JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

MINISTRY OF WATER AND IRRIGATION
THE HASHEMITE KINGDOM OF JORDAN

THE STUDY ON
BRACKISH GROUNDWATER DESALINATION
IN
JORDAN

FINAL REPORT
MAIN REPORT

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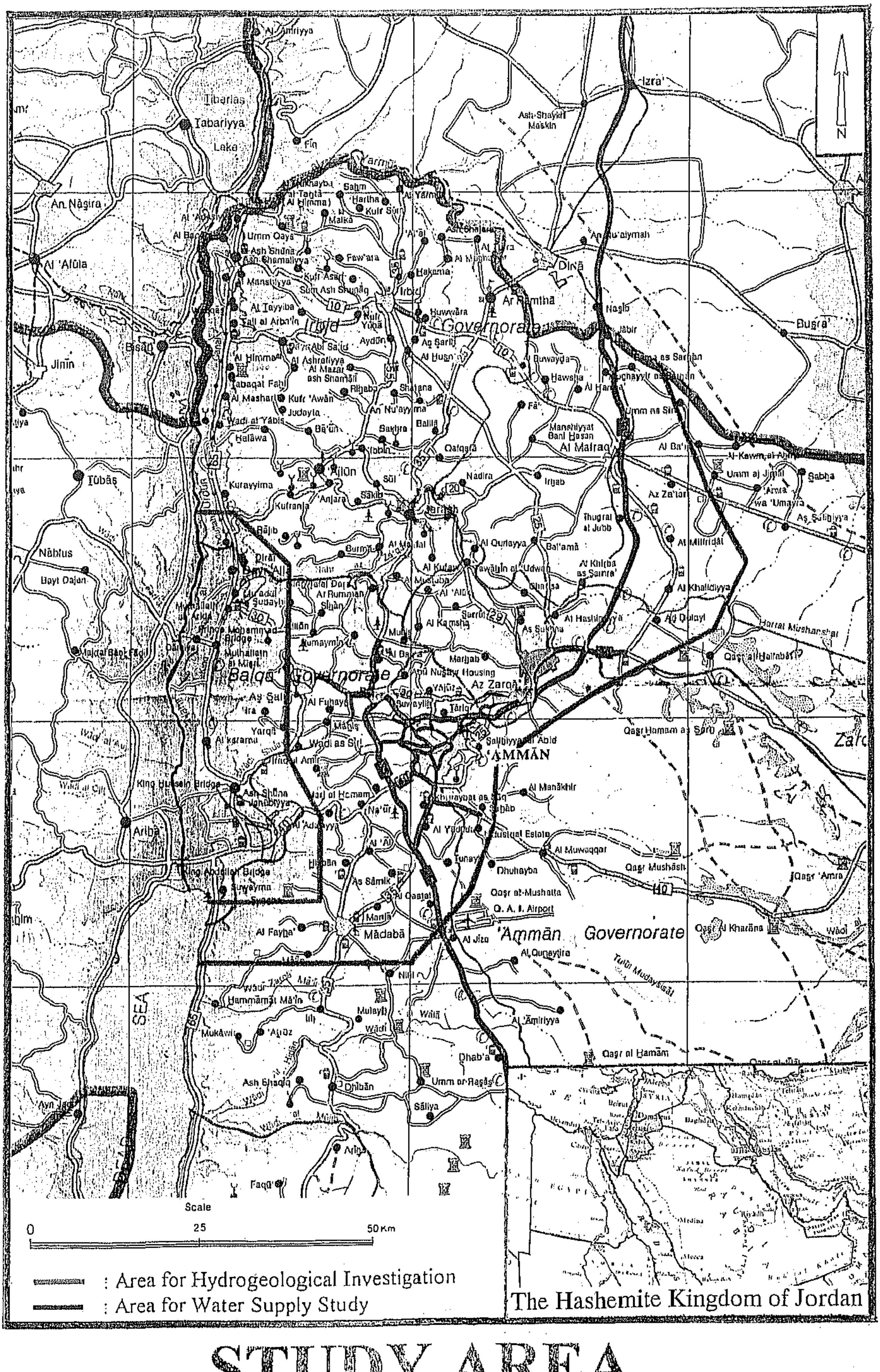
FINAL REPORT
MAIN REPORT

August 1995

Yachiyo Engineering Co., Ltd.
Mitsui Mineral Development Engineering Co., Ltd.
Tokyo Japan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: Area for Hydrogeological Investigation
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The Hashemite Kingdom of Jordan
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Irbid Governorate
Balqa' Governorate
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'AMMĀN
Az Zarqā
Al Mafraq
Ar Ramtha
Irbid
'Ajlūn
Jarash
As Salt
Mādabā
Q. A. I. Airport
Tiberias Lake
Tabariyya
An Nāsira
Al 'Afūla
Bisān
Jinīn
Ţūbās
Nāblus
Arīḩā
King Hussein Bridge
King Abdallah Bridge
Prince Mohammad Bridge
Hammāmāt Mā'īn
Dhībān
Umm ar Raşāş
Buşra
Dirā
Izra'
SEA

STUDY AREA

Final Report consists of the following three reports and one file of data and drawings.

- SUMMARY
- MAIN REPORT
- SUPPORTING REPORT
- DATA AND DRAWINGS

This is the Main Report of the Final Report.

PREFACE

In response to a request from the Government of the Hashemite Kingdom of Jordan, the Government of Japan decided to conduct a study on Brackish Groundwater Desalination in Jordan and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent to Jordan a study team headed by Mr. Ryosuke Teranishi, Yachiyo Engineering Co., Ltd., and composed of staff members of Yachiyo Engineering Co., Ltd. and Mitsui Mineral Development Engineering Co., Ltd., 3 times between April, 1994 and June, 1995.

The team held discussions with the officials concerned of the Government of Jordan, and conducted field surveys at the study area. After the team returned to Japan, further studies were made and the present report was prepared.

I hope that this report will contribute to the promotion of the project and to the enhancement of friendly relations between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of the Hashemite Kingdom of Jordan for their close cooperation extended to the team.

August, 1995

Kimio Fujita
President
Japan International Cooperation Agency

August 1995

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

Dear Mr. Fujita,

Letter of Transmittal

We are pleased to submit to you the report on the Brackish Groundwater Desalination Study in Jordan. The report contains the advice and suggestions of your Agency as well as the formulation of the above mentioned project. Also included are comments made by the Ministry of Water and Irrigation of Government of the Hashemite Kingdom of Jordan during technical discussions on the draft report which were held in Amman.

This report presents a strategy for the brackish groundwater development of 75 MCM/year by desalination which, in view of the great scarcity of water in the region, will provide a much needed new water resource. Development cost by desalination is higher than that by conventional methods but is still acceptable to the water supply sector.

In view of the urgency of water resource development in the northern part of Jordan and of the need for socio-economic development of Jordan as a whole, we recommend that the government of the Hashemite Kingdom of Jordan implement this project as a top priority.

We wish to take this opportunity to express our sincere gratitude to your Agency and the Ministry of Foreign Affairs. We also wish to express our deep gratitude to the Ministry of Water and Irrigation and other authorities concerned, of the government of the Hashemite Kingdom of Jordan, for the close cooperation and assistance extended to us during our investigation and study.

Very truly yours,

寺西良輔

Ryosuke Teranishi
Team Leader
Study on Brackish Groundwater Desalination
in Jordan

August 1995

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

Study on Brackish Groundwater Desalination in Jordan (Formulation of Strategy)

Study Period: March, 1994 - August, 1995
Executing Agency: Ministry of Water and Irrigation

1. Background

The annual population growth rate of the Hashemite Kingdom of Jordan was as high as 3% in the 1990s. The amount of water consumption has been increasing in accordance with not only population growth but also improvement of living standard. In order to meet the envisaged high future water demands, a plan of new water resources development needs to be formulated immediately. Water supply in Jordan mainly relies upon groundwater and fresh groundwater resources have already been developed on the margin of their exploitable potential. On the other hand, in the Jordan Valley and some other areas, large quantities of brackish goundwater resources have been found but have not been developed yet. A study on the applicability of these unconventional water resources for domestic use through desalination processing has thus been requested.

2. Objectives

The objectives of the study are to evaluate the potential and quality of the brackish goundwater resource in the Jordan Valley and to formulate a brackish groundwater resource development strategy for water supply to the northern part of Jordan toward a target year of 2010.

3. Study Area

The Study Area for the evaluation of the brackish groundwater potential covers the Jordan Valley including the Hisban and Kafrein area and the Karameh and Abu Zeigan area, and the Study Area for water supply covers the northern part of Jordan including the Jordan Valley and Amman City (see page iii Fig. 1).

4. Outline of the Strategy

4.1 Basic Policy

Potential of the Brackish Groundwater

As a result of hydrogeological investigation including geological reconnaissance, test well drilling and hydrogeological analysis, the potential and quality of the brackish groundwater in the Study Area have been understood. Two development sites have been identified where brackish groundwater desalination is thought to be feasible due to the high development potential and moderate quality.

6.2 Environmental Evaluation

Environmental issues related to the proposed projects are relatively simple. The results of initial environmental examination have shown that only a few environmental items will be involved during the implementation of the brackish groundwater desalination projects and negative impacts will not be severe. The environmental items where impacts are anticipated and counter measures have to be taken are listed below.

Table - 3 Items of Environmental Evaluation

Item	Evaluation	Counter Measures
Groundwater	B	Control of the draw-down of the upper shallow aquifer
Groundwater Pollution	B	Proper drainage of the concentrated brine
Soil Pollution	B	Proper drainage of the concentrated brine
Archaeological Treasures	C	The ruins from the Roman Era, may exist, and archaeological survey will be required before project construction.

B: A certain impact is anticipated. C: Unknown

7. Recommendations

Based upon the results of project evaluation, the following steps are recommended as collateral conditions for the implementation of the proposed projects.

1) Establishment of an organization for the study of the desalination technology and its application.
2) Long term hydrogeological observation of water level and quality of the Zarqa Group Aquifer.
3) Construction of a common drainage line for saline waste from agriculture return and concentrated brine from desalination facilities.
4) Modification of the water resource development strategy according to the progress of the regional peace process.
5) Further study on brackish groundwater resources.

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Acronyms

JICA	Japan International Co-operation Agency
MOWI	Ministry of Water and Irrigation
JVA	Jordan Valley Authority
WAJ	Water Authority of Jordan
MOP	Ministry of Planning
MSL	Mediterranean Sea Level
WHO	World Health Organization
RO	Reverse Osmosis
ED	Electrodyalisis
MSF	Multi Stage Flash
JD	Jordan Dinar
EIA	Environmental Impact Assessment
IEE	Initial Environmental Examination
EEM	Environmental Examination Matrix
BP	Before Present

Units

sq.km	Square kilometers
Dunums	1 dunum = 1000 square metres, or 10 dunums = 1 ha
MCM	Million cubic meters - also MCM/month, MCM/year, MCM/km/year, MCM/year/sq.km
L/sec	Litres per second
cu.m/sec	Cubic metres per second
m^3/sec	Cubic metres per second
L/min	Litres per minute
m/day	Metres per day
m^2/day	Square metres per day
/day	Per day
m^3/day/m^2	Cubic metres per day per square metre
Kw	Kilowatt
Kwh	Kilowatt hour
mg/L	Miligram per litre
meq/L	Mili-equivalent per litre

INTRUDUCTION

INTRODUCTION

1. Background of the Study

The annual population growth rate of the Hashemite Kingdom of Jordan (hereinafter referred to as "Jordan") was as high as 3.2% between 1992 and 1993. The water consumption amount is definitely supposed to increase in accordance with not only population growth but also improvement of living standard. Therefore a new water resources development plan to meet the future high water demands needs to be formulated immediately. The total water demand of domestic and industrial sector (excluding irrigation sector) reached 319MCM in 1992. However, the actual water supply amount in 1992 was 208MCM/year and this figure fell significantly below the water demand mentioned above.

Water supply in Jordan mainly relies upon groundwater resources and 55% of the total water supply amount is supplied by shallow groundwater aquifers. With the increase of water demands, abstractions of groundwater at an amount far over the exploitable capacities of these aquifers became a serious problem in many areas. Under a condition that no other fresh water resource is available, water supply by developing some unconventional water resources such as brackish groundwater aquifer becomes necessary. In the Jordan Valley and some other areas, large quantities of brackish groundwater resources have been found, but not been developed yet. A study on the applicability of these water resources for domestic use through desalination processing has thus been requested.

In the light of the activities of the Multilateral Peace Talks/Water Group, and upon the request of the Government of Jordan, the Government of Japan decided to implement the Study on Brackish Groundwater Desalination in Jordan (hereinafter referred to as "the Study") in accordance with the Agreement on Technical Cooperation between the Government of Jordan and the Government of Japan signed on July 16, 1985.

Accordingly, the Japan International Cooperation Agency (hereinafter referred to as "JICA"), the official agency responsible for the implementation of the technical cooperation programs of the Government of Japan, undertook the Study based on the Scope of Work signed on October 21st, 1993, in close cooperation with the relevant authorities of the Government of Jordan. And as stipulated in the Scope of Work, the Study was commenced in March 1994, by mobilizing JICA Study Team.

The Ministry of Water and Irrigation (hereinafter referred to as "MOWI") has acted as the counterpart agency to the JICA Study Team and also as a coordinating body in relation to other governmental and nongovernmental organizations concerned to ensure smooth implementation of the Study.

2. Objectives of the Study

The objectives of the study have been:

1) to evaluate the potential and quality of brackish groundwater resource,
2) to formulate a brackish groundwater resource development strategy including selection of possible sites, types and size of any operative/pilot desalination plant, and set priorities for candidate sites.

3. Study Area

The Study Area for the evaluation of the brackish groundwater potential has covered the Jordan Valley including the Hisban and Kafrein area and the Karameh and Abu Zeigan area, and the Study Area for water supply has covered the northern part of Jordan including the Jordan Valley and Amman City as shown in Fig. I-1.1.

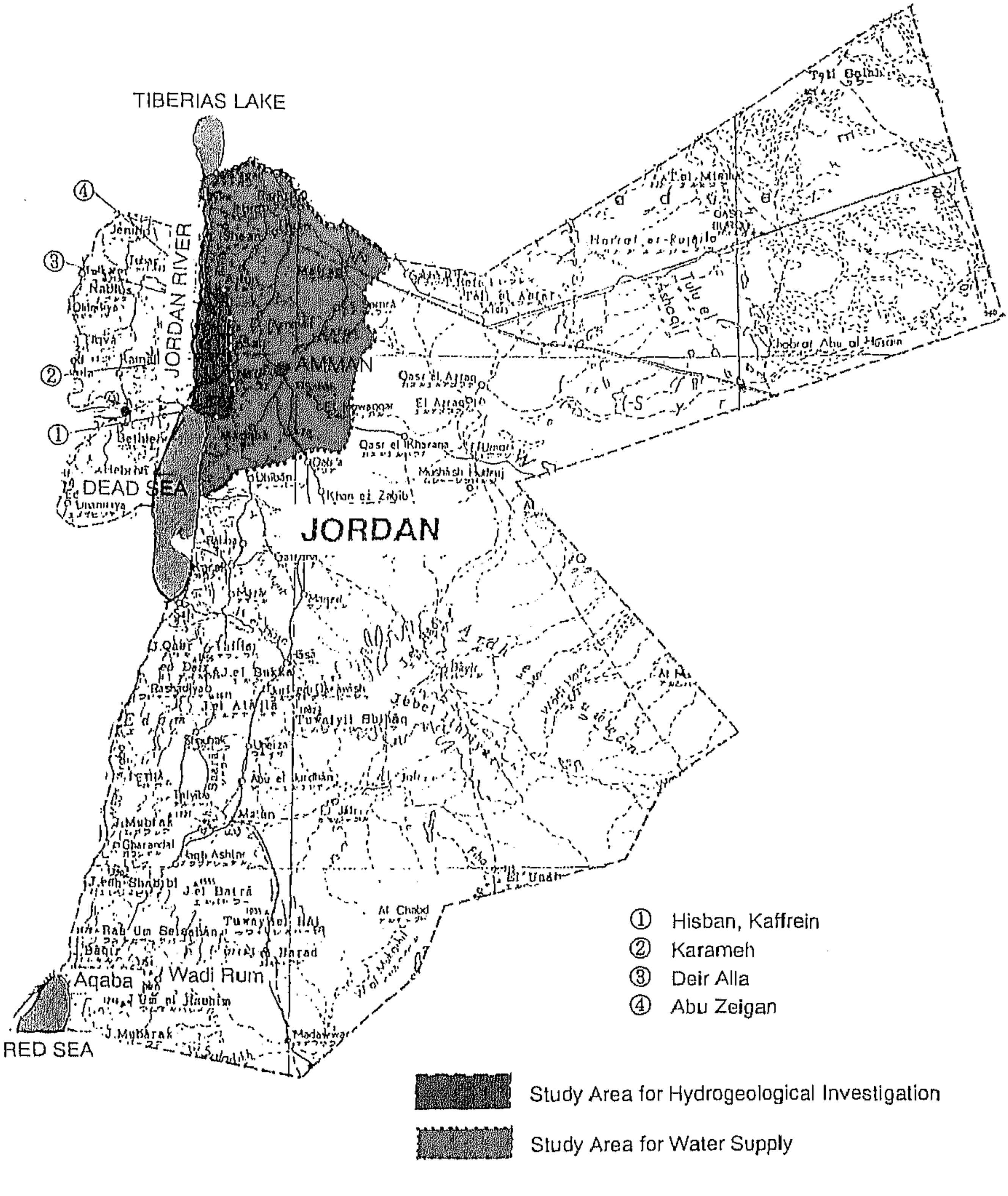


Fig-1 Location Map of the Study Area

4. Progress of the Study

4.1 Outline of the Study

The Study was divided into three phases, in accordance with the Scope of Work concluded between the Government of Jordan and JICA. The outline of the Study of each phase is described below.

(1) Phase I : Basic Study

The main contents and targets of the Phase I study are as follows;

1) Collection and review of existing data relevant to the Study
2) Formulation of the detailed work schedule of the Study in order to supplement the existing data
3) Reaching the consensus between the Government of Jordan and JICA concerning the Concept of the Study, including study methodology, frame work of the water demand projection, target of the brackish groundwater resource development strategy and so on

(2) Phase II : Evaluation of the potential and quality of brackish groundwater resource

The main contents and targets of the Phase II study are as follows;

1) Implementation of the investigations based on the work schedule formulated in Phase I study
2) Evaluation of the brackish groundwater resource potential and brackish groundwater quality including changes in water quality likely to be caused by brackish groundwater development

(3) Phase III : Brackish groundwater resource development strategy

The main contents and targets of the Phase III study are as follows;

1) Determination of target treated water quality
2) Examination of desalination technology
3) Formulation of alternatives
4) Selection of alternatives and formulation of brackish groundwater development strategy

4.2 Study Organization

For the implementation of the Study, JICA organized a study team consisting of the following experts and Jordanian Government organized a counterpart team consisting of the following members.

JICA Study Team

Mr. Ryosuke Tarnish	Team-Leader
Mr. Yosuke Sasaki	Hydrogeologist
Mr. Yoshihiro Tsuchiya	Geologist
Dr. Wang Xiaochang	Water Quality/Environmental Expert
Mr. Noboru Saeki	Water Supply Engineer
Mr. Masatoshi Yao	Desalination Expert
Dr. Masakazu Iwabuchi	Project Economist
Mr. Colin P. Fiddian	Hydrologist
Mr. Kazuhiko Kinoshita	Geophysicist
Mr. Takashi Suzuki	Drilling Expert
Mr. Makoto Honma	Simulation Expert

MOWI/WAJ/JVA Counterparts

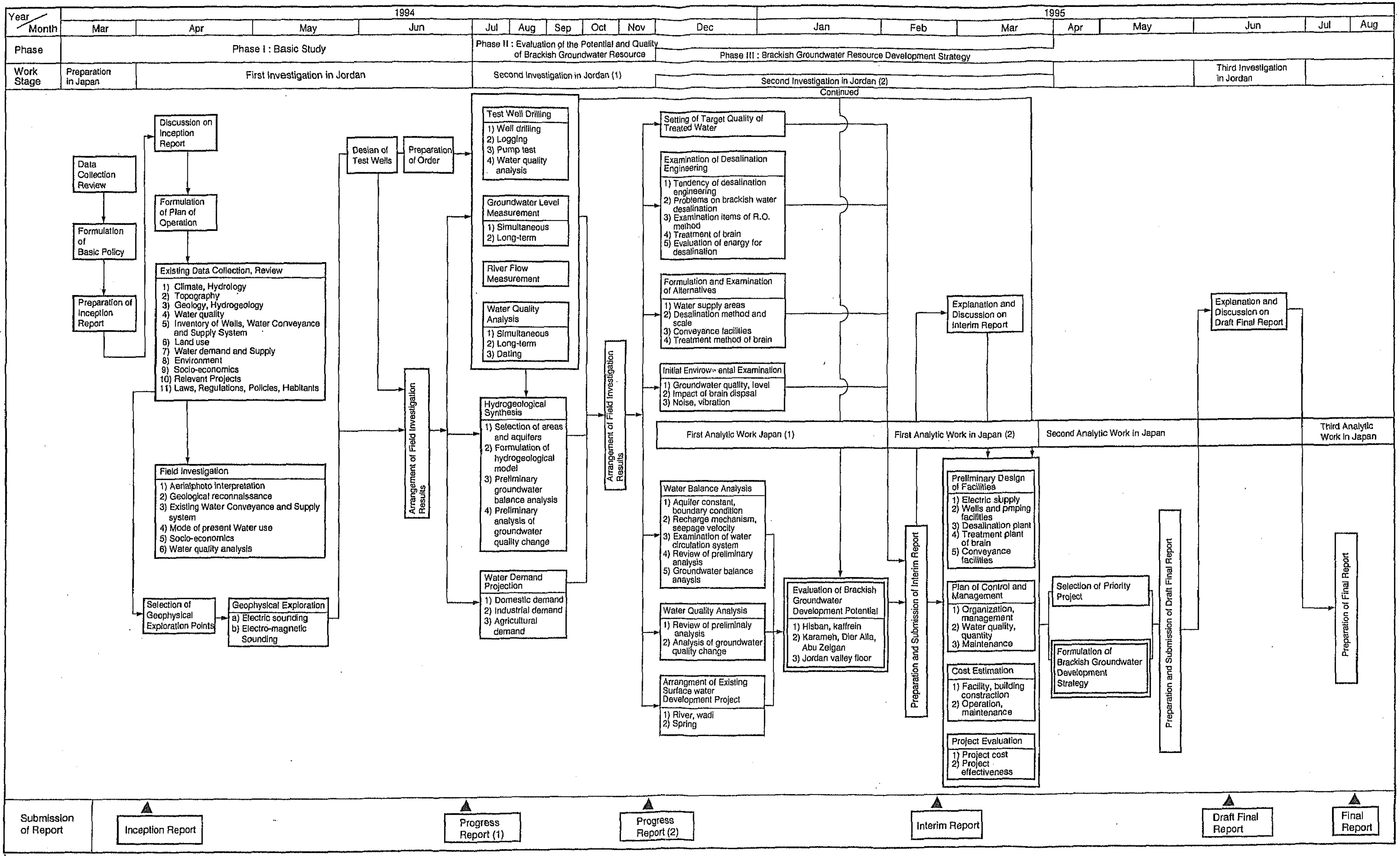
Key personnel

H.E. Dr. Mohammad Bani Hari	Secretary General, MOWI
Eng. Fawzi N. Abu-Niaaj	Coordinator, MOWI
Eng. Hamid Abu-Obeid	WAJ/MOWI
Dr. Samir Hijazin	WAJ/MOWI
Mr. Ghassan Mouasher	JVA/MOWI

Counterparts

Mr. Anwar Naim	WAJ/MOWI
Mr. Hisham Bashir	MOWI
Eng. Mohamed Edaily	MOWI
Eng. Benitta Sa'ad	MOP
Eng. Ayman Ismail	MOP

Fig- 2 Work Flow of the Study



4.3 Progress of the Study

All the activities scheduled in the Study were completed and the progress is shown by using the Study Flow Chart (Fig. II-1.2). During the all investigations in Jordan, the Study was carried out with the full cooperation of the Jordanian counterparts.

(1) Phase I : Basic Study

The Preparatory Work in Japan was commenced in March 1994. First Investigation in Jordan of Phase I Study was started in April 1994 and finished in June 1994.

(2) Phase II : Evaluation of the potential and quality of brackish groundwater resource

The Second Investigation in Jordan of Phase II Study was started in July 1994 and finished in February 1995. The long term observation of test wells and water quality analysis were completed at the end of March 1995.

(3) Phase III : Brackish groundwater resource development strategy

Based on the potential, the development areas, the quality of the brackish groundwater and the future water demand analyzed in the Phase II Study, the Phase III Study was started in December 1994 with an examination of desalination technology to be applied for the anticipated raw water quality and circumstances.

Alternative plans for brackish groundwater development were formulated for the examination of the various aspects of the strategy and were shown in the Interim Report in March 1995.

The priority project was identified from these alternatives through project evaluation, and then the development strategy was established in the Draft Final Report in June 1995.

5. Study Results

5.1 Potential and Quality of the Brackish Groundwater

(1) Hydrogeological Analysis

The hydrogeological analysis was conducted based on existing data and newly obtained data from the geological investigation and test well drilling. A hydrogeological model was established which provided the basis for the groundwater simulation.

The estimated hydrogeological structure consists of three layers: the Zarqa group aquifer in the lower layer and the Kurnob Sandstone aquifer in the top layer with an aquitard

(Marly layer) between them. There is a certain hydraulic interrelation between the two aquifers which has been considered in the hydrogeological model.

The thickness of the Zarqa group aquifer is around 600 meters in the Northern part of the study area (Deir Alla area) and around half that in the Southern part (Hisban/Kafrein area). The transmissibility of the Zarqa group aquifer varies widely area to area with a range of 50 m^2/day to more than 1,000 m^2/day. The average piezometric gradient of the Zarqa group aquifer is about 3 % and the brackish groundwater flows from East to West (from the Highlands to the Jordan River). There are two significant piezometric concavities in the Zarqa group aquifer along the Zarqa River and in the Kafrein area. Both are perpendicular to the Jordan Valley. The concavity along the Zarqa River is assumed to be formed by the groundwater discharging to the Zarqa River. The concavity in the Kafrein area is thought to be caused by highly permeable zones such as fractured zones formed along the syncline running in parallel with Wadi Kafrein.

(2) Test well drilling

Six test wells were drilled in the study area by the total depth of 1,700 meter and short-long term pumping tests and water quality analysis were conducted.

(3) Hydrology

The hydrological water balance in the study area was calculated utilizing existing flow data including flow measurement records of the Jordan River and newly obtained data from flow measurements of the Zarqa River and main wadis in the dry and wet seasons.

(4) Water quality survey

Water quality survey included water sampling and water quality analyses for the existing wells, springs and wadis in winter and summer seasons, and water quality analyses for the 6 test wells regarding the water quality items related to hydrochemical study and desalination engineering. As a result of the water quality survey, the salinity of the brackish groundwater in the study area was estimated as:

Deir Alla area:	7,500 mg/L
Kafrein area:	5,000 mg/L

(5) Evaluation of the brackish groundwater potential

A simulation model was established based on the hydrogeological analysis. The reappearance simulation of the present piezometric surface was conducted in this model using the results of the water balance calculation. Through this reappearance simulation, the basic flow of the brackish groundwater in the study area was estimated at about 120 MCM/year.

In the course of the reappearance simulation, it was found that the most promising areas for brackish groundwater development are Deir Alla (Area A) and Kafrein (Area C) in terms of both the volume of flow and the quality of brackish groundwater in the Zarqa Group aquifer. The total flow volume in Areas A and C was estimated to be 110 MCM/year.

The simulation of future abstraction was carried out in these two areas for four cases for a staged development. According to the simulation, brackish groundwater potential in the study area is estimated at about 75 MCM/year, is corresponding to 70% of the total volume of flow in the two areas. The maximum exploitable volume and maximum drawdown of the water table from ground surface are therefore estimated to be as follows:

Area	Brackish Groundwater Potential (MCM/year)	Maximum Drawdown from Ground Surface (m)
Deir Alla (Area A)	30	60
Kafrein/Hisban (Area C)	45	80
Total	75	---

Judging from the flow vector and volume of fresh water leakage from the upper Kurnob Sandstone aquifer derived from the future simulation of the brackish groundwater, it is inferred that the development will not cause a significant change in the quality of the brackish groundwater.

5.2 Strategy of the Brackish Groundwater Development

(1) Situation of Water Supply and Water Demand in the Study Area

Five governorates in the study area, i.e. Amman, Zarqa, Irbid, Mafraq and Balqa are connected with a water transfer network and are supplying domestic water of about 190 MCM/year for 3,920,000 people. Based on the population growth and economic development of the country, the water demand up to 2010, the target year of the strategy, has been projected in the two areas "the Northern part of Jordan including Amman" and "the Jordan Valley" and in the three categories of domestic, industrial and irrigation water.

The difference between demand in 2010 and existing production capacity is quite large at about 400 MCM/year for the whole study area.

(2) Examination of Desalination technology

Taking the water quality of the brackish groundwater into consideration, evaporation (MSF or ME), electrodialysis (ED or EDR) and reverse osmosis (RO) processes were examined for the application. Principles of the process, energy consumption, installation cost and operation and maintenance have been considered.

Because of the difference in energy consumption efficiency of the MSF, ED and RO processes, construction records around the world show that ED (or EDR) process is mostly applied to desalination of brackish water with TDS less than 3000 mg/L. In the study area, the TDS is about 7500 mg/L in the North, and about 5000 mg/L in the South. Therefore, RO is considered to be the most suitable process to be applied for the brackish water from the Zarqa aquifer.

(3) Formulation of Alternative Plans

The study methodology that has been applied to formulate a comprehensive strategy for developing the brackish groundwater, was to select alternative development plans, each of which had a clear frame work. Each alternative was examined technically, institutionally, economically and financially. As a result, the following five (5) alternative plans combining these components have been formulated:

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

(4) Initial Environmental Examination

Initial environmental examination for these alternative plans was conducted in accordance with JICA Environmental Guidelines. All the environmental elements were screened by an environmental examination matrix with reference to all the project activities involved. The selected environmental elements were then examined in detail. The main environmental problems associated with long term development of brackish groundwater in the study area are drawdown of the groundwater table, variation in groundwater quality, and water and soil pollution caused by brine disposal. The impact of these problems was discussed and counter measures to be taken were proposed.

(5) Project Evaluation

1) Supply Area

Water supply areas for the development are upland including Amman and other four northern governorates and lowland in the Jordan Valley. These five governorates are the social and economic centers of Jordan and the importance to secure water sources is obvious. On the other hand, the economic potential of the Jordan Valley has been under utilized for several decades because of hostilities. However it has traditionally been a natural north-south transport corridor and has a significant growth potential after the regional peace. Further development of transportation, mineral resources, tourism, high value agriculture and fish farming is planned and good quality water is clearly the most critical resource in this area.

2) Water Cost

Approximate water supply cost per unit volume for the five alternative development plans, covering the costs of raw brackish groundwater abstraction, desalination, brine discharge and pumping conveyance of the product water to the supply areas, are as listed below. These figures are naturally higher than the average cost (0.35 JD/m3) of the present production and supply in the water supply sector and therefore create more financial difficulty. However, expected water costs in the ongoing water resource development plans are almost the same as these figures and therefore they are within the acceptable range.

Alternative Plan	Development Area	Volume of Development MCM/year	Water Cost JD/m^3	Supply Area
Plan - A	Deir Alla	30	0.55	Amman
Plan - B	Deir Alla	6	0.55	Jordan Valley
Plan - C	Kafrein	45	0.60	Amman
Plan - D	Kafrein	6	0.52	Jordan Valley
Plan - E	Deir Alla/Kafrein	75	0.58	JV/Amman

3) Contents of the Project

From the view point of the desalination engineering, the proposed desalination plant needs a significant pretreatment system due to the quality of the raw brackish groundwater. Compared with the simple sea water desalination system, operation pressure of this plant is low but more chemicals and filters are necessary.

Present water supply in the Jordan Valley is basically served by scattered wells over the valley and there is no trunk pipe line system connecting the cities. To utilize the major source development, a North-South trunk line of 300 mm (12 inches) diameter is included.

4) Financial Analysis

Development of the 6 MCM/year of the brackish groundwater desalination at the Kafrein area is judged financially sound due to the relatively low water cost and the small scale development. For the other full scale development plans financial constraints are significant. However, water shortage is also critical and therefore implementation of projects will be commenced at minimum cost basis when the financial situation allows.

(6) Priority Project

For the reasons of the relatively low water cost, scarcity of the new water source and the water demand with high development potential in the region, 6 MCM/year of brackish groundwater desalination at the Kafrein area was selected as the first priority project.

Preliminary design of the priority project was prepared for the production wells, desalination facility, and water transfer line. Since there is a considerable amount of fouling substances in the raw water, such as Ca, Mg, Fe, Mn and HCO_3, a sophisticated pre-treatment system is required for removal or control of these substances before water is fed to the RO membrane unit. For this reason, the proposed desalination plant has chemical conditioning, filtering and adsorption treatment facilities, which result in a system much more complicated than that used in common practices for brackish groundwater desalination. From a view point of water quality and treatment technology, the brackish groundwater in the study area seems not to be an ideal water resource for water supply by desalination.

(7) Development Strategy

Purpose: Desalinated water shall be provided for domestic and industrial use but not for agriculture.

Supply areas: Jordan valley and Amman City which will consequently alleviate the shortage of the other four governorates.

Strategy: 6 MCM/year desalination at the Hisban/Kafrein area providing product water to Jordan Valley shall be given the first priority of the brackish groundwater development.

39 MCM/year desalination at the Hisban/Kafrein area providing product water to Amman City by high lift pumping shall be carefully studied with the comparison of the Disi fossil water development scheme in the southern Jordan. This project could be allocated after the Disi project.

Methods for 16 MCM/year desalination at the Deir Alla area providing product water to Jordan Valley should be considered to satisfy the demand after 1998. Individual disposal of concentrated brine would have economical difficulty. Therefore, the so called "Common Brine Discharge Line" for the Jordan River Valley, including Lake Tiberias north of the Dead Sea, should be organized so that brine from saline springs, irrigation returns and drains and desalination plants will be accommodated and disposed of safely at the Dead Sea.

Desalination utilizing the remaining potential at the Deir Alla area can be developed to provide product water to Amman City provided that the above "Common Brine Discharge Line" is resolved, and that allocation and conveyance methods of water promised in the Peace Treaty are finalized.

PART I

Potential and Quality of the Brackish Groundwater Resource

Part I <u>Potential and Quality of the Brackish Groundwater Resource</u>

1. Geomorphology and Geology of the Study Area

1.1 Geomorphology

The Study area for Hydrogeological investigation covers about 700 Km^2 and is located along the Jordan valley from the North of the Dead Sea to Kureiyima.

The Study area consists of four different distinctive topographic zones trending in a general north-south direction.

These zones were formed by a major tectonic event which is rifting along the Jordan Valley - Dead Sea - Wadi Araba - Red Sea line, which, during the last few tens of millions of years, has led to the formation of the rift valley along the same line.

These zones are as follows and as shown in Fig. I-1.1.1.

1. Highlands	(above 800 meters).
2. Escarpment	(0~800 meters).
3. Foot hills	(-200~0 meters).
4. Rift valley	(-400 ~ -200 meters).

(1) Highlands

The highlands form the Eastern-central part of the Study area around Salt city. The elevation of this zone varies from about 800 to 1,000 meters with a gradient of 0 to 10 degrees. The Upper Cretaceous formation is mainly exposed in this zone.

(2) Escarpment

The escarpment covers a wide area on the East slope of the Jordan Valley with an elevation of about Sea Level to +800 meters. Slopes in this zone are about 10~35 degrees. Triassic, Jurassic and Cretaceous formations are distributed in this zone.

(3) Foot hills

The foot hills are at the feet of the mountains which form the escarpment. The elevation of this zone varies from about -200 meters to Sea level with a slope of about 3 to 10 degrees.

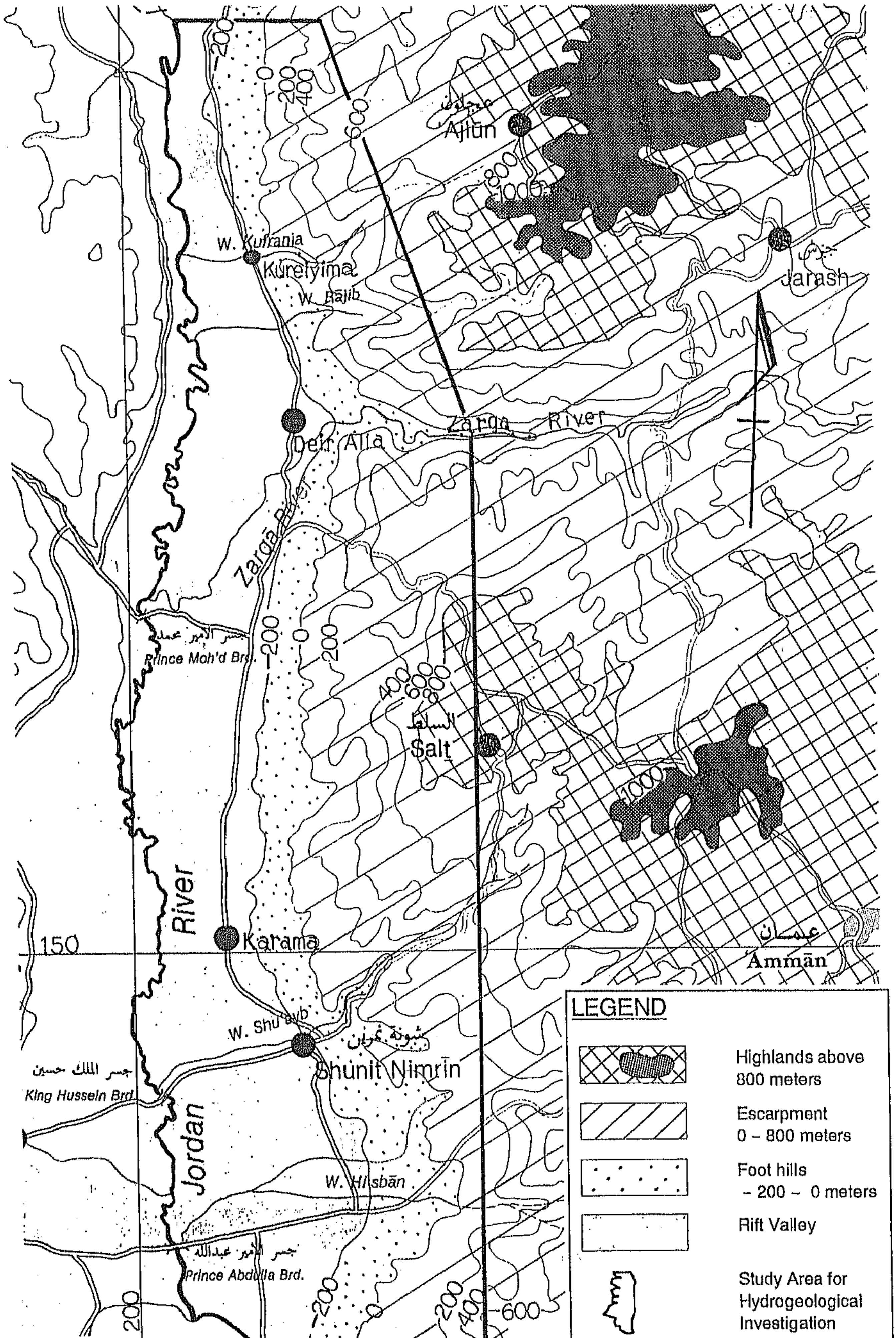


Fig. I-1.1.1 Topographical Classification Map

This zone is mainly composed of Triassic, Jurassic and Cretaceous formations. Neogene formation, talus deposit, fan deposit and terrace deposit are also distributed in this zone.

(4) Rift valley

The rift valley covers a wide area along the East side of the Jordan River, and is about 10 Km wide in the north of the Dead Sea and narrows to around 2 Km North of Kureiyima. The rift valley consists of the flood-plain of the Jordan River and the Jordan Valley floor.

There is a flood-plain alongside the meandering Jordan river which forms the Western boundary of the Study area. The elevation of the flood-plain ranges from about -300 near Kureiyima to -400 meters at the present shores of the Dead Sea. The recent river deposits are distributed in this plain.

The Jordan Valley floor occupies most of the rift valley and the elevation of the floor ranges from about -250 at Kureiyima to -370 meters near the Dead Sea.The floor is mainly composed of Lisan formation of Quaternary. Undifferentiated Neogene formation, talus deposit, fan deposit and terrace deposit are also distributed on the floor along the foot hills.

The greater part of the floor is covered with thin soil. Many types of crops are grown here, including tomato, green pepper, banana, orange, watermelon, egg plant, etc.

1.2 Geological Features of the Study Area

Triassic, Jurassic and Cretaceous systems are mainly distributed on the foot hills, the escarpment and the highlands in the Study area. Tertiary and Quaternary deposits cover the rift valley (refer to Table I-1.2.1 and see Fig. I-6.1.2).

No igneous rocks are recognized, but basalt flow in the Pleistocene Epoch is distributed locally in the south side of the Study area.

Triassic ~ Cretaceous systems are generally distributed in a North-East to South-West direction. The systems have folding axes in the same direction. The folds are gentle and are both synclines and anticlines.

The major tectonic fault which formed the rift valley passes in a North to South direction throughout the Study area. Triassic ~ Cretaceous systems which are well bedded horizontally or gently dipping step down into the Jordan Valley in a series of many small faults in the same direction as the major tectonic fault.

(1) Triassic - Jurassic systems

Triassic - Jurassic systems consist of the Zerqa Group which is subdivided into two formations, the Main Formation (Z1) of Triassic age and the Azab Formation (Z2) of Jurassic age.

1) Main Formation (Z1)

This formation consists of sandstone, calcareous sandstone, limestone, shale and gypsum. Outcrops of the formation in the Study area are restricted to the Zarqa River valley, Wadi Um Quseib and from Wadi Hisban to the North-Eastern corner of the Dead Sea.

In the Zarqa River valley, near Wadi Huna, about 100 meters of the formation is exposed. Here it consists of crystalline limestone, marly limestone, calcareous sandstone and clay with beds of massive gypsum. The formation is overlain by the Azab Formation but the base is not exposed.

2) Azab Formation (Z2)

This formation consists of limestone, marl, dolomite, sandstone and shale. The type locality is at Ain el Azab on the South bank of the Zarqa River in the Study area.

The formation is distributed in the Jordan Valley side wadis which are in a region extending southwards for about 20 kilometers from the Zarqa River to Wadi Bassat el Faras.

Table I-1.2.1 Geological Description in the Study Area

PERIOD	EPOCH	GROUP	FORMATION	SYMBOL	LITHOLOGY
Quaternary	Holocene (Recent)		fan, talus, terrace, river		sand, clay, gravel
	Pleistocene	Jordan Valley	Lisan	J	marl, clay, gypsum, sand, gravel
Tertiary	Pliocene		undifferentiated		conglomerate, marl
	Miocene				
	Oligocene				
	Eocene	Belqa	(Muwaqqar (B3); Rijam (B4), Wadi Shallala (B5) are not distributed in the Study Area)		
	Paleocene				
Upper Cretaceous	Maestrichtion				
	Campanion		Amman	B2	silicified limestone, chert
	Santonian		Wadi Ghudran	B1	chalk, chalky marl
	Turonian	Ajlun	Wadi Sir	A7	limestone
	Cenomanian		Shueib	A5-6	marly limestone
			Hummar	A4	limestone
			Fuheis	A3	marl
			Naur	A1-2	marl, limestone
Lower Cretaceous	Albian	Kurnub		K	white sandstone with dolomite and shale; varicolored sandstone with limestone, shale, dolomite and marl
	Aptian				
	Neocomian				
Jurassic		Zerqa	Azab	Z2	limestone, marl, dolomite, sandstone, shale
Triassic			Main	Z1	sandstone, calcareous sandstone, limestone, shale, gypsum

Further South between Wadi Hisban and the Northern end of the Dead Sea the formation has completely wedged out and the Kurnub Group immediately overlies the Main Formation. This formation consists of limestone, marl, dolomite, sandstone and shale. The type locality is at Ain el Azab on the South bank of the Zarqa River in the Study area.

(2) Lower Cretaceous system (Kurnub Group)

The Lower Cretaceous system consists of the Kurnub Group (K) which lies with conformity on the Azab Formation (Z2) of the Zarqa Group.

The Kurnub Group is a predominantly arenaceous deposit at the base of the Cretaceous sequence. This Group consists of two units, the lower "massive white sandstone" with thin dolomite and shale bands, and the upper “varicolored sandstone” containing thin intercalations of limestone, shale, dolomite and marl.

It underlies almost the whole of the Study area except the Jordan Valley Floor area and the area of outcrops of the Zerqa Group.

Exposures occur along the escarpment from the Zarqa River to the North-Eastern corner of the Dead Sea.

Elsewhere the Kurnub Group is overlain with conformity by deposits of upper Cretaceous-Tertiary age.

(3) Upper Cretaceous - Lower Tertiary systems

Upper Cretaceous - Lower Tertiary systems consist of a thick sequence of clastic and non-clastic carbonate rocks which range from Cenomanian to Upper Eocene in age.

Although the succession is conformable throughout it has been subdivided into two groups on the basis of the occurrence of abundant chert in the upper group. The lower part of the sequence in which chert is relatively rare, is termed the Ajlun Group and the upper part which has abundant chert is named the Belqa Group.

1) Ajlun Group

The Ajlun Group falls within the Cenomanian and Turonian epochs. The Group is essentially a carbonate sequence in the Study area and consists of seven litho - stratigraphic subdivisions (A1-7). The subdivisions are based on water-bearing characteristics of the sediments and separate the sequence into regionally important aquifers and aquicludes. It outcrops extensively along the escarpment in the Study area.

A1, A3, A5-6 are recognized as aquicludes and consist of mainly marl or marly limestone with shale. A2, A4, A7 are recognized as aquifers and consist of mainly limestone.

2) Belqa Group

The Belqa Group ranges in age from Santonian to Upper Eocene. The group is a sequence of clastic and non-clastic, predominantly carbonate rocks in the Study area and these rocks are conformable with the underlying Ajlun Group. They are regarded as a separate group because of the occurrence of abundant chert in the Belqa Group.

In the Study area, the group consists of two formations (B1, B2) and exposures occur mainly along the escarpment in the Northern part of the Study area.

B1, recognized as an aquifer, consists of mainly chalk and chalky marl. B2, also recognized as an aquifer, consists of mainly silicified limestone and chert.

(4) Upper Tertiary system

Upper Tertiary system is an undifferentiated formation of the Jordan Valley Group. In the Study area, this formation consists of mainly conglomerate and marl.

Its deposition was associated with the tectonism which formed the rift and it includes materials of fluviatile and lacustrine origin.

The formation lies unconformably on the other older systems and is overlain by Quaternary soil, sand and gravel.

Outcrops of the formation are scattered along the foot hills in the Study area.

(5) Quaternary system

The Quaternary system consists of the Lisan formation which may be considered as embracing all Pleistocene deposits found in the rift valley and the Recent superficial deposits.

1) Lisan Formation

This formation is lacustrine sediment and consists of marl, clay, gypsum and gravel.

It lies unconformably on the other older systems in the Jordan Valley, has not been deformed by the tectonic movement and is sensibly horizontal.

In the Study area, the exposures occur mainly along the Jordan River meandering through its alluvial-covered flood-plain and along the foot hills.

2) Recent

The Recent superficial deposits are composed of fan deposit, talus deposit, terrace deposit and recent river deposit. They cover the Lisan Formation over much of the Jordan Valley.

The talus and fan detritus material is distributed in the Jordan Valley and the major wadi slopes in the rejuvenated drainage.

Terraces cut at various stages in the formation of the wadis are covered with terrace alluvium.

Recent river deposit is distributed in the meandering Jordan River and composed of sand, clay and gravel.

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Reports

1. Hand book of the Geology of Jordan, 1959.
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5. Monitoring and Evaluation of the Amman-Zerqa Aquifers, 1983.
6. Water Resources Strategy, North Jordan, 1988.
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8. Water Pollution in Jordan, Cause and Effects, 1991.
9. Groundwater Resources of the Deep Aquifer Systems in NW-Jordan: Hydrogeological and Hydrogeochemical quasi 3-Dimensional Modeling, 1991.
10. Groundwater Investigation in the Hammand and Sirhan Basins, 1992.
11. Water Resources of Jordan Present Status and Future Potentials, 1993.
12. Evaluation of the Groundwater Potential of the Zerqa Aquifer in Lower Wadi Hisban - Jordan Valley, 1984.
13. Hydrogeological Study of the Zerqa Aquifer for the Wadi Hisban Fish Farm Feasibility Study, 1985.

Geological maps

14. 1/250,000 Geological map of Jordan, 1954, 3 sheets.
15. 1/250,000 Geological map of Jordan, 1986, 5 sheets.
16. 1/10,000 Geological map, 2 sheets.
17. 1/25,000 Geological map, 12 sheets.

Aerialphoto

18. 1/30,000 Aerial photos, 171 copies.

Well Drilling Record

19. Hisban No. 1, Hisban No. 2, Rawda No. 1, Rawda No. 2, Rawda No. 3, Wadi Shueib No. 1, Bassat el Faras, Kafrein No. 1, Kafrein No. 2, Kafrein No. 3, Kafrein No. 4, Kafrein No. 5, Kafrein No. 6, Kafrein No. 7, Kafrein No. 8, Kafrein No. 9, Kafrein No. 10, Sakna No. 1, Sakna No. 2, Sakna No. 3, Karamah JRV-9, Karamah g-b, Abu Zeigan No. 2, Abu Zeigan No. 3, Deir Alla No. 1, Deir Alla No. 2, Deir Alla No. 4, Deir Alla No. 7-A, Deir Alla No. 7-B

    Total 29 Wells

Inventory Data

20. 396 Existing well data
21. Existing well location map
22. 248 spring coordination and altitude data
23. Spring location map

2. Hydrology of the Study Area

2.1 Water System

The rivers, wadis and canals in the Study area are shown in Fig. I-2.1.1. Water enters the Study area by the King Abdullah Canal from the North and from the River Zarqa and the Wadis Shueib, Kafrein and Hisban which flow into the Jordan Valley from the highlands to the East.

Wadi Mallaha arises within the Study area to the West of the King Abdullah Canal and flows into the Jordan River. A dam and reservoir are under construction on the wadi.

The King Abdullah Canal receives most of its water from the Yarmouk River. The remainder comes from the smaller wadis between the Yarmouk River and the Study area.

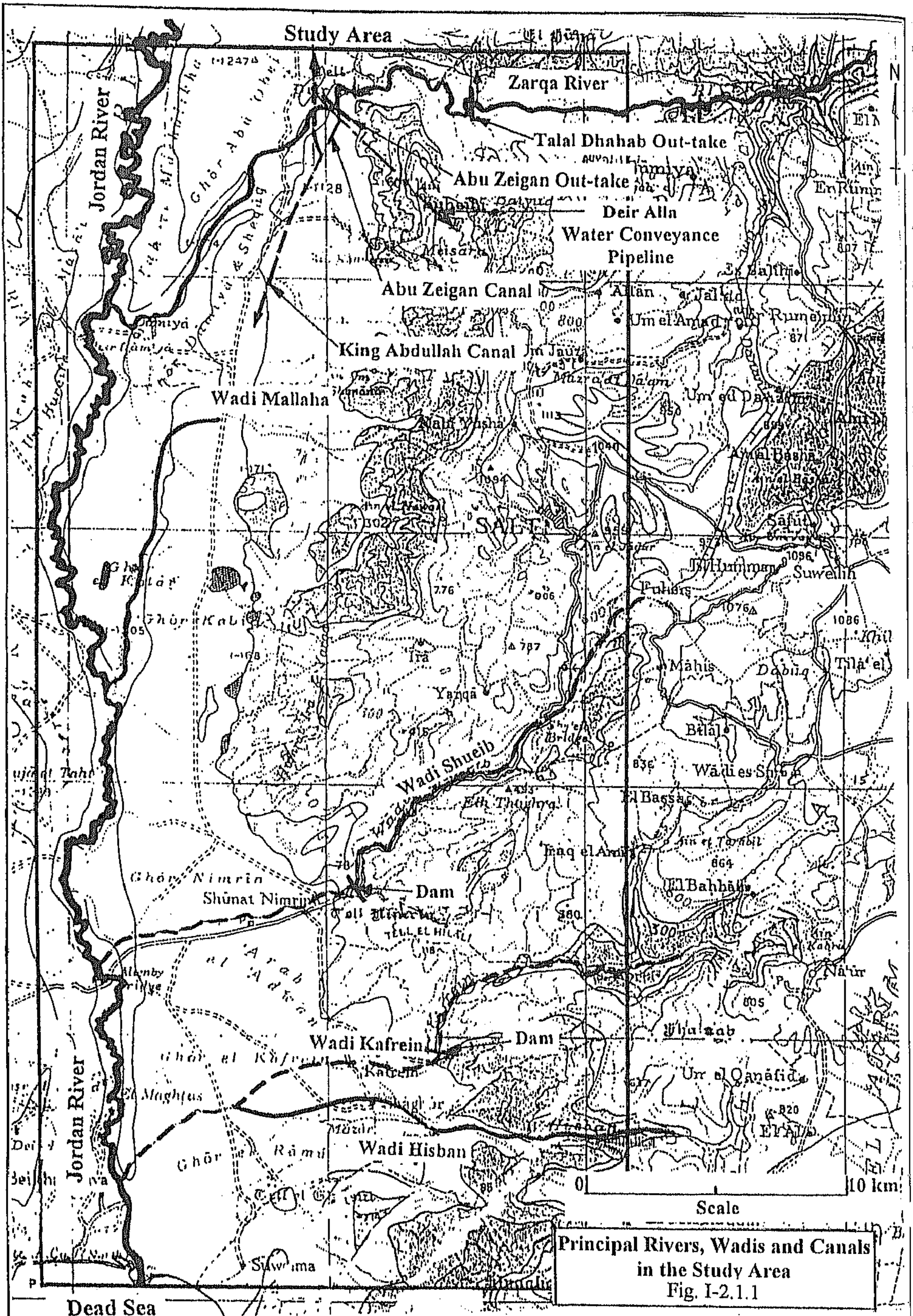
Flow into the Study area from River Zarqa is controlled by King Talal Dam. Downstream of the dam, water is diverted into the irrigation system from the out-take at Talal Dhahab and into the King Abdullah Canal from the out-take and canal at Abu Zeigan. (See Figures I-2.1.1 and 2.3.1).

There are smaller dams on the Wadis Shueib and Kafrein within the Study area. The dams are located as shown in Fig. I-2.1 2.1.

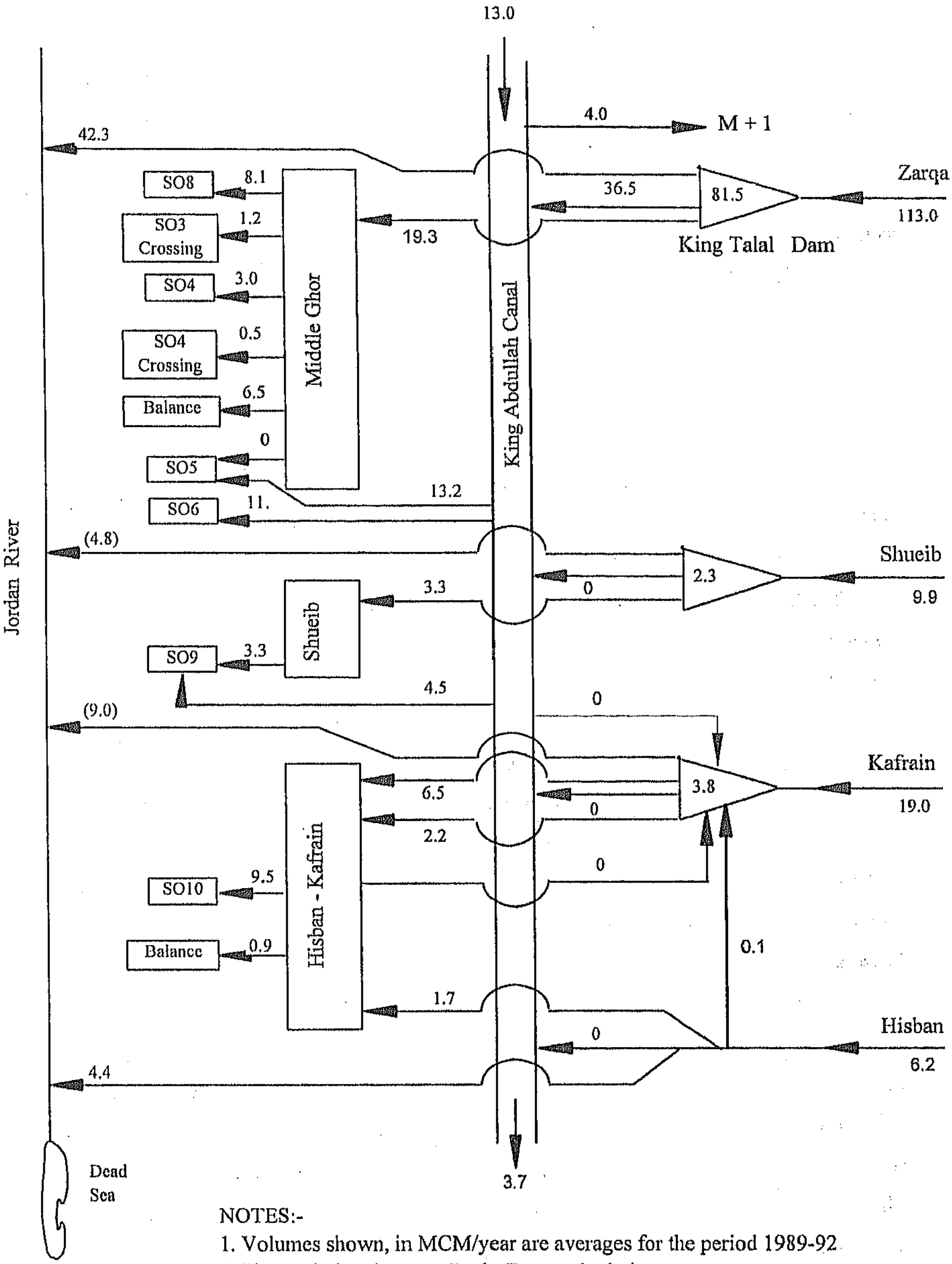
The out-take from King Abdullah Canal to Amman water supply is at Deir Alla, upstream of Abu Zeigan. The majority of the water in the Study area is used for irrigation. The surplus discharges to the Jordan River which flows along the Western edge of the Study area into the Dead Sea. Historically, the flow in the River Jordan was approximately 1,400 MCM/year. However, Reference 1, p 14 states that:-

"The present day flow in the River Jordan "has now declined to a mere 250 - 300 MCM/year - mostly as irrigation return flow, inter-catchment runoffs or saline spring discharges." The water in the Jordan River is not used in the Study area.

A schematic diagram showing the operation of the system is shown in Fig. I-2.1.2. The volumes of water shown are the annual averages for the water years 1989-1992 and have been abstracted from Reference 11. It should be noted that this period includes the very wet winter of 1991/1992.



Principal Rivers, Wadis and Canals in the Study Area
Fig. I-2.1.1



NOTES:-

1. Volumes shown, in MCM/year are averages for the period 1989-92
2. Figures in brackets are Study Team calculations
3. SO 8 = JVA Irrigation Stations

Fig. I-2.1.2

JVA Resources/Usage within the Study Area 1989-92

2.2 Climate

References 4, 8(a) and 8(b) contain comprehensive rainfall records for Jordan, including the Study area. The locations of the gauging stations are shown in Fig. I-2.2.1. The information in References 2 and 3 has been derived from the data obtained from these stations.

For the purpose of the Study, the climate of the catchments draining into the Study area has been divided into three zones:

(i) the desert to the East;

(ii) the highlands;

(iii) the Jordan Valley.

The Zarqa River catchment covers all three zones. The wadi catchments are all within zones (ii) and (iii).

The desert has a continental type climate with a wide range of temperature (Reference 4, p11). The average summer maximum is 37 °C, falling to 20 °C at night. Average daily minimum temperature in winter is 3 °C.

The highlands, reaching an elevation up to 1,000 m above Mediterranean sea level, have a moderate climate. Summer temperatures reach a maximum of 35 °C, falling to 20 °C at night. Winter minimum temperature is a few degrees below zero (Reference 1, p5).

The Jordan Valley (the Ghor) has an altitude ranging from 197 m below MSL in the North to 390 m below MSL at the Dead Sea. Average summer maximum temperature is 39 °C and the highest observed temperature in the country of 51.2 °C was recorded in this area (Reference 4).

Annual average rainfall in the three zones is shown in Fig. I-2.2.1, which is a copy of part of the latest revision of the isohyetal map compiled by WAJ. Annual average rainfall varies from less than 200 mm/year in the desert and the Jordan Valley to 600 mm/year at Salt in the highlands. Seasonal rainfall is given in the Reference 2, pp10 - 11.

Annual potential evapotranspiration varies from 2,000 mm/year in the desert to 1,600 mm/year in the highlands and Jordan Valley (see Reference 2, pp27 - 41). The maps of monthly evapotranspiration rates and seasonal rainfall in Reference 2 indicate that potential evapotranspiration is less than the rainfall amount during the rainy season. A calculation of the surplus volume for the River Zarqa shows it to be less than the holding capacity of the soil. There is therefore no surplus available to supply the flow in the river or to recharge the aquifer. The calculation is shown in Table I-2.2.1.

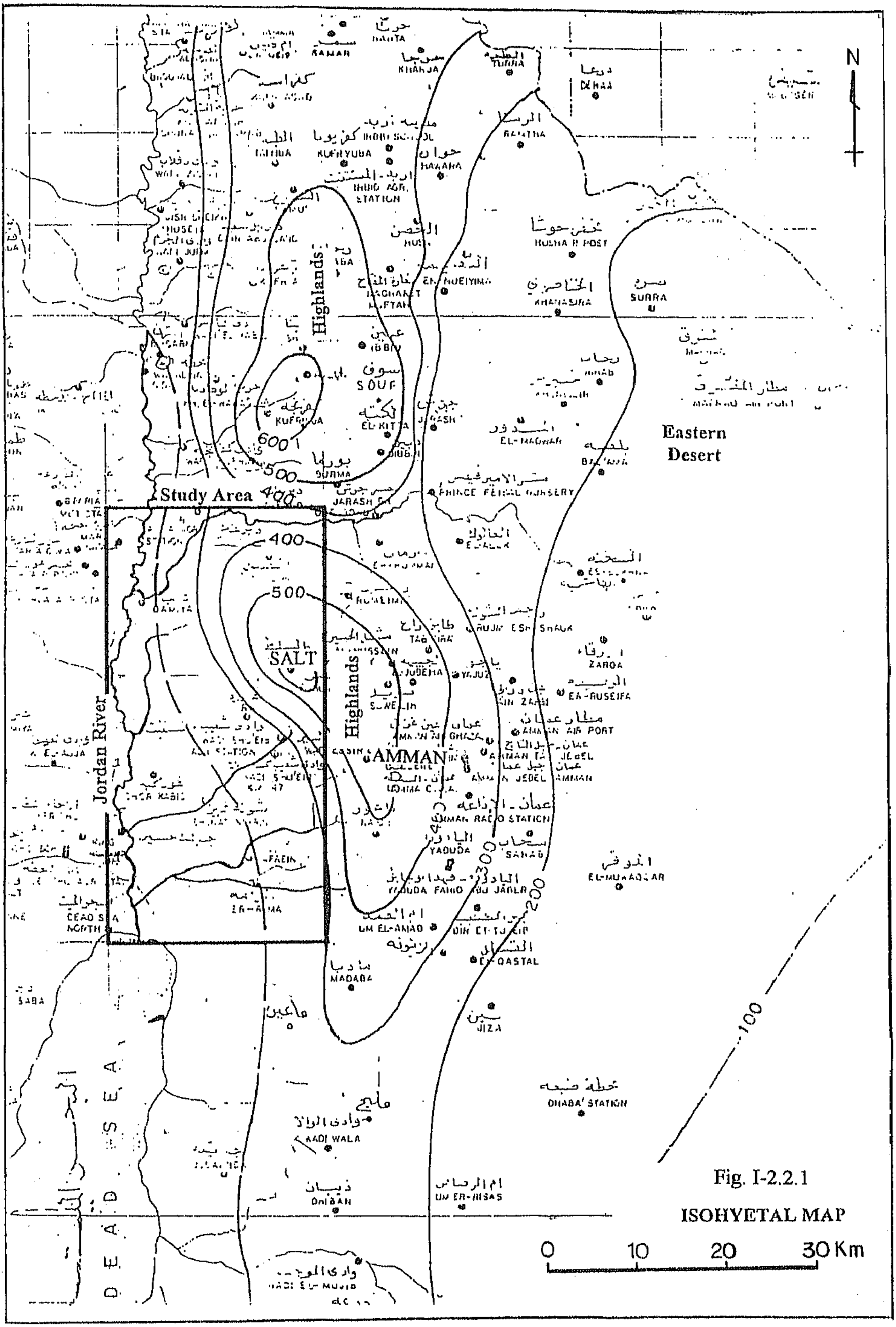


Fig. I-2.2.1

ISOHYETAL MAP

Table I-2.2.1 **Rainfall Surplus Calculation - River Zarqa**

	Desert			E Highlands			W Highlands		
Month	Rainfal	Pot Evap	Surplus	Rainfal	Pot Evap	Surplus	Rainfal	Pot Evap	Surplus
	mm/mo			mm/mo			mm/mo		
Jan	35	80		50	75		91	60	31
Feb	35	90		50	85		91	80	11
Mar							18	120	
Apr							17	150	
May									
Jun									
Jul									
Aug									
Sep									
Oct							45	120	
Nov							45	75	
Dec	35	65		50	60		91	60	31
Total Annual Surplus (mm)									73

Notes: 1. Winter rainfalls divided equally between December, January, February.
Spring rainfalls divided equally between March, April.
Autumn rainfalls divided equally between October, November.
2. Soil holding capacity = 200 mm (Reference 2, p IX).

2.3 River and Wadis

(1) River Zarqa

Flow from the River Zarqa into the Study area is controlled by King Talal Dam. Data about the dam are given in References 1, 9 and 10. The original dam, completed in 1977, comprised a 92 m high dam and a reservoir capacity of 56 MCM. In 1987, the dam was raised to a height of 108 m, increasing the reservoir capacity to 81.5 MCM. Sediment volume is 10.5 MCM.

The catchment area draining to the dam is 3,600 sq.km.

The annual average maximum inflow/outflow to/from the reservoir in the last seven years is 3.3cu.m/sec. This includes 1.0 cu.m/sec from the Samra sewage treatment plant.

Average annual rainfall at the dam site area is calculated to be 280 mm/year. However, rainfall in 1993 was only 160 mm.

Reference 1, p22 states that:

"The natural flow of the Zarqa River can not fill the dam in an average year. But since increasing amounts of water were imported into the catchment area ... the dam is expected to fill almost yearly. At present, the domestic and industrial wastewater contributions to the inflows of the river are estimated at 50% of its discharge".

The water in the reservoir is used entirely for irrigation.

Downstream of the dam, water is diverted into the irrigation system from the out-take at Talal Dhahab and into the King Abdullah Canal via the Abu Zeigan out-take and canal (See Figures 2.1.1 and 2.3.1). During summer, typical operation of the system at Talal Dhahab and diversion of all the remaining flow in the river into the Abu Zeigan Canal and thence into the King Abdullah Canal. In winter, irrigation demands are smaller. Both the outflow from the reservoir and the volumes diverted are reduced. Flow in the river continues beyond the Abu Zeigan diversion. In summer and winter, the exact volumes diverted are subject to diurnal variations depending on demand.

The average monthly dry season (September, October) outflow from King Talal Dam calculated from the figures given in Reference 9 is 8 MCM/month, equivalent to 3 cu.m/second. The average January outflow is 1 MCM/month, equivalent to 0.36 cu.m/second. The figures for the Study period, given by Reference 10, are:

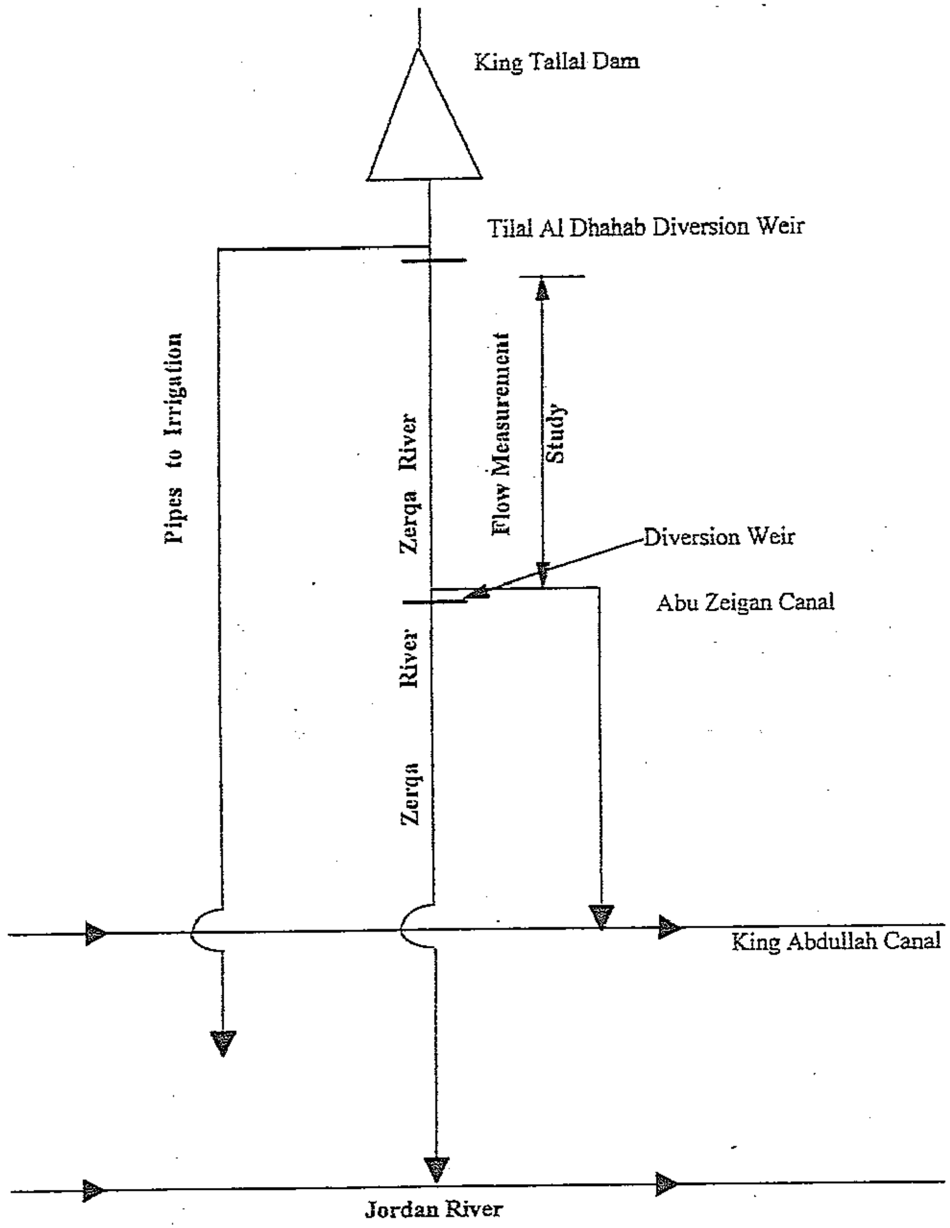


Fig. I-2.3.1 Zarqa River System Schematic Diagram

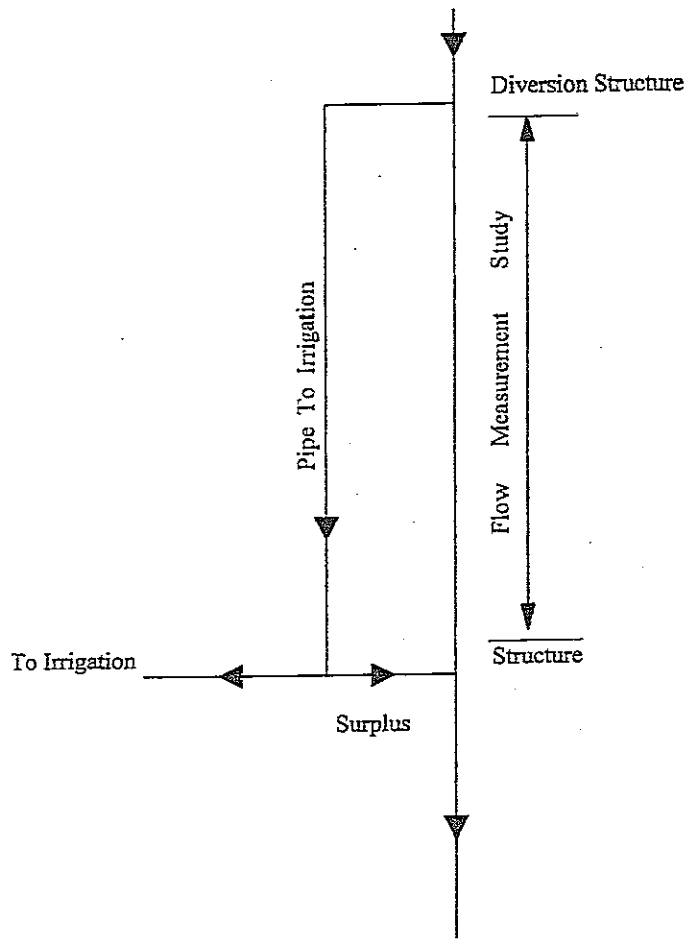


Fig. I-2.3.2 Wadi Hisban Schematic Diagram

September 1994 outflow = 9.1 MCM/month, equivalent to 3.5 cu. m/second

October 1994	"	= 8.4 MCM/month	"	"	3.1 cu.m/second
January 1995	"	= 3.4 MCM up to 29th,	"	"	1.4 cu.m/second.

(2) Wadi Mallaha

The Wadi Mallaha and its tributaries arise within the Zerqa Group distribution area downstream of the King Abdullah Canal and flow into the Jordan River. A dam and reservoir are presently under construction on Wadi Mallaha near to the downstream end of the catchment. The reservoir will be filled from the King Abdullah Canal and will be used to provide additional storage for irrigation water. In order to achieve satisfactory water quality in the reservoir, the brackish waters of the Wadi Mallaha and its tributaries will be diverted around the reservoir. Work commenced in Summer 1994.

(3) Wadis Shueib, Kafrein, Hisban

The Wadis Shueib, Kafrein and Hisban are the only other watercourses in the study area in which there is a continuous, all-year-round baseflow.

Dams have been constructed on the Wadis Shueib and Kafrein as shown in Fig. I-2.1.1.

The Wadi Shueib dam has a capacity of 2.3 MCM which is used to store water for irrigation in the Jordan Valley.

The Wadi Kafrein dam has a capacity of 3.8 MCM, which is used for irrigation and groundwater recharge. In addition to wadi flow, the reservoir also receives water from irrigation return flow and treated and untreated waste water.

Water is abstracted from the Wadi Hisban upstream of the flow measurement area and piped alongside the wadi. Immediately downstream of the flow measurement area, the pipe diverges from the wadi into the Hisban/Kafrein irrigation project. Surplus water is returned to the wadi. A schematic diagram of the system is shown in Fig. I-2.3.2.

The catchments of the wadis extend from the highlands into the Jordan Valley. The catchment areas are: Shueib : 180 sq.km; Kafrein: 189 sq.km; Hisban : 82 sq.km.

(4) Records and Analysis of Flows in the Wadis

Baseflows in the wadis Shueib, Kafrein and Hisban are measured monthly by WAJ. Records (Reference 7) date from 1981/82 for the Shueib, 1985/86 for the Kafrein and 1982/83 for the Hisban. In addition, records of flow readings prior to 1976 are given in Reference 3. Records prior to 1963 and a discussion of the quality of those records are given in Reference 6.

The WAJ measurement points on the wadis Shueib and Kafrein are a short distance upstream of the reservoirs. That on the Hisban is just upstream of the point where the surplus flow from the irrigation supply is returned to the wadi.

There are no permanent gauging stations. Measurements are taken using a current meter in a straight length of river course.

Statistical analysis of the WAJ flow records gives the following average January and September flows in the wadis for comparison with the flow measurement study:

Wadi Shueib:	Av. January flow = 220 l /sec	Av. September flow = 89 l /sec
Wadi Kafrein:	398 l /sec	154 l /sec
Wadi Hisban:	164 l /sec	74 l /sec

The relevant extract from the WAJ records and the calculations are shown in Table I-2.3.1.

Table I-2.3.1 WAJ January and September Flow Records for Wadis Shueib, Kafrein, Hisban and Calculation of Average January and September Flows

Year	Average Monthly Flows l /sec					
	Wadi Shueib		Wadi Kafrein		Wadi Hisban	
	January	September	January	September	January	September
1981/2	172	46				
1982/3	178	142			156	150
1983/4	168	121			178	56
1984/5	98	41			131	54
1985/6	174	48	295	71	133	31
1986/7	293	58	537	91	151	49
1987/8	302	103	236	244	183	96
1988/9	209	130	292	223	130	75
1989/90	382	110	629	140	246	82
Average	**220**	**89**	**398**	**154**	**164**	**74**

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   Source: University of Amman

2. National Atlas of Jordan, Part II - Hydrology and Agrohydrology. Royal Jordanian Geographic Centre, 1986.
   Source: JICA Preparatory Study Team

3. National Water Masterplan of Jordan. Prepared by Agrar und Hydrotechnik GMBH, Essen; Bundesanstalt fur Geowissenschaften und Rohstoffe, Hannover, 1977.
   Source: MOWI Library

4. Jordan Climatological Data Handbook. The Hashemite Kingdom of Jordan Meteorological Department, 1988.
   Source: Meteorological Department

5. Handbook of Applied Hydrology. V.T.Chow. McGraw - Hill, 1964.
   Source: B-M Library

6. Review of Streamflow Data prior to October 1963. The Hashemite Kingdom of Jordan Central Water Authority, Hydrology Division, Amman, 1964.
   Source: WAJ Counterpart Team

7. WAJ Flow records for River Zarqa and Wadis Hisban, Kafrein and Shueib, 1982 - 1990.
   Source: WAJ Counterpart Team

8(a) Rainfall Data in Jordan 1980 - 1985 (Technical Paper No. 52)
8(b) Rainfall Data in Jordan 1985 - 1990 (Technical Paper No. 54)
   The Hashemite Kingdom of Jordan Water Authority, Department of Water Resources Development, Amman, 1986 and 1992.
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9. King Talal Dam Monitoring Project. The Royal Scientific Society.
   Source: JVA, King Talal Dam

10. King Talal Dam Inflow/Outflow Records
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11. Water Balance Data for the Jordan Valley
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12. Storage Facilities in the Jordan Valley - Final Report on Technical, Economic and Financial Feasibility and Preliminary Design. Volume II, Part II - Main Report.
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