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

SUMMARY

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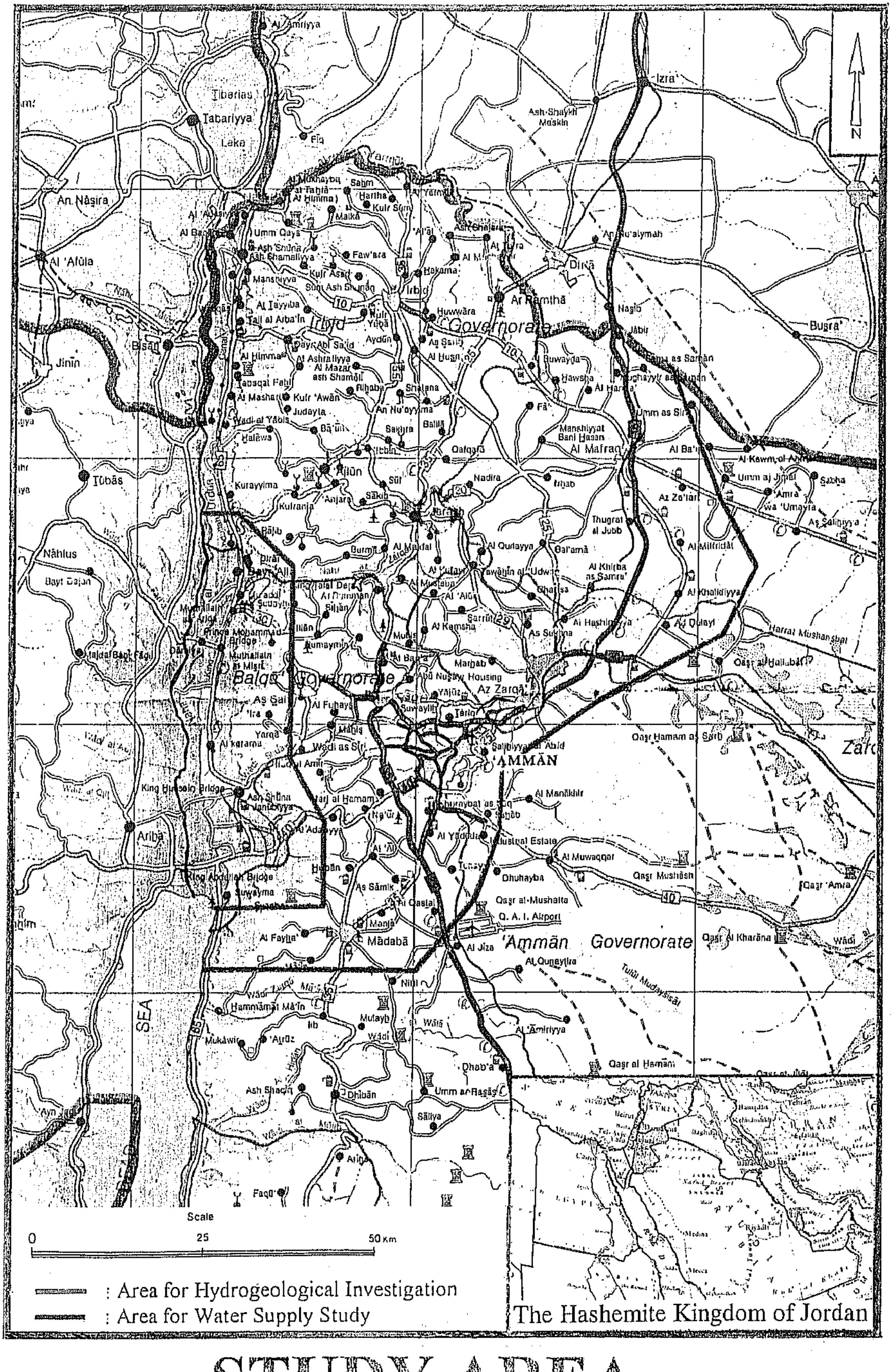
August 1995

Yachiyo Engineering Co., Ltd.
Mitsui Mineral Development Engineering Co., Ltd.
Tokyo Japan


Scale
0
25
50 Km
: Area for Hydrogeological Investigation
: Area for Water Supply Study
The Hashemite Kingdom of Jordan
Tiberias
Tabariyya
Lake
An Nāṣira
Al 'Afūla
Bisān
Jinīn
Ṭūbās
Nāblus
Arīḥā
SEA
Irbid
Irbid Governorate
Ar Ramthā
Al Mafraq
'Ajlūn
Jarash
Balqā' Governorate
As Salt
Az Zarqā'
'AMMĀN
'Ammān Governorate
Mādabā
Q. A. I. Airport
Izra'
Dir'ā
Buṣra
Umm Qays
King Hussein Bridge
King Abdullah Bridge
Prince Mohammad Bridge
Dhībān
Umm ar Raṣāṣ
Qaṣr al Kharāna
Qaṣr 'Amra
Al Muwaqqar

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 Summary 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).

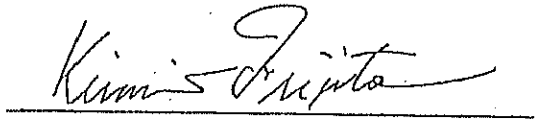
JICA sent to Jordan a study team headed by Mr. Ryosuke Teranishi, Yachiyo Engineering Co., Ltd., and composed of staff members of Yachiyo Engineering Co., Ltd. and Mitsui Mineral Development Engineering Co., Ltd., 3 times between April, 1994 and June, 1995.

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.

needed for plant operation and maintenance by Water Authority, Ministry of Water and Irrigation.

Table - 2 Project Cost (unit '000 JD)

Development Area	Production Wells and Desalination Plant	Water Transfer Line	Total
Stage I Hisban area (South)	14,141	7,366	21,507
Stage II Hisban area (South)	87,063	43,432	130,495
Stage III Deir Alla (North)	72,667	15,227	87,894

6. Project Evaluation

Implementation of the proposed projects may face economic and financial difficulties. However, considering the great scarcity of water resources in this region, it is strategic to develop the brackish groundwater as a new water resource. The priority project, i.e. the first stage, is especially significant in the aspects such as to supply water to the accelerated development area after the peace treaty and to bring about the spread of desalination technology. And above all, the financial burden is relatively small to the water sector.

6.1 Economic and Financial Evaluation

The construction cost, operation and maintenance cost have been evaluated by comparing with the current sales revenues and government subsidy. Economic internal rate of return (EIRR) has been calculated under an assumption of project implementation by loan finance. However, none of the proposed plans have been found economically attractive with the total income never exceeding the total expenditure throughout the project period of 25 years. This may not be practical in the near future, but an increase of sales revenues (50%) of subsidy (100%) will bring about positive EIRR (1.8 - 5.7%) .

Certain financial alleviation measures will be required for the priority project. If most of the construction cost can be born by government subsidy, project operation and maintenance, including the renewal of equipment after 15 years, will be soundly sustained.

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.

CONTENTS

Part II Strategy of the Brackish Groundwater Development

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.1.

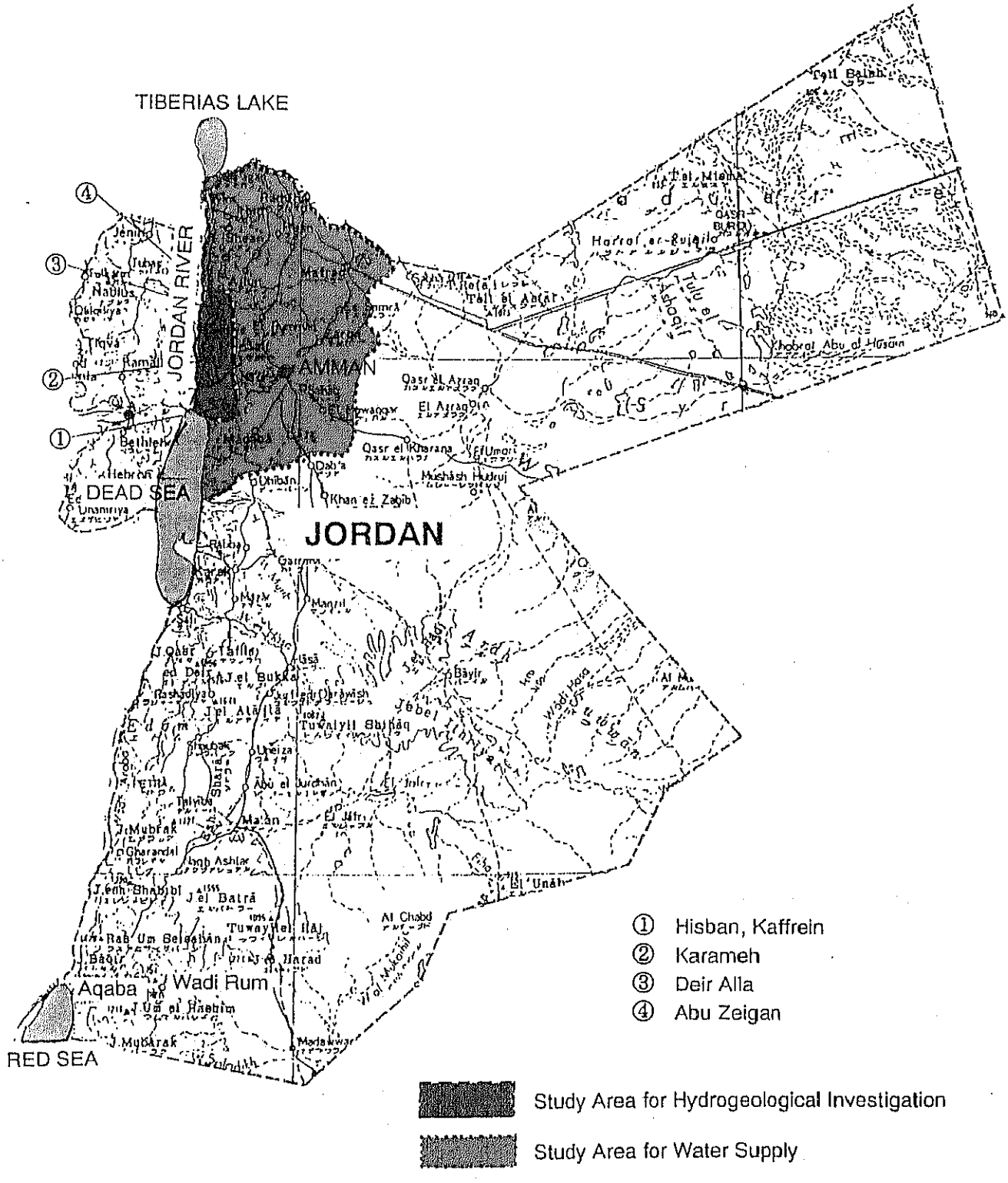


Fig-1 Location Map of the Study Area

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 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. 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.

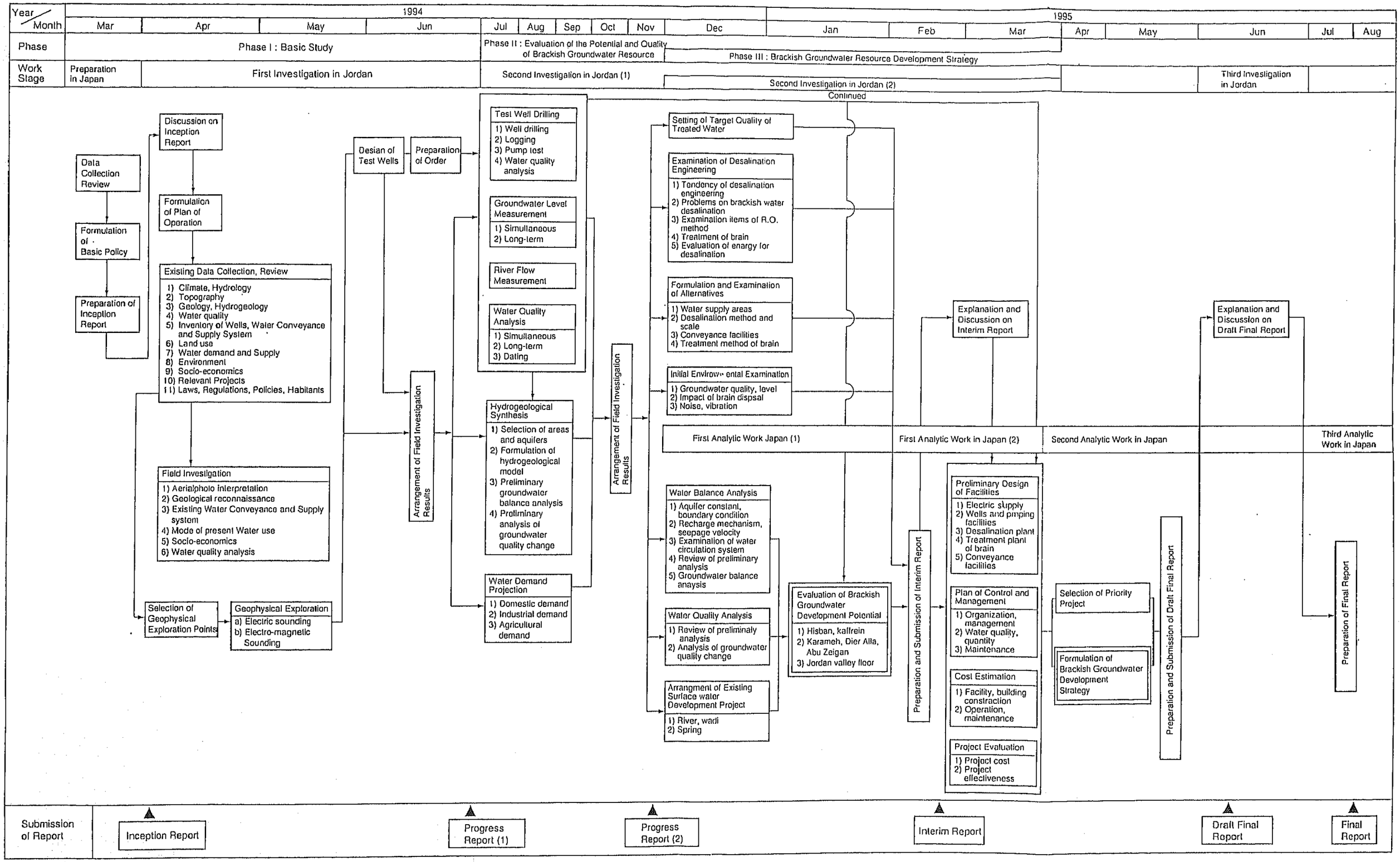
(3) Phase III : Brackish groundwater resource development strategy

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.

Fig- 2 Work Flow of the Study



PART I

Potential and Quality of the Brackish Groundwater Resource

Part I Potential and Quality of the Brackish Groundwater Resource

1. Outline of the Study Area

(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 (see Fig. I-1.1).

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.

(i) Highlands (above 800 meters).

(ii) Escarpment (0~800 meters).

(iii) Foot hills (-200~0 meters).

(iv) Rift valley (-400 ~ -200 meters).

(2) Geology

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. Geological distribution is shown in Fig. I-5.1 hydrogeological map.

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.

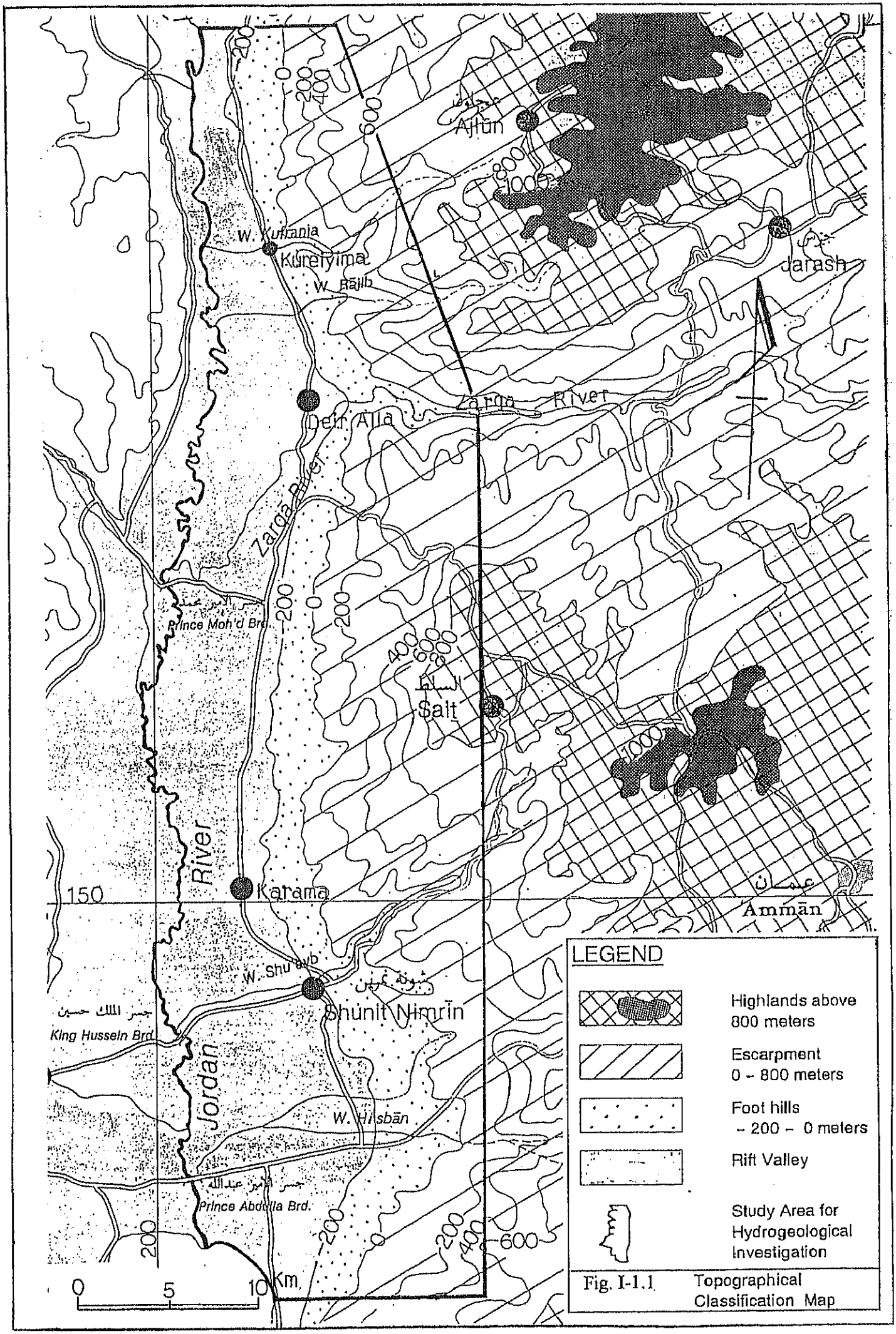


Fig. I-1.1 Topographical Classification Map

(3) Hydrology and Climate

1) Water System

The rivers, wadis and canals in the Study area are shown in Fig. I-1.2. 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. 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 Fig. I-1.2)

There are smaller dams on the Wadis Shueib and Kafrein within the Study area. The dams are located as shown in Fig. I-1.2.

2) Climate

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.

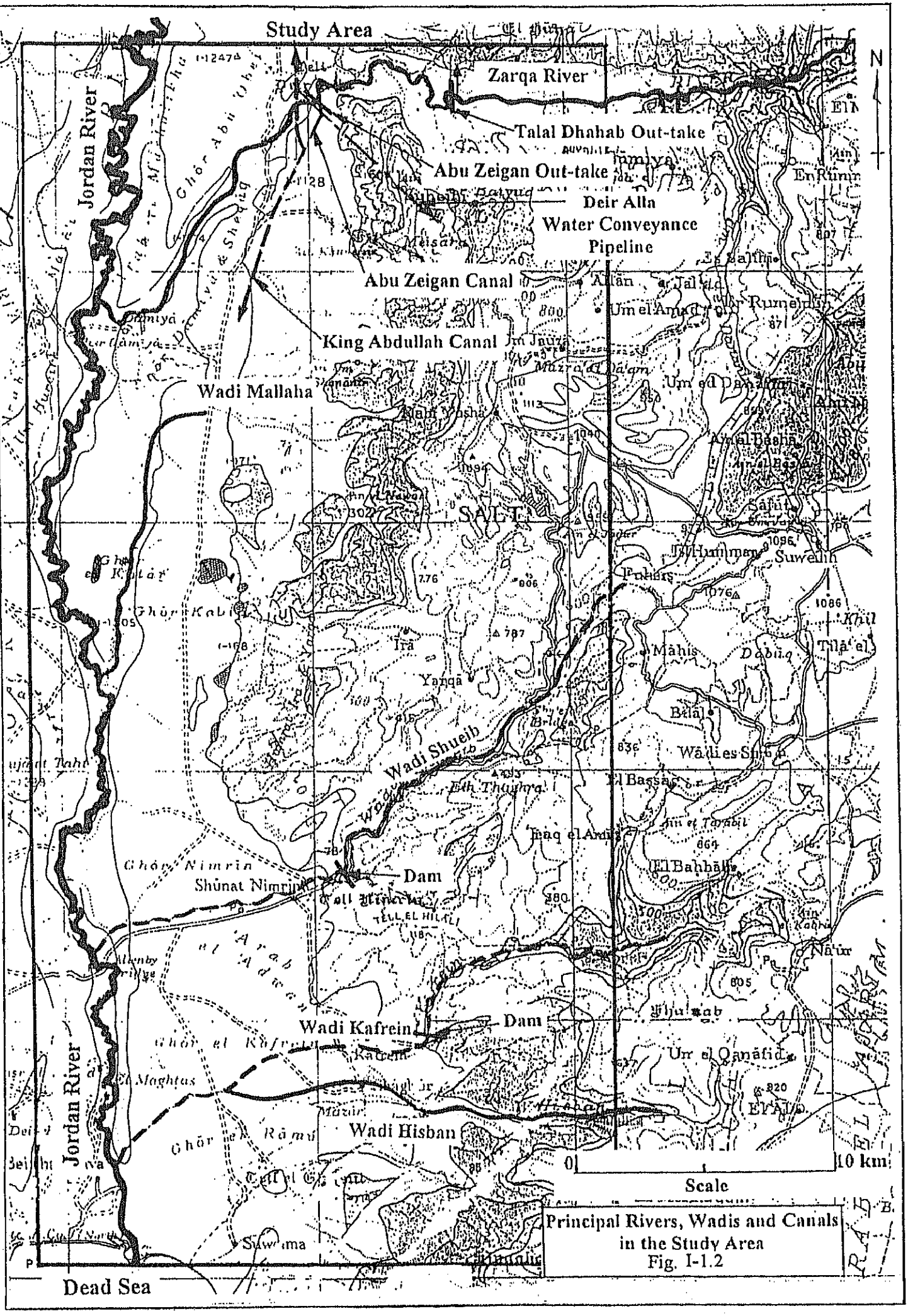
The Zarqa River catchment covers all three zones. The wadi catchments including the Study area are all within zones (ii) and (iii).

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.

The Jordan Valley (the Ghor) has an altitude ranging from 197 m below MSL in the North to 400 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.

Annual average rainfall in the three zones is shown in Fig. I-1.3. 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.

Annual potential evapotranspiration varies from 2,000 mm/year in the desert to 1,600 mm/year in the highlands and Jordan Valley. The potential evapotranspiration is less than the rainfall amount during the rainy season.


Study Area
Zarqa River
Talal Dhahab Out-take
Abu Zeigan Out-take
Deir Alla
Water Conveyance
Pipeline
Abu Zeigan Canal
King Abdullah Canal
Jordan River
Wadi Mallaha
SALT
Wadi Shueib
Dam
Shūnat Nimrin
Wadi Kafrein
Dam
Wadi Hisban
Dead Sea
N
0
10 km
Scale
Principal Rivers, Wadis and Canals
in the Study Area
Fig. I-1.2

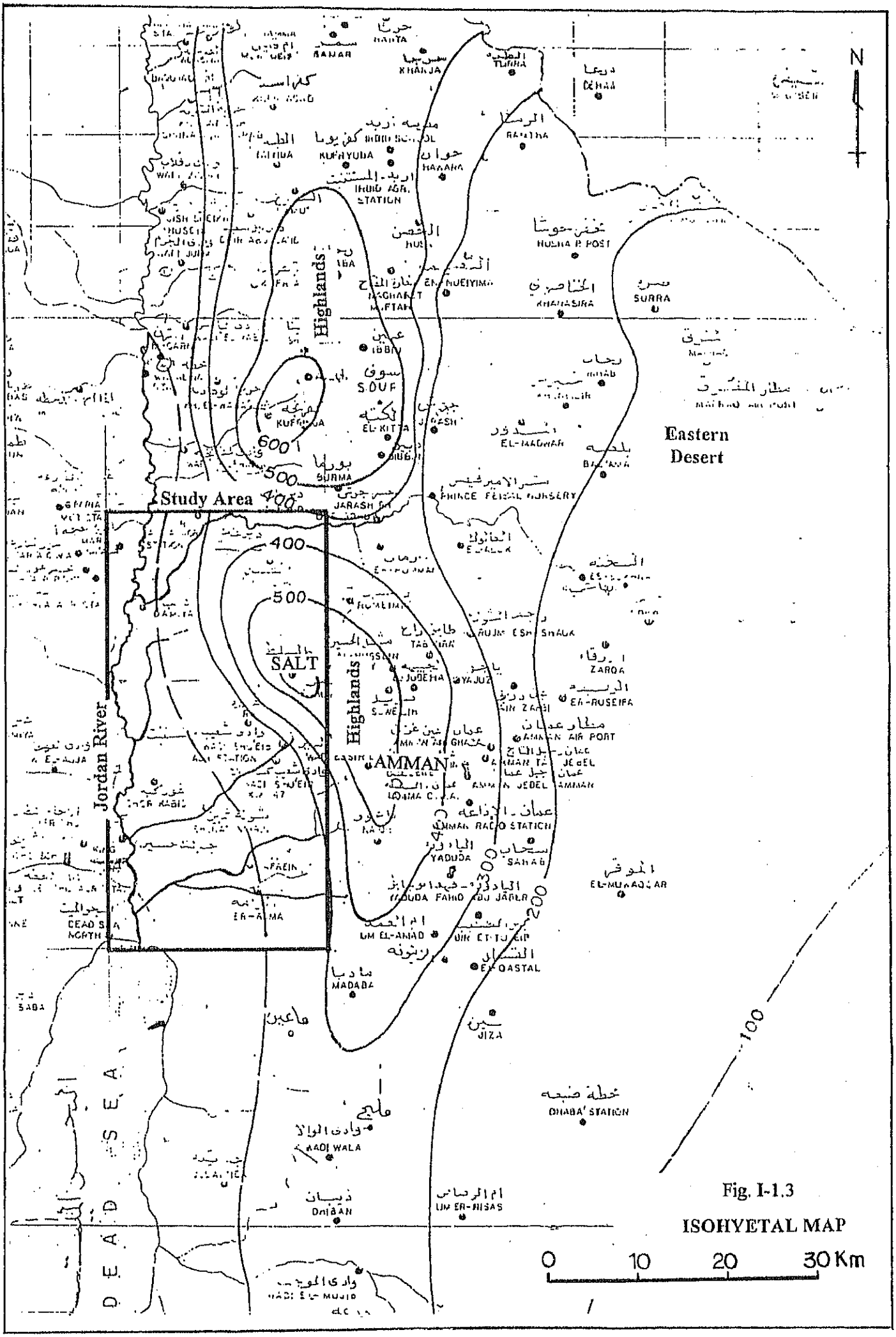


Fig. I-1.3

ISOHYETAL MAP

2. Hydrogeological Investigation

Hydrogeological investigations conducted in the Study are summarized as follows:

	Investigation Item	Quantity
①	Interpretation of Aerial Photographs.....	1,000 km^2 (photo scale: 1/30,000)
②	Geophysical Exploration	
	- Electrical Sounding.....	30 points (AB/2=300 m)
	- Electromagnetic Survey	11 lines, 1,039 points
③	Flow Measurement.....	27 measurements
④	Water Quality Analyses	116 samples including Groundwater dating
⑤	Well Survey.....	existing 170 wells
⑥	Test Well Drilling.....	6 wells, total drilling depth: 1,083 m, including logging, short term and long term pumping test

The sites of the hydrogeological investigations are shown in Hydrogeological Map. For the detail of the hydrogeological investigations, please refer to Main Report and Supporting Report. The lithological logs of the test wells are shown in Fig. I-2.1 (for the well location, see Fig. I-5.1).

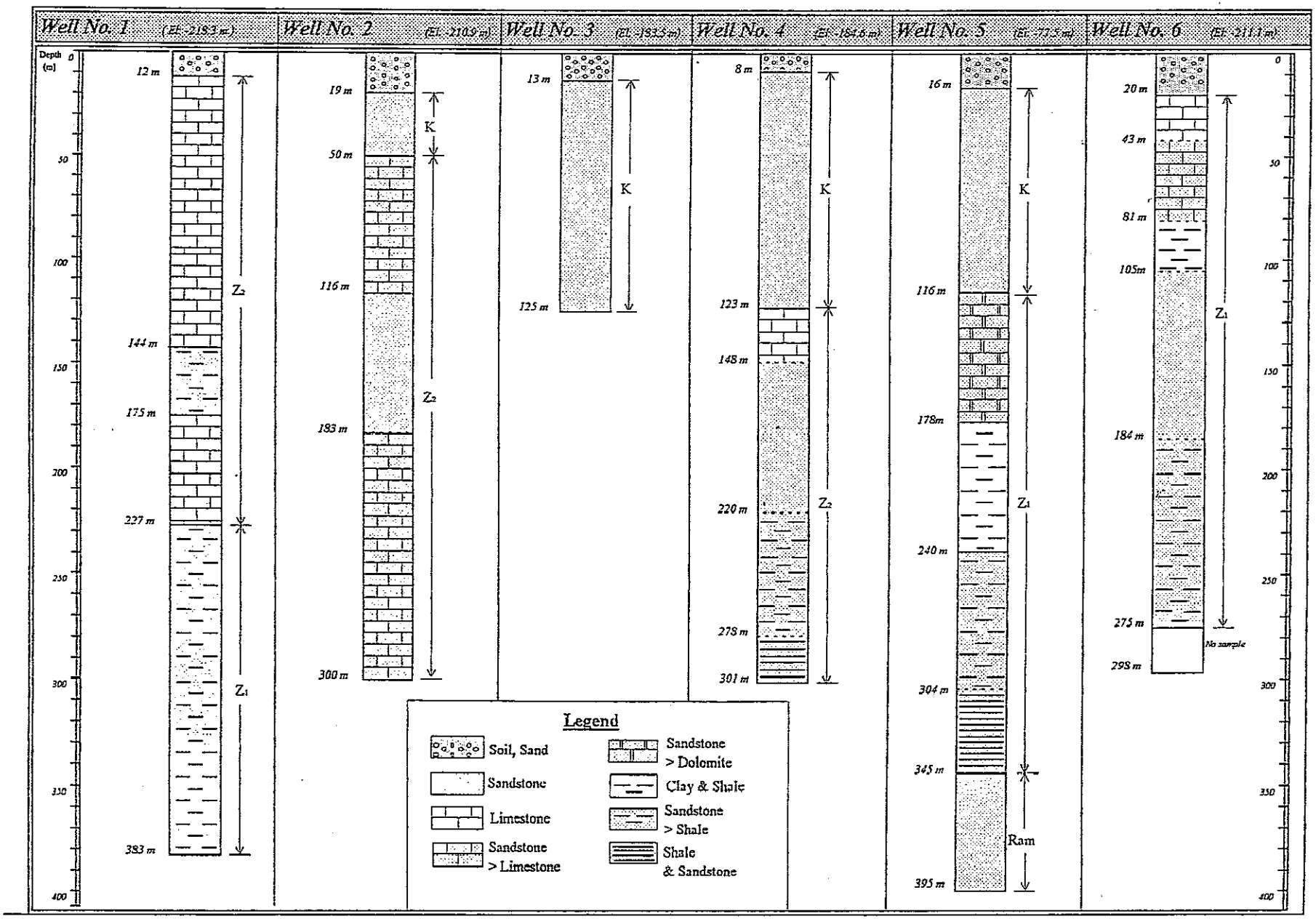


Fig. I-2.1 Lithological Logs of the Test Wells

(3) Water Balance Analysis of Brackish Groundwater

Calculations have been based on the flow measurements conducted in the Study and additional data which have been collected from JVA and WAJ.

The purpose of the calculations is to calculate the inflow from groundwater into the Jordan River and hence establish the Western boundary condition for the groundwater simulation model of the Study area.

Taking consideration of surface water basin divides, the Study area divides naturally into four areas from North to South for the calculations as follows:

Area A - the catchment of the Zarqa river;

Area B - the catchment of the Wadi Mallaha;

Area C extends from the Wadi Mallaha to the Wadi Hisban;

Area D is the small strip between the Wadi Hisban and the Dead Sea.

The areas are shown in Fig. I-31.

In general, the water balance is given by:

$$Q = G + E + S$$

In which, Q = groundwater entering the aquifer (from outside the Study area)

G = groundwater discharge to rivers and wadis (finally to the Jordan river)

E = evaporation

S = groundwater discharge through springs

The inflow to the Jordan River comprises groundwater inflow from the East Bank and the following components:

- base flows in rivers and wadis;
- irrigation return flow;
- infiltration from irrigation;
- evaporation;
- leakage from the King Abdullah Canal;
- flow from the West Bank.

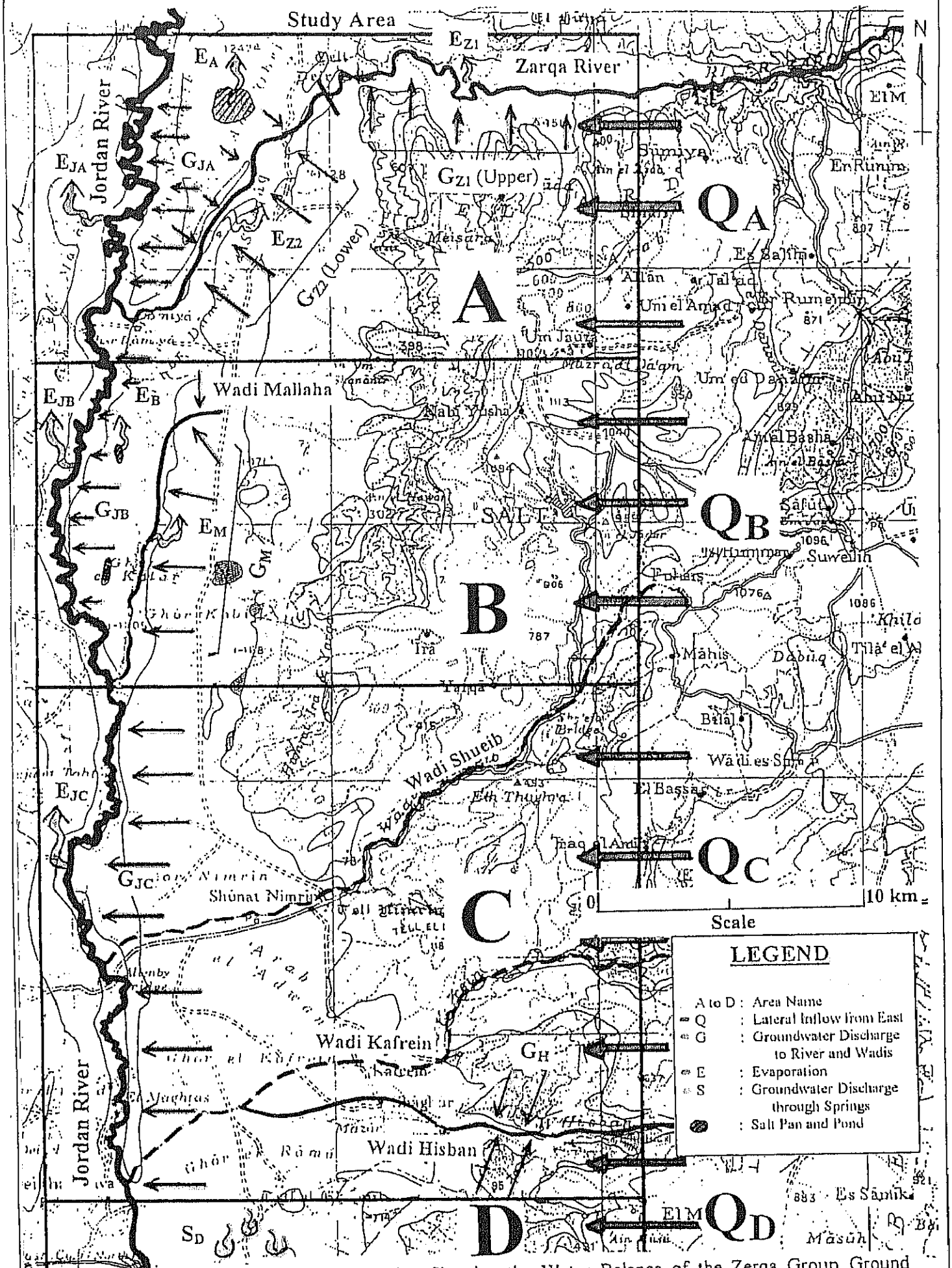


Fig. I-3.1 Schematic Drawing Showing the Water Balance of the Zerqa Group Ground Water

Additional data collected during the Study have been used to quantify the components of this inflow. Each of these components has been subtracted from the total inflow. The remaining flow has been assumed to be groundwater inflow from the East Bank. The Zerqa Group is widely exposed on the East Bank of the Jordan River in the Study area and has therefore been assumed to be the source of the groundwater inflow except Area C.

According to the calculation results described above, the total groundwater inflow from the Zerqa Group within the Study area was estimated to be approximately 120 MCM/year as shown in Table I-5.1.1 below.

Table I-3.1 Brackish Groundwater Inflow from the Zerqa Group within the Study Area

	Area A	Area B	Area C*	Area D	Total
Groundwater Inflow from the Zerqa Group (MCM/year)	40.8	8.4	70	2.6	121.8

* Inferred from groundwater simulation.

(4) Brackish Groundwater Quality

1) Water quality analyses

Water quality analyses were conducted for the 6 test wells following the progress of drilling work and pumping tests. Monthly water sampling from each test well started at the time when the well was completed and continued to the end of long term pumping and observation. The water quality analysis items were as follows.

- General analyses items (24 items)

  Temperature, pH, EC, TDS, Turbidity, SDI, Na, K, Ca, Mg, Fe, Mn, NH_4, Al, Cl, SO_4, HCO_3, NO_3, SiO_2, COD, H_2S, Total bacteria, Total coliform and F

  Analyses of these items were required for all the monthly collected samples.
- Heavy metals and toxic substances (13 items)

  Pb, Se, As, Cr, CN, Cd, Hg, Sb, Ag, Cu, Zn, Ni and Ba

  Analyses of these items were only required for one sample from each well.

2) Characteristics of brackish groundwater quality

Waters from the test wells except Well No. 3 which was an observatory well were from Zerqa Aquifers. Therefore, the analysis results were representative of the brackish groundwater quality in the different regions of the Study area - No. 1: North area (Deir Alla); No. 2 & No. 4: Middle area (Ma'di and Basset el Faras); No. 5 & No. 6: South area (Kafrein). The characteristics of brackish groundwater quality in there areas are as follows.

(i) North area

TDS of the water is about 7,000 mg/L with a temperature of 30 °C. From the concentrations of the main ions in the sample, NaCl is estimated to be about 3,000 mg/L which is 40% of the total salts in the water. Ca+Mg amounts to 40~47 meq/L and is equivalent to a hardness of 2,000~2,350 mg/L as $CaCO_3$. The concentrations of anions in the water show the relationship $[Cl]>[SO_4]>[HCO_3]$ both in equivalent and in weight. As for the other substances which would foul a membrane, SiO_2 is about 20 mg/L and Fe is about 10 mg/L.

The values of SDI and turbidity show that pre-treatment will be required if a membrane process is used for desalination.

The concentrations of heavy metals and toxic substances are very low in the water.

(ii) Middle area

Generally speaking, the brackish groundwater in this area is very brackish (TDS > 10,000 mg/L). The concentrations of the main cations and anions are in the orders of [Na]>[Ca]>[Mg] and [Cl]>[SO_4]> [HCO_3]. NaCl is more than 6000 mg/L and the total hardness is higher than 3000 mg/L.

The quality of this water may not be suitable for brackish water desalination.

(iii) South area

The brackish groundwater in this area has a TDS of 5000 - 5500 mg/L. The estimated NaCl concentration is about 3,400 mg/L which is 65% of the total salts in the water. From the Ca and Mg concentrations, the total hardness is calculated as about 1700 mg/L as $CaCO_3$. Unlike the test wells in the North and Middle areas, the concentrations of the main anions have a relation of [Cl]>[HCO_3]>[SO_4].

SDI of the water is less than 4.0. Fe and SiO_2 are also at low concentration levels. However, pre-treatment may still be required to prevent the membrane from scaling.

The details of water quality analysis results are shown in the Supporting Report.

From the above mentioned results, it can be concluded that there are regional differences in the brackish groundwater quality in the Study area, and priority of development should be put to the South area where water salinity and the concentrations of scaling substances such as Ca, Fe and so on are lower.