotted line is interpolated showing the White Nile contribution as it would be if it were unaffected by the Blue Nile. From this it appears that when the Blue Nile is rising rapidly, the White Nile discharge is ponded up and reduced, and only when the rise slows down does the White Nile discharge begin to increase. When the Blue Nile falls the White Nile discharge is increased by water which has been ponded back. The effect of the Blue Nile is therefore to make a natural reservoir of the White Nile, and this effect is increased artificially on a great scale by the Gebel Aulia Dam which is situated about 45 km from Khartoum some little distance up the White Nile.

About 800 km upstream from Khartoum, the White Nile is joined by the Sabat, of which 90 % of water comes from Ethiopia. About half the discharge of the White Nile comes from the Sobat, and the other half from the Bahr-el-Jebel through the swamps of the Sudd Region.

The average discharge of the White Nile is about $28x10^9$ m^3 per annum, of which the Sabat produces $13.5x10^9$ m^3, and the rest, except for a negligible amount contributed by the Bahr-el-Ghazal, comes from the Bahr-el-Jebel or its branch, the Bahr-el-Zeraf. This remainder is called swamps discharge in Fig.2.4.2-2.

Due to the regulating effect of the large swamps of the Sudd region on the

Bahr-el-Jebel, the discharge of the Bahr-el-Jebel varies very little throughout the year. When a rise occurs upstream of the swamps, most of it flows out of the river into the marshes, and only a very small part of the increase is felt at the tail of the swamps. When the river falls there is a tendency for the marshes to drain back to the river, but large areas are below river level and cannot drain back. The water which enters is lost by evaporation and by transpiration from the luxuriant vegetation, and in fact there is very little return of water to the river, with the result that the Bahr-el-Jebel loses nearly half its water in swamps (Swamps at Malakal).

The heavy evaporation and general dryness of the climate in Egypt, and most of the Sudan, have various implications, including the substantial evaporation loss from the surface of large reservoirs. The evaporation loss from the Lake Nasser is estimated to be about $10x10^9m^3$ per annum, which is about 10 % of the net storage volume of $90x10^9m^3$. In Egypt evaporation is at a maximum in June and a minimum in December and January. In the Northern Sudan it is the same, but May has practically the same evaporation as June. In the vicinity of Khartoum the maximum is in April and May, owing to the reduction later caused by monsoon rains, of which this area is on the fringe. In the Southern Sudan the minimum evaporation is in the months of July and August, at the height of the rains. The evaporation in Egypt and the Sudan, on the whole, follows the temperature. Potential evaporations at selected points in the Nile basin and the estimated monthly evaporation from the Lake Nasser (Aswan High Dam reservoir) is shown in Fig.2.4.2-3.

2.4.3 Water resources development of the Nile system

The national economy and social objectives of Nile resources development may vary from country to country. Certain Nile projects in the upper parts of the basin could be advantageous also for the more downstream countries. The timing of such projects could have a significant effect on the development of the basin resources as a whole.

The Nile is a geographical unit, and the projects for its full development must also form a unity, the parts of which must work together. The basic idea of a scheme of the 1950s, an account of which follows, was over-year storage or "Century Storage" as called by Hurst (Ref.2.4.2-1). The key projects in Hurst's master plan consisted of "Owen Falls Dam", "Lake Kioga Barrage", "Lake Albert Dam", "Jonglei Diversion Canal", "Lake Tana Dam", "Fourth Cataract Dam", "Aswan High Dam", and "Wady Rayan

Reservoir". The hydraulic works in the Nile Basin are shown diagramatically in Fig.2.4.3-1.

A major step in achieving collaboration among the Nile Basin states was initiated in 1967 when the five countries Kenya, Tanzania, Uganda, the Sudan and Egypt started a hydro-meteorological survey of the basins of lakes Victoria, Kyoga, and Albert, with the assistance of the U.N. Development Program.

2.4.4 Jonglei diversion canal project

The Jonglei Canal scheme (Fig.2.4.3-1), which was studied by the Sudan government in 1946, would make significantly more water available for use downstream. The original plans in 1954-59 could be reviewed taking into account the completion of Aswan High Dam in 1970 which has a gross storage capacity of $168.9x10^9m^3$ with a maximum spillway capacity of $11,000m^3/sec$, and now that more is known of the hydrology of the Blue Nile and hydro-meteorology of the Albert-Victoria catchment. The water from the southwestern tributaries (Bahr-el-Ghazal system) for all practical purposes does not reach the main river, and is lost through evaporation and transpiration in the swamps. It should be possible to reduce these losses and to lead at least a part of the water to the main river. This procedure would require international collaboration because storage and regulation would become necessary in Lake Albert to reduce flood levels in the Sudan. Furthermore, storage would probably be needed on the Blue Nile in Ethiopia because the reservoir of the High Aswan Dam by itself would not be large enough to regulate the combined floods of the Bahr-el-Ghazal, Bahr-el-Jebel, and the Blue Nile. Jonglei canal project is estimated to produce $4.8x10^9m^3$ per annum of water, including $2.4x10^9m^3$ of the 1st stage project and $2.4x10^9m^3$ of the 2nd stage project. There are, however, complex environmental and social issues involved which may limit the scope of the Jonglei Project in practical terms.

2.4.5 Hydropower potential

The hydro-potential of the Nile system is enormous, but the energy demand in the Nile basin countries is at present still small, with the exception of Egypt. According to the Ministry of Information of Ethiopia in 1966, the hydro-potential of the whole Nile system is preliminarily estimated to be about 8,000 MW (Ref.2.4.5-1). The most promising river for

hydroelectric power development is the Victoria Nile, of which the hydro-potential is preliminarily estimated to be 1,843 MW in total, including six potential stations such as Bujagali (180 MW), Busowoko (150 MW), Kalagala (125 MW), Kamdinia (234 MW), Aingo (490 MW), and Murchison (664 MW). (Ref.2.4.5-1)

2.4.6 Aswan High Dam

The importance of energy production at the Aswan High Dam to the Egyptian economy is perhaps about equal to that of making more water available for irrigation, taking into account the huge saving in crude oils for energy production.

The construction of Aswan High Dam has affected the entire economy of Egypt, allowing reliable irrigation throughout the year and satisfying about 40 % or less of the country's energy demands. The flow of the Nile River below the Aswan High Dam is fully regulated. Releases from the dam are authorized by the Ministry of Irrigation and are based on seasonal irrigation needs in the Nile Delta. The nature of Egypt's climate, as well as the established cropping patterns, require a very high release in the summer months when agricultural production at its peak. Monthly irrigation release requirements are shown below (Ref.2.4.6-1):

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Spt	Oct	Nov	Dec	Total
Requirement($x10^9m^3$)	3.5	4.0	4.2	4.0	5.3	6.5	7.0	6.3	4.3	3.7	3.6	3.0	55.3

Hydropower generation at the dam has always been viewed as a residual benefit. Since potential hydropower generation varies extensively between summer and winter months because of the uneven distribution of downstream irrigation requirements.

Egypt's irrigation practices require nearly $55x10^9m^3$ of water from the Nile every year. This amount is the volume of water allotted to Egypt by the 1959 Nile Water Agreement with the Sudan. The Sudan was allotted $18.5x10^9m^3$ by the same agreement but has been using only $16.5x10^9m^3$ per year in the 1970s. Monthly flows of the Nile River have been recorded since the late 1800s, at various point along the river. Flow records from 1871-1976 at Station Aswan were adjusted to account for Sudanese abstractions and other evaporation losses.

The water stored in the upper rule storage zone is considered to be live storage and can be released to meet irrigation demands or to prevent

flooding. Reservoir storage is discretized into 18 states, varying from a maximum of $168.9x10^9m^3$ (183-m elevation) to $89.2x10^9m^3$ (168-m elevation).

According to the world's inventory of hydropower in 1989 (Ref.2.4.6-1), the power house at Aswan has a rated capacity of 1,815 MW with an installed capacity of 2,100 MW, which accounts for about 40 % of the national power supply.

2.4.7 Water-logging and salinization problems of the Nile delta

Before implementing over-year storage at Aswan High dam, the Nile flood brought silt to the field of Egypt containing potassium and phosphorous and could also leach away accumulated salts.

The fine-grained alluvial soils of the Nile Valley do not drain easily and need artificial drainage. Due to the hot arid climate, irrigation water evaporates quickly, leaving behind salt which causes primary salinization. Consequently, farmers had to apply more water to wash the accumulated salts into the ground below the root zone. Deep percolation thus caused a rise in the water table to a few decimeters below surface level soon after the change to perennial irrigation. The soil then became water-logged. When the water table was less than two meters deep, capillary forces lift it to the surface where the salts accumulate after evaporation. This is known as secondary salinization. Thus, to avoid primary salinization it is essential to ensure quick infiltration of irrigated water, and to avoid the secondary salinization the water table must be kept low.

In 1982 almost all the irrigated area in Egypt was potentially affected by salt. At least half of the area (12,000 km^2) is more or less affected at present. Egypt's agriculture potential and Nile delta salinity are mapped on Fig.2.4.7-1. About 400 km^2 are provided with drainage systems each year at a cost of US$200 per hectare. Nevertheless, this is not sufficient to stop salinization. Farmers are unwilling to make this investment and the government authorities have difficulty in keeping open the drainage channels which are essential for proper functioning of the tile drainage underneath the farm lands. (Refs.2.4.7-1,2,3)

By regulating flows of the Nile River by the Aswan High Dam, costs of agriculture for the irrigated lands on the Nile delta have immensely increased by adding artificial fertilization, drainage system and water lifting. On the other hand, however, some costs were reduced such as

those for clearing the irrigation channels of silt.

2.4.8 Egypt's water crisis and Aswan High Dam

Until high flows occurred on the Blue Nile in 1990 which saved the situation Egypt was facing a national crisis as a result of nine years of falling of water levels in the Nile and Lake Nasser, the reservoir behind the Aswan High dam. Counter-measures taken to avert the water crisis comprised the following three strategies (Ref.2.4-1):

1) Rationalization
   - Improving irrigation systems; to save $86 \times 10^6 m^3$ of water per annum.
   - Recycling agricultural drainage; to recover $196 \times 10^6 m^3$ of water per annum
2) River development
   - Building a major new dam on the Nile at Rashid, near Alexandria; to reduce the Nile's flow into the Mediterranean.
3) Groundwater development
   - Exploiting underground reservoirs; to develop non-renewable groundwater in the deep sandstone aquifers.

The details of the groundwater development plan for the deep sandstone aquifers in the New Valley are shown in the following Section 2.7.4.

REFERENCES (2.4)

Ref.2.4-1
World News, 1988, "Egypt Moves to Avert Nile Crisis", Water Power and Dam Construction, February,1988, p.3.

Ref.2.4.2-1
H.E.Hurst, 1952, "The Nile", Constable and Company Ltd.,England, pp.237-278.

Ref.2.4.5-1
G.Deekker, 1972, "A Note on the Nile", Water Resources Research, vol8, no.4, pp.818-928.

Ref.2.4.6-1
Katherine Oven-Thompson, and David H.Marks, 1982, "Agriculture vs. Hydropower Tradeoffs in the Operation of the High Aswan Dam", Water Resources Research, vol.18, no.6, pp.1605-1613.

Ref.2.4.6-2
T.M.Mermel, 1989, "Major Dams of the World - 1989", Water Power and Dam Construction Hand Book 1989, pp.50-56.

Ref.2.4.7-1
Michel Meybeck, Deborah V. Chapman, Richard Helmer, 1989, Global Freshwater Quality: A First Assessment", WHO/UNDP, Basil Blackwell,Ltd.,London, pp.243-252.

Fig.2.4.7-2
Peter Breaumont, Gerald H.Blacke, and J.Malcom Wagstaff, 1988, "The Middle East: a Geographical Study, 2nd Edition", David Fulton Publishers, pp.521-525.

Ref.2.4.7-3
Mahmoud Abu Zeid and Asit K.Biswas, 1990, "Impacts of Agriculture on Water Quality", IWRA, Water International, vol.15, no.3, pp.160-167.

Tab.2.4.3-1 Existing Dams in the Nile Basin

Dam	Country	River	Storage Capacity ($10^9 m^3$)	Installed Capacity (MW)	Evaporation Loss ($10^9 m^3$)
Owen Falls	Uganda	Victoria Nile	*	120	
Jebel Aulia	Sudan	Bahr-el-Jebel	3.6		2.8
Tis Abbay	Ethiopia	Blue Nile	*	9.6	
Roseires	Sudan	Blue Nile	2.7(net)	15	0.45
Khashm-el-Girba	Sudan	Atbara	1.1	7	0.06
High Aswan	Egypt	Main Nile	90(net)	1,815	10
Aswan	Egypt	Main Nile	5	5	
Isna	Egypt	Main Nile	**		
Nag Hammadi	Egypt	Main Nile	**		
Assyut	Egypt	Main Nile	**		
Delta	Egypt	Main Nile	**		
Ziffa	Egypt	Main Nile	**		
Edfina	Egypt	Main Nile	**		

Remarks: *) Outflow regulation with lake storage, or run of the river
**) Barrage for irrigation intake

2.5 The Jordan River

Owing to the general aridity of the region, a very large portion of the total area consists of endoreic or inland drainage. The Jordan River which is the third largest perennial rivers in the Middle East receives most of its discharge from precipitation on the southern part of the Anti-Lebanon range. The discharge that feeds into the upper part of the Jordan River is derived principally from a group of Karstic springs located on the western and southern slopes of Mount Hermon (Jabel Esh-Sheikh)

The Jordan river is a multi-national river, which flows southwards for a total length of 228 km through Lebanon Syria, Israel and Jordan (Fig.2.5-1). The catchment area of the Jordan River is 18,300 km^2, of which 3 % lies in pre-1967 Israel. The Jordan river is already over-developed except for a winter flow in the largest tributary of the Yarmouk river which forms the present boundary between Syria and Jordan for 40 km before it becomes the border between the Israel and Jordan. In the absence of irrigation extraction, the Jordan system delivers an average annual flow of 1,850 $x10^6 m^3$ to the Dead Sea; this is 2 % of the annual flow of the Nile and 7 % of the annual flow of the Euphrates; 23 % of this discharge originates in pre-1967 Israel (Ref.2.5-1).

The discharge that feeds into the upper part of the Jordan River is derived principally from groundwater flow through a group of karstic springs located on the western and southern slopes of Mount Hermon (Jabel esh-Sheikh). There are three rivers in the headwaters of the north-folk of the Jordan River; namely the Dan River, the Hasbani River, and the Banias River, of which the quality of water is excellent with salinity less than 15 to 20 mg/l of chlorine. The flow in the lower reaches of the system is supplemented by springs, but much of their contributions are so saline that they degrade the quality of the river flow, to the extent of several thousand parts per million of total dissolved solids (TDS) at the Allenby Bridge near Jerico.

Few regions of the planet offer a more varied physiography or a richer mix of ethnicities, religions, languages, societies, cultures and politics than the Middle East. At the same time, no segment of the globe presents its diverse aspects in such an amalgam of conflicts and complexities. Out of this compound, one issue emerges as the most conspicuous, cross-cutting, and problematic: water - or other its scarcity and rapid diminution in some of the driest sectors of an area where there also

happen to exist some of the fiercest national animosities. River waters in the Middle East are a conflict-laden determinant of both the domestic and external policies of the region's principal actors.

As water shortages occur and full utilization is reached these policies tend to be framed more and more in zero-sum terms, adding to the probability of discord. The severity of Middle Eastern water problems will, unavoidably, increase significantly during the end of this century. In an already over-heated atmosphere of political hostility, insufficient water to satisfy burgeoning human, developmental, and security needs among all nations of the Middle East heightens the ambient tensions. By the end of 1990s, Israel, Jordan and the West Bank will have depleted virtually all of their renewable sources of fresh water if current pattern of consumption are not quickly and radically altered. In this circumstance, the Jordan River system, which includes the Al-Wuheda dam scheme on a major tributary of the Yarmouk river, unquestionable holds the greatest potential for conflict.

Despite of the hopeless political complications in the Middle East, there is a recent history of tacit, although limited, cooperation over multi-national river development even among the bitterest opponents, including rivers of the Jordan. Until Israel's invasion of Lebanon and her troublesome stand on clearing out obstructions to the intake of Jordan's East Ghor canal - have more or less informally agreed to share the Jordan River system within the framework of the 'Johnston Plan : 1955'. The Jordan river, which comprise the problems of not only quantity issue but quality issue such as increasing river salinity, are examined herewith to distinguish the complexities, commonalties, and conflict of riparian issues in the Middle East, where the peace of the world is at risk.

The largest water resources development project in Israel is the National Water Carrier, which is a huge aqueduct and pipeline network carrying the waters of the River Jordan southwards along the coastal region. The water is pumped from the En-Sheva intake in the northwest of Lake Tiberias at an elevation of 210 m below sea level to a height from which it flows by gravity to a reservoir at Rasalom. The installed capacity of the En-Sheva pumping station was 360 $x10^6 m^3$ per annum in 1968, and it could conceivably by increased to a maximum level of 500 $x10^6 m^3$ per annum which is 90 % of the inflow of Jordan River of 544 $x10^6 m^3$ per annum at the inlet to Lake Tiberias (Ref.2.5-2). This cutting of fresh water flows in the upper Jordan River would, however, have seriously adverse effects on the quality of Lake Tiberias and its lower reaches by increasing salinity.

A scheme to build a conduit to carry seawater from the Mediterranean to the Dead Sea and to exploit the 400 m altitude difference for generating hydroelectricity was dropped in 1984, owing to strong opposition from the Arab states and others on both environmental and political grounds. In the mid 1980s, Israeli studied pumped-storage schemes on both the Dead Sea and Lake Tiberias, to supplement the peak power generation. The pumped-storage scheme on Lake Tiberias, however, could damage plant and animal life there. Interest has now shifted back to the Dead Sea because of its total absence of flora and fauna.

Israel currently uses as much as 90 % or more stream water from the upper Jordan river. Jordan's water problems have undoubtedly been exacerbated by Israel actions to deny it the right to develop fully the Jordan water resources within its borders. The problem is particularly acute over the postponement of construction works of Al-Wuheda dam on the Yarmouk river. The upper Jordan River has already been developed to a maximum capacity. When undergoing project of the Al-Wuheda (Maqarin) dam is completed, the only major undeveloped tributary of Yarmouk will be also become fully utilized.

There have been several changes in the Israel-Arab situation since the Iraq invasion of Kuwait in 1990. From the integrated hydrological studies on the Jordan river system, it is now possible to conceive a comprehensive development plan which will be not only technically-economically feasible but also politically desirable and urgent. Both the Mediterranean-Dead Sea Conduit scheme and the Al Wuheda Dam project could be discussed simultaneously without threatening new political conflicts but rather to promote peace and economic development for the Palestinians. The dialogue between the two states would be based on a sense of the water cycle and balance of coordinating hydrology, energy and politics. The following Section describes the hydrology and water resources of the Jordan river system. The integrated planning concept to form the framework of comprehensive water resources development is given in Chapter-V.

2.5.1 The river basin

The catchment of the Jordan river, excluding the upper basin, is an integral part of the arid to semi-arid region. There is a marked spatial variation in the distribution of precipitation over the catchment. The

recharging area is confined to the upstream mountainous areas in the Anti-Lebanon range where the mean annual precipitation amounts to 1,400 mm. While the climate in the lower reaches of the Jordan river in the Rift Valley is arid to hyper-arid with an annual mean precipitation of less than 50-200 mm.

The Jordan river originates in the southwestern Anti-Lebanon range of Mount Hermon which is covered with permanent snow and flows through Lebanon, Syria, Israel, and Jordan. The river flows southwards for a total distance of 228 km along the bottom of a longitudinal graven known as the Rift Valley before emptying into the Dead Sea. Its principal tributary, the Yarmouk, forms the border between Syria and Jordan and divides Israel from Jordan in the Yarmouk triangle. The lower reaches of the Jordan river border on part the Israeli occupied West Bank to the west and Jordan to the east for a distance of about 80 km. (Fig.2.5-1)

The catchment area of the Jordan River is 18,300 km^2 in total, of which 3 % lies in pre-1967 Israel. The lower Jordan river between Lake Tiberias and Dead Sea has a catchment area of 1,050 km^2.

Based on the nature of the hydrology, hydrogeology and water use, the Jordan river system may be classified into three sections, namely:

(A) Upper Jordan River: Headwaters - Huleh Valley - Tiberias Lake
(B) Yarmouk River
(C) Lower Jordan River: Main stream - Dead Sea

2.5.2 The upper Jordan river

Upper Jordan River system includes: i) three major headwater streams of "Dan", "Hasbani" and "Basnias", ii) Huleh Valley, and iii) Lake Tiberias or Sea of Galilee (Fig.2.5.2-1).

i) The Dan River

The largest of the springs is the Dan Spring, which rise from Jurassic carbonate rocks and supplies a large and relatively steady flow that responds only slowly to rainfall events. The average discharge of the Dan spring is 245 $x10^6m^3$ per annum, which makes up effectively the entire flow of the Dan River. The Dan Spring is the least available in discharge among the major karstic sources of the upper Jordan: its discharge varies from 173 to 285 $x10^6m^3$ per annum. The Dan typically represents 50 per-

cent of the discharge of the upper Jordan.

ii) The Hasbani River

The Hasbani River derives most of its discharge from two springs, the Wazzani and the Haqzbieh, the latter being a group of springs on the uppermost Hasbani. All of these springs rise from subsurface conduits in cavernous Cretaceous carbonate rocks. The combined discharge of these two springs averages 138 $x10^6m^3$ per annum, but the range of values measured varies over a greater range than that of the Dan Spring. Over a recent twenty-year period, the flow of the Hasbani varied from 52 to 236 $x10^6m^3$ per annum. The Hasbani discharge responds much more rapidly to rainfall events than does the discharge of the Dan Spring.

iii) The Banias River

The Banias River is fed primarily from the Hermon springs that issue from the contact of Quaternary sediments over Jurassic limestone in the extreme northeast of the Jordan Valley. The average discharge of the Hermon Spring is 121 $x10^6m^3$ per annum; during a recent twenty-year period its discharge varied from 63-190 $x10^6m^3$ per annum.

In a typical year, these karstic springs provide 50 % of the discharge of the upper Jordan River: the rest is derived from surface runoff directly after the winter rainfall events. In dry years, spring outflow may make up as much as 70 % of the flow of the upper Jordan. The following is a summary of mean annual discharges of three rivers (Ref.2.5-1):

Name of river	Mean annual flow (10^6m^3)	Annual range of flow (10^6m^3)	Riparian states
Dan River	245	173-285	Israel
Hasbani River	138	52-236	Lebanon
Banias River	121	63-190	Syria/Israel
	(504)	(298-711)	

The Dan Spring, the largest of the sources of the upper Jordan, lies wholly within Israel close to the border with Syria. The spring sources of the Hasbani River lie entirely within Lebanon. The spring source of the Banias River is in Syria. These three small streams unite 6 km inside Israel at about 70 m above sea level to form the upper Jordan River.

These spring systems together provide more water than can be accounted for as a result of rainfall over their immediate watersheds; thus, it is surmised that the springs represent the outflow of a large, regional aquifer. The combined outflow of the springs and the precipitation that falls on the surface watershed of the upper Jordan is of the order of 500 $x10^6m^3$ per annum.

iv) Huleh Valley

The flow of the upper Jordan enters the Huleh Valley (formerly Lake Huleh), where it receives additional volume from the flow of sublacustrine springs. Among the minor springs and seasonal watercourses contributing the flow of the upper Jordan, the most important is the Wadi Bareighhit. The water budget of the Huleh Valley is show as below (Ref.2.5-1):

Source of Flow	Inflow (10^6m^3)	Plus (10^6m^3)	Minus (10^6m^3)	Outflow (10^6m^3)
Flow into Huleh Valley	504			
Local runoff Huleh to Jisr Banat Yaqub		140		
Irrigation in Huleh Valley			-100	
Flow into Tiberias Lake				544

v) Tiberias Lake

Beyond the Huleh, the North Fork of the Jordan falls 200 m to Lake Tiberias (Sea of Galilee), which lies 210 m below sea level. The upper Jordan contributes an average of 660 $x10^6m^3$ per annum to the lake, or 40 % of Israel's total identified renewable water resources. An additional 130 $x10^6m^3$ per annum enters Lake Tiberias as winter runoff from various wadis and in the form of discharge from sublacustrine springs which contain high salinity. The following is a summary of water budget of the Tiberias Lake (Ref.2.5-1):

Source of Flow	Inflow (10^6m^3)	Plus (10^6m^3)	Minus (10^6m^3)	Outflow (10^6m^3)
Flow into Tiberias lake	544			
Rainfall over the lake		65		
Flow from local runoff		70		
Springs in and around lake		65		
Evaporation from lake surface			-270	
Out flow to lower Jordan River				474

Lake Tiberias has a volume of $4x10^9$ m^3, which is 6.5 times the annual flow of the upper Jordan inflow and 8 times the annual Jordan outflow. The water depth is 26 m on average, including a maximum of 43 m. The surface area is 170 km^2, which loses about 270 $x10^6m^3$ per annum of water from the surface of Lake Tiberias by direct evaporation. The salinity of Lake Tiberias varies from a low value of 260 mg/l to a high of 400 mg/l of chlorine; this variation depends primarily on the flow of the upper Jordan, in which salinity does not exceed 15-20 mg/l of chlorine (Ref.2.5-1). About 500 $x10^6m^3$ per annum leaves Lake Tiberias via its outlet and flows south along the floor of the Dead Sea Rift for about 10 km to the confluence of the Yarmouk River.

2.5.3 The Yarmouk river

The Yarmouk river originates on the south-eastern slopes of Mount Hermon in a complex of wadis developed in Quaternary volcanic rocks. The main trunk of the Yarmouk forms the present boundary between Syria and Jordan for 40 km before it becomes the border between Jordan and Israel. Where it enters the Jordan River 10 km below Lake Tiberias (Fig.2.5.2-1), the Yarmouk contributes about 400 $x10^6m^3$ per annum (Ref.2.5.3-1).

There is no flow contribution from the part of the valley where Israel is a riparian. Of the 7,242 km^2 of the Yarmouk basin, 1,424 km^2 lie within Jordan and 5,252 km^2 within Syria. The flow of the Yarmouk is derived from winter precipitation that averages 364 mm per annum over the basin (Ref.2.5-1).

The Yarmouk River is the largest tributary of the Jordan river system, of which the potential resources have not been fully exploited except for a major part of the baseflow. The stream flow is supplemented by spring discharges from the highly permeable zones in the lavas; some further spring discharges may be channeled to the surface on wadi floors via solution pathways in the underlying limestones.

The mean annual flow discharge is 400 $x10^6m^3$ per annum, which is 65 % of the total discharge of 607 $x10^6m^3$ per annum of the East Bank. The flow is largely influenced by rainfall pattern in the Mediterranean climate, indicating maximum monthly discharge of 101 $x10^6m^3$ in February and minimum of 19 $x10^6m^3$ in September (Ref.2.5.3-1).

The water salinity of the Yarmouk river is quite low, being in the range between 280 and 480 mg/l of total dissolved solids (TDS).

East Ghor Main Canal (EGMC) Project

The Yarmouk river, which has a mean discharge of $400x10^6m^3$ per annum, provides almost half of the Jordan's surface water resources. The water in this river, after allowing for some $17x10^6$ m^3 per annum for downstream users in neighboring countries, is diverted through the East Ghor Main Canal (EGMC), an irrigation canal which runs along the Jordan river, to serve agricultural water needs in the Jordan Valley (Fig.2.5.2-1). The upper East Ghor Canal phase was completed in 1964, and by 1979, it had reached a length of 100 km, which could permit the irrigation of 22,000 ha (Ref.2.5-2).

Al-Wuheda (Maqarin) storage dam scheme

Al-Wuheda dam, first conceived as early as 1956, is going to be built in the northern part of Maqarin about 20 km north of Irbid to store the waters of the Yarmouk River, a largest tributary of the Jordan River (Fig.2.5.2-1).

The estimated streamflow at Maqarin gauging station is $273x10^6m^3$ per annum on average, which includes flood waters being discharged downstream without any use. Based on a bilateral riparian agreement between Syria and Jordan in 1988, preliminary work for opening an 800-meter long diversion tunnel had been completed by the end of 1989. The dam reservoir would have a gross capacity of $225x10^6m^3$ with effective storage of $195x10^6m^3$ annually. The water would irrigate an additional 3,500 hectares in the Jordan Valley, and supply $50x10^6m^3$ of water a year to the Greater Amman area and Eastern Heights. It will also generate an average of 18,800 MWh of electricity a year. Syria will be using part of the water and 75 % of the total hydroelectric power generated by a power station near the dam. However, this project has been stopped by strong opposition from Israel due to water allocation problems between the two states.

2.5.4 The lower Jordan river and Dead Sea

South of its confluence with the Yarmouk, the Jordan flows over late Tertiary rocks that partially fill the Rift Valley. For the first 40 km the river forms the international boundary between Israel and Jordan; south of that reach, it abuts the Israeli-occupied West Bank of Jordan, where it forms the present cease-fire line. The Jordan here flows through the deepest portion of the Rift Valley to enter the Dead Sea at

401 m below sea level, the lowest point of the earth. (Fig.2.5.2-1)

Runoff from winter rainfall within the valley is carried to the Jordan river via steep, intermittent tributary wadis incised in the wall of the Jordan Valley, primarily on the East Bank. The source represents an additional 523 $x10^6m^3$ per annum, of which only 20 % originates in Israel; 286 $x10^6m^3$ per annum is derived from perennial spring flow, while 237 $x10^6m^3$ per annum is provided by winter rainfall (Ref.2.5-1). The main tributaries on the East Bank including the Zarqa river and Wadi Arab, Ziglab, Jurm, Ubis, Kafrain, Rajib, Shueib, and Hisban are described in Chapter-IV.

The quality of the lower Jordan river is influenced both by rainfall patterns and the amount of baseflow extracted upstream. Water salinity is about 350 mg/l of total dissolved solids (TDS) in the rainy season, while it rises to 2,000-4,000 mg/l of total dissolved solids (TDS) in the dry season at Allenby bridge near Jerico.

Finally, the salinity of the Jordan river system reaches 250,000 mg/l of total dissolved solids in the Dead Sea, a level approximately seven times as high as that of the ocean. This salinity level is too high to sustain life, but certain minerals such as potash and bromines can be extracted by (solar) evaporative processes.

The Dead Sea is located in the lowest spot on the earth in the Jordan Rift Valley, and covers an area of of 1,000 km^2 at a surface elevation of 400 m below mean sea level. It has two basins separated by the Lisan Straits;the northern basin with an area of 230 km2, and the southern basin with an area of 720 km^2. The catchment area is 40,000 km^2 including parts of Israel, Jordan, and Syria. The shortest distance between the Dead Sea and the Mediterranean Sea is 72 km (Fig.2.5-1).

The Dead Sea is a closed sea with no outlet except by evaporation, owing to very high evaporation from the sea surface which amounts to 1,600 mm per annum. In the past, the evaporation losses were replenished by an inflow of fresh water from the Jordan River and its tributaries, as well as other sources such as wadi floods, springs and rainfall. The mean volume of water flowing into the sea before 1930 was about $1.6x10^9m^3$ per annum, of which $1.1x10^9m^3$ per annum were carried by the Jordan River (Ref.2.5.4-1). Under these conditions, the Dead Sea had reached an equilibrium level at a height around 393 m below sea level, with some seasonal and annual fluctuation due to variations in the amount of

rainfall. However, since the early 1950s, Israel and later on the Jordan, have taken steps to utilize the freshwater flowing into the Dead Seas for intensified irrigation and other purposes, which has reduced the amount of water entering the Dead Sea by $1x10^9m^3$ per annum. Consequently, the water level in the Dead Sea has declined in recent years, reaching as low as 403 m below sea level today, which is almost 10 m lower than its historic equilibrium level. The surface area of the Dead Sea and its evaporated volume vary only by a few percent between elevations from -402 to -390 m, while water levels fluctuate considerably.

2.5.5 Water Allocation Problems and International Riparian Agreement

In 1953, the four countries Lebanon, Syria, Israel, and Jordan, agreed basically upon the priority use of Jordan river waters, in the so-called "Johnston Agreement", including the priority use of the main stem of Jordan River by Israel and Lebanon. The biggest tributary of the Yarmouk river which runs along the northern border of Jordan with Syria would be exclusively used by Syria and Jordan. This established a water allocation of the usable Jordan river estimated at 1,380 $x10^6m^3$ per annum in total; 52 % (720 $x10^6m^3$) of Jordan, 32 % (440 $x10^6m^3$) of Israel, 13 % (180 $x10^6m^3$) of Syria and 3 % (40 $x10^6m^3$) of Lebanon (Ref.2.5-1). It is widely assumed that the technical experts of each country involved in this discussion agreed upon the details of this plan, although soon afterwards the governments rejected it for political reasons.

With the failure of these negotiations, both Israel and Jordan decided to proceed with water projects situated entirely within their own boundaries. As a result Israel began work on the National Water Carrier in 1958 which is currently abstracting 90 % or more flow of the upper Jordan river by through the intake in the northwest Tiberias lake.

Syria continued implementation of small-medium size dam development schemes for the upper Yarmouk. These plans could lead to increased salinity levels in the lower Yarmouk and lower Jordan rivers, lower water levels in the Dead Sea, and reduced irrigation water for Jordan's East Ghor Development Project. From a strategic point of view, this long-term Syrian effort could reduce Jordanian access to the Yarmouk, on which Jordan relies to irrigate the Jordan valley, and may affect downstream availabilities for Israel. Ultimately, the possibility of heightened tension or even armed conflict among the riparians might increase (Ref.2.5.5-1). In 1988, Jordan and Syria signed a protocol of understanding which paves the way to the commencement of Al-Wuheda dam on

the international border of the Yarmouk River.

After completing the diversion tunnel for the Al-Wuheda dam at the end of 1989, the storage dam project could not be continued owing to a strong opposition by Israel. The Israel has been demanding an increase, rather than a decrease of the Yarmouk's flow, after facing the serious water problem that utilizing almost all of its replenishable fresh-water resources such as surface water from Jordan river and renewable groundwaters in the limestone-sandstone aquifers in the 1970s-1980s.

REFERENCES (2.5)

Ref.2.5-1
Thomas Naff and Ruth C.Matson, 1984, "Water in the Middle East; Conflict or Cooperation", Westview Press / Boulder and London, pp.17-27.

Ref.2.5-2
Peter Beaumont, Gerald H.Blake, and J.Malcolm Wagstaff, 1988 "The Middle East; A Geographical Study, 2nd Edition", David Fulton publishers, pp.100-105.

Ref.2.5.3-1
John Huang and Arun Banerjee, 1984, "Hashemite Kingdom of Jordan: Water Sector Study, Sector Report", World Bank Report No.4699-JO,1984, pp.35-36.

Ref.2.5.4-1
Dan Weiner, and Arie Ben-Zvi, 1982, "A Stochastic dynamic Programming Model for the Operation of the Mediterranean-Dead Sea Project, Water Resources Research, vol.18, no.4, pp.729-734.

Ref.2.5.5-1
Joyce R.Starr and Daniel C.Stoll, 1987, "U.S. Foreign Policy on Water Resources in the Middle East", The Center for Strategic & International Studies: Washington D.C., pp.5-8.

2.6 Colorado River

Increasing salinity is one of the most significant and certainly the most widespread forms of groundwater and/or stream flow pollution. The most important causes are the increase in salinity of groundwater from the effects of irrigation, and the intrusion of saline water (seawater), mainly in basins of internal drainage, islands and coastal areas.

In arid climates infiltration from rainfall may be negligible and leaching is not effective in diluting soil salt solutions enriched by evaporation. Any infiltration that does reach the groundwater table will be relatively highly mineralized. In poor drainage areas, particularly basins of internal drainage which are groundwater discharge areas, evaporation can produce significant increases in salinity.

Changes in salinity of rivers along their courses and with time are mainly the result of influences of return flows from the subsurface drainage water. The effect of irrigation returns on river salinity as described here for the Colorado river in Arizona has been illustrated by rivers in other arid regions in the advanced countries including Upper Rio Grande in Texas U.S.A, Colorado river in Arizona U.S.A, Murray river in Australia (Ref.2.6-1).

Section 2.6 provides a case study in the control of river salinity problems by using the world's largest desalting facility to salvage about 72.4 mgd (280,000 m^3/day) of brackish water from irrigation drainage in the Colorado valley, Arizona, U.S.A. The reverse osmosis (RO) desalination project, which is located at Yuma city in the southwestern corner of the Arizona state in the U.S.A., aims to control the quality of the Colorado river where it crosses the border between U.S.A. and Mexico.

2.6.1 Background

The Colorado River is one of the world's most regulated rivers. But the regulation necessary to ensure a sufficient quantity of water for users has also exacted a price in the quality of the water available. As the Southwest U.S.A. was being developed during the early part of this century, the big question was "Will there be enough water ?". Today people also ask, "How good will the available water be ?". Under a 1944 treaty with the U.S.A., Mexico has a guaranteed allotment of $1.85 \times 10^9 m^3$ of water per year. Between 1945 and 1961 there were no major problems

resulting from the Treaty, as the salinity of the water crossing the border into Mexico was generally within 400 mg/l at Imperial Dam, the last major diversion for U.S.A. users.

In regulating the Colorado by constructing a series of large dams (Fig.2.6.1-1), stream salinity has been substantially increased by two processes; the tremendously increased evaporation surface, and contaminated irrigation return flows. The stream salinity (TDS) has been doubled from 400 mg/l in the early 1900s to 800 mg/l in the 1950s that arrives at the Mexican border. In 1961 Mexico began complaining that the increase salinity was harming crops in the Mexicali valley. In 1973 U.S.A. agreed in "Minute No.242" to a salinity level for water being delivered to Mexico at Morelos Dam.

This agreed upon salinity level has had to be achieved by constructing a massive desalination plant. Enough of the salts have to be removed from irrigation return flows to make the water acceptable for discharge into the river, and later delivery to Mexico. The plant will be the world's largest reverse osmosis (RO) desalting facility with an installed capacity of 27,600 m^3/day. When the Yuma desalting plant is completed in 1992, it will salvage most of the irrigation return flows of 98 $x10^6 m^3$/year which are at present being diverted to the Gulf of California. (Ref.2.6.1-1)

2.6.2 The river basin

The Colorado River is an international drainage system that drains an area of approximately 583,000 km^2 and flows through seven states in the U.S.A. and the Republic of Mexico (Fig.2.6.1-1).

The average annual natural flow of the river at Lee Ferry, Arizona, the dividing point between the Upper and Lower Basins, has been estimated at about $18x10^9 m^3$/year which also approximates to the present consumptive use within the basin plus deliveries to Mexico. The total annual salt load at Lee Ferry is $7.4x10^6$ metric tons, of which the irrigated agriculture is estimated to contribute a further 1.8 to $3x10^6$ metric tons. Eighty-eight (88) per-cent of the total salt load from irrigated agriculture in the entire basin is estimated to originate in the Upper Basin. (Ref.2.6.2-1)

2.6.3 Salinity problems of Colorado river

Salinity is a naturally occurring phenomenon in almost all rivers in the arid zone. The salinity of the Colorado river water at its headwaters in

the Rocky Mountains is about 50 mg/l of total dissolved solids (TDS) yet where the river crosses the border into Mexico, it was already about 400 mg/l in the early 1900's. Owing to the tremendously increased evaporative surfaces in the over 20 reservoirs and the numerous irrigation systems in arid terrain, the salinity of river water at the border now reached an unacceptable level.

In southwestern Arizona, the Wellton-Mohawk Irrigation and Drainage District, east of Yuma, was one of the last districts to be developed in the early 1950's (Fig.2.6.1-1). This project included a system of drainage wells, the discharge of which included a substantial amount of of highly saline groundwater that had been concentrated through re-use during the previous 50 years. Initially it had a salinity of 6,000 mg/l. This resulted in a sharp increase in the salinity of the water crossing the border into Mexico from around 850 mg/l in 1960 to more than 1,500 mg/l in 1962. At about the same time releases into Mexico were greatly reduced in anticipation of storage behind the newly constructed Glen Canyon Dam. This loss of dilution water is illustrated by the fact that for the period 1951-60 the average delivery to Mexico was $5.2x10^9 m^3$/year, while in the succeeding one-year periods to 1970, the flow averaged only $1.9x10^9 m^3$/year, Mexico raised strenuous objections.(Ref.2.6.2-1)

In 1961 Mexico began complaining that the increased salinity was harming crops in the Mexicali Valley, and in 1973 the United States had to agree to reduce the salinity level. Specifically, the salinity of water as it enters Mexico at Morelos dam must average no more than 115 mg/l plus or minus 30 mg/l over the average annual salinity of waters arriving at Imperial Dam (Ref.2.6.2-1).

2.6.4 Counter-measures to control river salinity

To comply with the above agreement the U.S.A. has planned the following works; (Fig.2.6.4-1)

1) A major desalting plant for Wellton-Mohawk drainage waters.
2) Extension of the Wellton-Mohawk drain by 85 km to the Gulf of California.
3) Lining or construction of a new Coachella Canal in California.
4) Reduction in Wellton-Mohawk District acreage and improved irrigation efficiency.
5) Construction of a wellfield on the U.S.A. side of the international boundary to balance wellfields recently installed by Mexico near the

border.

All of the costs in money or water to achieve the new guarantee are to be borne by the U.S.A. at a cost of several hundred million dollars annually. Both the U.S.A. and Mexico will receive tangible benefits. The United States Bureau of Reclamation estimates that an increase of one mg/l in salinity at Imperial Dam results in cost of US $240,000/year to water users in Arizona, California, and Nevada. In the absence of any measures to control salinity, the total impact of salinity increases on users in the three Lower Basin states was predicted to be about US $80x10^6 per year by the year 2000. (Ref.2.6.2-1) Dollar values of detriments to users in Mexico would be additional, but have not been estimated.

Authorization to commence the salinity control work was provided by the Colorado River Basin Salinity Control Act, passed by Congress in June 1974. This legislation was in two parts; Title One (for salinity control measures downstream of Imperial Dam), and Title Two (for salinity control measures in the seven Colorado River basin states upstream of Imperial Dam).

2.6.5 Salinity control by world's largest RO desalting facilities

The agreed upon salinity level is to be achieved by constructing a desalination plant. Enough of the salts will be removed from irrigation return flows to make the water acceptable for discharge into the river and later delivery to Mexico. Until the desalination plant is completed, drainage water from the farmlands east of Yuma will be bypassed around Mexico's diversion point at Morelos dam and will be carried in a concrete-lined drain to the Santa Clara Slough at the Gulf of California (Ref.2.6.1-1). Meanwhile, these bypassed flows will be replaced by water from upstream storage to fully meet the quantity of 1.5x10^6 acre-feet (1.85x10^{9}m^3) of water owed to Mexico. When the Yuma desalting plant is completed, it will salvage most of the irrigation return flows now being diverted.

The Yuma desalting plant provides for salinity control measures downstream of Imperial dam. Approximately 100 mgd (= 166 x10^{6}m^3/y) of saline irrigation drainage from the Wellton-Mohawk farmland will be delivered to the Yuma desalting plant via an existing concrete lined drain. The anticipated performance of the desalting plant is shown in Tab.2.6.5-1. The RO plant has an installed design capacity of about 72 mgd (262,520 m^3/d), which can be expanded to 96 mgd (363,360 m^3/d). A flow diagram of

the treatment system is shown in Fig.2.6.5-1.

Pre-treatment

Before being desalted, the water passes through three pre-treatment steps to remove all solids in the water which would quickly clog the expensive desalting membranes if not removed. Pre-treating the water will ensure that membrane life of 3 to 5 years can be realized.

As the water flows into the plant, chlorine will be added to prevent growth of algae and other organisms. The water will first go through the grit sedimentation basin to remove heavy grit, sediment and sand suspended in the water. The water will also be softened by removing some of the calcium. Lime and ferric sulfate will both be used in the solid contact reactors. The last step in the pre-treatment process will be dual media filters which will remove any fine particles or organisms remaining in the water.

Processing

Reverse osmosis is the separation of one component of a solution from another component. (in this case, the salt from the H_2O) This is accomplished by means of pressure exerted on a semi-impermeable plastic membrane. A total of about 9,000 membrane elements, inserted into fiberglass pressure vessels will desalt the water. While the pressure tubes are all 60 cm (20 feet) long, some membranes have a diameter of 30 cm (12 inches) while the diameter of others is 20 cm (8 inches). The element is made up of a number of sheets that are rolled into a spiral wound membrane.

The separation of the salt from the product water is both a chemical process and a physical diffusion process. The water is forced through the walls of the cellulose acetate membranes by applying pressure at about 30 kg/cm^2 (about 400 pounds per square inch), allowing only the freshly desalted water to pass through. This process removes about 97 % of the salts from the water. The fresh water is forced by the pressure down towards the center tube.

Water control and management

After desalination, the product water (with a salinity level of 285 mg/l) will be collected and combined with untreated drainage water (with

salinity around 3,000 mg/l of TDS) to achieve the desired salinity level of about 700 mg/l. The salvaged water will then be conveyed in a concrete channel to the Colorado river. RO brine (with 10,000 mg/l salinity) will be piped to the existing bypass drain, where it will mix with excess untreated Wellton-Mohawk drainage. Anticipated performance of the reverse osmosis desalination is shown in Tab.2.6.5-1. This effluent/drainage flow will then travel to the Santa Clara Slough above the Gulf of California, where it will combine harmlessly with 30,000 mg/l salinity ocean water. (Ref.2.6.1-1) No adverse effects on the water environment in the Gulf of California is foreseen.

Until the desalting plant is completed, these bypassed flows are being replaced by water from upstream storage in order to fully meet the quantity of 1.85×10^9 m^3 (1.5 million acre-feet) of water owed to Mexico.

Cost

The United State Bureau of Reclamation estimated the project cost of the Yuma desalting plant in 1975. The capital cost of US$ 149,446,000 includes;

Pre-treatment	US$ 56,000,000
Desalting plant	US$ 70,300,000
Control and operating system	US$ 5,300,000
Appurtenant works	US$ 17,860,000

The annual cost is estimated to be US$ 8,988,500 of the capital investment with US$ 11,520,000 of the operation and maintenance for $126.^6 \times 10^6 m^3$/y of design product water with salinity at 386 mg/l of the total dissolved solids (TDS). The unit cost of the product water is estimated to be US$ 0.16 based on 1975 prices without interest during the construction. From a recent cost study on the Yuma desalting project, the unit cost of the product water with salinity at 285 mg/l of TDS for the design product water of $85 \times 10^6 m^3$ per annum is estimated to be US$ 0.48/m^3, assuming the construction period of three years with an interest rate at 8 %. The project cost of the Yuma desalting plant which is based on 1990 prices is estimated to be as follow;

Capital cost	US$ 211,518,000
Design and construction management	US$ 52,911,000
Financial expenditure	US$ 66,672,000
Annual operation and maintenance cost	US$ 20,551,000

The unit water costs of the various waters including seawater desalination by MSF and RO (practice in Kuwait; Ref.2.6.5-2), brackish water desalination by RO (Yuma, USA) and advanced waste water treatment (Water Factory-21, USA; Ref.2.6.5-3) are compared as shown below;

	Seawater desalination		Brackish water desalination		Advanced waste water treatment
	MSF	RO	(Yuma)	(Water Factory-21)	
Salinity of source water (mg/l; TDS)	45,000	45,000	3,000	1,000	less than 500
Unit water cost (US$/$m^3$)	2.7	1.6	0.46	0.14	0.17

The operation and maintenance cost of the RO desalination is likely to be reduced by introducing low pressure type membrane modules. The major cost items of the power and membranes are expected to be minimized by the advances in the membrane technology.

2.6.6 Remarks on Colorado river salinity control and water resources management

The product water from the desalting plant will be blended with raw drainage water to develop a total of $89 \times 10^6 m^3$ per annum of blended water to be delivered to the Colorado River. Salinity control of the Colorado river by desalting facility is not only to protect the water quality environment but also to sustain the arid land agriculture of both U.S.A. and Mexico. The Colorado river salinity control program, of which the Yuma desalting plant is a key element, may be a significant development in water resources management of the river. The large scale RO system will be applicable, however, only in countries when plant operational skills are already at a high level.

REFERENCES (2.6)

Ref.2.6-1
Michel Meybeck, Deborah Chapman, and Richard Helmer, 1989, "Global Freshwater Qaulity: A first Assessment", WHO/UNEP, Basil Blackwell Ltd.,UK, pp.139-156.

Ref.2.6.1-1
Robert Applegate, 1986, "World's Largest RO Desalting Facility to Salvage 72.4 mgd", Waterworld News, May/June 1986, pp.17-19.

Ref.2.6.2-1
E. Barton Worthington, 1977, "Arid Land Irrigation in Developing countries: Environmental Problems and Effects", Pergamon Press, pp.149-152.

Ref.2.6.5-1
Wayne Wagner, 1989, "The Yuma Desalting Plant - A Status Report", Seventh Annual Membrane Technology/Planning Conference, Nov.17-19,1989,Cambridge,Massachusetts, pp.102-111.

Ref.2.6.5-2
M.A.Darwish and Abdel-Jawad, 1989, "Technical Comparison Between Large Capacity MSF and RO Desalting Plants" International Desalination Association (IDA), Proceedings of the 4th congress in Kuwait, vol.4, pp.281-304.

Ref.2.6.5-3
Orange County Water District, 1989, "Annual Report; Water Factory-21", California State Water Council, USA, p.10.

Tab.2.6.5-1 Anticipated Performance of Yuma Desalting Plant

Constituent	Feed Water (mg/l)	Reject Water (mg/l)	Product Water (mg/l)
Ca	145	477	3
Mg	85	279	2
Na	739	2,246	93
K	9	27	1
HCO_3	19	15	<1
SO_4	1,011	3,380	11
Cl	870	2,563	145
NO_3	1	3	<1
SiO_2	23	63	6
TDS	2,987	9,047	261

2.7 Non-renewable Groundwater Development in the Middle East

In the Middle East it is possible to distinguish two major types of aquifers. Along river valleys and beneath alluvial fans and plains, there are shallow alluvial aquifers. These are generally unconfined, small in area, and have water tables which respond rapidly to local precipitation conditions. The second type are deep rock aquifers of sedimentary origin, usually sandstone and limestone. These are often confined systems, sometimes of considerable areal extent, and store water which can in part be many thousands of years old.

The deep rock aquifers often extend over many thousands of square kilometers in area, with natural recharge occurring in upland and foothill zones where the rocks have surface outcrops. With these large rock aquifers there is still considerable uncertainty as to the degree to which recharge is taking place at the present day, partly because little is known about how much runoff is generated during the rare, but often intense, local storm events.

The potential for conventional water resources such as river water and renewable groundwater is extremely limited in the Arabian peninsula and North Africa excluding minor areas in the mountain ranges where annual rainfall exceeds 10 inches or 250 mm. By over-exploiting major rivers such as Nile, Jordan, Tigris and Euphrates, groundwater resources in deep sandstone aquifers, such as Nubian sandstone aquifers and its equivalent formations, could have been conceived a major source of water for development in the Middle East and North Africa in the 1980s. Groundwater in the deep sandstone aquifers, however, is non-renewable or "fossil" water which may offer an opportunity for short term and emergency uses. Large scale deep sandstone aquifer development projects in the Saudi Arabia, Libya, and Egypt are illustrated in this Section.

2.7.1 Groundwater resources in the deep sandstone aquifer

Nubian Sandstones

Sandstones of Nubian facies underlie most of the Arabian Peninsula and the Sahara, and represent one of the most extensive artesian groundwater basins of the world. Nubian sandstones derive from the Pre-Cambrian and form reworked sandy Paleozoic deposits and have not been altered by metamorphic process.

The sediments, as a rule, are deposited either in flood facies represented by poorly sorted, coarse to medium grained, commonly cross-bedded, brownish sandstones containing mud flakes and quartz pebbles, or in lacustrine facies consisting of clay banks and sandstone tongues and reaching a maximum thickness of 3,500 m. Rapid facies changes are typical and marine incursions common, particular over the less stable parts of the platform.

The age of the Nubian sandstone is poorly defined. In Libya, late Jurassic to early Cretaceous age is indicated, while the formation extends into the Paleocene in Egypt. It seems that name of "Nubian Sandstone" is best regarded as a purely litho-stratigraphic unit which does not easily fit into a chrono-stratigraphic system.

Groundwater basins in Sahara

The groundwater of the Sahara is to be found mainly in the following seven major basins: the Great Western Erg and Great Eastern Erg in the north, Fezzan and Tonezroft in the central region, the Western Desert of Egypt in the east, and Chad and Niger in the south (Fig.2.7.1-1). A very large groundwater reservoir of fresh water is found in the Libyan part of the Sahara up to a depth of approximately 3,000 m. The water in the aquifers of Nubian sandstone correlates with "Continental Intercalaire" in the Western Sahara and is normally of good quality with total dissolved solid (TDS) content being usually less than 500 mg/l (Ref.2.7.1-1). The Nubian aquifer system of the North-Eastern Sahara, which is one of the largest groundwater systems of the Sahara, covers an area of about $2x10^6 km^2$, has two principal basins: the Kufra basin in Libya, northeastern Chad and northwestern Sudan, and the Dakhla basin of Egypt. (Fig.2.7.1-2)

Recharge

Despite the hyper-arid climate, a huge reserves of fresh groundwater is contained in Nubian sandstone in several thousand meters of saturated rock. The average rainfall is less than 5 mm per annum, from which it is obvious that there has been no recent groundwater recharge in most of system. For the occurrence of the groundwater, two flow mechanisms have been discussed including steady-state and non-steady (Ref.2.7.1-2). The steady-state concept, that suggests renewable conditions, is based on observations of piezometric heads and postulates a large-scale flow from mountainous recharge areas in the southwest such as the Tibesti mountains

on the Chad/Libyan border and Ennedi mountains on the border with Sudan to a northeast discharge area along the Mediterranean Sea coast. Such artesian water generally moves very slowly over considerable distances from the recharge area.

The non-steady concept, that suggest a non-renewable condition, is based on isotope dating of water samples, indicating ages of groundwater of 25,000 to 40,000 years. The apparent age of a groundwater sample, taken from a certain depth in an aquifer, is not only influenced by the flow time of the groundwater particle from the recharge area. To a large extent it is the result of diffusive and convective processes in the aquifer and of mixing within the well.

A recent model simulation study in 1989 (Ref.2.7.1-2), which took into account paleo-climatological factors in the Holocene period, showed that groundwater in Egypt and Libya was probably derived from precipitation during humid and semi-arid climatic periods and entered the aquifer in the unconfined parts of the aquifer.

Aquifers in the Arabian Peninsula

Aquifers in the Arabian peninsula are found in arenaceous and/or carbonate formations, including the major formations "Saq"/"Disi", "Tabuk" and "Wajid" of Paleozoic age, "Minjur", "Dhruma", "Biyadh" and "Wasia" of Mesozoic age, and "Umm er Radhuma" and "Damman" of Tertiary period (Fig.2.7.1-3).

The Saq/Disi sandstone, which is of Cambrian to Early Ordovician age, constitutes the most extensive aquifer in the Arabian peninsula (Fig.2.7.1-2). The Saq formation in Saudi Arabia is equivalent to the Disi formation in Jordan. Its outcrops form the western and southern fringes of the Great Nafud basin of Saudi Arabia which extends northwards into southern Jordan (Figs.2.7.1-4). It underlies at great depth the whole of Jordan and a large part of the Nafud and Sirhan basins in Saudi Arabia, and is composed of a complex sequence of cross-bedded quartz sandstone, shales and siltstone more than 600 to 900 m thick.

The mechanism of groundwater recharge in such a hyper-arid region is still under discussion among hydrogeologists, but isotope datings of water in the Disi sandstone in Jordan and Saq sandstone in Saudi Arabia indicate ages of up to 35,000 years and 20,000 years, respectively (Ref.2.7.1-3).

The current hypothesis is that the observed hydraulic gradients cannot be attributed to replenishment and must be the result of dewatering of an ancient recharge area at outcrops. Groundwater reserves in the Disi/Saq aquifer are therefore most probably of fossil origin with very little, if any, additions from modern recharge.

Development strategy

The dominance and importance of non-renewable groundwater reserves in the national water planning is demonstrated in the 1985-1990 development plans of Saudi Arabia and Libya. These, and the New Valley project in Egypt, are described below:

2.7.2 Non-renewable groundwater development in Saudi Arabia

Non-renewable groundwater in the deep sandstone aquifers is concentrated in the northern, northeastern, and central part of the country. The surface water and renewable groundwater usually concentrated in the west and southwest near the Hijaz and Assir mountains. While non-renewable groundwater with brackish quality in the Mesozoic to Neogen aquifers is found in extensive areas in the northeastern part of the country as shown in Fig.2.7.2-1.

Saudi Arabia is one of the world's leaders in production of wheat for self-sufficiency in food. The production of wheat, however, is dependent almost wholly on the mining of non-renewable groundwater resources.

According to the "Fourth Development Plan (1985-1990); Ministry of Agriculture and Water", agricultural water demand in Saudi Arabia in 1985 amounted to 8,000 $x10^6m^3/y$, whereas water demand for urban, rural and industrial (M&I) use was 1,600 $x10^6m^3/y$. It was estimated that the total water demand will increase to 16,500 $x10^6m^3/y$ by the year of 2000, comprising an agricultural water demand of 14,000 $x10^6m^3/y$ and a M&I water demand of 2,500 $x10^6m^3/y$. This huge water demand for agricultural use is based on the Kingdom's policy of self-sufficiency in food. The wisdom of growing grain which generally requires 2,000 to 3,000 tons of water per ton of grain is constantly under discussion. (Ref.2.7.2-1).

Quality and water use

Quality of groundwater in the deep sandstone aquifers is generally fresh with a low-salinity in the range between 300 and 1,000 mg/l of TDS. This

water is used mainly in growing wheat, with a total yield of 741,000 tons per annum. The unit water requirement is calculated to be 10.8 m^3 per kilogram of wheat (Ref.2.7.2-2). The most commonly used method of irrigation in Saudi Arabia is by central pivot sprinkler system, which loses a significant amount of water through evaporation.

Problems in sustainable development

Salt accumulations in surfacial soil layers and/or underlying aquifers, which is a typical and difficult problem for groundwater irrigation in the arid region, cannot be neglected in any long term development project. In Saudi Arabia this has already caused with a substantial depletion of nonrenewable groundwater resources.

Water demand in various sectors is increasing at an alarming rate. Measures to control demand have become increasingly important to water resources planners and decision-makers in balancing the needs of agricultural development with depletion of nonrenewable groundwater resources, and strategic parameters for self-sufficiency in food.

In the Fifth Development Plan of Saudi Arabia (1990-1995), total water use in the Kingdom will be reduced by 8 %, from $16.2 \times 10^9 m^3$ per annum in 1990 to $14.9 \times 10^9 m^3$ per annum in 1995, compared with a total increase of 89 % during the Fourth Plan period. The reduction in water consumption will be the result of the projected decline in agricultural consumption from $14.6 \times 10^9 m^3$ per annum at the beginning of the Fifth Plan to $12.7 \times 10^9 m^3$ per annum at the end of the Plan period. The change in the consumption rate by agriculture is expected to take place through changing crop patterns, the intensification of water saving techniques and other appropriate measures, all of which will not affect the desirable growth rate of agricultural production or its value added. This 8 % of reduction in the national water supply may be the world's first application to conserve the non-renewable groundwater resources. (Ref.2.7.2-3) Many countries in the Middle East must consider the conservation policy for the sustainable development including the reduction of national water supply.

2.7.3 The Great Man-Made River project in Libya

Sahara/Libyan Desert in Libya

Libya, is located in the northern part of the Sahara desert in Africa, extends from 19 to 33 degrees of north latitude and from 9 to 25 degrees

of east longitude with a land area of 1,759,540 km^2 (Fig.2.7.1-2). Except for the Mediterranean coastal belt, the country consists of barren rock deserts, undulating sand seas, salt-marsh depressions and mountains that rise to 1,200 m in the southwest and to 1,800 m in the southeast. Climatically Libya is influenced by both the Mediterranean and the Sahara. The coastal region has a Mediterranean climate: winters are mild with 250 to 400 mm of rain and summers hot and dry. Conditions in the desert interior are extremely hot and arid with an annual rainfall 0 to 120 mm.

Hydro-meteorologically Libya is a desert in which the surface hydrology is of no direct practical importance, while huge amounts of fossil groundwater are stored in the Nubian sandstones which underlie wide areas of the Libyan desert. Groundwater development and/or mining of the Nubian sandstones in the inland desert depressions, named the "Great Man Made River Project", will be the key to the nation's development strategy from the year 2000.

Great Man-Made River Project

A vast aquifer estimated to hold an amount of fresh water equivalent to the total flow of the Nile River over a 200-years period was accidentally discovered by American geologist during the crude oil exploration on the Sahara desert in the early 1960s. The Libyan government saw an opportunity to pump the water, at a rate of 5.7×10^6 m^3/d (66 m^3/s), then convey it over 600 km north to farms on the Libyan coast. The total length of the water pipeline is estimated at 4,000 km which will be the worlds largest water pipeline system. (Fig.2.7.3-1)

Some agricultural development has already begun around the desert oasis of Kufra using the self-flowing artesian wells in the depression. Acres of wheat, barley and alfalfa grow where there were only desert and gravel plains before. According to an article in the British journal "New Scientist", the amount of sustained yield of groundwater resources is in some doubt. Professor Ahmad, a hydrogeologist at the University of Ohio says that the water is moving into the two aquifers which are to be tapped at 80 m^3/s, whereas Dr.E.Wright from the British Geological Survey says that the figure is close to 5 m^3/s. The life of the Nubian sandstone aquifer is estimated to be 20 to 200 years, owing to the lack of data for estimating groundwater recharge through the wadi beds and/or the depressions during occasional and temporary flash floods. The total pipeline system is therefore designed on the assumption on the aquifer life of 50 years.

In 1984 the Libyan government commenced the 1st phase construction for the "Great Man-Made River (GMR) project. This comprises a $2x10^6$ m^3/d twin pipeline in eastern Libya leading from wellfields in the Tazerbo and Sarir regions, deep in the desert, to the small coastal town of Agedabia. Single lines will then lead along the coast east to Benghazi and west to Sirte.

The 2nd phase commenced in 1986 which consists of a 600 km long pre-stressed concrete pipeline to convey $2x10^9$ m^3/d from beneath the western deserts to the Tripoli area on the coast, includes an option for an 18 MW hydroelectric station to be built adjacent to a terminal reservoir with a planned capacity of $28x10^6m^3$ (Ref.2.7.3-1). The station would use a difference head of water of some 200 m, and the power output would compensate for the energy used to pump the water to the coast.

2.7.4 New Valley project in Egypt

Sahara Desert in Egypt

Egypt is located in the northeast of Africa, extending from 22 to 31.5 degrees of north latitude and from 25 to 36 degrees of east longitude with a land area of 1,002,000 km^2 (Fig.2.7.1-2). About 96 % of Egypt is desert. The area west of the Nile is an arid plateau some 200 m high, crossed by belts of sand dunes in the center and west. The Nile is Egypt's most important feature. The Nile divides 25 km north of Cairo into the Rashid and Dumyat the two main channels of the 22,000 km^2 delta. Rainfall is minimal: Cairo receives only 60 mm annually, while the desert often has no rain at all. A narrow stretch of the Mediterranean coast is milder and wetter with 250 mm of rain a year.

Hydro-meteorologically Egypt is a desert, however, in which the surface hydrology of the Nile river is of direct practical importance. The Nile is the basic source of water and, with aid of dams and barrages, supplies an extensive network of distributary canals. West of the Nile, Nubian sandstones which store a huge amount of fossil to semi-fossil water underlie the desert. Groundwater development in the depressions, where the saturated Nubian sandstone aquifer underlies, is the worthy complement of the green revolution in the western Egypt.

Kharga and Dakhla Oases in the Western Desert

In 1950 the cultivated area in the Kharga oasis was about 24 km^2 out of a total of 4,000 km^2. Abstraction of groundwater from shallow wells amounted to $38.7x10^6$ m^3/year in Kharga oasis and $92.7x10^6m^3$/year in Dakhla oasis (Fig.2.7.4-1). Seven deep boreholes drilled between 1938 and 1952, with depths varying between 342.5 and 509.3 m, encountered artesian flow. The yield of these deep wells was $20.6x10^6m^3$/year in total, however, they were decreased after a few years of operation by not less than 40 % of their initial values.

Groundwater development in New Valley project

Extensive deep production wells were drilled in the mid-1950s, to correspond with the New Valley project which aims to expand the cultivated area in the Kharga and Dakhla oases. At first, much of the water self-flowed under artesian conditions. The pressure quickly fell, however, and ever greater amounts of pumping had to be employed by increasing use of water. In some wells, saline water began to be contaminated, limiting the crops which could be grown. In 1963 the combined discharge of shallow wells and deep production wells in El-Kharga amounted to about $117x10^6m^3$/year but this had dropped to a level of $80x10^6m^3$/year by the end of 1967. The construction of deep production wells in Dakhla oasis completed by 1966 increased the combined yield of shallow and deep systems up to $190x10^6m^3$/year but this had decreased to a level of $159x10^6m^3$/year by the end of 1969. The response of the head of water to the growing abstractions from the deep production wells in Kharga and Dakhla oases from 1956 to 1975 is shown in Fig.2.7.4-1. The Egyptian authorities are planning to augment extraction until it reaches $2,400x10^6m^3$/year by the year 2000. (Ref.2.7.4-1) Extraction of the target volume will lead to a further decline in the piezometric head to cease the artesian flow. Another problem of the development project is the human problem that many of the managerial staff do not like living in such isolated areas. Overall the project cannot be considered a success (Ref.2.7.4-2)

REFERENCES (2.7)

Ref.2.7.1-1
Gischler, Christiaan E., 1979 ,"Water Resources in the Arab Middle East and North Africa", UNESCO Working Document, No.SC-76/CASTARAB/3

Ref.2.7.1-2
Manfred Heinl and Paul J.Brinkmann, 1989, "A Groundwater Model of the Nubian Aquifer System", Hydrogical Science, vol.34, no.4, pp.425-447.

Ref.2.7.1-3
Howard Humpherys Ltd., 1986 ,"Groundwater Resources Study in the Shidiya Area", Natural Resources Authority of Jordan, pp.109-110.

Ref.2.7.2-1
Rogers,Peter, 1986, "This Water Costs Almost Nothing. That's Why We're Running Out.", Technological Rewiew, Nov.-Dec.,1986, pp.30-43.

Ref.2.7.2-2
Adnan A.Akkad, 1990 ,Conservation in the Arabian Gulf Countries", Journal AWWA, Management and Operations, May,1990, pp.40-50.

Ref.2.7.2-3
Ministry of Planning, Kingdom of Saudi Arabia, 1990, "Fifth Development Plan", pp.169-177.

Ref.2.7.3-1
World News, 1986, "Libya plans groundwater hydro plant", Water Power and Dam Construction, September,1986, p.3.

Ref.2.7.4-1
Mamdouh Shahin, 1987, "Groundwater Resources in Egypt: Potentials and Limitation, Water for the Future: Hydrology in Perspective (Proceeding of the Rome Symposium, April 1987), IAHS Publ.no.164, pp.179-192.

Ref.2.7.4-2
Peter Beaumont, Gerald H.Blake, J.Malcolm Wagstaff., 1988, "The Middle East: A Geographical Study, 2nd Edition", David Fulton Publishers, pp.81-88.

2.8 Brackish Groundwater Reverse Osmosis (RO) Desalination in Bahrain

Groundwater in the Damman aquifer in the Bahrain island has been seriously contaminated by seawater intrusion or upward leakage from the underlying saline aquifer of Umm Er Radhuma since the 1960s, owing to the intensive pumping which exceeded the safe yield. The world's largest reverse osmosis (RO) plant for the treatment of saline groundwater, which is located at Ras Abu-Jarjur, 25 km south of Manama, the capital of Bahrain, was commissioned in 1984. The plant has an installed capacity at 45,000 m^3/d (10 migd), of which source of raw water is dependent on the highly saline brackish groundwater in the "Umm Er Radhuma" formation. The RO plant was designed to meet the domestic water demand of the Manama city, capital of Bahrain, taking into account its several advantages over a seawater distillation (MSF) plant; namely i) short construction time, ii) lower energy cost, and iii) ease of operation and maintenance.(Ref.2.8-1) The use of reverse osmosis desalination for saline groundwater in the Bahrain island was commenced in 1984-1986. Its monitoring data examined here is one of the key sources of experience in the development of marginal water resources in the Middle East.

2.8.1 Background

Bahrain consists of 33 islands, islets, coral reefs, and is located in the Arabian Gulf between Saudi Arabia and Qatar between the latitudes $25^{o}45'$-$26^{o}27'$ north and longitudes $50^{o}25'$-$50^{o}54'$ east. The country has a land area of 662 km^2, of which Bahrain comprises 85 % with the capital of Manama. (Fig.2.8.1-1) The climate is arid to extremely arid. The mean monthly temperature varies from $17^{o}C$ in January to $34^{o}C$ in July and August. Owing to the surrounding Arabian sea, the humidity is generally high. Rainfall is confined to the period between November and April with an annual average of 76 mm, which occurs essentially in a form of ephemeral thunder showers. The country has no rivers, streams or lakes.

The country is occupied by Tertiary sediments which are rather gently folded on a regional scale into elongate domes or periclines of near north-south trend. Bahrain main island is dominated by one such dome, developed principally in carbonate sediments of Cretaceous - Tertiary age which dip gently outwards. The Bahrain dome is elongate (about 30km x 30km) and with slight asymmetry as seen in Fig.2.8.1-1.

The sequence is composed of three formations: "Damman", "Rus", and Umm Er

Radhuma" as seen in the schematic geological profile on Fig.2.8.1-2. The Damman formation, which consists of fossiliferous dolomitised limestone, dolomitic marl, and dolomitic limestone, has two forms known as "Alat Limestone" and " Khobar Dolomite" from the middle Eocene. The Rus formation of the lower Eocene consists of chalky dolomitic limestone, shale, gypsum and anhydrite. The Umm Er Radhuma formation of the Paleocene is composed of dolomitic limestone and calcarenite with some argillaceous and bituminous facies, which is underlain by shales, marls and argillaceous limestone of the upper Arma formation of the Cretaceous. The geological sequence and aquifer characteristics are shown in Fig.2.8.1-3.

The population and its growth rate are estimated at 427,271 capita and 4.2 % per annum in 1985, respectively (Ref.2.8.1-1).

2.8.2 Water resources

Historically Bahrain has utilized groundwater for supplies of both agriculture and municipal requirements. Natural fresh water springs used to flow freely in the northern part of Bahrain but, with increased demand, spring flow has decreased and pumped boreholes became the normal means of obtaining water. Prior 1925, water supply was dependent on free-flowing springs and some hand dug wells, of which the discharge was estimated to be $93x10^6m^3/y$ in total. With increased water demand after exploration of offshore reservoirs of crude oil and gas in 1946, spring flow decreased and pumped boreholes became the normal means of procuring water. Groundwater use in Bahrain at that time was estimated to be $153x10^6m^3/y$ in total, which included $138x10^6m^3/y$ of tubewell abstraction and $8.1x10^6m^3/y$ of land springs and $6.6x10^6m^3/y$ of marine springs (Ref.2.8.2-1). During the 1980s, most of the springs have ceased flowing, and further increase in water demand has caused deterioration in water quality including the intrusion of seawater into the aquifer system.

Faced with rising demand and contamination of the aquifers by seawater intrusion, Bahrain turned to desalination of seawater to provide for the increasing demand for M&I water supply. Based on a groundwater model study in 1983 (Ref.2.8.2-2), which included the recommendation to reduce groundwater abstraction from the Damman aquifer to the level of 90 $x10^6m^3/y$, the Ministry of Works, Power and Water instigated a crash program to increase Bahrain's desalinated water capacity from 22,680 m^3/d (5 mgd) to 204,120 m^3/d (45 mgd). Production of water for M&I water supply was estimated to be $101x10^6m^3/y$ in 1987, including $53x10^6m^3/y$ of

groundwater and $48x10^6m^3/y$ of desalinated water (Ref.2.8.2-2).

2.8.3 Hydrogeology and seawater intrusion

The principal aquifers are pervious limestone units in Paleocene to Eocene sedimentary rocks. "Damman" and "Umm Er Radhuma" are the important aquifers in Bahrain.

The Alat limestone in the upper Damman formation used to sustain small artesian flows or springs in the northern island. The Khobar dolomite in the lower Damman formation is a highly pervious unit, and was the main productive aquifer to produce fresh groundwater with a typical salinity at 2,500 mg/l of TDS. Due to over abstraction, however, piezometric levels in the Khobar aquifer declined continuously with substantial increase in water salinity (Figs.2.8.3-1,2). This aquifer has become saline in the Ali-Buri area, due to upward leakage of brackish water, and on Sitra, due to seawater intrusion (Fig.2.8.3-2). Significant upward leakage of brackish water from the underlying aquifer of Umm Er Radhuma occurs only in eastern and central Bahrain where the evaporite layers in the Rus formation have been removed by solution.

The deeper aquifer of "Umm Er Radhuma", which is composed of dolomitic limestone and calcarenite, is a salinity stratified aquifer with a thickness about 200 m in total. A further highly saline groundwater contains hydrogen sulfide and hydrocarbons from bituminous as specific contaminants.

2.8.4 Desalination

Since it has became the policy to curb abstraction of groundwater resources in the Damman aquifer and to improve the quality such as salinity of domestic water supply, further development of water resources will undoubtedly be means of desalination either by thermal process or reverse osmosis (RO) process. The choice will depend on the site specific conditions and economy or cost.

The first multi-stage flash (MSF) distillation plant was introduced in Bahrain in 1976. The installed capacity of this plant was 22,650 m^3/d (5 mgd) in total in 1981, which was 15 % of the total demand of 154,000 m^3/d (34 mgd). The present installed capacity of desalination plants in Bahrain is 205,000 m^3/d (45 mgd), including 160,000 m^3/d (35 mgd) of seawater distillation by MSF and 45,000 m^3/d (10 mgd) of desalination of brackish

groundwater by RO. A further 45,000 m^3/d (10 mgd) of seawater desalination capacity by RO is under construction. (Ref.2.8.2-1)

2.8.5 Brackish groundwater Reverse Osmosis (RO) Desalination

The reverse osmosis desalination plant at Ras Abu Jarjur, 25 km south of Manama, the capital of Bahrain, which has an installed capacity of 45,000 m^3/d (10 mgd), and the world's largest RO plant with seawater membranes in the 1980s, was commissioned in 1984 (Ref.2.8.5-1). The raw water source is a highly saline (13,000 mg/l TDS) groundwater in the 'Umm Er Radhuma (UER)' formation, containing hydrogen sulfide and hydrocarbons from oil as specific contaminants. The water quality is predicted to deteriorate with time, implying significant increases in the hydrocarbon concentration from a trace to 2 mg/l, the hydrogen sulfide concentration from about 2 mg/l initially to about 13 mg/l, and the total dissolved solids (TDS) from about 13,000 mg/l to up about 30,000 mg/l after 20 years operation . The design TDS for the plant is 19,000 mg/l and this concentration is predicted to be reached after 10 years operation. The predicted range in feed-water salinity is shown in Fig.2.8.5-1. The permeate is being produced from highly brackish well water at a conversion rate averaging 65 percent, of which the salinity is as low as averaging 210 mg/l of TDS or well below the design criterion of 500 mg/l of TDS. The plant contains five basic systems: a well water supply, a pre-treatment, RO desalination, post-treatment, and product water transfer systems, as shown in the process flow diagram in Fig.2.8.5-1.

Well Water Supply System

Raw water is pumped from fifteen boreholes which include thirteen of duty wells and two standby wells. Submersible pumps are designed to abstract an average of 3,200 m^3/h of brackish groundwater from a group of boreholes. Four anti-surge tanks at the high and low points of the wellfield are installed to protect the collection pipes from sudden pressure surges. The anti-surge tanks are pressurized with nitrogen gas to prevent oxidation of hydrogen sulfide in the well water.

Pre-treatment System

To protect the RO system, well water entering the plant is filtered and chemically treated to remove silt, oil and other hydrocarbons. The raw water passes through a series of dual media filters and carbon filters.

Sodium hexametaphosphate and sulfuric acid are then injected downstream of the carbon filters to prevent scaling of the RO system.

RO System

Before entering the heart of the RO system, the water passes through 8 micro-guard filters (10 micron) with polypropylene cartridge elements. Seven units of horizontal multistage diffuser type high pressure pumps are installed to feed water with an average pressure of 60 bar (maximum pressure 69 bar). Each pump is equipped with Pelton wheel impulse type of energy recovery turbines. The RO membrane unit comprises a total of 2,100 permeators. The permeators are hollow fiber type such as DuPont B-10.

Post-treatment

Since the well water contains a high level of hydrogen sulfide, the RO product water must pass through a series of stripping towers to remove the gas. pH-adjustment of the permeate with sulfuric acid is also needed before stripping for maximum removal of hydrogen sulfide. In-line mixers are installed in the pipeline for post treatment with chlorine, lime and carbon dioxide.

2.8.6 Development strategy for the RO desalination

As stated earlier, Bahrain officials of the Water Supply Directorate chose reverse osmosis (RO) desalination over multi-stage flash (MFS) distillation for reasons of; 1) short construction time, ii) lower energy cost, and iii) ease of operation and maintenance. The parameter that most readily demonstrates the performance of the system is the energy consumption per unit of product. Specific electric power consumption per product water is estimated to be as low as 5.3 KWh/m^3, which is the mean value during two years (1984-1986) operation (Ref.2.8.6-1).

REFERENCES (2.8)

Ref.2.8-1
Adnan A.Akkad, 1990, "Conservation in the Arabian Gulf Countries", Management and Operations, Journal AWWA, May, pp.41-50.

Ref.2.8.1-1
Peter Breaumont, Gerald H.Blake, and J.Malcolm Wafstaff, 1988, "The Middle East; A Geographical Study, 2nd Edition", David Fulton Publishers, pp.184-198.

Ref.2.8.2-1
Rasul Mussayab, 1988, "Water Resources and Development in the State of Bahrain", Middle East - Japan Conference on Development and Utilization of Water Resources, Japan Cooperation for the Middle East, Country Report.

Ref.2.8.2-2
R.P.Birch, M.Al-Arrayedh, 1985, "Bahrain's Fresh Groundwater situation and the Investigations into Using Bahrain's Brackish Water Resources as a Feedwater for the Reverse Osmosis Desalination Program", Proceedings of the Second World Congress on Desalination and Water Reuse, Bermuda, IDA, vol.55, pp.397-492.

Ref.2.8.5-1
Al-Arrayedh, B.Ericsson, and M.Ohtani,1985, "Construction and Operation of 46,000 m^3/d Reverse Osmosis Desalination Plant, Ra's Abu Jarjur, Bahrain", Proceedings of the Second World Congress on Desalination and Water Reuse, Bermuda, IDA, vol.55, pp.319-342.

Ref.2.8.6-1
M.Al-Arrayedh, B.Ericsson, M.Amin Saad, and H.Yoshioka, 1987, "Reverse Osmosis Desalination Plant, Ra's Abu Jarjur, State of Bahrain; Two years operational experience for the 46,000 m3/day RO Plant", Proceedings of the Third World Congress on Desalination and Water Reuse, Cannes, IDA, vol.65, pp.197-230.

2.9 Desalination of Seawater in the Arabian Gulf Countries

Owing to the rapid increase in demand for water in the Arabian Gulf countries, namely Saudi Arabia, Kuwait, United Arab Emirate (UAE), Qatar, Bahrain, and Oman, where conventional water resources such as fresh surface water and renewable groundwater are extremely limited, other alternatives such as waste-water reclamation and desalination have been adopted since 1960s. Countries such as Saudi Arabia, Kuwait, Qatar, and Bahrain all use nonrenewable groundwater resources in large quantity, causing depletion of these valuable resources and deterioration in the quality of water. Although conventional water resources such as renewable groundwater and surface runoff are available in countries like Oman, the United Arab Emirates and Saudi Arabia, these resources still need to be properly developed in an integrated water resources planning context.

In some of the more arid parts of the Middle East, in particular the Gulf states, where good quality water is not available or is extremely limited, desalination of seawater has been commonly used to solve the problems of water supply for municipal and industrial (M&I) uses.

Kuwait was the first state to adopt seawater desalination, linking electricity generation to desalination. The co-generation station, as it is called, re-use the low pressure steam from the generator, to provide energy for the desalination process. As a result both energy and costs are minimized. Kuwait began desalinated water production in 1957 when 3.1×10^6 m^3 per annum of water were produced. By 1987 this figure had risen to 184×10^6 m^3 per annum.

In Qatar, too, an intensive program of desalinated water production has been started, which should be supplying about 150 million cubic meter per annum of water by the year 2000. This is believed to be about three-quarters of the total water demand, with the rest being supplied from groundwater sources which are mostly brackish. About half of the country's demand will be generated in the urban/industrial centers.

Saudi Arabia entered the desalinated water field much later than Kuwait. The first plant was commissioned in 1970. It has, however, gone in for an ambitious program of desalination plant construction on both the Red Sea and Gulf coasts. So far Saline Water Conversion Corporation (SWCC) has installed 30 desalination plant projects by the end of 1980s. The total production of desalinated water is estimated to be 2.16×10^6 m^3/day (572

mgd), including a one million cubic meter per day facility at Al-Jubail which is currently the world's largest the distillation plant.

In spite of the high cost of seawater desalination, of which the unit water cost is five to ten times as high as that of conventional water resources development, a vast quantity has been produced to meet the increasing demand for domestic water in the Arabian Gulf countries. As in Kuwait, however, there is increasing government concern about the production cost of desalinated water and every effort is being made to ensure that water use is as efficient as possible.

2.9.1 Installed capacity of desalination plant

There are about 1,483 desalination units operating in the Arabian Gulf countries, which accounts for 57.9 % of the worldwide desalting plants capacity. The dominant plant type is multi-stage flash (MSF) which accounts for 86.7 % of the desalting capacity, while the reverse osmosis (RO) only accounts for 10.7 %. The installed capacity of the desalination plant in the Arabian Gulf countries such as Saudi Arabia, Kuwait, United Arab Emirates, Qatar, Bahrain, and Oman is estimated at 5.76×10^6 m^3/d in total, including 2.98×10^6 m^3/d in Saudi Arabia which is approximately half of the total desalination capacity of the Gulf countries. (Ref.2.9.1-1) The installed capacity with shares of each process are shown in Tab.2.9.1-1.

The multi-stage flash (MSF) desalting system has proved to be the most simple, reliable and commonly used seawater system in large capacities. It has reached maturity with very little improvement in sight. This maturity is expressed in reliable designs of large units up to 10 mgd, long operation experience with high on-line stream factors (up to 95%), confidence in material selection and very satisfactory water pre-treatment. However, there has been a recent trend towards the use of reverse osmosis (RO) in seawater desalination both for new plants and in connection with the present MSF plants, taking into account the possible reduction in the energy requirements and the lower operation and maintenance cost for RO system.

2.9.2 World's largest seawater desalination with high pressure pipeline system.

To meet the water demands of the increasing population and water short regions, the Saline Water Conversion Office (SWCO) under the Ministry of

Agriculture and Water of the Kingdom of Saudi Arabia has been responsible for providing fresh water by desalination of seawater since 1965. The first seawater desalination plant was commissioned in 1970. With its increasing responsibilities to provide fresh water SWCO was changed into an independent corporation (SWCC) in 1974. Then an elaborate plan was developed by the succeeding Saline Water Conversion Corporation (SWCC) to construct dual purpose plants on both east and west coasts of the Kingdom.

So far SWCC has constructed 24 plants by 1985, including 17 plants on the western coast along the Red Sea from Haql on the Gulf of Aqaba in the north to the tiny Farasan island in the south, and 7 plants on the east coast along the Arabian Gulf from Al-Khafji to Al-Khobar (Fig.2.9.2-1). These plants are producing 1.821×10^6 m^3/day (481 mgd) of fresh water and 3,631 MW of electric power. By the end of the 1980s the total production of fresh water was estimated to have increased to 2.165×10^6 m^3/day (572 mgd) of fresh water and 4,079 MW of electric power by adding 6 co-generation plants. (Ref.2.9.2-1)

In addition to desalination and power plants SWCC is providing water to inland regions by means of water pipelines. "Al-Jubail - Riyadh" water pipeline is one of the world's largest water pipeline systems with seawater desalination plants. The pipeline has a diameter of 60 inches, a length of 466 km, differential head of 690 m, and a pumping capacity of 830,000 m^3/day as shown in Fig.2.9.2-1 (Ref.2.9.2-1).

2.9.3 Cost constraints of seawater desalination

The multi-stage flash (MSF) process has served very well during the past ten years, especially in the Middle East. During this period operating experience has been developed that should result in substantial extensions to what was heretofore considered a reasonable operating life. Certainly this favorable experience will be a factor in selection of future plants.

However the lower capital and operating costs for the RO process should receive increasing attention in selection of a desalination process in coming years. There are still opportunities for further lowering of costs through improved membrane technology, notably in increasing membrane life. Another new development with good potential for reducing costs for the RO process are membranes for operating at high pressures up to 1,500 psi (105 Kg/cm^2) and 50 % conversion when operating on 45,000 mg/l of total dissolved solids (T.D.S) of seawater. Another alternative of the process will be low temperature multi-effect (ME) of horizontal tube evaporators

(HTE). If aluminum tubes and tube sheets can be shown to have a reasonable life in Middle East seawater, the capital cost can be reduced or a higher performance ratio will be achieved.

Another factor which will favor RO in coming years is that it is the most energy efficient of all of the processes. This will be of increasing importance as fuel/oil prices rise and environmental considerations increase in importance. The cost of the energy consumption is also the largest single cost item in the desalted water cost. It is significant that for either a single purpose or a dual purpose plant, RO appears to be the most cost effective. On the basis of world fuel costs in 1989 the RO process would save over 10 % as compared with the MED and 32 % as compared with MSF (Ref.2.9.3-1).

2.9.4 Hybrid RO/MSF seawater desalination to compromise quality-cost constraints

It seems that the race for the second generation of seawater desalters has been settled with reverse osmosis (RO) and low temperature multi-effect (ME) of horizontal tube evaporators (HTE) as front runners. Both system are characterized by their low requirement of energy consumptions as compared with the MSF system. As shown in Fig.2.9.4-1 which gives the worldwide market shares of various desalination processes, reverse osmosis (RO) accounted for 65 % of market share in 1987 (Ref.2.9.4-1). Beside these two options (RO and ME), there are combination possibilities of different desalting plant types. In the hybrid MSF/RO desalination-power process, a seawater reverse osmosis (RO) plant is combined with either a new or existing dual purpose MSF plant with the following advantages:

- Capital cost of the combined RO-MSF plant can be reduced.
- A common seawater intake is used.
- Product waters from the RO and MSF plants are blended to obtain suitable product water quality. Taking advantage of the fact that the MSF product (25 mg/l of TDS) typically exceeds potable water water specifications (WHO standard: 500-1,000 mg/l of TDS), the product water specification in the RO system can thereby be reduced.
- A single stage RO process can be used and the RO membrane life can be extended because of the reduced product water specification. (The life of the RO membrane can be extended from 3 to 5 years or the annual membrane replacement cost can be reduced by nearly 40 per-cent)
- Electric power production from the MSF plant can be efficiently utilized in the RO plant, thereby reducing net export power production. In addition, electric power requirement to drive the high pressure pumps of the RO system, which is a major factor energy consumption, can be reduced by 30 % by adding an energy recovery unit to the brine discharge in an RO system. (Power consumption for a single-stage seawater RO plant at 30 % of recovery/conversion is estimated to be 9.24 KWh/m^3 or 6.38 $KWh/^3$ for without or with energy recovery on brine discharge, respectively (Ref.2.9.4-2).
- By blending with RO product water , the temperature of the MSF product water is reduced. A problem common in areas in the Middle East is the high temperature of the product water. Application of RO high pressure brine when no energy recovery is used, can be used to cool the MSF product water with an eductor.

<u>Jeddah RO/MSF hybrid project</u>

The first large scale MSF/RO hybrid project, the Jeddah I Rehabilitation project in the Kingdom of Saudi Arabia, is now in operation by the Saline Water Conversion Corporation (SWCC). This 15 mgd (56,800 m^3/day) RO plant, which is the world's largest facility for seawater conversion, has demonstrated the attractiveness of the hybrid concept. In 1970, Jeddah I MSF desalination plant with an installed capacity at 5 mgd (18,925 m^3/day) was completed in Saudi Arabia. It was one of the world largest plants in the early 1970s, therefore it has a significant place in history. The installed capacity of the Jeddah desalting complex was expanded by steps to a nominal capacity of 85 mgd (329,375 m^3/day), all by MSF. In 1985, the operation and maintenance of the Jeddah I MSF plant had become increasingly costly. To correspond with the increasing water demand, 5 MGD Jeddah I MSF plant was replaced by 15 mgd RO plant (Phase I) in 1986-1989. The RO system is incorporated in a hybrid RO/MSF desalination system. The RO unit has the following design criteria (Ref.2.9.4-2):

- Feed water quality; TDS=43,300mg/l, Chloride as Cl^-=22,400mg/l, pH=8.2, Water temperature 24.5 to 32.5°C.
- Operating pressure at 60 kg/cm^2. (maximum design pressure; 70 kg/cm^2)
- A single stage design including 10 RO trains, each train includes 148 RO modules.
- Hollow fine fiber (TOYOBO Hollosep made of cellulose triacetate) RO module with 10 inch diameter.
- Recovery ratio of 35 % of product water.
- Product water salinity as specified at 625 mg/l of chloride (= 1,250 mg/l of TDS).

Since MSF product water has a salinity as low as 25-50 mg/l of TDS, salinity of the permeate from Jeddah I RO plant (Phase I) was specified as 625 mg/l of chloride (1,250 mg/l of TDS), which is a major factor to minimize the cost for RO. In a cost analysis done by Bechtel (Ref.2.9.4-3), it was shown that the product water cost from the RO system in a hybrid MSF/RO plant can be reduced by 15 % compared with a stand-alone RO plant.

REFERENCES (2.9)

Ref.2.9.1-1
I.S.Al-Mutaz, M.A.Soliman and A.M.Daghthem, 1989, "Optimum Design for a Hybrid Desalting Plant", International Desalination Association (IDA), 4th World congress on Desalination and Water Reuse, Kuwait, Volume-IV/Desalination-76, pp.177-188.

Ref.2.9.2-1
SWCC, 1988, "Kingdom of Saudi Arabia, Saline Water Conversion Corporation Advatisement Feature", Developing World Water, Grosvenor Press International, pp.144-145.

Ref.2.9.3-1
Gordon F.Leitner, 1989, "Cost of Seawater Desalination in Real Terms, 1979 Through 1989, and Projections for 1999", International Desalination Association (IDA), 4th World congress on Desalination and Water Reuse, Kuwait, Volume-IV/Desalination-76, pp.201-213.

Ref.2.9.4-1
International Desalination Association (IDA), 1988, "1988 IDA Worldwide Desalting Plants Inventory; Worldwide inventory of land-based desalting plants, capable of producing $100m^3$/unit or more fresh water daily, delivered or under construction as of December 31,1987", Wangnick Consulting and IDA.

Ref.2.9.4-2
Leon Awerbuch, Sherman May, Landall Soo-hoo and Victor Van Der Mast, 1989, "Hybrid Desalting Systems", International Desalination Association (IDA), 4th World congress on Desalination and Water Reuse, Kuwait, Volume-IV/Desalination-76, pp.189-197.

Ref.2.9.4-3
Mohammed Muhurji, Victor Van Der Mast, Hisao Imai, 1989, "Jeddah I Ro Plant - Phase I, 15 MGD Reverse Osmosis Plant", International Desalination Association (IDA), 4th World congress on Desalination and Water Reuse, Kuwait, Volume-IV/Desalination-76, pp.75-88.

Ref.2.9.4-4
Michel Meybeck, et.al,1989,"Global Freshwater Quality, AFirst Assessment", WHO/UNEP, pp17-21

Ref.2.9.4-5
M.A.Darwish and Abdel-Jawad, 1989, "Technical and Economic Comparison Between Large Capacity MSF and RO Desalting Plants", International Desalination Association (IDA), Proceedings of the 4th congress in Kuwait, vol.4, pp.281-304.

Tab.2.9.1-1 Installed Capacity of Desalting Plant and Share of Process of the Gulf Country

(Unit: $10^6 m^3$/day)

Plant Type	Saudi Arabia	Kuwait	U.A.E.	Qatar	Bahrain	Oman	Total
No. of units	874	279	99	47	143	41	1,483
Capacity	2.98	1.09	1.02	0.31	0.26	0.10	5.76
MSF share (%)	80.7	95.5	98.3	97.9	56.7	91.1	86.7
RO share (%)	16.2	1.8	0.9	-	37.2	1.9	10.7
ED share (%)	2.6	0.55	0.5	-	4.9	0.9	1.8
VC share (%)	0.5	1.6	-	0.7	0.8	1.7	0.65
MED share (%)	-	0.25	-	0.9	0.4	-	0.15

Remarks: MSF; Multi-stage Flash
RO ; Reverse Osmosis
ED ; Electrodialisis
VC ; Vapour Compression
MED; Multi-effect Distillation

2.10 Groundwater-Hydro Development in Chile and Libya

Groundwater-hydro has been studied in two development projects in the arid regions of northwest Chile and Sahara desert in Libya. The Chilean plan involves constructing a high-pressure pipeline to exploit the height difference between the wellfield in the Andes (3,750m) and the coastal terrain (1,700m). The Libyan plan involves installing a mini-hydro station at the end of the Great Man-made River pipeline which will carry $2x10^6 m^3$ of groundwater a day, to exploit the height difference of 200 m.

2.10.1 Groundwater-hydro in multi-purpose Salar del Huasco scheme in Chile

The coastal plains in the northern part of Chile may be classified as arid to extremely arid (Fig.2.10.1-1). The extremely arid Iquique region is located in the northern corner of Chile where rainfall is very scarcely, such as 0 to 10 mm or less per annum. No water resources are available in these arid coastal regions except for a very limited amount of groundwater of which the quality is likely to be saline or brackish. By contrast huge renewable groundwater resources with excellent quality can be tapped in the Andes mountain ranges. The hydro-potential of the Andes mountain ranges in the South America is one of the world's biggest, and includes both surface water and groundwater.

The Salar del Huasco project is being planned to develop the groundwater resources of the Andes, including water supply, irrigation, and hydroelectric power. The groundwater-hydro scheme to be incorporated will use the substantial difference head of water between the wellfield on the mountain range (3,750 m) and the irrigation lands on the coastal terrain (1,400 m). Iquique's drinking water will be supplied from a wellfield 76 km away, by a pipeline which will cross the mountains using pumping stations. The Salar del Huasco project will assure adequate drinking water supplies to Iquique until the middle of the next century and will increase by 50 per cent the local availability of irrigation water. This will provide for the cultivation of 4,800 ha of land on extremely arid terrain. The hydro units will have a combined capacity of 50 MW (Ref.2.10.1-1).

The scheme will comprise the extraction of 2.4 m^3/s of groundwater from 54 wells in the area of Lake Huasco, which is at an elevation 3,785 m. The water will be piped through a central collector to Iquique and Pica, and

the available head will be used to generate electricity. The first or upper station will be built between wellfield and Pica, at an elevation 3,000 m, and the second or the lower station will be built in Pica, at an elevation 1,400 m (Fig.2.10.1-2). The theoretical hydro-power is estimated to be 50 MW in total, 16 MW at the first power station and a 34 MW at the second. The installed capacities of the power stations are preliminarily estimated to be 42 MW in total, consisting of 13 MW at the first station and 29 MW at the second.

2.10.2 Groundwater-Hydro in Great Man-Made River project, Libya

A hydroelectric power station will be installed in a part of the massive pipeline system which will carry an eventual $6x10^6$ m^3/d of water from beneath the southern Sahara desert for agricultural, industrial and domestic use in the heavily populated coastal regions in Libya (Refer to clause 2.7.3). This groundwater-hydro plant will be the first major instance.

A vast aquifer estimated to hold an amount of fresh water equivalent to the total flow of the Nile River over a 200-years period was accidentally discovered by American geologist during crude oil exploration in the Sahara desert in the 1960'. The Libyan government saw the opportunity to pump the water, at a rate of $5.7x10^6$ m^3/d (66 m^3/s), then convey it over 600 km north to farms on the Libyan coast. The total length of the water pipeline will be about 4,000 km which will be the worlds largest water pipeline system.

Some agricultural development has already begun around the desert oasis of Kufra using the self-flowing artesian wells in the depression. Acres of wheat, barley and alfalfa grow where there were only desert and gravel plains before. According to the article in the British journal "New Scientist", the amount of sustained yield of groundwater resources is in some doubt. Professor Ahamad, a hydrogeologist at the University of Ohio says that the water is moving into the two aquifers which are to be tapped at 80 m^3/s, whereas Dr.E.Wright from the British Geological Survey says that the figure is close to 5 m^3/s. The life of Nubian sandstone aquifer is estimated to be 20 to 200 years, owing to the lack of data of estimating groundwater recharge through the wadi beds and/or the depressions during occasional and temporal flash floods. The pipeline system has therefore been designed on the assumption of an aquifer life of 50 years.

In 1984 the Libya government commenced 1st phase construction for the "Great Man-Made River (GMR) project. This comprises a $2x10^6$ m^3/d twin pipeline in eastern Libya's leading wellfields in the Tazerbo and Sarir regions, deep in the desert, to the small coastal town of Agedabia. A single line will then lead along the coast east to Benghazi and another west to Sirte. No idea of groundwater-hydro, however, was incorporated in the 1st phase scheme.

The 2nd phase commenced in 1986 consists of a 600 km long pre-stressed concrete pipeline to convey $2x10^6$ m^3/d from beneath the western deserts to the Tripoli area on the coast. This includes an option for an 18 MW hydroelectric stations to be built adjacent to a terminal reservoir with planned capacity of $28x10^6m^3$ (Ref.2.10.2-1). The station would use a difference head of water of some 200 m, and power output would compensate for the energy used to pump the water to the coast.

REFERENCES (2.10)

Ref.2.10.1-1
WPDC, International News, 1988, 'Tenders; Chile Groundwater-Hydro', Water Power and Dam Construction, May 1988, p.8.

Ref.2.10.2-1
WPDC, WorldNews, 1986, 'Libya plans groundwater hydro plant', Water Power and Dam Construction, Sept.1986, p.3.

2.11 Mediterranean-Qattara Solar-Hydro and Pumped-Storage Development

Two projects of this type are being considered in Israel and Egypt. The Israeli plan involves constructing the a long pipeline/tunnel between the Mediterranean and Dead Sea (the lowest point on the earth, 400 m below sea level) to exploit the hight differences between these two bodies of water. The Egyptian plan involves transfer of water from the Mediterranean Sea to the Qattara Depression (a basin in the western desert of about 26,000 km^2, the floor of which is 120 m below sea level). Both plans involve an initial development stage at which the basins are filled with water from the Mediterranean Sea up to a certain design level that will be maintained later by transfer of water to replace the amount evaporated. Very similar type of the solar-hydro scheme is also studied on the Assal lake in Djibouti, which has the shortest conduit with a length of about 15 km from the Red Sea to the Assal depression. World five deepest depressions are shown as below:

Name of Lake/Sea	Lowest Elevation (m)	Area Below Sea Level (km^2)	Distance from Ocean or Sea (km)	Name of State
Dead Sea	-401	3,800	72	Israel, Jordan
Tiberias (Galilee)	-212		(72)	Israel, Syria
Assal	-174	80	15	Djibouti
Turfan	-154	5,000	1,500	China
Qattara	-133	44,000	56	Egypt

This particular type of hydro-electrical station, also known as a hydro-solar power station, would be made possible by the combination of such factors as the existence of a vast depression at a distance not too far from the sea, and the region's characteristically scare rainfall with resulting high degree of evaporation.

This clause 2.11 describes the Mediterranean-Qattara solar-hydro scheme in Egypt which was the world first idea of developing solar-hydro energy in the large desert depression under the hot-arid climate. The hydro-solar scheme incorporated the pumped-storage to cover the peak power demand, of which the function is becoming increasingly important owing to the forced reduction of the Nile hydro-electric power generation in the 1980s. An example of Galala-Red Sea seawater pumped-storage scheme is examined in this Section to evaluate the development alternatives for pumped-storage scheme in Egypt.

2.11.1 Scheme

The scheme involves flooding a natural depression in the Western desert (the Qattara) through a canal or tunnel from the Mediterranean Sea, 56 km away (Fig.2.11.1-1). At its lowest point, the depression is 134 m below sea level. The plan envisages generating power utilizing the fall in water to the lake which will eventually be formed, and of which surface will be 60 m below sea level, with an area of 19,500 km^2. It could supply 670 MW of basic load during the first phase of operation (Ref.2.11.1-1).

2.11.2 Topography of Qattara depression

Qattara is located in the northwestern part of Egypt, which comprises the world's 5th deepest natural depression. The depression is limited to the north and west by deep escarpment, and becoming comparatively flat towards the south and the east (Fig.2.11.2-1). The lowest point is found at a level of 133 m below sea level. The depression has a length of about 300 km at sea level, a maximum width of 145 km and an area of 19,500 km^2. The northern edge of the escarpment is bounded by the hilly ridge with an elevation about 200 m above sea level, in which the shortest distance from the Mediterranean Sea is 56 km.

2.11.3 Previous studies

The utilization of the Qattara depression to develop the hydro-electric power, was suggested for the first time by the Berlin geographer, Professor Penk in 1912, and later by Dr.Ball in 1927. Dr.Ball studied in particular the possibility of utilizing it for hydroelectric purposes by the formation of lakes at final levels of -50m, -60m, and -70m below sea level, to which the corresponding surface areas were 13,500, 12,100, and 8,600 km^2, respectively. Moreover, he indicated the most convenient water inflow routes (lines E,E,F in Fig.2.11.2-1) with reference to the formation of the lakes. After examining the effect by the climatic changes, evaporation, seepage, minor transmission losses, and the lowest cost per KW installed, he showed that the most convenient solutions were those relating to lakes at -50 and -60m below sea level. From the geological and topographical conditions, he left the final selection at -50m below sea level with the supply system along route-D in Fig.2.11.2-1. Dr.Ball, moreover, anticipated the possibility of using a power surplus during period of off-peak demand to pump some part of the inflowing water into a high-level reservoir on top of the escarpment around the

depression, and using the 200m head to generate power to meet peak-load requirements. (Ref.2.11.1-2)

2.11.4 Pumped-storage application

Egypt's power supply has been dependent on the Nile river, including 9,801 GWh from Aswan High Dam Power Station, which is 53.2 % of the total power production of 18,430 GWh in 1980. After the Nile hydroelectric development, a series of steam power stations have been constructed in the northern part of Egypt such as Ismailia, Abu Qir, Kafr El Dawar, El Suezu, Shoubra El Kheima, Damanhour, and Al Kuraimat in the 1980s (Fig.2.11.1-1). A number of gas-turbine power stations has been installed in El Suif, El Mahmodia, Damanhour to cover the deficit in peak-load requirement. Egypt's power development will be based on the nuclear power generation, of which the installed capacity is scheduled to be extended upto 8,400 MW by the year 2000.

Water levels in the Nile have been falling for nine years, which gave a strong restriction for generating the power at Aswan. The power house at Aswan accounts for 40 % or less of national power supplies in the end of 1980s. The production of energy from the waters of the Nile river is, in fact, subordinated to the demand for water to be used for agriculture purposes, and this does not correspond generally to the demand for electric energy. Moreover, the firm electric power that these waters can produce is used mainly in the production zones in the Nile Valley (Fig.2.11.1-1), and there is a only fluctuating energy supply available for the northern industries.

2.11.5 Conjunctive operation of solar-hydro and pumped-storage

A project in the region of Qattara is even more significant for pumped-storage (Fig.2.11.5-1) to satisfy the peak-load requirements of an electricity supply system that would be aimed mostly at the northern region of Egypt (Ref.2.11.1-1). Two development alternatives either by tunnel or by canal have been examined in 1975, which assume the combined hydro-solar and/plus pumped-storage with a total installed capacity of 2,400 MW (Ref.2.11.5-1).

In the tunnel plan, the hydro-solar plant is based on the amount of evaporation from the lake surface when it rise up to a design level such as 60 m below sea level. The theoretical hydro-potential at a equibrium point of 60 m below sea level is estimated to be 315 MW, by assuming the

water surface area of 12,100 km^2, evaporation of 1.41 m per annum, specific weight of the sea water of 1.0278%, and effective difference head of water at 57 m.

It was estimated to have an installed capacity of 315 MW, assuming the twin tunnels with a maximum flow discharge of 656 m^3/sec (328x2=656) in total, which will require approximately 35 years to fill up the level of 62.5 m below sea level.

The pumped-storage portion is estimated to be 2,085 MW (2,400-315=2,085 MW). For this an additional discharge of 936 m^3/sec is required from the upper reservoir, by assuming the specific weight of Mediterranean Sea water of 1.0278%, pumping efficiency of 84.3%, and differential head of water at 262 m.

The upper basin is situated in the natural depression at elevation of 188.0 m above sea level with a maximum capacity of about $45x10^6 m^3$. The design volume of the upper reservoir is estimated to be $15.16x10^6$ m^3 per day, by assuming 4.5 hours per day of peak operation.

In the canal plan, a nuclear blasting was a given condition for excavating the open canal with a total length of 60 km. Following construction program for the nuclear-blasted canal is given (Ref.2.11.5-1);

Stage	Type of Power Plant	Capacity (MW)	Construction Time (years)	Period of Operation (years)
1	Hydro-solar	670	7	1st-10th
2	Hydro-solar	1200	3	11th-15th
3	Hydro-solar +pumped storage	2400	4	16th-

Compared with the hydro-solar plan, the nuclear blasting canal plan could have double capacity of hydro-solar for 15 years after the commencement of taking water from the Mediterranean Sea. The nuclear method for open blasting, which was proposed in the 1970s including a serious environmental and socio-psychological problems, was put aside. The tunnel boring machine (TBM) method could solve the cost problems of the civil works in the sedimentary rocks of the Neogen Tertiary.

2.11.6 Galala-Red Sea seawater pumped-storage scheme

Construction of new thermal or nuclear power stations in Egypt has

encouraged the Electric Authority to build a pumped-storage plant. In 1989, feasibility study on the 600 MW of seawater pumped-storage scheme was carried out in the North Galala plateau, 55 km south of Suez (Fig.2.11.6-1). The scheme will utilize seawater which would be pumped directly to a natural basin located 587 m above sea level with a storage capacity of $8.2 \times 10^6 m^3$ (Ref.2.11.6-1). To compare with the Qattara solar-hydro scheme, Galala-Read Sea seawater pumped-storage scheme has two advantages as shown below;

- Delete a substantial capital cost of intake tunnel or canal with a length 60 to 80 km.
- Minimize the environmental problems of the artificial lake.

The world first seawater pumped-storage scheme, which has been conceived in the early 1980s in Egypt, includes some technical problems such as corrosion of pipe and tirbine system. This unique application of non-conventional hydro-power, however, would be marginally feasible in the arid region where deficit of the peak power demand is substantial. The same type of the seawater pumped-storage scheme have just been examined in the inland sea of Israel, including two development alternatives at Galilee Sea and Dead Sea (Ref.2.11.6-2).

REFERENCES (2.11)

Ref.2.11.1-1
International News, 1978, "Qattara Project Imperative", Water Power and Dam construction, October,1978, p.3

Ref.2.11.3-1
Giuseppe De Martino, 1973, "The Qattara Depression", Water Power and Dam Construction, January,1973, pp.27-31.

Ref.2.11.5-1
F.Bassler, 1975, "New Proposals to Develop the Qattara Depression", Water Power and Dam Construction, August 1975, pp.291-297.

Ref.2.11.6-1
WPDC - World News, 1989, "Egypt Plans Seawater Pumped-Storage Plant", Water Power & Dam Construction, January-1989, p.4

Ref.2.11-6-2
WPDC, WorldNews, 1989, "Dead SEa P-S Scheme Revived", Water Power and Dam Construction, May 1988, p.3.

2.12 Concluding Remarks on the Review Study and Marginal Waters as Non-Conventional Water Resources in the Arid Zone

2.12.1 Concluding remarks on the review study in Chapter II

The study has been initiated to review problems and constraints of the water resources development and management in the arid zone including non-conventional water resources development alternatives as summarized below;

- Many states in the Middle East have experienced serious water supply problems since the 1950s, corresponding with the rapid increase in water demand. The potential for renewable water resources development is limited, owing to the scarce rainfall with very high potential evaporation.

- Multi-National River Development: There are two major water resources issues in the world's large river developments in the arid region: the quantity issue in inter-state water allocation and the quality issue of salinity problems. Various and serious salinity problems have been major issues in the basin management of large rivers since the mid twenty-century, including Indus river in Southwest Asia, the Tigris-Euphrates and Jordan rivers in the Middle East, the Nile river in the North Africa, and the Colorado river in the southwestern Arizona of the United States of America.

- Riparian Issues: River waters in the Middle East are a conflict-laden determinant of both the domestic and external policies of the region's principal actors. All the countries of the Middle East, except for those in the Arabian peninsula and Libya, depend on three major river basins; the Tigris-Euphrates, the Nile and the Jordan. Given that these rivers do not respect national boundaries and that those states located upstream have obvious advantages both political and economic over those downstream, the potential for conflict over water is great.

- Most of the flows in the major rivers in the Middle East have fully been developed in the 1960s-1980s with increasingly salinity problems and riparian issues such as inter-state water allocation problems. Salinity control of the rivers is needed not only to protect the quality environment of river system but also to manage the desirable quantity of water to be re-used for the downstream irrigation or other water supply. Reverse osmosis (RO) application for the brackish water desalination in

line with sustainable basin management will be a key application of controlling the salinity problems of the twenty-first century.

- Renewable groundwater resources conservation: Owing to increasing demand and limited recharge potential on the conventional fresh groundwater resources, many states in the Middle Eat have already over-exploited the sustainable yield. Careful groundwater management is required to sustain the development of the nation's valuable water resources.

- Non-Renewable Groundwater Resources Development: A vast amount of the non-renewable or fossil groundwater is tapped in the Paleozoic to Mesozoic-Neogen (Nubian) sandstones which underlie wide areas of the Arabian peninsula and the eastern Sahara desert including Saudi Arabia, Jordan, Egypt and Libya. The dominance and importance of the non-renewable groundwater reserves in national water resources planning became clear in the 1980s, such as with the "Man-Made River" project in Libya and "New Valley" project in Egypt. In Saudi Arabia, a total increase of 89 % was made in the national water supply during the Fourth Plan period (1985-1990). Many of the traditional and conventional uses of non-renewable or fossil water developments which have been practiced in the arid countries including Egypt, Libya, Saudi Arabia, Kuwait, Qatar, and Bahrain, have been suffered from the depletion of these valuable resources or deterioration in quality of their water. Taking into account the nation's needs for the water conservation and the dominant use of fossil groundwater in the agriculture sector of about 90 % of the Kingdom's water supply, the government of Saudi Arabia suggested the first reduction program including 8 % cut of total water supply, from $16.2 \times 10^9 m^3$ per annum in 1990 to $14.9 \times 10^9 m^3$ per annum in 1995 in the Fifth Plan period (1990-1995).

- Non-renewable or fossil groundwater resources should be regarded as a strategic reserves except for a emergency or short-term use.

- Desalination of Seawater: The oceans hold $1.338 \times 10^6 km^3$ of seawater, which accounts 96.5 % of the total water reserves of the earth of $1.386 \times 10^6 km^3$. In some of the more dry parts of the Middle East, in particular the Arabian Gulf states, where conventional good quality waters are not available and/or extremely limited, desalination of seawater has been commonly used to solve the water supply problems for the increasing demand in the municipal and industry (M&I) uses. The cost of the seawater desalination is invariably high, however, and is

influenced by petroleum prices, that have enabled the oil-rich states of the Middle East to finance the buying of massive quantities of desalting equipment. Two-thirds of the world installations of the desalination plant are located in the oil-rich states in the Middle East, especially in the Arabian Gulf states.

- The prevailing multi-stage flash (MSF) desalination is going to be replaced by steps to develop more low capital and operating cost process such as low pressure type of the reverse osmosis (RO) membrane. The role of the ocean, which is the largest water reserves on the earth, will be important to sustain water resources development in the twenty-first century.

- Solar-Hydro Development: The solar-hydro scheme of the Mediterranean-Dead Sea (MDS) Canal was proposed by Israel in 1980. The scheme which has multiple socio-economic and political ramifications was intended to convey water from the Mediterranean Sea to the Dead Sea via canals and tunnels utilizing the height difference of close to 400 m to generate electricity of totaling 600 MW. However, there has been no presentation of the concept of sharing resources and no effort at joint development. The MDS project was put aside, owing to the strong opposition of the Arab states and others and with the confusions and in the world oil market price in 1984. In recent days, however, talk of the much-discussed Mediterranean-Dead Sea (MDS) Canal has again been revived with worldwide attentions of using clean energy for sustaining global environment.

- Applications of the groundwater-hydro and the solar-hydro in non-conventional water resources development in the arid regions, which are typical clean energy developments in the non-conventional water resources development context, are likely to be a strategic priority to save the fossil energy and the global environment with economic feasibility.

- The strategic priority is to be given to the reverse osmosis (RO) desalination, including researches on the hydro-powered co-generating applications, which will result in developing more low energy dependent membranes with significant cost reduction.

- The water conservation and sustainable water resources management are the key measures to sustain the economic development of the arid states, which may even includes the cutting of a part of national

water supply from non-renewable sources. The conservation approach has to be performed in line with developing non-conventional water resources, by taking into account the new developments in the technology of desalination, waste water treatment and water saving techniques.

- Water resources planning study in the arid regions, especially developing countries in the Middle East, must be based on water conservation including the following strategic development alternatives:

  a) Water conservation including the diversion of existing water system from one use to another.
  b) Strategic reserves of the fossil or non-renewable groundwater resources, with the exception of emergency or short-time use for specified purposes.
  c) Non-conventional water resources development including desalination and re-use of treated sewage.
  d) Inter-state water transfer or importation.

- The priority will, however, have to be given to domestic water resources development and management and conservation including non-conventional measures rather than that of introducing water importation from outside countries. Inter-state riparian issues of water allocation have to be resolved in a context of basin master plan.

- The water resources planning study, especially master planning for inter-state basin development of the arid zone should incorporate not only technical, engineering, economical, social and environment issues but also political issues in a context of engineering-political science. It is suggested that the engineering-political feasibility is to be evaluated in a context of a master plan.

2.12.2 Potential marginal waters as non-conventional water resources

After reviewing problems and constraints of the water resources development and management, the study is focused on marginal waters as non-conventional water resources in the arid to semi-arid regions. Almost all the fresh and renewable natural water resources in the rivers, lakes, and aquifers in the arid zone, which are referred to as "conventional" water or "traditional" water, have already been exploited or are going to be fully developed by the end of the twentieth-century. Besides the major rivers in the arid zone have already been seriously contaminated by the accumulated salt in the return flow from irrigated land. By the early decades of the twenty-first century almost all the countries in the Middle East will have been forced to solve severe water shortages in urban centers as populations continue to grow. After completing the exploitation of renewable water resources, we may have only limited options to sustain water development including:

- Making more efficient use of available water supplies,
- Diverting water from one use to another,
- Developing marginal waters as non-conventional water resources, and
- Importing fresh water from neighboring countries

The marginal waters may occur in any category of hydrologic system: atmospheric, surface water, groundwater and ocean systems as shown below:

Hydrologic System	Conventional Water Resources	Non-conventional (Marginal) Water Resources
Atmosphere	Rainfall	-Cloud seeding or artificial rain
Surface water	River, Stream flow, Lake	-Treated sewage effluents -Return flow with accumulated salts from irrigation drainage -Urban storm drainage water -Wadi runoff -Playa lake water
Groundwater	Renewable groundwater	-Non-renewable groundwater (fresh) -Non-renewable groundwater (saline) -Brackish groundwater desalination -Artificial recharge
Oceanic		-Seawater desalination

Potential applications in the atmospheric system include cloud seeding or artificial rain. It may sound little in the Middle East, however, except in some very limited areas in high mountain ranges such as the Anti-Lebanon where winter precipitation exceeds 1,000 mm or more. The probability that the results are positive may dependent only on chance (Ref.2.12.2-1).

The marginal waters in the surface water system such as treated sewage effluents and irrigation return flow are the major source of the water reclamation. The probability that the results satisfy economic feasibility is high but these will be dependent on advanced wastewater treatment technologies to be applied in the twenty-first century. The increasing demand for water supply, especially in urban centers, may create an increasing potential for reclaimed waters. These treated waters will be used mainly for the secondary purposes such as garden/landscape irrigation and irrigation of specific crops.

The marginal waters in the groundwater system include non-renewable or fossil groundwater, brackish groundwater, and artificial recharge from surface waters and treated sewage effluents (Ref.2.12-2-2). Artificial recharge of groundwater is a marginal water in the arid zone, and includes application of the conjunctive surface-groundwater uses.

The brackish groundwaters, which have higher salinities such as 2,000-10,000 mg/l of TDS, have not been been developed except for use in blending with fresh surface water or distilled water from desalination plants. In the arid zone, however, the reserve potential of brackish groundwaters in deep aquifers is great as compared with fresh groundwaters in shallow aquifer systems near the recharging area. The brackish water reverse osmosis (RO) desalination have been only marginally feasible in the 1980s, but it is becoming more cost-effective, and is regarded as an energy conserving measure to develop water resources in the arid region. The development of brackish groundwater resources in line with the reverse osmosis (RO) desalination will be a key application for non-conventional water resources development in the arid countries.

An extremely minor amount of the seawater is being used for the water supply through the desalination plants. Seawater desalination has been practiced mainly in the oil-rich desert countries of Arabian Gulf where conventional water resources were scare. In the 1970s, large-scale seawater desalination projects were considered that would be both technically and economically feasible as water supply alternatives in the

early 1990s (Ref.2.12.2-3). Cost constraints remain, but there is no doubt that seawater will be the ultimate water resource in the arid zone. Current innovative researches in desalination technology and specially on the reverse osmosis membranes are changing the cost environment by reducing both capital costs and operation and maintenance costs over the conventional MSF desalination process which has been used almost exclusively in the Middle East states (see ANNEX-I).

The potential marginal waters as non-conventional water resources are composed primarily of brackish waters, seawater, and reclamation of urban waste waters. These are the keys to develop water resources in the 21st century, taking into account that almost all the arid states in the Middle East are completing or depleting the development of the conventional water resources.

Cost and viability of technology are the key factors in non-conventional water resources development. Brackish water desalination can provide a relatively liable source of water for costs ranging from US$0.25/$m^3$ to US$1.0/$m^3$ in the mid-1980s, and is becoming even more cost effective by development of low-pressure (energy) types of reverse osmosis (RO) process. The seawater desalination and water transport by tanker may provide water for costs of US$1.25/$m^3$ to US$8.0/$m^3$ (Ref.2.12.2-1). The re-use of waste water gives a lower quality water at a cheapest price, while the weather modification has a potential to provide a low-cost but relatively unreliable source of water and technology for it.

2.12.3 Applications in hydro-power and co-generation developments

Use of marginal waters is not be limited to exploit water for M&I water supply and irrigation. After the Iraqi invasion in Kuwait in August 1990, worldwide attention was focused on the energy crisis and the needs of minimizing or reducing world energy consumption to sustain both human life and global environment. Application of non-conventional water resources development with co-generation of thermal and hydro-power energy conversion may be used to 1) reduce the capital investments, 2) cut power supply costs and 3) contribute to saving precious energy. The following is a list of possible measures to develop hydro-potential and thermal energy in a water resources system;

Water system	Potential energy use	Thermal energy use
Surface water	Hydro-power	
	Pumped-storage	
		Stream heat pump
	Reclaimed wastewater	
Groundwater	**Groundwater-hydro**	
		Aquifer heat exchange
Seawater	**Solar-hydro**	**Solar pond**
	Pumped-storage	
	Tidal-power	Ocean thermal energy conversion

2.12.4 Integration of marginal waters in national water master plans

This study aims to identify development alternatives for marginal waters as the non-conventional water resources. These development alternatives are likely to be integrated in nation-wide and/or multi-national level water master plans. This study focused on the development and management of saline water resources including desalination co-generation alternatives. The study suggest that marginal waters produced by reverse osmosis (RO) desalination will play an increasingly important role in twenty-first century's water resources planning in the arid countries in the Middle East. Kuwait, Jordan, Palestine and Israel are selected for case studies the following chapters III, IV,and V.

REFERENCES (2.12)

Ref.2.12.1-1
Elisha Kally, 1974, Extension of Israel's National Water System as a Function of Artificial Rainfall Prospects", Water Resources Research, Vol.10, No.5, pp.917-920.

Ref.2.12.1-2
George M.Wesner and Roy L.Herndon, 1990, "Water Reclamation and Seawater Intrusion Barrier Project", Engineering Report, Orange County Water District, State of California, U.S.A., pp.4-6.

Ref.2.12-1-3
N.Buras and P.Darr, 1979, "An Evaluation of Marginal Waters As a Natural Resource in Israel", Water Resources Research, vol.15, no.6, pp.1349-1353.

Ref.2.12.2-1
Department of Technical cooperation for Development, United Nations, 1987, "Non-conventional Water Resources Use in Developing Countries", Proceedings of the International Seminar Willemstad, Curacao, Netherlands Amtilles, 22-28 April 1985, Natural Resources/Water Series, No.22, pp.31-36.

III. APPLICATION OF HYDRO-POWERED REVERSE OSMOSIS (RO) DESALINATION IN THE NON-CONVENTIONAL WATER RESOURCES DEVELOPMENT IN KUWAIT

3.1 Background and Objectives

3.1.1 Background

Kuwait is located in the northwestern corner of the Arabian Gulf between latitudes $28^{o}30'$-$30^{o}05'$ north and longitudes $46^{o}30'$-$48^{o}30'$ east. The country is bounded to the north and northwest by Iraq and to the southwest and south by Saudi Arabia, with a land area of 17,818 km^2 and a coastline of 195 km. (Fig.3.1.1-1)

The population was estimated at 1.79 million in 1987. Crude oil production and petroleum related investments provide the main governmental revenue. The gross national product per capita (GNP) was estimated to be U.S.$19,610 in 1987. The occupation of Kuwait by Iraq in August 1990 and its recent liberation in March 1991 are too recent for further comment except that water development will the key to future habitability of Kuwait as it was before.

During the period 1925 to 1950, Kuwait imported fresh water by tankers from Shatt-Al-Arab in Iraq some 100 km north-west from Kuwait city. The exploitation of water resources was initiated by the rapid development of oil industry and commerce in the 1950s which required large quantity of fresh water to be safely supplied. The constraints of economic development of Kuwait in the 1950s was the water shortage problems to meet a growing demand.

Limitations of water, are likely to impact increasingly on the economic development of states in the Middle East and North Africa. The Center for Strategic and International Studies, Washington D.C. has stated that "By the year 2000, water -not oil- will be the dominant resources issue of the Middle East. (Ref.3.1.1-1) The situation is particularly acute in the Arabian Gulf states such as Kuwait, Bahrain, Qatar and Saudi Arabia. Of them, Kuwait is a pioneer state of developing desalination to supply fresh water for domestic use since 1950s, owing to its hyper-arid climate without conventional water resources such as renewable fresh river water and groundwater.

Kuwait had no alternatives to develop water resources except for the non-conventional options such as (i) importing water from Iraq or Turkey by through Euphrates river, (ii) exploiting brackish groundwater, (iii) desalting seawater. The first option of importing water from Iraq or Turkey may not a realistic option which needs to solve the inter-state security problems as questioned by the Gulf War in 1991. Therefore, Kuwait had only two options to develop either brackish groundwater or desalting seawater. The desalination was the key issue of non-conventional water resources development in Kuwait, in which the cost problems have long been a major constraints.

Two experimental desalination practices have been carried out in the 1980s, including seawater reverse osmosis (RO) desalination at Doha co-generation station and brackish groundwater reverse osmosis (RO) desalination with skid mounted operating system, which give an opportunity to compare the unit cost of water over the different methods of desalination. These RO systems are characterized by their low energy requirement, in which the cost of the energy consumption is the largest single cost element in the desalination engineering.

3.1.2 Objectives

The major purpose of studying the new method of hydro-powered reverse osmosis (RO) desalination is to examine the technical feasibility and the cost effectiveness of the proposed system, which aims not only to minimize the desalting cost but also to demonstrate the strategic priority of saving fossil energy and global environment.

REFERENCES (3.1)

Ref.3.1.1-1
Starr, Joyce R. and Stoll, Daniel C., 1987, "Foreign Policy on Water Resources in the Middle East", The Center for Strategic and International Studies, Washington,D.C.,Panel Report.

3.2 Potential of Water Resources

The climate is characterized by an extremely hot summer with occasional periods of extreme humidity, which last from June to September with an average maximum daily temperature of 45°C. The winter season is mild to cool with a minimum temperature of -1°C.

Rainfall is concentrated in the four months from November to February. The average annual rainfall is about 115 mm, with a minimum of 30 mm in 1960 and a maximum of 360 mm in 1954. The rainfall records at four gauging stations, the International Airport, Ahmadi, Umm Al-Aish, and Shuwaikh since 1952 are shown in Fig.3.2-1. Histogram of the monthly rainfall at the International Airport and Shuwaikh are also shown in Fig.3.2-1, which indicate that the 75 % of the rainfall occurs in the four months from November to February. There is a spatial variation of rainfall, including a typical example of rainfall of 136.2 mm at Ahmadi station in 1972 while it was only 18.1 mm at Alomaria.

The mean annual potential evaporation as measured by Class A-pan and Piche evaporimeter are 3,460 mm (1962-1977) and 5,460 mm (1957-1977), respectively. Theoretical annual average potential evaporation as estimated by Penman method is approximately 2,630 mm (1957-1977). The monthly average potential evaporation and rainfall at Kuwait International Airport is shown in Fig.3.2-2

Kuwait is a hyper-arid state without rivers and fresh water aquifers. The non-conventional water resources including brackish groundwater, seawater (desalination), and reclamation of treated waste-water are the major sources of current water supply, of which the quality is as saline as 1,000 to 45,000 mg/l of the total dissolved solids (TDS) as show below:

Maximum permissive level of WHO standard for drinking water	:	1,000 mg/l
Groundwater (shallow)	:	1,000-2,000 mg/l
Brackish groundwater	:	2,000-8,000 mg/l
Seawater	:	45,000 mg/l
Product water from MSF desalination	:	25-50 mg/l
Reclamation of treated waste water	:	2,500 mg/l

3.2.1 Surface water

The prevailing hyper-arid climate of Kuwait is not favorable for the existence of any river systems in the country. There are no rivers or lakes, but small scale wadis are developed in the shallow depressions in the desert terrain. Surface runoff sometimes occurs in the large wadi depressions during the rainy season from November to April. There is no permanent stream gauging station but flash floods are reported to last for only a few hours to several days. Due to the extremely high evaporation losses and the high deficit in soil moisture, only a small percentage of the precipitation infiltrates into the groundwater. Run-off ratio must be extremely small.

The average annual volume of rainfall within the Kuwait is estimated to be $1.780 \times 10^6 m^3$ by assuming a mean annual rainfall of 100 mm. However, with such high evaporation losses, the net annual runoff is simply estimated to be $17.8 \times 10^6 m^3$ by assuming a runoff ratio of 1 %.

3.2.2 Groundwater

Thick geological sequences are of sedimentary origin from Paleocene to Recent, in two groups known as "Hasa" and "Kuwait". The Hass group, which consists of limestone, dolomite, anhydrite, and clays, comprises three formation units known as "Umm El Radhuma" in the Paleocene to Middle Eocene, "Rus" in the Lower Eocene, and "Damman" in the Middle Eocene. The Kuwait group, which consists of fluviatile sediments of sand and gravel, calcareous sand and sandstone with some clays, gypsums, limestones and marls, comprises three formation units known as "Ghar" in the Miocene, "Fars" in the Pliocene, and "Dibdibba" in the Pleistocene. (Fig.3.2.2-1)

Two economic aquifers are found in the "Damman" formation in the Hasa Group and and "Dibdibba" formation in the Kuwait Group.

Damman limestone aquifer

The Damman aquifer of the middle Eocene, which consists of carbonate rocks and extends all over the country, has a thickness varying from about 150 m in the southwest to about 275 m in the north.

The dissolution of the quantities of gypsum and anhydrite in the Kuwait group, Damman formation and Rus anhydrite formation is an important factor conditioning the chemical quantity of groundwater in Kuwait. The total

dissolved solids (TDS) of groundwater in the Damman limestone aquifer varies from 2,500 mg/l in the extreme southwest to about 200,000 mg/l in the northeast (Fig.3.2.2-2).

Groundwater isotope analysis of ^{14}C in the Damman aquifer has been performed by taking water samples from thirteen wells in the southwest of Kuwait. From the absence or zero concentration of ^{14}C, the age of the groundwater in the Damman aquifer is estimated to be more than 400,000 years. While the ^{14}C concentration in the Kuwait group groundwater indicates an age of 14,000-22,000 years (Ref.3.2.2-1).

Owing to the nature of limestone geology, the permeability of the Damman limestone aquifer varies considerably. The aquifer parameters vary from 27 to 7,100 m^2/day of transmissivity and 3.4-8.9x10^{-4} of storage coefficient, based on the results obtained from thirty-eight testing sites in the southwest and south of Kuwait (Ref.3.2.2-1).

No natural groundwater recharge from rain water source is not likely in the confined Damman limestone aquifer, although there is some lateral inflow or recharge through the Saudi border which is preliminarily estimated to be 8.3-24.9x10^6 m^3 per annum (Ref.3.2.2-1).

Dibdibba aquifer

The Dibdibba aquifer, which is composed of unconsolidated sands and gravels, is generally a water table aquifer with fresh to brackish groundwater.

Most of the groundwater recharge of the Kuwait group is dependent on upwards leakage from the underlying confined Damman limestone aquifer. The quality of groundwater is generally of similar characteristics to that of the Damman aquifer. The total dissolved solids (TDS) of the groundwater in the Kuwait group increases generally from about 3,000 mg/l in the southwest to about 130,000 mg/l in the northeast over a distance of about 150 km. Some lenses of fresh water with TDS ranging between 800 and 1,200 mg/l are perched on the brackish groundwater body in the wellfields of "Rawdatain" and "Um-Al Aish", Qashaniya and Hannabiyah in northern Kuwait, which are recharge by infiltration through the wadi beds during occasional flash floods in the wadi depressions. (Fig.3.1.1-1)

The piezometric level in the Kuwait group varies from about 90 m in the southwest to zero at along the coast. The groundwater flows generally

northeastwards.

3.2.3 Seawater

The seawater is unlimited water source for Kuwait which has a long coastline along the Arabian Gulf. The Arabian sea, which covers an area of 3,683x$10^3$$km^2$ and reserves 10.07x$10^{12}$$m^3$ of seawater. (Ref.2.3.3-1)

The high mineral content in waters from the Arabian Gulf requires special attention or control of salt deposition in plants located there. The total dissolved solids (TDS) of the feed water from Kuwait bay at Doha is 44,885 mg/l in average (Ref.3.2.3-2), which is as high as 1.3 times compared with other standard seawaters such as 33,600 mg/l in the Pacific Ocean and 36,000 mg/l in the Atlantic Ocean (Ref.3.2.3-3). The seawater has been a major source of fresh water supply in Kuwait since the end of 1960s. The desalination of seawater will continues to be a key application for developing water resources in Kuwait in the twenty-first century.

3.2.4 Treated sewage effluents

Marginal waters in the artificial category are composed primarily of municipal waste water and urban storm drainage water. With regard to reclaimed sewage effluents, potential reclaimed sewage effluents in Kuwait city were estimated to be 190 x$10^6$$m^3$ per annum in 1988, assuming a water supply of 293 x$10^6$$m^3$ per annum with a rate of return flow at 65 per-cent. The amount of re-use of the sewage effluents was 97 x$10^6$$m^3$ per annum, which was one-third of the volume of water supplied in 1988. The potential for water re-use will increase, corresponding to the increasing water use in future.

REFERENCES (3.2)

Ref.3.2.2-1
S.M. Abusada, 1988, "The Essentials of Groundwater Resources of Kuwait", Technical Report, Kuwait Institute for Scientific Research, KISR2665, pp.34.

Ref.3.2.3-1
IHD, 1978, "World Water Balance and Water Resources of the Earth", UNESCO, ISBN 92-3-101497-8, pp.23-46.

Ref.3.2.3-2
A.A.J Al-Zubaidj, 1989, "Parametric Cost Analysis Study of Seawater Reverse Osmosis Systems Design in Kuwait", International Desalination Association (IDA), Desalination-76 vol.IV, pp.241-280.

Ref.3.2.3-3
Everett D.Howe, 1962, "Saline Water Conversion", UNESCO, Problems of the Arid Zone, Proceedings of the Paris Symposium, pp.271-297.

3.3 Water Resources Development Projects

The water needs of Kuwait expanded after crude oil marketing was initiated in 1946, requiring the import of water by lighter and barge from the Shatt Al Arab in Iraq some 100 Km to the northwest. Intensive test well drillings were performed in 1945, which discovered an extensive brackish water aquifer in the Abduliya area. The first desalination plant was commissioned in 1950 at Fahahil in Kuwait city. A parallel development followed to meet the growth of Kuwait city, including the Sulaibiya brackish water wellfield. The combined development of co-generation and this brackish water wellfield was commissioned in 1953. Kuwait is now dependent on distilled water to blend with brackish groundwater as the main source of its water supply. Another source of water is treated sewage effluents, which are being used for landscape irrigation and agriculture.

A summary of present water supply for M&I in Kuwait is shown as below;

Water source	Salinity (mg/l:TDS)	Annual supply ($x10^6m^3$/year)
- Groundwater (shallow)	1,000-2,000	2.5
- Brackish groundwater	2,000-8,000	109
- Seawater desalination by MSF	25-50	184
- Reclaimed waste water	2,500	97

Small scale crop irrigation is being carried out to exploit brackish groundwater of 57-67x10^6m^3 per annum. Water resources development projects which have been performed in Kuwait after 1950s are described as below.

3.3.1 Surface water and artificial recharge

Kuwait's hydrology, topography, and geology, and surface water resources do not favor the country, and no promising storage dam scheme may be possible. Effective use of the temporary surface runoff in the wadis was examined in a research project on groundwater recharge at Rawdatain in 1962, by installation of recharge pits with a total volume of 25,000 m^3 in the wadi depression. The recharge scheme aims to evaluate the infiltration potential of wadi runoff into the upper Kuwait group aquifer where the water table is shallow. The prospects of increasing the potential of fresh groundwater in the shallow Kuwait group are good, but

artificial recharge will not be a key application, owing to the limited amount of surface runoff.

3.3.2 Groundwater exploitation

Groundwater has been exploited in two major aquifers, in the Kuwait group of the Neogen-Quarternary and in the Hasa group of the Eocene.

The selection of wellfields in Kuwait has been governed by many factors. In areas such as Jahara, Abdally and Wafra farms, groundwater exploitation has been concentrated on the shallow water table aquifer with salinity 2,000 to 8,000 mg/l of TDS for local irrigation. At the initial stage of the development, large-diameter hand-dug wells were constructed in the shallow aquifer at a depth of between 10 and 15 m. Later, tubewells with a depth of 50-60 m were drilled in the saturated section of the Kuwait group at the end of 1960s. Relatively deep groundwater wells which penetrate into the upper part of the confined Damman aquifer were drilled by the Kuwait Oil Company in the early 1940s to provide brackish water for the oil industry and gardening at Abdally and other areas. Sulaibiya wellfield was developed in the early 1950s to supply water for gardening and mixing with distilled water. The exploitation of fresh groundwater resources in Raudhtain and Umm El Aish was later initiated to Kuwait city. In view of limited sustainable yield of the aquifer system and possible leakage contamination from the underlying saline water body, the abstraction has been controlled since the mid-1970s. The Damman aquifers in remote areas were also explored by steps in the mid-1960s to coordinate with the substantial increase in water demand in Kuwait city. The Shigaya wellfield in the southwest of Kuwait city was commissioned for use in the early 1970s.

Annual abstraction of groundwater for water supply is estimated at 109 $x10^6 m^3/y$ of brackish water and 2.5 $x10^6 m^3/y$ of rather fresh water (Fig.3.3.2-1). Crop irrigation is being carried out by pumping 53-67 $x10^6 m^3/y$ of brackish groundwater from the wellfields in "Wafra" and "Abdali-Um Nigga". The existing yield, estimated potential yield, and water salinity of each wellfield are shown in Tab.3.3.2-1.

3.3.3 Seawater desalination

Kuwait is one of the world's leaders in production of fresh water from the sea. The development of "Co-generation Stations" has been practiced since the early 1950s as shown in Tab.3.3.3-1. The multi-stage flash

process (MSF) is used to distill the seawater and the annual production of the fresh (distilled) water is estimated to be now 184 $x10^6 m^3/y$ as shown in Fig.3.3.2-1.

Shuwaikh co-generation station

Shuwaikh is the oldest co-generation station in Kuwait to have been built since 1953. Corresponding to a rapid increase in fresh water demand, distillation units were installed over the period between 1965 and 1982. In 1987 installed capacities of the power generation unit and distillation plant were 324 MW and 32 migd (1445,504 m^3/d), respectively. Distillation plants have been installed as a part of the co-generation stations including the following: (Ref.3.3.3-1)

Shuaiba co-generation station

The Shuaiba station is composed of two stations, Shuaiba North and Shuaiba South. The installed capacity of the power generation units is 1,204 MW in total, being 400 MW at the Shuaiba North and 804 MW at the Shuaiba South. Distillation plant with a total installed capacity of 44 migd were installed over the period between 1965 and 1975, including 14 migd (63,658 m^3/d) at Shuaiba North (1965-1971) and 30 migd (136,410 m^3/d)at Shuaiba South (1971-1975).

Doha co-generation station

The Doha station is composed of two stations, Doha West and Doha East. The installed capacity of the power generation units is 3,558 MW in total, being 1,158 MW at Doha East and 2,400 MW at Doha West. Distillation plant with a total installed capacity of 139 migd (195,521 m^3/d) were installed over the period between 1978 and 1985, including 43 migd at Doha East (1978-1979) and 96 migd (436,512 m^3/d) at doha West (1983-1985).

Al-Zour co-generation unit

The Al-Zour station was designed to have an installed capacity of 2,511 MW of power generation and 72 migd (327,384 m^3/d) of distillation, and was scheduled to be completed by 1991.

The problem with seawater distillation is the high cost of producing water by the multi-stage flash (MSF) evaporation process. The cost of the thermal process is largely dependent on the rate of energy (fuel)

consumption for operating the system, which is as high as about 50 % of the unit water cost and is sensitive to the unstable world market price of crude oil.

3.3.4 Reuse of treated sewage effluents

The amount of reuse of the sewage effluents was 97 $x10^6 m^3$ per annum, which is one-third of the volume of water supply in 1988.

Three municipal waste-water treatment plants had been constructed at Ardiya, Rekka, and Jahara, which were aimed to treat municipal waste-water through by tertiary treatment for re-use in landscape irrigation. The installed capacity is 290,000 m^3/day in total, comprising 150,000 m^3/day of Ardiya, 65,000 m^3/day of Rekka, and 80,000 m^3/day of Jahara. The output of the treatment plants is 265,000 m^3/day, including 175,000 m^3/day of Ardiya, 30,000 m^3/day of Rekka, and 60,000 m^3/day of Jahara. After tertiary treatment by sand filtration, the quality of the treated water is controlled to be 10-20 mg/l of BOD, 3-40 mg/l of NH_3-N, and 2,500 mg/l of TDS (Tab.3.3.4-1). Some of the reclaimed sewage water is being used for landscape irrigation and some for agriculture.

REFERENCES (3.3)

Ref.3.3.3-1
Khaled H.Al Farhoud, 1988, "The Present and Future Development and Utilization of Water Resources in Kuwait", Middle East - Japan Conference on Development and Utilization of Water Resources, Japan Cooperation for the Middle East, Country Report.

Tab.3.3.2-1 Wellfields in Kuwait

Wellfield (1985)	Existing Yield ($10^6 m^3/y$)	Potential Yield ($10^6 m^3/y$)	Salinity T.D.S (mg/l)	Aquifer	Nos. of Wells	Purpose
Rawdatain & Um-Al Aish	2.5	6.6	700-1,200	Dibdibba F.	52	Water supply
Shiqaya						
A,B,C	53	66	3,000-4,000	Kuwait G. &	60	Water supply
D,E	_	42	3,000-4,500	Damman F.	54	Water supply
Sulaibiya	25-33	33	4,500-5,600	Damman F.	133	Water supply
Abdulliya	8	_	4,500	Damman F.	14	Water supply
Wafra	33-42	50	4,000-6,000	Kuwait G.	(110)	Irrigation
Abdali-Um Nigga	20-25	33-42	3,000-7,000	Dibdibba F.	(110)	Irrigation

Table 3.3.3-1 Installed Capacity of Co-generation Stations in Kuwait

Stations	Fresh Water Production ($x10^6 m^3/y$)	(MIGD)	Power Generation (MW)	Remarks
Shuwaikh	53	32	324	1960-1970
Shuaiba North	23	14	400	1965-1971
Shuaiba South	50	30	804	1971-1975
Doha East	71	43	1,158	1978-1979
Doha West	159	96	2,400	1985
Az Zour South	10	6(72)	-(2,511)	Stage I,(II)
Total	366	221	5,769	

Tab.3.3.4-1 Sewage Treatment Plants for Reuse in Kuwait

Plant	Installed Capacity (m^3/d)	Present Output (m^3/d)	Water Quality (mg/l) Actual/Standard
Ardiya	150,000	175,000	BOD = 10-20 / 30
Rekka	60,000	30,000	NH_3-N = 3-40 / 1-10
Jahara	80,000	60,000	T.D.S = 2,500 / 1,500-4,500
Total	290,000	265,000	

3.4 Experimental Seawater Reverse Osmosis (RO) Desalination

3.4.1 Background

Kuwait has been developing fresh water by distilling seawater since 1950s. The multi-stage flash (MSF) desalting process, which has has been used exclusively in the Arabian peninsula, has proved to be a most simple and reliable process but requires extensive materials and energy. The MSF system reached its maturity with very few improvements. It seems however that the race for the second generation of Seawater desalters will be won by reverse osmosis (RO), and low temperature multi-effect (ME) horizontal tube evaporators (HTE). (Ref.3.4.1-1). Both systems are characterized by their low requirements for energy consumptions, as compared with MSF. The cost of energy consumption is the largest single cost item in desalination. In 1980s, intensive efforts were made to evaluate the feasibility of the seawater reverse osmosis (RO) desalination, including a pilot RO plant in Doha, in which the cost analysis on the seawater desalination was made to compare the cost between experimental RO and existing MSF.

3.4.2 Doha experimental RO plant

This pilot plant, which has an installed capacity of 3,000 m^3/day, was installed in 1984, to evaluate the optimum membrane and operating system. It has three lines which are equipped with different types of modules, namely spiral wounded, hollow fine fiber, and plate-frame as shown below: (Ref.3.4.2-1)

RO line 1: 1st stage - Spiral wound, UOP-PA 1501
2nd stage - Spiral wound, UOP-PA 8600

RO line 2: 1st stage - Hollow fine fiber, Dupont B10
2nd stage - Hollow fine fiber, Dupont B9

RO line 3: 1st stage - Plate & Frame, Enro+Scheicher&Schuell Film Tec.
2nd stage - Spiral wound, Hydronautics 8040B

The feed seawater to the RO plant usually contains high concentrations of inorganic salts and foreign materials which can foul membranes and decrease their productivity. The main foulants which are associated with feed seawater are due to biological slime formation, suspended solids, colloids, metal oxide and scale formation. Pre-treatment is an essential process to control the life of the membranes. Different methods of conventional pre-treatment were also examined in each line.

Since the beginning of the plant's operation, pre-treatment has been running satisfactorily with availability of more than 96 %. Most of the time, it has been successfully controlled to give a silt density index (SDI) less than 4, but in some cases it has failed to produce an acceptable quality, owing to the clogging of the dual media filters, failing or overdosing of $FeClSO_4$, breakdown of the destabilizer mixer, and climatic conditions such as temperature, dust storms and wind.

3.4.3 Cost evaluation

The cost effectiveness of the membrane (RO) process can be compared with the cost of the predominant thermal (MSF) process. The cost is composed of two major items such as 1) direct capital cost and 2) operation and maintenance (O&M) cost. The equipment cost is a major factor of the capital cost, while the cost of consumed energy and chemicals make up the major part of the O&M cost.

Typical design for a large scale MSF and RO with an installed capacity of 27,360 m^3/day (6 migd) each may be used to compare the unit water cost. The feed water assumes the quality of seawater in the Arabian Gulf with concentrations of 45,000 mg/l of total dissolved solids (TDS), 800 mg/l of Ca^{++}, 1,700 mg/l of Mg^{++}, 12,500 mg/l of Na^{+}, 500 mg/l of K^{+},3,600 mg/l of SO_4^{--}, 24 mg/l of CO_3^{--}, 24,000 mg/l of Cl^{-}, 180 mg/l of HCO_3^{-}, 12 mg/l of Sr^{++}, and 0.04 mg/l of Ba^{++}. The cost evaluates assume the unit electric energy cost of US$ 0.07/KWh, the rate of replacement of the membrane 20 % per annum, twenty years plant life, 90 % load factor, and interest rate of 10 % per annum. The results of this cost comparison between MSF and RO as follows (Ref.3.4.2-1):

Facilities

- The seawater intake size and flow rate of the MSF unit are twice as much as those of the RO unit.

- The volume of the MSF unit is about three times as large as that required for the RO permeators. The land area required for the MSF unit is at least four times as large as that required for the RO permeators.

- Extensive and heavy materials are used in the MSF unit, which are more than ten times as much as those required for the RO unit. The heavy weight of the MSF unit requires heavy foundation and extensive civil work.

Energy consumption

- Thermal energy is consumed only by the MSF unit, and amounts to 89 MW. This thermal energy can be very expensive if it is obtained directly from boilers (not extracted from steam turbine).

- The energy consumptions for pumping the seawater to the pre-treatment system and the high pressure feed pump are estimated to be 0.25 KWh/m^3 and 7.98 KWh/m^3, respectively. The pumping energy consumption for RO is 8.23 KWh/m^3 in total, which is about 25 % more than that required for the MSF unit. However, the pumping energy for the RO can be decreased about 30 %, from 8.23 KWh/m^3 to 5.9 KWh/m^3, by installing an energy recovery unit such as a reversed centrifugal pump or Pelton wheel.

- The average energy consumption per cubic meter of the product water for the MSF unit is 15.27 KWh/m^3, which is about three times as high as the rate for the RO plant of 5.9 KWh/m^3.

Unit cost of product water

- From the above analysis, the on-site unit water costs of seawater desalination were estimated to be US$ 2.7/m^3 by MSF and US$ 1.7/m^3 by These costs are about two times as high as the unit municipal water supply cost of US$1.0/$m^3$ and wastewater treatment cost of US$0.95/$m^3$ in Japan (Ref.3.4.3-1) which are the world standard cost of M&I water supply and waste-water treatment.

Conjunctive use plan for MSF and RO

- Introducing RO seawater desalting plants in Kuwait is not a substitution for phasing-out old desalter units. Combination of new RO and existing MSF units could be cost effective in a water supply plan as illustrated in section 3.6 of Fig.3.6.4-1.

REFERENCES (3.4)

Ref.3.4.1-1
M.A.Darwish and Abdel-Jawad, 1989, "Technical Aspect of Reducing Desalting Water Cost by Distillation Methods, International Desalination Association (IDA), Proceedings of the 4th World Congress on Desalination and Water Reuse, Vol.4, pp.306-322.

Ref.3.4.2-1
M.A.Darwish and Abdel-Jawad, 1989, "Technical and Economical Comparison Between Large Capacity MSF and RO Desalting Plants", International Desalination Association (IDA), Proceedings of the 4th World Congress on Desalination and Water Reuse, Vol.4, pp.281-304.

Ref.3.4.3-1
Ministry of Finance of Japan, 1991, "White Book : Water Resources of Japan", 1991 (Japanese) edition, pp.153-156.

3.5 Experimental Brackish Groundwater Reverse Osmosis (RO) Desalination

3.5.1 Background

The quality of groundwater in Kuwait is mostly brackish, including total dissolved solids (TDS) of the order 2,000 to 8,000 mg/l. Brackish groundwater, of which the salinity is more than two to eight times as high as the maximum permitted level of WHO drinking water standards (TDS=1,000 mg/l) is being used to blend with permeate from MSF distillation plants or to irrigate the garden crops. No direct use of brackish groundwater for drinking purposes is possible without desalination. Reverse osmosis (RO) is the best means of demineralizing brackish waters, as has been practiced in United States of America since the 1970s. Brackish groundwater desalination is usually three to five times less expensive than seawater desalination (Ref.3.5.1-1), and has the following advantages:

- Low initial capital cost
- Compact design
- Short construction time required and easy mobilization
- Less energy requirement
- Cost flexibility in small to large scale units

Skid mounted mobile brackish water reverse osmosis units 13 in number, have been introduced since 1987, to supply fresh water for emergency purposes. Each RO unit equipped with a standby power generating unit. These skid mounted units, which have an installed capacity of 0.25 migd (1,137 m^3/day) each, were installed in the Labour Institute for Juvenile, Shwaikh storage area, two army camps and nine hospitals. The skid mounted RO desalination with brackish groundwater was the first practice in Kuwait, of which the technical and cost feasibilities are revived herewith to extend a new idea of the hydro-powered reverse osmosis (RO) desalination system as proposed in the following Section 3.6.

3.5.2 Experimental reverse osmosis unit

The first of the thirteen skid mounted RO units commenced the operation in 1988, and has been running continuously 8,260 hours according to specification. During the one year test operation, no membrane unit was added or replaced, but frequent changes of the cartridge filter elements were needed to avoid the bio-fouling. The test operation was successfully

completed without encountering any significant problems. (Ref.3.5.2-1) The skid mounted RO desalination with brackish groundwater was the first practice in Kuwait, of which the technical and cost feasibilities are reviewed herewith to extend a new idea on the hydro-powered reverse osmosis (RO) desalination system as proposed in this Section 3.6.

RO system unit

The reverse osmosis unit is housed in two standard containers. The first, the operation container, includes the membranes, high-pressure pumps, cartridge filter, flushing/cleaning tank, transfer pump, dosing stations, control panel, electrical switch board, etc. The second contains two dual-media filters, feed pump, backwash air blower and associated pipes and valves.

- Brackish water is supplied to the feed water tank (227 m^3) through the existing brackish water network/pipelines.

- The pre-treatment system consists of dual-media filters (hydro-anthracite/fine sands) and cartridge filters (5 micron size). Sulphuric acid (5 mg/l) and antiscalant flocon (6 mg/l) are dosed prior to the cartridge filters. Sodium bisulfate (2 mg/l) is added at the suction of the feed pump.

- After passing through the cartridge filter, the pressure of the feed water is increased up to the operating pressure of 15-25 kg/cm^2 by centrifugal pump.

- The RO unit consists of eight pressure vessels. The membrane is a low-pressure type, spiral wounded BW-8040 composite membrane of 8 inch diameter.

- The permeate from the modules flows to the flushing/cleaning tank. A neutral pH value is achieved in the final product water by dosing caustic soda (5-10 mg/l). Sodium hypochlorite (1 mg/l as Cl_2) is injected to sterilize the product water.

Bio-fouling problems

The feed brackish water includes bacteria with count-concentrations of the order of 60 to 400 CFU/ml, which was the main cause of blockage in the cartridge filter elements. Frequent replacements and/or cleanings of the

cartridge filter elements were needed at every 300-400 hours which is five times as much as the standard rate of 1,500-2,000 hours. To improve the rate of replacing filter element, the brackish feed water tanks and sand filters were disinfected by 5 mg/l of chlorine. This chlorination improved the rate of the filter replacement up to 700-800 hours. The cartridge filter was also periodically shock-chlorinated with 5 mg/l chlorine, which could significantly improve the replacement time to about 1,800 operating hours.

Membrane cleaning

Periodical cleaning of the membrane every 1,000 hours using a solution of NaOH (0.1%) and EDTA (0.1%), along with the replacement of cartridge filter every 1,800 hours, was found to be more economical and safe than other method such as increasing the chlorine dose rate (0.2 to 2 mg/l) in the feed water.

3.5.3 Technical performance

One year (8,260 hours) of test operation of the brackish water reverse osmosis desalination was successfully completed in 1989. The skid mounted RO unit can operate continuously with an availability of 94.3 %. The average rate of the product water was 46.83 m^3/hour, which is 98.9 % of the designed value of 47.4 m^3/hour. (Fig.3.5.3-1)

Quality of feed water and product water

Salinity of the brackish feed water varied from 3,134 mg/l to 3,874 mg/l, with an average of 3,407 mg/l of TDS. The salinity of the product water had an average of 73.5 mg/l of TDS, with a minimum of 62 mg/l and maximum of 122 mg/l of TDS. The feed water temperature was in the range between 26°C and 37°C. The pH of the feed water was 7.87 on average with a minimum of 7.65 and a maximum of 8.0.

Operating pressure and power consumption

The operating pressure varied from a minimum of 15 kg/cm^2 to a maximum of 21 kg/cm^2. The average power consumption during the 8,260 hours operation was 2.00 KWh/m^3 of product water, which includes all auxiliaries such as air conditioners, lights, mixers, etc.

Recovery and salt rejection

The recovery of the fresh water was 59.86 % on average, ranging between 56 % and 64 %. The average salt rejection was 98.4 %, with the minimum at 98 %.

3.5.4 Cost performance

This is a case study on a very small scale brackish water RO desalination unit, which aims to evaluate the cost-effectiveness of supplying fresh water in for a remote isolate towns or emergency needs by installing a skid mounted unit. The costs estimates of initial capital cost and operation and maintenance cost assume the following;

- 15 years of plant life
- 3 years of membrane replacement
- Interest rate at 8 %
- Electricity charges of KD.0.020/KWh (=US$0.07/KWh)
- Source water cost of brackish groundwater is not included

The initial capital cost includes mechanical equipment 49.8 %, membrane 19.5 %, electric generators 17.5 %, instrumentation equipment 5.0 %, training 4.5 %, and civil 3.5 %. The operation and maintenance (O&M) cost, which includes the labor, chemicals, spare parts, energy/electricity, and membrane replacements, was estimated to be KD.0.16(US$0.48)/$m^3$. The O&M cost is the more important cost item in a small scale plant, and is five times as high as that of the capital cost. The energy costs and labor costs are the dominant cost elements in O&M, and account for 31.7 % and 27.0 % respectively. Other costs are less than half that of O&M, including 14.6 % for membrane replacement, 14.4 % for chemicals, and 12.3 % for spare parts. The unit cost of the product water from a small scale skid mounted mobile system was estimated at as high as KD.0.726(US$2.18)/$m^3$ (Ref.3.5.2.-1), owing to its scale demerit.

REFERENCES (3.5)

Ref.3.5.1-1
O.K.Buros, 1989, "Desalting Practices in the United States", Management and Operations, November 1989, p.39.

Ref.3.5.2-1
A.L.A.Malik, N.G.Younan, B.J.R.Rao and K.M.Mousa, 1989, "Skid Mounted Mobile Brackish Water Reverse Osmosis Plants at different Sites in Kuwait", IDA, Desalination, vol.75, pp.341-361.

3.6 Hydro-Powered Brackish Groundwater Reverse Osmosis (RO) Desalination: A New Proposal

A new method of the hydro-powered reverse osmosis desalination is proposed in this study to minimize the cost of energy consumption which is the largest single cost element in the desalination engineering. The hydro-powered application takes into account the effective use of hydro-potential energy in a water pipeline system which carries brackish groundwater from wellfield to terminal reservoir with differential head of 200 or more. This new idea is applied in the existing Shigaya groundwater development project in Kuwait to evaluate the cost feasibility of the proposed desalination system.

3.6.1 Brackish groundwater wellfield

Proposed wellfield is located in the potential wellfields of West Shigaya and a part of North Shigaya, about 100 km west from the Kuwait city (Fig.3.6.1-1). The ground elevation is as high as 200 to 300 m. The Damman limestone at this point has a thickness of about 150 m. The piezometric levels are rather low being in the range between 50 and 100 m above sea level. The quality of the groundwater is brackish with a salinity in the range between 2,500 and 7,000 mg/l of TDS. The potential yield has been estimated to be 68,000 m^3/day in each potential wellfield.(Ref.3.6.1-1) For this study, the potential yield is assumed to be 45x106m3/y (123,400 m^3/day), for which the wellfield covers an area with an elevation of more than 200 m (Fig.3.6.1-1). The total number of production wells is estimated to be 46, by assuming a unit rate of 2,700 m^3/day per well.

3.6.2 Pressure pipeline system and pre-treatment plant

The hydro-powered RO desalination scheme will utilize the piezometric head difference between the collecting reservoir (E.L. at 230 m) and Jahara RO plant (E.L. at 20 m). The pre-treatment plant is sited immediately east of the collecting reservoir where the feed water gravitates to the Jahara RO plant. A ductile iron pressure pipe 750 mm in diameter and 60 km long, which has a specification of limited pressure to a maximum of 25 bar, will carry the feed water to the Jahara RO plant. The design flow discharge and the velocity in the pressure pipe are 1.42 m^3/sec and 3.2 m/sec, respectively.

3.6.3 Estimate of hydro-potential energy in the trunk main

The head difference between the collecting reservoir (230 m) and the RO plant (20m) is 210 m. The energy loss is composed mainly of friction loss in the pressure pipe and other losses. The energy loss is estimated to be 10 m of water head, which is as small as 5 % of the total head of 210 m. From the effective head of water at 200 m or 20 kg/cm^2, the theoretical hydro-potential of the scheme is estimated to be 2,780 KW. The following equations are used to estimate the theoretical hydro-potential, installed capacity and power generation:

$$Pt = 9.8*Ws*Q*He$$
$$P = Pth*Ef$$
$$Wp = 365*24*Gf*P$$

where, Pth : Theoretical hydro-potential (KW)
Ws : Specific weight of water (=1.0)
Q : Flow discharge (m^3/sec)
He : Effective difference head of water (m)
P : Installed capacity (KW)
Ef : Synthesized efficiency (assumed to be 0.80)
Wp : Potential power generation per annum (KWh)
Gf : Generating efficiency (assumed to be 0.68)

In the design of the water supply system, the hydraulic pressure in the trunk main is to be broken at a limit of 20-25 kg/cm^2 to prevent the mechanical failure of the pipe. The flow discharge (Q) of 1.18 m^3/sec at a differential head of water of 210 m or effective head (He) of 200 m has a potential yield of generated electric power (Wp) of $11x10^6$ KWh per annum.

3.6.4 Hydro-powered reverse osmosis desalination system

The application of hydro-potential energy, which is a typically clean energy, is the key to hydro-powered reverse osmosis desalination, to minimize the energy consumption and operating costs.

The potential energy in the trunk main can be used more effectively to provide hydraulic pressure in the pressure-pumping unit of RO than in generating electricity, owing to the direct use of hydro-potential energy as hydraulic pressure rather than through turbine and generator. The energy losses in a turbine and generator are generally 16 % and 5 %, respectively, which is 20 % in total of the theoretical hydro-potential

energy. The energy requirement or consumption of the pressure-pumping system is a major cost factor in operating an RO plant. The hydro-powered reverse osmosis desalination has the great advantage of two stages of energy conversion costs, to electricity and then to hydraulic pressure. It also has other advantages as shown below:

- Low initial capital cost
- Compact design
- Short construction time
- Minimize the energy requirement and cost

The brackish feed-water will be pumped from the Damman limestone aquifer into a collecting reservoir at an elevation of 235 m above sea level. The average feed water quality is estimated to have a salinity of 4,000 mg/l of TDS, temperature between 26°C and 37°C, pH of 7.87 in average ranging 7.65 and 8.0 (Ref.3.5.2-1). Following design criterion are used:

Installed capacity of RO desalination system: 100,000 m^3/d
Design feed water (85% of operating factor) : 86,400 m^3/d ($36.5x10^6 m^3$/y)
Design product water (60 % of feed water) : 51,840 m^3/d ($18.9x10^6 m^3$/y)

The reverse osmosis unit will be in two parts. The first will be pre-treatment unit to be sited immediately east of the collecting reservoir with dual-media filters (hydro-anthracite/fine sands) and cartridge filters (5 micron size), and with sulphuric acid (5 mg/l) and antiscalant flocon (6 mg/l) dosed prior to the cartridge filters. Sodium bisulfate (2 mg/l) will be added at the suction of the feed pump.

After passing through the cartridge filter, the feed water will enter a pressure pipeline (trunk main) to sustain a hydraulic pressure head of 20 kg/cm^2, which is directly used to apply the osmotic pressure needed to permeate the membrane.

The RO module will have a low-pressure type membrane, spiral wounded composite type and 8 inch diameter. The specifications of the RO module will be as follows:

- Salt rejection rate : 87.5%
- Design operating pressure : 20 kg/cm^2
- Design quantity of permeate : 30 m^3/day
- Maximum operating water temperature : 40°C
- pH of feedwater to be adjusted : 6.0-6.5

A unit line of the RO vessel consists of a circuit with six modules in series. Recovery is estimated to be 70 % of the feed-water, yielding $31.5 \times 10^6 m^3/y$ of permeate with TDS at 500 mg/l and $8.0 \times 10^6 m^3/y$ of brine reject with TDS at 17,700 mg/l. Periodical cleaning of the membrane every 1,000 hours using a solution of NaOH (0.1%) and EDTA (0.1%) will be performed along with the replacement of the cartridge filters every 1,800 hours.

The effective pressure of the brine reject is estimated to be 17 kg/cm^2 assuming a friction loss of 3 kg/cm^2 in the RO circuit. The potential energy recovery of the RO brine reject is preliminarily estimated to be 333 KW by assuming total efficiency of turbine and generator at 80%, which generates $1.98 \times 10^6 m^3$KWh per annum electricity with load factor at 65%.

The permeate from the modules then flow to the flushing/cleaning tank. A neutral pH value is achieved in the final product water by dosing with caustic soda (5-10 mg/l). Sodium hypochlorite (1 mg/l as Cl_2) is injected to sterilize the product water.

The schematics of the proposed hydro-powered reverse osmosis (RO) desalination system are shown in Fig.3.6.4-1.

3.6.5 Cost effectiveness

The investment cost of the proposed desalting plant with hydro-powered application is preliminarily estimated to be US$94,065,000 in total with annual capital cost at US$ 5,656,000, including US$74,488,000 of the capital cost and US$19,577,000 of the design and construction supervision. The capital cost comprises the following major cost elements:

- Pre-treatment	: US$ 13,898,860
- Desalting plant	: US$ 22,144,570
- RO membrane, equipment	: US$ 26,679,960
- Control and operating system	: US$ 1,871,900
- Appurtenant works	: US$ 8,495,200
- Powerline and substation	: US$ 1,142,680
- Energy recovery/turbine	: US$ 254,940

Financial expenditure is estimated to be US$ 24,428,700 which is based on 1990 prices with 8 % interest during three years construction.

The annual cost of the operation and maintenance is estimated to be US$ 5,653,600 including the following major items:

- Labour	: US$ 1,169,200
- Material and supplies	: US$ 584,920
- Chemicals	: US$ 2,339,690
- Membrane replacement	: US$ 1,559,790

Cost for source water and benefit from energy recovery are not included in this cost estimate. The above cost estimates are based on the following assumptions:

- Plant life : 20 years
- Membrane life (replacement) : 3 years
- Unit price of RO module : US$ 1,300

The unit water cost of the hydro-powered reverse osmosis desalination for the annual product water of $31.5 \times 10^6 m^3$ is estimated to be US$0.4/$m^3$, which is the least cost to compare with other existing methods such as seawater desalination by MSF (US$2.7/$m^3$), seawater desalination by RO (US$1.7/$m^3$) and brackish groundwater desalination by RO without hydro-powered application (US$0.6/$m^3$) as shown in Fig.3.6.5-1. Such application of retrieving the hydro-potential energy in a pipeline system is likely to have a strategic priority to save fossil energy and the global environment on top of minimizing the cost in desalination engineering.

REFERENCE (3.6)

Ref.3.6.1-1
S.M.Abusada, 1988, 'The Essentials of Groundwater Resources in Kuwait', Kuwait Institute for Scientific Research, KISR-2665, pp.1-52.

3.7 Development Alternatives and Conjunctive Use Plan

3.7.1 Development alternatives

The predominant multi-stage flash (MSF) desalination process in Kuwait, which consumes extensive materials and more energy than RO, is going to be replaced by steps after completing the plant life of about 15-20 years. RO seawater desalting plants in Kuwait are going to replace old MSF desalter units. The unit cost of RO brackish groundwater desalination is also much lower than that of seawater desalination, implying lower energy consumption and less capital investment. Hydro-powered RO desalination is the least cost method minimizing both energy consumption and capital cost. The development alternatives include the following methods of desalination;

- MSF distilling of seawater (existing plant; highest cost)
- RO desalination of seawater (completing experimental stage)
- RO desalination of brackish groundwater (existing skid mounted RO)
- Hydro-powered RO desalination of brackish groundwater (proposed herewith; will be the least cost method)

3.7.2 Conjunctive use plan

A number of old MSF plants in Kuwait are going to be phased out by the year 2000. Seawater RO will replace the old MSF by steps, but it will also contribute to blend with almost pure water from the existing MSF system from RO product water with salinity of about 500 mg/l of TDS to obtain suitable quality for drinking purpose. The range in salinity of the product water and world standards of drinking water are shown as below;

	Seawater		Brackish water	WHO drinking water standards	
Product water	MSF	RO	RO	Europe-USA-Japan	Middle East
Salinity (mg/l;TDS)	25-50	300-1,500	100-500	250-500	500-1,000

In the hybrid RO/MSF seawater desalination system, a seawater reverse osmosis (RO) plant is combined with either a new or existing MSF co-generation plant with following advantages;

- Both the capital and operating cost for the RO system are reduced.

- A single stage RO process can be used, and the life of RO membrane can be extended by reducing the water quality specification for the permeate.

- The temperature of the MSF product water is reduced by blending hot product water from MSF with RO permeate.

The combination of the new RO system with the present MSF system will be the key application for developing the water supply system in the 1990s.

The combination of the proposed hydro-powered RO desalination system with the present MSF system will make more effective use of desalting brackish groundwater at least cost, taking into account the limited potential of brackish groundwater resources over the unlimited potential source of seawater. The salinity of permeate from brackish groundwater desalination (RO) can be controlled in the range 100 to 500 mg/l of TDS, while the brine reject water has a salinity as high as 10,000 mg/l of TDS or more. The salinity of product water from MSF plant is as low as 25 to 50 mg/l of TDS. The RO brackish groundwater desalination will contribute; i) direct supply of good quality drinking water to meet with WHO standards, ii) indirect supply by blending brine reject water from RO with almost pure water from the existing MSF system not only to supply good quality drinking water but also to blend almost pure water from the existing MSF system with the brine reject. The conjunctive use plan suggests the following prior uses of the water-energy elements;

- RO product water (permeate) : $31.5 \times 10^6 m^3/y$ with 500 mg/l of TDS.
  Direct use for drinking water supply.

- RO brine reject water : $8 \times 10^6 m^3/y$ with 17,700 mg/l of TDS.
  Indirect use to blend with MSF product water.

- MSF product water : 632,000 m^3/d maximum with 25-50 mg/l of TDS.
  To blend with brine reject from RO.

- MSF brine reject water : 45,000>mg/l of TDS.
  To be safely wasted in offshore Kuwait bay.

- Energy recovery from RO : 1.98×10^6 KWh/y of electricity.
  Will be used to supplying electricity for treatment and/or pumping.

A proposed conjunctive use plan is also illustrated in flow diagram on Fig.3.6.4-1.

3.7.3 Remarks on the future development plan

The desalination of saline water by the membrane process with low energy requirements, will play an increasingly important role in the water resources planning of the arid states in the twenty-first century. The reverse osmosis (RO) is the least cost process today, but it may not be the optimum solution which may be neither reverse osmosis nor thermal desalination. Membrane desalination, however, will be a key application for water resources planning in the twenty-first century. A new desalination system of the reverse osmosis (RO) either with or without application of the hydro-powered process will be incorporated in the existing MSF system in Kuwait by steps, to make a reality of promoting the energy saving desalination technology.

IV. APPLICATION OF HYDRO-POWERED REVERSE OSMOSIS (RO) DESALINATION IN THE NON-CONVENTIONAL WATER RESOURCES DEVELOPMENT PLAN OF JORDAN

4.1 Background and Objectives

4.1.1 Background

Jordan is located to the northwest of the Arabian peninsula, and extends from 29 to 33 degrees of north latitude and from 35 to 39 degrees of east longitude with an area of 89,555 km^2 (Fig.4.1.1-1).

More than 80 % of the country is covered by desert where the population is very scarce. The population of the country was estimated to be about 2.8 millions in 1985. About 90 % of this population lives in the northwest quadrant of the country. Greater Amman, which is a metropolitan district within a 30 km radius from the center of Amman city, occupies an area of 3 % of the country. The population of the Greater Amman area, however, is as much as 1.62 millions (573 head/km^2), which is about 60 % of the whole population of Jordan. The national population growth rate was as high as about 3.7 % annum in the 1970s (Ref.4.1.5-1), mainly due to migration from the West Bank and the Gaza Strip.

The growth rate is expected to decline only slowly to reach 3.2 % by year 2010. M&I water as a proportion of total water use is expected to increase from 24 % in 1985 to 30 % in 2005 and 45 % in 2015, by assuming only modest per capita consumption rate of 83 litre per capita per day for domestic use. The national water demand was simply projected to increase upto $1,209 \times 10^6 m^3/y$ by year 2000, assuming a growth rate of 2.5 to 3.5 % in population, 5 % in industrial uses and 4 % in agriculture uses. (Ref.4.1.1-3) While the effective rainfall as potential renewable water resources was estimated to be $1,123 \times 10^6 m^3/y$ including $245 \times 10^6 m^3/y$ groundwater and $878 \times 10^6 m^3/y$ of surface flow (Ref.4.1.1-1).

Limitations of water, one of the important resources of Jordan, is likely to have a major impact on the economic development of the country. By the year 2000, most of the conventional water resources in the country will have been fully exploited by conventional measures such as constructing dams and drilling wells. The development of marginal non-conventional water resources will then become a key application in the twenty-first century to sustain economic development of the country.

Non-conventional waters are composed primarily of brackish waters, seawater, and reclamation of urban waste waters in Jordan. In the 1970s, it was considered that large-scale seawater desalination projects would become both technically feasible and economically viable as water supply alternatives in the early 1990s (Ref.4.1.1-4). Innovative researches on the desalination technologies for membranes in the 1980s are changing the world market by reducing the share of the conventional MSF distillation plant which has been used exclusively in the Middle East countries (see ANNEX-I). The development of saline water resources by desalting with reverse osmosis (RO) or other membrane process will play an increasingly important role in a context of the national water master plan.

4.1.2 Objectives

The major purpose to study the application of hydro-powered reverse osmosis (RO) desalination in a case study on the Aqaba-Disi groundwater development and water supply project is to evaluate the technical feasibility and cost-effectiveness of the proposed co-generation system.

The proposed co-generation system aims not only to conserve the fossil groundwater resources in the Disi aquifer but also to retrieve the hydro-potential energy in a pipeline system for generation both electricity and desalting brackish groundwater from the Kurnub aquifer.

The potential application of the non-conventional water resources developments including proposed hydro-powered reverse osmosis (RO) desalination are examined in a context of the national water master plan of Jordan, which aims to make a new concept and framework of water master plan for the sustainable development of Jordan in the twenty-first century.

REFERENCES (4.1)

Ref.4.1.1-1
World Bank, 1984, "Hashemite Kingdom of Jordan; Water Sector Study, Sector Report", World Bank Report No.4699-JO, p.1.

Ref.4.1.1-2
World Bank, 1989, "Jordan Water Resources Sector Study", World Bank Report, No.7099-JO, pp.1-44.

Ref.4.1.1-3
Ministry of Planning (MOP), 1990, "Jordan's Water Sector", Seminar note prepared by MOP of Jordan, pp.1-3.

Ref.4.1.1-4
N.Buras and P.Darr, 1979, "An Evaluation of Marginal Waters As Natural Resources in Israel", Water Resources Research, vol.15, no.6, pp.1349-1353.

4.2 Water Resources of Jordan

Hydro-meteorologically Jordan is a semi-arid to arid state with relatively abundant water resources to compare with other states in the Middle East such as Kuwait. About 80 % of the territory is steppe and desert where water is only minimally available. The Jordan, however, has various source of waters such as river streams, springs, wadi flash floods, renewable and non-renewable groundwaters, and reclamation of treated sewage effluents.

4.2.1 Water resources potential

Water resources in Jordan depends mainly on precipitation within the country, except for the Yarmouk river of which the flow is mainly fed from rainfall on Syrian territories. Average rainfall ranges from 600 mm/year in the northern uplands to less than 500 mm/year in the south and eastern desert areas. The rainfall occurs between October and May, and is at its height between December and March when over 80 % of the annual rainfall occurs.

Average annual volume of rainfall within the Jordan was estimated to be $8,500 \times 10^6 m^3$. However, with high evaporation losses, the average net annual yield is only about $1,120 \times 10^6 m^3$ (13 %) with $875 \times 10^6 m^3$ (10 %) in the form of surface water and $242 \times 10^6 m^3$ (3 %) in groundwater (Ref.4.2.1-1). About two-thirds of Jordan's potential usable water resources is surface water. About $400 \times 10^6 m^3$ per annum of the surface flow, which is 46 % of the total runoff, forms the discharge in the Yarmouk river. Sustained yield and/or renewable groundwater resources is preliminarily estimated at 3 % of the annual rainfall, of which the recharge is mostly dependent on the rainfalls on the Western Highlands. In addition, it is estimated that over $11,000 \times 10^6 m^3$ of stored fresh groundwater exists within the state. It is, however, mostly non-renewable groundwater which may offer an opportunities for short-term and emergency uses.

4.2.2 Surface water resources

Surface water resources, which are two-thirds of Jordan's potential usable water resources, are at present used exclusively for agriculture, except for spring water which is sometimes collected for municipal use. Most of the municipal water supply systems and industries in Jordan are presently dependent upon groundwater and springs. Although surface water resources

exist on the northern border such as in the Yarmouk river, in the Jordan valley, and in some of the wadis flowing into the Jordan River, exploitation of surface water for municipal and industrial water supply has not so far occurred to any great extent due to sporadic flow patterns, priority use for irrigation, and relatively low elevation and long distance to population center.

Flows in rivers are generally of a flashy nature with large seasonal and as well as annual variation. Annual baseflows, however, of which the volumes are estimated to be $540 \times 10^6 m^3$, vary at least 15 to 20 % depending on the rainfall patterns with a return period of five years (Ref.4.2.1-1). The base flow of $150 \times 10^6 m^3$ per annum in the Yarmouk river has been developed by the East Ghor Main Canal (EGMC) irrigation project since 1965. Corresponding to the rapid increase in water demand in the metropolitan area, $45 \times 10^6 m^3$ of canal water has been diverted from EGMC to Amman for municipal and industrial use by constructing a treatment plan and pipeline with a total difference (pumping) head at 1,300 m.

Since the beginning of the 1960s', a number of storage dams have been constructed together hold an estimated $452 \times 10^6 m^3$ of water. The Al Wuheda dam, which is being built on the Yarmouk river near the Syrian border to store $225 \times 10^6 m^3$, will supply irrigation water for the downstream of Jordan Valley and generate electric power. Syria will be using part of the water and 75 % of the total hydro-electric power (Ref.4.2.2-1).

4.2.3 Groundwater resources

Major potential aquifers are found in the pervious sequences in the basalt system of the Pleistocene, Rijam (B4) formation of the lower Tertiary, Amman-Wadi Sir (B2/A7) formation of the upper to middle Cretaceous, Lower Ajlun (A1-6) formation of the middle Cretaceous, Kurmub-Zarqa formations of the lower Cretaceous, and Disi formations of the Paleozoic age.

The shallow aquifer systems of basalt-Rijam(B4) forms a locally important aquifer in the central part of the Jafr basin and Al Azraq - Wadi as Sirhan basin. Groundwater irrigation has been practiced in and around the Jafr town since 1970s, of which the underlying aquifer of B4 has been contaminated by steps by irrigation returns, increasing salinity (TDS) from 500 mg/l to 4,000 mg/l during the ten years operation. The sustained yield is estimated to be less than $2 \times 10^6 m^3$ per annum, due to the limited groundwater recharge through the wadi beds during the occasional flash floods. The basalt-Rijam system in the Azraq basin has intensively

exploited for the purpose of Amman municipal water supply. The annual abstraction from the Azraq wellfield amounted to 15.6 $x10^6m^3$ in 1985, which exceeded the safe yield lowering the piezometric head and increasing the water salinity. The groundwater in the Sirhan basin, of which the recharge mechanism is as same as that of the Jafr basin, is untapped.

The most important aquifer system is the Amman-Wadi Sir (B2/A7), which consists of limestone, silicified limestone, chert, sand limestone and sandstone of upper to middle Cretaceous age. This aquifer system extends throughout entire country with thickness about 100 to 350 m. The depth of groundwater table below the ground surface generally ranges 50 to 250 m in the uplands. Good groundwater recharge occurs from the Western Highlands where annual rainfall ranges 200 to 600 mm. To the east aquifer is confined by thick marl layer such as Muwwaqar (B3) formation, and water salinity is increased. This economic aquifer system of the B2/A7 has excessively exploited in the northern part of the country, lowering the piezometric levels and deteriorating quality of water. In the southern part of the country such as Mujib basin, Upper Hasa basin, and Jafr basin, the B2/A7 aquifer is the most important economic aquifer, of which the quality is as good as less than 500 mg/l of the total dissolved solids. The groundwater is being pumped for M&I water supply from the wellfields of Qastal, Siwaqa, Qatrana, Sultani, Karak, Shoubak, and Hasa.

An intermediate aquifer system is the lower Ajlun (A1-6), which consists of alternating limestone, marl, shale, chert and sandstone of middle Cretaceous age. This aquifer system is underlain by the Amman-Wadi Sir (B2/A7) formation, which is mostly confined by its relatively impervious layer of marl and shale in the A5/6 of the upper unit of A1-6. The lower Ajlun formation extends throughout country with variable thickness and litho-facies. To the southwards, the aquifers in the lower Ajlun formation becomes more sandy where salinity of water becomes as less than 350 mg/l of TDS. The aquifer system is mostly untapped, however, due to its complicated hydrogeology and deep formation.

Deep sandstone aquifers are Kurnub/Zarqa of lower Cretaceous age and Disi of Paleozoic age, which are unconformably separated by a less permeable layer of sandstone, siltstone and shale. The Kurnub formation intercalates frequent argillaceous layers in the south, while the Disi is composed of massive and rather homogeneous arenaceous. Groundwater in these aquifers are mostly non-renewable due to limited groundwater recharge through small outcrop area. Quality of groundwater in the Kurnub/Zarqa system varies from fresh to brackish. Excellent quality with

low salinity, however, is found in the Disi aquifer in the southern part of the country, which has been exploited for the water supply of Aqaba and local experimental irrigation. Development potential of the Disi groundwater has been estimated to be about 100-200 $x10^6m^3$ per annum for the period over 50-100 years. The aquifer complex, however, forms a huge groundwater reservoir extending under the whole of the country. This groundwater storage offers opportunity for short-term and emergency uses.

Groundwater is presently used for municipal, industrial and agriculture purposes. In the northern uplands, which includes the heavily populated Greater Amman and Irbid areas, groundwater in the Amman-Wadi Sir aquifer has been over-exploited in the 1980s. Significant irrigation water use is also found in the Zarqa River Basin, where about 70 % of the water is from groundwater. The abstraction in the northern uplands is estimated at about $120x10^6m^3/y$ against an estimated sustainable yield of 90 $x10^6m^3/y$.

It is said that 96 % of the Kingdom's population is now supplied with drinking water from springs and groundwater wells. A series of water supply schemes have been carried out, including $20x10^6m^3/y$ of Wadi Arab groundwater schemes west of Irbid, $15x10^6m^3/y$ of Azraq groundwater project, $14x10^6m^3/y$ of Amman-Zarqa groundwater project, $45x10^6m^3/y$ of Deir Alla-EGMC pipeline project, $9x10^6m^3/y$ of Qatrana-Siwaqa-Qastal groundwater project, $3.5x10^6m^3/y$ of Sultani groundwater project near Karak, $1.5x10^6m^3/y$ of Shoubak groundwater project, and $17x10^6m^3/y$ of Disi groundwater project (Ref.4.2.2-1). Mukheiba wellfield of $26x10^6m^3/y$, which has been developed for the irrigation water supply in the downstream of the Yarmouk/Gohr, will be diverted to upland water supply, by taking into account the difference in the water head at about 200 m between the artesian wellfield and the Ghor.

4.2.4 Treated sewage effluents

Significant work on sewerage has taken place in the past decade, and about 40 % of the urban population (25 % of the country's population) are now being to be served. In many urban areas, household cesspits and septic tanks are still commonly used, with liquid effluents discharging into the soil via open joint pipes or openings in pit wells. This return flow mixes with groundwater recharge from rainfall, which is re-used for water supplies, however, in groundwater located under densely populated areas and a gradual increase in mineral content, sometimes in nitrate concentration, has been monitored.

Groundwater in the Wadi Arab wellfield, of which the aquifer is Amman-Wadi Sir (B2/A7), has been contaminated by direct infiltration from the sewage effluents through the outcrop of the B2/A7 in the upstream area in 1988. The drainage of the sewage effluents from the Irbid city was diverted to the north to protect the quality of groundwater in and around the outcrop area of the B2/A7. The direct recharge of sewage effluents into the limestone aquifers is not planned.

The Zarqa river, which runs through the heavily populated cities of Amman, Zarqa and Ruseifa, collects the return flows of sewage effluents. The sewage effluents mix with surface water in the river system and are stored in the reservoir of King Talal dam, which is exclusively used for the irrigation water supply in the Jordan Valley downstream, but not for municipal water supply.

REFERENCES (4.2)

Ref.4.2.1-1
World Bank, 1984, "Hashemite Kingdom of Jordan; Water Sector Study, Sector Report", World Bank Report No.4699-JO, pp.1-25.

Ref.4.2.2-1
World Bank, 1988, "Hashemite Kingdom of Jordan; Water Sector Study, Sector Report", World Bank Report No.7099-JO, pp.1-38.

4.3 Water Resources Development and Management

The United Nation's partition proposal of 1947, which decided to divide Palestine into Jewish and Arab states, ignored water problems. The 1948 Arab-Israeli war aggravated the difficulties of cooperative water development and management. Failure of negotiations to develop a multi-lateral approach to water resources development and management reinforced unilateral action. Though the Unified Plan (see Annex-II) was not ratified, both Jordan and Israel undertook to operate within their allocations. The two major projects undertaken were the Israeli National Water Carrier (INWC) and Jordan's East Ghor Main Canal (EGMC).

The design of the East Ghor Canal was begun in 1957. The construction of the canal commenced in 1959 and the first phase upto Wadi Zarqa was commissioned in 1966. The King Talal dam, which is situated on the Zarqa river with a storage capacity of 56 $x10^6m^3$ and an 18 km extension of the East Ghor Main Canal (EGMC), were completed in 1977 at a cost of US$52 million.

Smaller dams were built on the rift side wadis in 1980-85, including Kafrain dam (3.8 $x10^6m^3$) and the Wadi Ziqlab (4.3 $x10^6m^3$). The rift-side dam scheme on the wadi Shueib was intended to store winter flows for downstream irrigation, however, it could not effectively store the design volume, owing to substantial leakage through gravel formation and limestones geology in and around the reservoir. The reservoir has never been filled with water up to design high water level since completion of the dam structure.

The Wadi Arab dam, completed in 1987, has a total storage capacity of 20 $x10^6m^3$ at a cost of US$50 million. The combined capacity of the King Talal and Wadi Arab dams were increased to 130 $x10^6m^3$ in total after raising the dam heights at the end the 1980s. (Fig.4.3-1)

Present surface water consumption is currently estimated at 336 $x10^6m^3$ per annum of which almost all is for irrigation, including approximately 102 $x10^6m^3$ for upland irrigation and 229 $x10^6m^3$ for irrigation in the Jordan Valley. Of this approximately 110 $x10^6m^3$ is diverted from the Yarmouk River through the East Ghor Main Canal (EGMC), and about 119 $x10^6m^3$ comes from the rift-side wadis.

Owing to topographic and hydro-geotechnical problems, the construction of

storage dams in Jordan is extremely costly. New investment on storage dams in Jordan can be justified only for supply of municipal and industrial water, or for irrigation of high value, high yielding crops using water conserving technologies.

The water shortage in Jordan is most noticeable in domestic use. The Deir Alla pumping station, which has an installed capacity to pump, treat and convey 45 $x10^6m^3$ per annum of water from EGMC, was completed in 1988. The scheme involves pumping water up about 1,300 m, and the operating costs are excessively high to sustain the quality for drinking purpose. Due to priority use in the irrigation sector, the system is not allowed to supply precious water during the summer season, and consequently only about 28 $x10^6m^3$ per annum of water are being pumped. (Fig.4.3-1)

The Government strategy up to the present has been to use groundwater resources for both M&I and agriculture use, and to use surface water primarily for irrigation. Domestic water supply is exclusively dependent on the groundwater supply, owing to its better quality and higher elevation of water body than that of the surface water resources. Groundwater pumping amounted to 155 $x10^6m^3$ per annum in 1985, which exceeded the safe yield in some wellfields including Amman/Zarqa aquifer. Almost all the renewable groundwater resources have been excessively developed, lowering piezometric level and deteriorating quality of water in some aquifer systems. The Disi is only one remaining significant aquifer. It is, however, a fossil aquifer with an estimated safe yield of about 110 $x10^6m^3$ per annum over a 100 year period.(Fig.4.3-1)

When Jordan's last major potential water sources of Disi groundwater and Al-Wuheda dam are fully developed, there will be no alternative except the use of non-conventional water resources and/or importation of water from foreign countries.

4.3.1 Surface water resources

Surface water resources are dominated by the Yarmouk river and the Zarqa river, which provide the majority of the irrigation water for the Jordan Valley. Irrigation in the Jordan Valley in the past has been made possible only by large scale public investments in water diversion such as East Ghor Main Canal (EGMC) and in the water storage dam including King Talal and Wadi Arab, to utilize potential of surface water resources. The King Talal dam on the Zarqa river was completed in 1979, to collect not only natural flows in the river system but also sewage effluents,

either treated or untreated, from the population centers of Amman and Zarqa. An increasing proportion of water stored in the dam comprises major parts of the return of sewage effluents, of which the amount of treated sewage is expected to increase from 29 $x10^6m^3$ in 1985 to 116 $x10^6m^3$ in 2005 and 165 $x10^6m^3$ in 2015 in the Northern Jordan (Ref.4.3.1-1). Although the water quality of the reservoir is still good, and suitable for cultivation of most crops through drip irrigation except for leafy vegetables, use of King Talal water for M& I, even after treatment, should be avoided, taking into account the health risk imposed on it.

Small dam schemes have been implemented to provide embankment type dams on small scale streams in the riftside wadis including Ziqlab (4.3 $x10^6m^3$ of storage), Shueib (2.3 $x10^6m^3$ of storage), Kafrain (3.8 $x10^6m^3$ of storage) since 1968, despite their heights between 30 and 38 m. As mentioned earlier, the riftside dam scheme on the wadi Shueib was intended to store winter flows for downstream irrigation, but it could not effectively store the design volume owing to substantial leakage through gravel foundation and limestone geology in and around the reservoir.

The Wadi Arab dam, which was completed in 1987, has a total storage capacity of 20 $x10^6m^3$ at a cost of US$50 million. The scheme was originally planned to store 30 $x10^6m^3$ per annum of spring flow in the wadi Arab, however, the flowing spring was suddenly stopped owing to groundwater development in the adjacent wellfield in the wadi in 1985. The dam design had to be amended to store an excessive winter flow from the EGMC by pumping up 100 m for M&I water supply during the summer season. The feasibility was made by raising the dam height and changing the supply objectives including the M&I. The combined capacity of the King Talal and Wadi Arab dams were increased up to 130 $x10^6m^3$ in total after raising the dam heights at the end of 1980s.

Water resources development in Yarmouk river basin

The Yarmouk river, which has a mean discharge of $400x10^6m^3$ per annum, provides almost half of the Jordan's surface water resources. The water in this river, after allowing for some $17x10^6$ m^3 per annum for downstream users in neighboring countries, is diverted through the East Ghor Main Canal (EGMC), an irrigation canal which runs along the Jordan river, to serve agricultural water needs in the Jordan Valley. Shortage and/or limitation of groundwater resources to meet growing municipal and industrial water demands in North Jordan was required conveyance of $45x10^6m^3$ per annum of water from EGMC to Amman by pumping an extremely

high head of 1,300 m from Deir-Alla treatment and pumping station (-200 m below sea level) to the terminal reservoir (+1,100 m above sea level). The schematics of water transport systems in North Jordan are shown on Fig.4.3.1-1.

Al-Wuheda (Maqarin) storage dam scheme

Al-Wuheda dam, first conceived as early as 1956, is soon to be constructed in the northern area of Maqarin about 20 km north of Irbid to store the waters of the Yarmouk River, a tributary of the Jordan River (Fig.4.3-1).

Estimated stream-flow at Maqarin gauging station is $273x10^6m^3$ per annum on average, which includes the flood waters being discharged downstream without any use. Based on the riparian agreement between Syria and Jordan in 1988, preliminary work for opening an 800-meter long diversion tunnel were completed in the end of 1989. The dam reservoir would have a gross capacity of $225x10^6m^3$ with effective storage volume of $195x10^6m^3$ annually. The water would irrigate an additional 3,500 hectares in the Jordan Valley, supply $50x10^6m^3$ of water a year to the Greater Amman area and Eastern Heights. It will also generate an average of 18,800 KW per hour of electricity a year. Syria will be using a part of the water and 75 % of the total hydro-electric power generated by a power station near the dam. The project has been stopped, however, by a strong opposition from Israel, demanding more water in the Yarmouk river downstream.

4.3.2 Groundwater resources

Groundwater has been exploited extensively in northern Jordan, because the population was originally concentrated in this region. Groundwater has been used exclusively in M&I water supply, owing to its better quality and higher elevation of water body than that of the surface water resources.

Amman-Zarqa wellfields were developed to supply water for Amman-Zarqa municipalities, which had a capacity to provide 16-17 $x10^6m^3$ per annum in the 1950s supplying of only 50 % of the demand. Azraq oasis which is located 100 km east from Amman was developed to supply M&I water for Amman municipality. To meet the increasing demand for M&I use in the 1980s, both Amman-Zarqa and Azraq wellfields were over-developed by lowering piezometric head and deteriorating its quality.

Two important artesian wellfields were exploited in the mid-1980s in

north-west Jordan including the Mukheiba wells and Wadi Arab wells. The Mukheiba wells near Adasiya intake site of the EGMC is currently used for irrigation in the Jordan Valley, by use of an 11.5 km long canal with 3 m^3/sec capacity. The sustained yield of the wellfield was estimated to be 20-25 $x10^6m^3$ per annum and its quality is is good for drinking purpose. The Mukheiba wells represent the best available source for incremental supply of M&I water to the Jordan uplands. The Wadi Arab wellfield, which is located just upstream of the Wadi Arab dam and reservoir, has been developed to tap the highly confined aquifers in Amman formation (B2) with an estimated safe yield at 10 $x10^6m^3$ per annum. The highly confined groundwater in the Amman formation (B2) is conceived to supply a group of springs in the wadi beds which was the source of baseflow of the wadi Arab. However, abstraction of the artesian water from Amman formation (B2) has substantially reduced the baseflow of the Wadi Arab and the Wadi Arab reservoir. The Wadi Arab dam is now largely dependent on pumping from East Ghor Main Canal (EGMC) for recharge/storage.

Other two wellfield of "Wadi Ajib (15 $x10^6m^3$ per annum of safe yield)" and "Wadi Dhuleil (20 $x10^6m^3$ per annum of safe yield)", which are situated in the north and the northeast of Amman, have been exploited for the purpose of local upland irrigation and M&I (Ref.4.3.1-1). The Wadi Ajib wellfields is being over-developed to abstract 14 $x10^6m^3$ per annum for M&I water supply and 14 $x10^6m^3$ per annum for irrigation, while the Wadi Dhuleil wellfield is exclusively developed for irrigation purpose. The quality of the aquifer below the irrigation land has been deteriorating progressively, by over pumping and the contamination of poor quality of irrigation return flows.

The Disi aquifer (350 km south of Amman) is the most precious and expensive aquifer in Jordan. The Disi has been exploited for M&I water supply for Aqaba to supply 8.5 $x10^6m^3$ per annum fresh water, and for arid land irrigation. Recorded abstraction for 1986 was 14.5 $x10^6m^3$, but 3000 ha have now been developed for agriculture, implying an extraction of over 30 $x10^6m^3$ per annum. Licenses have been granted to drill wells for irrigation over 20,000 ha, implying annual abstraction of over 200 $x10^6m^3$ per annum. It should be noted that the aquifer is extremely expensive to develop for irrigation; it lies 250-300 m below the ground surface and requires drilling to depth of 750-1000 m. Irrigated agriculture is unlikely to be economic. Furthermore Disi is a typical fossil groundwater, and represents with Al-Wuheda dam, Jordan's last substantial un-exploited fresh water resources, and should be regarded as a strategic water reserves.

4.3.3 Hydro-power

Owing to the scarcity rainfall and water resources, the potential for hydro-power generation is quite small. Since priority is given to irrigation and M&I purposes, most of the energy produced cannot be dependable. There are only two existing mini-hydro-power plants which were completed in 1987. These include two 2 MW units installed at King Talal dam and a 375 KW unit at Wadi Arab dam. For the Wadi Arab plant, the water is pumped from East Ghor Main Canal (EGMC) for storage of surplus water (1.2 m^3/sec) and released back to the canal during time of deficit (1 m^3/sec). The annual potential energy generation of these two plants (12$x10^6m^3$ KWh) represents only 0.2 % of the expected total power generation in Jordan in 1990. The only future hydro-power plant would be associated with Al-Wuheda dam with installed capacity of 15 MW. The recent Riparian Treaty between Jordan and Syria envisages that 75 % of the electricity produced would be consumed in Syria.

REFERENCES (4.3)

Ref.4.3.1-1
World Bank, 1988, "Jordan Water Resources Sector Study", World Bank Report No.7099-JO, pp.1-38.

4.4 Non-Conventional Water Resources Development

Jordan, which is a semi-arid to arid country in the Middle East, has a limited potential of rainfall with a mean of 114 mm per annum. The potential of exploitable-renewable water resources, which is subsequently limited to be about 900 $x10^6m^3$ per annum, is going to be fully exploited by the end 1990s, owing to the increasing demand specially in the population centers. The hydrology and hydrogeology of Jordan has a unique nature comprising variable alternative water source such as river streams, springs, flash floods in the wadis, renewable and non-renewable groundwaters, return flow of treated sewage effluents, and seawater. The non-conventional waters in Jordan are primarily composed of reclamation of urban waste waters, brackish groundwaters and seawater, of which the present status and the future development plan are described in this Section.

4.4.1 Reclamation of urban sewage waters

The Water Authority of Jordan (WAJ) has an ambitious sewage treatment program which is on-going. The program will not only have a positive environmental and health impact, but it will also provide for the collection and treatment of sewage in a way that effectively lends itself for re-use of treated effluents. Sewage collected in North Jordan is expected to increase from 29 $x10^6m^3$ in 1985 to 116 $x10^6m^3$ in 2004 and 165 $x10^6m^3$ in 2015, and it will be re-used mostly in the downstream irrigation of the Jordan Valley. The on-going sewage projects include construction of new sewage treatment plants in Baqa and Wadi Sir and extension of the existing plants in Salt and Jerash. These plants should be given priority because their effluents are discharged upstream of the Zarqa basin and will be re-used in downstream irrigation through the regulation by King Talal reservoir.

4.4.2 Brackish groundwater

Brackish groundwater is generally stored in the deep aquifers in the country except in the area of the southwest where the Disi formation or Pre-Cambrian complex outcrops. The quality of the brackish groundwater has a wide range from 1,000-2,000 mg/l to 5,000-10,000 mg/l of the total dissolved solids (TDS), which could be used for neither domestic nor irrigation. The brackish groundwater with lower salinity in the order of less than 2,000-3,000 mg/l of TDS would be directly used for limited crop

irrigation with specified (pervious or sandy) soil conditions. Another potential use of the brackish groundwater is for the specific purpose of mining industries such as their requirement for washing water. In general, brackish groundwater can be safely used by through desalination or mixed with very fresh water.

Brackish groundwater has been found some places in the Jordan Valley, and accidentally detected in some deep sandstone aquifers such as in Kurnub formation on the upland during either exploratory or exploitation drillings. No systematic potential study or investigation has been performed. However, a large storage potential for the brackish groundwater is conceived in the rather shallow aquifers of the eastern desert of Jordan including areas of Azraq, Shirhan, and Hamad. In these areas, the target aquifers are found in the Amman-Wadi Sir (B2/A7) formation which underlain by the shallow aquifer unit of Rijam (B4). The brackish aquifer may exist at depths of 200-300 m and 500-700 m with total dissolved solids of 2,000-5,000 mg/l. The piezometric data are very few, the depth to the water table from the ground surface is expected to be only 100 to 200 m in wadi depressions including Azraq and Shirhan. This brackish groundwater potential is situated 100-150 km east of Amman, which suggests a potential source of water supply to the Amman municipalities if cost-effective desalination can be performed. The most important cost factor in the desalination is the energy cost, which can be controlled by introducing off-peak power operation taking into account the dominant steam-power generation with high peak demand in Jordan. The recent innovative research in the high-molecular membrane industry could provide the necessary energy saving or low-pressure type of reverse osmosis (RO) modules for brackish water demineralization.

In southern Jordan, a large amount of exploitable brackish groundwater is conceivably stored in the deep sandstone aquifers such as the Kurnub and Khreim formations, of which the nature and potential use for desalination and water supply are described in the following case study of section 4.5.

4.4.3 Seawater

Desalination of seawater for M&I water supply is the commonest method in the oil producing Gulf countries. The cost of the conventional distillation by the dominant multi-stage flash (MSF) method will be too expensive, except for specific projects in Jordan. Furthermore a small scale MSF desalination, for example to satisfy the local water demand in Aqaba municipal water supply, has a scale demerit to achieve the cost

feasibility. Seawater desalination by reverse osmosis (RO) process may improve costs even for small-medium scale desalination plants. Aqaba steam-power station might be viable as a co-generation system either with MSF or RO. Hybrid desalination with MSF-RO and power will be a key application for regional water resources planning in Aqaba district.

4.5 A Case Study on the Hydro-Powered Brackish Groundwater Desalination by Reverse Osmosis (RO): A New Proposal of Co-generation Application in Disi-Aqaba Water Supply Scheme

Aqaba with population of 42,400 is the largest city in the Ma'an Governorate and the fourth largest city in Jordan (Ref.4.5-1).

The Aqaba port is a strategic point of the commerce and industry of Jordan. The highest growth of the water demand is projected in the Ma'an governorate from $11x10^6m^3/y$ in 1990 to $29x10^6m^3/y$ in 2005, in which the major increase in water demand is dependent on the anticipated growth in the industrial complex (Ref.4.5-2). The constraints of the Aqaba regional development will be a definite shortage of water supply for municipal and industry, taking into account the current dependence of source of water supply from the non-renewable or fossil groundwater in the deep sandstone aquifer of Disi about 50 km northeast from Aqaba town.

Groundwater mini-hydro and its application for brackish groundwater reverse osmosis (RO) desalination is demonstrated in this Section, in which the mini hydro-power plants and RO desalting plant are annexed in the existing Disi-Aqaba water pipeline system. A new proposal for the co-generating application includes the following objectives to sustain the regional economic development of the driest commercial and industry center of Aqaba in Jordan.

- Retrieval of the potential energy in the existing groundwater pipeline (trunk main) system, which is being wasted.
- Conservation of non-renewable fresh groundwater in Disi aquifer to replace it by developing brackish groundwater in the Kurnub sandstones.
- Desalting brackish groundwater by hydro-powered reverse osmosis (RO) process to retrieve the hydro-potential energy in the existing water pipeline (trunk main).
- Testing the technical feasibility and cost-effectiveness of the proposed co-generating application with mini-hydropower and RO desalination.
- Conservation of energy and water resources by introducing hybrid hydro-powered reverse osmosis (RO) desalination with energy recovery system.

4.5.1 Background of Aqaba water supply

Aqaba is situated at the head of the Gulf of Aqaba on the Red Sea and at the southern end of Wadi Araba (Fig.4.3-1). Only 40 years ago Aqaba was a

sleepy little fishing village whose small population lived in mud brick houses nestling among palm groves which are still a delightful feature of the town.

However, as well as being Jordan's only outlet to the sea, Aqaba occupies a strategic position on the Gulf, providing an important link between the Middle East and East Africa. Aqaba port was a strategic point in the war between Iraq and Iran in the 1980s, and it was again focused in Gulf War of 1990-91. It now handles all the sea imports and exports of Jordan as well as much of those for Iraq, Syria and the Lebanon. The volume of traffic through the port has increased spectacularly over the past few years before Gulf War and Aqaba is still an important commercial center. This expansion has been accompanied by a rapid growth of industrial development along Jordan's limited coastline.

As a small fishing town, water needs were readily met from shallow wells which were excavated near the sea and which produced sufficient quantities of good fresh water permeating to the sea through the alluvial fan of Wadi Araba. But shortly after the World War II as demand for water increased, boreholes were drilled further inland and well No.1 was constructed in 1958, 2 km north from the sea. In 1964 Well No.2 was drilled further inland and water pumped to a 2,250 m^3 reservoir, augmenting the supply.

Over-pumping of these wells resulted in sea water intrusion. To satisfy the increasing demand, additional holes were drilled in the deep alluvial deposits of Wadi Yutm. Until middle of 1970s these wells have provided the whole of the water supply to Aqaba, but with the limited yield of the alluvial aquifer, there have been increasing shortage especially during the hot summer months and rationing has been necessary for a number of years.

4.5.2 The Disi aquifer

Since the heart of the project is the water source, and the success of the scheme depends entirely on correct assessment of the yield of the aquifer, intensive hydrogeological studies have been carried out since 1976 (Refs.4.5.2-1&2).

Groundwater flow through the Disi area originates in the Um Sahm mountains, discharging in a north easterly direction around each end of the geological feature named the Kharawi Dyke which forms a natural underground barrier. The new wellfield at Qa Disi will intercept a large

proportion of the flow at present passing round the north western limit of the Dyke and will slowly develop in the groundwater a large depression, centered at Disi. The extent and rate of development of this depression was simulated by digital computer models (Ref.4.5.2-3). From the model simulation studies which have been carried out it was concluded that the aquifer will support a maximum abstraction from the Qa Disi area of between 17-19x$10^6$$m^3$/year for at least 50 years. The maximum capacity of the scheme has therefore been fixed at 17.5x$10^6$$m^3$/year.

4.5.3 Aqaba-Disi water supply scheme

The Aqaba Water Supply Scheme comprises four main elements: 1) the wellfield and headworks complex, 2) the trunk main from Disi to Aqaba, 3) the trunk distribution main from Aqaba to the Fertilizer Factory near the Saudi border and 4) the distribution network within the town (Fig.4.5.3-1). The scheme was completed and in operation by the end of 1981.

Headworks

For the first stage development to exploit 10x$10^6$$m^3$/year, seven boreholes 400 m deep have been drilled to penetrate the Disi sandstone aquifers. The finished diameter of the upper half of the borehole is 219 mm and of the lower half 171 mm. The boreholes are each equipped with twin submersible pumps delivering water through collecting mains into a reservoir from where the water gravitates to Aqaba. Power for the pumps is provided by a power station equipped with four diesel generating sets each 550 KW.

Trunk Mains

A ductile iron trunk main 800-450 mm in diameter and 92 km long carries the water to Aqaba and southwards to the Fertilizer Factory near the Saudi border. Pressure is broken at three locations along the pipeline to limit pressure to a maximum of 25 bar as shown in profile of the trunk main (Fig.4.5.3-2).

A large reservoir, capacity 9,000 m^3 is sited immediately north of Aqaba and provides a buffer to absorb fluctuation in demand downstream and reservoir storage in the event of a pipeline failure. A 4,500 m^3 reservoir is constructed at the Fertilizer Factory to provide service storage for the factory and for other industrial developments expected in the same area.

Project Cost

Total cost of the Aqaba-Disi water supply project was estimated at US$ JD.11x10^6 (=US$44x$10^6$: 1978 price of Jordan Water Supply Corporation), including the following major cost elements:

Major cost element	US$
Borehole construction	5,464,000
Borehole pumps	1,110,000
Generating (diesel) equipment	2,648,000
Pipeline/Trunk main	21,172,000
Distribution	13,104,000
Valves and specials	444,000

Total cost of the Aqaba-Disi water supply project is estimated at US$ 74.8x10^6, by assuming the price escalation rate at 170 % form 1978 to 1990 (IMF International Financial Statics ; 1990/1978).

4.5.4 Application of mini-hydro development

The theoretical hydro-potential of the Qa Disi wellfield which is situated at an elevation of 840 m above sea level is preliminarily estimated to be 5.2 MW, by assuming a flow discharge of 0.663 m^3/sec with an effective difference head of water at 800 m (95 % of a total head). The hydro-potential energy is being wasted by breaking the water pressure at three locations along the pipeline to limit pressure to a maximum of 25 bar which is the ceiling bearing capacity of the ductile iron steel pipe used in this project.

This study aims to evaluate the effectiveness of the hydro-potential use in the trunk main between Disi and Aqaba, by installing a series of mini-hydro stations in the existing trunk main at each difference head of water of about 200 m. The head difference between the collecting reservoir (840 m) and the terminal reservoir (220 m) is 620 m. Hydro-potential of the existing trunk main between collecting reservoir and terminal reservoir is estimated to be 3.2 MW. Following equations are used to evaluate the hydro-potential and power.

$$Pth = 9.8*Q*He$$
$$P = Pth*Ef$$
$$Wp = 365*24*Gf*P$$

where; Pth : Hydro-potential (KW)
Q : Flow discharge (m^3/sec)
He : Effective difference head of water (m)
P : Installed capacity (KW)
Ef : Synthesized efficiency (-)
Wp : Potential power generation per annum (KWh)
Gf : Generating efficiency

The flow discharge is assumed to be 17.5×10^6/year (0.555 m^3/sec), which is equivalent to a design capacity of 0.663 m^3/sec with a unit operating time of 21 hour per day. The effective difference head of water is estimated to be 589 m, by assuming a 5 % friction head loss.

From the optimal layout of the pressure pipeline system (Fig.4.5.3-2), two hydro-power stations No.1 and No.2 would be installed at ground elevations of 630 m and 410 m, respectively.

By assuming the synthesized efficiency of 0.80 and generating efficiency of 0.873, the installed capacity and annual power output are estimated to be 2.0 MW and 15,900 MWh/year, respectively, of which the details are shown in Tab.4.5.4-1.

4.5.5 Conservation of fossil groundwater in Disi

Disi is currently exploited for M&I water supply for Aqaba (8.5 $\times 10^6 m^3$ per annum), and for irrigated agriculture. Recorded abstraction for 1986 is 14.5 $\times 10^6 m^3$ but 3,000 ha have now been developed for agriculture, implying an extraction of over 30 $\times 10^6 m^3$ per annum. Licenses have been granted to drill wells for irrigation over 20,000 ha, implying annual abstraction of over 200 $\times 10^6 m^3$ per annum. It should be noted that the aquifer is extremely expensive to develop for irrigation of growing wheat: the water table lies 250-300 m below the surface and the drilling requires 500-1,000 m of depth. Furthermore Disi represents with Al-Wuheda dam, Jordan's last substantial unexploited water resource, and should be regarded as a strategic water reserve. According to the World Bank study in 1988 (Ref.4.5.5-1), it was recommended that the aquifer be monitored at present abstraction levels to confirm the most reasonable long-term yield for M&I supply in South Jordan.

4.5.6 Brackish groundwater resources

The Kurnub Group of the lower Cretaceous age underlies almost the entire Jordan, which is composed of sandstones with poorly to very well cemented facies interbedding silts, clays, shales, and occasionally dolomitic layers, has been conceived deep aquifer unit to have a large storage potential with maximum thickness of about 1,000 m or more. The water table is, however, as deep as about 200-300 m or more from the ground surface and permeability and salinity vary in place and depth. Quality of groundwater varies from 300 to 2,800 mg/l of the total dissolved solids, but it is conceived mostly brackish nature except the minor recharging areas in the northwestern Highlands.

In the southern part of Jordan, the Disi aquifer is unconformably overlain by Khreim formation which has a thickness of about 100-300 m and stores brackish groundwater in the upper to middle section. Brackish groundwater is also found in the Kurnub formation along the zone of the southern edges of the Jafr basin at about 25 km north from the Disi. (Fig.4.5.3-2) The depth of pumping water level will range from 100 to 250 m in the Khreim formation between Disi and Muddawwara, while it is as deep as 230-325 m in the Kurnub formation along the southern fringe of the Jafr basin. These brackish waters with salinity between 1,000-5,000 mg/l of the total dissolved solids in the southern Jordan would mostly be fossil with limited amount of natural recharge from the rain. The storage potential was, however, estimated to be as large as 16,600 $\times 10^6 m^3$ (Ref.4.5.6-1). The brackish groundwater development with desalination may have a chance to replace the amount of existing fossil groundwater abstraction from Disi aquifer.

4.5.7 Hydro-powered brackish groundwater desalination by RO

The co-generation system, which is an application of annexing a brackish groundwater reverse osmosis (RO) desalination unit to the groundwater-hydro system. Hydro-potential energy as differential head of water between the Disi wellfield (840m) and Aqaba terminal reservoir (220m) is estimated to be 620 m in total; two-thirds of the differential head of water will be used to generate the hydro-powered electricity and one-thirds of the head at 190 m will be used to produce the hydraulic pressure for permeating the RO (Fig.4.5.3-2). The proposed co-generating system for Disi-Aqaba water supply scheme includes the following objectives and measures;

- Developing clean energy of the hydro-potential in the existing water trunk main between Disi and Aqaba, amounting to 620 m of difference head of water; indirect conservation of fossil (oil) energy to generate

electricity.

- Co-production of hydro-powered electricity and fresh water for Aqaba M&I water supply.
- Development of brackish groundwater resources in the Khreim and/or Kurnub formations; conservation of fossil groundwater in the Disi aquifer which is being abstracted for M&I water supply to Aqaba since 1970.
- Direct use of hydro-potential energy for generating pressure on the reverse osmosis; utilization of a part of hydro-potential energy at 150-250 m of differential head of water in the trunk main, of which pressure at 15-25 kg/cm^2 is an optimum requirement for operating reverse osmosis.
- Pioneer research on the brackish groundwater reverse osmosis desalination in Jordan: evaluation of cost-effectiveness of minimizing the operation and maintenance cost which is a major cost factor of the desalination engineering.

The brackish groundwater with amount of 0.663 m^3/sec will be pumped from the Khreim and/or Kurnub formations underlying in the area of Disi - Muddawwara - Shidiya, and it is conveyed to a collecting reservoir at elevation 840 m. The design value of the salinity of the feed water is 4,000 mg/l of TDS.

The brackish water flow down from the collecting reservoir (E.L=840m) to the desalination plant - terminal reservoir (E.L=220m), through existing pipeline system passing by two mini-hydro-power stations by steps; the 1st mini-hydro-power station (E.L=630m) and the 2nd mini-hydro-power station (E.L=410m). The estimated installed capacity and annual power output of the two stations are estimated to be 2,078 KW and 15,900 MWh per annum, respectively.

The hydro-powered reverse osmosis (RO) system is composed of three parts; 1st part of the pre-treatment unit, 2nd part of the pressure pipeline unit, and the 3rd part of the RO unit. The pre-treatment unit is to be sited just beside the outlet of the 2nd mini-hydro-power station (E.L=410m), including dual-media filters (hydro-anthracite & fine sands), and cartridge filters (5 micron size). After passing through the cartridge filter, the flow water is connected with a pressure pipeline (trunk main between 410 m and 220 m) to obtain the hydraulic pressure at 18 kg/cm^2, which is directly used to transfer the osmosis pressure to be needed to permeate the RO membrane. The main heart of the RO unit is a membrane, which is a low-pressure type, spiral wounded compost type with 8

inch diameter, including the following specifications:

- Salt rejection rate : 87.5%
- Design operating pressure : 18 kg/cm^2
- Design quantity of permeate : 30 m^3 per day
- Maximum operating water temperature : 40°C
- pH of feed water : 6.0-6.5 (be controlled at pre-treatment unit)

A unit line of the RO vessel consists of a series circuit with six modules. Recovery is estimated to be 70 % of the feedwater, including 40,100 m^3/day of permeate with salinity at 500 mg/l of the total dissolved solids (TDS) and 10,200 m^3/day of brine reject with TDS at 17,700 mg/l. The effective pressure of the brine reject is estimated to be 15 kg/cm^2 by assuming the friction loss of 3 kg/cm^2 in the RO circuit. The potential energy recovery from the RO brine reject is preliminarily estimated to be 136 KW by assuming total efficiency of turbine-generator at 80 %, which generates 0.81x10^6 KWh per annum of electricity with load factor at 68 %. Another alternative to develop 0.72 m^3/sec of brackish groundwater may produce 15.8x10^{6}m^3 of permeate, which is equivalent to the current water supply volume of 15.8 x10^{6}m^3 per annum.

Unit Water Cost

Total investment cost for the proposed hydro-powered reverse osmosis (RO) desalination, which is based on 1990 prices with 8 % interest during three years construction is preliminarily estimated to be US$ 56,088,000 with annual capital cost at US$ 2,677,000 as shown below:

Major Capital Cost Element	US$(1990 price)
- Pre-treatment	6,468,000
- Desalting plant	10,306,000
- RO membrane/equipment	12,417,000
- Control and operating system	871,000
- Appurtenant works	3,954,000
- Powerline and substation	1,143,000
- Energy recovery/turbine	255,000
Sub-total	35,414,000
Design and construction management:	9,111,000
Financial expenditure:	11,563,000

The annual cost for the operation and maintenance is estimated to be US$ 2,631,000 including the following major cost elements;

Major O&M Cost Element	US$ per annum
- Labour	544,000
- Material supply	272,000
- Chemicals	1,089,000
- Membrane replacement	726,000
sub-total	2,631,000

The above cost estimates are based on 1990 price and including following assumptions;

- Plant life : 20 years
- Membrane life (replacement) : 3 years
- Cost benefit from energy recovery is not included.
- Costs for source water (groundwater) and pipeline/distribution are not included.

The unit water cost of the hydro-powered reverse osmosis desalination for the design annual product water of $14.6 \times 10^6 m^3$ is estimated to be US$0.41/$m^3$.

Cost for Groundwater Hydro-power

The capital cost for the proposed two unit of mini hydro-power stations (No.1 and No.2), which equip with 1 MW pelton-turbine each, is preliminarily estimated to be US$ 2×10^6, accounting only 5.7 % of the capital cost of the reverse osmosis (RO) unit. The generated power with 16×10^6 KWh per annum will be effectively used to supply electricity for pumping groundwater wells and others to recover the investment cost for the plants. Other costs of existing hydraulic structures such as pipelines and reservoirs are referred in Section 4.5.3.

Other Development Alternatives

After completing the use of hydro-potential energy in the recovery unit, the pressure-free brine water with salinity 17,700 mg/l of TDS would be directly disposed in the Aqaba bay where it combines harmlessly with 45,000 mg/l of salinity seawater, or it could be jointly used to blended with the potential distillated water source if the seawater desalination by thermal or solar system were constructed. The Aqaba seawater

desalination is an important key of supplying fresh water from the non-conventional source, which may includes the following four options;

i) distillation by conventional MSF
ii) reverse osmosis (RO) desalination
iii) solar-distillation
iV) hybrid MSF and RO desalination

Non-conventional water resources development alternatives including hydro-powered brackish groundwater desalination and seawater desalination in the Aqaba are to be integrated in a frame of regional water master plan which makes it possible of self-supplying the region.

REFERENCES (4.5)

Ref.4.5-1
Department of Statistics of Jordan, 1988, "Statistical Yearbook : 1988", No.39, pp.23-25.

Ref.4.5-2
World Bank, 1988, "Jordan Water Resources Sector Study", World Bank Report No.7099-JO, pp.30-33.

Ref.4.5.2-1
Howard Humphreys Co.,Ltd., 1977, "Aqaba Water Supply, Hydrogeological Study Report", Natural Resources Authority of Jordan

Ref.4.5.2-2
Howard Humphreys Co.,Ltd., 1978, "Report on Pumping Simulation of Proposed Qa Disi Phase I Boreholes", Natural Resources Authority of Jordan

Ref.4.5.2-3
Howard Humphreys Co.,Ltd., 1982, "Modeling of the Disi Sandstone Aquifer - Southern Desert of Jordan", Natural Resources Authority of Jordan

Ref.4.5.6-1
Natural Resources Authority (NRA) - Howard Humphereys Ltd., 1986, "Groundwater Resources Study in the Shidiya Area", Main Report, pp.49-112.

Tab.4.5.4-1 Installed Capacity and Annual Power Output of Disi-Aqaba Groundwater-hydro Scheme

Power Station	Elevation (m)	Effective Head (m)	Installed Capacity (KW)	Potential Power Generation (MWh/y)	
No.1	630	200	1,039	7,946*	-
No.2	410	200	1,039	7,946*	-
No.3	220	180	-	-	810**
(Total)			(2,078)	(15,900)*	(810)**

Remarks: * Hydro-power potential of groundwater-hydro
** Energy recovery from hydro-powered reverse osmosis (RO) desalination.
1) Friction head loss is assumed to be 5 % of the total head.
2) Synthesized efficiency is assumed to be 0.80.
3) Load factor of mini hydro-power generation at 83.7 % (0.555/0.663).
4) Elevation of the collecting reservoir is at 840 m above sea level.
5) Elevation of the terminal reservoir is at 220 m above sea level.

4.6 Non-conventional Water Resources Development in National Water Master Plan of Jordan

Potential contribution of the non-conventional water resources development including the proposed co-generating application with hydro-powered reverse osmosis (RO) desalination in a national water master plan of Jordan for the twenty-first century is studied herewith, taking into account that 95 % or more of the national renewable water resources are going to be fully exploited to meet the increasing demand, especially in the population centers, by the end of 1990s. Non-conventional water resources development will be increasingly important in formulating a national water master plan for the twenty-first century.

4.6.1 Development alternatives and priority

The general characteristics of non-conventional water resources are that they are generally more complex in development and operation than conventional sources, and are almost always more expensive. In most cases non-conventional measures involve considerably more risk than conventional solutions, and no single non-conventional solution is suitable for all water short-areas. At the same time, by providing water to an arid area, non-conventional water resources may offer an opportunity for development previously considered impossible.

In any situation where a conventional source of water can be developed, it will almost always be not preferred to a non-conventional source. However, if conventional groundwater or surface water supplies are inadequate, consideration should be given to some of the non-conventional water resources techniques. No single non-conventional solution is suitable except an experimental development. Accordingly, the non-conventional water resources are considered here in the context of a national water master plan for Jordan.

A) Conventional Alternatives (namely fresh renewable surface water and groundwater.)

The main potential for further surface water utilization is through construction of new water storage facilities on the Yarmouk river and rift-side wadis, including:

- Al Wuheda dam on the Yarmouk river
- Northern Ghor side-wadis development (Karameh, Kifranja, Al-Yabis and raising of Kafrein dam)
- Southern Ghor side wadis development (Wala recharge dam, Nkheila dam, Tannour dam)

Most important of these is the Al Wuheda dam, of which the gross capacity is 230 $x10^6m^3$. The total gross water storage potential of the proposed projects was estimated to be 300-350 $x10^6m^3$.

The construction of storage dams in Jordan is extremely costly. New investments for storage dams in Jordan can be justified only for supply of municipal and industrial water, or for irrigation of high value or high yielding crops using water conserving technologies.

The potential for further renewable groundwater resources development is small. Current intensive abstraction amounts to 333 $x10^6m^3$ per annum, which accounts for more than 90 % of the estimated long-term safe yield of 356 $x10^6m^3$. More attention is to be given not for development but for management of the aquifer system, taking into account the sustainable development concept to avoid the over-drawing and deteriorating quality.

Non-renewable groundwater resources, of which the main potential lies in the fossil aquifer of Disi, is Jordan's last major exploitable source of good quality water after Al Wuheda dam. The Disi groundwater scheme will require expensive conveyance over a distance of about 350 km to the population centers of the north-west highlands (Amman). The mining yield potential, which has been evaluated by a series of computer model simulation studies, has been estimated to be 110 $x10^6m^3$ per annum for over a 100 years. This non-renewable alternative should be regarded as a strategic reserve, guided by careful monitoring of the aquifer and stepwise development over a decade.

The Disi aquifer is a part of an extensive inter-state deep sandstone aquifer system in the Arabian peninsula underlying southeast of Jordan and the northwest of Saudi Arabia. In the early 1980s, Jordan feared that hydraulic influence of Saudi Arabia's intensive abstraction might cross the state boundary. However, Saudi's rapid increase in abstraction from the Tabuk wellfield between 1982 and 1985 dropped the pumping levels by more 120 m of water head. In its Fifth (1990-1995) Development Plan, the government of Saudi Arabia has just decided to cut part of the national water supply by decreasing the abstraction of non-renewable groundwater

for the supply of irrigation. From the experience in Saudi Arabia, the economic limit of abstraction from the Disi aquifer will probably be reached sooner than expected.

B) **Non-conventional Alternatives**, which comprise desalination of saline waters such as brackish groundwater and seawater, waste-water re-use, weather modification and transportation of water by inter-state pipeline and tanker as listed below:

- Desalination of brackish groundwater and seawater, including co-generation,groundwater-hydro and hydro-powered reverse osmosis (RO) desalination.
- Reclamation and re-use of municipal sewage effluents.
- Weather modification.
- Inter-state water transportation, including "Euphrates-North Jordan transmission scheme" and "Peace Pipeline project".

Brackish groundwater reserves are found in most deep aquifer system including the middle to the lower Cretaceous sequences such as lower Ajlun and Kurnub formations. In the extensive eastern desert, groundwater has generally brackish nature, and is even found in shallow aquifer systems including the Amman-Wadi Sir (B2/A7) formation. The salinity of such brackish groundwater is in the range of 2,000- 5,000 mg/l of total dissolved solids, which fit with the effective range of reverse osmosis (RO) desalination.

In 1982, Jordan's first reverse osmosis (RO) desalination plant with an installed capacity at 800,000 gal/day (300 m^3/d) was commissioned in Zarqa oil refinery, where the supply source of the groundwater had been contaminated with increasing salinity from 336 mg/l of TDS in 1960s to 1,700 mg/l of TDS in 1980 (Ref.4.6.1-1).

The most promising brackish groundwater resources are to be found in the Amman-Wadi Sir (B2/A7) formation in and around the Azraq springs about 100 km east of Amman/Zarqa. The prior use of the brackish groundwater reverse osmosis (RO) desalination of the Azraq wellfield will be given to M&I water supply, taking into account that the piezometric head of the B-4 aquifer system is being lowered with increasing salinity by over-pumping.

The Azraq brackish groundwater wellfield has the following characteristics:

- Piezometric elevation at 500 to 600m. (Amman is at 800-1,000 m)
- Depth to groundwater table 50 to 200 m.
- 100 km distant from population center of Amman.
- Desirable salinity range between 1,000 and 5,000 mg/l of the total dissolved solids (TDS) for demineralizing brackish groundwater by low-pressure type of reverse osmosis membrane.

Brackish groundwater in the deep aquifer system such as the Kurnub formation has a depth to water table of more than 200-250 m. The storage potential for brackish groundwater in the deep aquifer system is more than that for the fresh water reserves in the shallow aquifer system. The hydrological characteristics of the brackish groundwater system are, however, between renewable and non-renewable. Careful assessment and management of the brackish groundwater resources would be required to sustain the development by application of desalination.

Seawater desalination is only possible in Aqaba bay. Small scale seawater reverse osmosis desalination has been carried out for boiler water supply in Aqaba steam-power plant since the mid-1980s. It is quite clear that the cost of seawater desalting is usually three to five times as high as brackish water desalting (see Annex-I). Aqaba water supply is being performed by developing fossil groundwater in the Disi aquifer, and it is recommendwd in this study to replace it by brackish groundwater in the adjacent Kurnub aquifer by applying hybrid hydro-powered reverse osmosis desalination, which is expected to reduce both the cost and the energy requirement and to sustain valuable groundwater resources as a long-term policy. Seawater desalination to cooperate with the National Water Carrier of Jordan, which aims to convey water from the sea to the population center of Amman, would requires lifting water about 1,000 m or more. At the present time seawater desalination has no feasibility except for the supply of water for M&I in the Aqaba coastal region. There is still the opportunity desalinate seawater and to lift the product water up to 1,000 m elevation, by developing new renewable energy alternatives including solar energy conversion and ocean thermal energy conversion in the hot and arid climatic region of the Aqaba bay.

The development priority is given to the desalination of brackish groundwater for the municipal water supply, including two possible feasibility studies;

- Brackish groundwater desalination at Azraq for Amman water supply.
- Hybrid hydro-powered brackish groundwater reverse osmosis desalination

from the Kurnub aquifer for Aqaba water supply.

Reclamation and re-use of municipal sewage effluents as additional water resources continue to increase the potential water resource corresponding to the increases in water demand and supply in Greater Amman which consumes about 60 % of the total water supply in Jordan. Almost all the sewage effluents in the Amman-Zarqa region are discharged into the Zarqa river system whether treated or not. The Kherbet Samra sewage plant, which collects the effluents from metropolitan Amman and Zarqa, treated 33.2×10^6 m^3 in 1989, and discharged it to the Zarqa river to enhance the base flow of the river system. The King Talal dam on the lower reaches of the Zarqa river subsequently harvests all the sewage effluents which flow into the river system. The Zarqa is mainly polluted by the untreated sewage effluents in the upper reaches, while there is some natural purification in both the flowing and impounding processes. The sewage effluents which are harvested in the King Talal dam is exclusively re-used for irrigation water supply in the Ghor (Jordan Valley). The exceptional topography of the north-west plateau and escarpment to the Jordan Valley permits re-use for irrigation in the Valley of the bulk of the return flow of water used in the uplands.

The weather modification alternative, which includes artificially induced precipitation or cloud seeding, could probably provide an inexpensive source of water under certain meteorological conditions. However, specific verification is necessary in each mountainous region of Jordan. From experiments in the upper Jordan river in Israel, encouraging results were obtained under the certain orogenic and climatological conditions on the southern slopes of the anti-Lebanon range (Mt. Hermon) where the ground elevation exceeds 1,500-2,000 with annual rainfall of more than 500-1,000 mm per annum (Ref.4.6.1-2). In Jordan, the potential area for cloud seeding is limited to Ajlun mountain. Cloud seeding may not a promising application, however, taking into account that the orogenic and climatic conditions of the Ajlun mountain zone are less attractive than those of the upper Jordan river in Israel. Cloud seeding on the southeastern slopes of Mt.Hermon in Syria, where the headwaters of the Yarmouk river originates, may have the same effect as experienced in Israel. International cooperation is needed to develop a weather modification program.

Inter-state water transportation alternatives include the Euphrates transmission scheme to Jordan and the Peace Pipeline scheme. The transport of water by tanker and barge is a more remote alternative for

Jordan, taking into account that the main demand area is in northern Jordan where the ground elevation exceeds 800-1,000 m.

A feasibility study on the Euphrates - North Jordan Transmission Scheme was made in 1983. This would transport water from the Euphrates river in Iraq to North Jordan (Amman) by water pipeline. Al Qaim, situated on the Euphrates river where it enters Iraq at elevation of 163-165 m, offers the highest abstraction level thereby minimizing the overall static lift between the river and the delivery point in North Jordan. The scheme was scheduled to abstract up to 160 $\times 10^6 m^3$ (5 m^3/sec) of water annually form the Euphrates river. The pipeline system was designed for a 5 m^3/sec rated capacity, 605 km in length, 1.5-2.0 m diameter, 830 m static lift, and 1,380 m of total pumping head. (Ref.4.6.1-3) Such an inter-state water transport scheme might be technical and economically feasible if the water were used for domestic purposes.

The ambitious Turkey's Peace Pipeline proposal, which aims to transfer water from the Ceyhan and Seyhan rivers in Turkey to eight states in the Arabian peninsula, includes the assumed potential water delivery of 600,000 m^3/day (219 $\times 10^6 m^3$/year) to Jordan.

Both the 'Euphrates-North Jordan Transmission' and the 'Peace Pipeline' have been put aside, however, owing to political constraints including inter-state riparian right questions on the Euphrates river in which the use of water as a political weapon has been increasing. These inter-state water transportation projects have now been emphatically rejected by all Arab states who have said that if necessary they will depend on non-conventional waters in their territories including seawater desalination. Development priority is therefore likely to be given to marginal waters as non-conventional water resources, taking into account not only technical-financial-economic feasibility but also political feasibility.

4.6.2 The development strategy for desalination in the national water master plan

Desalination to develop previously unusable brackish groundwater and seawater as sources of potable water, including energy saving applications of co-generation and hydro-powered reverse osmosis processes, should be included in the context of a master plan for water resources development of Jordan. In such a plan, the use of this relatively expensive water treatment process should be entered into with caution, after the possibility of utilization of more conventional and possibly less

expensive sources of water have been carefully weighted. The master plan should include measures for the conservation and optimum development and management of all these natural resources. Steps should be taken to ensure rational use of water and minimize wastage. Water quality should be maintained at acceptable levels, and an appropriate pricing policy should be established including the diversion of water from irrigation to municipal and industrial use. The use of fossil groundwater in Disi for growing wheat is one particularly questionable application.

Taking into account the planning period of a water master plan for 20 to 30 year, steps such as short-term (1990-2000), mid-term (2000-2010), and long-term (2010-2020) are used to delineate the development stage of the non-conventional water resources in a master plan.

i) Short-term (1990-2000) development strategy;

- Water conservation
- Al Wuheda dam
- North Jordan National Water Carrier
- Storage dams on the side wadis
- Retention dams on the wadis, including Wala groundwater recharge dam
- Renewable groundwater development in southern Jordan
- **Waste water treatment and re-use**, Zarqa river - King Talal dam system

ii) Mid-term (2000-2010) development strategy;

- Diversion of water from irrigation to M&I, including application of more efficient irrigation techniques.
- **Desalination of brackish groundwater**, including co-generation and hydro-powered reverse osmosis applications.
- **Desalination of seawater**, including solar energy and ocean thermal energy conversion applications.
- Mediterranean-Dead Sea conduit scheme, including **solar-hydro and hydro-powered reverse osmosis desalination** by joint development with Israel and Palestine/Jordan.

iii) Long-term (2010-2020) development strategy;

- **Inter-state water transportation**, including pipeline, tanker and barge applications.
- **Weather modification**, including upper Jordan and Yarmouk rivers artificial rain project to be performed jointly with Israel, Syria and

Jordan.

The most important with highest priority scheme of the Al-Wuheda dam and other storage dams on the side-wadis of the East Bank, which are conceived to minimize the inflow of the Dead Sea, are to be linked with the Mediterranean-Dead Sea conduit scheme in the context of an inter-state basin development master plan. These storage or flood retention or groundwater recharge dam schemes for which the reduction of the inflow from the river system to the Dead Sea will be beneficial for both Jordan and Israel. Further discussions with water politic issue of the inter-state basin development of the Jordan river system are shown in the following chapter V.

REFERENCES (4.6)

Ref.4.6.1-1
A.K.Alawin, 1983, "Choosing the Best Desalination Arrangement: The Jordan Petroleum Refinery System - A Case Study", Second Arab Water Technology Conference, Dubai, United Arab Emirates, Organized by Middle East Water and Sewage Journal, pp.15.1-15.10

Ref.4.6.1-2
Elisha Kally, 1974, "Extension of Israel's National Water System as a Function of Artificial Rainfall Prospects, Water Resources Research, vol.10, No.5, pp.917-920

Ref.4.6.1-3
National Planning Council of Jordan and Howard Humphreys & Partners, 1983, Water Supply Project from the River Euphrates", Vol 1, Technical Assessment, pp.1-208.

V. APPLICATION OF SOLAR-HYDRO AND CO-GENERATING HYDRO-POWERED REVERSE OSMOSIS (RO) DESALINATION IN THE INTEGRATED JOINT JORDAN RIVER DEVELOPMENT; ISRAEL-PALESTINE-JORDAN RIPARIAN ISSUE

5.1 Background and Objectives

5.1.1 Background

By the year 2000, water --- not oil --- will be the predominant resources issues of the Middle East. This situation is particularly acute in the non-oil-producing countries such as Israel and Jordan, in which the renewable water resources such as fresh surface waters and groundwater will have already been exploited or is going to be fully developed in these two states.

Concerns over the global environment and the Gulf (oil) crisis in August 1990's Iraq invasion to Kuwait have improved our understanding of the importance of clean energy such as non-polluting hydro-electric power.

A solar-hydro scheme by a Mediterranean-Dead Sea (MDS) Canal was proposed by Israel in 1980. The scheme which has multiple socio-economic and political ramifications was intended to convey water from the Mediterranean Sea to the Dead Sea via canals and tunnels utilizing the height difference of close to 400 m to generate 600 MW electricity. In addition, proposals were made to use the water for cooling nuclear power stations rated at 1,800 MW, and to investigate the feasibility of generating 1,500 MW from Dead Sea as a solar pond. There has been no presentation of the concept of sharing resources with other countries and no effort at joint development. The MDS project was soon put aside, owing to the strong opposition by Arab states and others with the confusion and drop of the world oil market price in 1984. Major constraints of realizing the 1980-MDS project were:

- Jordanian fears of environmental and economic effects - these may be no longer be valid.

- Neglecting of the concept of shared resources including the riparian issue on the Dead Sea and no effort at joint development between the two states - this could now be removed by linkage of MDS and Al-Wuheda dam project.

- Territorial questions on the West Bank - with cooperation from the Palestines these could be dealt with separately from cooperation in water development.

There are now several changes in the political situation after the Iraq invasion to Kuwait in 1990-1991, that may facilitate a comprehensive resolution of Israel-Arab problem. This may make integrated development not only technically and economically feasible but politically desirable and urgent.

5.1.2 Objectives

To delineate the strategic dimensions of water problems in one of the world's driest region such as Israel where the peace of the world has been at risk for more than forty years.

To evaluate the technical feasibility and cost effectiveness of the proposed co-generating system which combines solar-hydro scheme of MDS scheme of generating electricity with hydro-powered seawater reverse osmosis (RO) desalination of producing fresh water.

To elaborate an inter-state basin development master plan of the Jordan river system, taking into account the non-conventional alternatives with advanced water technologies.

In recent days, talk of the much-discussed Mediterranean-Dead Sea (MDS) Canal has again been revived with the end of the Gulf War and the international political drive for peace in the Middle East and an end of the Arab-Israel conflict.

5.2 **Water Resources of Israel**

In an average year rainfall over Israel is estimated to be 5,000 $x10^6m^3$ per annum: about 3,500 $x10^6m^3$ per annum of this are lost through irretrievable absorption-evaporation, leaving only 1,500 $x10^6m^3$ per annum to the country's water reservoirs on the surface and underground.

The characteristic of Israel's water resources is shown as below:

- Rains fall in winter only with wide fluctuation ranging from around 25 % of the long-term average in dry years to 160 % of the long-term average in particularly rainy years.
- Most water sources are situated in the northern and central region of the country.
- Most water sources are located at low elevations, from which water must be pumped with high operation and maintenance costs.

Owing to the substantial fluctuations in annual rainfall, groundwater aquifers are conceived as more reliable potential reservoirs than surface storage. About one-third of Israel's water use is dependent on surface water resources, and mainly the Jordan river. Groundwater is therefore a major source of supply, amounting to two-thirds of the national consumption. The aquifer connected are dependent on limestone formations 300 to 400 m thick and deep sandstone formations of 600 to 800 m thick. The deepest groundwater wells penetrate to a depth of 1,000 m or more.

Marginal waters or non-conventional waters are primarily composed of brackish groundwater, seawater and treated sewage effluents, which are looked to for additional water supplies available for the next decade.

5.2.1 Potential of water resources

The potential of renewable water resources is exclusively dependent on the annual precipitations over the state which fluctuate considerably from year to year with significant spatial variations. Over half of Israel's area receives annual rainfall of less than 180 mm, while it is 1,000 mm or more in the high mountain zones in the northern Israel. Although renewable water resources accumulate in the northern part, the demand area is concentrated in the central and southern regions. The rainy season begins in October or November and ends in April or May: for the rest of the year there is very little rain, three or four months being completely

rainless. The replenishment occurs exclusively in the winter, while irrigation with its highest water demand occurs in the summer.

In an average year rainfall over Israel is estimated to be 5,000 $x10^6m^3$ per annum: about 3,500 $x10^6m^3$ per annum of this being lost through irretrievable absorption-evaporation, and leaving only 1,500 $x10^6m^3$ per annum to reach the country's water reservoirs on the surface and underground (Ref.5.2.1-1). Fresh renewable waters as surface and groundwater, of which the recharge is dependent on the effective rainfall over the country, are distributed accordingly: the Sea of Galilee in the north stores effectively 500 $x10^6m^3$ per annum; aquifers in the coastal plain store 1,000 $x10^6m^3$ per annum.

5.2.2 Surface water resources

Surface drainage is largely by a few east and west flowing streams. Throughout the southern half of the state, streams are ephemeral.

About one-third of the Israel's potential usable fresh water is dependent on surface water, which is largely dependent on the Jordan river. The river is entirely land-locked, terminating in the Dead Sea. The hydrology and water resources of the Jordan river system have been discussed in the previous Section 2.5.

Galilee as a whole is the wettest region of the state, receiving over 1,000 mm per annum of rainfall in places, and both springs and streams are more numerous than in other areas.

N.Harod (Bet She'an) river is a tributary of the lower Jordan river, which is replenished by abundant springs or groundwater flow, but has a high salinity and is useless for irrigation purposes.

The Yarqon river is a short stream on the coastal plain, which is fed by large springs at Rosh Ha'ayin 15 km east of Tel Aviv. The Yarqon river basin lies on economic aquifers with high development potential.

The mountainous and hilly zones in Samaria and Judaea receive more than 500 mm of average annual rainfall, but surface water is not plentiful. The permeable strata dipping westward are valuable for groundwater recharge to the underlying potential aquifers.

5.2.3 Groundwater resources

The main aquifers to supply water for irrigation, municipal and industrial use are found in permeable strata of Cenomanian-Turonian carbonate rocks and Plio-Pleistocene sandstones.

One of the main sources of groundwater is the thick carbonate rock aquifers of the Cenomanian-Turonian formations, which consist mainly of dolomite and limestone intercalating some clay and chalk layers. The total thickness amounts to 600-700 m in the central and the northern part of Israel. The aquifer supplies several hundred million cubic meters of water annually, which is a significant portion of the water supply in Israel (Ref.5.2.3-1).

The coastal plain is rich in water resources from wells and springs. Up to 700 mm per annum of precipitation may be received over the hills and permeable strata dipping westward yield valuable groundwater for the coastal plains. This gave the early Jewish settlers a wide choice of sites for their villages, while today it is one reason why Israel wishes to retain control of the West Bank as a major source of groundwater recharge. The aquifer lies at depths of 18 to 120 m in the middle Plio-Pleistocene formation. Groundwater abstraction from the coastal aquifer amounts to around 30 % of the total water supply volume in Israel. (Ref.5.2.3-2)

5.2.4 Non-conventional water resources

The marginal waters of Israel are composed primarily of brackish waters, seawater, and urban waste waters. The potential contribution of marginal waters to meet the anticipated water demand include the following alternatives:

- Reclaimed sewage effluents of the Dan region (Greater Tel Aviv).
- Water harvesting for the Sea of Galilee by artificial rainfall.
- Brackish waters to the north of the Sea of Galilee and in the south in the area adjoining the port town of Eilat on the Red Sea.
- Seawater desalination.
- Peak-power generation by seawater pumped-storage by the Dead Sea.
- Co-generation of water by reverse osmosis (RO) with peak-power generation by Mediterranean-Dead Sea (MDS) conduit scheme.

With regard to the brackish groundwaters in the north near Lake Tiberias and in the south in the area adjoining the port town of Eilat on the Red

Sea, the salinity is in the range from 1,000 to 10,000 mg/l of total dissolved solid (TDS) which fits with desalination by reverse osmosis (RO) at a feasible cost. The renewable supplies from the underlying aquifers has been estimated at about 200 $x10^6m^3$ per annum. (Ref.5.2.1-2) The seawater desalination by distillation such as by the multi-stage flash (MSF) process used in the Gulf states is still too expensive in the non-oil producing countries such as Israel and Jordan.

The second source of marginal waters is urban waste-water for which the demand has been increasing since the late 1970s and early 1980s. On the basis of a returnable useful flow of 65 % and 30 % of domestic and industrial water consumption, respectively, the urban waste water potential for the year 1985 was estimated at 370 $x10^6m^3$ per annum (Ref.5.2.1-2).

Evaluation of the marginal waters in a national water master plan will be needed, taking into account the recent innovative researches on saline water conversion including desalination of brackish and seawater by the reverse osmosis (RO) process.

5.2.5 Water consumption in Israel

Almost all renewable water resources such as surface water in the upper part of the Jordan river and groundwater in the aquifers of limestone and deep sandstones had already been exploited by the end of the 1970s. Water consumption in Israel was 1,565 $x10^6m^3$ per annum in 1973, including 1,180 $x10^6m^3$ (75.4%) of agricultural water, 288 $x10^6m^3$ (18.4%) of domestic water, and 97 $x10^6m^3$ (6.2%) of industrial water. It was then predicted that further water resources development would be needed, including 20.5 $x10^6m^3$ of domestic consumption, 28.5 $x10^6m^3$ of industrial consumption, and 8.1 $x10^6m^3$ of agricultural consumption by the year of 1992 (Ref.5.2.1-2).

Israel is utilizing almost all of its renewable fresh-water resources such as surface water from the Jordan river and renewable groundwaters in the limestone-sandstone aquifers, of which the potential supply is preliminarily estimated at 1,500-1,600 $x10^6m^3$ per annum. Water demand had already exceeded the potential of renewable sources by the late 1960s. Israel's per capita consumption (537 m^3 per year; 86 m^3 per year for domestic purpose only) are not out of line with other industrial nations, although it is as much as double that of its neighbors. (Ref.5.2.5-1). The agricultural sector is using more than three-quarters of Israel's total water use.

REFERENCES (5.2)

Ref.5.2.1-1
Micha Gisser and Samuel Pohoryles, 1977, "Water Shortage in Israel: Long-Run Policy for the Farm Sector", Water Resources Research, Vol.13, No.6, pp.865-872.

Ref.5.2.1-2
N.Buras and P.Darr, 1979, "An Evaluation of Marginal Waters as a Natural Resources in Israel", Water Resources Research, vol.15, no.6, pp.1349-1353.

Ref.5.2.3-1
Robert Schneider, 1967, "Geologic and Hydrologic Factors Related to Artificial Recharge of the Carbonate-Rock Aquifer System of Central Israel", Symposium of Haifa: Artificial Recharge and Management of Aquifers; IASH-IASH, Pub.no.72, pp.37-45.

Ref.5.2.3-2
Peter Breaumont, Gerald H.Blake, and J.Malcolm Wafstaff, 1988, "The Middle East; A Geographical Study, 2nd Edition", David Fulton Publishers, pp.412-422.

Ref.5.2.5-1
Thomas Naff and Ruth C.Matson, 1984, "Water in the Middle East; Conflict or Cooperation ?", Westview Press / Boulder and London, pp.1-62.

5.3 Water Resources Development and Management of Israel

The primary users of the waters of the Jordan River are Israel and Jordan. Between them, the Jordan River system has been extensively exploited; it satisfies about one-half of their combined water demand. The other riparian states are Lebanon and Syria; their use of the Jordan River at present is minor as compared to the others, and satisfies about 5 % of their total demand for water. The water resources of the Hashemite Kingdom of Jordan are described in the previous Chapter IV.

The most comprehensive water resources development and management in the Middle East up-to-date is undoubtedly found in Israel. Following establishment of the state in 1948, the government decided to undertake a comprehensive program of water resources development based on the ideas outlined in Lowdermilk's "Palestine: Land of Promise" (refer to Annex-II). Two factors had considerable importance in the initial stage of development. The first was the lack of capital in the new state, and secondly, the urgent necessity to provide water supplies for the many immigrants pouring into the country.

Up to about 1965 and completion of the National Water Carrier, there was enough water awaiting development to satisfy all needs. All that was required was new schemes to tap the resources and make efficient use of them. From the late 1960s onwards it became extremely difficult to make any extra water supplies available, and so emphasis had to be shifted to making more efficient use of available supplies.

In the late 1970s and early 1980s Israel has had to face a growing demand for water from urban and industrial sectors of its economy. It will now have to face the issue of diverting water from the agricultural sector, which still accounts for more than three-quarters of Israel's total water use, to the municipal and industrial sectors of the economy.

5.3.1 Initial stage of water resources development

Initially, attention was concentrated on low cost projects, such as the drilling of wells, which produced quick results. These pumped wells permitted the irrigation of new lands on the coastal plain and in the northern Negev.

An effort to improve the flow of the upper Jordan River was carried out in

the Huleh Valley during 1950-60 by Jewish rural settlers. The Huleh Valley, which is situated in the northern most corner of Israel, was a marshy area where nobody could live before 1950s. The marshy area was flooded by the winter flow of the upper Jordan river, of which the stored water evaporated without productive use in the semi-tropical climate. The land reclamation works were performed by the immigrants to construct a series of canal drain systems to control both flood water and the groundwater levels in the depressions, to enable them to convert the valley from a useless marsh into fertile irrigation land.

Development of the upper river basin in conjunction with irrigation and drainage of the Huleh Valley, however, increased both the saline-nutrient flows into Lake Tiberias and has resulted in a heightened concern over eutrophication. The chloride ion concentration in the water of Lake Tiberias (Sea of Galilee) rose from below 300 mg/l to nearly 400 mg/l during the years 1949-50 to 1963-64 as shown in Fig.5.3.1-1. The increased utilization of water resources may not have been the only cause of this sharp increase in salinity, nevertheless it is conceivable that it played a major role on it.

5.3.2 Medium-term stage of water resources development

Medium term development projects were chosen which permitted the maximum investment per unit of water supplied, which were not technically complex, and which were capable of having the investment divided into a number of stages. At the same time, the idea evolved that every project within the country, no matter what its size, should be capable of being integrated into a nationwide hierarchical water supply system. A number of long term projects, which possessed a regional, rather than local significance, were also implemented.

<u>The Yarqon-Negev Project</u>, which was one of the early schemes of the National Water Carrier and completed in 1955, carries water from Rosh Ha'ayin springs and groundwaters east of Tel Aviv in the Yarqon river basin southwards towards the Negev desert. The system provides 270 $x10^6 m^3$ per annum for Tel Aviv and for irrigating the Lachish area (Ref.5.3.2-1).

<u>The Western Galilee-Kishon Project</u>, which was the first large scale conjunctive use scheme for developing both surface water and groundwater. By this scheme, 85 $x10^6 m^3$ per annum are carried from western Galilee to the fertile but dry Jezleel Plain. In this, 85 $x10^6 m^3$ per annum area carried by this system (Ref.5.3.2-1). The water mainly surface water

during the winter months, when these are relatively abundant, and groundwater during the drier summer period.

The Beit She'an Valley Project, which is situated at about 15 Km south to south by south-west from Lake Tiberias, has a perennial stream with high salinity. The stream water was too salty to be used for either drinking or irrigation purposes. However, it has been found possible to utilize this water by diluting it with purer water obtained from Lake Tiberias.

5.3.3 Integrated development stage: Israel National Water System (INWS)

The largest water resources development project in Israel is the National Water Carrier, which is a huge aqueduct and pipeline network carrying the waters of the River Jordan southwards along the coastal plain region (Fig.5.3.3-1). This scheme stems from earlier ideas and concepts for the integrated development of all the waters of the River Jordan for the mutual benefit of the states of Lebanon, Syria, Jordan and Israel.

In the earlier 1950s, discussions took place between Israel and the adjoining Arab states in an attempt to reach an understanding as to how the waters of the River Jordan might be mostly fairly allocated among the four states. This plan, which was drawn up for the United Nations, is usually referred to as the "Main Plan : 1953" (see Annex-II). After prolonged negotiations, modifications to the original plan were made and this new version became known as the "Johnston Plan : 1955" (see Annex-II), named after the American mediator, Eric Johnston. The potential use of the River Jordan water was estimated to be 1,287 $x10^6m^3$ per annum in total. This gave Israel 31 % of the allocation, compared with 56 % for Jordan, 10 % for Syria and 3 % for Lebanon. It is widely assumed that the technical experts of the various countries involved agreed upon the details of this plan, although soon afterwards the governments rejected it for political reasons.

With the failure of these negotiations, both Israel and Jordan decided to proceed with water projects situated entirely within their own boundaries.

As a result Israel began work on the National Water Carrier in 1958. The main storage reservoir, and also the starting point of the scheme, is Lake Tiberias. From here water is pumped through pipes from 210 m below sea level, to a height from which it flows by gravity to a reservoir at Tsalmon. After a further lift, the water flows via a canal to a large storage reservoir at Beit Netofa, which forms a key part of the system.

South of Beit Netofa, the water is carried in a 270 cm dia. pipeline to the starting point of the Yarqon-Negev distribution system at Rosh Ha'ayin. In the initial stages 180 $x10^6m^3$ per annum of water were carried. This capacity was increased to 360 $x10^6m^3$ per annum in 1968, and it is now believed that the maximum capacity approaches 500 $x10^6m^3$ per annum (Ref.5.3.3-1). This has, however, not yet been attained owing to water salinity problems of the Lake Tiberias. At the present time, the national water grid interconnects all the major water demand and supply regions of the country, with the exception of a number of desert regions in the south. In total, it supplies approximately 1,400 $x10^6m^3$ per annum, or about 90 % of all Israel's water resources. More than half of the water is obtained from the River Jordan and its tributaries, with a further 14 % from the Yarqon river basin.

5.3.4 Conjunctive use and groundwater management

Many of the main groundwater aquifers in Israel are integrated operationally within the National Water Scheme. The pumpage from these aquifers has to be coordinated with releases of water from surface sources. The conjunctive operation of surface reservoirs and aquifers has been performed in conjunction with artificial groundwater recharge schemes. Owing to the scarcity of suitable surface storage sites and the arid climate with high potential evaporation, part of the aquifer system, which is composed of Turonian-Cenomanian carbonate rocks, has been used as an underground reservoir to store the excess of winter stream flows through pumping wells and/or recharge wells. (Ref.5.3.4-1&2)

5.3.5 Israel's water conservation

The total annual water supply was is about 1,750 $x10^6m^3$ in 1988, approximately 74 % of which is used for irrigation, 19 % for domestic use, and 7 % for industrial use (Fig.5.3.5-1). Approximately 43 % of the cultivated land is irrigated, which amounts to 185,000 ha. Present estimates indicate that Israel currently uses as much as 95 % or more of its total renewable water resources including both surface water and groundwater. (Ref.5.3.3-1)

In agriculture there have been spectacular achievements and today in Israel almost all irrigation is carried out by sprinkler, drip or sub-surface systems. This has meant that a given irrigated area can now be watered with much less water than previously. At the same time it does mean, however, that little future water savings can be made by agriculture

by increasing efficiency, as irrigation in Israel is as economical of water use as any in the world.

In the late 1970s and early 1980s Israel had to face a growing demand for water from the urban and industrial sectors of its economy. Experiments have been made to re-use urban waste waters through the Dan Waste-water Recovery project, but success has been less than had been hoped for owing to difficulties in removing contaminants from the waste waters. Similarly research into different water desalination systems has concluded that distillation, such as the dominant multi-stage flash (MSF) process used in the Middle East is too expensive except for specific projects.

The result has been that Israel has been faced with the fact that the only way to obtain water for growing cities is to divert water from one use to another. This requires facing the issue of diverting water from the agricultural sector, which still accounts for more than three-quarters of Israel's total water use, to the municipal and industrial sectors, taking into account the net effect on the economy of the state.

What seems likely to happen increasingly in Israel, as has happened in states such as Arizona in the USA, is that irrigated land adjacent to urban centers will be taken out of cultivation and the water diverted to urban and industrial uses. By the earlier decades of the twenty-first century almost all the countries of the Middle East region will be facing similar severe water shortages in urban centers as their populations continue to grow. It seems inevitable, therefore, that water will have to be diverted away from irrigation to urban/industrial uses. Israel has just started to reduce the national supply amount since 1987, by cutting the supply of irrigation water as seen in Fig.5.3.5-1. It has been announced that in 1991 allocations of water for agriculture will be reduced by 30 % from the 1990 level.

5.3.6 Israel's occupation policy and water resources of West Bank

The occupied lands, most notably the West Bank and Golan Heights, are important in the water economy and security of Israel. It is estimated that one-third of Israel's water resources originates in rainfall over the western slopes of the West Bank and is drawn from the same aquifer system that supplies the West Bank. Hence, during the post-1967 period, the Israeli occupation of the West Bank has allowed greater exploitation of this aquifer by preventing new water resources development by the Arab population. The effect is to maximize groundwater recharge so that the

aquifer under Israel may be more extensively developed. At the same time, Israeli settlements in the West Bank are tapping the aquifer.

It should also be noted that another one-third of Israel's water comes from Jordan River. The 1967 conquests are important in this light also because the Golan Heights afford control over the upper Jordan, enabling Israel to block any Arab attempt to divert its headwaters. (Fig.5.3.3-1) Almost one-half of Israel's total water supply therefore consists of water that has been diverted or pre-empted from Arab sources located outside its pre-1967 boundaries (Ref.5.3.2-1).

REFERENCES (5.3)

Ref.5.3.2-1
Thomas Naff and Ruth C.Matson, 1984, "Water in the Middle East; Conflict or Cooperation ?", Westview Press / Boulder and London, pp.1-62.

Ref.5.3.3-1
Peter Breaumont, Gerald H.Blake, and J.Malcolm Wafstaff, 1988, "The Middle East; A Geographical Study, 2nd Edition", David Fulton Publishers. pp.100-105.

Ref.5.3.4-1
Robert Schneider, 1967, "Geologic and Hydrologic Factors Related to Artificial Recharge of the Carbonate-Rock Aquifer System of Central Israel", Symposium of Haifa: Artificial Recharge and Management of Aquifers; IASH-IASH, Pub.no.72, pp.37-45.

Ref.5.3.4-2
Nathan Buras, 1967, "Systems Engineering and Aquifer Management", Symposium of Haifa: Artificial Recharge and Management of Aquifers; IASH-IASH, Pub.no.72, pp.466-473.

5.4 Joint Israel/Jordan Mediterranean-Dead Sea Conduit Development with Co-generation Concept

A new co-generation method for Israel and Jordan is proposed herein, which aims to produce both electricity and fresh water from the sea by means of a co-generating system including both solar-hydro and hydro-powered reverse osmosis (RO) desalination, based on exploitation of the 400 m elevation difference between the Mediterranean Sea and Dead Sea.

The co-generation system could produce 500 MW of electricity and $100 \times 10^6 m^3$ per annum of fresh water from the Mediterranean Sea. The generated power would be shared by the two countries in proportion to their investments either peak-power demand or base load increment. It is assumed that the product of fresh water of $100 \times 10^6 m^3$ per annum would be used exclusively for the supply to central Ghor (Jordan Valley, in and around the Dead Sea) where the ground elevation is as low as 210-400 m below sea level.

The application of solar-hydro with RO desalination, which is a new type of co-generation system proposed herewith, is likely to be a key technological development in this region for the strategic objective of saving fossil energy and the global environment.

5.4.1 Background

This particular type of hydro-electric power development, also known as a hydro-solar power, is made possible by the existence of a vast depression at a distance not too far from the sea, and the region's characteristically arid climate (with the resulting high degree of evaporation). Two such hydro-solar projects have been studied in depth; the "Mediterranean-Qattara" canal scheme in Egypt and the "Mediterranean-Dead Sea" canal scheme in Israel.(Fig.5.4.1-1) Both plans would involve an initial development stage during which the basins would be filled with water from the Mediterranean Sea up to a certain design level that would be maintained thereafter by transfer of water to replace the amount evaporated.

<u>Israeli plan</u>

Israel announced its performance of feasibility study on a seawater hydro-electric power generation project in 1980, but this had been proceeded by pre-feasibility studies over many years before this. The Mediterranean-

Dead Sea Canal hydro-power project, as it was called, was designed to exploit the 400 m elevation difference between the Mediterranean Sea (zero meters) and the Dead Sea (-402 meters) by linking the two seas (Fig.5.4.1-2). The "Central Route" canal would be 72 km long, including a 15 km section of pipeline which would be open and a 57 km tunnel with 5 m in diameter. The first 30 km section would cross Israeli territory, and the second 42 km section would traverse the West Bank (occupied Palestine). The minimum distance route option was, however, put aside to fear the possible saline (seawater) water leakage through the tunnel which could contaminate fresh groundwater aquifers in the Judaea mountain range.

After considering 27 alternative conduit routes to connect the two seas, the "Gaza - Ein Bokek" route with 80 km tunnel length (Fig.5.4.1-2) was selected to minimize the capital cost in 1982. The selected route, however, would cross the occupied Gaza Strip . For political reasons, an alternative route was considered which would move the entrance of the canal northwards into Israeli territory (Fig.5.4.1-2). This would add 60 million U.S. dollars to the cost, and 20 km to the planned 100 km-length (Ref.5.4.1-1). However, even if political problems in Gaza Strip are avoided, they would be certainly have been encountered in Jordan which shares the Dead Sea with Israel and also extracts minerals such as potassium from it (Fig.5.4.1-2). The planned effect of the canal was to raise the level of the Dead Sea by 17 m from -402 to -385 m below sea level. This would have meant that the mineral processing plants in both countries would have to be moved and potash production could fallen by 15 per-cent (Ref.5.4.1-1).

Project Cost of MDS

The Israeli solar-hydro development project as MDS would generate 800 MW electricity with annual generated electricity of $1.4\text{-}1.85 \times 10^9$ KWh by assuming gross water head at 444-472 m and maximum discharge of 200 m^3/sec with annual average flow intake of $1.23\text{-}1.67 \times 10^9 m^3$ (Ref.5.4.1-2). The total project cost was estimated to be US$ 1.89×10^9 (at 1990 price) by assuming 140 % of price escalation from 1982 to 1990, including the following major cost elements;

	US$
- Main tunnel (=80.4 km)	732×10^6
- Power station (=400MWx2)	385×10^6
- Other facilities and structures	310×10^6
- Design and supervision, etc.	142×10^6
- Financial expenditure	319×10^6

Jordan's counter-proposal

Jordan vied with Israel over the canal power scheme in 1981, by offering a counter-proposal to bring seawater from Aqaba bay to the Dead Sea. This scheme would have also exploited the 400 m drop between the Gulf of Aqaba and the Dead Sea to generate electricity. Seawater would have been pumped into a series of channels and reservoirs from Aqaba to Gharandal, 85 km further north (Fig.5.4.1-2). From there, the water would fall into the Dead Sea to generate about 330 MW for 8 hours a day at peak demand (Ref.5.4.1-3).

Environmental problems and political conflict

The flow of water from the Jordanian carrier would have forced Israel to cut back its own influx of water into the Dead Sea, or the level would have risen so high as to flood the potash works (of both Israel and Jordan) and the surrounding hotels on the Israeli side. The Mediterranean-Dead Sea hydropower project was then put aside, owing to the strong opposition from the Arab states and others, and with the confusion and the drop of the world oil market prices in 1984. Israeli interest turned then to the seawater pumped-storage from the Dead Sea. (Refs.5.4.1-4&5). It should be noted that a United Nations mission found that the maximum level by the Dead Sea would have been -390.5 m which would not have flooded any religious or archaeological remains, would not have triggered earthquakes as this level was comparable with previous equilibrium levels, and would not increase reflectivity. These studies therefore demonstrated that the project would not have had any adverse environmental effects. (Ref.5.4.1-3) The possible increased evaporation through introduction of Mediterranean water discussed below could have additional beneficial effects.

Dead Sea pumped-storage scheme by Israel

Israel's Energy Ministry has recently shown renewed interest in a pumped-storage scheme on the Dead Sea, first proposed earlier 1980s but shelved in favor of a similar project proposed for the Sea of Galilee. The power could be produced even more cheaply and efficiently from the pumped-storage on the Sea of Galilee in northern Israel, but the project could damage plant and animal life there. The interest has shifted back to the Dead Sea because of its almost total absence of flora and fauna. The Dead Sea pumped-storage scheme could produce 400-800 MW equivalent to 10-20 %

of the national grid's capacity of 4,060 MW in 1989.

Co-generation approach with joint development concept : future plan

Israel's Mediterranean-Dead Sea (MDS) canal scheme was conceived to provide hydro-electric power, but it did not offer any solution to the urgent need for fresh water supply (Ref.5.4.1-6). The use of hydro-electric power to make desalination cost-effective, was a consideration of the scheme in the early 1980s, but it was not sustainable to use valuable clean energy from the hydro-electricity for conventional desalination due to the substantial energy losses which would be incurred through conversion and transmission. Discussion of the much-discussed MDS scheme in the early 1980s may have overlooked concept of shared resources and the benefit of joint development. Indeed up to now there has been no attempt to conceive comprehensive development of the Jordan river system including linkage of MDS and Al-Wuheda dam on the Yarmouk tributary. The proposed new co-generation approach to the MDS scheme thus takes into account; i) recent innovative developments in membrane technology for the reverse osmosis (RO) desalination which aim to save energy and to make reverse osmosis (RO) desalination more cost-effective, and ii) recent changes in the Middle East political situation following the Gulf War that may make comprehensive basin development not only technically and financially feasible, but politically desirable and urgent.

5.4.2 Hydrology of the Dead Sea and evaporation from saline lake

The climate of the watershed ranges from "hot-arid" in the bottom of Jordan Valley to "Mediterranean semi-arid" in the surrounding highlands. The Sea is a brine water body with the extremely high salinity of 250,000 mg/l of total dissolved solids (TDS), The Dead Sea is a closed sea with no outlet except by evaporation which at present amounts to 1,500-1,600 mm per annum (Ref.5.4.2-1).

Evaporation from the surface of the saline lake is the most important key factor to estimate the capacity for generating electricity by solar-hydro development. For the same meteorological inputs and aerodynamic resistance, a decrease in salt concentration will increase evaporation rates and reduce lake temperature, whereas an increase in concentration will have the reverse effect. Increased use of water from the Jordan river specially for irrigation has increased salt concentrations, whereas the proposed introduction of Mediterranean sea water into the Dead Sea via a canal, for hydroelectric purpose, would reverse this trend.

A model analysis to predict the annual evaporation rate and surface temperature as a function of aerodynamic resistance and thermodynamic activities of water (Ref.5.4.2-1), which assumed that on a long-term basis (annual) the heat flux into the lake is negligible and the available energy could be equated to the net radiation, calculated from the parameters of the Dead Sea: T=23.6^{o}C of air temperature, e=15.9 mbars of vapor pressure of air, e_s(T)=29.05 mbars of saturation vapor pressure of water at temperature T^{o}C, H=Rn=146 W-m^2 of total available energy or the net radiation flux density. By assuming the changes in activity of water in solution (a_w=1.00 of pure water); a_w=0.75 before 1958, a_w=0.71 in 1980s, and a_w=0.98 after introducing Mediterranean seawater into the Dead Sea, the mean annual rates of evaporation and surface temperature of the Dead Sea for the different levels of salinity were estimated to be 17.7^{o}C-1,563mm and 23.4^{o}C-1,908mm, respectively. If the proposed canal development were completed, the formation of an unmixed Mediterranean sea water surface layer (a_w=0.98) overlying a denser Dead Sea water would (possibly on a localized scale in the vicinity of the canal outlet) decrease surface water salt concentration and raise a_w values; model predictions suggest a large increase in the (local) evaporation rate by 345 mm per annum to 1,908 mm per annum and a marked decrease in surface water temperature of 3.3^{o}C to 23.4^{o}C. These estimated rates of the evaporation are conceived as conservative and comparative to that measured at Mead lake in Arizona, U.S.A which amounted 2,000 mm per annum (Ref.5.4.2-3). This study assumes 1,600 mm of mean annual evaporation for the present condition. The actual evaporation rate after impounding seawater from the Mediterranean sea is assumed to be 1,900 mm per annum for the proposed co-generating plan in the following Sections.

5.4.3 Co-generating plan: solar-hydro and hydro-powered reverse osmosis (RO) desalination

The proposed Solar-Hydro Development Plan would exploit the sharp difference in elevation of 400 m between the Mediterranean Sea and Dead Sea. The Dead Sea water level would be maintained at a steady-state level with some seasonal fluctuations of about 2 meters to sustain the sea water level between 402 m and 390 m below mean sea level, during which the inflow into the Dead Sea should balance the evaporation.

The Israel/Jordan Mediterranean-Dead Sea (IJMDS) conduit plan is a co-generation alternative which would combine solar-hydro and hydro-powered seawater reverse osmosis (RO) desalination (Fig.5.4.3-1). The IJMDS plan

would have the following major components:

1) An upstream reservoir (the Mediterranean) at zero sea level, with essentially an unlimited amount of water.
2) A water carrier, assuming several alternative schemes, depending the route considered, including a gravitational canal, a tunnel with booster pumping, or an open gravitational canal.
3) An upper reservoir and surge shaft at the outlet of the water carrier to allow for regulating the water flow.
4) A storage type hydroelectric unit capable of reverse operation to allow the system to also work as a pumped-storage unit, if required.
5) A downstream reservoir of the Dead Sea, at a present surface elevation of approximately 402 m below sea level.
6) A hydro-powered reverse osmosis (RO) desalination plant, including pre-treatment unit, pressure converter unit, RO unit, energy recovery unit, post-treatment unit, and regulating reservoirs for distribution.

5.4.4 Estimate of hydro-power

The theoretical hydro-potential to exploit a head difference between the Mediterranean Sea (=0 m) and Dead Sea (=-400 m) by transferring 56.7 m3/s ($=1.6x10^9 m^3/y$) of seawater is estimated to be 194 MW following installed capacity for peak-power operation at 495 MW with $1.3x10^9$ KWh/y of electricity. Another option of exploiting the gross head at 444-472 m (Israeli plan 1982, Ref.5.4.1-2) by transferring 43 m^3/s of seawater would have 198 MW of of the theoretical hydro-potential following installed capacity for peak-power operation at 505 MW with $1.33x10^9$ KWh/y of electricity. The estimates are based on the following conventional equations:

Pth = 9.8*Ws*Q*He
P = Pth*Ef
Wp = 365*24*Gf*P

where, Pth : Theoretical hydro-potential (KW)
Ws : Specific weight of seawater (=1.03)
Q : Flow discharge (m^3/sec)
He : Effective difference head of water (m)
P : Installed capacity (KW)
Ef : Synthesized efficiency (=0.85)
Wp : Potential power generation (output) per annum (KWh)
Gf : Generating efficiency (=0.30); 8 hours a day of peak operation
* : Multiply

5.4.5 Hydro-powered seawater reverse osmosis (RO) desalination

The co-generation system is an application of a seawater reverse osmosis (RO) annexed to the solar-hydro-power system which requires 8 hours a day of peak operation. The marginal operation of the RO system is designed to use the hydro-potential energy in the pipeline-tunnel (penstock) system (481.5 m of differential head of water) for 16 hours a day of the off-peak time. The feed water requirements to produce $100x10^6 m^3$ per annum of permeate with 1,000 mg/l of the total dissolved solids (TDS) are estimated to be $333x10^6 m^3$ per annum by assuming 30 % of recovery ratio (70 % for brine reject). The installed capacity is estimated to be 322,300 m^3/d with load factor at 85 %. The energy recovery from the brine reject is estimated to be 24,000 KW with annual generation of $134.7x10^6$ KWh of electricity with load factor at 68 %. The recovered energy (electricity) will be used to supply electricity for the post-treatment process or others as shown in Fig.5.4.5-1.

Cost Estimates

The total investment cost for the proposed hydro-powered seawater reverse osmosis (RO) desalination unit, which is based on 1990 prices with 8 % of interest rate during the three years construction, is preliminarily estimated to be US$ 389,355,000 with with annual capital cost at US$ 18,568,000 as shown below;

Major Capital Cost Element	US$(1990 price)
- Pre-treatment	44,195,000
- Desalting plant	70,414,000
- RO membrane/equipment	84,835,000
- Control and operating system	5,952,000
- Appurtenant works	27,013,000
- Powerline and substation	11,427,000
- Energy recovery/turbine	2,999,000
Sub-total	246,835,000
Design and construction management	62,250,000
Financial expenditure	80,270,000

The annual cost for the operation and maintenance is estimated to be US$

44,387,000 including the following major cost elements;

Major O&M Cost Element	US$ per annum
- Labour	3,718,000
- Material supply	1,860,000
- Chemicals	7,440,000
- Power (pumped-storage for RO feedwater)	3,100,000
- Membrane replacement	28,269,000
Sub-total	44,387,000

The above cost estimates are based on 1990 price and including some assumptions as shown below:

- Plant life : 20 years
- Membrane life (replacement) : 3 years
- Cost benefit from energy recovery is not included.
- Costs for source water (groundwater) and pipeline/distribution are not included.

The unit water cost of the hydro-powered seawater reverse osmosis desalination for the design annual product water of $100x10^6m^3$ is estimated to be US$ $0.68/m^3$, which may be reasonable value to compare with the international water tariff (Ref.5.4.5-1) as shown below;

City	Water tariff : $22m^3$/month (Yen/month)	(US$/$m^3$)	Electricity tariff : 180KWh/month (Yen/month)	(US$/KWh)
Tokyo	4,070	1.23	4,962	0.18
New York	746	0.23	12,000	0.44
Los Angels	4,800	1.45	3,600	0.13
London	2,860	0.87	3,913	0.14
Paris	2,513	0.76	4,700	0.17
Cairo	12,892	3.91	1,055	0.04

The project cost of the Israeli MDS Canal for the hydro-power scheme was estimated at US$ $1.9x10^9$ as described in the previous Section 5.4.1.

5.4.6 Method of sharing and allotment

The Dead Sea surface which is the source of evaporation for the MDS solar-hydro scheme comprises two riparian states: Israel (300 km^2 : 30%) and Jordan (700 km^2 : 70%). While the conduit route of MDS pass through the Gaza strips (10 km : 10%) and Israel (90 km : 90%).

The water balance of the Dead Sea for the co-generation scheme to produce 500 MW of electricity and $100x10^6m^3$ of fresh water is estimated as below;

-Evaporation after impounding seawater	: $1,900x10^6m^3$
-Seawater intake for MDS hydro-power at steady-state level	: $1,220x10^6m^3$
-Brine reject water from proposed hydro-powered RO plant	: $233x10^6m^3$
-Inflow from catchments	: $447x10^6m^3$

The two riparians of Israel and Jordan must share the resources and benefit, which may need a further discussions on the water politic issue as described in Annex-II.

If the cost sharing were to be made by fifty-fifty between the two countries to assure the fifty-fifty benefit allotment, the project formulation including the financing, construction, operation and maintenance could be done by an international consortium organized by an international agency such as the United Nations. The possible benefits and their allocation are discussed in the Supplement in Annex-II.

5.4.7 Remarks

This study of hydro-solar development has been made to test the technical feasibility of exploiting seawater resources by taking into account the distinctive nature of the arid zone hydrology and topography in and around the Dead Sea. Reverse osmosis (RO) is the cheapest process for desalination today, but it may not be the optimum solution which may be encountered in the twenty-first century. Further researches will be needed to evaluate its technical feasibility, including 1) rate of actual evaporation from Dead Sea surface after impounding, 2) design of materials to avoid corrosion of hydraulic structures from seawater and brine reject water, 3) TBM methods of construction for the pipeline tunnel, 4) application of low pressure (30-50 kg/cm^2) type RO membrane modules for seawater desalination, 5) efficient energy recovery system in RO, 6) methods of hybrid desalination, and 7) power generation by solar pond.

REFERENCES (5.4)

Ref.5.4.1-1
WPDC,International News, 1980, "Israel Decides on Canal Route", Water Power & Dam construction, October 1980, p.4

Ref.5.4.1-2
Tahal, Israel, 1982, "MDS Project, Project summary", Feasibility Study Report

Ref.5.4.1-3
WPDC,International News, 1983, "Jordan attacks Dead Sea Project", Water Power & Dam Construction, March 1983, p.4.

Ref.5.4.1-4
WPDC,World News, 1989, "Dead Sea P-S Scheme Revived", Water Power & Dam Construction", May 1989, p.3.

Ref.5.4.1-5
Thomas Naff and Ruth C.Matson, 1984, "Water in Middle East, Conflict or Cooperation?", Westview Press / Boulder and London, pp.25-26.

Ref.5.4.1-6
P.Glueckstern, 1982, "Preliminary Consideration of Combining A Large Reverse Osmosis Plant with the Mediterranean-Dead Sea Project", Desalination, vol.40, pp.143-156.

Ref.5.4.2-1
I.R.Calder & C.Neal, 1984, "Evaporation from Saline Lakes: A Combination Equation Approach", Journal of Hydrological Science, Vol.29,No.1, pp.89-97.

Ref.5.4.2-2
Dan Weiner, and Arie Ben-Zvi, 1982, "A Stochastic dynamic Programming Model for the Operation of the Mediterranean-Dead Sea Project, Water Resources Research, vol.18, no.4, pp.729-734.

Ref.5.4.2-3
William D.Sellers, 1965, Physical Climatology", The University of Chicago Press, pp.100-114.

Ref.5.4.5-1
Japan Water Resources Association, 1989, '89' Water Resources Inventory", Sankando Shuppan Ltd. Tokyo, p.184 (in Japanese)

5.5 Integration of Development Alternatives in a Inter-State Water Master Plan

Integrated water resources development and management plan of the Jordan river system including Mediterranean-Dead Sea (MDS) conduit scheme for co-generation with Al-Wuheda dam scheme, which aims to mitigate the historical complexities, commonalties and conflict between Israel and Jordan, is elaborated to provide the idea of sharing resources and joint development of the Jordan river.

Prior to elaborate a new inter-state basin development plan of the Jordan system, following three major existing development alternatives are examined to delineate the status and the priority in a master plan.

5.5.1 Alternative 1; inter-state water transportation by pipeline

Two inter-state water transportation projects have been proposed, either by bi-lateral or multi-lateral, including "Euphrates-North Jordan Transmission" and "Peace Pipeline". These two schemes were set aside, however, owing to the fears over the political constraints including inter-state riparian right questions on the Euphrates river on which the fear of using water as a political weapon was increasing. The Peace pipeline project has now been emphatically rejected by all Arab states who have said that if necessary they will depend on non-conventional waters in their territory including seawater desalination. Both Israel and Jordan, which are not oil producing countries, have been unable to adapt seawater desalination by the thermal method which requires substantial energy or electricity.

5.5.2 Alternative 2; water transportation by tanker and barge

The transport of water by tanker and barge have been discussed mainly in the oil-producing Gulf countries and for small islands, up to now it has been conceived that this method was not an attractive alternative for non-oil producing countries.

Jordan has only a short sea coast at Aqaba, while the water demand is located 400 km north of the highland desert at an elevation of 800 to 1,000 m for the population centers of Amman and Zarqa. This alternative may not attractive since it requires a water pipeline of more than 400 km and a high pumping head exceeding 1,000 m.

Israel and the occupied Gaza Strip have a long coastline along the Mediterranean Sea, with major coastal population centers such as Tel Aviv, Haifa and Gaza. Water by tankers could provide significant relief to all the coastal towns and cities in the Middle East. Provision of water by Turkey for the Israeli "water-bag" scheme should go a long way towards developing credibility for its good intentions as regards the Euphrates and Tigris and will reduce one of the most serious problems for Israel in discussion with the Palestines (Ref.5.5.2-1). Turkey also holds the key to future full use of the river systems of the Euphrates, Tigris, Ceyhan, Seyhan and Manavgat.

5.5.3 Alternative 3; non-conventional water resources development

Development priority is likely to be given to marginal waters in the non-conventional water resources development of Israel and Jordan, taking into account not only the technical-financial-economical feasibility but also the political feasibility.

Israel provides an example of a country which has long experience with almost all the non-conventional technologies, including the use of saline water for agriculture. From experimental practices in the late 1970s to the mid-1980s, Israel recognized that i) the re-use of urban waste waters through the Dan Waste-water Recovery project had a success but less than had been hoped for owing to difficulties in removing contaminants from the waste-waters, and ii) seawater desalination was too expensive, except for specific projects.

Non-conventional water resources are generally more complex in development and operation than conventional sources, and are almost always more expensive. However, there are no further opportunities for development of renewable waters in its territory, including its present dependence on about 50 % of renewable water from the occupied Palestine and other Arab territories. There is a clear linkage between the Israeli occupation policy on Palestine and the water resources issue. The Israeli dilemma is not only based on the quantity and quality issues of water resources but also occupation policies against the United Nations (UN) security council resolution 242 in November 1967.

5.5.4 Mediterranean-Dead Sea (MDS) conduit scheme in the context of inter-state development and Jordan river basin management.

The Dead Sea, has a huge hydro-solar (evaporation) potential which is shared by Israel, Palestine and Jordan. The Dead Sea hydro-solar development should be discussed in the context of a master plan for inter-state development and management with sharing of resources concept, and providing the basis for peace collaboration between Israel and its neighbors. The much-discussed Mediterranean-Dead Sea (MDS) Canal has been including the four main alternative routes as shown below (Fig.5.4.1-2);

Alternative route	Riparian Intake-Outlet	Conduit (km)	Remarks
1) Southern route (1)	Gaza -Israel	100	Bilateral plan - UN/UNRWA
2) Southern route (2)	Israel-Israel	120	Unilateral plan
3) Central route	Israel-West Bank	72	Bilateral plan - UN/UNRWA
4) Aqaba route	Jordan-Jordan	175	Unilateral plan

From the environmental and economic point of views, the shorter conduit route of the "Southern route (1)" has an advantage to minimize the constraints of both cost and environment. This study supports the concept of bi-lateral plan which has been suggested to be managed by international agency such as United Nations as proposed in the supplement of Annex-II.

The Mediterranean-Dead Sea (MDS) conduit scheme, which includes solar-hydro and hydro-powered reverse osmosis desalination by joint development with Israel-Palestine-Jordan, is a key proposal studied in this thesis. The stream discharges into the Dead Sea from the Jordan river and Wadi Mujib will be minimized to maximize the seawater diversion capacity from Mediterranean, and to maximize the hydro-potential. To make a reality of the physical basis, the following alternatives are included to minimize the winter flows in the river and wadi systems;

- Al-Wuheda multi-purpose storage dam scheme on the Yarmouk river, which has been postponed since 1989, owing to Israeli opposition for downstream water allocation questions.
- Storage dam schemes on the riftside-wadis in the East Bank, including Wala and Nukheila dams on the wadi Mujib and Tannour dam on the wadi Hasa, which have not any political constraints but need financial supports from international aiding agencies.
- Flood retention - groundwater recharge dam schemes on the side-wadis in the West Bank (Occupied Palestine) where limestone geology is predominant as illustrated in Fig.5.5.4-1 of the schematic profile of the hydrogeology and groundwater of the Palestine, with aims of: i) cutting flash floods which are being dumped into the Jordan river or the Mediterranean Sea, and ii) recharging underlying the aquifer system to sustain regional groundwater development. This may lead to improve the hard situation that the Israel is depending on 40-50 % or more present water supply from an aquifer underlying the West Bank.

Jordan's last major river development, the Al-Wuheda dam scheme with an effective storage of 195 $x10^6m^3$, is urgently needed for the national water supply grid to add 155 $x10^6m^3$ per annum. This will also reduce the amount of winter flow into the Dead Sea. Meanwhile to the west the Jordan Valley downstream of the Al-Wuheda dam including Palestine and a portion of Israel, needs more fresh water to extend irrigation development, and to the southeast almost all the population centers in Jordan are located on highland desert at an elevation of 800-1,000 m, which suggests the prior use of the Yarmouk river water for M&I water supply by diverting it from Al-Wuheda (E.L=300m) to Amman (E.L=800m) as illustrated in Fig.5.5.4-2 of the schematic profile of Jordan Valley and Yarmouk river system.

An engineering proposal of co-generation by coupling solar-hydro with hydro-powered reverse osmosis (RO) desalination on the Mediterranean-Dead Sea (MDS) conduit scheme will generate following two products, electricity and water:

- either 200 MW for base load or 500 MW for peak load.
- 100 $x10^6m^3$ per annum of fresh water by desalination.

The schematic of the MDS co-generation system is also shown in Fig.5.5.4-2. The capital/investment costs of the hydro-power and the RO desalination are preliminarily estimated to be 1,900 and 400 million U.S.$, respectively (see Section 5.4) Annual potential outputs such as $1x10^9$ KWh of electricity and $100x10^6m^3$ of fresh water for M&I water supply from the co-generation system are estimated to be equivalent with US$ $80x10^6$ per annum (US$$160x10^6$ in total) each by assuming the electricity tariff of US$0.08/KWh and water tariff of US$0.8/$m^3$. These cost indices simply suggest a feasible approach to the joint development of the two states.

Present national power generation of Israel is $18.76x10^9$kwh per annum in 1988, which is about ten times as much as that of Jordan. The installed

capacity of 500 MW would be equivalents to 12 % of Israel's grid capacity of 4,060 MW in 1988. The electricity from the Dead Sea hydro-power would, however, be a resource to be shared by Israel and Jordan to supply peak demands to optimize their power supply systems.

By the end of 1990s, Israel, Jordan and the West Bank or Palestine will over commit or deplete virtually all of their renewable sources of fresh water if current patterns of consumption are not quickly or radically altered. In the circumstances, the Jordan river system, which includes the Al-Wuheda dam scheme on the Yarmouk river, unquestionably holds the greatest potential for either conflict or compromise. In the Southern Ghor of the Dead Sea catchment, the driest area of the Jordan Valley with annual rainfall less than 50-100 mm, there has been substantial water demand to develop the region, but no alternative source of the fresh water could be found in the area. M&I water demand in and around the Dead Sea is about 100 $x10^6m^3$ per annum including increasingly demands for mining (potash works) industry, agro-industry and resort hotels. The product water of 100 $x10^6m^3$ per annum from hydro-powered reverse osmosis (RO) desalination could be mainly used for M&I water supply with aim of supplying water exclusively in the southern Ghor (Jordan Valley) in the twenty-first century.

All the water resources development schemes on the Jordan river system, including the proposed Al-Wuheda dam and side-wadi dams, should be linked with the Mediterranean-Dead Sea (MDS) conduit scheme in the context of an inter-state basin development master plan, to promote economic development in Jordan, Palestine and Israel through sharing of the resources and benefits.

The basic framework for allocation of Jordan river water is enshrined in the "Main Plan: 1953" and the "Johnston Plan: 1955" which were negotiated by the United Nations but never formally endorsed by the governments concerned. Flow diagram and water allocation of the Jordan river system is illustrated in Fig.5.5.4-3, including A) Johnston Plan : 1955, B) unilateral Jordan River Development as current situation, C) on-going or postponed projects which comprise political and/or financial constraints, and D) proposed new schemes for integrated joint development plan : 1991 which include MDS conduit scheme for co-generation and side-wadi dam scheme for flood retention and groundwater recharge in the West Bank. The framework for a new inter-state Jordan river development plan for the twenty-first century as conceived in this study would build into the "Unified (Johnston) Plan: 1955" the new engineering proposal for hydro-

powered reverse osmosis (RO) desalination in the Mediterranean-Dead Sea conduit scheme which would not only provide additional fresh water and clean energy (electricity) in the driest area but would promote integrated economic development between Israel and Jordan as a basis for lasting peace.

It should be recognized that issues of security of water resources and inter-state riparian problems of the Jordan river system, including Israel's heavy dependence on water supply from an underground aquifer that underlies the West Bank (Fig.5.5.4-1), have been some of the reasons why Israel could not withdraw from areas occupied since 1967. Thus, without resolution of these inter-state water resources problems, no settlement of the Palestine-Israel and Arab-Israel problems can be achieved.

Following is a proposed model of inter-state water allocation including the proposed non-conventional development alternatives:

Sources of Water	Lebanon (10^6m^3)	Syria (10^6m^3)	Jordan (10^6m^3)	Israel (10^6m^3)	Total (10^6m^3)
Unified (Johnston) Plan : 1955					
Hasbani	35				35
Banias		20			20
Jordan (main stream)		22	100	375	497
Yarmouk		90	377	25	492
Side wadis			243		243
Integrated Joint Plan : 1991					
MDS hydro-powered RO desalination			50	50	100
Side-wadi dams for groundwater recharge			50	50	100
Source of Energy (electricity)					
MDS solar-hydro for peak-power (MW)			(60)	(440)	(500)

The implementation of the inter-state basin development and management of the Jordan system is a complicated issue with water politics, of which the idea of project formulation is further discussed in the Annex-II.

REFERENCES (5.5)

Ref.5.5.2-1
Christopher Savage, 1990 (in press), "Middle East Water" - lecture given to the Royal Society for Asian Affairs on 20 March 1990, London, Journal of the Royal Society for Asian Affairs.

VI. CONCLUDING REMARKS AND RECOMMENDATIONS FOR FURTHER STUDY

This Chapter-VI focuses on the conclusions of the application studies in Chapter III-VI. The concluding remarks on the technical feasibility and cost effectiveness of the proposed new technology of the hydro-powered reverse osmosis (RO) desalination and its application in the non-conventional water resources development alternatives are summarized in a context of the national and/or inter-state water master plan, taking into account the concluding remarks on the review study in Section 2.12 of Chapter-II.

6.1 Concluding Remarks

- From the case study on the non-conventional water resources development in Kuwait, the unit cost of brackish groundwater reverse osmosis (RO) desalination for "with" and "without" application of the hydro-potential energy in the water pipeline system (200 m of differential head of water) was estimated to be US$0.4/$m^3$ and US$0.6/$m^3$, respectively, in which the cost of hydro-powered brackish groundwater reverse osmosis (RO) is estimated to be as low as one-sixth to one-fourth of the conventional seawater desalination either by MSF (US$2.7/$m^3$) or RO (US$1.7/m^3).

- Potential of brackish waters including both groundwater and surface water, which have long been neglected in the water resources study, has to be evaluated in a context of national water master plan, taking into account the prevailing water quality in the arid zone aquifers and the promising progress in the reverse osmosis(RO) desalination technologies.

- From the case study of national water resources master plan in Jordan, two schemes of the "Al-Wuheda" dam and the "Disi" fossil groundwater development are identified, which are the key applications to sustain the national water resources development after the 1990s. The fossil groundwater in the Disi aquifer is, however, to be conserved and may be used temporarily or short time during the emergency. After completing the Al-Wuheda dam on the Yarmouk river by the end of the 1990s, which is the last major renewable water not fully utilized, the non-conventional water resources development including brackish groundwater and re-use of treated sewage effluents will become the key

applications to formulate the future national water master plans of Jordan.

- The proposed co-generating approach of brackish groundwater development with hydro-powered reverse osmosis (RO) desalination using the existing Disi-Aqaba water supply system conserves the fossil groundwater in the Disi aquifer and produces both hydro-electricity and fresh water, including $14.6 \times 10^6 m^3$ per annum of fresh water with potential hydro-power generation at 15,900 MWh per annum. The sustainable management or conservation of the non-renewable fresh groundwater in the Disi aquifer is possible by developing the brackish groundwater in the Kurnub aquifer which has never been tapped. The unit cost of brackish groundwater desalination by hydro-powered reverse osmosis (RO) desalination is estimated to be US$0.41/$m^3$.

- The proposed co-generating approach by coupling Mediterranean-Dead Sea (MDS) solar-hydro scheme with hydro-powered reverse osmosis (RO) desalination will be able to produce 100×10^6 m^3 per annum of fresh water and 500 MW of electricity which is 12 % of the Israel's national grid's capacity of 4,060 MW. The generated electricity of 1×10^9kWh per annum must be shared by the two riparians of Israel and Jordan to supply their peak demands, while the product fresh water is to be exclusively used and shared in the water supply of the central Ghor (Jordan Valley). The unit water cost of the seawater desalination by hydro-powered reverse osmosis (RO) desalination is estimated to be US$0.68/$m^3$. The much discussed MDS scheme will be revived by introducing the new technology including the non-conventional approach with sharing resources concept in a context of the inter-state water resources development master plan.

- The Al-Wuheda dam project and other side-wadi dam schemes such as flood retention or groundwater recharge dams, which enhance the solar-hydro potential of the Dead Sea, should be linked with the Mediterranean-Dead Sea (MDS) conduit scheme, to share the valuable inter-state resources and benefits in a context of the integrated joint development plan, not threatening new political conflicts but rather promoting peace and economic development for the Jordan and Israel. The dialog among the states are to be based on a sense of water cycle and balance of coordinating hydrology, water potential energy, and politics.

- The proposed inter-state basin development master plan of the Jordan river system is based on the changes in the Israel-Arab situation since

the 1990's Gulf crisis. It is now possible to conceive a comprehensive joint development plan which is not only technically-economically feasible but also politically desirable and urgent.

6.2 Recommendations for the Further Study

Further researches will be needed to evaluate the technical and institutional feasibilities of the Mediterranean-Dead Sea (MDS) conduit scheme, including;

Technical Issue

- Rate of actual evaporation from Dead Sea surface after impounding seawater from the Mediterranean, including in-situ measurement and laboratory model test.

- An application study on low pressure (30-50 Kg/cm^2) type of membrane module for seawater reverse osmosis (RO) desalination.

- Design of materials to avoid corrosion of hydraulic structures from seawater and brine reject water.

Institutional Issue

- Riparian right issue on the multi-national use of the Dead Sea surface including the allocation of potential energy from evaporation from its surface.

- Demilitarization of the Mediterranean-Dead Sea (MDS) conduit route and arrangements for project management for 50 years by international agency such as United Nations.

ARID ZONE WATER RESOURCES PLANNING STUDY WITH APPLICATIONS OF NON-CONVENTIONAL ALTERNATIVES

APPENDIX : FIGURES

Masahiro Murakami

A Thesis submitted to the University of Tokyo
in Partial Fulfillment of the Requirements
for the Degree of Doctor of Engineering

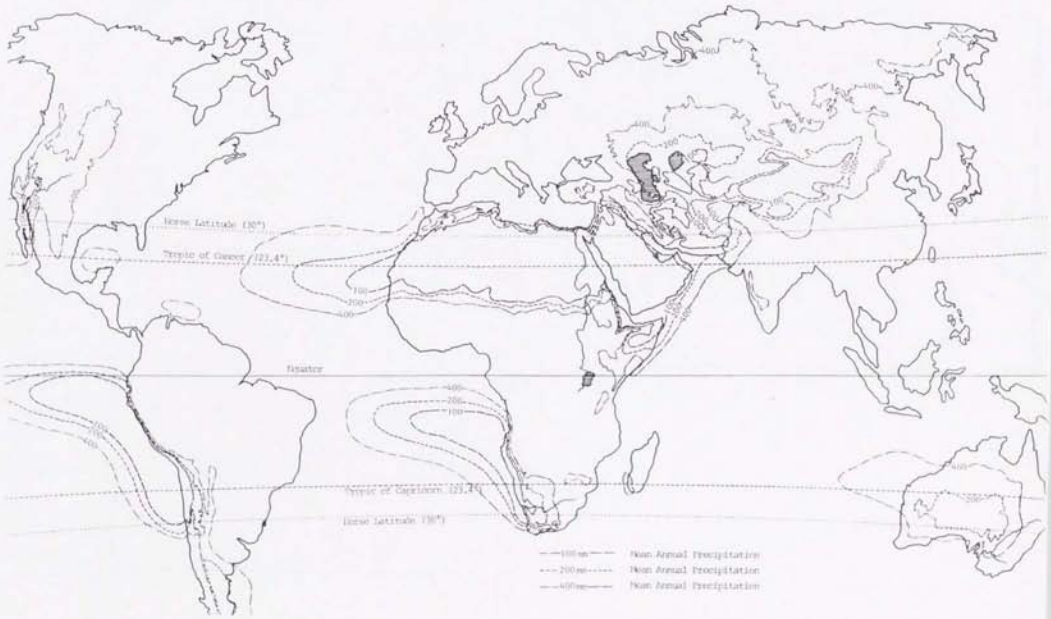


Fig. 2.1.1-1
Arid zone and Mean Annual Precipitation

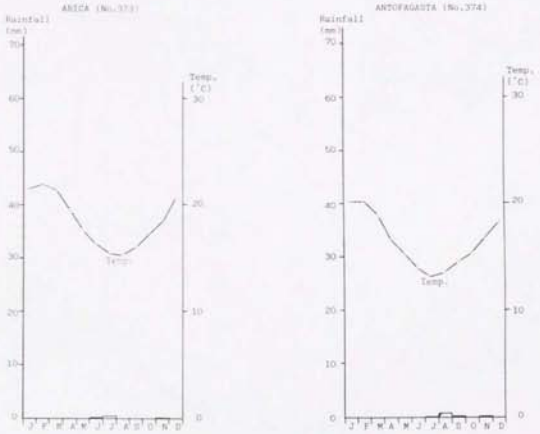
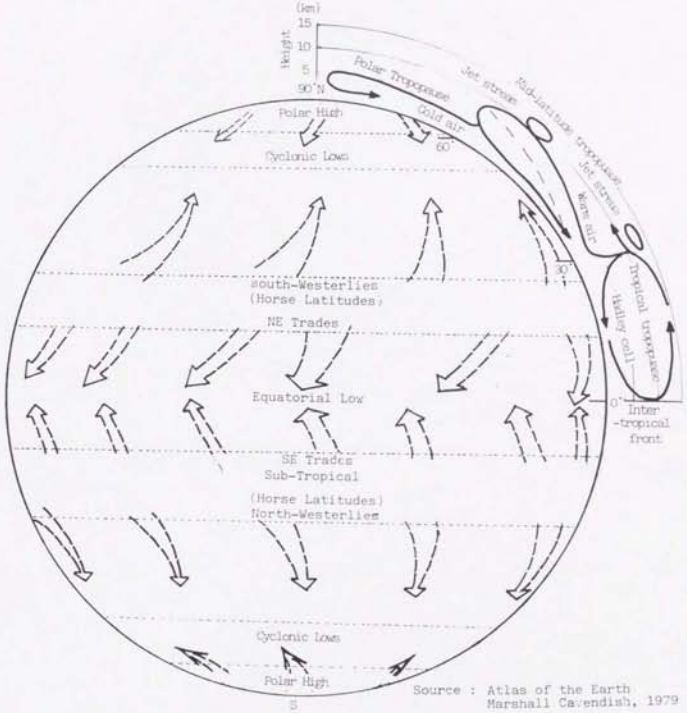
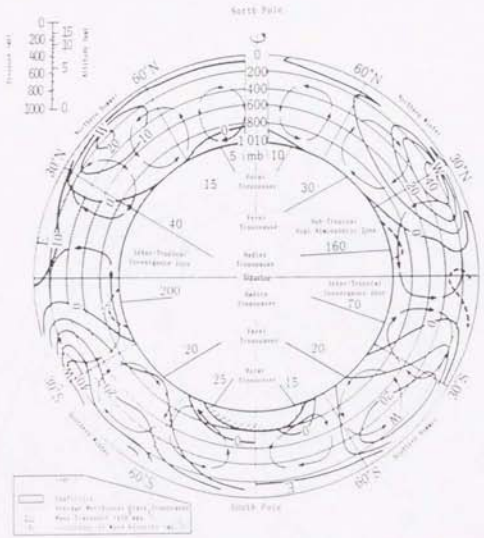


Fig. 2.1.1-2
Climate Graphs of the Arid Region



Source : Atlas of the Earth
Marshall Cavendish, 1979

Fig. 2.1.1-3
Global Wind Convection and Atmospheric Pressure Zones



Source; Arid Zone Research Vol.17,
UNESCO 1961 (Ref.2.1.1-2)

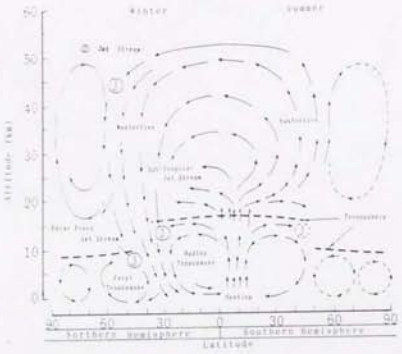


Fig. 2.1.1-4
Schematic Global Circulation and Tropopause

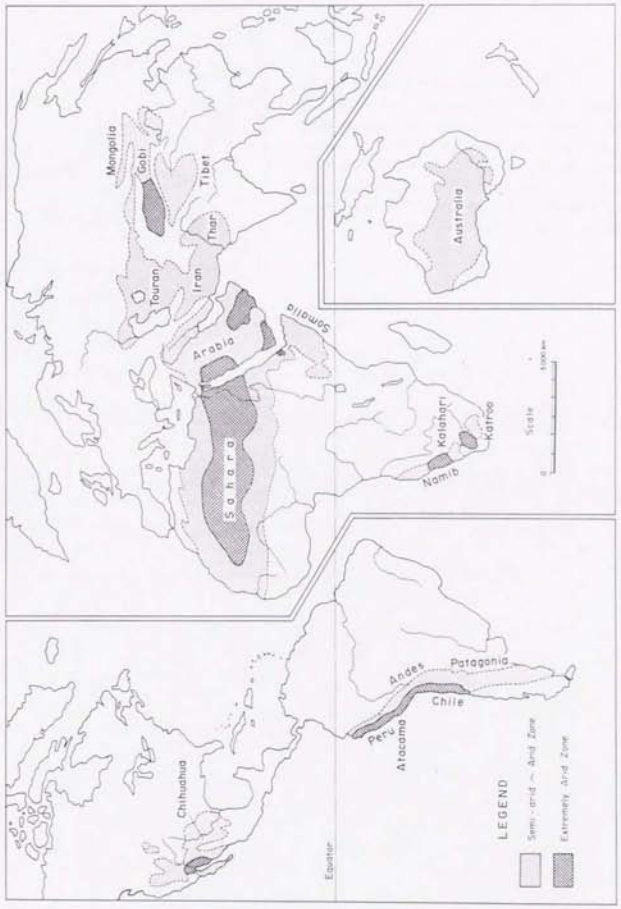


Fig. 2.1.2-1
World Arid Zones: by Meigs

The 400-year runoff record in the Colorado River Basin reconstructed from tree rings (plotted as a 10-year moving average) [from *Stockton and Jacoby*, 1976]. Note the anomalously high runoff during the early twentieth century. This short period was used to determine allocations for the 1922 Colorado River compact. (Ref.2.1.4-4)

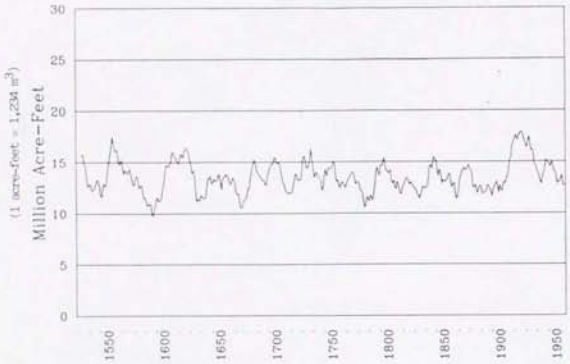
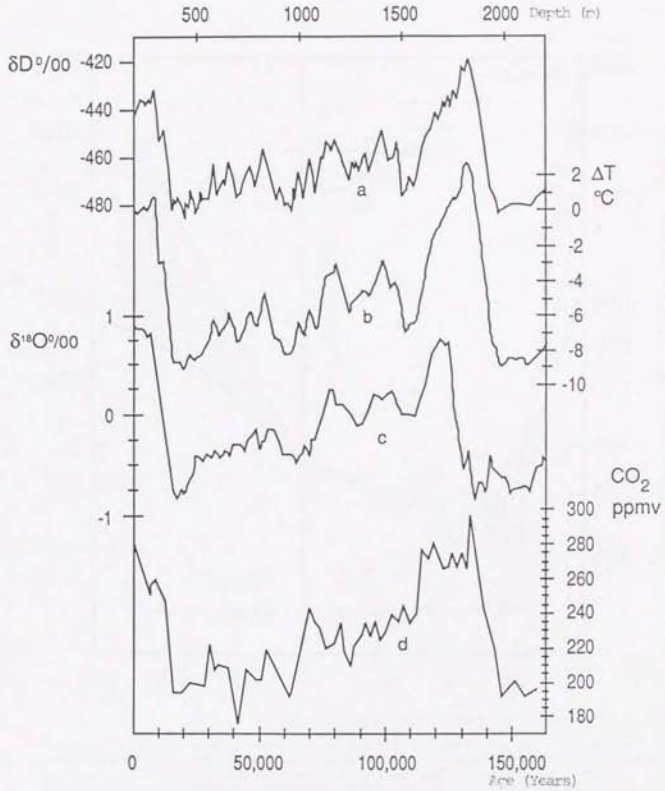
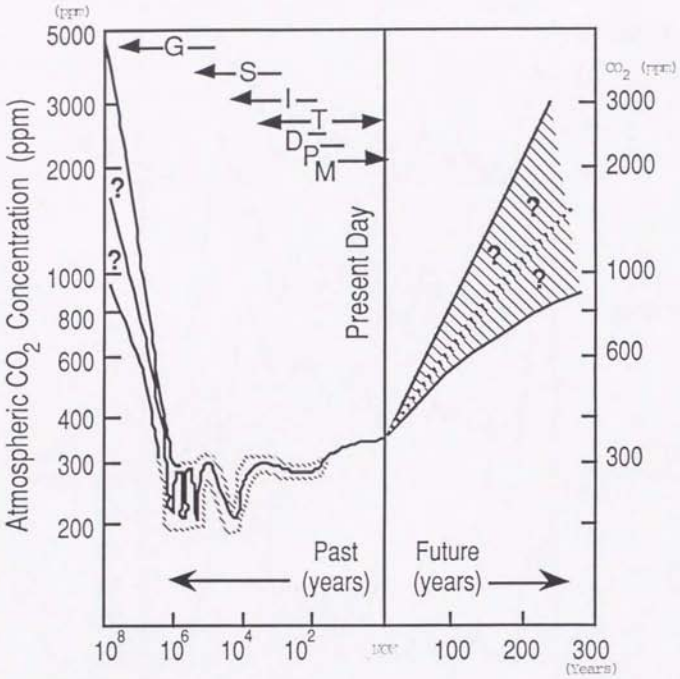


Fig. 2.1.4-1
Carbon-thirteen (^{13}C) Isotope of Tree Rings; Paleo-hydrology of Colorado River



Note: Curve a: Vostok isotope profile (deuterium content per mile versus SMOW). Curve b: Smoothed Vostok isotope temperature record expressed in degrees Celsius as a difference with respect to current surface temperature value. Curve c: Marine $\delta^{18}O$. Curve d: CO_2 concentrations (ppmv). The upper scale gives the depth of the Vostok ice core: the lower scale indicates the time (in years) of the various records. (Source; Loruis,C, 1988) (Ref.2.1.4-5)

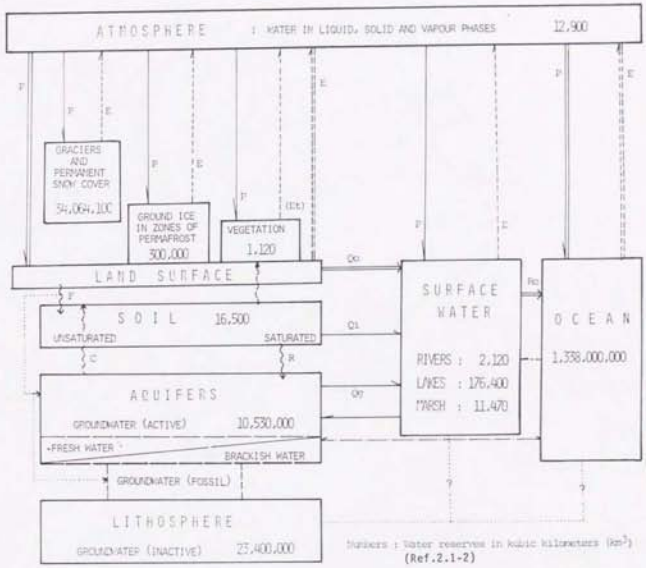
Fig. 2.1.4-2
Carbon Dioxide (CO_2) Concentrations in the Vostock Ice Cores



(Source; Gammon,R.H.,1985) (Ref.2.1.4-6)

Note: Overview of the history of atmospheric CO_2 from 10^8 years ago to the present day on a log-log scale. For comparison, the possible future CO_2 levels projected for the next few centuries are shown on a linear time scale. The analytical method appropriate to each time scale is indicated by letters and arrows: (G) geological carbon cycle models, (S) ocean sediment cores, (I) trapped air bubbles in ice cores, (T) ^{13}C isotopic studies of tree rings, (D) direct chemical measurements of the past century, (P) spectroscopic plates from Smithsonian Solar Constant Program, (M) Mauna Loa record and subsequent precise atmospheric CO_2 measurements by nondispersive infrared spectroscopy. The hatching and dashed lines indicate the general level of uncertainty about the estimated CO_2 concentration in each time interval. The ice-age cycling is only representative of the range of CO_2, not the specific number of glaciations.

Fig. 2.1.4-3
Carbon Dioxide (CO_2) Concentrations In Geologic Time Scale



(Ref.2.1-2)

Notes:
W : Precipitable water in atmosphere
P : Rainfall/Precipitation
E : Evaporation
Qo : Overland flow
Qi : Lateral interflow
Qg : Groundwater outflow
F : Filtration/Infiltration(surface to unsaturated soil)
I : Groundwater recharge
Ro : Runoff to ocean
C : Capillary rise from groundwater

Fig. 2.1.5-1
Diagram of Global Hydrological Cycle

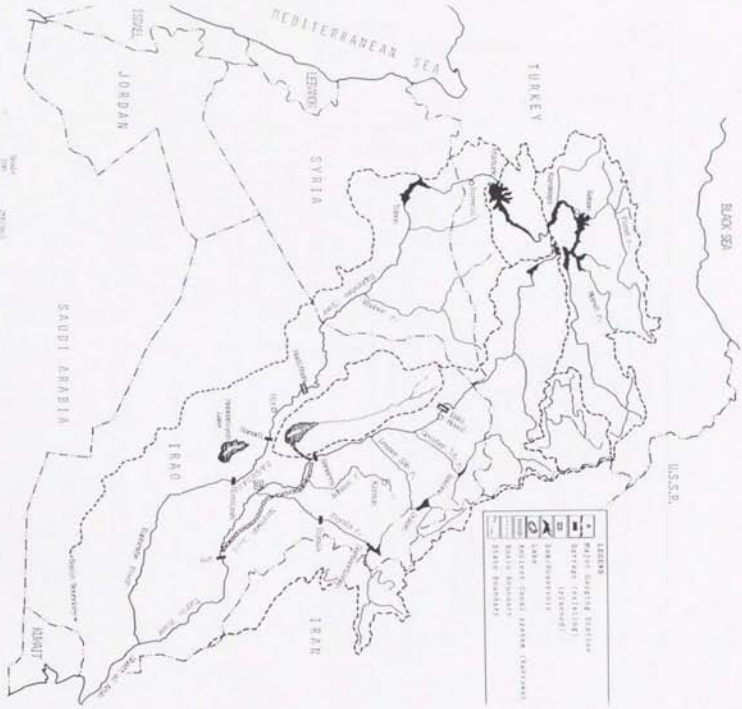


Fig. 2.2-1
The Tigris-Euphrates River Basin

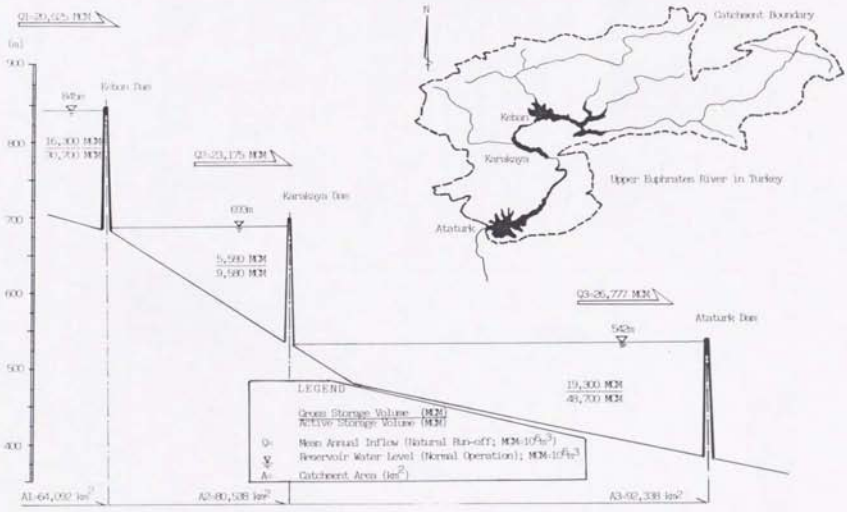
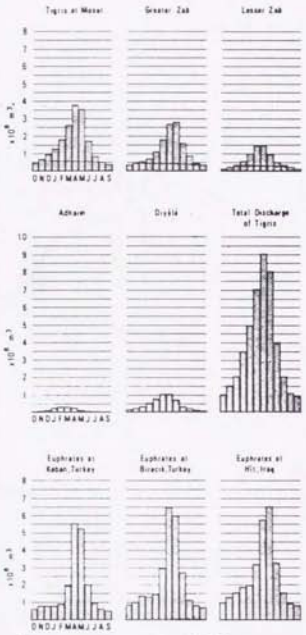
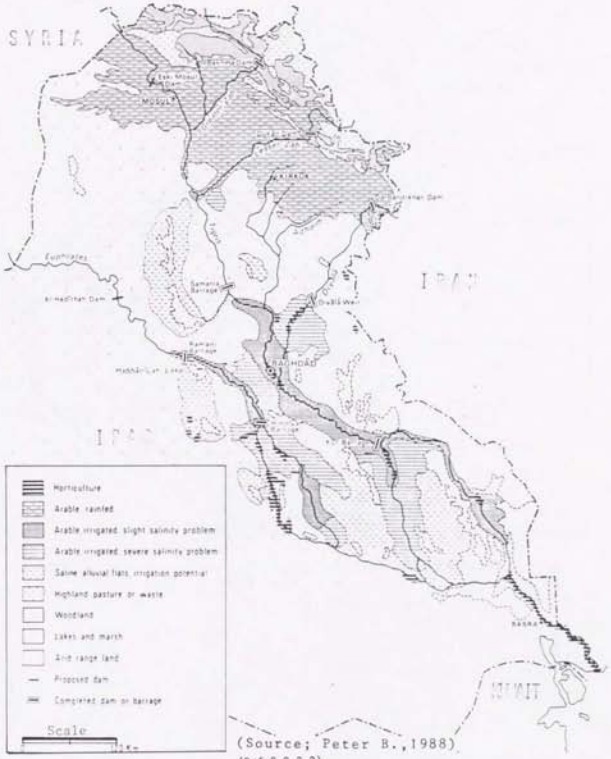


Fig. 2.2.2-1
The Upper Euphrates River Basin: Firat and Murat



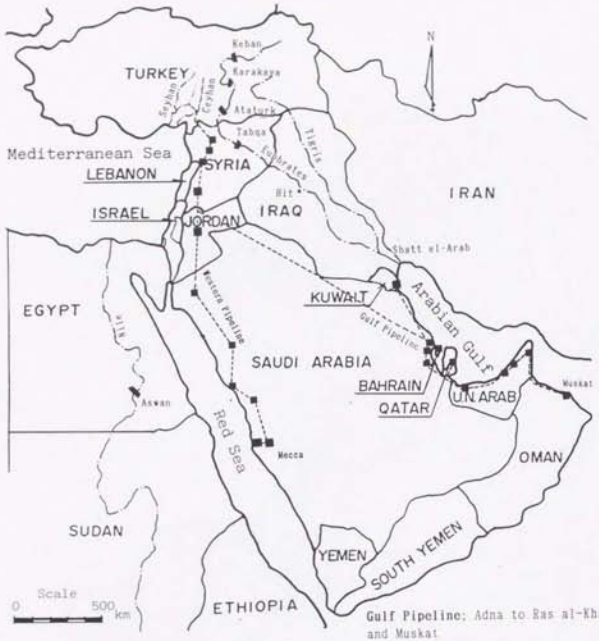
(Source; Peter B.,1988)
(Ref.2.2.2-2)

Fig. 2.2.2-2
Selected Regime Hydrograph of the Tigris-Euphrates Rivers



(Source; Peter B.,1988)
(Ref.2.2.2-2)

Fig. 2.2.3-1
Salinity of the Tigris-Euphrates Delta



Western Pipeline: Adna to Mecca

State	City	(m^3/day)
Turkey		300,000
Syria	Allepo	300,000
	Hama	100,000
	Homs	100,000
	Damascus	600,000
Jordan	Amman	600,000
Saudi Arabia	Tabuk	100,000
	Medina	300,000
	Yanbu	100,000
	Jeddah	500,000
	Mecca	500,000
Total		(3,500,000)

Gulf Pipeline: Adna to Ras al-Khaimah and Muskat

State	City	(m^3/day)
Kuwait		600,000
Saudi Arabia	Jubail	200,000
	Damman	200,000
	Al-Khobar	200,000
	Hofuf	200,000
Bahrain	Manama	200,000
Qatar	Doha	100,000
U.A.E	Abu Dhabi	280,000
	Dubai	160,000
	Sharjah/Ajman	120,000
	Umm al-Qaiwain/ Ras al-Khaimah/ Fujarah	40,000
Oman	Muscat	200,000
Total		(2,500,000)

Fig. 2.2.4-1
Peace Pipeline Scheme

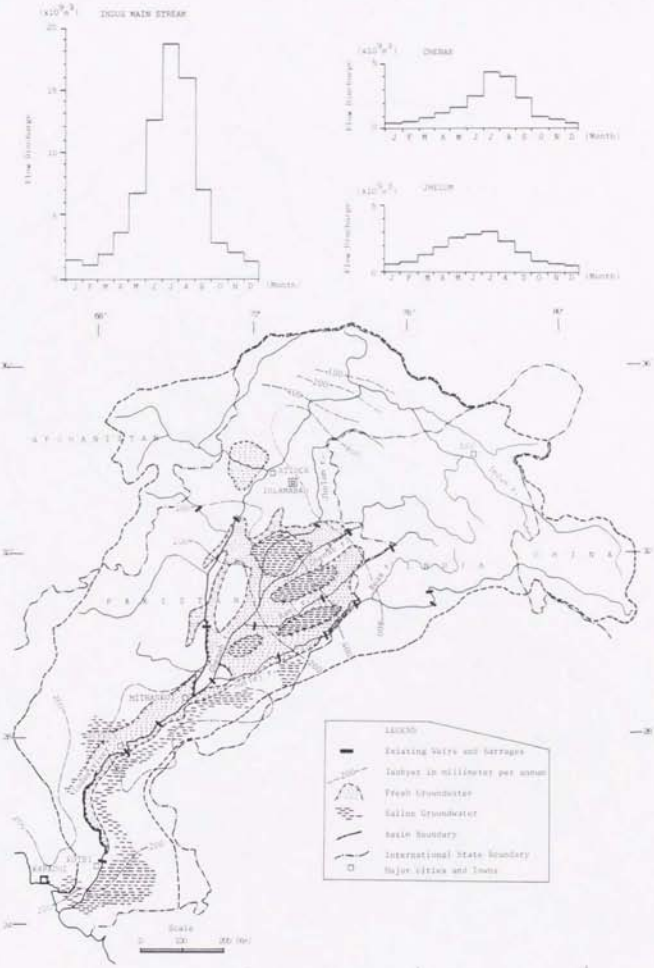
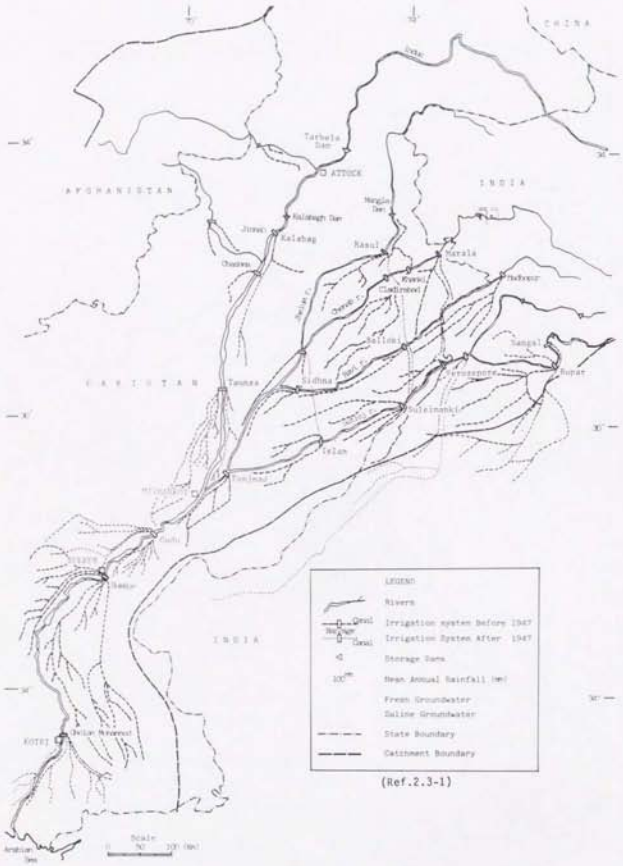
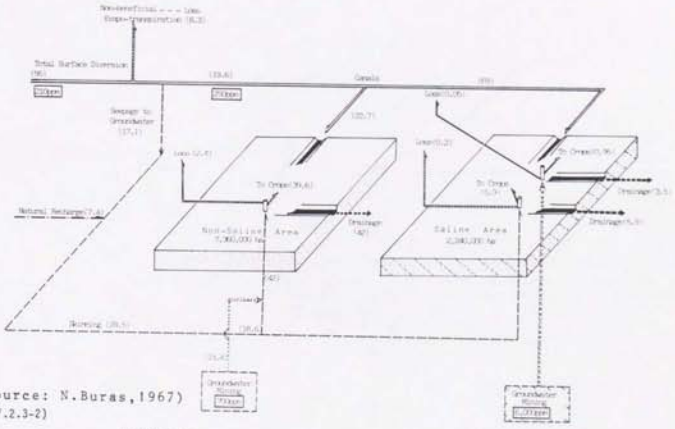


Fig. 2.3.1-1
Indus River Basin



(Ref.2.3-1)

Fig. 2. 3. 3-1
Indus River Development



(Source: N.Buras,1967)
(Ref.2.3-2)

Fig. 2. 3. 4-1
Schematic Diagram of Indus River Salinity

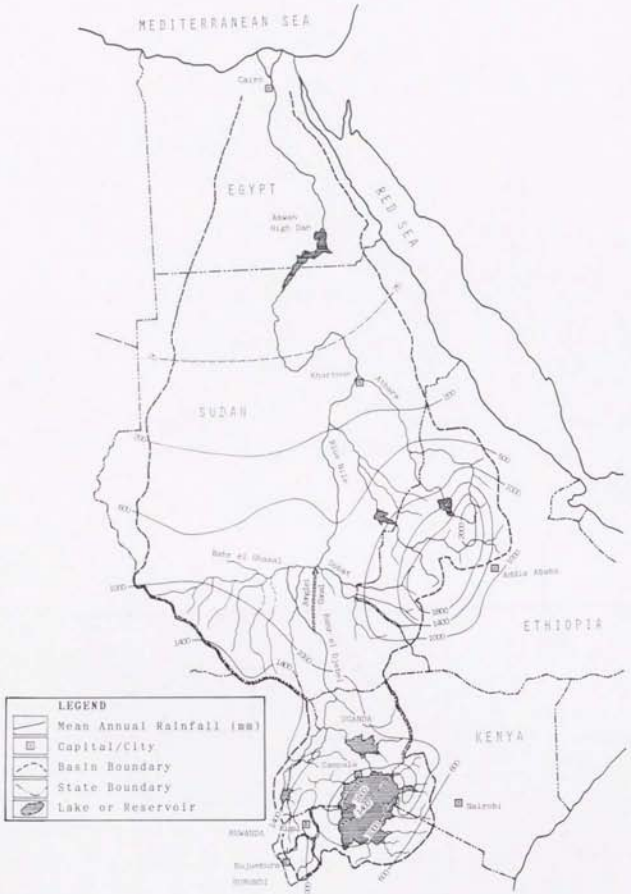
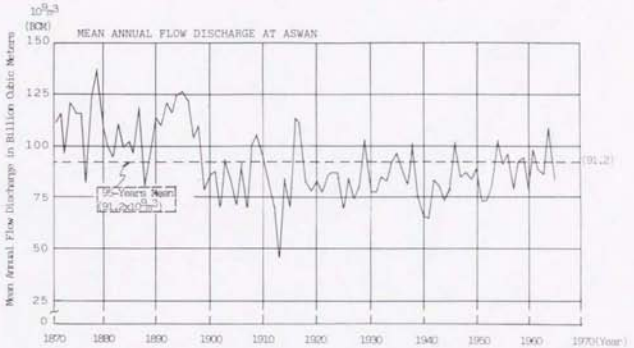


Fig. 2.4-1
The Nile River Basin



(Source; Peter B.,1988)
(Ref.2.4.7-2)

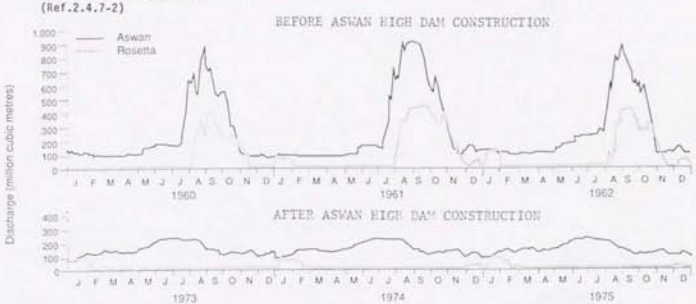
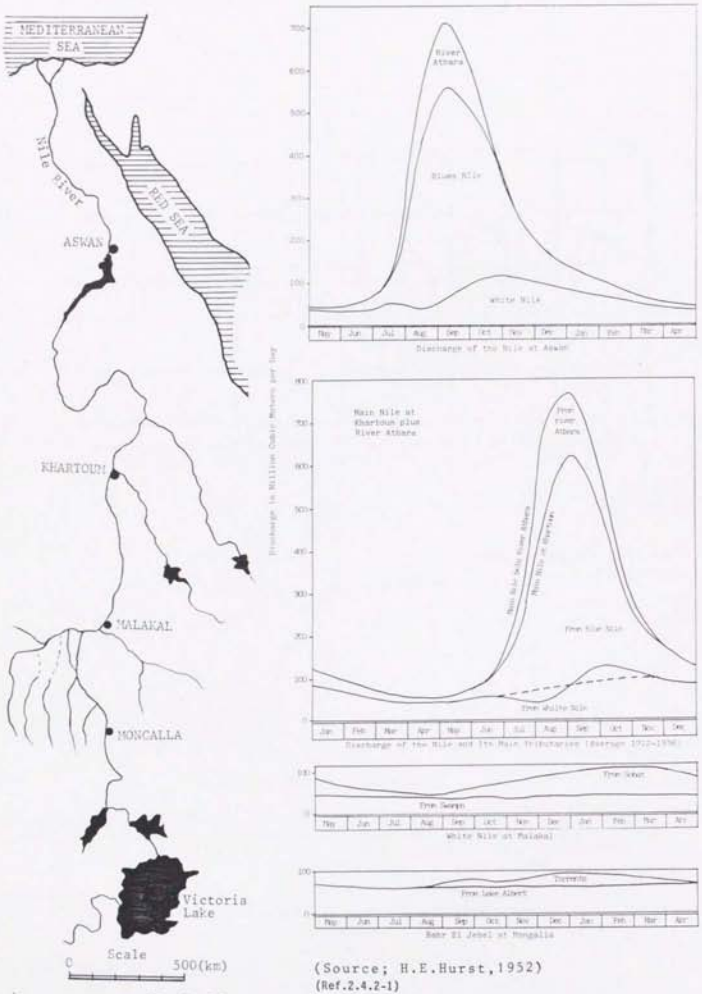
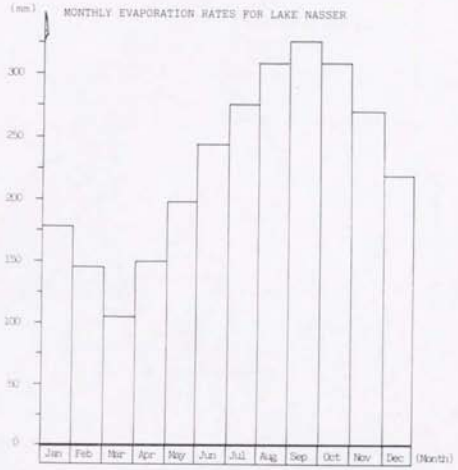


Fig. 2.4.2-1
Mean Annual Flow Discharge at Aswan and Rosetta;



(Source; H.E.Hurst,1952)
(Ref.2.4.2-1)

Fig. 2.4.2-2
Flow Diagram of the Main Nile at Aswan and Khartoum

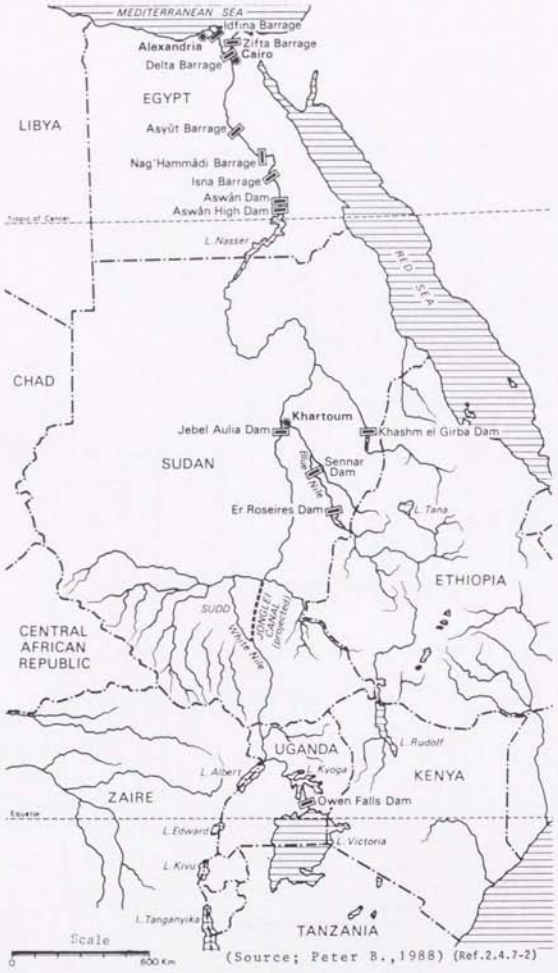


MEAN DAILY POTENTIAL EVAPORATION AT SELECTED POINTS IN NILE BASIN

Mean Daily Potential Evaporation / Locality	Piche (mm)	Open water (mm)
Meditarranean coast	6.1	3.0
Nile delta	4.6	2.3
Cairo and neighbourhood	5.5	2.8
Fayum	7.9	4.0
Oases	13.0	6.5
Upper Egypt	9.0	4.5
Northern Sudan (Halfa Atbara)	15.1	7.6
Khartoum and neighbourhood	15.5	7.8
Central Sudan (Dueim to Rosaires)	12.6	6.3
Southern Sudan (Malakal and south swamp	6.8	3.4
Lake Albert		3.9
Lake Edward		3.9
Lake Victoria		3.8

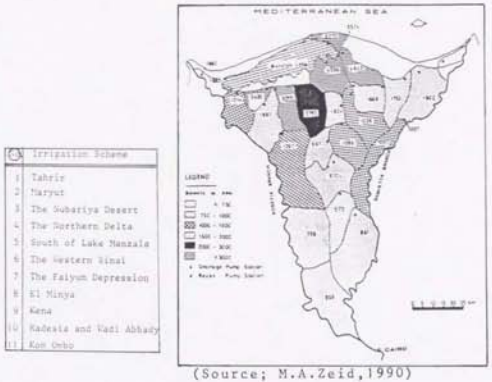
(Ref.2.4.2-1)

Fig. 2.4.2-3
Potential Evaporation of the Nile Basin

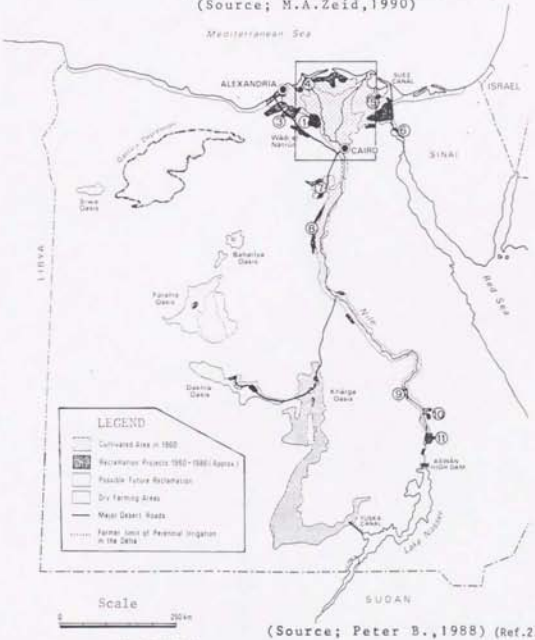


(Source; Peter B.,1988) (Ref.2.4.7-2)

Fig. 2.4.3-1
The Hydraulic Works of the Nile Basin



(Source; M.A.Zeid,1990)



(Source; Peter B.,1988) (Ref.2.4.7-2)

Fig. 2.4.7-1
Egypt's Agricultural Potential and Nile Delta Salinity

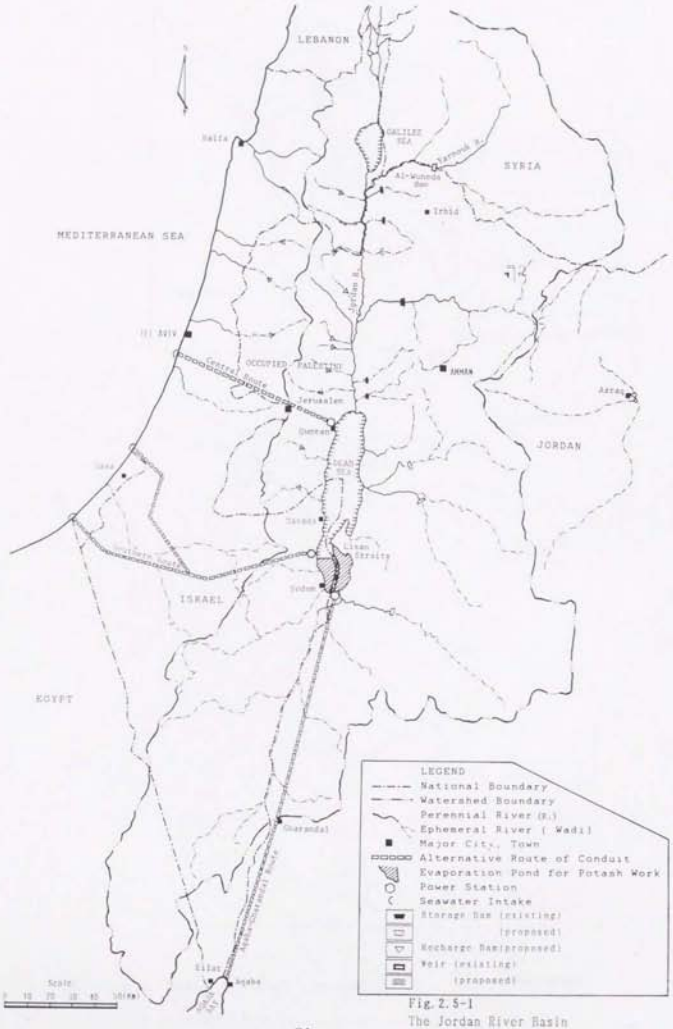


Fig. 2.5-1
The Jordan River Basin

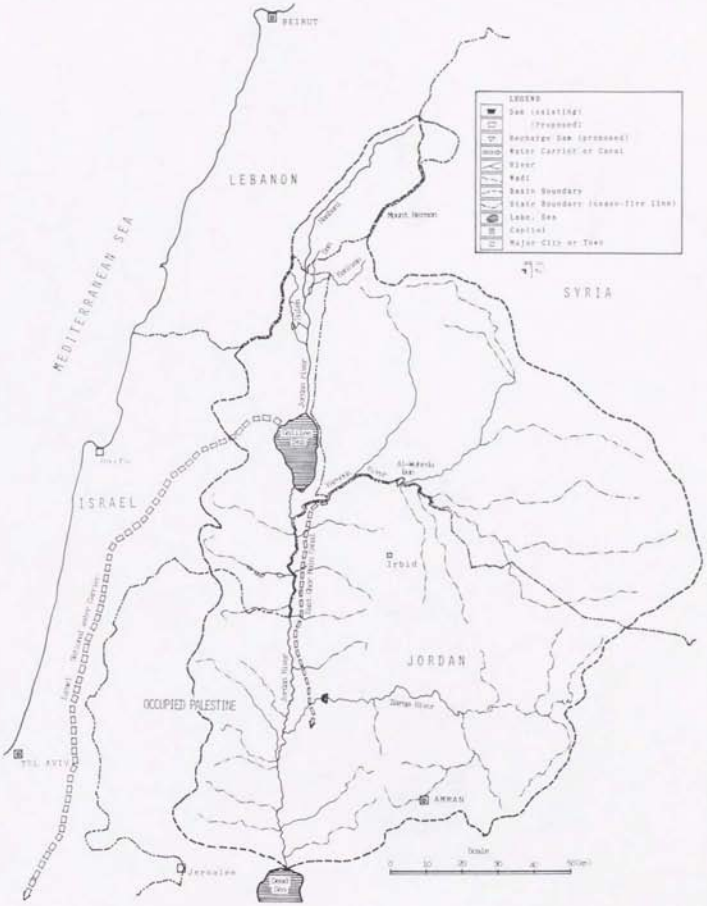


Fig. 2.5.2-1
The Upper Jordan River System

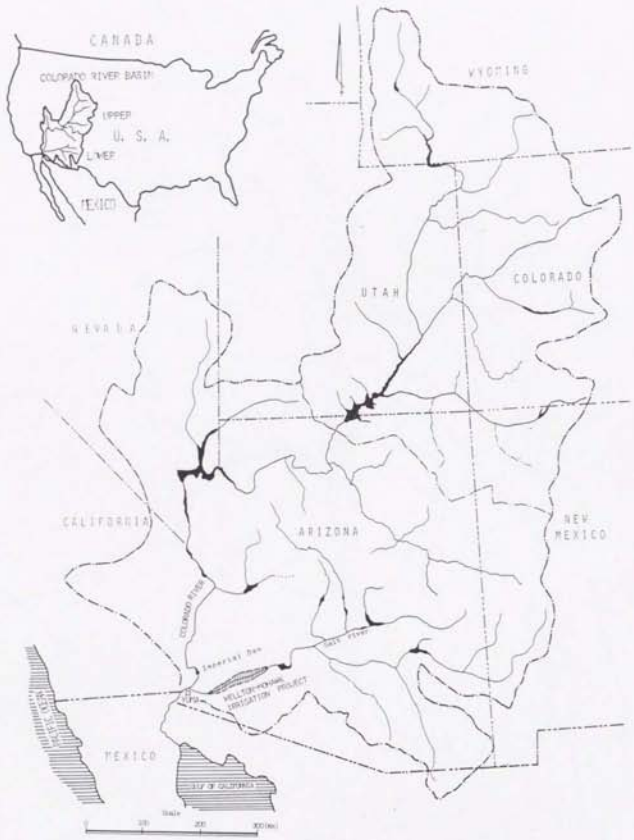


Fig. 2. 6. 1-1
The Colorado River Basin

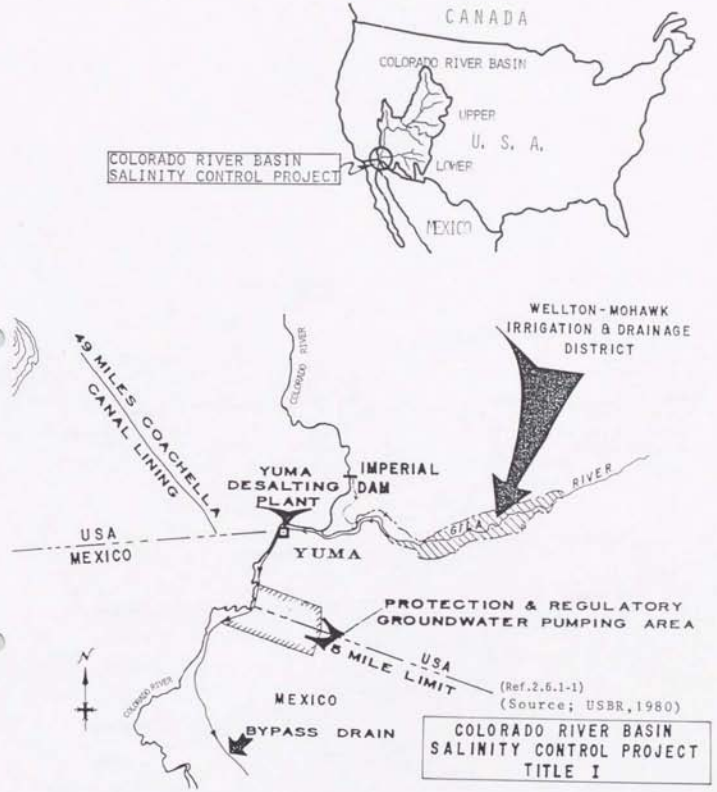
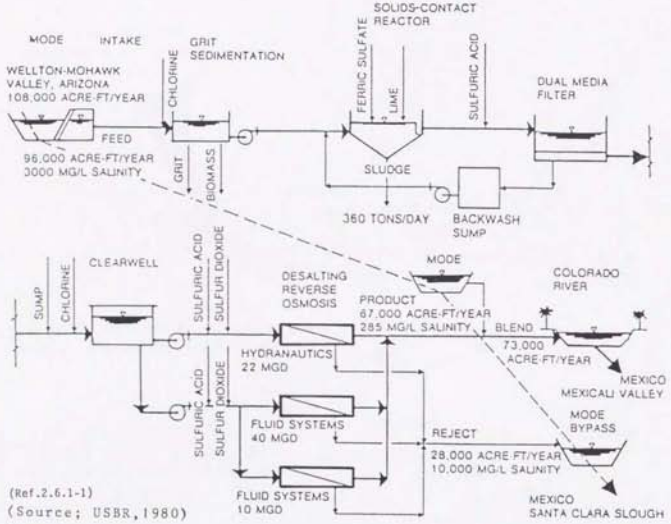


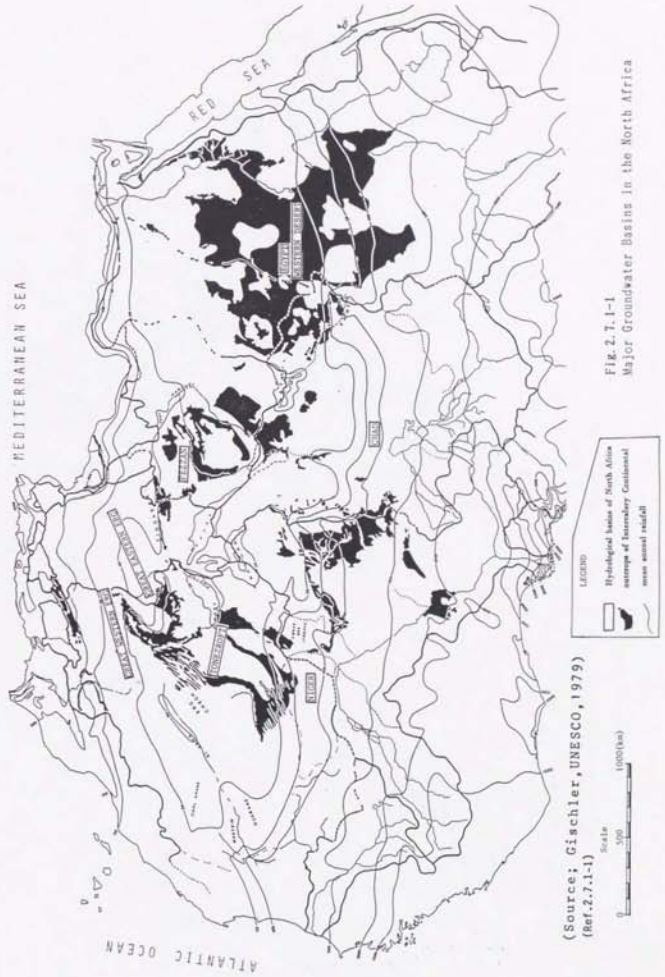
Fig. 2. 6. 4-1
Colorado River Salinity Control in Arizona



(Ref.2.6.1-1)
(Source; USBR, 1980)

Note: *Flow diagram shows sequence of high-salinity inflow as it is converted to usable outflow of about 80.4 mgd. (Some 72.4 mgd of desalted water is blended with 8 mgd of high-salinity water.)*

Fig. 2.6-5-1
Flow Diagram of Water Treatment and Reverse Osmosis (RO)



(Source; Gischler, UNESCO, 1979)
(Ref.2.7.1-1)

Fig. 2.7.1-1
Major Groundwater Basins in the North Africa

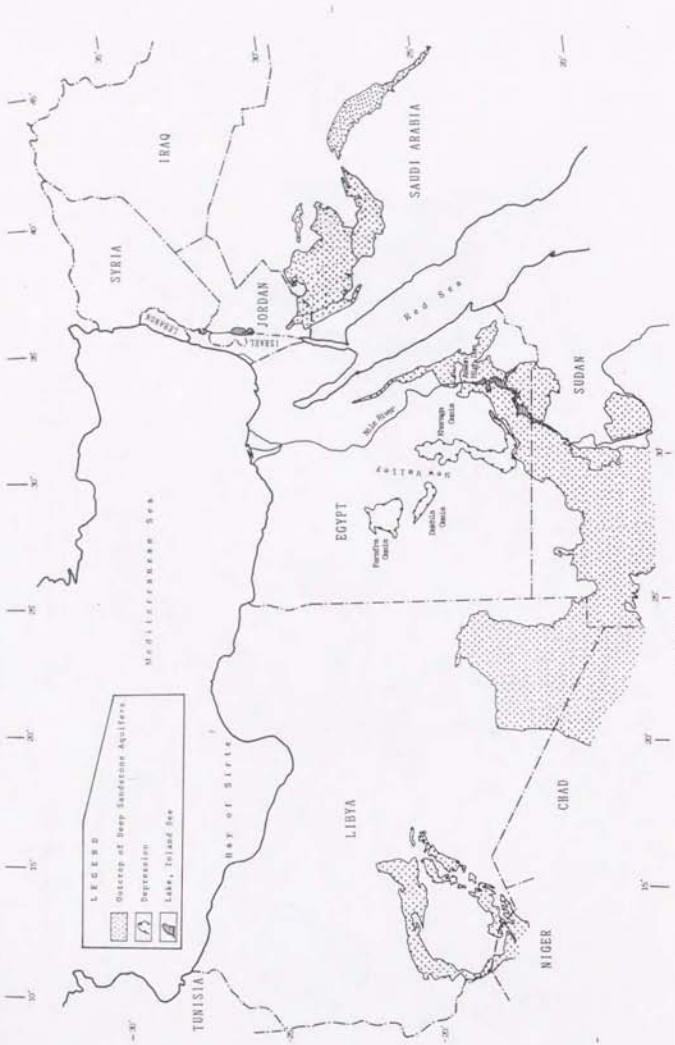
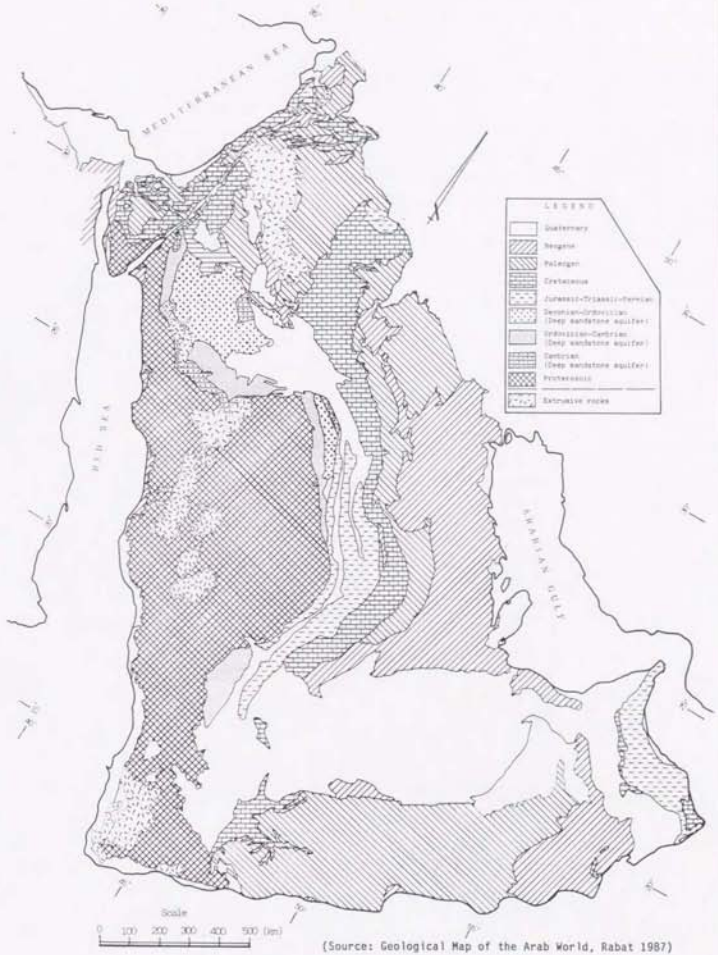


Fig. 2.7.1-2
Deep Sandstone Aquifers in the Middle East



(Source: Geological Map of the Arab World, Rabat 1987)

Fig.2.7.1-3
Geological Map of Arabian Peninsula

SYSTEM	SERIES	FORMATION IN JORDAN	FORMATION IN SAUDI ARABIA
CRETACEOUS			AMURA
SILURIAN	Upper		
	Lower		TABUK
ORDOVICIAN	Middle-Upper		
	Lower	DISI	UMM SAHM and RAM
CAMBRIAN			QUWEIRA
			SIQ

Fig. 2.7.1-4
Stratigraphic Section of Sandstone Aquifers in Jordan- Saudi Arabia

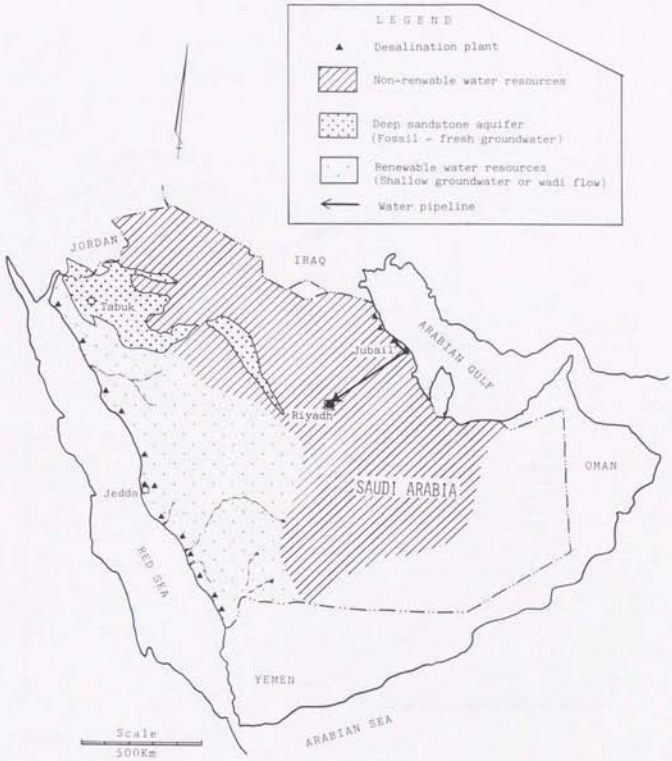


Fig. 2.7.2-1
Water Resources Map of Saudi Arabia

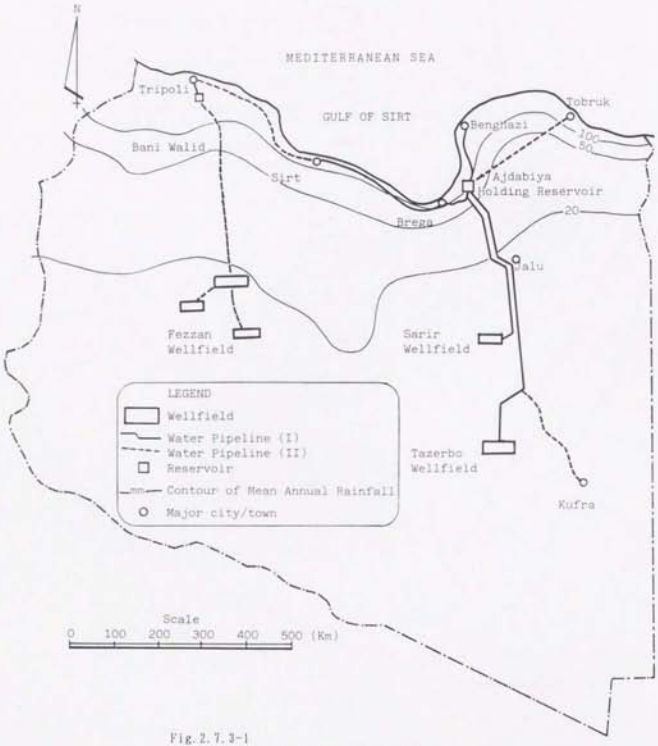
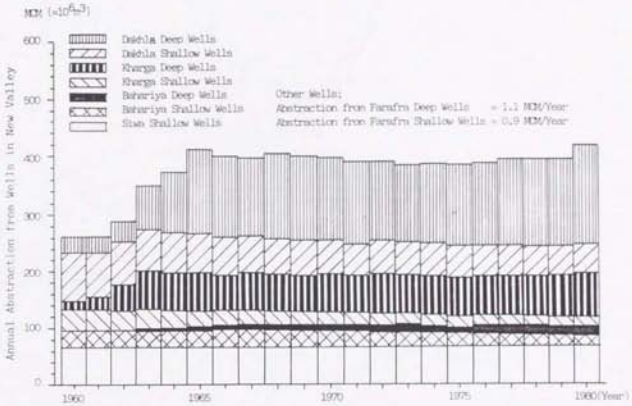
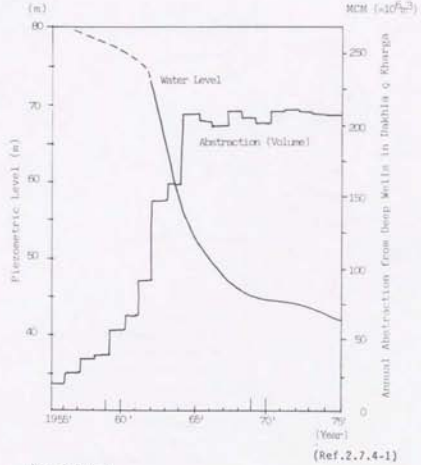


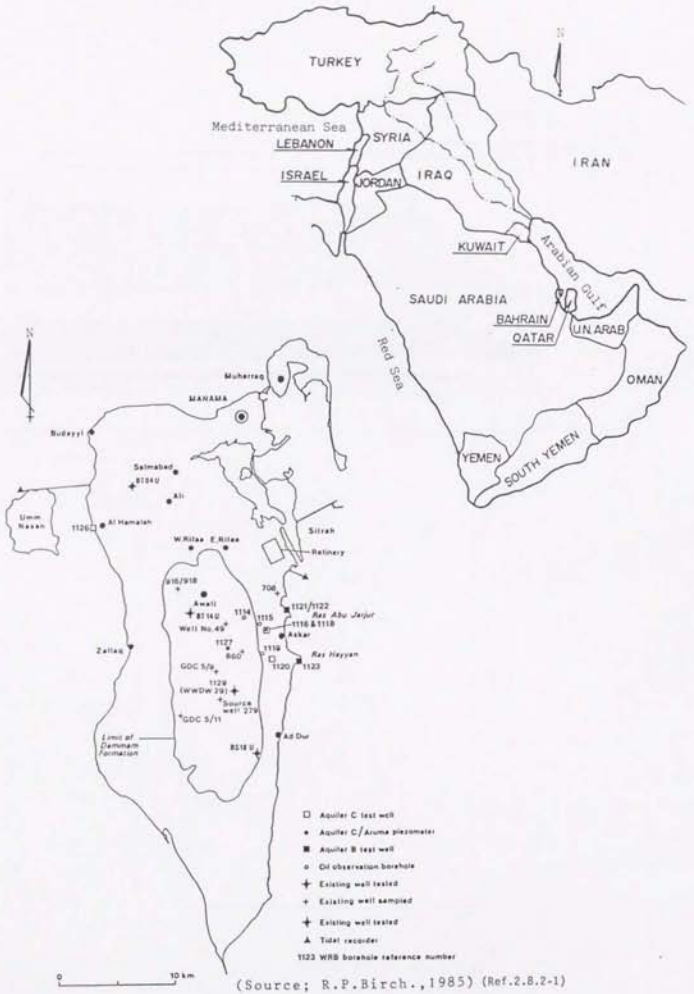
Fig. 2.7.3-1
Great Man-Made River Project in Libya





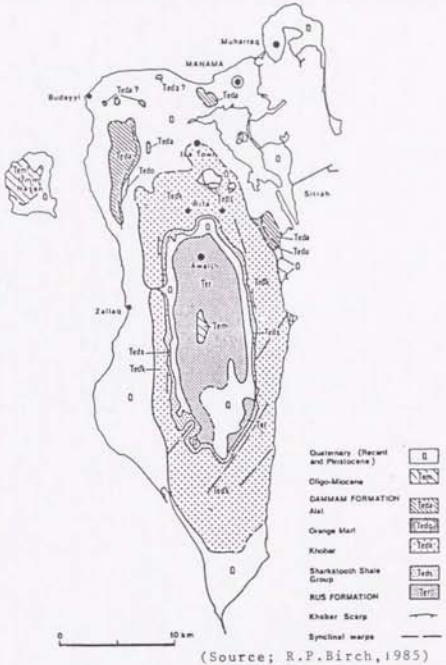
(Ref.2.7.4-1)

Fig. 2.7.4-1
Groundwater Development in the New Valley Project



(Source; R.P.Birch.,1985) (Ref.2.8.2-1)

Fig. 2.8.1-1
The Bahrain Island



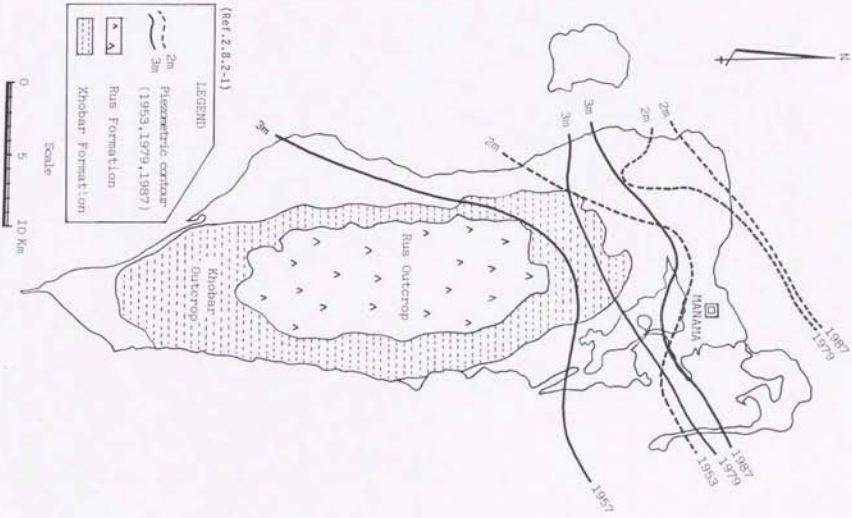
(Source; R.P.Birch,1985)
(Ref.2.8.2-1)

Fig. 2.8.1-2
Schematic Geological Profile of Bahrain and Arabian Peninsula

ERA	PERIOD	FORMATION	MEMBER	APPROXIMATE THICKNESS (M)	LITHOLOGY	HYDROGEOLOGICAL SIGNIFICANCE
QUATERNARY	Recent	Superficial		5	Aeolian sand, bioclastic limestone, beach deposits	Unsaturated.
	Pleistocene	Superficial		10	Sand, sabkha deposits	Unsaturated.
TERTIARY	Oligocene -Miocene	Jabal Cap		33	Dolomitic bioclastic limestone, algal coral breccia	Forms cap to Jabal Dukhan.
		Neogene		10-60	Marl with subordinate sandy limestone	Confines Dammam aquifers. Basal limestone forms part of the 'A' aquifer.
	Eocene	Dammam	Alat Limestone	15-25	Fossiliferous dolomitised limestone	Main 'A' aquifer. Formerly sustained small artesian flows. Low productivity. Used in NE and W coast.
			Orange Marl Khobar Dolomite	19-15 30-39	Orange-brown dolomitic marl Dolomitic limestone	Confines Aquifer B when present Main 'B' aquifer, usually confined. Highly permeable in top 5-10m. Main source of freshwater.
			Khobar Marl Alveolina Limestone Sharks Tooth Shale	Discontinuous c. 10 8-20	Marl and shale Friable brown dolarenite Shale with silty dolomitic limestone	Forms part of the 'B' aquitard. Aquitard
		Rus		60-150	Chalky dolomitic limestone, shale, gypsum and anhydrite	Part of 'C' aquifer. Aquitard if evaporites present.
	Palaeocene	Umm Er Radhuma		115-350	Dolomitic limestone and calcarenite, often argillaceous and bituminous	'C' aquifer in upper UER and Rus. Salinity stratified. Lower UER saline with low permeability.
MESOZOIC	Cretaceous	Aruma		c.400	Mainly shale in the upper part, limestone predominant below	Aruma shales form hydraulic base to Umm Er Radhuma.

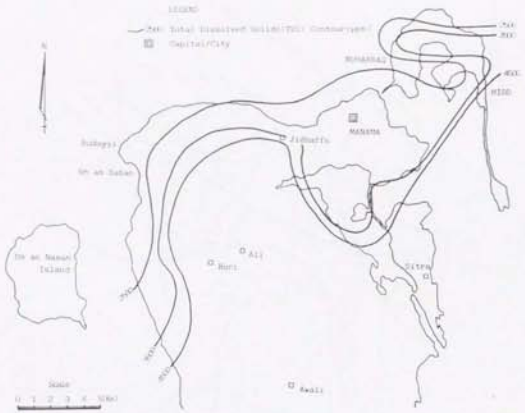
Fig. 2.8.1-3
Geological Sequences of Bahrain

(Source;R.P.Birch.,1985) (Ref.2.8.2-1)



(Ref.2.8.2-1)

Fig. 2.8.3-1
Piezometric Level Change in Khobar Aquifer in Bahrain



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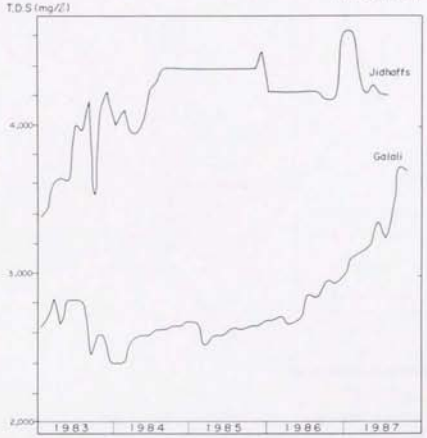
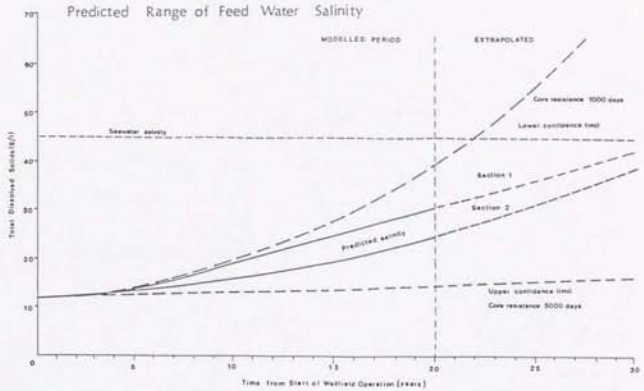


Fig. 2. 8. 3-2
Total Dissolved Solids (TDS) of Khobar Aquifer in Bahrain



(Source; R.P.,Birch,1985) (Ref.2.8.5-1)

Process flow scheme

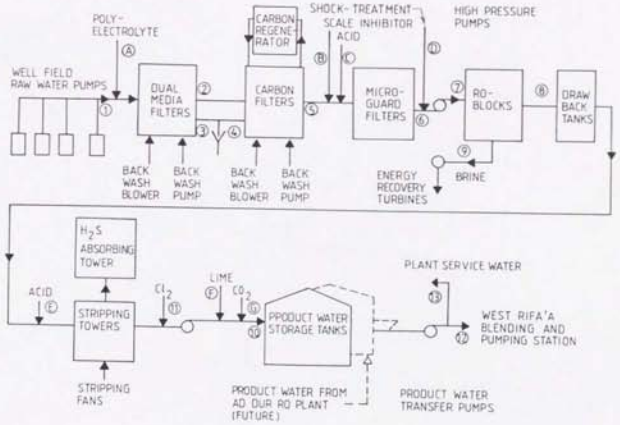


Fig. 2. 8. 5-1
Predicted Range in Feedwater Salinity and Diagram of Reverse Osmosis (RO) System

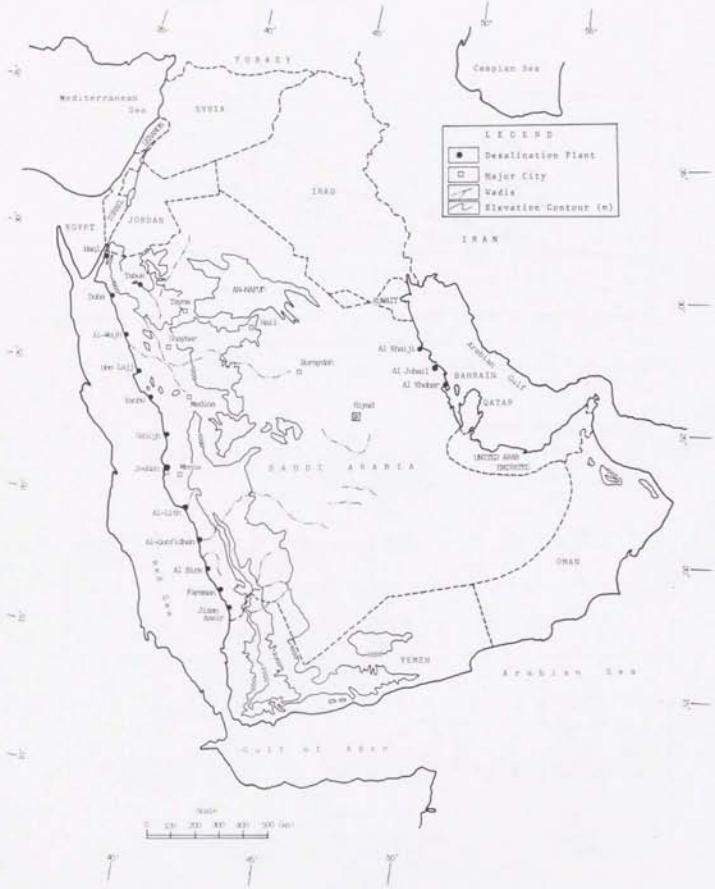
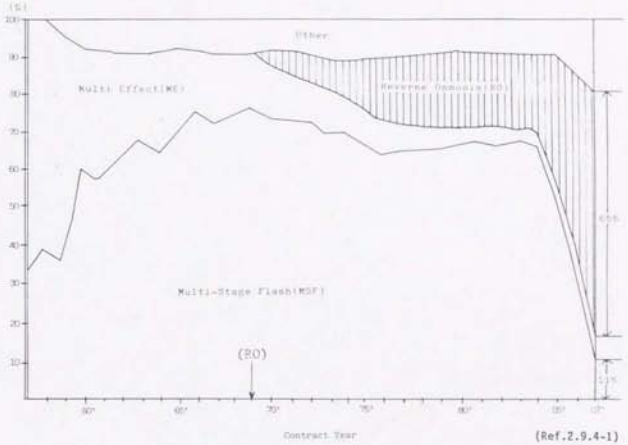


Fig. 2.9.2-1
Desalination Plant and Water Supply in Saudi Arabia

(Source; Desalting Plants Inventory, No.11, 1988)



(Ref.2.9.4-1)

Fig. 2.9.4-1
Worldwide Market Share of Various Desalination Process

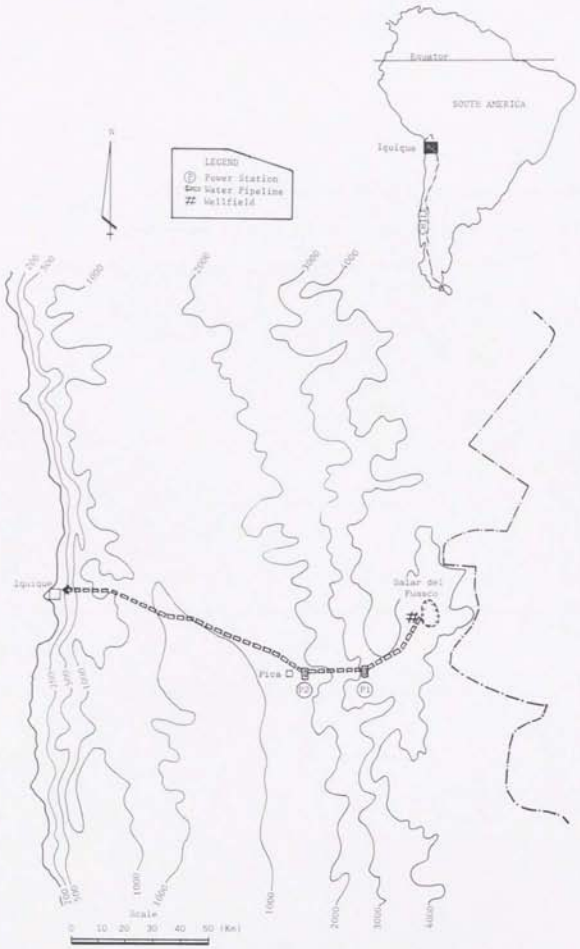


Fig. 2.10.1-1
Salar del Fuasco Groundwater Development Scheme and Water Pipeline System

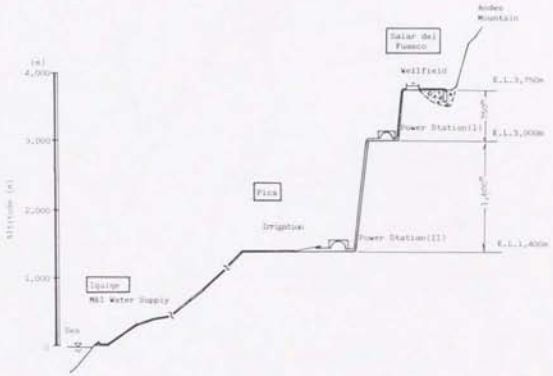


Fig. 2.10.1-2
Schematic Profile of Salar del Fuasco Groundwater-hydro Scheme

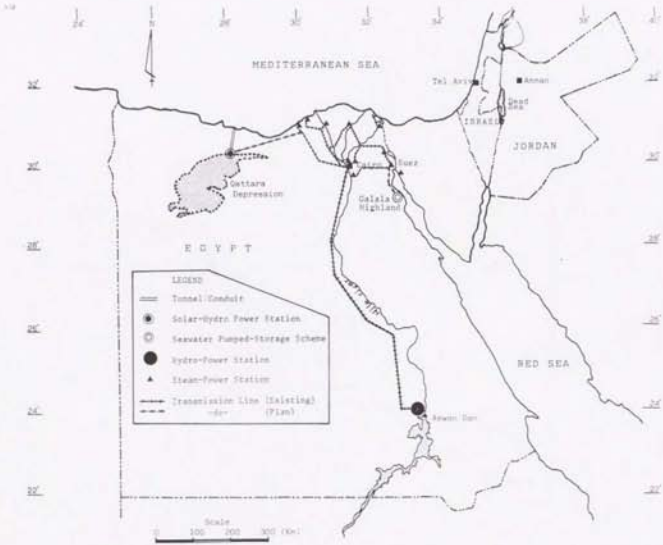


Fig. 2. 11. 1-1
Qattara Depression and Electric Power Supply System

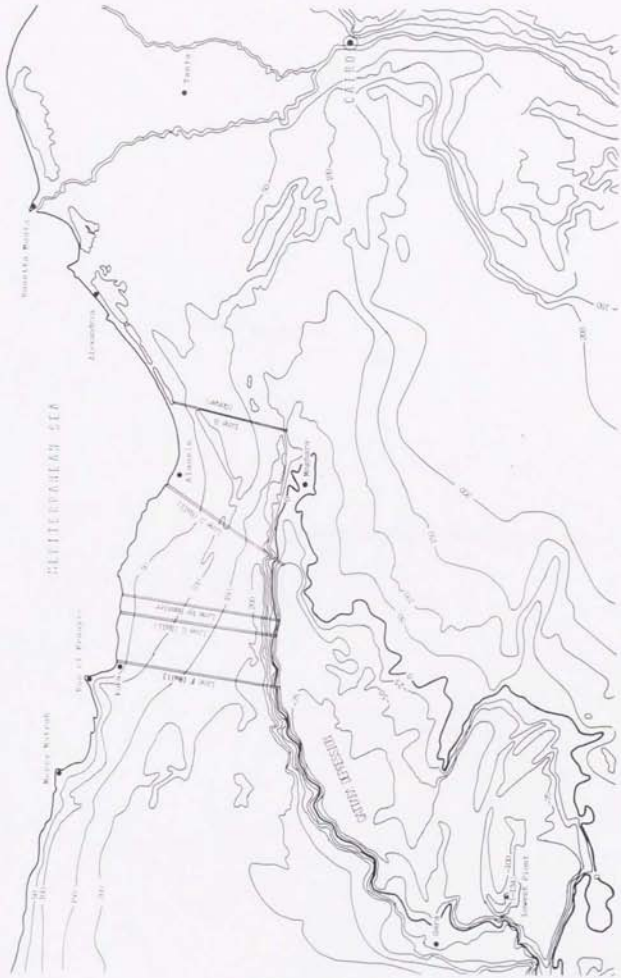
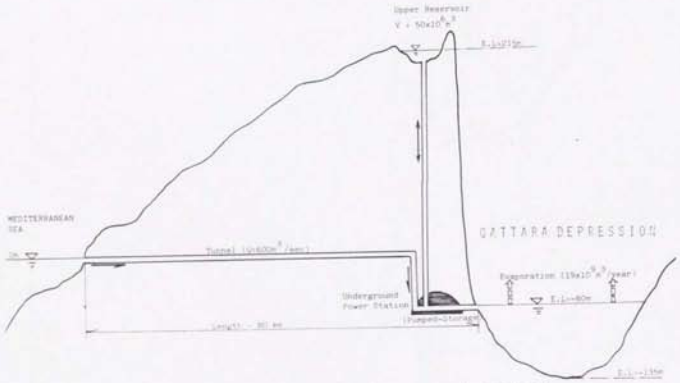
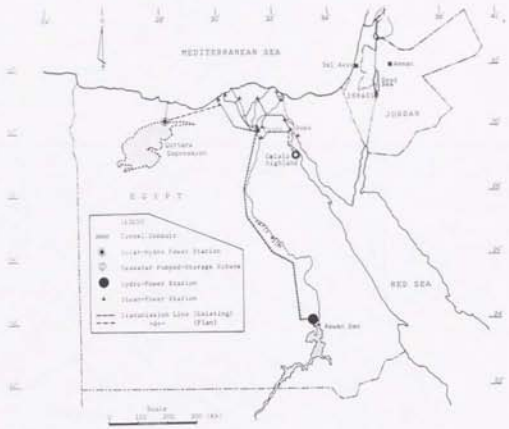


Fig. 2. 11. 2-1
Qattara Depression and Hydro-solar Development Scheme



(Ref.2.11.5-1)

Fig. 2.11.5-1
Schematic Profile of Mediterranean-Qattara Hydro-Solar with Pumped-Storage Scheme



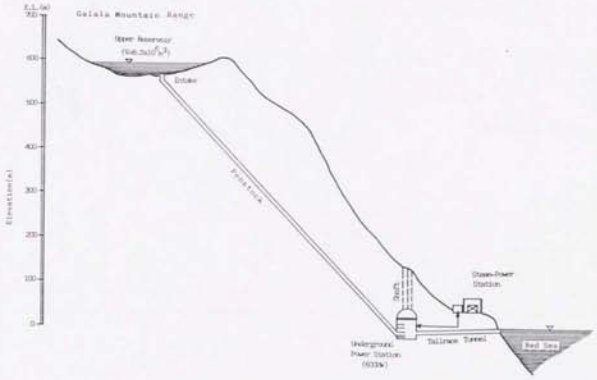


Fig. 2.11.6-1
Schematic Profile of Galala-Red Sea Pumped-Storage Scheme

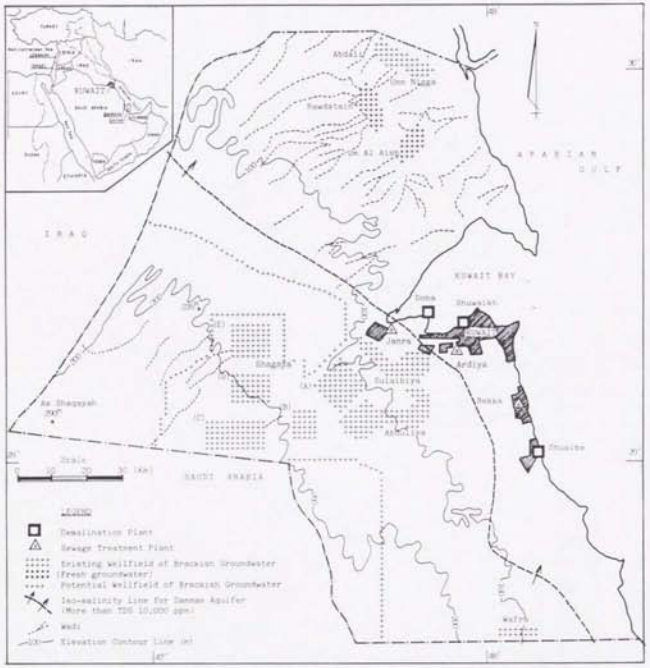
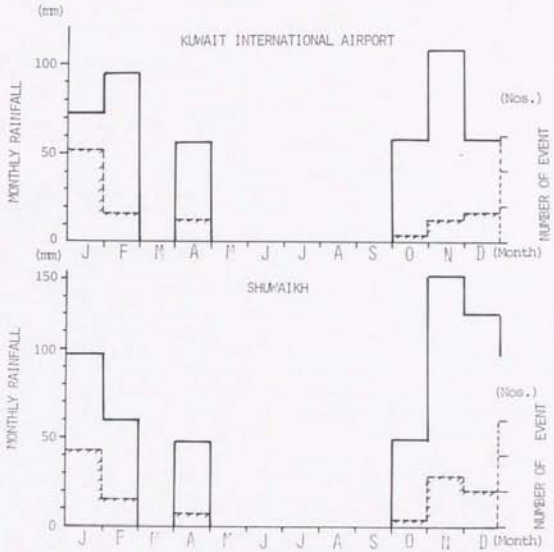
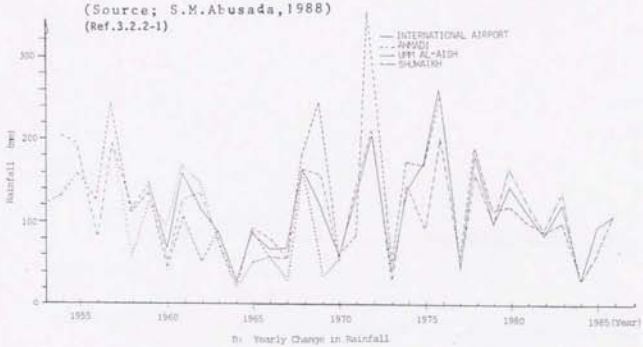


Fig.3.1.1-1
Kuwait and Water Resources



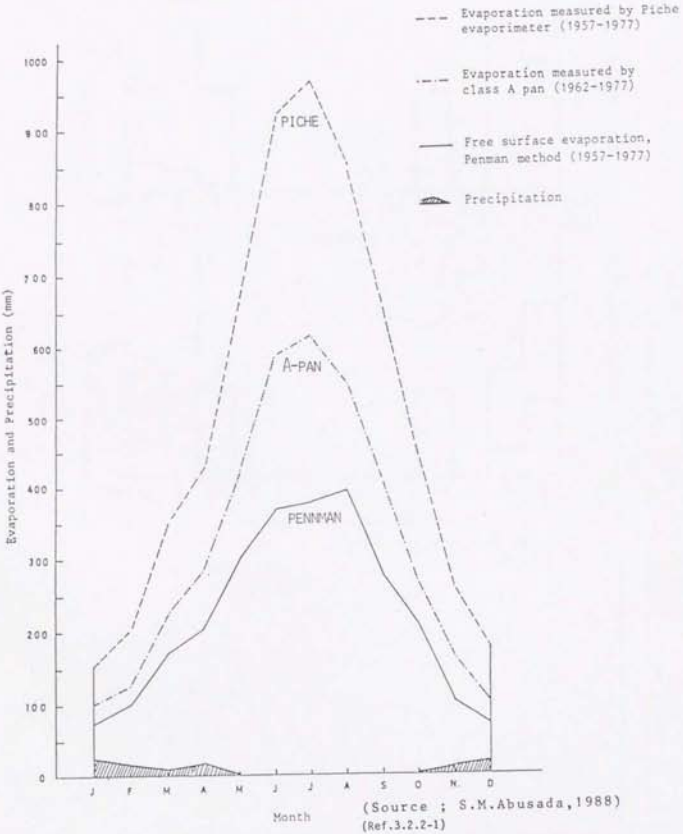
A: Monthly Rainfall and Histogram

(Source; S.M.Abusada,1988)
(Ref.3.2.2-1)



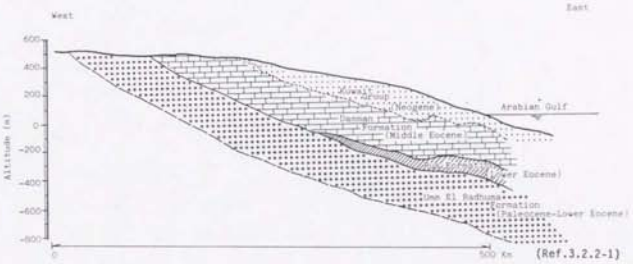
B: Yearly Change in Rainfall

Fig.3.2-1
Rainfall Records: Kuwait International Airport, Ahmadi, Umm Al-Aish, Shuwaikh



(Source ; S.M.Abusada,1988)
(Ref.3.2.2-1)

Fig.3.2-2
Monthly Average Potential Evaporation and Rainfall at Kuwait International Airport



(Ref.3.2.2-1)

Fig.3.2.2-1
Schematic Geological Profile

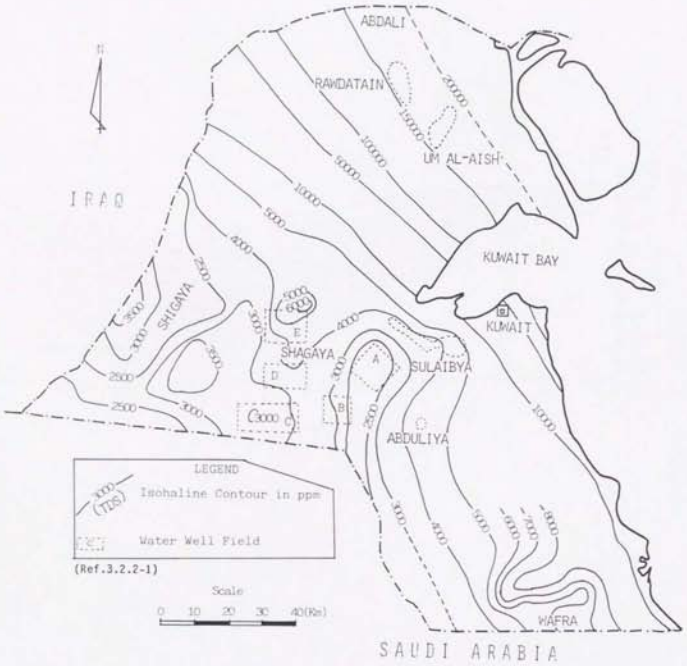


Fig.3.2.2-2
Salinity (TDS) Contour Map of Damman Aquifer

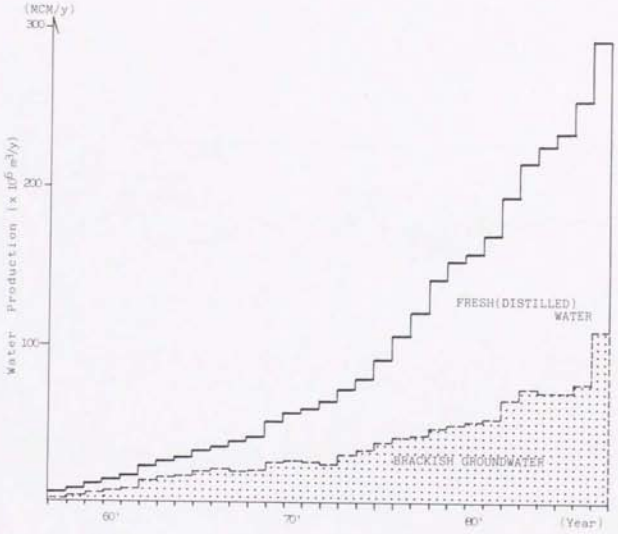
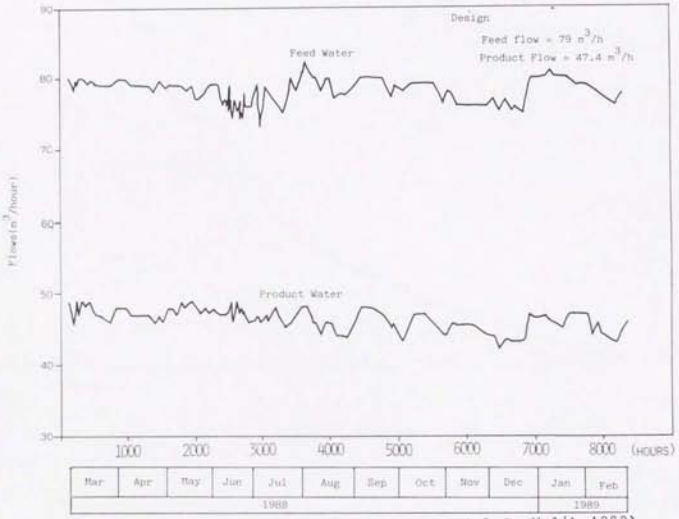
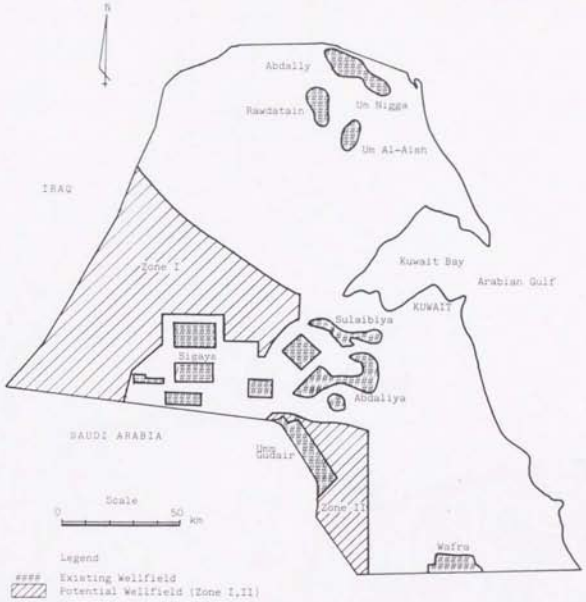


Fig.3.3.2-1
Production of Brackish Groundwater and Distilled Water in Kuwait



(Ref.3.5.2-1) (Source; A.L.A.,Malik,1989)

Fig. 3.5.3-1
One Year Test Operation of the Brackish Groundwater Reverse Osmosis Desalination



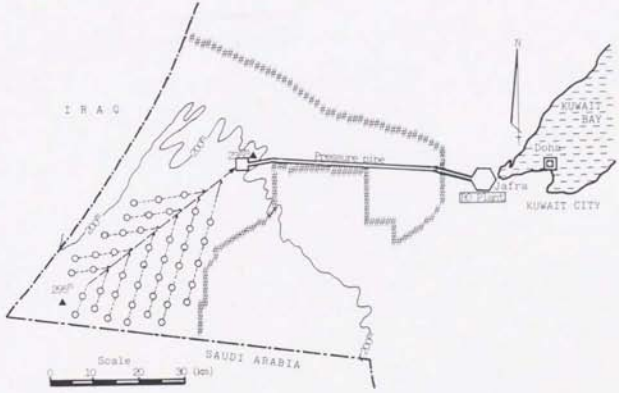


Fig. 3.6.1-1
Proposed Layout of Hydro-Powered Reverse Osmosis (RO) Desalination System

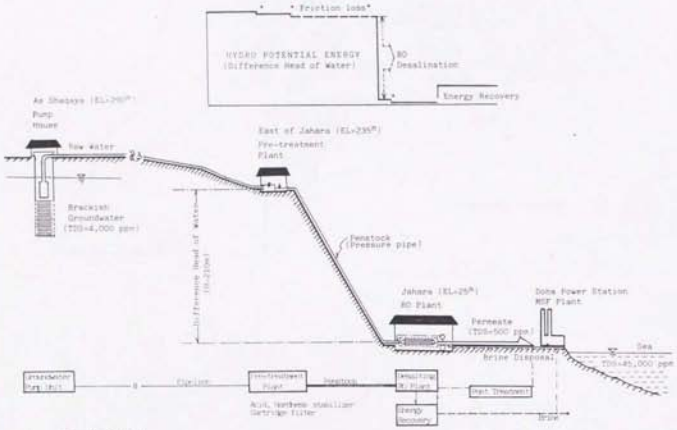
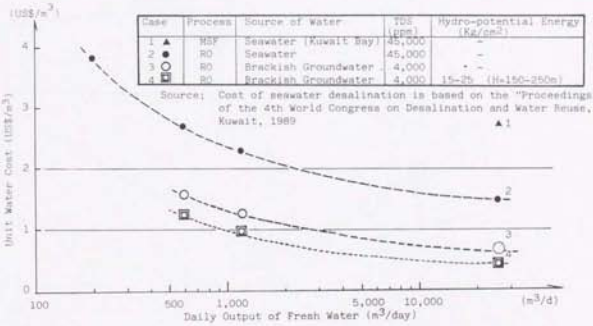


Fig. 3. 6. 4-1
Schematic Profile of Hydro-Powered Brackish Groundwater Reverse Osmosis (RO) Desalination System



Case	Process	Source of Water	TDS (ppm)	Hydro-potential Energy (Kg/cm2)
1 ▲	MSF	Seawater (Kuwait Bay)	45,000	-
2 ●	RO	Seawater	45,000	-
3 ○	RO	Brackish Groundwater	4,000	- -
4 ⊡	RO	Brackish Groundwater	4,000	15-25 (H=150-250m)

Source; Cost of seawater desalination is based on the "Proceedings of the 4th World Congress on Desalination and Water Reuse, Kuwait, 1989 ▲1

Fig. 3. 6. 5-1
Unit Water Cost of Desalination in Kuwait

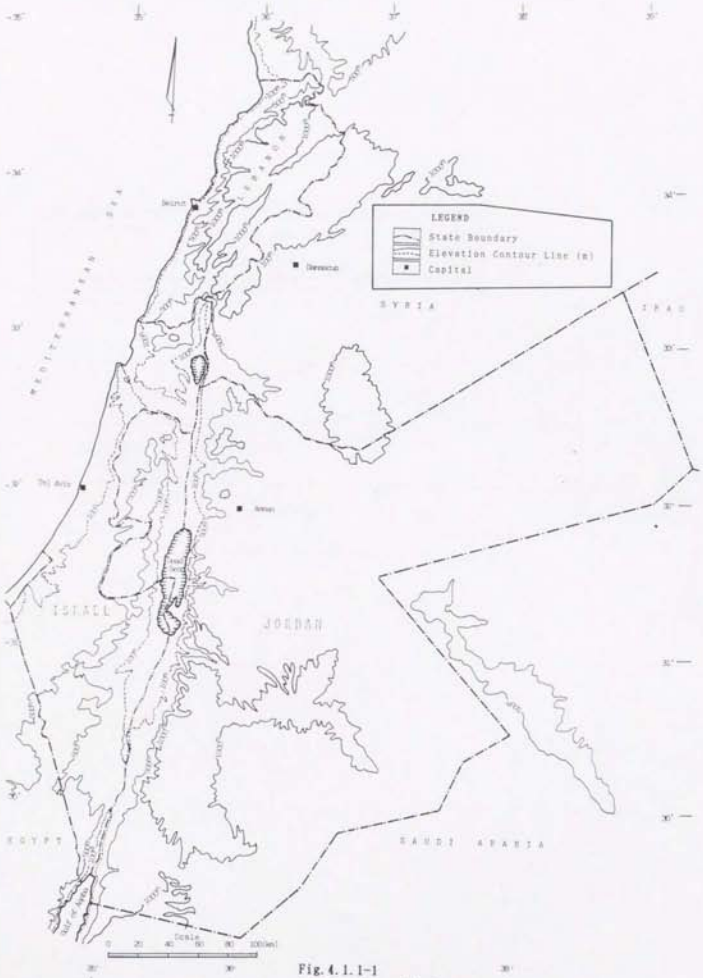
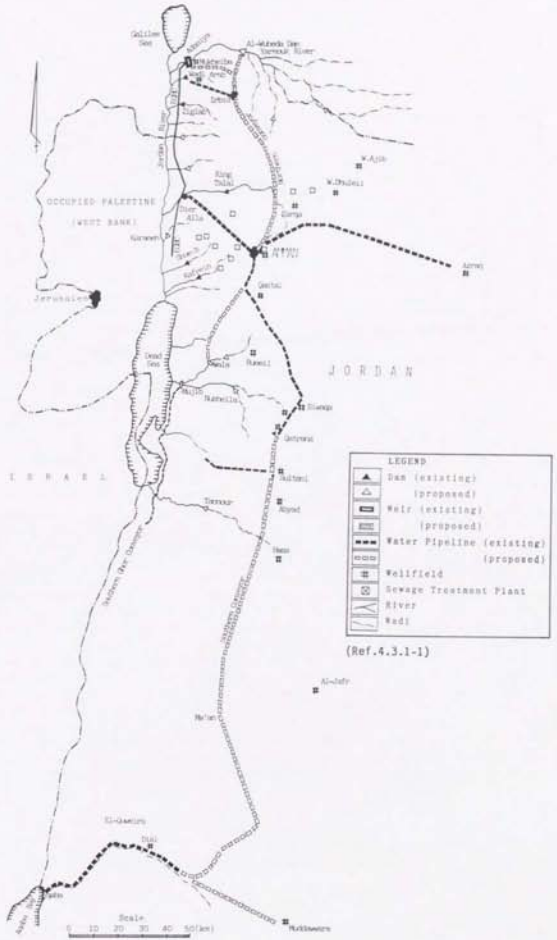


Fig. 4.1.1-1
Location Map of Jordan



(Ref.4.3.1-1)

Fig. 4.3-1
Water Resources System of Jordan

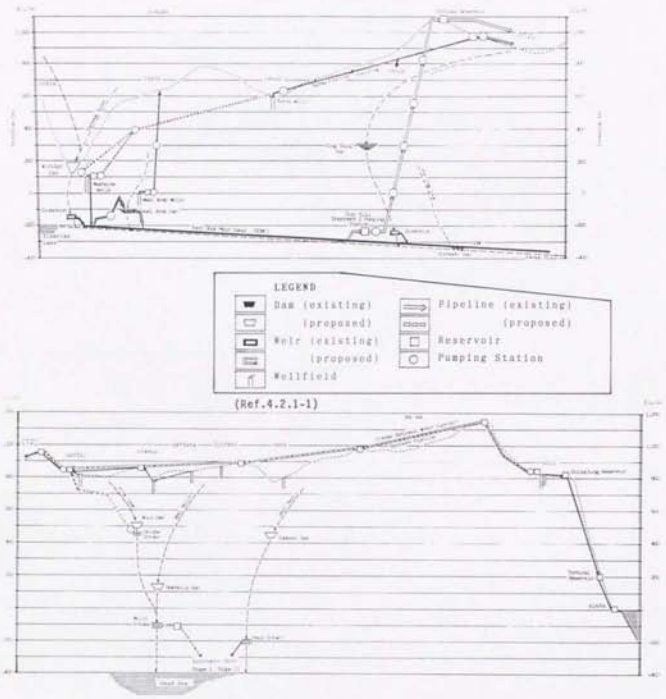


Fig. 4. 3. 1-1
Schematic Diagram of Water Transport Systems

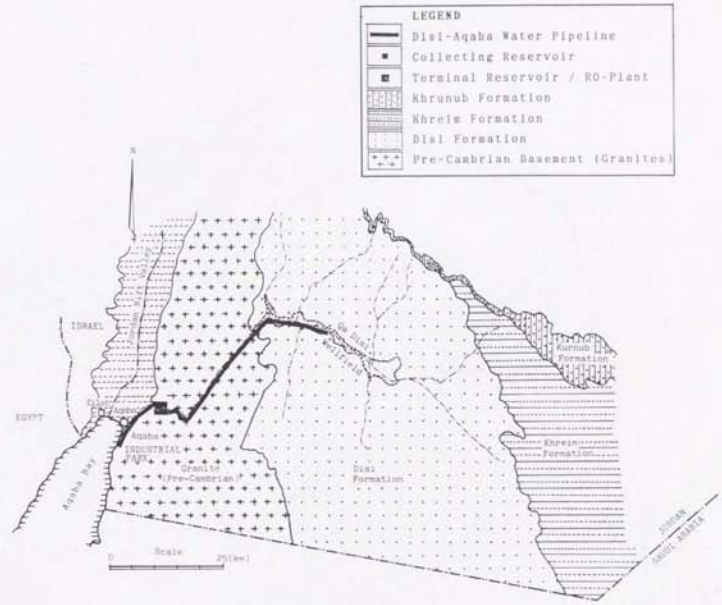
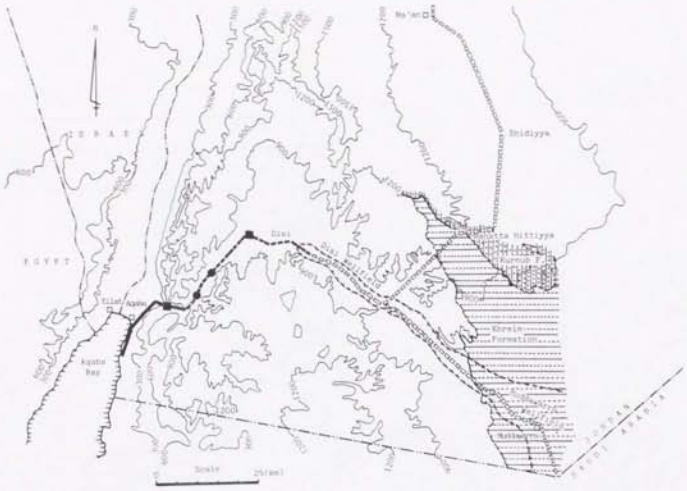


Fig. 4. 5. 3-1
Aqaba-Disi Water Supply System



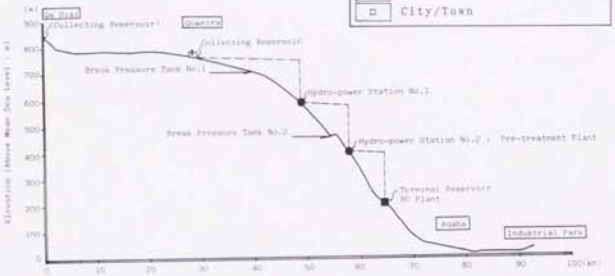
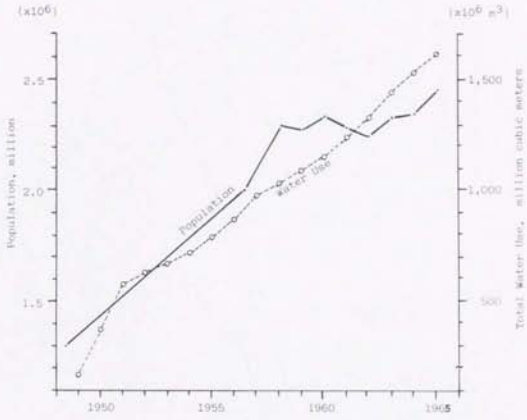


Fig. 4.5.3-2
Disi-Aqaba Hydro-Powered RO Desalination Scheme and Brackish Groundwater



(Ref.5.3.4-2)

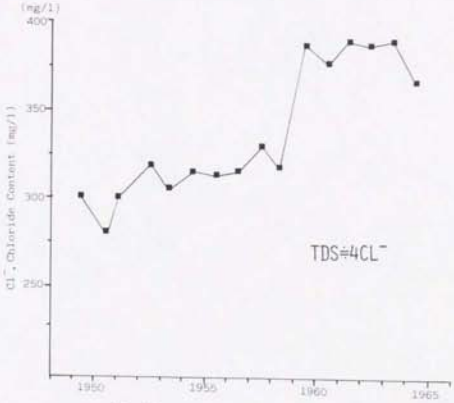


Fig. 5.3.1-1
Salinity Change in Galilee Sea (Tiberias Lake)

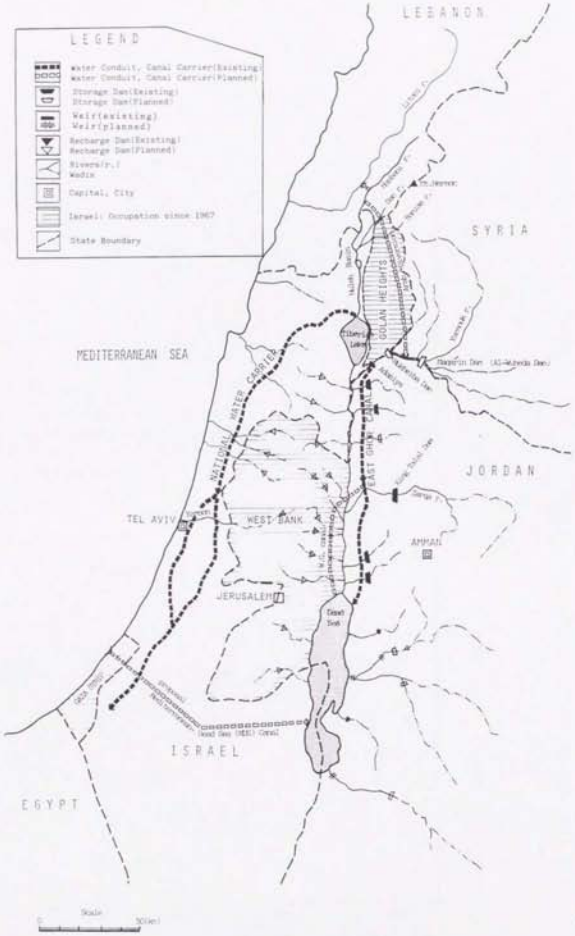
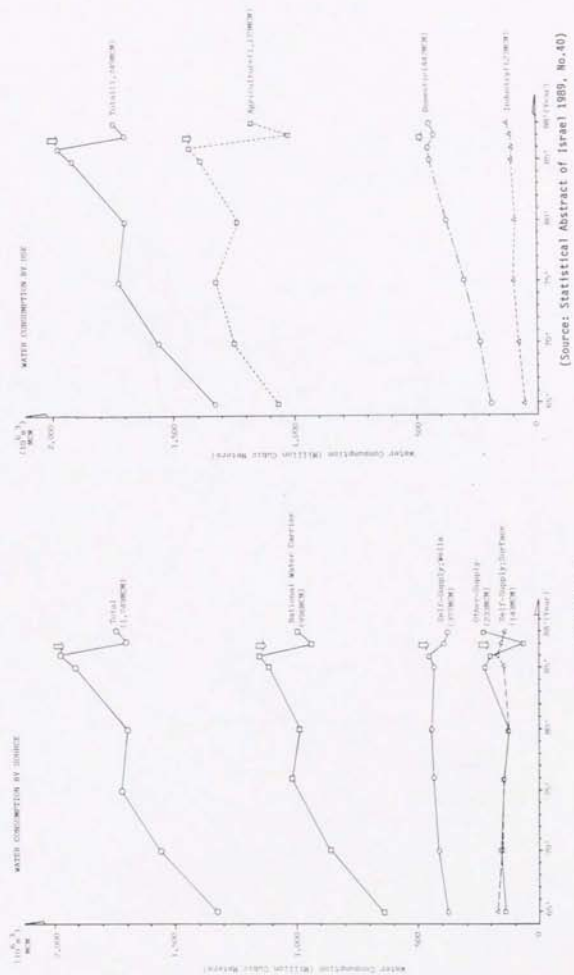


Fig.5.3.3-1

Major Existing and Proposed Projects in the Jordan River System



(Source: Statistical Abstract of Israel 1989, No.40)

Fig.5.3.3-1

Israel Water Consumption by Use source and Use

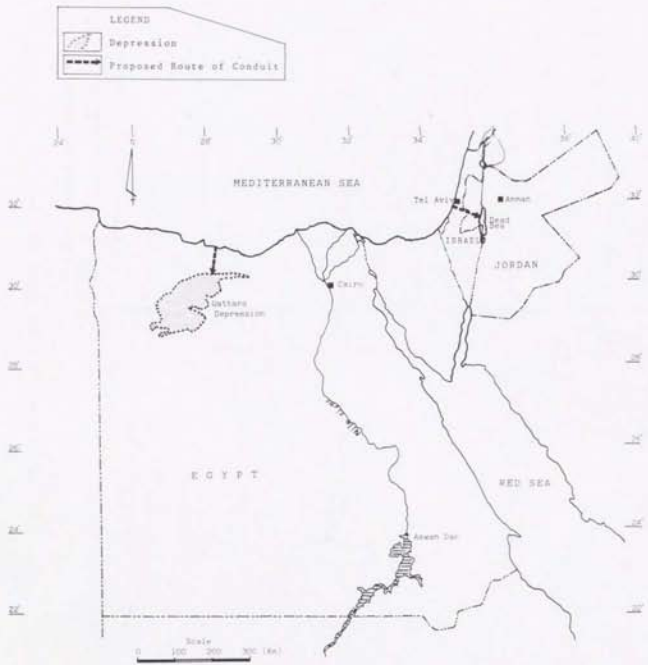


Fig. 5.4.1-1
Location Map of Mediterranean, Qattara and Dead Sea

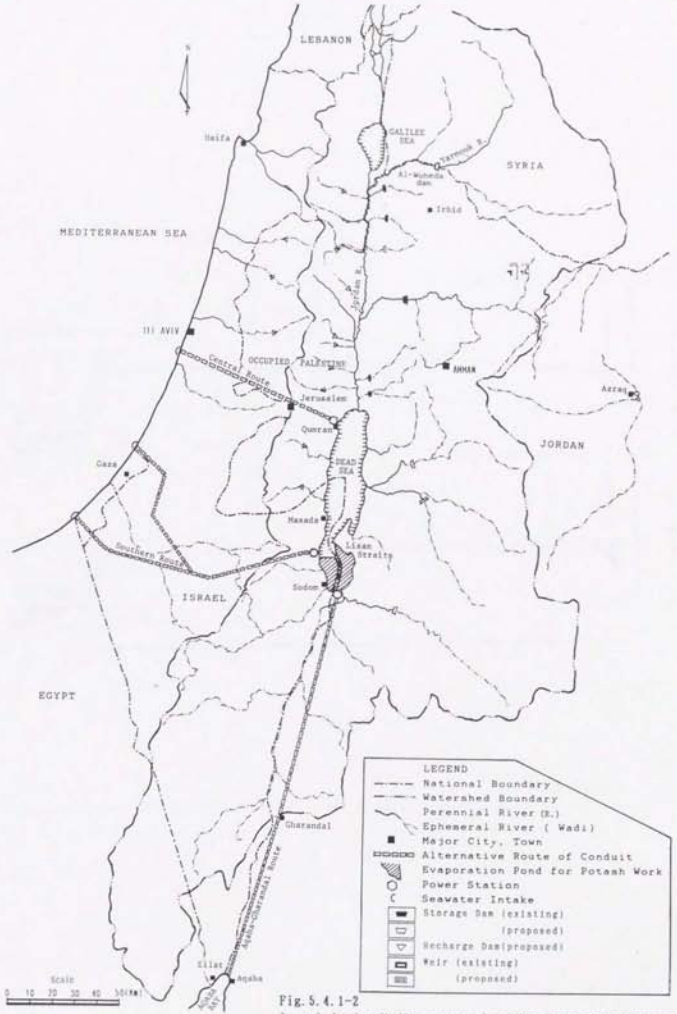


Fig. 5.4.1-2
Israel Jordan Mediterranean-Dead Sea Hydro-Solar Scheme: Project Map

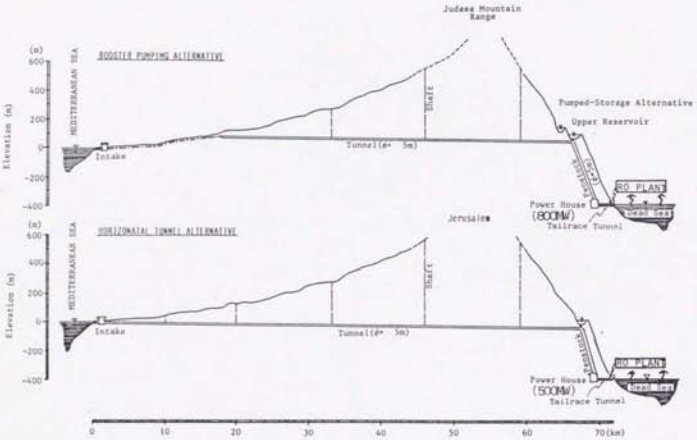
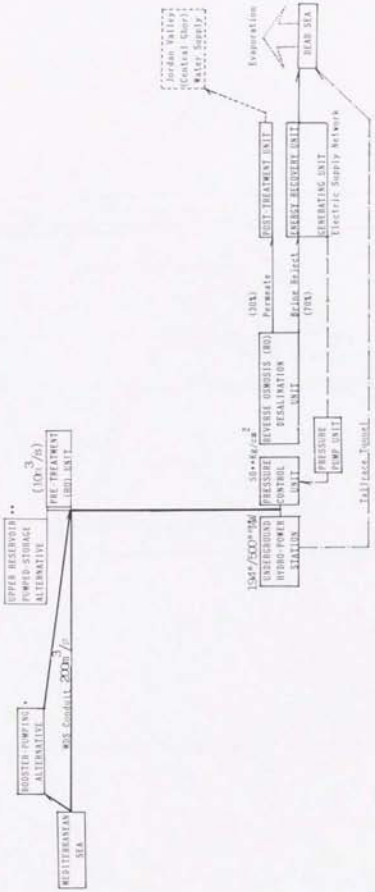


Fig. 5.4.3-1
Israel/Jordan Mediterranean-Dead Sea Solar-Hydro Conduit: Development Alternatives



Remarks: * Booster pumping alternative
** Pumped-storage alternative

Fig. 5.4.3-1 Schematic Diagram of Co-generation System for the Mediterranean-Dead Sea (MDS) Conduit Scheme

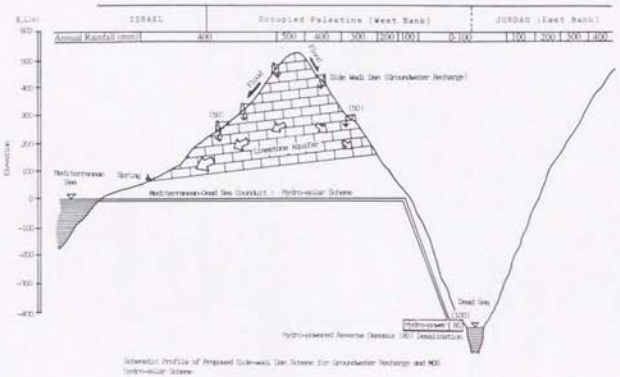


Fig.5.5.4-1
Schematic Profile of Hydrogeology and Groundwater of Palestine

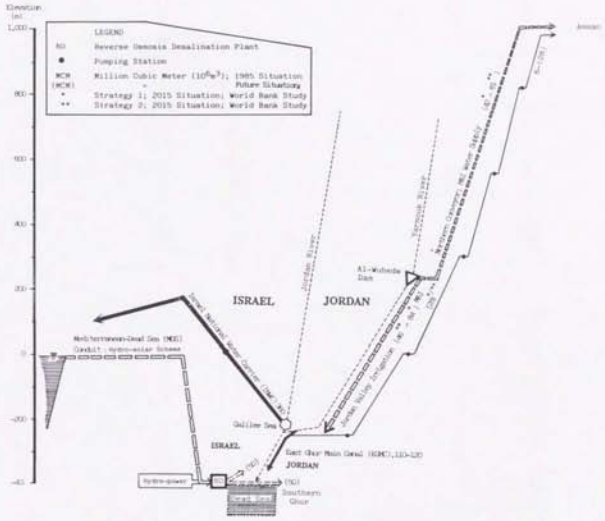
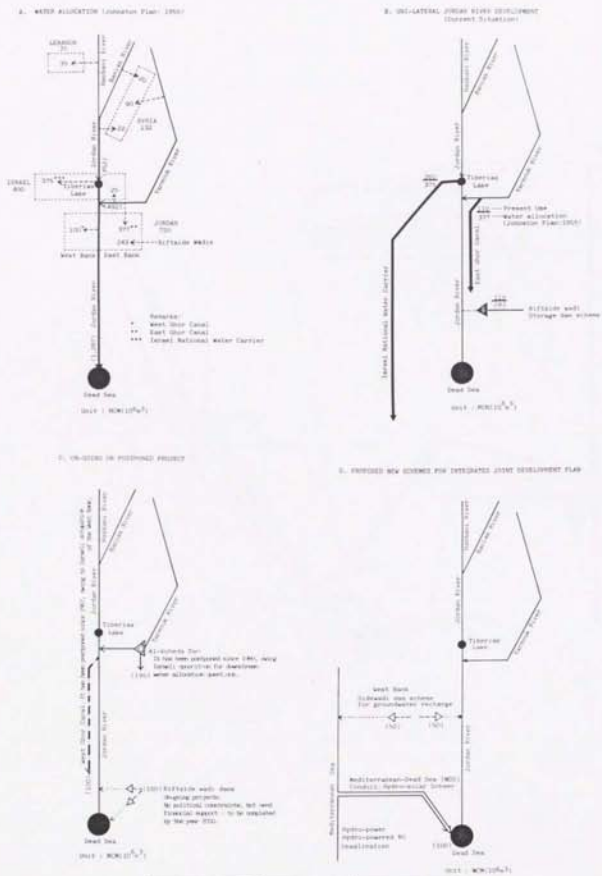


Fig.5.5.4-2
Schematic Diagram of Integrated Joint Development Plan : 1991 with Al-Wuheda Dam and MDS Conduit Schemes



ISRAEL/JORDAN	WEST BANK	EAST BANK
-MDS Solar-hydro scheme for co-generation	-Sidewadi dam scheme for groundwater recharge	-Al-Wuheda dam scheme -Riftside-wadi dam scheme for storage

Fig.5.5.4-3

Jordan River System and Water Allocation

ANNEX-I

REVERSE OSMOSIS (RO) DESALINATION

ANNEX-I

REVERSE OSMOSIS (RO) DESALINATION

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ANNEX-I

REVERSE OSMOSIS (RO) DESALINATION

A1.1 Background

Desalting techniques are primarily intended for the removal of dissolved salts that generally cannot be removed by conventional treatment processes. Distillation units have been used on some American ships for more than 100 years. The desalting was used on a limited scale for municipal water treatment in the late 1960s. The past four decades can be divided into three phases of desalting. The 1950s were a time of discovery, the 1960s were concerned with research, and the 1970s and 1980s have been the time of commercialization. Beginning in the 1970s, the industry began to concentrate on commercially viable desalination applications and processes. (Ref.A1.1-1)

The first commercial plant for the production of potable water from a saline source using electrodialysis and ion exchange membranes was put into operation in 1954 (Ref.A1.1-2). In 1968 use of membranes for brackish water treatment started with the construction of an electrodialsis (ED) plant in Florida, USA. This process was not favorably received in view of its inability to adequately reduce dissolved solids. The first reverse osmosis (RO) water treatment plant was constructed in 1970 for a comdominium project on Longboat Key in Florida, USA (Ref.A1.1-3). Significant advances in membrane technologies in the last 20 years have improved the cost-effectiveness and performance capabilities of the processes. Reverse osmosis (RO) membrane processes are increasingly used worldwide to solve a variety of water treatment problems.

A1.2 World Desalination

The arid region, with its very limited freshwater potential, has generally used high salinity waters such as seawater as a major water supply sources. As shown in Tab.1, more than two thirds of the world's desalting capacity is located in the arid, oil rich areas of North Africa and Western Asia (Middle East). (Ref.A1.1-1)

A1.2.1 Desalting technology and processes

The major desalting technologies used today are distillation (several types of evaporative process), reverse osmosis (RO), electrodialysis (ED), electrodialysis reversal (EDR), and ion exchange demineralization. The typical concentration ranges of total dissolved solids (TDS) in the feedwater for distillation, RO, ED, and EDR demineralization are; between 10,000 mg/l and 100,000 mg/l for distillation and other thermal (nonmembrane) processes, up to about 35,000-45,000 mg/l (seawater concentrations) for RO membrane, up to approximately 10,000 mg/l for ED and EDR membrane (Ref.A1.2.1-1, and Fig.A1.2.1-1). Ion exchange, in which anion and cation resins are used to exchange ions for hydrogen and hydroxide, is primarily used in industrial applications for which very pure water is required and the feedwater TDS is relatively low. Distillation and other thermal processes are used primarily for seawater conversion and special industrial applications , such as brine concentration.

A1.2.2 Desalination capacity by process

As shown in Tab.A1.2.2-1, 70% of the world's desalination capacity is dependent on the distilling process. In the Middle East and North Africa, distillation of seawater is the main process being used, while the processes favored by the United States and other countries are quite different, reflecting the numerous applications for the desalination of brackish water (Ref.A1.1-1).

In 1985 the total worldwide installed capacity of land-based desalting plants exceeding 10 m^3/d (25,000 gallon per day) capacity was more than $11.4 \times 10^6 m^3/d$ (3 bgd), which is more than three times as much as that of the capacity in 1975. Seawater and brackish water sources with salinity in a range between 1,000 to 40,000 ppm of TDS account for nearly all of this installed capacity, comprising approximately 75 percent of seawater and 23 percent of brackish water sources (Refs.A1.2.2-1&2). Membrane processes represent about 30 percent of this total capacity and nearly all of the brackish water treatment capacity. (Ref.A1.2.1-1)

A1.2.3 Economics

The cost of desalination has generally decreased from more than 3 US$/$m^3$ to as low as 0.5 US$/$m^3$, over time as a result of both technological advances and market processes (Ref.A1.1-1). The historical cost of

desalting brackish water and seawater with available technologies is shown in Fig.A1.2.3-1, which is based on a recent cost assessment study by the Office of Technology Assessment for the U.S.A Congress.

Improvements in reverse osmosis (RO) membranes have been the main technological change in desalination in recent years. U.S.A and Japan are the world's leading countries in innovative research for the membrane industry. A high level of competition on both a national and international basis has also played a significant role in containing prices for capital equipment. The distribution of overall cost, including capital cost recovery, for the operation of a brackish water desalting plant, is illustrated in Tab.A1.2.3-1 (Ref.A1.1-3). The main item of cost in brackish water desalination is capital recovery, which represents almost half of the overall cost. Energy, membranes, and labor are the next most significant cost items.

A1.3 **Desalination of Seawater in the Arabian Gulf Countries**

In extremely arid countries, where good quality water is not available, seawater desalination is commonly used to supply water for municipal and industrial (M&I) uses. In spite of the high cost of desalinated water, a vast quantity is produced to meet the demand for domestic water in the Gulf countries.

A1.3.1 Installed capacity of desalination plant

The installed capacity of desalination plant in Saudi Arabia, Kuwait, United Arab Emirates, Qatar, Bahrain, and Oman is estimated at 5.075×10^9 m^3/d in total, including 2.395×10^9 m^3/d in Saudi Arabia which is approximately half of the total installed desalination capacity in the Gulf countries. Dual-purpose multistage flash (MSF) is the most commonly used techniques to desalt seawater, which represents 97% of the total installed capacity as shown in Tab.A1.3.1-1.

A1.3.2 World's largest water pipeline and seawater distillation for M&I water supply

To meet the demand for domestic water, Saudi Arabia commissioned several desalination plants, which are located mainly on its Red Sea and Arabian Gulf coasts, which produce 2,165,000 m^3/d (481 mgd) of potable water and 4,079 MW of electricity (Fig.A1.3.2-1, Tab.A1.3.2-1). "Al-Jubail - Riyadh"

water pipeline is one of the largest high pressure pipeline systems in the world, of which the water source is wholly dependent on seawater distillation (Fig.A1.3.2-1). The pipeline has a diameter of 60 inches, length of 466 km, differential head of 690 m, and a pumping capacity of 830,000 m^3/day. (Ref.A1.3.2-1)

A1.3.3 Remarks on seawater distillation

The problem with seawater distillation is the high cost of producing permeate by the multi-stage flash (MSF) process which is the most prevalent thermal type of distillation system in the Middle East. The thermal process is largely dependent on the rate of energy consumption in MSF, which is high and influenced by the unstable world market price of crude oil (Fig.A1.2.3-1).

A1.4 Reverse Osmosis (RO) Desalination

Desalination of brackish water and seawater by the membrane process will probably be the key applications for desalination technologies over the next 10 years. Although RO, ED, and EDR membrane processes are used worldwide to solve a variety of water treatment problems, it is likely that RO will continue to have the greatest market share. Where fresh water supplies are limited or must be imported over long distances, RO desalting of nearby brackish water can be cost-effective. Most of the countries in the Middle East and North Africa have rather long sea coasts with a total length of about 25,000 km. Seawater desalination will continue to increase in these countries, either by distillation or RO, depending on site-specific conditions.

A1.4.1 Brackish water

Good quality water is neither abundant nor available to meet the growing demand in much of the coastal areas and arid to semi-arid countries. However, sufficient brackish water is normally available on site to support development. Since the early 1970s, advances in desalination have been mostly directed towards improving the abundant sources of brackish water rather than towards the comparatively expensive conversion of seawater. Significant advances in membrane technologies in the last 20 years have improved the cost effectiveness and performance capabilities of the RO process. Brackish water desalination usually costs only one-fifth to one-third of seawater desalting (Ref.A1.1-1).

i) Brackish Surface Water

The Colorado river water in its lower reaches has been contaminated by excessive saline return flows or irrigation drainage since the 1950s. The world biggest RO plant with an installed capacity of 27,900 m^3/d (72 mgd) is being constructed at a site 6 km west of Yuma, just south of the Colorado River's South Levee and on the national border between the USA and Mexico (Fig.A1.4.1-1). The desalting complex unit is specifically intended to fulfill the USA's obligations to Mexico in accordance with "Minute No.242" of 1973. "Minute 242" of the International Boundary and Water Commission is aimed to improve, enhance and protect the quality of water available in the Colorado river for use in the USA and Mexico. (Ref.A1.4.1-1)

ii) Brackish Groundwater

Groundwater in Damman aquifer on Bahrain island has been seriously contaminated by seawater intrusion or upward leakage from the underlying saline aquifer of Umm Er Radhuma since the 1960s, owing to intensive pumping which exceeded the safe yield. (Fig.A1.4.1-2) It was here that the world's largest RO plant with an installed capacity of 45,000 m^3/d (10 migd) was commissioned in 1984, to desalt highly saline brackish groundwater from the "Umm Er Radhuma" formation. The RO plant was designed to meet the domestic water demand of Manama city, capital of Bahrain, taking into account several advantages over seawater distillation (MSF) plant; namely i) short construction time, ii) lower energy cost, and iii) ease of operation and maintenance.(Ref.A1.4.1-1)

A1.4.2 Seawater

From environment reasons, thermal distillation plant, which is largely dependent on high specific energy consumption, is likely to be replaced progressively, by low specific energy consumption types of RO desalination plant. Thus at the end of 1989, the world's largest seawater reverse osmosis (RO) desalination plant with an installed capacity at 56,500 m^3/day constructed on the West Coast of Saudi Arabai at Jeddah, replaced the phasing-out (20 years old) MSF distilling plant (Fig.A1.3.2-1). It may be noted that a case study on Doha desalination plant in Kuwait in 1989, showed that the unit cost of seawater desalination was estimated at US$ 2.7/m^3 by MSF of distilling process and US$ 1.7/m^3 by RO of membrane process (Ref.A1.4.2-1).

A1.4.3 Treated sewage effluents

Although it is clear that membrane desalting is a cost-effective alternative to importing fresh water over long distances, use of membrane process for the removal of turbidity, organic, and hardness has typically been more expensive than conventional treatment. The cost gap is narrowing, however, with the continuing improvements in membrane technology, increasing competition among manufacturers of capital equipment, and the ever-escalating cost of meeting increasingly stringent water quality standards by conventional approaches (Ref.A1.4.3-1).

A1.4.4 Key application in the 21st century

Membrane processes, which of low energy and/or energy saving types, are expected to continue to be popular in coastal regions and other areas such as arid to semi-arid regions, wherever brackish surface waters or groundwaters are available and good quality water is limited or not available. Applications of the RO process in Arabian Gulf countries will be mainly for seawater and brackish groundwater desalinations and the membrane process could indeed be the technology to take the drinking water industry gradually into the twenty-first century.

A1.5 Method and Process of Reverse Osmosis (RO)

The aim of this Section is to support our understanding of reverse osmosis desalination, including the mechanism of reverse osmosis, membranes, system units of the RO process, potential water sources, feedwater quality, pretreatment, pumping system, energy recovery, and posttreatment.

A1.5.1 Mechanism of reverse osmosis

Osmosis is a natural process whereby a solvent (water) diffuses through a semipermeable membrane from a solution of lower concentration to one of higher concentration (part A, Fig.A1.5.1-1). The membrane readily passes the solvent but act as a barrier to the solutes (dissolved solids). At equibrium conditions, the pressure differential across the membrane is called the osmotic pressure (Part A, Fig.A1.5.1-1). For example, the osmotic pressure of brackish water containing about 2,000 ppm TDS at a typical water temperature of 25 degrees centigrade is only about 1.6 kg/cm^2, whereas it is 27.7 kg/cm^2 for standard seawater of 35,000 ppm TDS

at 25 degrees centigrade. In RO, a pressure greater than the osmotic pressure is applied to the concentrated solution (saline water), and dilute permeate (product water) is produced (part C, Fig.A1.5.1-1).

Fig.A1.5.1-2 is a flow schematic of a simplified RO unit. The pressure of the feedwater, pretreated to meet certain established RO membrane feedwater quality guidelines, is boosted before the water enters the RO membranes. Two flows exit the membranes: the combined product (permeate) and the combined concentrate (reject). The fraction of feedwater that results as permeate is called the recovery and is usually expressed as a percentage. The maximum allowable ratio of permeate to reject depends on the water's scaling potential, which is a function of the feedwater quality. This ratio is maintained by the use of a control valve on the reject piping. This valve controls the flow rate of the reject, thus forcing the permeate flow rate to the desired value.

A1.5.2 RO membranes

The first commercially available membranes, developed in the mid-1960s,were made of cellulose acetate (CA) manufactured in flat sheets. Modern CA membranes are modifications of the cellulose acetate structure, including blends and different surface treatments, and are called cellulosic. Noncellulosic membranes include polyamide membranes with relatively thick asymmetric polyamide support structures and composite membranes with thin-film polyamide or other membrane materials on a porous support structure.

Use of each membrane material has advantages and disadvantages. The CA based membranes are now generally the least expensive per gallon of installed capacity (first cost). The price difference between CA and composites, however, is decreasing as the number of manufactures supplying the composite-type membranes increases and with new developments in the manufacturing process. Use of CA membranes generally requires chlorinated feedwater and higher operating pressure than that needed by the composite membranes. Composite membranes generally operate over wider pH and temperature ranges than CA membranes. In some cases these operating characteristics of composite membranes result in savings in electric power and chemical costs. Their greater pH tolerance provides additional advantages in cleaning for some applications.

Sensitivity to chlorine and other strong oxidants in the feedwater is a disadvantage of polyamide-based membranes. New developments in membrane

research to product chlorine-tolerant composite membranes are overcoming this limitation.

A1.5.3 Unist of the RO process

RO membranes are placed inside pressure vessels in several different configurations: hollow fiber, spiral wound, tubular, and plate-and-frame. In the past 20 years, the hollow-fiber and spiral-wound configurations (Figs.A1.5.3-1&2) have become industry standard for RO water treatment. The predominance of the spiral-wound configuration has resulted from recent advances in membrane technology, which have been more easily translated into commercial flat-sheet membranes than into the hollow-fiber configuration.

Depending on the desired capacity of an RO system, one or more pressure vessels containing RO membranes are used to form a modular block. Pressure vessels within an RO block can be arranged in parallel, in series, or both, depending on the design requirements. Often this membrane-pressure vessel arrangement is called a membrane array or a pressure vessel array. For example, a 2:1 pressure vessel array indicates a two-stage system with two pressure vessels in the first stage and one vessel in the second stage. In a reject-stage arrangement, the membranes in the second-stage vessel would treat the waste concentrate (reject) water from the first stage, thus recovering more product water from the feedwater supply.

A1.5.4 Potential water sources

Although some locations have a shortage of water of any quality, the most common situation is a shortage of water of potable quality. Desalting processes can expand the availability of potable water supplies by converting previously unusable supplies to potable water. The potential sources of water for membrane desalting include: brackish groundwater, brackish surface water, hard water, municipal wastewater, high-nitrate groundwater, irrigation return flows, and seawater.

A1.5.5 Feedwater quality

The composition of raw water from the supply source must always be considered in the design of both conventional water treatment and desalting processes. However, the design of desalting systems and their operating economics are much more interrelated with feedwater composition

and the required product composition than most conventional treatment processes. The composition of raw water is probably the most important component in. desalting process design The typical water quality parameters needed for the process design of membrane desalting systems are;

- -Dissolved solid
- -pH
- -Temperature
- -Sparingly soluble salts
- -Suspended solids
- -Iron and manganese
- -Microbial growth
- -Organics

A1.5.6 Pre-treatment

Pretreatment is usually required to protect the membrane system, to improve performance, or both. The type of pretreatment required depends on the feedwater characteristics, the ,membrane type, and the system design parameters. Pretreatment requirements can be minimal, such as cartridge filtration of well water, or extensive, such as conventional coagulation, sedimentation, and filtration of surface water supply.

For RO systems, standard pretreatment usually consists of adding chemicals for scale control followed by cartridge filtration (usually 1-, 5-, 10-, or 20-micron-m nominal rating) for membrane protection. The feed water is often acidified to lower its pH; this step is nearly always required for cellulosic membranes. Scale inhibitors such as sodium hexametaphosphate or proprietary chemicals are also added to reduce carbonate and sulfate scale potential.

A1.5.7 Pump system

The pump system raises the pressure of the pretreated feedwater to the level required for operation of the desalting system. For RO, the pump system discharge pressure typically is 8.8-28.1 kg/cm^2(125-400 psi) for low TDS and brackish water systems and 56.2-84.3 kg/cm^2 (800-1,200 psi) for seawater systems. The pump system for RO might also include energy recovery devices, particularly for seawater systems.

A1.5.8 Post-treatment

Posttreatment that must be done for municipal membrane processes commonly includes product water pH adjustment for corrosion control and chemical addition for disinfection. Typically entrained gasses such as carbon dioxide and hydrogen sulfide (if present) are removed before final pH adjustment and disinfection.

Removal of these gasses is normally accomplished by stripping in a forced-draft packed column. In the most cases, carbon dioxide must be removed to stabilize RO product water. If hydrogen sulfide is presented, degassing of product water is usually provided to control odor and minimize the amount of disinfectant (e.g.,chlorine) The final product water pH is often adjusted by caustic soda, soda ash, or lime. A noncorrosive water can be produced by using these alkaline chemicals and in some cases, other chemicals and blending with raw or other water supplies that may also feed the distribution system.

Posttreatment disinfection is normally accomplished with chlorine, however, if the desalting process allows the passage of trihalomethane (THM) precursors, chlorine dioxide, or chloramines, some additional posttreatment may be required to comply with THM drinking water quality standards.

REFERENCES (Annex-I)

Ref.A1.1-1
O.K Buros, 1989, "Desalting Practices in the United States", Management and Operations, Journal AWWA, November, pp.38-42

Ref.A1.1-2
J.H.Powell and E.M.Guild, 1961, "Salinity Problems in the Arid Zones; Field Operation of Electric Membrane Equipment for Water Desalinating", UNESCO, Proceedings of the Teheran Symposium, pp.363-370.

Ref.A1.1-3
Glenn M. Dykes and William J.Colon, 1989, "Use of Membrane Technology in Florida", Management and Operations, Journal AWWA, November, pp.43-46.

Ref.A1.2-1
AWWA Water Desalting and Reuse Committee,1989, "Committee Report: membrane Desalting Technologies", Management and Operations, Journal AWWA, November, pp.30-37.

Ref.A1.3.1-1
Adnan A.Akkad, 1990, "Conservation in the Arabian Gulf Countries", Management and Operations, Journal AWWA, May, pp.41-50.

Ref.A1.3.2-1
SWCC, 1988, "Kingdom of Saudi Arabia: Saline Water Conversion Corporation", Developing World Water, Graosvenor Press International, pp.198.

Ref.A1.4.1-1
Robert Applegate, 1986, "World's Largest RO Desalting Facility to Salvage 72.4 mgd", Waterworld News, May/June 1986, pp.17-19.

Ref.A1.4.1-2
Al-Arrayedh, B.Ericsson, and M.Ohtani,1985, "Construction and Operation of 46,000 m^3/d Reverse Osmosis Desalination Plant, Ra's Abu Jarjur, Bahrain", Proceedings of the Second World Congress on Desalination and Water Reuse, Bermuda, IDA, vol.55, pp.319-342.

Ref.A1.4.2-1

M.A.Darwish, M.Abdel Jawad and G.S.Aly, 1989, "Technical and Economical Comparison Between Large Capacity MSF and RO Desalting Plants", Proceedings of the Fourth World Congress on Desalination and Water Reuse, Kuwait, IDA, vol.76, no.4, pp.215-240.

Ref.A1.4.3-1
AWWA, 1989, "Theme Introduction: Membrane Processes", Management and Operation, Journal AWWA, Nov.1989, pp.29.

Ref.A1.6.1-1
USBR, 1976, "Plan of Development; Yuma Desalting Plant", U.S. Department of the Interior, Bureau of Reclamation, 1976, pp.2

Ref.A1.7.3-1
Mohammad Yousuf Al Ali, 1988, "Development and Utilization of Water Resources in the Middle East: Country Report for Qatar", Middle East - Japan Conference on Development and Utilization of Water Resources, Japan Cooperation for the Middle East, Country Report.

Ref.A1.8.2-1
Rasul Mussayab, 1988, "Water Resources and Development in the State of Bahrain", Middle East - Japan Conference on Development and Utilization of Water Resources, Japan Cooperation for the Middle East, Country Report.

Ref.A1.8.2-2
R.P.Birch, M.Al-Arrayedh, 1985, "Bahrain's Fresh Groundwater situation and the Investigations into Using Bahrain's Brackish Water Resources as a Feedwater for the Reverse Osmosis Desalination Programme", Proceedings of the Second World Congress on Desalination and Water Reuse, Bermuda, IDA, vol.55, pp.397-492.

Ref.A1.8.5-1
Al-Arrayedh, B.Ericsson, and M.Ohtani,1985, "Construction and Operation of 46,000 m^3/d Reverse Osmosis Desalination Plant, Ra's Abu Jarjur, Bahrain", Proceedings of the Second World Congress on Desalination and Water Reuse, Bermuda, IDA, vol.55, pp.319-342.

Ref.A1.8.5-2
M.Al-Arrayedh, B.Ericsson, M.Amin Saad, and H.Yoshioka, 1987, "Reverse Osmosis Desalination Plant, Ra's Abu Jarjur, State of Bahrain; Two years

operational experience for the 46,000 m3/day RO Plant", Proceedings of the Third World Congress on Desalination and Water Reuse, Cannes, IDA, vol.65, pp.197-230.

Tab.A1.2-1 Distribution of Desalination Capacity Worldwide

Western Asia (Middle East)	North America	North Africa	Europe	Pacific	Caribbean	USSR	Others
63%	11%	7%	7%	4%	2%	2%	4%

Tab.A1.2.2-1 Distribution of Desalination Capacity by Process

Desalination Process	Distillation	Reverse Osmosis	Electrodialisys
Worldwide	70%	25%	5%
United States	21%	73%	6%

Tab.A1.2.3-1 Distribution of Overall Operating Cost for Brackish Water Desalting

Cost category	Capital cost recovery	Membranes	Energy	Labor	Chemicals	Other Expendable
%	41	12	26	11	7	3

Tab.A1.3.1-1 Installed Capacity of Desalination Plant in Arabian Gulf Countries

(Unit: $x10^3m^3/d$)

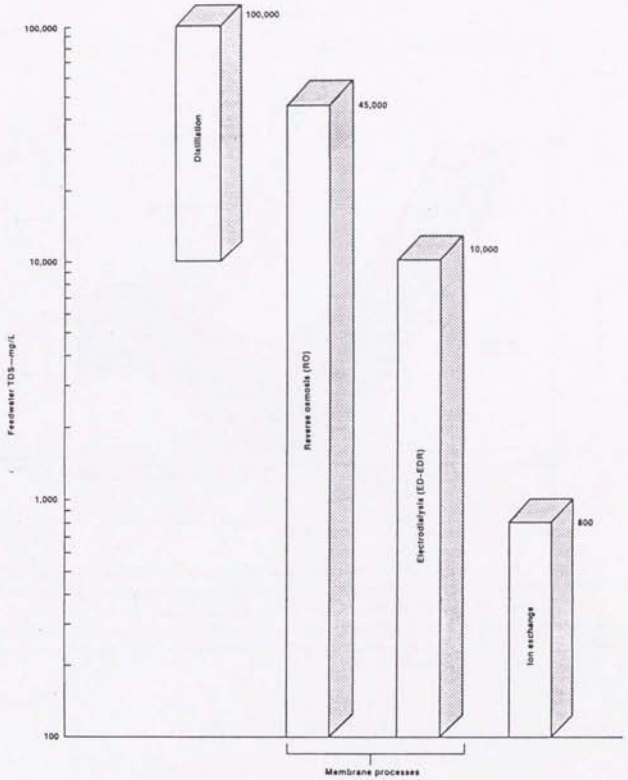
Plant Types	Saudi Arabia	Kuwait	United Arab Emirates	Qatar	Bahrain	Oman	Total
MSF	2,316	1,409	709	295	115	105	4,949
RO	77	-	-	-	45	1	123
Others	2	-	-	-	-	1	3
Total	2,395	1,409	709	295	160	107	5,075

Tab.A1.3.2-1 Existing Desalting Plants in Saudi Arabia

Locality	Phase	Installed Capacity (m^3/day)	Installed Capacity (MW)	Water Source
Al Khafji	Phase I	550	-	Arabian Gulf
Al Khafji	Phase II	22,727	-	Arabian Gulf
Al Khafji	Rush Units	1,250	-	Arabian Gulf
		(24,527)		
Al Jubail	Phase I	136,363	360	Arabian Gulf
Al Jubail	Phase II	958,333	1,295	Arabian Gulf
		(1,094,696)	(1,655)	
Al Khobar	Phase I	28,400	-	Arabian Gulf
Al Khobar	Phase II	195,075	750	Arabian Gulf
		(223,475)		
Haql	Phase I	882	-	Red Sea
Haql	Phase II	6,590	-	Red Sea
		(7,472)		
Duba	Phase I	230	-	Red Sea
Duba	Phase II	550	-	Red Sea
Duba	Phase III	3,788	-	Red Sea
		(4,568)		
Al Wajh	Phase I	230	-	Red Sea
Al WAjh	Phase II	550	-	Red Sea
		(780)		
Umm Lajj	Phase I	550	-	Red Sea
Umm Lajj	Phase II	3,788	-	Red Sea
Umm Lajj	Two Units	910	-	Red Sea
		(5,248)		
Yanbu-Medina	Phase I	107,954	250	Red Sea
Yanbu-Medina	Phase II	90,900	105	Red Sea
		(198,854)	(355)	
Rabigh	Phase I	1,288	-	Red Sea
Jeddah	Phase I Rehab	56,800	50	Red Sea
Jeddah	Phase II	43,181	84	Red Sea
Jeddah	Reverse Osmosis	12,120	-	Red Sea
Jeddah	Phase III	87,878	240	Red Sea
Jeddah	Phase IV	220,750	600	Red Sea
Jeddah	Jeddah Krupp	750	-	Red Sea
		(420,804)	(974)	
Taif-Makkah	Phase I	181,818	320	Red Sea
Al Birk	Phase I	2,272	-	Red Sea
Assir	Phase I	94,696	128	Red Sea
Farasan	Phase I	500	2.3	Red Sea
Al-Leeth	Phase I	568	-	Red Sea
Qunfuda	Phase I	3,788	-	Red Sea

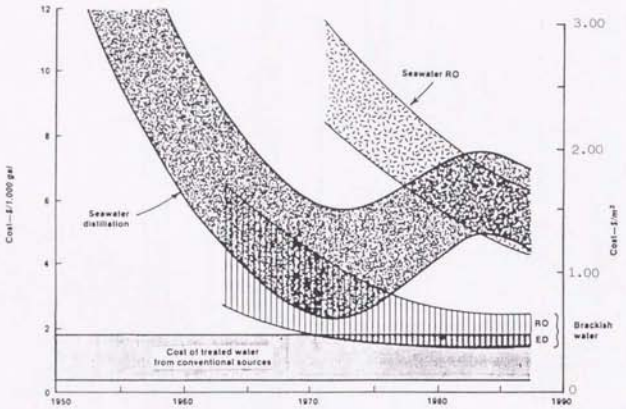
ANNEX - I

FIGURES



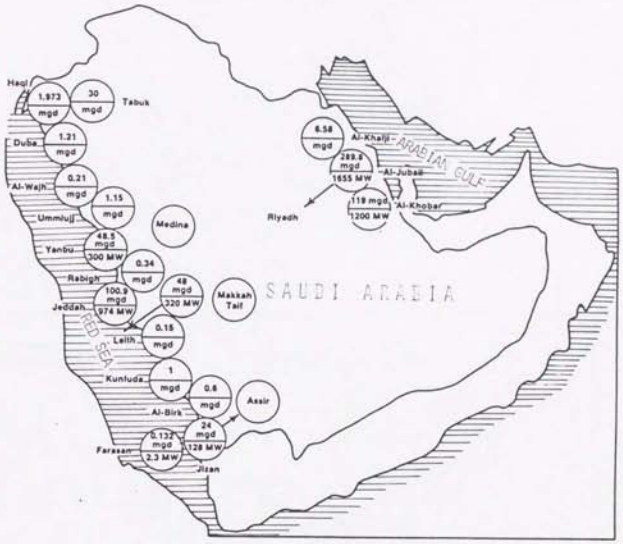
NOTE: Typical feedwater TDS operating ranges for desalting processes (*the processes can also be used for feedwaters with <100 mg TDS/L if desired for a particular application*) (Ref.A1.2-1)

Fig.A1.2.1-1
Typical Feedwater TDS Operating Range for Desalting Process



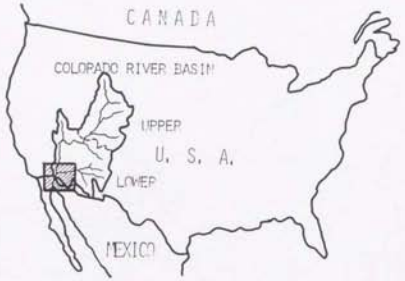
NOTE: Range of desalting costs—1950-87 (*Costs for distillation and RO, including capital and operating costs, are for plants producing 3,700-18,500 m³/d [1-5 mgd] of "polished" potable water. Costs may be higher than indicated when desalination equipment is operated inefficiently. The increasing distillation costs during the 1970s primarily reflect rising capital and energy costs. All costs are given in 1985 dollars.*) (Ref.A1.1.1-1)

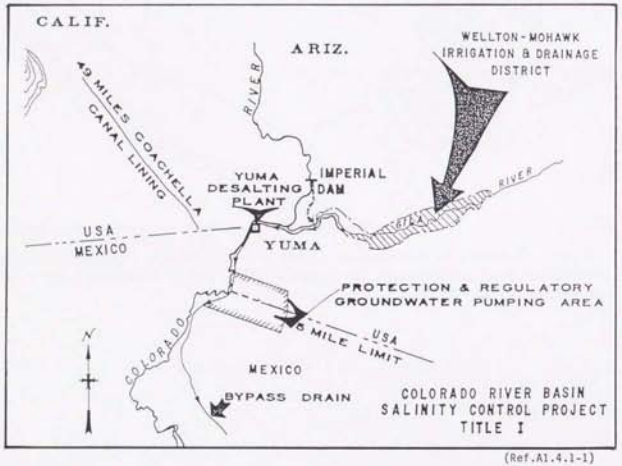
Fig.A1.2.3-1
Range of Desalting Cost



NOTE: Location of desalination plants in Saudi Arabia, together with their capacities (million gallons per day of potable water and, in some cases, megawatts of electricity) (Ref.A1.3.2-1)

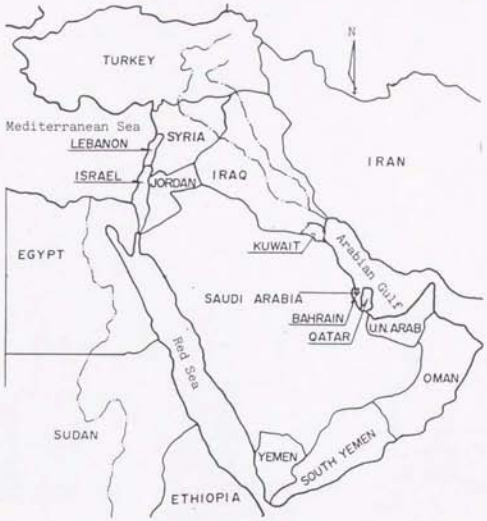
Fig.A1.3.2-1
Desalination Plants in Saudi Arabia

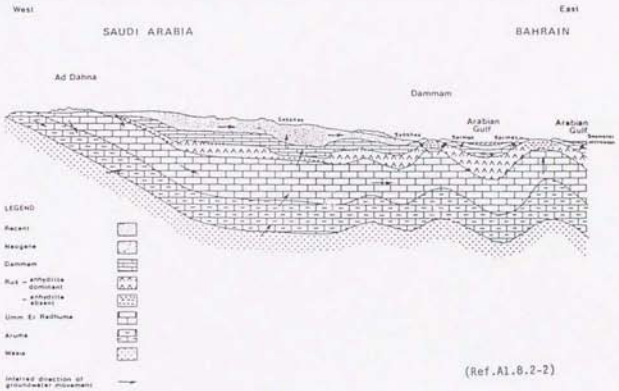




(Ref.A1.4.1-1)

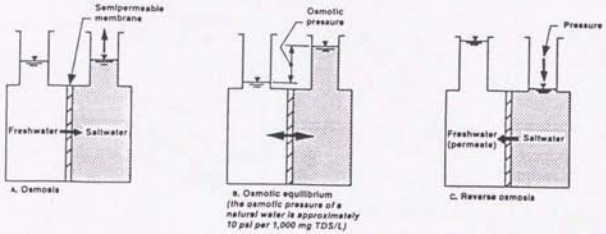
Fig.A1.4.1-1
Colorado River Salinity Control Project





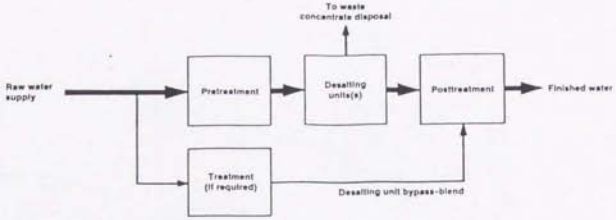
(Ref.A1.8.2-2)

Fig.A1.4.1-2
Bahrain Hydrogeological System

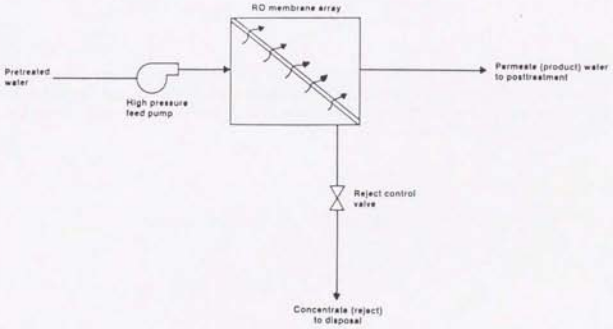


NOTE Simplified concepts of osmosis, osmotic pressure, and RO (Ref.A1.2-1)

Fig.A1.5.1-1
Simplified Concept of Osmosis, Osmotic Pressure, and RO

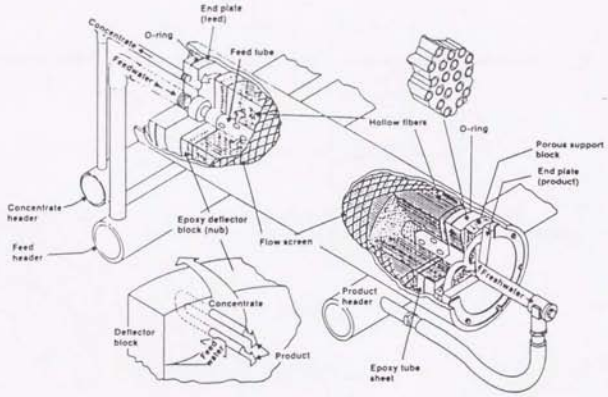


NOTE Flow diagram of typical desalting system with split treatment (*split treatment using a bypass flow stream is not always applicable*)



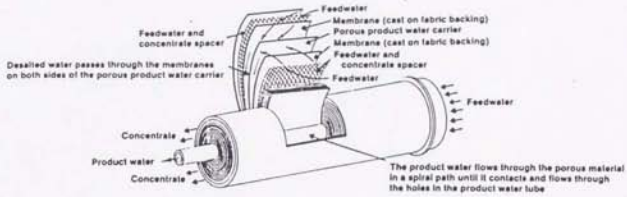
NOTE Flow schematic of an RO unit (Ref.A1.2-1)

Fig.A1.5.1-2
Flow Diagram and Schematic of Typical Reverse Osmosis (RO) System

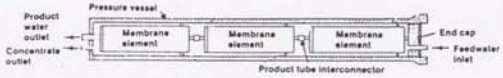


NOTE Typical hollow-fiber RO membrane element (*adapted from* The USAID Desalination Manual *by courtesy of the US Agency for International Development; permeator adapted from the sales literature of E.I. duPont de Nemours and Co., Wilmington, Del.*) (Ref.A1.2-1)

Fig.A1.5.3-1
Typical Hollow-Fiber RO Membrane Element



Cutaway View of a Spiral Membrane Element



Cross Section of Pressure Vessel

NOTE Typical spiral-wound RO membrane element (*cross section of the pressure vessel adapted from* The USAID Desalination Manual *by courtesy of the US Agency for International Development; the cutaway of the spiral membrane element adapted from the sales literature of Hydranautics Water Systems*) (Ref.A1.2-1)

Fig.A1.5.3-2
Typical Spiral-Wounded RO Membrane Element and Pressure Vessel

ANNEX-II

PHYSIOGRAPHY OF JORDAN AND ISRAEL
AND
HISTORICAL REVIEW OF THE POLITICAL RIPARIAN ISSUES
IN
DEVELOPMENT OF THE JORDAN RIVER AND BASIN MANAGEMENT

ANNEX-II

PHYSIOGRAPHY OF JORDAN AND ISRAEL
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IN
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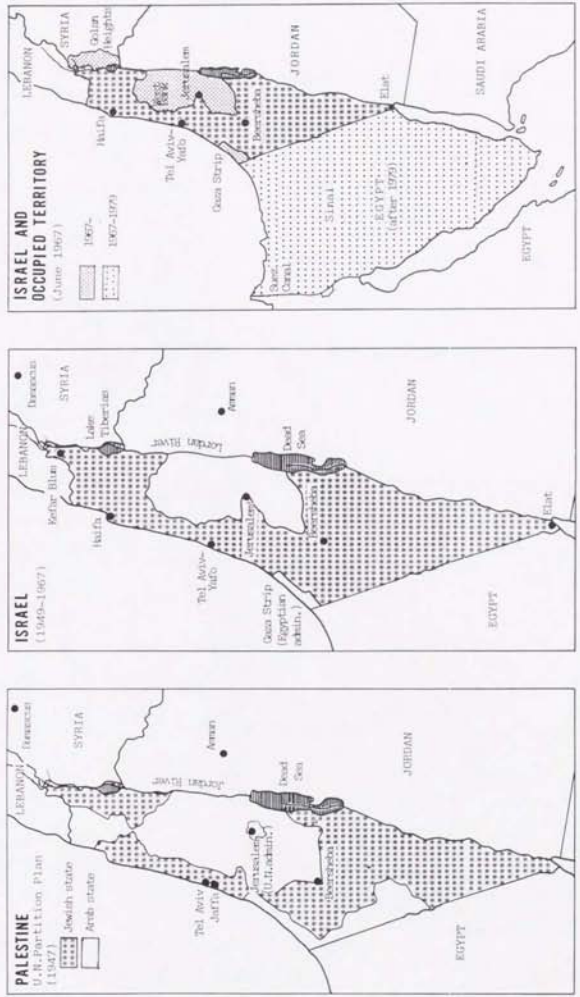
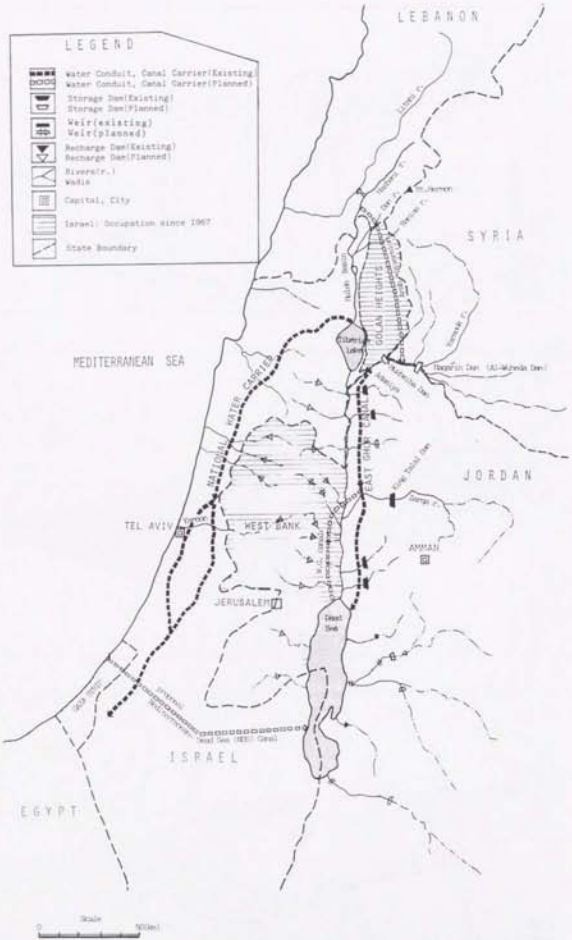


PALESTINE, ISRAEL, AND OCCUPIED TERRITORY



MAJOR EXISTING AND PPOPOSED PROJECTS
IN THE JORDAN RIVER SYSTEM

MAJOR GROUNDWATER AQUIFERS AND GEOLOGICAL TIME SCALE

Era	Period	Epoch	Years Ago	Major Aquifers
CENOZOIC	QUARERNARY	Recent Pleistocene	2,000,000	
	TERTIARY	Pliocene Miocene Oligocene Eocene Paleocene	65,000,000	Rammah
MESOZOIC	CRETACEOUS		135,000,000	Kurnub
	JURASSIC		193,000,000	
	TRIASSIC		225,000,000	
PALAEOZOIC	PERMIAN		280,000,000	Nubian Sandstone Series
	CARBONIFEROUS		345,000,000	
	DEVONIAN		395,000,000	
	SILURIAN		435,000,000	
	ORDOVICIAN		500,000,000	Disi
	CAMBRIAN		570,000,000	
PRE-CAMBRIAN	PROTEOZOIC			

Legend

Fossil groundwater aquifers in North Africa and Jordan

Brackish groundwater aquifers in Arabian peninsula

ANNEX-II

PHYSIOGRAPY OF JORDAN AND ISRAEL
AND
HISTORICAL REVIEW OF THE POLITICAL RIPARIAN ISSUES
IN
DEVELOPMENT OF THE JORDAN RIVER AND BASIN MANAGEMENT

Part A : Physiography of Jordan and Israel

A2.A1 Jordan

Topography

In contrast to the more uniform and monotonous morphology of most of the Arabian Peninsula, the territory of Jordan is morphologically distinctive and may be divided into seven physiographic provinces, which coincide with geologic provinces as shown in Fig.A2A1-1 (Ref.A2A1-1):

- Southern Mountain Desert;
- Mountain Range and Northern Highlands East of the Lift;
- Central Plateau, including Al Jafr and Al Azraq - Wadi as Sirhan Basin;
- Northern Plateau Basalt;
- Northeastern Plateau;
- Wadi Al Arabah - Jordan Rift;
- Highlands West of the Lift;

The most remarkable physical feature of the country is Jordan Rift/Valley which is a narrow depression extending from the Gulf of Aqaba for approximately 360 km north to Lake Tiberias. Much of the land in this graven is below sea level with the the lowest levels in the Dead Sea at -400 m. The Jordan river flows into the Dead Sea which has no outlet. The Rift valley, however, continues to the Gulf of Aqaba where Jordan has 20 km of coast line. To the east of the Rift Valley, the land rises steeply to a plateau with an average altitude of about 800 m above mean sea level with peaks rising to over 1,500 m in the south. Ninety (90) percent or more of the surface water resources, which cover two-third of the country's total potential water resources, are drained into the Dead Sea

catchment.

Hydrology

Jordan lies in the transitional zone between the Mediterranean climate in the west and the arid climate in the east and the south. The synoptic climatic zone of Jordan is a part of the Mediterranean bio-climatic region of which an essential feature is the concentration of rainfall during the cool winter season and a very marked summer drought. This relatively simple climatic regime is due to the interaction of two major atmospheric circulation patterns. During the winter months Jordan is within the sphere of influence of the temperate latitude climatic belt, and moist, cool air moves eastward from the Mediterranean over the area. In the summer months the area lies within the subtropical high pressure belt of dry air; temperatures are relatively high and no rainfall occurs. The regional distribution of rainfall within the area is related to the orographic effect of the Western Highlands which are oriented normal to the direction of movement of moist air during the winter months. This produces high rainfall zones coincident with the higher mountain ranges and a marked rain shadow in the lee of the hills. Altitude has also a strong effects on temperature. Frost is common during the winter months and snow falls occur in most years in the Western Highlands from December to March.

The highest rainfall zones correspond to the major mountain blocks of the Western Highlands, including the highest mean annual rainfall of 664 mm per annum at Ajlun station in the northern Western Highlands. The mean annual rainfall is relatively abundant in the range between 200 and 600 mm in the Western Highlands, but it decreases rapidly from the Western Highlands into Jordan Valley, Dead Sea, and Wadi Araba. From the northern end of the Dead Sea southwards and from the Wadi Araba to Aqaba the mean annual rainfall decreases less than 100 mm and 50 mm, respectively. From north of Dead Sea to Lake Galilee (Tiberias) the rainfall increases up to 400 mm per annum. In the most of the Central Plateau and in the eastern desert the mean annual rainfall decreases to less than 50-100 mm where the land slopes gently to the Arabian Desert. Rainfall occurs between October and May, and is at its highest between December and March when over 80 I of the annual rainfall occurs. The annual rainfall varies frequently year to year. The range is most marked in the Central Plateau and in the southern part of the Western Highlands, including extreme records of only 2 mm per annum and a maximum of 233 mm per annum. The distribution of annual rainfall is shown in Fig.A2A1-2.

Owing to the hyper-arid climate with a substantial deficit in soil moisture, the actual evaporation from the desert land is estimated to be very small and less than the amount of annual rainfall plus residual soil moisture, while the potential evaporation which is measured by class A-pan is as high as about 2,400-7,400 mm per annum. The highest rate of 7,400 mm per annum occurred in the eastern and the southern Bayir, while it is less than 3,000 mm per annum in the northern and central mountain ranges and it is less than 2,800 mm per annum in the mountains of Shoubak and Tafila (Ref.A2A1-1). The highest potential evaporation occurs during the hottest months of the year from June to August. The months with lowest evaporation are December to February.

Average annual volume of rainfall within the Jordan is estimated to be 8,500 $x10^6m^3$. With high evaporation losses, however, the average net annual runoff is only about 1,120 $x10^6m^3$ including 242 $x10^6m^3$ in the form of groundwater and 878 $x10^6m^3$ in surface flow.

About 80 I of the area of Jordan belongs to the arid zone with desert basins of restricted drainage. The drainage basin includes the following four sub-basins;

- Eastern Jordan Valley Basin
- Dead Sea Basin
- Wadi Araba Basin
- Desert Basins

The Eastern Jordan Valley Basin which includes the Syrian area of the Yarmouk river basin is the largest, including the Yarmouk river, Wadi Arab, Wadi Ziglab, Wadi Jurum, Wadi Yabis, Wadi Kufrinja, Wadi Rajib, Wadi Zarqa, Wadi Shueib, and Wadi Kafrein. The annual average runoff is estimated to be 607 $x10^6m^3$ in total which includes 357 $x10^6m^3$ of baseflow.

The Dead Sea Basin is the second largest, including Wadi Zerqa Ma'an, Wadi Wala, Wadi Mujib, Wadi Al-Karak, and Wadi Hasa. The annual average runoff is estimated to be 191 $x10^6m^3$ in total which includes 141 $x10^6m^3$ of baseflow.

A small amount of surface flow occurs in the Wadi Araba Basin which is located south of the Dead Sea. The Wadi Araba Basin includes Wadi Feifa, Wadi Khuneizir, Wadi Fidan, Wadi El-Buweirida, and Wadi Musa. The annual average runoff is estimated to be 31 $x10^6m^3$ in total which includes 21.6

$x10^6m^3$ of baseflow.

The Desert Basin is mostly located in the eastern and southern part of Jordan, of which the wadi systems are not clearly defined.

The Yarmouk river, which runs along the northern border of Jordan with Syria, provides almost half (400 $x10^6m^3$/year at Adasiya) of Jordan's surface water resources. The total stream-flows of Jordan are estimated to be about 878 $x10^6m^3$ per annum which includes 540 $x10^6m^3$ of baseflow.

Geology

The Hashemite Kingdom of Jordan is situated in the northwestern corner of the Arabian Peninsula. Part of the Nubo-Arabian Shield is exposed in the southwestern Jordan. It is characterized by Plutonic and metamorphic rocks, and by some minor occurrences of upper Proterozoic sedimentary rocks. Cambrian, Ordovician, and Silurian sandstone and shale of continental and marine origin have a maximum thickness of 1,800 m and unconformably overlie the rocks of the Precambrian basement complex.

A belt of sedimentary rocks deposited chiefly on the stable shelf area of the Tethys Sea borders the northern fringe of the shield. Most of southeastern and central Jordan is within this belt. It is a zone of inter-fingering sedimentary rocks of continental, littoral, and neritic origin, rapid lateral facies changes, and many stratigraphic unconformities caused by pulsation and, at certain periods, transgression and regression of the Tethys Sea. Regionally, the marine influence on the deposition increases toward the north and west. The total thickness of all post-Proterozoic sedimentary rocks is 2,000-3,000 m; it exceeds 4,000 m in the baylike sedimentary basin of Al-Jafr in south-central Jordan, and 5,000 m in the Al- Azraq - Wadi Al-Sirhan Basin in the north-central Jordan. These sedimentary basins strike northwest and thus seem to merge with the unstable shelf area of the Tethys Sea in the northwest.

In the transition zone to and in the area of the unstable shelf in northwestern, northern, and probably northeastern Jordan, neritic and bathyal sedimentary rocks form the greater part of the post-Paleozoic rocks. There, the stratigraphic sequence is more complete with fewer unconformities and lateral faces changes are less pronounced than in the stable shelf area to the south and southeast. In the northwestern Jordan, west of the Jordan River, the total thickness of sedimentary rocks above the Precambrian basement may be as much as 7,000 m; in the Dead Sea area

of the Wadi Al-Araba - Jordan Rift province, repeated structural subsidence resulted in the accumulation of sedimentary rocks as much as 10,000 m thick.

No evidence is known of post-Proterozoic structural movements characteristic of alpine orogenesis. The crustal movements affecting the country since the Cambrian were gentle regional tiltings (epeirogenic movements) and a combination of faulting, block folding, and taphrogenic movements. The majority of structural features were caused by tensional forces. Evidence of compression is rare and chiefly restricted to west Jordan and to north Jordan east of the Rift.

Major volcanic activity occurred during i) the late Proterozoic and Early Cambrian (quarts porphyries; Wadi Al-Araba) , ii) the late Jurassic (?) and Neocomian (mafic and intermediate eruptive rocks; Wadi Al-Araba and west of the Jordan River), and iii) the Neogene Tertiary (includes Miocene and Pliocene) and Pleistocene (extensive basalt volcanism). (Ref.A2A1-2)

Hydrogeology

The main aquifers have been recognized in the pervious sequences in the formation of 1) the Basalt system, 2) Rijam (B4) system, 3) Amman-Wadi Sir (B2/A7) system, 4) Lower Ajlun (A1-6) system, 5) Kurnub system, and 6) Disi system (Fig.A2A1-3).

Basalt system : The basalt system of the Pleistocene age is a regional shallow aquifer system to the north of Azraq. High rainfall on the Jabel Druze mountains in Syria is a source of groundwater recharge, which discharges southwards to the Azraq depression. The aquifer is formed by very permeable scoriaceous zones in the basaltic rock unit.

Rijam (B4) system : The Rijam (B4) system of the Eocene-Paleocene age is a regional shallow aquifer which is formed in the central parts of the Jafr and Azraq basins. The Rijam formation has a thickness of 50-150 m or less, which is underlain by the chalky marls or chalks of the upper Muwaqqar (B3) formation. The aquifer is in a isolated-independent hydrologic system, forming a water table condition in general. Within the basin the saturated zone of the Rijam formation occurs in an area of very low rainfall less than 50 mm per annum. The aquifer receives limited recharge by infiltration of the flash floods through the wadi courses, which flow to an easterly direction. The wadi system and groundwater flow in the Jafr basin have no outlet. The Rijam formation of the Azraq basin

comprises a part of a composite aquifer system with basalt system which discharges at the Azraq springs and swamps. The permeability of the Rijam formation is variable, owing to varying degree of karstification. The water is highly saline in the areas of stagnant environment and in the discharging area, while it is fresh in the area along the wadi courses where direct infiltration from the flash floods occur. The Rijam aquifer is a local aquifer with limited potential.

Amman-Wadi Sir (B2/A7) aquifer : The most important aquifer system is the Amman-Wadi Sir (B2/A7), which consists of limestone, silicified limestone, chert, arenaceous limestone and sandstone of the middle to upper Cretaceous age. This aquifer system extends throughout entire country with thickness about 100 to 350 m. The depth of groundwater table below the ground surface generally ranges 50 to 250 m in the uplands. Good groundwater recharge occurs from the Western Highlands where annual rainfall ranges 200 to 600 mm. To the east aquifer is confined by thick marl layer such as Muwwaqar (B3) formation, and water salinity is increased.

Lower Ajlun (A1-6) aquifer : Intermediate aquifer system is the lower Ajlun (A1-6), which consists of alternating limestone, marl, shale, chert and sandstone of middle Cretaceous age. This aquifer system is underlain by the Amman-Wadi Sir formation, which is mostly confined by its relatively impervious layer of marl and shale in the A5/6 of the upper unit of A1-6. The lower Ajlun formation extends throughout country with variable thickness and litho-facies. To the southwards, the aquifers in the lower Ajlun formation becomes more sandy with less salinity of water. The aquifer system is mostly untapped, due to its complicated hydrogeology and deep formations.

Deep sandstone aquifer: Kurnub/Zarqa/Disi aquifer : Deep sandstone aquifers are Kurnub/Zarqa of lower Cretaceous age and Disi of Paleozoic age, which are unconformably separated by a less permeable layer of sandstone, siltstone and shale. The Kurnub formation intercalates frequent argillaceous layers in the south, while the Disi is composed of massive and rather homogeneous arenaceous. Groundwater in these aquifers are mostly non-renewable due to limited groundwater recharge through small outcrop area. Quality of groundwater in the Kurnub/Zarqa system varies from fresh to brackish. Excellent quality with low salinity, however, is found in the Disi aquifer in the southern part of the country, which has been exploited for the water supply of Aqaba and local experimental irrigation. The aquifer complex, however, forms a huge groundwater

reservoir extending under the whole of the country. This groundwater storage offers opportunity for short-term and emergency uses.

REFERENCES (A2.A1)

Ref.A2A1-1
Royal Jordanian Geographic Center, 1986, National Atlas of Jordan, Part II, Hydrology and Agrohydrology" , First Edition, pp.5,56.

Ref.A2A1-2
Friedrich Bender, 1975, "Geology of the Arabian Peninsula Jordan", U.S. Geological Survey Professional Paper 560-I, pp.11-136.

A2.A2 Israel

Topography

The Israel is one of the smallest states in the Middle East, and covers an area of approximately 21,000 km^2 in the northeastern part of the Arabian Peninsula. Israel's shore-line is the eastern border of the Mediterranean Sea, and its territory extends northwards through the Golan Heights and southwards through the Negev to Eilat on the Gulf of Aqaba. Israel has four geomorphologic provinces such as; i) coastal plain, ii) mountains and hills, iii) Negev desert, and iv) Rift valley (Fig.A2A2-1).

The Mediterranean coastal plain, which is fertile land relatively rich in water resources from wells and springs, stretches from Rosh Hanikra south to Ashkelon with a length of about 200 km. The source of the valuable groundwater recharge for the coastal plains is mainly dependent on rainfall over the mountains and hills with permeable strata dipping westward. The 'Emek Yizre'el is a graven with northwest-southeast direction as shown in Fig.A2A2-1, of which alluvial plain is floored by a thick layer of heavy and rich soils.

The mountains and hills include the regions of upper and lower Galilee, Samaria, and Judaea. Upper Galilee is structurally part of the mountains of Lebanon; a picturesque limestone plateau dominated by Mount Hermon (2814m). Lower Galilee to the south, is a mountainous block broken into many smaller hills of lower altitude with gentle slope. Galilee as a whole is the wettest region of Palestine where both springs and streams are more numerous and rich than that in Judaea. Samaria is dissected into hills and valleys, which roughly correspond to the heartland of the ancient Kingdom of Israel, between the 'Emek Yizre'el and the plateau of Judaea (Fig.A2A2-1). Samaria is lower in elevation than Galilee or Judaea with rainfall up to 630-750 mm, but surface water is not plentiful. The boundary between Samaria and Judaea is not physically well-defined, but may be thought of as passing some 15 km north of Jerusalem. Judaea is more like a high plateau between 450 m and 900 m high, with a dominating bleaker and barer rocky landscapes. The Judaean mountains rises to nearly 1,000 m, with precipitation of up to 700 mm: to the east it becomes dry with under 300 mm of rainfall.

The Negev which forms a large triangular desert region constitutes about half of the area of Palestine and over six-tenths of pre-1976 Israel. A ridge of mountains and hills runs across the central Negev at heights

between 500 m and 600 m, rising towards the Egyptian border to above 900 m in places. The northwestern part of the Negev receives fair but unreliable rainfall, while the rest of the Negev receives from 200 mm to less than 50 mm of mean annual rainfall. The Negev was never thickly populated but its economic significance is considerable since almost all of Israel's important mineral resources such as copper, phosphates, natural gas, and glass sand are found there.

The Jordan Rift Valley is about 360 km long and is the northern part of the world's largest graven system known as "Rift Valley" which connects East Africa and Northern Syria over a total length of about 6,000 km. The Wadi Araba - Jordan" rift strikes N-15°-E from the gulf of Aqaba to the Dead Sea, and forms the "south graven" which has a length of approximately 200 km. The floor of the Rift rises gradually from the Gulf of Aqaba to altitudes of 250 m above sea level at the watershed of Jabal ar Rishah in the center of Wadi al Araba. From there the floor falls gently northwards to the surface of the Dead Sea at 401 m below sea level. The maximum depth of the Dead Sea is 793 m below sea level. It covers an area of 1,000 km^2, and has two basins which are separated by the Lisan Straits, namely "North Sea" and "South Sea" with areas of 720 km^2 and 230 km^2, respectively.

The rift turns from N15^{o}E to about N5^{o}E to Galilee Sea (Lake Tiberias) to form the "north graven". From the mouth of the Jordan River at 401 m below sea level, the 105-km-long Jordan Valley rises to 212 m below sea level at Lake Tiberias (Galilee Sea). Jordan river which runs on the floor of the "north graven" separates the "West Bank" areas of the Palestine block to the west and the Trans-jordan block to the east.

The catchment includes parts of Lebanon, Syria, Israel and Jordan. The watershed between the Dead Sea and Mediterranean Sea extends approximately north-northwest from the Al Khalil (Hebron) region through Bethelem-Jerusalem-Ramallah to the Nablus region, and reaches altitudes of about 1,000 m. The shortest distance between the Dead Sea and the Mediterranean Sea is 72 km, which corresponds to the proposed Central Alternative, namely the canal/tunnel route "Tel Aviv"-"Jerusalem"-"Qumran" for Mediterranean-Dead Sea solar-hydro scheme (Fig.A2A2-1).

Hydrology

For about eight months of the year Israel enjoys warm and sunny weather. Winter rains fall between December and March, sometimes even in April, usually in storms of two or three days duration. Precipitation is confined

to the winter season and varies from an average of 1,000 mm in Galilee in the north to 500 mm on the Coastal Plain near Tel-Aviv, to 200 mm near Beersheba and to less than 50 mm at Eilat in the south. (Fig.A2A2-1) Rainfall varies considerably from one winter season to another from around 25 % of the long-term average in dry years to 160 % of the long-term average in particularly rainy years. Over half of Israel's area receives less than 180 mm of precipitation annually. (Ref.A2A2-1)

The southern part of Israel is desert, namely the Negev desert, which has a high potential evaporation in the range between 1,700 and 2,700 mm per annum, and whose values of relative humidity and solar radiation register 40-60 % and 195-201 kcal/cm^2 per annum, respectively (Ref.A2A2-2). Owing to low levels of precipitation and and high potential evaporation, large water deficiencies have been experienced in the southern part of the Israel. Droughts, particularly in the southern part of the country, are not infrequent.

The climate of the Rift Valley ranges from "hot-arid" with a mean annual rainfall of less than 100-300 mm in the bottom of Jordan Valley to "Mediterranean semi-arid" with more than 300-700 mm in the surrounding highlands. The climate of the Dead Sea and the "southern graven" is hyper-arid. Sodom, which is situated just beside the southwest shore of the Dead Sea, has an average annual rainfall of 47 mm (1931-1969), with monthly means of daily minimum temperature of 12°C in January, and maximum of 39°C in August. The mean relative humidity is rather high at 56 % in January and 38 % in August. To the south of Dead Sea, the climate becomes more dry. Eilat, which is located on the shore of Aqaba bay, has an average annual rainfall of 25 mm, with monthly mean of daily minimum temperature of 10°C in January, and maximum of 40°C in August. The mean relative humidity is as low as 46 % in January and 28 % in August. Selected climatic data, including "Tel Aviv" of the coastal plain, "Jerusalem" of the mountain range, "Sodom" of the Dead Sea, "Deganya" of the Rift Valley, "Beersheba" of the Negev desert, and "Eilat" of the Aqaba bay, are given in Tab.A2A2-1.

Surface drainage is largely controlled by a few east and west flowing streams, some of which have cut deeply into the highlands with their numerous head-streams. The largest river, the Jordan, is an entirely land-locked river terminating in the Dead Sea.

The Dead Sea is a closed sea with no outlet except by evaporation which amounts to 1,500-1,600 mm per annum (Ref.A2A2-3). In the past, the

evaporation losses were replenished by an inflow of fresh water from the Jordan River and its tributaries, as well as from other sources such as wadi floods, springs and rainfall. The mean volume of water flowing into the sea before 1930 was about $1.6 \times 10^9 m^3$/year, of which $1.1 \times 10^9 m^3$/year were contributed by the Jordan River (Ref.A2A2-4). Under these conditions, the Dead Sea had reached an equilibrium level of around 393 m below sea level, with some seasonal and annual fluctuation due to variations in the amount of rainfall. However, since the early 1950s, Israel, and later on Jordan, have taken steps to utilize the freshwater flowing into the Dead Sea for intensified irrigation and other purposes, which has reduced the amount of water entering the Dead Sea by 1×10^9m3/year. As a consequence, the level of the Dead Sea has declined in recent years, reaching as low as 402 m below sea level today, which is almost 10 m lower than its historic equilibrium level. The surface area of the Dead Sea and the volume of evaporation vary only by a few percent between the elevations from -402 to -390 m, while the water levels fluctuate considerably. The Dead Sea and its variations of water level from 1840 to 1980 are shown in Fig.A2A2-2.

The Sea is a brine water body with vast mineral wealth including potash, common salt, bromide, magnesium chloride, calcium chloride. The extremely high salinity amounts to 230,000-300,000 mg/l of total dissolved solids (TDS). The specific gravity of the brine water has been estimated to be 1.22-1.23.

Geology

The Palestine of the Israel and the occupied areas is part of a physiographic region consisting of marine sedimentary formations lying along the western margins of the ancient Arabian landmass, which were folded in Miocene and early Pliocene times to form a long anticline running roughly parallel with the Mediterranean coast. The geology is mostly of sedimentary origin, ranging in age from Triassic to Neogene-Quaternary, except in the surroundings of the Tiberias lake where volcanics of the Miocene-Quarternary age widely cover the areas. The sedimentary succession which has a thickness more than 1,000 m is mainly due to a series of regional regressions and transgressions of the Tethys Sea. The stratigraphic sequence of the sedimentary rocks includes: Quarternary, Pliocene-Miocene, Eocene-Paleogene, upper to middle Cretaceous of Cenonian and Cenomanian-Turonian, lower Cretaceous, Jurassic and Triassic. The lowest formation of the Paleozoic-Precambrian system, which consists mainly of acid intrusives, outcrops in some small areas in the southern Negev near the Eilat. The sedimentary

sequences comprise mainly carbonate rocks and sandstones from Triassic to Plio-Pleistocene. A geological map is shown in Fig.A2A2-3 (Ref.A2A2-5). The main aquifer is found in the Cretaceous (Cenomanian-Turonian) formations, which consist largely of dolomite and limestone intercalating some clay and chalk layers, and which has a maximum thickness of about 600-700 m (Ref.A2A2-6), as indicated in Fig.A2A2-4 of the schematic geological profile crossing central Israel.

The taphrogenic structural movements, which initiated the formation of the present graven apparently occurred along old structural zones of weakness, started during the late Eocene (?) to Oligocene. The east of the "south graven" in the trans-jordan block was structurally elevated in the late Oligocene to Miocene. In the graven area itself, marine sediments were deposited during the Oligocene and Neogene. The thick evaporite series of late Miocene (?) to Pliocene age in the Dead Sea area may demonstrate the gradual decrease and termination of marine deposition in a part of the graven.

The Lisan formation, which consists mainly of shale and marl intercalating gravels and some gypsums and native sulfurs, unconformably overlies all older rock sequences in the Rift province. The Lisan formation was deposited in a fluctuating oligohaline and miohaline lacustrine environment in the late Pleistocene age. The ancient Lisan Lake covered the entire Rift Valley from Lake Tiberias to approximately 80 km south of the Dead Sea. Along the margin of the Rift province, the Lisan formation intercalates with coarse clastic and sandy deposits derived from the elevated areas bordering the Rift Valley.

The Rift Valley is covered with Holocene and Pleistocene fluvial, aeolian, and lacustrine sediments.

Israel and occupied areas: Palestine issues

During the latter half of the nineteenth century more than half of the Jews in the world lived in Eastern Europe and in Tsarist Russia, where their conditions were as miserable as they had been everywhere in Europe for several centuries. In the 1880s their distress was added to by a series of anti-Jewish riots in southern Russia which resulted in large scale emigration. Among these was the first wave of Zionists to reach Palestine in modern times. It was their conviction that the only possible solution to the plight of Jewish communities in the east, and the threat of assimilation in the west, was the formation of a Jewish state. Pre-1948

Jewish colonization in Palestine thus laid the foundations for the emergence of Israel in 1948.

After the First World War and the break-up of the Ottoman Empire a "Mandate" for Palestine was entrusted to Britain by the league of Nations and continued until the eve of the birth of Israel in 1948. The boundaries of Palestine in the east followed the natural divide of the Jordan Valley and the Araba depression. In the southwest the 1906 boundary between the Ottoman Empire and Egypt remained, from the Gulf of Aqaba to Mediterranean Sea south of Gaza. This border, with the Gaza Strip enclave on the coast, was restored with Israel's withdrawal from Sinai in 1979. The northern and northeastern boundaries of Palestine were established by Anglo-French agreement in 1920 and 1923, and remained unchanged until Israel seized the Golan Heights in June 1967.

The configuration of Israel's pre-1967 boundaries was largely determined by the location of Jewish rural settlements, and the distribution of the Jewish population was the basis of the UN's partition proposals. Jewish colonization of the Arab territories of Sinai (with the Gaza Strip), the Golan, and the West Bank began after the Six Day War of June 1967. Here again, the geographical dimension of the settlement strategy is of great interest, but the real significance of the occupied area settlements is that they may hold the key to the future of the state of Israel. (Fig.A2A2-5)

Although substantially larger than the area popularly thought of as Biblical Palestine, the Mandated territory was one of the smallest political units in Southwest Asia. Its total population was only 752,000 at the 1922 census. Yet throughout history, control of this part of the earth's surface has been the ambition of succeeding powers, not only because of its unrivaled strategic significance at the crossroads of Asia, Africa and Europe, and between the Mediterranean and Red Sea, but also because Palestine is revered by millions of Muslims, Christians, and Jews, for its religious associations.

In many ways the West Bank is by far the most important of the remaining occupied areas, being not only the largest (5,900 km^2) and most populous, but being the natural focus of Palestinian political aspirations. In 1984 the Arab population, including those temporarily abroad, was over 900,000, an increase of approximately one-third since Israeli occupation began in 1967. The West Bank is also the focus of intensive Jewish settlement effort, spurred on by a variety of factors.

Israel's stake in the West Bank is now so great that voluntary withdrawal seems inconceivable. Apart from the heavy financial and political investment in the new settlements in the West Bank, Israel is now dependent upon the West Bank for some 475 $x10^6m^3$ per annum of its water supply out of a total of 1900 $x10^6m^3$, a quarter of the annual water potential. This would be less critical if Israel was not already over-exploiting its water potential while facing increasing demands for water which were thought could result in a deficit of 230 to 340 $x10^6m^3$ per annum by 1990 as indeed they have. Since 1982 Israel's national water company MEKOROT has been integrating the West Bank supplies into the Israeli network. It seems clear that control of these sources will not be surrendered until alternative resources have been served. The water resources in the West Bank being diverted into Israel, probably account for 70 % of the West Bank's water resources. (Ref.A2A2-7)

REFERENCES (A2.A2)

Ref.A2A2-1
Samuel Pohoryles, 1977, "Water Shortage in Israel: Long-Run Policy for the Farm Sector", Water Resources Research, Vol.13, No.6, pp.865-872.

Ref.A2A2-2
N.Buras and P.Darr, 1979, "An Evaluation of Marginal Waters as a Natural Resources in Israel", Water Resources Research, Vol.15, No.6, pp.1349-1353.

Ref.A2A2-3
I.R.Calder & C.Neal, 1984, "Evaporation from Saline Lakes: A combination Evaporation Approach", IAHS, Journal of Hydrological Sciences, Vol.29, No.3, pp.89-97.

Ref.A2A2-4
Dan Weiner and Arie Ben-Zvi, 1982, "A Stochastic Dynamic Programming model for the Operation of the Mediterranean-Dead Sea Project, Water Resources Research, Vol.18, No.4, pp.729-734.

Ref.A2A2-5
Arab Organization for Mineral Resources, 1987, "Geological Map of the Arab World", 1/2,250,000:Sheet-3.

Ref.A2A2-6
Robert Schneider, 1967, "Geology and Hydrogeologic Factors Related of the Carbonate Rock Aquifer System of Central Israel", IAHS, Proceedings of Symposium of Haifa, Israel, pp.467-473.

Ref.A2A2-7
Thomas Naff and Ruth C.Matson, 1984, "Water in the Middle East: Conflict or Cooperation ?", Westview Press / Boulder and London, pp.1-62.

Tab.A2A2-1 Selected Climatic Data: Rift Valley and Israel

Location	Altitude (m)	Average annual rainfall (mm)	Monthly mean of daily minimum & maximum temperatures (°C)				Mean relative humidity (%)	
			January		August	(Period)	January	August
			Min	Max	Min	Max		
Tel Aviv	20	564	8	18	22	31(1949-58)	74	73
Jerusalem	810	486	6	13	20	30(1951-60)	65	54
Sodom	-390	47	12	21	29	39(1961-70)	56	38
Deganya	-200	384	9	18	24	37(1948-58)	70	54
Beersheba	280	204	7	17	19	33(1961-70)	65	58
Eilat	12	25	10	21	26	40(1956-65)	46	28

Part B : Historical Review of the Political Riparian Issues in Development of the Jordan River and Basin Management

The political riparian issues in development of the Jordan river and basin management between 1948 and 1967 is described in this Annex. Basic information for understanding the riparian right problems in the inter-state basin development of the Jordan river system are provided, with respect to UNRWA's pioneering work on the "Main PLan and Johnston Plan" in 1951-55. The source of this information is the book "Water in the Middle East" published by the Middle East Research Institute, University of Pennsylvania" in 1984. The research was unclassified and derived from totally open sources of information. Some recommendations for the future planning of the joint development and management are described in a supplement this Annex to conclude the study on the joint development and management of the Jordan river system. The supplement to Annex-II includes two key maps namely as "Israel and Occupied Territory" and the "Major Existing and Proposed Projects in the Jordan River System".

A2.B1 Unilateral Planning and Action after the First Israel-Arab War

The 1948 Arab-Israeli war aggravated the difficulties of cooperative water management. The fragile armistic agreements signed by the Arab states and Israel in 1949 did not deal with water, nor was the post-war atmosphere conductive to negotiation. In consequence, each of the riparians moved to utilize the Jordan River system uni-laterally.

Israel resumed water planning immediately after 1948. The comprehensive All Israel Plan was completed in 1951. (Tab.A2.B1-1) It included the draining of the Huleh swamp, the diversion of the Jordan River, and the construction of a carrier system. Subsequently consolidated into the National Water Carrier (Hereinafter referred to as "Carrier"), this plan was to became the keystone of Israel's water development, diverting the Jordan waters to the Coastal Plains and the Negev Desert.

The first part of the project, the draining of the Huleh swamps, began in 1951. Israel delayed construction of the first leg of the Carrier for foreign policy reasons. Work on the Huleh swamp, which infringed on the demilitarized zone with Syria, provoked a number of military incidents. These incidents were the first of many clashes between Israel and Syria

and between Israeli and Arab residents in disputed territories and demilitarized zones. Some incidents were designed to harass and remove unwanted population elements or protect personal property; other incidents were intended to inter-personal property; other incidents were intended to inter-personal property;other incidents were intended to interfere with the development of water resources in ways that the contesting party viewed as inimical to its interests. In some cases, over a period of some two decades, water-related actions were used as a mask for other conflicts (e.g., shooting on Lake Tiberias in 1954-55 was escalated to incursions that took hostages to exchange for prisoners of war held by the other side.) Throughout the period, incidents threatened to shatter the Armistice Agreements. Some analysts have held that water was a major factor leading to the 1967. (Tab.A2.B1-2)

Jisr Banat Yaqub (Hebrew: Gesher Bnot Yaacov), the targeted diversion point for the large-scale Israei project, was located in the demilitarized zone between Israel and Syria Israel was apprehensive that this fact would provoke Arab opposition and international condemnation. It delayed the decision to proceed with the larger diversion scheme until July 1953.

By the early 1950s, both the Jordanian government and **UNRWA** (United Nations of Relief and Works Agency for Palestine Refugees in the Near East) were working on irrigation schemes to improve Jordanian agriculture and re-settle the Palestinian refugees. In 1950, Jordan received a commissioned study from British consultant Sir Murdoch MacDonald which proposed diverting the Yarmouk into Lake Tiberias and constructing irrigation canals down both sides of the Jordan Valley. A 1952 plan for **UNRWA** by American engineer M.E.Bunger envisaged a dam on the Yarmouk River at Maqarin with storage capacity of 480 $x10^6 m^3$. The impounded water would be diverted by a second dam at Addassiyah into gravity-flow canals along the EAst Ghor of the Jordan Valley. Bunger reckoned the work would irrigate 435,000 dunums (= 43,500 ha) in Jordan and 60,000 dunums (= 6,000 ha) in Syria. Hydroelectric plants at the two dams would generate 28,300 KWh per year for JOrdan and Syria. Experts estimated the Bunger Plan would settle 100,000 people.

In March 1953, Jordan and **UNRWA** signed an agreement to execute the Bunger Plan. (Tab.A2.B1-1) In June 1953, Jordan and Syria agreed on sharing the Yarmouk water. The actual work on the project began in July 1953. However, even before it commenced, Israel protested that its riparian rights to the Yarmouk were not recognized in the Bunger Plan. The Yarmouk Triangle demilitarized zone controlled by Israel only had ten km of

frontage on the Yarmouk.

Israel, in July 1953, commenced the diversion of the Jordan at Jisr Banat Yaqub. This site was in the demilitarized zone, but had two technical advantages over lower alternative sites: 1) it had a lower salinity level than points farther down the Jordan River Fork, 2) the 270 m drop in elevation between the site and Lake Tiberias was sufficient to enable the use of gravity as the means of diversion. The Israeli Government underestimated both Syrian and international reaction. In September 1953, the Syrians protested to the United nations. Unlike the Huleh drainage case, which the U.N. had commenced, the U.N. ruled in favor of Syria. Israel ignored the order to discontinue work. Only an American threat in November 1953 to cut off funds channeled to Israel by the Foreign Operation Administration convinced Israel to terminate construction. Subsequently, a point at Eshed Kinrot on Lake Tiberias was chosen. It was technically inferior to the original site; water salinity was high and hydro-electric power had to be used to pump the water to the Carrier.

Meanwhile, the Jordanian had to abandon the Bunger Plan entirely. One factor was Israel's objection on the ground that the original Rutenberg concession gave Israel right to the Yarmouk. Another factor was a change in American perceptions. King Hussein, in his autobiography, alleges that the United States accepted the Israeli legal position and hence denied funding to the Bunger plan.

A2.B2 **The Johnston Negotiations**

The U.S. Government then moved toward deeper involvement. On October 16, 1953, President Eisenhower appointed Eric **Johnston** as a special ambassador to mediate a comprehensive plan for regional development of the Jordan River system. Philosophically based on the Marshall Plan in Europe, it sought to reduce the conflict potential of the region by promoting cooperation and economic stability.
The large number of plans issued between 1953 and 1955 represents bargaining stages in the negotiation over the sharing of the Jordan River system. The major bargaining issues pertained to: 1) the water quotas for the riparians, 2) the use of Lake Tiberias as a storage facility, 3) the use of Jordan waters for out-of-basin areas, 4) the used of Litani as part of the system, 5) the nature of international supervision and guarantees.

The "base plan" for **Johnston's mission** was an **UNRWA-sponsored** desk study prepared by Charles T.Main under the supervision of the TVA with the backing of the American State Department (Tab.A2.B1-1). The plan featured:

(1) a dam on the Hassbani to provide power and irrigate the Galilee area;
(2) dams on the Dan and Banias rivers to irrigate the Galilee; drainage of the Huleh swamps;
(3) a dam at Maqarin with 175 $x10^6m^3$ storage capacity to be used for power generation;
(4) a dam at Addassiyah to divert water to Lake Tiberias and into the East Ghor area;
(5) a small dam at the outlet to Lake Tiberias to increase the lake's storage capacity;
(6) gravity-flow canals down the east and west sides of the Jordan Valley to irrigate the area between the Yarmouk and the Dead Sea;
(7) control works and canals to utilize perennial flows from the wadis.

The Main Plan favored primary in-basin use of the Jordan waters and rules out integration of the Litani. Provisional quotas gave Israel 394 $x10^6m^3$, Jordan 774 $x10^6m^3$, and Syria 45 $x10^6m^3$.

Israel opened the bargaining by publishing a seven-year plan. Its major features, modeled after the Lowdermilk and Hayes plans, included the integration of the Litani, the use of Lake Tiberias as the main storage facility, out-of-basin use of the Jordan waters , and the Mediterranean-Dead Sea canal. Since water flow was based on the combined Jordan-Litani output of 2,500 $x10^6m^3$, Israel sought an initial quota of 810 $x10^6m^3$.

The Israeli proposals were elaborated in the plan prepared for it by Josep Cotton in 1954. the combined annual Litani-JOrdan water resources were estimated at 2,345.7 $x10^6m^3$. Israel was to receive 1,290 $x10^6m^3$/year. The Arab share of 1,055.7 $x10^6m^3$/year was to be divided by allocating 575 $x10^6m^3$/year to Jordan, 450.7 $x10^6m^3$/year to Lebanon and 30 $x10^6m^3$/year to Syria.
The Arabs responded to the Main "base plan" with the Arab Plan of 1954. It reaffirmed the Ionides, MacDonald, and Bunger principle of exclusive in-base use of the water, rejected storage in Lake Tiberias, and rejected integration of the Litani. Because 77 % of the water of the Jordan water system originated in the Arab countries, it objected to the quota allocations proposed in the Main Plan. According to the Arab proposal,

Israel was to get 200 $x10^6m^3$/year, Jordan $861x10^6m^3$/year, and Syria 132 $x10^6m^3$/year. The Arab plan recognized Lebanon as a riparian of the Jordan River system and allocated it 35 $x10^6m^3$/year.

The Baker-Harza study was published in 1955 (Tab.A2.B1-1). The American engineers were commissioned by the Jordanian Government to conduct a hydrological survey to determine the amount of water needed to irrigate the Jordan Valley. The plan was technically oriented and not directly related to the negotiations. It recommended construction of an elaborate canal system to irrigate 460,000 dunums (46,000 ha) in the Jordan Valley. It increased the estimate of cultivable land but decreased the water duty (the amount of water required per unit of land to produce crops).

A2.B3 **Toward the Unified Plan**

As negotiations progressed, disagreements were gradually reduced. Israel gave up on integration of the Litani, the Arabs removed their objection to out-of-basin use of waters. Lake Tiberias was rejected by ARabs as a reservoir for Yarmouk water. An alternative Arab proposal to treat Lake Tiberias (without diversion of the Yarmouk) as a regional storage center to benefit all riparians was rejected by Israel. The Arabs demanded and Israel opposed international supervision over withdrawals.

Allocation of water quotas was the most difficult issue. As illustrated in Table A2.B3-1, the disparity between the opening demands was considerable. After the claim for the Litani was dropped, Israel downgraded its quota demand to 550 $x10^6m^3$/year. After extremely hard bargaining the so-called "Gardiner Formula" was adopted as the final version of the Unified (Johnston) Plan (Table A2.B3-1). Compared to the Main Plan figures, the Johnston Plan quotas are significantly different only with regard to Syria and Lebanon. Jordan's share was slightly scaled down and Israel was to receive the variable residue after other quotas had been met; most estimates place this average residue at 400 $x10^6m^3$/year.

The Unified Plan stipulated that supervision would be exercised by a three-member Neutral Engineering Board. The Board's mandate included the supervision of water withdrawal, record keeping, and preventing the sprit and letter of the agreement.

The Unified Plan was accepted by the technical committees from both Israel

and the Arab League. The Israel Cabinet discussed the Plan in July 1955 without taking a vote. The Arab Experts Committee approved the Plan in September 1955 and referred it for final approval to the Arab League Council. the Council decided on October 11,1955, not to ratify the Plan. According to most observers, including Johnston himself, the Arab non-adoption of the Plan was not total rejection; while they failed to approve it politically, they were determined to adhere to the technical details. The issue of impartial monitoring was not resolved, which made for problems in the future.

A2.B4 **Unilateral Implementation** : (1955-1967)

The failure to develop a multi-lateral approach to water management reinforced unilateral development. Though the Unified Plan failed to be ratified, both Jordan and Israel undertook to operate within their allocations.

The two major successful projects undertaken were the Israeli National Water Carrier and Jordan's East Ghor Main Canal.

The National Water Carrier diverted water from the Jordan River Fork at Eshed Kinrot to the Coastal Plain and the Negev desert. Although sections of it were begun before 1955, it was only completed in 1964. The initial diversion capacity of the National Water Carrier without supplementary booster pumps was 320 $x10^6m^3$, well within the limits of the Johnston Plan.

Design of the East Ghor Canal was begun by Jordan in 1957. It was intended as the first section of a much more ambitious plan known as the Greater Yarmouk Project. Additional sections included: 1) construction of two dams on the Yarmouk (Mukheiba and Maqarin) for storage and hydro-electricity; 2) construction of a 47-km West Ghor Canal together with a siphon across the Jordan River near Wadi Faris to connect it with the East Ghor Canal; 3) construction of seven dams to utilize seasonal flow on side wadis flowing into the Jordan; 4) construction of pumping stations, lateral canals , and flood protection and drainage facilities. In the original Greater Yarmouk Project, the East Ghor Canal was scheduled to provide only 25 % of the total irrigation scheme. Construction of the Canal started in 1959. By 1961 its first section was completed; sections two and three, down to the Wadi Zarqa, were in service by June 1966.

Shortly before completion of the Israeli Water Carrier in 1964, an Arab

summit conference decided to try to thwart it. Discarding direct military attack, the Arab states chose to divert the Jordan headwaters. Two options were considered: either the diversion of the Hasbani to the Litani and the diversion of the Banias to the Yarmouk, or the diversion of both the Hasbani and the Banias to the Yarmouk. The latter was chosen, with the diverted waters to be stored behind the Mukheiba Dam.

According to neutral assessments, the scheme was only marginally feasible, it was technically difficult and expensive. Its estimated cost was between $190-$200 million, comparable to the cost of the entire Israeli National Water Carrier. Financial issues were to be solved by contributions from Saudi Arabia and Egypt.

Political considerations cited by the Arabs in rejecting the 1955 Johnston Plan were revived to justify the diversion scheme. A particular emphasis was placed on the Carrier's capability to enhance Israel's capacity to absorb immigrants to the detriment of Palestinian refugees. In response, Israel stressed that the National Water Carrier was within the limits of the Johnston Plan. It declared that as a sovereign state it had the right to set immigration policies without external interference, and refused to make concessions regarding Arab refugees.

The Arab started work on the Headwater Diversion in 1965. Israel declared that it would regard such diversion as an infringement of its sovereign rights. According to estimates, the completion of the Headwater Diversion Project would have deprived Israel of 35 % of its contemplated withdrawal from the upper Jordan, constituting one-ninth of Israel's annual water budget, but having its supply for the Carrier.

In a series of military strikes, Israel hit the diversion works. The attacks culminated in April 1967 in air strikes deep inside Syria. The increase in water-related Arab-Israeli hostility was a major factor leading to the 1967 June War.

A2.B5 The Militarization of the Water Conflict

The 1967 war increased the trend towards competitive unilateral utilization of the Jordan River system.

Israel improved its hydrostrategic position through the occupation of the Golan Heights and the West Bank. The occupation of the Golan Heights made

it impossible for the Arab states to divert the Jordan Headwaters. The 1967 cease-fire lines gave Israel control of half the length of the Yarmouk River compared to 10 km before the war. This made development of the Yarmouk contingent upon Israeli consent. Even small-scale unilateral impoundment by Jordan can easily be detected by Israel and attacked militarily.

The ability of Arab riparians to proceed with unilateral schemes decreased in proportion to Israel gains. When the war started, about 20 % of the Greater Yarmouk Project was completed. In the wake of the war, the two most important projects, the Mukheiba and Maqarin (renamed Al Wuheda in 1987) Dams, had to be abandoned. The Mukheiba Dam had been planned to store 200 $x10^6 m^3$ of water and the Maqarin Dam to store up to 350 $x10^6 m^3$ and manufacture 25,000 KWh of electricity annually.

When the Palestine Liberation Organization (PLO) emerged under new leadership after the 1967 War, it mounted an intensive campaign against Israeli settlements in the Jordan Valley. It included raids against water installations, such as that on the Nafaraim pumping station in the summer of 1969. The Israeli-PLO skirmishes soon deteriorated into Israeli conflict with Jordanian and Iraqi detachments stationed in the East Jordan Valley.

After unsuccessful military efforts to stop PLO activities, Israel raided the East Ghor Canal in 1969 and put most of the system out of commission. Israel conjectured that extensive damage to irrigation would pressure king Hussein to act against PLO. Conflict over the East Ghor Canal was mediated by the United States. After secret negotiations in 1969-1970, Jordan was allowed to repair the Canal; in exchange Jordan reaffirmed its adherence to Johnston plan quotas and pledged to terminate PLO activity in Jordan. King Hussein expelled the PLO from Jordan in 1970-1971.

SUPPLEMENT

Recommendations for the Future Joint Development and Management; Mediterranean-Dead Sea (MDS) Canal and Al-Wuheda Dam Projects

By the end of 1990s, Israel, Jordan and the West Bank or Palestine will have depleted virtually all of their renewable sources of fresh water if current patterns of consumption are not quickly and radically altered. In the circumstances, the Jordan river system, which includes the Al-Wuheda dam scheme on the Yarmouk river, unquestionably holds the greatest potential for either conflict or compromise.

The proposed co-generation system of coupling solar-hydro with hydro-powered reverse osmosis (RO) desalination on the Mediterranean-Dead Sea conduit scheme could produce 500 MW of electricity, and $100 \times 10^6 m^3$ per annum of fresh water. The generated power would be shared between Israel and Jordan to supply their peak demands, while the product of fresh water of $100 \times 10^6 m^3$ per annum would be used exclusively for the water supply in the central Ghor (Jordan Valley, in and around the Dead Sea) by Israel and Jordan.

The proposed integrated Jordan river development and management scheme will include following three key project elements, of which the gross project cost is preliminarily estimated to be US$ 4.5×10^9 as shown below;

1) MDS Canal with hydro-power plant	: US$ 2 $\times 10^9$
2) Hydro-powered reverse osmosis (RO) desalination	: US$ 0.5×10^9
3) Al-Wuheda dam and flood retention/recharge dams	: US$ 1 $\times 10^9$
1)-2)-3) Management, administration and O&M	: US$ 1 $\times 10^9$
Total	US$ 4.5×10^9

Recommendations

- It is suggested that the Mediterranean-Dead Sea (MDS) Canal scheme and the Al-Wuheda dam project be linked in an integrated Jordan river development master plan which would be make a beneficial economic development for the two states. The water cycle and benefits of coordinating water development, water potential energy, and politics, are with understood by all the parties concerned.

- It is suggested that the United Nations Relief and Works Agency for Palestine Refugees in the Near East (UNRWA), which once played an important role in developing the comprehensive Jordan river development plan ("Main Plan" and "Johnston Plan") in the beginning to mid 1950s, initiate the negotiations between Israel and Jordan, and organizes a new executive agency with an international funding program for the specific purpose of developing the Jordan river basin.

- It is suggested also that the Japanese government should play an catalytic role in the above with consolidated ideas, strategies, policy and plan, by providing a strategic fund of say two billion U.S.dollars to United Nations to cover the initial project costs. International co-operation agency with United Nations will be responsible to manage the project including administration, investigation and planning, design, construction, operation and management throughout the project life for 50 years.

Table A2.B1-1 Development Schemes for Jordan River System

Year	Plan	Sponsor
1913	Franhia Plan	Ottoman Empire
1922	Mavromatis Plan	Great Britain
1928	Henriques Report	Great Britain
1935	Palestine Land Development Co.,	World Zionist Organization
1939	Ionides Survey	TransJordan
1944	Lowdermilk Plan	U.S.A.
1946	Survey of Palestine	Anglo-American Committee of Inquiry
1948	Hays-Savage Plan	World Zionist Organization
1950	MacDonald Report	Jordan
1951	All Israel Plan	Israel
1952	Bunger Plan	Jordan/U.S.A.
1953	**Main Plan**	**UNRWA/UN**
1953	Israelli Seven-Year Plan	Israel
1954	Cotton Plan	Israel
1954	Arab Plan	Arab League Technical Committee
1955	Baker-Harza Plan	Jordan
1955	**Unified (Johnston) Plan**	**U.S.A.**
1956	Israeli Ten-Year Plan	Israel
1956	Israeli National Water Plan	Israel
1957	Great Yarmouk Poject	Jordan
1964	Jordan Headwaters Diversion	Arab League

Table A2.B1-2 Water-related Cease-fire Violations in Jordan River System from 1951 to 1967

Date	Incident	Immediate Issue	Underlying Issue	Resolution
Spring 1951	Shooting in DMZ, both sides invade, Israel expels Arab villagers from DMZ, Israel air-force bombs al-Himah	Arab resistance to Israeli land seizure, expulsion from DMZ	Huleh drainage in DMZ	Security Council orders return of Arabs, but villages had been razed
9/3/53'	Shooting in DMZ	Water diversion by Israel in DMZ	Sovereignty over DMZ	UN orders work halt, US threatens to end aid, Israel moves intake out of DMZ
12/12/55'	Israel's hit Arab villages northeast of Lake Tiberias, kill 50 (follows by two days firefight on lake)	Fishing rights	Israeli saboteurs captured (1954) inside Syria	Security Council condemns Israel, Syria says no to Johnston Plan, prisoners return two months later
1/31/62'	Israel destroys Lower Tawafiq in DMZ	Israeli drainage ditch in Arab village	Use of land	Syria complains to MAC, Israel boycotts
11/13/64'	Patrols, exchange of fire, bombing of Tell el-Qadi (source of Dan river)	Road building by Israel in disputed territory	Sovereignty over source of Dan river	Both parties complain to Security Council, Soviets veto
1/1/65'	Fatah hits pump station (first in series of attacks on Israel)	Israeli existence	Palestine self-determination	None
Spring 1965	Patrols, firing on Israel-Syria border	Road building by Syria in Golan Heights	Arab water diversion	None
7/14/66'	Israeli airforce bombs Syrian construction vehicles, air battle at Banias	Alleged Syrian provocation	Arab water diversion	Security Council
8/15/66'	Exchange of fire on Lake Tiberias	Patrolling, fishing	Land use in DMZ	Syrian note to Security Council
4/2/67'	Firefight in DMZ	Arab water diversion	Arab water diversion	None
4/7/67'	Israeli airforce bombs Golan, seen over Damascus	Arab water diversion	Arab water diversion	MAC reconvened, no action

Table A2.B3-1 Water Allocations to Riparians of Jordan River System

Unit : MCM($x10^6 m^3$) per annum

Plan/source	Lebanon	Syria	Jordan	Israel	Total	Remarks
Main Plan	nil	45	774	394	1,213	
Arab Plan	35	132	698	182	1,047	
Cotton Plan	450.7	30	575	1,290	2,345.7	includes Litani

Unified (Johnston) Plan

Hasbani	35				35	
Banias		20			20	
Jordan (main stream)		22	100	375*	497*	*residues
Yarmouk		90	377	25	492	
Side wadis			243		243	
Total	(35)	(132)	(720)	(400)*	(1,287)*	

* According to the compromise "Gardiner Formula" the share to Israel from the main stream of the Jordan was defined as the "residue" after the other co-riparians had received their shares. This would vary from year to year, but was expected to average 375 $x10^6 m^3$.

Table for Supplementary:

Water Allocations to Riparians of Jordan River System with Mediterranean-Dead Sea (MDS) Conduit Scheme

Unit : MCM($x10^6 m^3$) per annum

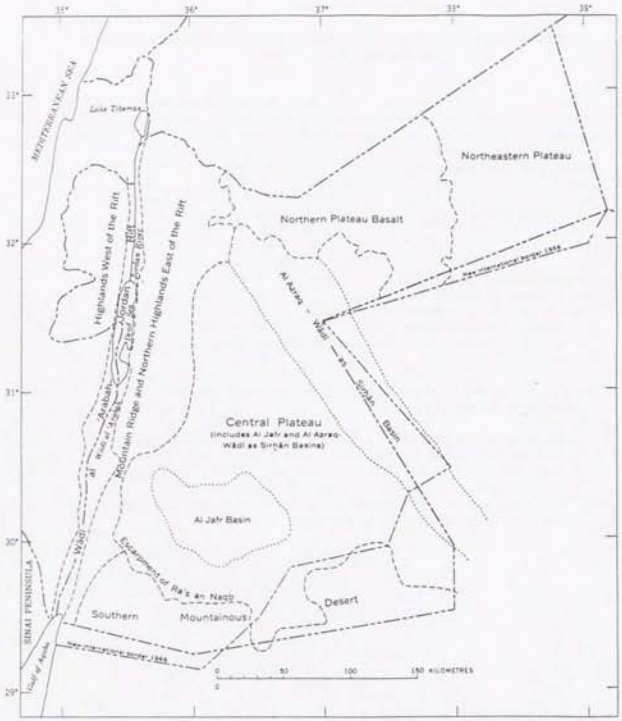
Sources	Lebanon	Syria	Jordan	Israel	Total
Unified (Johnston) Plan : 1955					
Hasbani	35				35
Banias		20			20
Jordan (main stream)		22	100	375*	497*
Yarmouk		90	377	25	492
Side wadis			243		243
Integrated Joint Plan : 1991					
MDS hydro-powered RO desalination			50	50	100
Side-wadi dams for groundwater recharge			50	50	100
MDS solar-hydro for peak-power (MW)			53**	427**	480**

Remarks:

Assuming the southern route (Gaza-Ein Bokek) which is the least-cost alternative in the MDS plan.

* ; According to the compromise "Gardiner Formula" the share to Israel from the main stream of the Jordan was defined as the "residue" after the other co-riparians had received their shares. This would vary from year to year, but was expected to average 375 $x10^6 m^3$.

** Installed capacity of hydro-power plant in MW, which may generate $1.26x10^9$ KWh per annum of peak-power electricity.



(Ref.4.1.1-1)(Source; F.Bender,1975)

Fig.A2A1-1
Physiographic-Geologic Provinces of Jordan

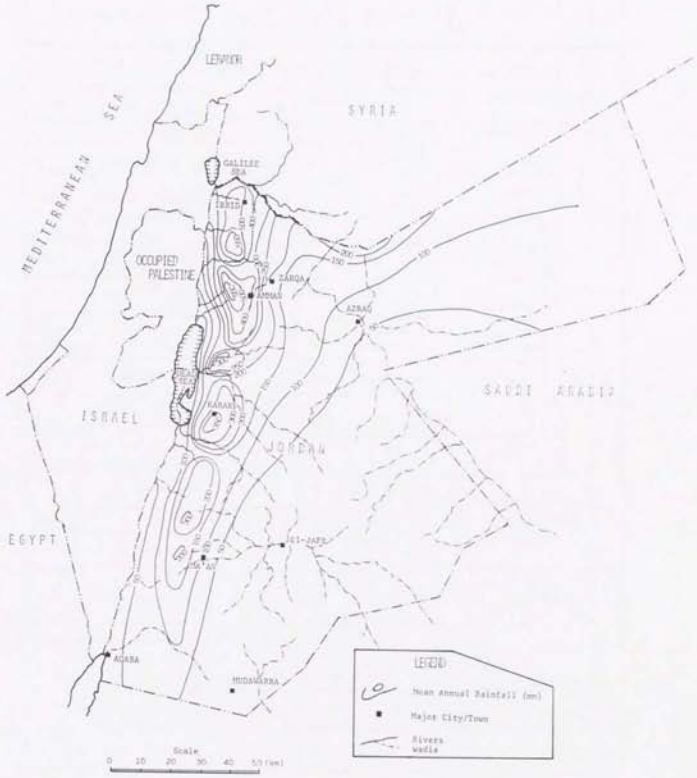


Fig.A2A1-2
Mean Annual Rainfall Map of Jordan

Era	Period	Epoch	Group	Formation	Thickness (m)	Aquifer Potential	Lithological Description
CENOZOIC	QUATERNARY	RECENT		Alluvium	0-300	Poor-Excellent	Gravel, sand, clay
		PLEISTOCENE		LISAN	0-300	Poor Good	Calcareous clay, gravels
				SAWRA		Poor	Calcareous reddish clay and gravels
	TERTIARY	PLIOCENE-MIOCENE		NEOGENE		Poor	Conglomerates
		OLIGOCENE		Volcanics (Basalt)	-100	Moderate-good	Basalt and conglomerates
		EOCENE					
		PALEOCENE		FALEJ RIJAM (B4)	-300	Moderate-excellent	Limestone, chert, marl, chalk, shale
MESOZOIC	CRETACEOUS	Upper: DANIAN-MAASTRICHTIAN	BELQA	RAKFUN	-190	Poor	
				MUNAQQAR (B3)	250	Poor	Chalky marl, bituminous marl, limestone, marls
		Upper: CAMPANIAN		AMMAN (B2)	100-150	Moderate-good	Limestone, silicified limestone chert, marl
		Upper: SANTONIAN-CONIACIAN		HUSEIFA (B1)	10-250	Poor	Chalk, marl, chert, limestone
		TURONIAN	AJLUN	WADI-SIR (A7)	70-200	Good	Limestone, sandstone, dolomite
		Middle: CENOMANIAN, Upper		SHEIB (A5/6)	70-150	Poor	Marl, limestone
		Middle: CENOMANIAN, Middle		HEMMAR (A4)	30-200	Good-excellent	Dolomite, limestone
		Middle: CENOMANIAN, Lower		FUHEIS (A3)	80-150	Poor	Marl, chalk, limestone
		Middle: CENOMANIAN, Lower		NAUR (A2)	-120	Good	Limestone, marl, chalk
				(A1)	-300	Excellent	Dolomitic limestone, marl
	LOWER			Upper: KUROR	-200	Poor	Fine sandstone,
				Lower	-110	Moderate-good	White coarse sandstone
	JURASSIC						
	TRIASSIC			Upper: ZARQA	-300	Good	Limestone, dolomite, sandstone
				Lower	-70	Poor	Shale, gypsum, marl
							Unconformity (Main)
PALEOZOIC	SILURIAN			KUSEIR	-400	Poor	Fine-grained sandstone, mudstone, shale
	ORDOVICIAN	(Upper)					
	ORDOVICIAN	(Middle)		DISI	-250	Good	Bedded brownish sandstone
		(Lower)			130-350		Massive whitish sandstone
	CAMBRIAN	(Lower)			190-350		Massive brownish sandstone
	CAMBRIAN	(Lower)		UM ISHRIN	50-60	Moderate	Bedded arkosic sandstone
PRECAMBRIAN				AQABA	-	Poor	Granite, diabase

(Source: John W.Harshbarger, 1966)

Fig.A2A1-3
General Hydrogeological Section of Jordan

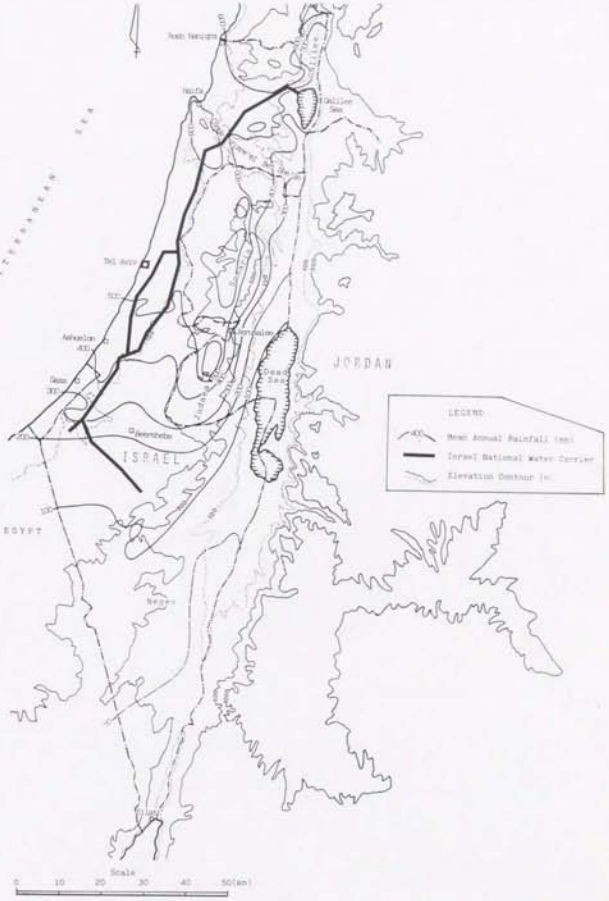
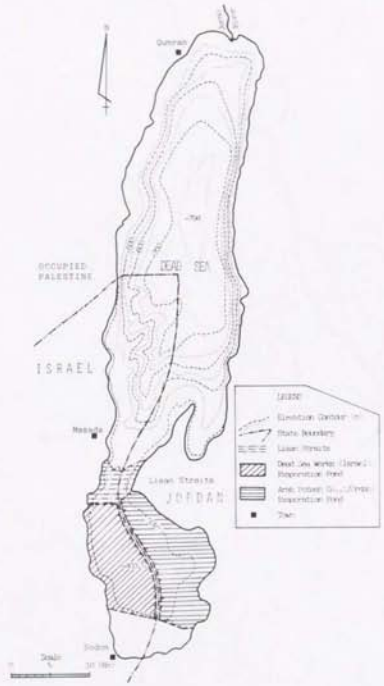


Fig.A2A2-1
Israel and Jordan Rift Valley



Ref.
Dan Weiner and Arie Ben-Zvi, 1982, "A Stochastic Dynamic Programming model for the Operation of the Mediterranean-Dead-Sea Project, Water Resources Research, Vol.18, No.4, pp.729-734.

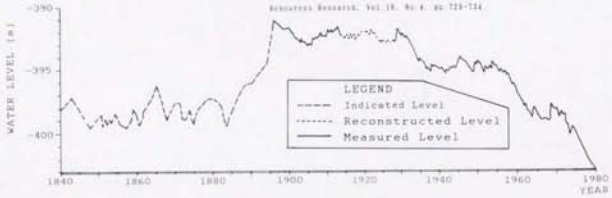
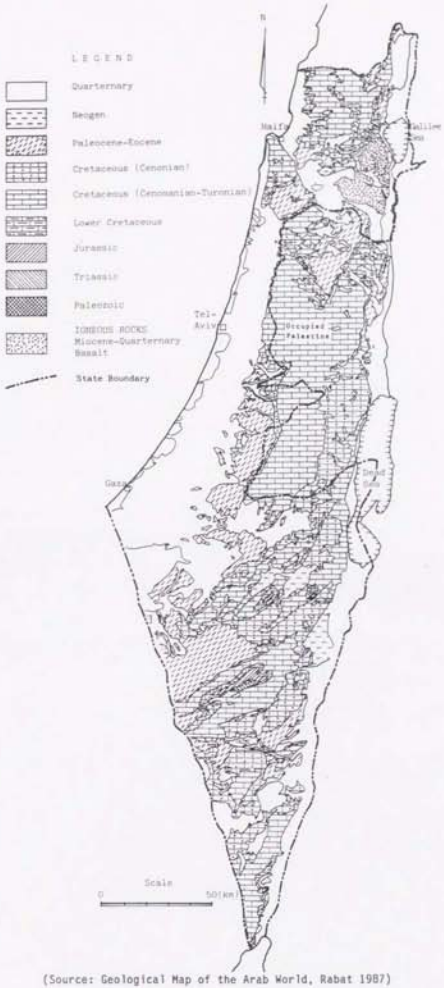


Fig.A2A2-2

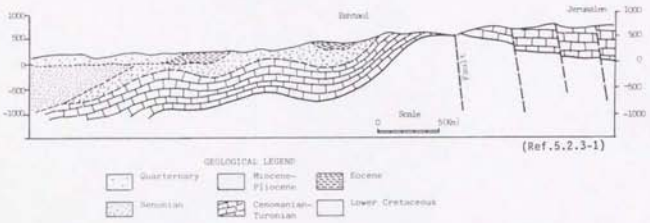
Dead Sea and Water Level change



(Source: Geological Map of the Arab World, Rabat 1987)

Fig.A2A2-3

Geological Map of Israel/Palestine



(Ref.5.2.3-1)

Fig.A2A2-4
Typical Hydrogeological Profile of the Central Israel

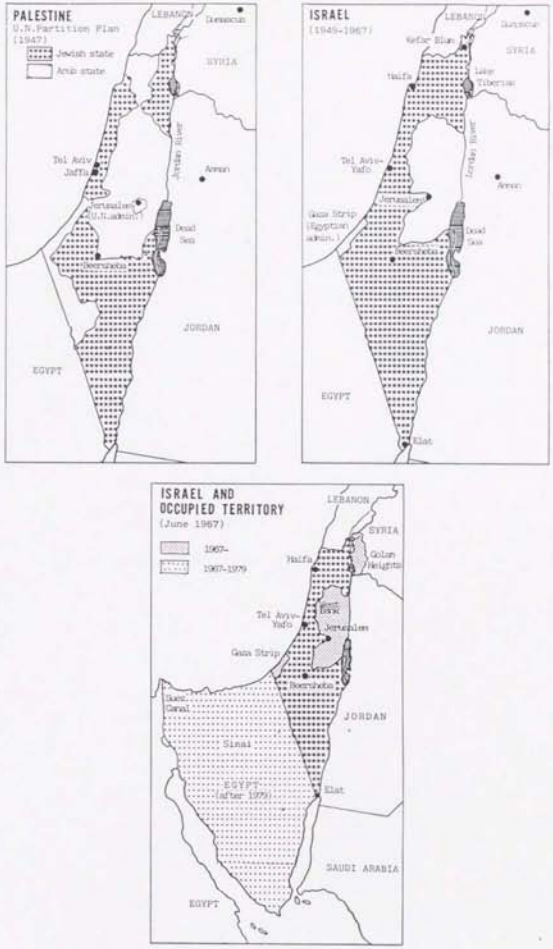


Fig.A2A2-5
Israel and Occupied Palestine