WATER RESOURCES OF JORDAN PRESENT STATUS AND FUTURE POTENTIALS

BY

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Elias Salameh and Helen Bannayan

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FES

Jordan is suffering from both water scarcity and maldistribution. The water shortage in Jordan has been exacerbated by the complexity of hydropolitics in the region, the high rate of population growth, and the forced immigration of hundreds of thousands of Jordanian and Palestinian returnees from the Arab Gulf countries. Within the next few years, Jordan will not be able to meet its increasing demands, even if it uses all conventional and nonconventional local water resources.

Against this background, the Friedrich Ebert Foundation which was founded in 1925 as a non-profit, private institution to sponsor academically promising youths with underprivileged social backgrounds, and is present today in Germany and in 74 countries all over the world, supporting academical, social, economic and political projects in over a 100 different countries has concentrated its efforts in Jordan in raising the water awareness: In cooperation with the University of Jordan, the Higher Council of Science and Technology and the Goethe-Institute in Amman, the Friedrich Ebert Foundation organized two international conferences on "Water Pollution in Jordan - Causes and Effects" (1990) and on "Jordan's Water Resources and Their Future Potentials" (1991). The book written by Prof. Elias Salameh and Helen Bannayan represents both integration and expansion of the major findings of these conferences and proposes solutions to meet the future challenges of increased demands and limited supplies: increasing the local water supply; efficient use of the available supply; intrastate water transfer and regional cooperation; and restrictions on water use.

Supporting this publication the Friedrich Ebert Foundation hopes to contribute to rationalize the water discussion both in Jordan and the region and to make water a catalyst of cooperation rather than a substance of conflict.

Dr. Andrae Gaerber
Representative of the
Friedrich Ebert Foundation
Amman

Foreword
RSCN

The problem of water scarcity is a critical one that has occupied many scientists throughout recent times. There has been a massive increase in the global population during the latter half of the twentieth century. Coupled with the exploding water needs of an industrialized society, this has placed tremendous strain on a limited water supply.

The situation in Jordan is even more critical. The need for water will increase at high rates in the near future because of several factor: mainly, the high rate of increase in population, the rise in water consumption per capita and the growing demand for water to meet the needs of socio economic growth for a better quality of life. This will happen at a time when the already scarce water resources in Jordan are being overexploited.

This water shortage is a problem we Jordanians have to live with and try to find solutions for. Every drop of water should be wisely managed and utilized. We may have to make painful decisions by redefining our priorities regarding water use thus shifting shares from agriculture into domestic and industrial use. Steps have to be taken to contain water pollution. We also have to face the rising cost of water in Jordan.

This book will be a very valuable and useful document that defines the problems and suggests constructive solutions. It will help set a framework for the discussion of water management, and it will lay an outline for the hard decisions that have to be made. The effort of the authors Prof. Elias Salameh and Mrs. Helen Bannayan is greatly appreciated and their work, which came about in part through a series of seminars and discussions of this problem involving many experts, contains advice that we would all do well to need.

The book starts with a definition of the scope of the problem and resources, and goes on to define how we can create solutions both by managing usage and by reducing waste. No address of the problem would be complete without this thorough analysis of both dimensions.

The Royal Society for the Conservation of Nature which has always been concerned with the problems facing our natural resources including water is very happy to be sponsoring this book and acknowledges the efforts of the coauthors and appreciates the assistance of the Friedrich Ebert Foundation for financing this project.

Dr. Anis Mu'asher
Royal Society for the
Conservation of Nature

Preface

During the years 1990 and 1991 two seminars concerning the water resources of Jordan were held at the University of Jordan in cooperation between the Friedrich-Ebert-Foundation and the University of Jordan with the assistance of the Higher Council of Science and Technology and the Goethe Institute in Amman.

The seminars entitled:

* Water Pollution in Jordan - Causes and Effects, and
* Jordan's Water Resources and their Future Potentials

were highly appreciated and received by concerned individuals. The proceedings of both seminars published in 1991 and 1992 respectively, were ordered by universities, scientists, research centers, national, regional and international organizations from within Jordan and abroad.

To date, orders for these proceedings continue, but soon both publications will be out of print. Instead of issuing new editions and because of the fragmentary nature of conference proceedings, Friedrich-Ebert-Foundation and the Royal Society for the Conservation of Nature agreed to support the publication of a new book about the water resources of Jordan.

The new book is designed to incorporate information about water resources, quality, treatment, pollution, future perspectives and economy in one document for use by experts, policy-makers and interested parties.

In this book the information about water resources quantities is primarily derived from the Ministry of Water and Irrigation. Information about water quality, pollution and waste water was gathered by the authors during their work at the University of Jordan.

Figures and numbers are interpreted according to valid norms and knowledge accepted in the scientific community. Future expectations are the results of the authors interpretation and analyses.

The authors highly appreciate the support and help granted by Friedrich-Ebert-Foundation (FES) and the Royal Society for the Conservation of Nature (RSCN).

Both Dr. Andrä Gärber, director of FES - Amman and H. E. Dr. Anis Muasher, president of RSCN, are sincerely thanked for their encouragement and great assistance.

We hope this book contributes an organized document about the water resources of the country to specialists, policy-makers and all those concerned with this vital life-giving resource.

Elias Salameh
(Prof. Dr.)

Helene Bannayan
(M.Sc. Eng.)

I

INTRODUCTION

Nature does not know water shortages, it is we who perceive and suffer the shortage.

The scarcity of water resources in Jordan seems to be dictated by climatic conditions, such as aridity and abundance of high solar radiation, by population pressure as a result of natural multiplication and refugee waves coming to Jordan, and by the rapid development of the available potentials of the country to satisfy the needs of the growing population.

The increasing pressures on the available resources represent a challenge for scientists, engineers and policy-makers because the entire development of the country in the different fields depends on the availability of this vital resource.

To properly address the water problems in Jordan, basic background information concerning water resources, water use, technologies, pollution, future demand and the potentials of an economic approach towards sustainable development has to be made available.

Current sources contains only fragmentary information about the water resources of Jordan; a document about the status quo of the water sector in its different branches is lacking.

This book attempts to address the different aspects of Jordan's water resources, their development, management potentials, and their future prospects.

The first chapters (I, II, and III) of the book deal with the available resources, their quantities, qualities and distribution, and form the basis of any discussion about present and future planning. Chapters IV, V, VI and VII deal with the status quo of waste water treatment and reuse, water projects, water needs at present and in the future and water pollution. They illustrate human activities' effects on the water resources and vice versa.

Chapter VIII demonstrates the special features of the groundwater system in Jordan and their implications on water-related matters like oil and gas accumulation, hydrothermal energy, Dead Sea water levels and water radioactivity. It illustrates the vulnerability of the groundwater system to human activities and the sensitivity to quality deterioration.

In Chapter IX some ideas are put forward to demonstrate the economic and social dimension of water resources, development, management and use. In this chapter it becomes most evident that population pressure coupled with financial, technical and time restrictions have, in the last few decades, given the society of

Jordan only limited choices to absorb the unemployed labor force as a means for survival. The prevailing conditions in the last 40 years forced Jordan into quick and easy solutions to its economic problems. Irrigated agriculture as a field of employment was the most attractive and reliable choice in creating jobs and easing the economic problems of the population. It was a relatively cheap investment, labor intensive with rapid returns and yields.

This same chapter shows that it soon became clear that in general, irrigation and agriculture have limitations conditioned by the natural environment of Jordan or, in more exact terms, its aridity is expressed in water shortages. Nevertheless, water shortage is in itself not a problem; but it is an expression of natural and social shortcomings, such as aridity, population pressure, lack of energy and a malfunctioning economy.

As a result, it seems that the simple solutions applied in Jordan until now to escape the population pressure and the urge for better living conditions have had water as a limiting factor. Therefore, the development which took place in Jordan, including population growth is imposed on the natural environment which is unable to yield more. Hence, solutions have to be man-made, more realistic, country-relevant and environmentally sound.

The options for solutions are few indeed, and as illustrated, economic restructuring offers the best option for solving the water problems, which may also lead to alleviating other problems.

1. Country Profile

Area: 89,900 km², (Fig. 1).
Population (estimated 1992) = 3.6 million
Rate of growth: 3.6% per year
Population projection: 4.7 million by the year 2000 and 6.8 million by 2010.

Economic sectors:

Agriculture ≈10%, industry 22%, services 68%.

Labor force:

Agriculture ≈11%, industry 27%, services 62%.

Literacy rate: ≈80%.

Export: Potash, phosphate, fertilizers, small industrial products, man power, vegetables and fruits.

Imports: Fuel, food (grain, meat, etc..), vehicles, heavy machinery, industrial plants, wood, iron, paper... etc.

Energy: Only very limited gas fields, large oilshale deposits which are not yet mined.

Food production covers around 50% of the country's needs.

2. Topography:

The country consists of different distinctive topographic units trending in a general north-south direction. These units seem to be dictated by a major geologic event which incorporates 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, with the corresponding highlands on both sides, sloping in Jordan to the steppe in the east.

The rift valley forms the western part of the country. It trends in a general north-south direction from the Gulf of Aqaba through the Dead Sea to Lake Tiberias. The elevation of the bottom of the valley ranges from sea level in Aqaba at the shores of the Red Sea to around 240m ASL at a distance of 80 km to the north. From there it drops gradually to about 400m BSL at the present shores of the Dead Sea and further to around 750m BSL at the bottom of the Dead Sea, (Emery and Neev 1967).

To the north of the Dead Sea the floor elevation rises gradually to around 210m BSL at the shores of Lake Tiberias.

This rift valley, with a length of 375 km, is about 30km wide in the area of Wadi Araba and narrows to around 4 km in the Lake Tiberias area.

The highlands east of the Jordan rift valley rise to elevations of more than 1000m ASL in the north at Ajlun and Belqa and to more than 1200m ASL in Shoubak and Ras El Naqab areas. The width of this zone ranges from 30 to 50 kms and extends from the Yarmouk River in the north to Aqaba in the south. These elevations drop gradually to the plateau in the east, but more sharply to the rift valley in the west. The mountains forming the highlands consist mainly of sedimentary rocks with deeply incised wadis draining in a westerly direction.

The steppe or plateau of Jordan developed at the eastern toes of the highlands with elevations of drainage areas ranging from 1000m ASL in the south to 700m in the north east. The deepest part of this plateau lies at an elevation of 500m ASL; Azraq Oasis.

The plateau is a peneplain with hills and weakly incised wadis, but generally a smooth topography. Surface water, if not captured by westerly draining wadis, discharge into desert

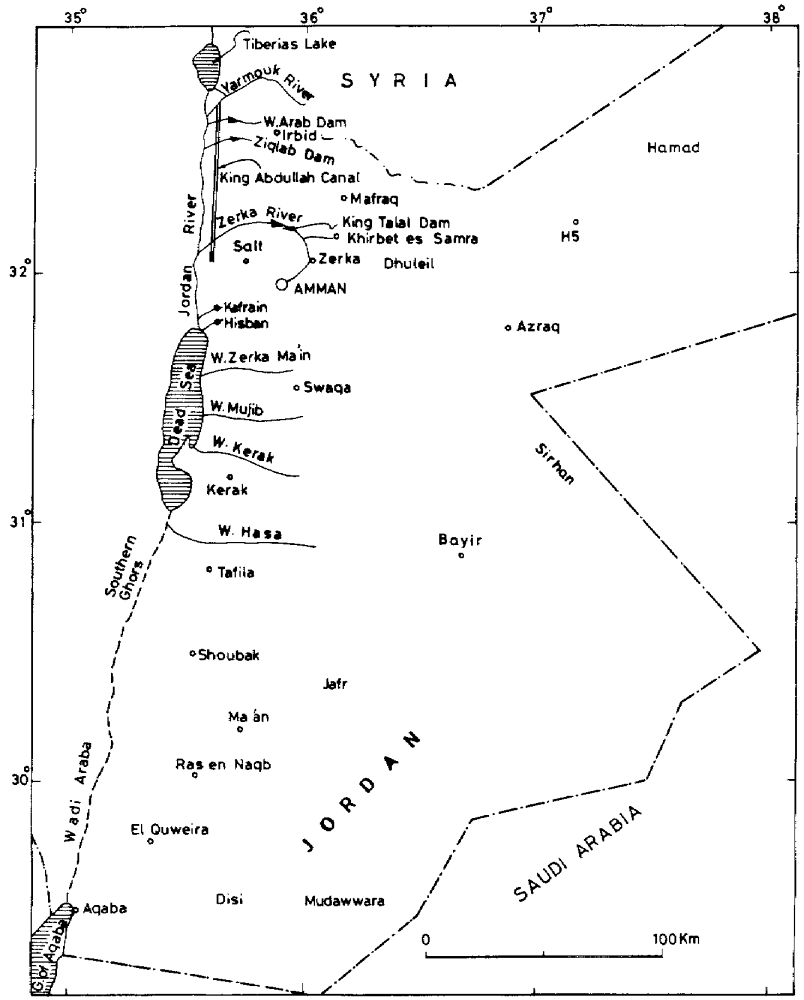

Figure (1) Location map

playas; qaas forming extended shallow lakes in winter and dry mud flats in summer.

The most southern part of the plateau which lies to the south of the Ras El Naqab escarpment is considered a different topographic unit, although it belongs to the same plateau. This is because it is separated from the plateau by the prominent topographic feature; the escarpment, because it drains to the Dead Sea and because of its steep topography dictated by different geology consisting of sandstones and granitic basement complex. The elevation of the area is around 900m ASL, with a north-south width of around 300 kms. This part of the country is sometimes referred to as the southern desert.

3. Climate:

Jordan can be classified as a semi-desert area. Only the highlands, with a width of around 30km and a length of some 300 km, enjoy a mediterranean type climate.

Temperatures in the Jordan Valley, Wadi Araba and Aqaba can rise in summer to 45°c with an annual average of 24°c. In winter the temperature in this area reaches a few degrees above zero. Frost is a seldom event.

Along the highlands the climate is relatively temperate; cold and wet in winter with temperatures reaching a few degrees below zero during the night, to hot and dry in summer with temperatures reaching 35°c at noon, but with a relative humidity of 15 - 30%, which makes the heat more acceptable. During the hot summer, temperatures at night drop to less than 20°c and cause dew to form.

The plateau; the eastern and southern deserts are hot in summer and cold in winter. The temperature may reach more than 40°c during summer days and drop in winter to a few degrees below zero, especially during the night. Also here, the relative humidy is low. In winter it is generally around 50 - 60%, and in summer it sometimes drops to 15%.

The low relative humidity throughout most of the year makes the hot summer days more tolerable and the cold winter days more severe.

4. Precipitation:

Precipitation (ppt) in Jordan falls normally in the form of rainfall. Snowfall occurs generally once or twice a year over the highlands. The rainy season extends from October to April, with the peak of precipitation taking place during January and February. These peaks become less pronounced the scarcer the rainfall an area receives (Fig. 2).

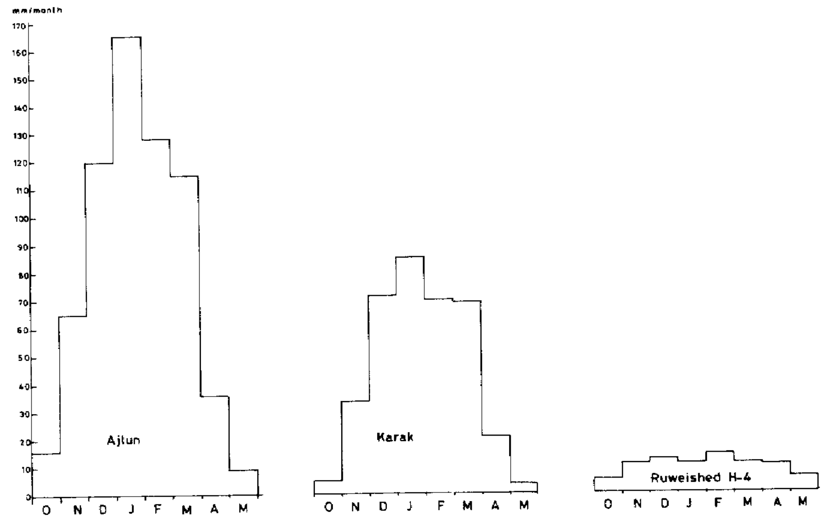

Figure (2) Monthly Rainfall Distribution (Average 1938 - 1990)

The highest rates of ppt are commenced over the highlands of Ajlun, Belqa, Karak and Shoubak which receive long-term annual averages of 600, 550, 350 and 300mm. To the east of these highlands, and more strongly to the west, ppt decreases drastically (Fig. 3a, 3b,3c), e.g.: it decreases from an average of 600 mm/year in Ajlun to 250 mm/year in the Jordan Valley within a distance of 10 kms and a difference in altitude of 1200m. The decrease in easterly direction is twice to three times slower than due west; e.g., from 300mm/year in Shoubak to 50 mm/year some 30 kms east of the town.

The maps in figures (3a, 3b, 3c) indicate the following facts about precipitation in Jordan:

- The average annual amount of water falling over Jordan's territories is 7200 MCM increasing to 12000 MCM in a wet year and decreasing to 6000 MCM in a dry year.

- Only around 1.3% of Jordan's area receive an average annual ppt of more than 500 mm, only 1.8% between 300 and 500 mm, 3.8% between 200 and 300mm, 12.5% between 100 and 200 mm and the rest of 80.6% receive less than 100mm/year.

Still, the above is an inadequate picture of Jordan's water situation. But knowing that only about 3% of the total area of the country receives an average annual amount of ppt exceeding 300mm may illustrate the situation better. Worth mentioning is that 300mm/year of ppt is the least amount needed to grow wheat in dry farming areas under the prevailing climatic conditions.

In addition, 83% of the total amount of ppt occurs in areas receiving less than 300mm/year, which means that only 17% of ppt can be used in dry farming. The rest of 83% requires certain technologies to be made available for the different uses. An exception, is range land, where 300 - 150mm/year of ppt may be adequate.

A part of ppt water flows in wadis, and it either collects in dams or in desert playas. Another part infiltrates and joins the groundwater resources of the country.

5. Evaporation:

The climatic conditions in Jordan do not only affect the amount and distribution of precipitation, but they also impact strongly on the potentials of evaporation.

The potential evaporation rates range from about 2000mm/year in the extreme northwestern edge of the country, to more than 4000mm/year in the Aqaba and Azraq areas.

Along the rift valley the potential evaporation increases from a minimum of 2000mm/year in the north, to some 2500mm/year in the Dead Sea and to more than 4000mm/year in Aqaba. These rates are 5 to 80 times the average amounts of ppt these areas receives.

Potential evaporation rates of the plateau areas increase in easterly and southerly directions. From an average of 3000mm/year at the eastern toes of the highlands to around 4000 in the center of the plateau. The southern desert exhibits potential evaporation rates of 3500 to 4400 mm/year.

Potential evaporation rates of the plateau and southern desert are 12 to 100 times the amount of ppt falling over these areas.

The high evaporation potential all over the country makes precipitation, especially in the eastern and southern parts of the country, ineffective because ppt-water readily evaporates, leaving soils deprived of their moisture contents and hence, not allowing for the development of plants.

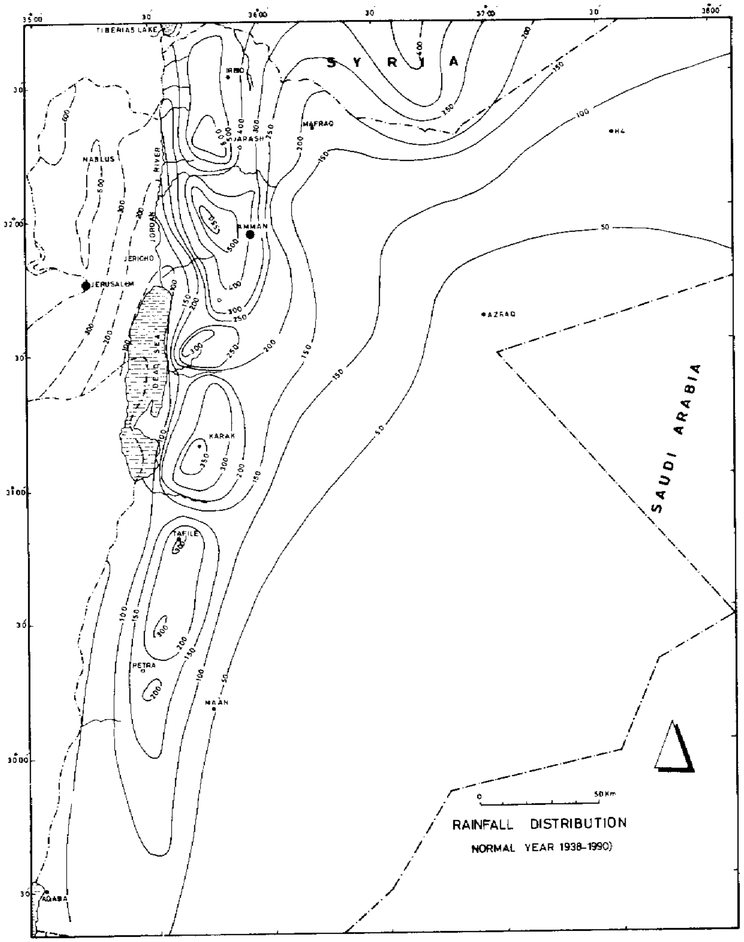

Figure (3a) Rainfall Distribution
(Normal year 1938 - 1990)

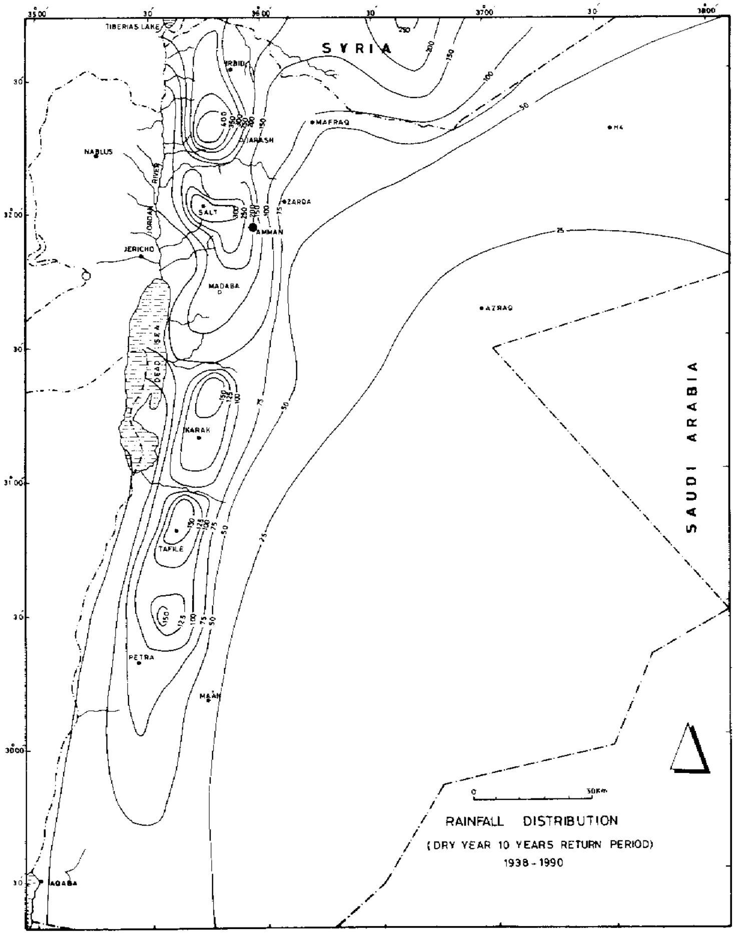

Figure (3b) Rainfall Distribution
(Dry year 10 years return period, 1938 - 1990)

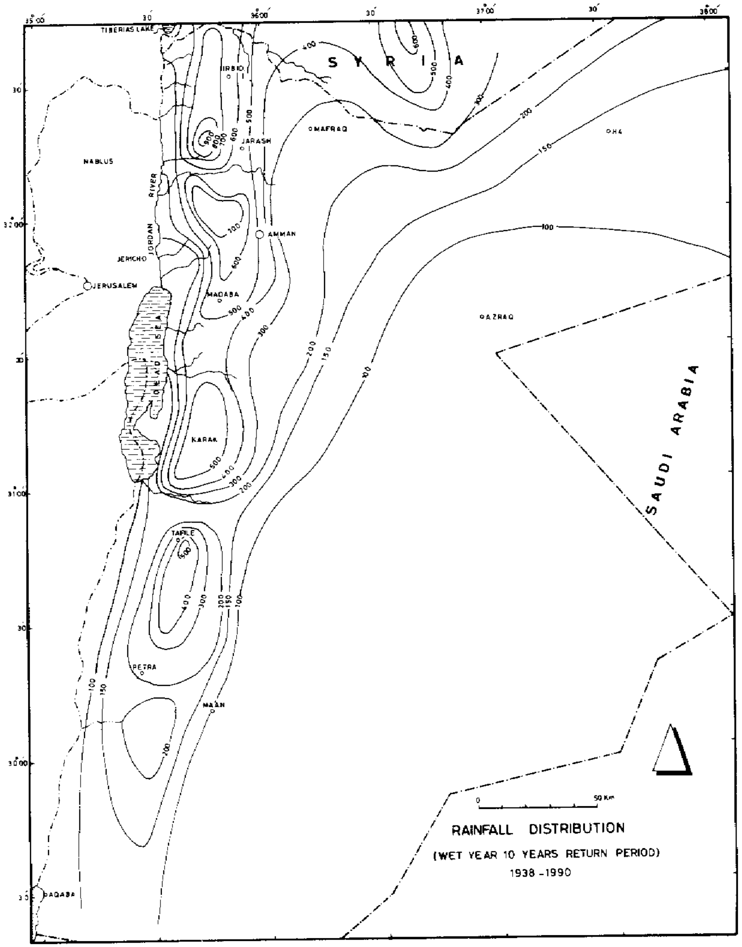

Figure (3c) Rainfall Distribution (Wet year 10 years return period, 1938 - 1990)

II

Surface Water Resources

Jordan does not possess rivers in the world-wide known scale, except the Jordan River which used to discharge around 1400 MCM/year into the Dead Sea before the development of the water resources in its catchment (Fig. 4). Even this river is a very small water source compared with international rivers like the Nile or Euphrates, because its total annual discharge amounts to only 1.5% of the former and 4.3% of the latter.

Other surface water resources in Jordan are found in the Yarmouk and Zerka rivers and in wadis like Karak, Mujib, Hasa, Yabis and El-Arab, in addition to small flood flow wadis in different parts of the country.

1. The Jordan River Area:

1.1. <u>The Jordan River:</u>

The initiation of the Jordan Graben (rift valley), as an offspring of the Great African Rift extending from Ethiopia through the Red Sea into Jordan, created a new base level for the surrounding surface and groundwater.

The deepening of this graben (Dead Sea Level 1992, 402m BSL) attracted increasing catchments of surface and groundwater into its trough. Gradually the surface catchment of the Dead Sea rose to around 40,000 km². The main tributary of the Dead Sea is the Jordan River which drains all the northern, relatively rain-rich catchment. The eastern and western catchments of the Dead Sea are very small and hence, their resultant contributions. The southern catchment, consisting of the northern part of Wadi Araba and its eastern and western highlands, is poor in ppt and small in area so that its contributions to the Dead Sea are very minor.

The surface catchment area of the Jordan River is 18,194 km², of which 2833 km² lie upstream of the Lake Tiberias outlet. The eastern catchment area, downstream of Tiberias, measures 13,027 km², and the western, 2344 km².

The headwaters of the Jordan River originate from three main springs: Hasbani in Lebanon; Dan in Israel; and Banias in Syrian territory occupied by Israel (Fig. 5). The three streams join in Israel to form the Upper Jordan River. The surface catchments of the springs do not alone account for the large quantities of water discharged from them; therefore, their underground watershed must extend further to the north, northeast and eventually north-west, beyond the surface catchments and into Syria and Lebanon.

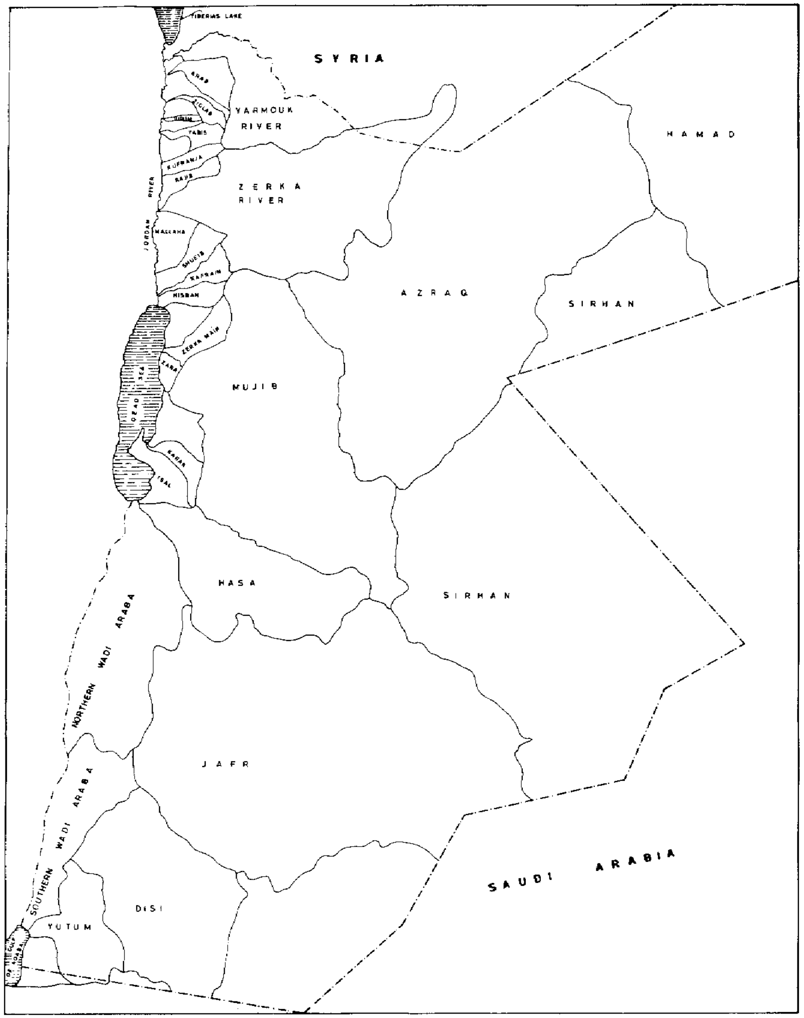

Figure (4) Surface Water Catchments

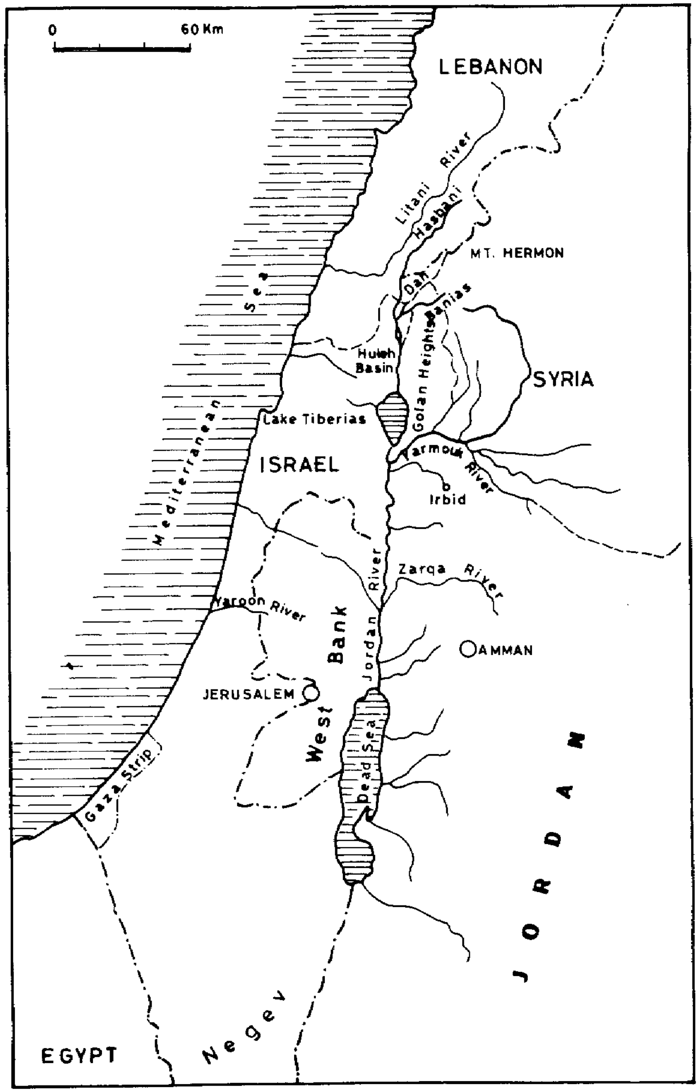

Figure (5) The Jordan River System

The upper Jordan River once flowed into Lake Hula, where more water joined the river course. In the 1950s, however, Lake Hula and the surrounding area were drained and dried; since then, the water has flowed through the so-called Hula valley, joining Lake Tiberias further to the south.

Downstream of Tiberias is the onset of the Lower Jordan, where different streams join the main river course. The biggest of these are the Yarmouk and Zarka Rivers, which join the Lower Jordan from its eastern side. The Yarmouk flows from Jordan's borders with Syria and the Occupied Territories, while the Zarka River lies within Jordan. The Jordan River then flows into the exitless Dead Sea.

The total discharge of the Jordan into the Dead Sea -- prior to the implementation of the different water projects in Jordan, Syria and Israel -- was 1370 MCM/year. This amount has now declined to a mere 250-300 MCM/year -- mostly as irrigation return flow, inter-catchment runoffs or saline spring discharges.

Israel uses all the water of the Upper Jordan (a net total of 650 MCM/year), so that no fresh water flows downstream of Lake Tiberias from the Upper into the Lower Jordan River, except during very wet years when Lake Tiberias can not accommodate the total inflows, as happened in the rainy years 1991/1992, 1992/1993.

Saline springs in the immediate surroundings of Lake Tiberias and at its bottom are channelled downstream of Tiberias into the headwaters of the Lower Jordan River.

The discharge of the Yarmouk River into the Jordan River was around 400 MCM/year prior to the use of the water by the different riparians. In the last few years, this amount has gradually declined to very small discharges, only as a result of large floods which cannot be accommodated by the existing extraction facilities.

The other wadis and springs on both sides of the Jordan Valley are dammed or captured by other constructions. That which remains - runoffs due to rains over areas downstream of water collection constructions, return flows or saltwater discharges -- then joins the river.

From the Yarmouk River, Syria extracts 160 - 170, Jordan 100 - 110 and Israel around 100 MCM/year.

1.1.1. Water sharing: recent history

In the case of the Jordan River system, there are no valid agreements pertaining to sharing the jointly-owned water resources. An agreement was signed between Syria and Jordan in 1953 regarding water allocation of the Yarmouk River, providing for the construction of a dam on the Yarmouk River and the subsequent division of water resources at a ratio of about 1:3 between Syria and Jordan, respectively. Revisions were made in 1987, and according to the new agreement, Jordan was supposed to construct the Unity Dam on the Yarmouk River, designed to collect 180 - 200 MCM/year of water for its own use.

Because of water scarcity in the Jordan area, a very small river like the Jordan represents a vital source of water for its riparian states.

Plans to develop water resources go back to the 1940s and 1950s, when different countries developed individual programs for water utilization. The disparities found among these plans led U.S. President Eisenhower to send a special envoy, Eric Johnston, to the area in 1953 to design a comprehensive proposal for sharing the Jordan River water. After two years of negotiations, Johnston offered a plan which was accepted by the Arab and the Israeli technical committees, but the Arab League refused to ratify the plan for political reasons.

According to the plan, the Upper Jordan and the Yarmouk waters were to be shared as follows:

Table 1
Johnston Plan allocations: MCM/year

	Syria	Lebanon	Jordan	Israel
Jordan River	42	35	100	375*
Yarmouk River	90	00	377*	25**

* The rest: what remains in the river after extracting the fixed shares.
** The Yarmouk Triangle: water allocated for irrigating the Yarmouk Triangle between the Jordan River, the Yarmouk River and Lake Tiberias.

At present, Jordan takes only 100-110 MCM\year from the Yarmouk River and no water from the Jordan

River. Syria takes 160-170 MCM-year from the Yarmouk and nothing from the Upper Jordan. Lebanon takes nothing from the Jordan River, while Israel takes 650 MCM\year from the Jordan and around 100 MCM\year from the Yarmouk.

By comparison, Jordan is the major loser and Israel the major winner.

1.2. Yarmouk River

The Yarmouk flows at the borders of Syria and Jordan and joins the Jordan River in an area partly occupied by Israel (Fig. 6). The river drains both flood and base flows of Jordanian and Syrian territories. The total catchment area of the river measures 6790 km^2, of which 1160 km^2 lie within Jordan upstream of Adasiya and the rest within Syria and in the Jordan River area downstream of Adasiya.

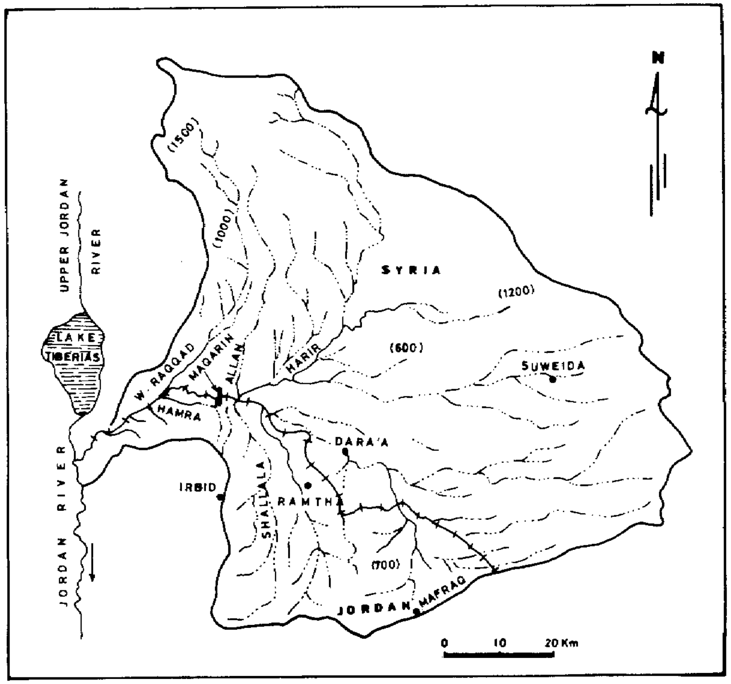

Figure (6) Catchment Area of the Yarmouk River.
(700): Area Elevation m ASL

Along its course from the foothills of Jabel Druz to its confluence with the Jordan River, different wadis and creaks join the Yarmouk. The most important of them, in terms of water quantities, are Harir, Allan and Raqqad in Syria and Shallala and El Humra in Jordan.

The catchment area of the Yarmouk River is agrarian, with small types of industries located in the main towns in Jordan and Syria. The small effluents of two wastewater treatment plants (stabilization ponds) reach the river during floods. Also, the leachates of El Ukheider solidwaste disposal sites directly reach the river course on days when their liquid loads exceed evaporation and infiltration potentials.

The average annual, rainfall over the catchment area is 372 mm/yr. In the northwestern parts of the catchment which border on the Hermon Mountains, precipitation increases to an average of more than 1000 mm/yr. It decreases to 250 mm in the southeastern corner of the catchment (Fig. 7).

Precipitation all over the catchment and especially in its northwestern parts may fall in the form of snow.

The potential evaporation ranges from 3300mm in the southeast to some 1500mm in the northwest, indicating that there is not enough water to satisfy the evaporation force of the climate. Since precipitation takes place during the rainy season, when the evaporation is minimum, precipitation water is allowed to infiltrate and recharge the aquifers.

The discharge of the Yarmouk River in Adasiya during the forties, fifties and beginning of the sixties of this century is given in the literature to equal 467 MCM/yr. (1927-1954). More recent measurements, although masked by unknown usage of the riparians, indicate a decline in the river discharge, conditioned by: increasing extractions from the groundwater in the catchment area, which leads to declining base flow; and decreasing precipitation in the last five decades, as illustrated in Table 2 which shows the development of the average amounts of precipitation in relevant stations of the catchment area.

Table 2
Average precipitation for 10-year periods: 1938 to 1988 (mm/yr.)

Name of station	1938-1947	1948-1957	1958-1967	1968-1977	1978-1987
Um Qeis	520	480	458	336	342
Irbid School	512	442	330	355	360
Ramtha	330	286	267	242	248

The average decrease in precipitation during the last five decades averaged 30%.

The river flow during the period 1950 to 1976 averaged 400 MCM/year. Recent measurements of flows and estimates of riparian extractions indicate an average total discharge of around 360 MCM/year.

The water quality of the Yarmouk River reflects the land uses within the catchment area which are still restricted to rainfed and some irrigated agriculture. Pollution parameters can be measured in the discharged water especially during low flows.

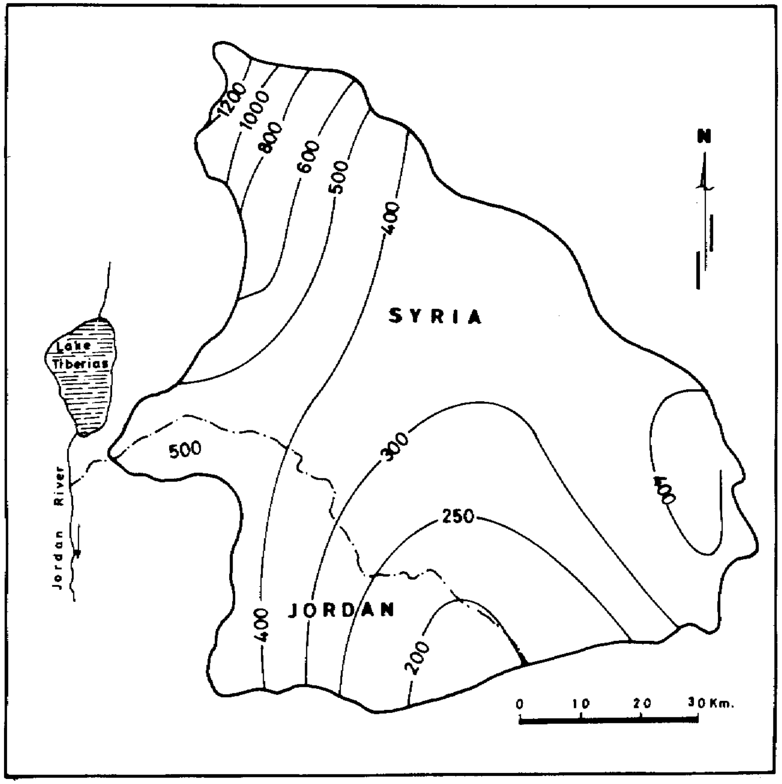

Figure (7) Long-Term Average Precipitation, Yarmouk Catchment.
———— 400 mm/year

Table (3) shows the water quality of the river during floods and during low summer flows.

Table 3
Water quality of the Yarmouk River at the end of the rainy season and at the end of the dry season

Date: 17.03.91			09.91
EC μS/cm		813	1000
pH		7.98	8.43
NO3	meq/l	0.18	0.35
HCO3	meq/l	3.38	4.39
SO4	meq/l	1.36	0.84
Cl	meq/l	2.95	3.63
Ca	meq/l	2.36	2.97
Mg	meq/l	2.37	2.66
Na	meq/l	4.0	3.52
K	meq/l	0.08	0.16
Br	mg/l	1.62	2.10
COD	mg/l	57.0	9.63
PO4	mg/l	0.18	0.8

1.3. Zerka River:

This river is the second largest in Jordan in the area of its drainage basin and its mean annual discharge. The catchment area measures 4025 km² and extends from the foothills of Jabel Druz to the Jordan River (Fig. 8).

The river consists of two main branches; Wadi Dhuleil, which drains the eastern part of the catchment area, and Seel-Zerka, which drains the western part. Both meet at Sukhna to form the Zarka River. Naturally, the eastern branch drains only flood flows as a result of precipitation, whereas the western branch drains flood and base flows.

Much evidence indicates that historically (geologic), the river was discharging into Azraq and Wadi Sirhan in the east. But, in its recent history retrogressive erosion diverted the flow direction in the Zerka - Sukhna area to the west and allowed the river water to reach the Jordan Valley area and to discharge via the Jordan River into the Dead Sea.

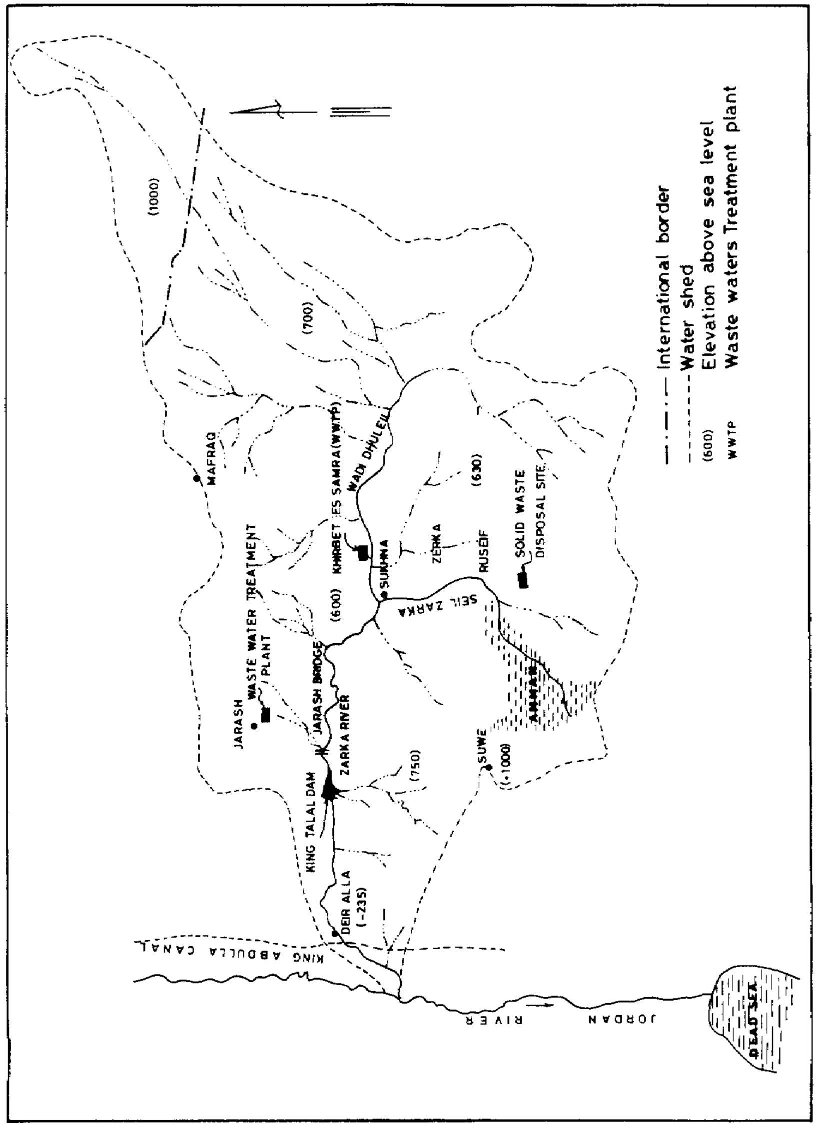

Figure (8) Catchment Area of Zerka River

The most densely populated area in Jordan, the catchment area of Zerka River comprises around 65% of the country's population and more than 80% of its industries.

The urban waste waters are generally sewered and treated in different wastewater treatment plants to varying degrees. Also, most industries located in the catchment area treat their waste waters before discharge into the surface water system.

In addition, solidwaste disposal sites are located within the catchment area. Their leachates reach surface and groundwater resources, causing local pollution and threatening to contaminate the aquifers.

The catchment area of Zerka River receives an average annual precipitation of 237mm. The eastern catchment, which comprises around half of the total catchment area, receives an average amount of precipitation of 182 mm/year. The middle part, between the eastern catchment and the western highlands, receives an average of 243 mm/year. The western catchment, comprising the highlands and the Jordan Valley area, receives an average of 397 mm/year.

Precipitation over the highlands may be in the form of snow; in the eastern part of the catchment it is generally rainfall.

The highest amount of precipitation falls over the highlands of Salt and Amman. In an average year it reaches 550mm; it increases in a wet year to 750mm and decreases in a dry year to 350mm. In the most eastern part of the catchment the average precipitation in a normal year is 80mm, increasing to 150mm in a wet year and decreasing to 50mm in a dry year.

The potential evaporation ranges from 1600mm/year along the western highlands, to 2000mm/year in the eastern part of the catchment. Meanwhile, there is not enough water to satisfy the needs of the evaporation force of the climate, which is far less during the winter months than during the summer months -- a fact which allows precipitation water to infiltrate and recharge the ground water during the rainy season.

The average annual discharge of Zerka River at Deir Alla for the years 1950 to 1976 was 64.88 MCM/year. After 1976, the natural system of the river was changed by different factors like constructing the King Talal Dam on the Zerka River (1977), importing water into the catchment area for domestic and industrial uses and discharging their effluents to the Zerka River system.

Such activities controlled the river flow and increased its discharge on the one hand, and negatively affected its water quality on the other.

The King Talal Dam on Zerka River was commissioned in 1977 with a total capacity of 56 MCM, which was raised in 1988 to 89 MCM. The natural flow of Zerka river can not fill the dam in an average year. But since increasing amounts of water were imported into the catchment area from other areas to satisfy the increasing effluents, 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 quality of the river changes dramatically between summer and winter. In winter, flood water constitutes most of the river discharge, and although it contains domestic refuse and wastewater, the quality remains acceptable for most uses (Table 4).

Table 4
Water quality of Zerka River at Jerash Bridge during the rainy and dry seasons

Date:		02.02.91	17.08.91
T°c		6.7	29.3
EC	µS/cm	766	3440
pH		7.45	8
NO3	meq/l	0.33	0.538
HCO3	meq/l	2.33	13.26
SO4	meq/l	1.45	1.27
Cl	meq/l	2.83	12.0
Ca	meq/l	3.00	4.55
Mg	meq/l	0.96	4.36
Na	meq/l	3.3	12.38
K	meq/l	0.34	1.33
PO4	mg/l	1.24	415.62
COD	mg/l	56.2	210.1
DO	mg/	7.6	3.3

In former decades and until the middle of the eighties, the water quality of the river was acceptable, even in the upper reaches. In the Ruseifa area, when in the summer it consisted of treated waste water, the water quality was satisfactory for irrigational uses. From there it improved gradually by flowing downstream due to self-purification of the river bed itself and the outflow of a better quality groundwater into the river.

After 1985, the water quality of the river deteriorated rapidly because of the inflow of the semitreated effluent of Khirbet es Samra wastewater treatment plant. This action rendered the water, especially that which collects in King Talal dam, unsuitable even for irrigation. (This subject will be discussed in detail in the chapter on pollution).

1.4. Wadi El-Arab:

The catchment area of Wadi El-Arab borders the Yarmouk catchment and measures 267km² (Fig. 4).

The average amount of precipitation ranges from 500mm over the highlands west of Irbid, to 350mm in the Jordan Valley (North Shuna). The potential evaporation ranges from 2000mm/year in the northwest, to 2400mm/year in the southwest of the catchment.

The average discharge of the wadi is around 28 MCM/year equally distributed between flood and base flows.

A dam was constructed on Wadi El-Arab in 1987, with a total capacity of 20 MCM to collect flood and base flows for use in irrigation in the Jordan Valley area. Since its completion the dam was filled by waters originating within its catchment only in the very wet year of 1991/92. In the other years, water was pumped from King Abdallah Canal during floods to increase the stored amount of water in the dam for use during the dry season.

The catchment area is agrarian, but Irbid City is expanding westward into the catchment which may put increasing pressure on the quality of the water collected in the dam.

The wastewater treatment plant for Irbid City was constructed in the upper reaches of Wadi El-Arab. And although the effluent of the treatment plant is piped to bypass the dam, floodwaters still enter the treatment plant and wash its contents and the wastes along Wadi El-Arab into the dam reservoir, negatively affecting its water quality.

Drilling of wells and pumping of water upstream of the dam resulted in groundwater level declines and hence the ceasing of groundwater natural discharges. In the last seven to eight years the drop in the ground water levels in Wadi El-Arab wells exceeded 20m -- a fact which questions the future reliability and durability of this drinking water source supplying Irbid governorate.

The water collected in the dam is generally of good quality and can be used for different purposes. When used for domestic purposes, conventional treatment of filtration and chlorination is sufficient. Of some concern is the relatively high trihalomethane potential, especially the formation of bromoform during the dry season upon water chlorination.

Table 5

Water quality of Wadi El-Arab Dam 26.05.1991

T°c		24.4	Ca	meq/l	1.2
EC	µS/cm	750	Mg	meq/l	2.2
pH		8.9	Na	meq/l	3.66
NO3	meq/l	0.18	K	meq/l	0.08
HCO3	meq/l	3.06	COD	mg/l	34.1
Cl	meq/l	2.74	PO4	mg/l	0.04
SO4	meq/l	1.06	Br.	mg/l	0.280

1.5. <u>Wadi Ziqlab:</u>

The catchment area of Wadi Ziqlab measures 106km² and extends from the Jordan Valley eastwards into the highlands (Fig. 4). Its eastern parts receive an average amount of precipitation of 550mm/year, whereas its western parts in the Jordan Valley receive only 300mm/year.

The potential evaporation ranges from 2050mm/year in the west to 2200mm/year in the east.

Various springs issue along Wadi Ziqlab with a total discharge of some 5 MCM/year. In addition Wadi Ziqlab drains another 5 MCM/year of floodwater.

A dam was constructed in Wadi Ziqlab with a total capacity of 4.3 MCM in 1966 and the aim of using its water for irrigation in the Jordan Valley area. The catchment area is agrarian with natural forests and very little population. Therefore, the water collected in the dam is of high quality and can be used for different purposes. For drinking uses the water has to be treated conventionally; filtration and chlorination as prohibitive measures. The water quality of the dam is illustrated in Table (6).

Table (6)
Water quality of Ziqlab Dam 28.07.1991

T°c		29
EC	µS/cm	600
pH		8.41
NO3	meq/l	0.1
HCO3	meq/l	4.28
Cl	meq/l	1.47
SO4	meq/l	0.46
Ca	meq/l	2.1
Mg	meq/l	3.21
Na	meq/l	1.33
K	meq/l	0.1
COD	mg/l	1960
PO4	mg/l	0.035
Br.	mg/l	0.82

1.6. <u>Wadi Shueib:</u>

Wadi Shueib drains an area of approximately 180km² lying to the west of Suweileh at elevations of 1200m down to below sea level (Fig. 4). Precipitation over the catchment area partly falls in the form of snow in its eastern parts and ranges on average from 500mm/year in Suweileh and Salt mountains to 150mm in the Jordan Valley area.

The potential evaporation ranges from 2700mm/year in the eastern parts to 2500 mm/year in the western parts.

The average natural flow of the wadi is 1.8 MCM/year as flood flow and 3.9 MCM/year as base flow. In addition the effluent of the Salt town wastewater treatment plant, one of the best- functioning in Jordan, is discharged into the wadi.

In the catchment area different towns and villages, like Salt, Fuheis and Mahis, discharge their treated and untreated wastes along the wadi and its tributaries.

A dam was constructed in Wadi Shueib in 1968 with a capacity of 2.3 MCM and the aim of using its water for irrigation in the Jordan Valley.

In addition to base and flood flows, this dam now receives irrigation return flows and the effluent of the well-functioning Salt town wastewater treatment plant.

The water quality of this dam is intermediate and can be used to irrigate all the crops produced in the Jordan Valley area. Attention should be paid if using drip or subsoil irrigation systems. Wadi Shueib, with a length of several kilometers and relatively high gradients, possesses a good self-purification capacity, but the waters which reach the dam still contain pollution parameters and relatively high concentrations of trace elements (Table 7).

Table (7)
Water quality of Shueib Dam
24.02.1991

T°c		20
EC	µS/cm	829
pH		8.98
NO3	meq/l	0.56
HCO3	meq/l	3.65
SO4	meq/l	1.05
Cl	meq/l	2.45
Ca	meq/l	4
Mg	meq/l	2.4
Na	meq/l	2.49
K	meq/l	0.2
COD	mg/l	25.3
PO4	mg/l	1.57
pb	mg/l	0.005
Mn	mg/l	0.3
Fe	mg/l	0.15
Br.	mg/l	1.5

1.7. Wadi Kafrain:

Wadi Kafrain drains an area west of Amman with an extent of 189 km² lying at elevations ranging from 1200m ASL down to areas lying below sea level in the Jordan Valley (Fig 4). Precipitation in the eastern parts of the catchment, averaging 550mm/year, may fall in the form of snow, whereas in the western parts the average reaches only 150mm/year and falls completely in the form of rain.

The potential evaporation ranges from 2700mm/year in the eastern parts to 2400 mm/year in the western parts.

The average discharge of Wadi Kafrain is 6.4 MCM/year, consisting of 1.6 MCM/year flood flow and 4.8 MCM/year base flow. In addition, Wadi Sir and Hussein Medical Center waste water treatment plants end up in Wadi Kafrain or its tributary wadis.

In the catchment area different towns and villages, like Wadi Sir and Naur, discharge their wastes along Wadi Kafrain or its tributaries.

In 1968, a dam was constructed at the entrance of Wadi Kafrain into the Jordan Valley with a capacity of 3.8 MCM. This dam now serves as a storage facility for irrigating downstream lands and for recharging the underlying aquifer.

At present, the dam receives in addition to flood and base flows, irrigation return flows, treated and untreated waste waters and groundwater discharged from

artesian wells drilled into the lower pressurized aquifer. Hence, it receives good quality water from springs and artesian wells, medium quality water of floods mixed with treated and untreated waste waters and bad quality water from irrigation return flows and wastewater treatment plants (Table 8).

Table (8)
Water quality of Kafrain Dam
Data 22.04.1991

T°c		26.7	Na	meq/l	2.65
EC	µS/cm	890	K	meq/l	0.15
pH		832	PO4	mg/l	0.35
NO3	meq/l	0.32	DO	mg/l	4.5
HCO3	meq/l	3.67	Br.	mg/l	1.5
SO4	meq/l	1.76	Fe	mg/l	0.3
Cl	meq/l	2.94	Zn	mg/l	0.03
Ca	meq/l	3.6	pb	mg/l	0.01
Mg	meq/l	2.8			

Generally the water can be used for irrigation. Using subsurface or drip irrigation is not advised. It is also not recommended to use the water as a source for possible domestic uses because of the water's high trihalomethane potentials, high biological contamination and high algal concentration, which will make the purification process very difficult and ineffective.

1.8. Other wadis discharging into the Jordan Valley.

These wadis are not damed and include Yabis, Kufranja, Jurum, Rajib, Hisban and other small catchments (Fig. 4).

The rainfall on these areas ranges from 150 mm/year up to 550 mm/year, with potential evaporation rates ranging from 2100 mm/year to 2700 mm/year.

The base flow of these wadis is used in irrigation along their courses and partly at the foothills on the Jordan Valley. Flood flows still reach the Jordan River lower stem.

Since the amount of discharge is relatively small and since the base flow which makes around 70% of the total discharge is being used, constructing dams on each wadi will be very expensive and of little efficiency. But one can think of diverting the flows of a number of wadis into the Jordan Valley area and constructing collective dams for them or using the flood water to artificially recharge the shallow aquifers in the Jordan Valley area via spreading basins or small weirs.

Table (9)
The area and average annual discharges of other wadis discharging into the Jordan Valley

Catchment	Area km²	Discharge MCM/yr
Yabis	124	3.1
Kufranja	111	6.0
Jurum	22	11.0
Rajib	85	4.3
Hisban	82	3.1
Other small catchment (total)	436	estimated 18

The water quality of these wadis is good and can be used for irrigating all the crops produced in the Jordan Valley area. Table (10) gives an example of the water quality of these wadis.

Table (10)
Examples of water qualities of small wadi catchments

		Wadi Kufranja	Wadi Zamaliya
Date		03.02.1991	27.01.1990
T	c°	9.4	16.8
EC	µS/cm	890	860
pH		8.33	8.51
NO3	meq/l	0.62	0.21
HCO3	meq/l	4.82	4.64
SO4	meq/l	1.24	1.42
Cl	meq/l	1.96	1.86
Ca	meq/l	4.4	4.3
Mg	meq/l	2.0	2.8
Na	meq/l	1.9	2.2
K	meq/l	0.26	0.15
PO4	mg/l	0.43	0.03

2. Dead Sea Wadis:

2.1. Wadi Zerka Ma'in:

The catchment area of Wadi Zerka Ma'in measures 272 km² and ranges in elevation from 1000m ASL to 400m BSL (Fig. 4). Precipitation over the catchment falls in the form

of rain and ranges from 350 mm/year in the highlands surrounding Madaba city to 100 mm/year at the shores of the Dead Sea.

The potential evaporation rates range from 2900 mm/year in the east to 2400 mm/year in the west at the shores of the Dead Sea.

Zerka Ma'in discharges directly into the Dead Sea an average amount of 23 MCM/year, of which only around 3 MCM/year as flood flows and 20 MCM/year as base flow. The base flow consists of thermal water issuing from tens of springs ranging in discharge from seepage size to 150 l/s.

A relatively large spa has been constructed there to serve as a therapeutic center utilizing the thermal mineral water of the springs. Table (11) gives the average composition of the thermal water:

Table 11
Chemical composition of
Shallala Spring Ma'in No. 47

(average of 3 years, 36 samples)

T	c°	56.6	CO²	mg/l	241.66
pH		6.33	F	mg/l	0.38
EC	µS/cm	3050	Br.	mg/l	7.75
Na	meq/l	19.6	I	mg/l	0.089
K	meq/l	1.14	Fe	mg/l	0.099
Mg	meq/l	3.26	Mn	mg/l	0.599
Ca	meq/l	7.22	Sr	mg/l	4.078
Cl	meq/l	21.57	H2S	mg/l	0.166
NO3	meq/l	0.063	NH4	mg/l	0.946
SO4	meq/l	3.83	Rn	nCi/l	4.18
HCO3	meq/l	4.81			

The therapeutic agents are: heat, up to 63c°, radon gas up to 8 nCi/l and bromide up to 9.9 mg/l.

The water of Wadi Zerka Ma'in shows at its inlet into the Dead Sea the following composition (Table 12):

This is defined as brackish water, but such water can still be used for the irrigation of crops tolerating medium salinity, especially if the irrigated land is properly drained.

Table (12)
Water quality of Zerka Ma'in discharge into the Dead Sea

EC	µS/cm	2780	NO3	meq/l	0.02
Ca	meq/l	4.75	F	mg/l	0.4
Mg	meq/l	7.42	I	mg/l	0.07
Na	meq/l	14.35	Br.	mg/l	5.3
K	meq/l	0.9	Fe	mg/l	0.002
Cl	meq/l	19.9	Ma	mg/l	0.05
HCO3	meq/l	4.08	Sr.	mg.l	3.6
SO4	meq/l	4.56			

Such water can also be easily desalinated and used for domestic purposes. This is especially valid if reverse osmosis desalination is used, because it requires pressure, and pressure head is available in this case.

2.2. Wadi Mujib (including Hidan):

The catchment area of Wadi Mujib measures 6,596 km² and ranges in elevation from 1100m ASL to 400m BSL(Fig. 4). Precipitation over the catchment area falls in the form of rain and seldom in the form of snow. It ranges from 350 mm/year along the mountain highlands to 100 mm/year at the shores of the Dead Sea.
The potential evaporation in this catchment ranges from 2450 mm/year at the shores of the Dead Sea to 3500 mm/year in the eastern part of the catchment.

The rocks forming the catchment area consist of fractured limestones, dolomites, shales, sandstones and chert beds, which allow precipitation water to infiltrate into the aquifers. But the wadis in the area, especially Hidan (Wala) and Mujib are deeply incised and hence are strongly draining surface and groundwater bodies.

Wadi Mujib downstream of the confluence of Wadi Hidan discharges an average amount of 83 MCM/year directly into the Dead Sea.

Half of the river flow consists of base flow and the other half of flood flows.

The lower reaches of the wadi system contribute with an average base flow of around 30 MCM/year of mostly lightly mineralized water issuing from the sandstone aquifer complex. The salinity of some springs resembles those of Zerka Ma'in, containing around 2000 mg/l of dissolved salts.

The catchment area is sparsely inhabited, with moderate agricultural activity and almost no industry. Therefore, water pollution is not a major issue in Wadi Mujib area.

The water of the upper reaches of the wadi is of low salinity and is suitable for different uses (Table 13). Along the lower reaches, especially during the dry season when the water flowing along the wadi mainly consists of spring flow, the salinity rises, and the water itself can only be used in irrigating salt-tolerant crops (Table 13). During floods, the water quality is intermediate, with a salinity at the mouth of Wadi Mujib of around 1200 µS/cm.

Table 13
Water quality of Wadi Mujib

		Wadi Hidan	Wadi Mujib mouth	
Date:		17.02.1990	14.08.1991	11.03.1990
EC	µS/cm	480	1830	1455
pH		8.05	7.55	8.45
NO3	meq/l	0.1	0.08	0.06
HCO3	meq/l	2.9	5.10	4.15
SO4	meq/l	0.77	3.94	5.1
Cl	meq/l	1.30	7.04	6.4
Ca	meq/l	2.50	7.62	4.8
Mg	meq/l	1.20	5.35	4.7
Na	meq/l	1.50	7.91	6.05
K	meq/l	0.15	0.3	0.15
Br.	mg/l	0.33	1.20	0.82
F.	mg/l	0.43	0.60	0.42
PO4	mg/l	0.20	0.2	0.30

Between Wadi Zerka Ma'in and Wadi Mujib (Zara area), tens of thermal springs issue along the lower lying areas of the slopes overlooking the Dead Sea. Their water quality resembles that of Zerka Ma'in, with the main difference being the lower salinities. The total discharge of Zara springs is set at around 6 MCM/year.

2.3. Wadi El-Karak:

The catchment area of Wadi El-Karak measures 190 km² and lies at elevations ranging from 1000m ASL to 400m BSL (Fig. 4). The average precipitation falling over the catchment area ranges between 350 mm/year in the high mountains and 100 mm/year along the shores of the Dead Sea. The potential evaporation ranges from 2600 mm/year at the shores of the Dead Sea up to 3100 mm/year along the highlands.

The catchment of Wadi El-Karak is a moderately inhabited and agrarian area. It includes the city of Karak and numerous towns and villages. Karak city possesses a waste water treatment plant the effluent of which discharges into Wadi Karak.
As in the case of other Dead Sea wadis, the lower reaches of Wadi El-Karak are rich in springs and water seepage issuing from the sandstone aquifers.

The average discharge of Wadi El-Karak is around 18 MCM/year, of which 15 MCM/year issue as base flow. The base flow is generally used in irrigation along the intermediate reaches of the wadi.

The water quality of upper Wadi El-Karak is of low salinity, but it shows pollution signs (Table 14), whereas that of lower Wadi El-Karak has a higher salinity, but lower concentration of domestic pollution parameters and higher concentrations of agricultural pollution parameters.

Table 14
Water quality of Wadi El-Karak

		Upper Wadi El-Karak Date: 16.04.1991	Lower Wadi El-Karak Date: 22.05.1991
EC	µS/cm	780	1050
pH		8.2	7.8
Ca	meq/l	2.04	3.58
Mg	meq/l	1.60	2.82
Na	meq/l	4.2	3.72
K	meq/l	0.14	0.20
HCO3	meq/l	2.14	3.80
Cl	meq/l	3.82	4.2
SO4	meq/l	1.76	2.4
NO3	meq/l	0.42	0.32
PO4	meq/l	0.46	0.30
Br.	mg/l	0.24	0.36

The higher salinity of the water along the lower reaches to the Dead Sea is caused by the discharge of groundwater with higher salinities, irrigation return flows and possible contacts with Lisan Formation, which consists of saline deposits.

2.4. Wadi Hasa:

The catchment area of Wadi Hasa lies to the southeast of the Dead Sea, but the water flowing in Wadi Hasa discharges directly into the Dead Sea, hence, it is considered one of the Dead Sea catchments. The catchment area measures 2520 km² and is the second largest among the Dead Sea catchments after Mujib.

Precipitation over the area ranges from 300 mm/year along the highlands down to 100mm/year in the Dead Sea area and 50mm/year over the eastern parts of the catchment. Precipitation over the highlands sometimes falls in the form of snow.

The potential evaporation rates range from 2800 mm/year in the Dead Sea area up to 3900 mm/year in the eastern parts of the catchment.

The catchment area is sparsely populated, with no industries and very low agricultural activities. Therefore, it is not expected that water pollution has taken place.

The average discharge of Wadi El-Hasa is around 34 MCM/year. Only about 2 MCM/year flow as floods, and the rest consists of groundwater discharges along the lower reaches of the wadi. Like the other catchments of the Dead Sea, the groundwater discharged along the lower reaches consists partly of mineralized thermal water.

The flood water of Wadi El-Hasa is of very low salinity and almost no pollution indicators (Table 15). Along the lower reaches, the salinity increases because of the discharge of thermal, partly mineralized water (Table 15). The high phosphates concentration is attributed to the presence of phosphate mines and mining activities in the catchment area.

Along Wadi Afra, a tributary wadi of Wadi El-Hasa and in Wadi El-Hasa itself, thermal springs issue from sandstone formations. These springs are considered excellent for therapeutic uses. A small spa now operates in Wadi Afra. Table (15) shows the composition of one of the major thermal springs in Wadi Afra.

The therapeutic agents are heat, radon gas and carbon dioxide.

Wadi El-Hasa water is used in the southern Ghors for irrigation. Only flood flows still reach the Dead Sea.

2.5. Wadis between the major Dead Sea catchments:

Different small areas between the major Dead Sea catchments discharge directly into the Dead Sea (Fig. 4).

These areas between Wadi Hisban and Zerka Ma'in, Zerka Ma'in and Mujib, Mujib and Karak and Karak and Hasa measure a total of 972 km², with a total discharge of around 30 MCM/year. This discharge comes almost completely from groundwater issuing along the lower reaches of the wadis as thermal water.

The salinity of this water ranges from 1200 µS/cm up to 3500 µS/cm, with temperatures ranging from ambiant to 63c° in Zara springs. Some of these springs discharge H2S, gas and sulfur forms at the surface. Nonetheless, the water of these springs can be used in irrigating salt-semi-tolerant crops. The same water can also be desalted or mixed with better quality waters for different purposes.

Table 15
Water quality along Wadi Hasa and its main tributary Wadi Afra

		Wadi Hasa flood flow	Wadi Hasa base flow	Afra Thermal Water average
Date		20.03.1991	06.05.1991	06.05.1991
EC	µS/cm	301	1130	550
pH		8.38	7.4	7.0
NO3	meq/l	0.11	0.2	0.0
HCO3	meq/l	2.04	2.75	1.85
SO4	meq/l	0.48	1.44	1.36
Cl	meq/l	0.39	4.12	1.99
Ca	meq/l	1.6	3.0	2.32
Mg	meq/l	0.2	2.6	1.43
Na	meq/l	1.02	4.94	1.55
K	meq/l	0.09	0.36	0.06
PO4	mg/l	0.873	2.23	0.23
F	mg/l			0.25
Br	mg/l		1	0.76
I	mg/l			0.22
CO2	mg/l	0.0	0.0	90.0
H2S	mg/l	0.0	0.0	0.01
Fe	mg/l			0.65
Mn	mg/l			0.10
Rn	nCi/l	0.0	0.0	7.14

The eastern shore of the Dead Sea is a potential international spa center with around 90 MCM/year of thermal mineralized water being discharged. The qualities of the water differ from iron to radon to carbon dioxide to sulfur springs, giving the area an extreme therapeutic importance as a curative center.

3. Wadi Araba Catchments:

Wadi Araba itself is not a base level for either surface or groundwater. Both discharge either to the Dead Sea or to the Red Sea. The northern part of Wadi Araba discharges into the Dead Sea and the southern one into the Red Sea via the Gulf of Aqaba.

3.1. The Northern Wadi Araba Catchment:

The northern Wadi Araba catchment extends for about 100 km from the Dead Sea shore southward, with a width of 25 to 30 km and a total area of 2938 km². Precipitation falls in the form of rainfall, except on the highlands where it may fall in the form of snow. The average long term precipitation is 300 mm/year over the mountains and 100 mm/year in Wadi Araba area. The potential evaporation ranges from 2800 mm/year at the southern

shores of the Dead Sea to 3500 mm/year in the southeastern parts of the catchment.

Different wadis drain the catchment into Wadi Araba. The major ones are Wadi Fifa, Wadi Khuneizir, Wadi Fidan and Wadi Buweirida, with average discharge of about 11, 4, 5.5 and 3 MCM/year respectively. The major part of discharge comes from the base flow of the wadis.

In addition to the major wadis, numerous small ones drain the area. The overall total discharge of all the northern wadis into Wadi Araba is 26 MCM/year.

The flood flows which reach Wadi Araba infiltrate rapidly into the course-grained alluvial building the bottom of the wadi. They seldom directly reach the Dead Sea. But the infiltrated water flows in a northerly direction to reach the Dead Sea as seepage or submarine springs.

The catchment area is sparsely populated. The main centers are Tafila and Shoubak which are devoid of industries. Agriculture is practiced in the highlands, where rainfed crops are produced, and along the wadi courses and in Wadi Araba, where the base flows of wadis and pumped groundwater are used for irrigation. The area still possesses a certain potential for developing agriculture and for improving the efficiency of irrigation projects.

The domestic waste water of Tafila is treated in a waste water treatment plant, and the effluent is discharged along Wadi Fifa. The amount of effluent is very small (a few hundred cubic meters daily) and it infiltrates along the wadi and discharges with the groundwater issuing along the lower reaches of Wadi Fifa or it joins the groundwater in Wadi Araba.

The total groundwater throughput of northern Wadi Araba into the Dead Sea is calculated to average 22 MCM/year (Abu Zirr, 1989).

3.2. The Southern Wadi Araba Catchment:

The area extends around 75 km north of the Gulf of Aqaba, with a maximum E - W width of 30 km (Fig. 4). The total catchment area measures 1278 km², with an average precipitation of 150 mm/year in the northeastern parts and less than 50 mm/year in the southern parts and Aqaba area. The potential evaporation rates range from 3300 mm/year in the north to 4100 mm/year in the southern part.

The area is barren, with very low population density (less than 1 person/km²).

The type of climate and aridity do not support life and do not allow urbanization.

The total water discharge from the eastern wadis into the area is estimated at 1 MCM/year, indicating the very low potentialities of the area.

The throughput of southern Wadi Araba into the Red Sea is around 10 MCM/year. This groundwater originates as an aquifer to aquifer discharge coming from the eastern highlands.

At the southern end of Wadi Araba, a few kilometers from the Gulf of Aqaba, a flowless water treatment plant was constructed to serve Aqaba city. The semi-treated waste waters infiltrate into the alluvial aquifer and flow with the ground water towards the northern shore of the Gulf, which may threaten the water quality of that portion of the Gulf.

The original quality of the water in southern Wadi Araba showed no signs of pollution. But the water is brackish, with sodium chloride as the main salinity parameter.

The infiltration of the waste water treatment plant effluent has, in recent years, negatively affected the ground water quality as indicated from the analyses of the Palm Forest Well No. 1 (Table 16).

Table 16

Ground water quality of southern Wadi Araba
Palm Forest Well No. 1

Date: 24.03.1988	
EC µS/cm	1980
pH	8.05
T C°	28.4
Ca meq/l	3.6
Mg meq/l	2.7
Na meq/l	13.14
K meq/l	0.14
Cl meq/l	12.95
SO4 meq/l	2.97
HCO3 meq/l	2.67
NO3 meq/l	0.77
BOD5 mg/l	86.8
COD mg/l	125

4. Wadi Yutum Catchment:

Wadi Yutum catchment drains an extensive area in southwest Jordan, east of Aqaba into the Read Sea. The extent of the catchment is 4,440 km² (Fig. 4). Precipitation over the area falls in the form of rainfall and ranges from 150 mm/year in

the highlands to less than 50 mm/year in the central and eastern parts of the catchment area. The potential evaporation is very high and ranges from 3400 mm/year in the western parts up to 3800 mm/year in the eastern and southern parts.

Since the area is flat, precipitation water infiltrates into the barren rocks, mostly consisting of sandstones and weathered rocks.

There are no groundwater discharges in the area, and the surface water forms as floods resulting from intense precipitation. But even that is a very small amount of 1.5 MCM/year compared with the extent of the catchment area.

5. Jafr Basin Catchment:

Jafr Basin is an exitless depression in southern Jordan, with a catchment area of 12,200 km². It is a flat area bordering the highlands in the west (Fig. 4). The average precipitation ranges from 200 mm/year at the foot of the highlands to 30 mm/year in the middle and eastern parts of the catchment. The potential evaporation ranges from 3300 mm/year in the western parts of the catchment to 4000 mm/year in the center of the depression.

The total discharge of the catchment is around 15 MCM/year, of which 10 MCM/year flow as floods into the Jafr depression, where they either evaporate or infiltrate into the ground down there. The base flow, in the form of spring discharge, is totally used in irrigation.

In the early sixties, the groundwater resources were developed and used for irrigation. Due to over-pumping, the produced water became increasingly saline, and the water levels dropped rapidly. The project was abandoned in the seventies. What remained are very small farms for local production.

The catchment area is very sparsely populated, with Ma'an and Shoubak as major urban centers. Agriculture has been developed along the foothills of the mountains in the west by extracting groundwater. The main industry in the area is a cement factory located in the northwestern edge of the catchment.

No signs of pollution can be registered in the area as a whole, although local pollution by cesspool, solidwaste disposals and wastes of the cement factory (fuel, oil, dust etc..) is affecting the area.

6. Azraq Basin Catchment:

The Azraq Basin is an exitless depression in the eastern plateau of Jordan. The bottom of the basin lies at an altitude of 500m ASL. The drainage basin measures 11,600 km² and extends in the north beyond the borders of Jordan (Fig. 4).

Precipitation falls in the form of rain and ranges from 300 mm/year over the Jabel Druz southern slopes to less than 50 mm/year in the Azraq depression itself. The average precipitation over the area is 90 mm/year.

The potential evaporation ranges from 3300 mm/year in the northern parts of the catchment to 4000 mm/year in the central and eastern parts.

The total discharge into the basin is around 27 MCM/year, of which 15 MCM/year issue as groundwater from different springs in the Azraq Oasis itself. Surface water comes as floods from wadis pouring into the depression as a result of precipitation events over the catchment.

The surface water quality is excellent, but as soon as it mixes with the water in the Oasis it becomes saline.

Few dispersed urban centers and industries are found in the catchment area, but still with no major impacts on the water quality.

The only pollution concern nowadays is the wastewater of Azraq villages and the agricultural activities in their surroundings. But that is a problem of groundwater more than one of surface water pollution.

7. Hammad Basin Catchment:

Hammad Basin is a very large, flat plateau extending in four countries: Jordan, Syria, Iraq and Saudi Arabia. In Jordan, the area measures 19,270 km² (Fig. 4).

Precipitation over the area ranges from 150 mm/year to 50 mm/year, with potential evaporation rates of 3800 mm/year. Since the area is flat, different surface water collection sites (playas) developed. As a result of precipitation, during the rainy season hundreds of flat areas fill with up to two meters of water, which either evaporate or infiltrate to the underlying aquifers and flow very slowly to ultimate base levels like Sirhan depression, the Dead Sea or the Euphrates area. What remains in the playas after evaporation are salty silts waiting for the next flood.

The amount of surface runoff is relatively small and averages 5 MCM/year, whereas the groundwater which forms in the area averages around 10 MCM/year.

Generally, the water is of relatively high salinity 1500 - 2000 µS/cm. Before it collects in playas, the salinity of the water is low, around 200 µS/cm (Table 17).

This water quality is excellent for different uses. But, as soon as the water collects in the playas, it dissolves the salts which accumulated in previous years as a result of evaporation, and it becomes saline.

The area possesses a certain potential for surface water harvesting in small weirs. The collected water can then be used in limited irrigation or groundwater recharge.

Table 17
Flood water analysis Ruweished area

Date		24.02.1990
EC	µS/cm	197
pH		8.45
NO3	meq/l	0.05
HCO3	meq/l	1.25
SO4	meq/l	0.25
Cl	meq/l	0.2
Ca	meq/l	1.05
Mg	meq/l	0.10
Na	meq/l	0.47
K	meq/l	0.08
PO4	mg/l	0.07

III

Groundwater

Groundwater can generally be of recent or of old recharge, which, for its extraction, is a vital issue of sustainability and continual yield. Hence, two terms in groundwater planning are essential for sustainable development: the amount of available groundwater in a certain area and its renewability.

In humid areas aquifers are more easily recharged and the water in them renewed, than those in semi-arid or arid areas. Hence, utmost care should accompany any dealing with the groundwater resources in semi-arid and arid areas to which Jordan belongs. Here, groundwater issues are extremely delicate. The recent history of groundwater extraction, with all its complications of quality deterioration, exhaustion of resources and collapse of irrigation projects and the accompanying socio-economic impacts, demand detailed studies of the impacts of groundwater extractions before taking decisions about groundwater exploitation.

Depletion and salinization of aquifers, ground subsidies, collapse of structures, etc. can result if no detailed studies are carried out from the start or if no careful monitoring and control to study the reaction of the aquifer accompany all the activities of exploitation.

1. Groundwater Recharge and Discharge:

Under natural, practically stable geologic conditions the long-term (tens of years) discharge of an aquifer equals its recharge. This means that water tables fluctuate about the same level under equilibrium. In the case of non-renewable aquifers, water levels, although sometimes very slowly, are continuously dropping. Geologic events like uplift movements may compensate for dropping water levels, and the system appears to be under equilibrium.

Recharge to an aquifer can take place from direct precipitation, by lateral or vertical flow from other aquifers, by return flow or by artificial groundwater recharge.

Discharge of aquifers can be in the form of springs, wells, seepages, submarine flows or lateral and vertical flows to other aquifers.

In this book, spring flows and seepages to the surface, as

long as they flow at the surface, have already been taken care of in the surface water section under a collective name; base flow.

In this section water discharged through seepages or submarine springs, without being measured, or from one aquifer to the other, is considered groundwater which can be extracted as a part of the safe yield of an aquifer.

In Jordan, aquifers contain hundreds of billions cubic meters of water distributed all over the underground of the country, overlying the basement in its southern parts and measuring a few kilometers in thickness in the central and northern parts.

In certain parts and at certain depths the groundwater is saline, most of it is even fossil and was recharged in former times (hundreds to tens of thousands of years ago), and some of the aquifers may still contain formation water (water trapped in the aquifer at the time of its deposition).

In general, the water encountered at depths of a few hundred meters below the surface is saline. But this saline water forms the backbone or the support system of all overlying groundwater. In the recharge areas, the water may be fresh but with the passage of time and under different pressure and temperature conditions, interaction of both solid and liquid phases takes place and results in new hydrochemical equilibria and generally higher salinity of the groundwater.

2. Groundwater Aquifers:

The groundwater aquifers of East Jordan are divided into three main complexes, (Fig. 9).

Deep Sandstone Aquifer Complex.
Upper Cretaceous Aquifer Complex.
Shallow Aquifer Complex.

2.1. <u>Deep Sandstone Aquifer Complex:</u>

This complex forms one unit in southern Jordan. To the north, gradually thick limestones and marls separate it into two aquifer systems which, nonetheless, remain hydraulically interconnected.

a. Disi Group Aquifer (Paleozoic):

This is the oldest, and in the north, the deepest water bearing sediment sequence in Jordan consisting of sandstones and quartzites. It crops out only in the southern part of Jordan and along Wadi Araba - Dead Sea Rift Valley. It underlies the entire area of Jordan. The southern part of the complex forms the fresh water aquifer of the upper Wadi Yutum -

Disi-Mudawara area.

The main flow of the groundwater in this system is directed towards the northeast. Only in the southern parts a groundwater divide in the Ram area separates a small southern region where the groundwater moves towards the west and south.

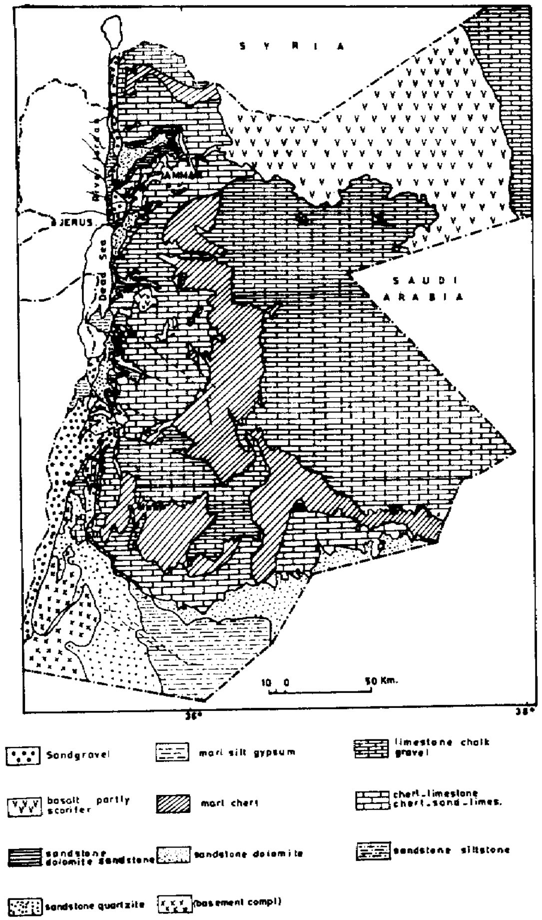

Figure (9) Surface Extension of Groundwater Aquifer Systems in Jordan (NWNP)

b. *Kurnub and Zerqa Group of Jurassic-Lower Cretaceous Age:*

This is also a sandstone aquifer underlying the area of Jordan and overlying the Disi group aquifer. It crops out along the lower Zerqa River basin and along the escarpment of the Dead Sea, Wadi Araba and Disi region.

Wells drilled in this fine-grained sandstone aquifer have fairly good yields. Direct recharge, however, is limited to small outcrop areas. The groundwater in this aquifer, aside from the recharge areas, is mineralized.

The Kurnub - Zerqa aquifer system is being exploited mainly in the lower Zerqa River catchment and in the Baq'a areas.

The direction of groundwater flow in this aquifer system is towards the northeast in the southern part of Jordan, towards the west in central Jordan and towards the southwest in northern Jordan (Salameh & Udluft, 1985).

The sandstone aquifer complex (Disi and Zerqa/Kurnub) is interconnected through the Khreim group and is regarded as one basal aquifer and hydraulic complex.

2.2. Upper Cretaceous Hydraulic Complex:

This complex consists of an alternating sequence of limestones, dolomites, marl stones and chert beds. The total thickness in central Jordan is about 700m. The limestone and dolomite units form excellent aquifers.

The lower portions of this sequence (A1/2), consisting of about 200m of marls and limestone, possess in some areas relatively high permeabilities and form a potential aquifer. An aquitard (A3) consisting of about 80m of marl and shale overlies the A1/2 and separates it from the overlying A4 aquifer. The latter consists of pure semicrystalline karstic limestones and hence it has very high permeability and porosity. The A4 aquifer crops out along the highlands and is recharged there. To the east this aquifer is confined by the overlying aquitard consisting of marls and limestones (A5/6).

The A5/6 aquitard is overlain by the most important aquifer of the sequence; namely the Massive Silicified Sandy Units B2 A7, which consists of limestones, chert-limestones, sandy limestones and marly limestones. It crops out along the highland and is being recharged there. To the east, like the A4 aquifer, it goes over in a confined aquifer, overlain by layers of marls.

The whole aquifer complex is overlain in the eastern desert by a thick marly layer (B3), forming a competent confining bed. Therefore, in some locations, flowing artesian wells are drilled into this aquifer.

The groundwater flow in this complex is directed from the recharge mounds in the eastern highlands, partly to the western escarpment within the faulted blocks and mainly to the east, where it discharges along deeply incised wadis or flows further eastwards. Along its way to the east, a part of the water seeps to the underlying sandstone aquifer complex, and the other part appears in Azraq and Sirhan basins as spring discharges.

2.3. Shallow Aquifers Hydraulic Complex:

It consists of two main systems:

a. Basalt Aquifer:

Basalts extend from the Syrian Jabel Druze area southward to the Azraq and Wadi Dhuleil region, forming a good aquifer of significant hydrogeological importance.

The recharge to this aquifer system is provided by precipitation in the elevated area of Jabel Druze. From there the groundwater moves radially to all directions. Geological structures favoured the formation of three main discharge zones namely, the upper Yarmouk River basin, the Wadi Zerqa basin and the Azraq basin.

b. Sedimentary Rocks & Alluvial Deposits of Tertiary and Quaternary Ages:

These rocks form local aquifers overlying partly the previously mentioned aquifer complexes or are separated from them by aquitards. They are distributed all over the country, but are mainly concentrated in the eastern desert, Wadi Araba - Jordan Valley, Jafr Basin and the Yarmouk River area.

Recharge takes place directly into these aquifers themselves or via the underlying basalt aquifer, as in the case of the Azraq basin, or from the surrounding aquifers, like the cases of the Jordan and Wadi Araba valleys.

The groundwater flow in this system, in the eastern desert, is directed radially towards the Azraq oasis and towards El-Jafr from the west and south of the Jafr basin.

The groundwater flow in the main valley fills depends

on the underground conditions. But it mainly takes place from the escarpments into the valley deposits.

3. Groundwater Basins in Jordan:

Groundwater basins or groundwater balance areas are those areas which could be separated and defined to include appropriate and regionally important aquifer systems. The groundwater divides are either aquifer limits or important and relevant geomorphologic or geologic features.

Groundwater basins in Jordan (Fig. 10) are also separated according to the same criteria, with some of these basins recharge and discharge taking place within the same basin. In most basins more than one aquifer complex is present and hence, any definition of groundwater basins should refer to a certain aquifer system and not necessarily to all aquifer systems underlying the basins.

The National Water Master Plan of Jordan (NWMP, 1977) defined the groundwater basins in Jordan. In this work Jafr is subdivided into Jafr and Disi-Mudawara:

1. Yarmouk basin.
2. Northern escarpment to the Jordan Valley.
3. Jordan Valley floor.
4. Zerqa River Basin.
5. Central escarpment to the Dead Sea.
6. West Bank.
7. Escarpment to Wadi Araba.
8. Red Sea basin.
9. Jafr basin.
10. Azraq basin.
11. Sirhan basin.
12. Wadi Hammad basin.
13. Disi-Mudawara.

3.1. Groundwater in the Yarmouk basin and the northern part of the Jordan Valley escarpment:

The groundwater in the Yarmouk River basin is found in the B2A7 aquifer at depths of less than 200m in the highlands. The groundwater flow is directed towards the Jordan Valley area. The geologic formations which overlie the B2 A7 consist of marly layers and form aquicludes dipping with increasing angles towards the Yarmouk and Jordan rivers. This configuration results in confining conditions with piezometric heads measuring tens of meters above the ground surface along the mountain slopes of the Jordan Valley.

Mukheiba wells at the slopes to the Yarmouk river and Wadi El-Arab wells in Wadi El-Arab, upstream of the dam, tap the B2 A7 aquifer and discharge artesian water.

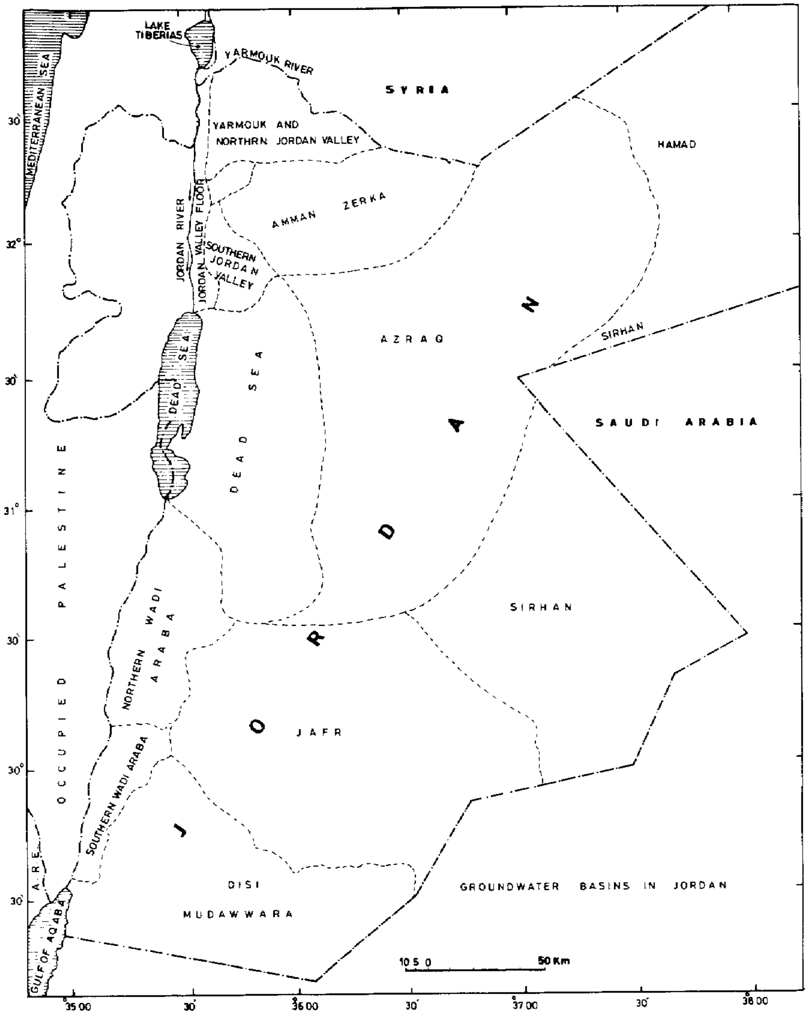

Figure (10) Groundwater Basins in Jordan

The recharge to the aquifer takes place in the highlands of Irbid and Ajlun and further to the northeast beyond Jordan's territories.

The deeper lying aquifers of A4 and Kurnub release some water to the B2 A7 in an upward movement, through the overlying aquicludes because their piezometric heads are higher than those of the B2 A7 (El-Nasser 1991).

El-Nasser (1991) calculated a recharge to this aquifer of 127 MCM/year, with base and spring flows of 100 MCM/year. In this figure the groundwater resources extending to Wadi Yabis, Wadi Jurum, Wadi El-Arab and the Yarmouk river are included.

Present day artificial extractions of 73 MCM/year indicate that the aquifer is being overpumped by around 56 MCM/year.

In the National Water Master Plan of Jordan (NWMP, 1977), the renewable groundwater amount which does not appear as base flow is calculated to be 23 MCM/year.

The Water Authority of Jordan gives estimate of 47 MCM/year of available groundwater for the area.

The quality of the water in the unconfined portion of the aquifer is suitable for different uses (Table 18).

In the confined portion of the aquifer higher temperatures and pressures result in the dissolution of minerals which add more salts to the water. Upon release of pressure the water suffers from chemical disequilibrium and it hence requires purification to be made suitable for domestic uses.

The dissolution of uranium minerals and its disintegration, together with the daughter elements, results in high concentrations of radon gas in the discharged water, making its treatment a conditional necessity for domestic use.

The water of the Mukheiba and Wadi El-Arab wells requires chemical treatment, because it is in chemical disequilibrium with the ability to precipitate carbonates in the supply system and water use facilities. Irbid governorate water network has been suffering from this shortcoming since 1986 because Wadi Arab well water reached this net work.

These analyses indicate that the water quality in the unconfined portions of the aquifer (Nuayma and Yarmouk University wells) is suitable for all uses, although some signs of pollution are becoming more evident in the increasing concentrations of nitrates and phosphates.

The high radon concentrations in Mukheiba and Wadi El-Arab wells make the water treatment essential to rid drinking water of this carcinogenic agent.

3.2. Southern Part of the Jordan Valley Escarpment:

The groundwater in this area is found in two aquifer systems; the Upper Cretaceous limestone system and the Lower Cretaceous sandstone system. Conditioned by the geology and morphology of the area, the groundwater table of the limestone aquifers is not continuous, and the groundwater is mainly found in blocks which may extend for a few kilometers in length and width and are separated from each other by faults or other unconformities. The general groundwater flow is directed towards the Jordan Valley and discharges there, either as springs or seepages, or flows laterally to the lower lying areas and enters the recent deposits occupying the Jordan Valley floor.

Table (18)
Groundwater Analyses of Yarmouk Basin

	Wadi El-Arab Well No. 3	Mukheiba Well	Nuayma Well	Yarmouk University Well
Date	4/1990	2/1990	2/1990	2/1990
Ec µS/Cm	835	963	590	593
pH	7.53	6.43	7.34	7.6
Ca meq/l	5.52	4.7	3.28	3.15
Mg "	2.66	2.5	2.15	2.17
Na "	1.09	1.85	0.44	0.78
K "	0.07	0.11	0.04	0.09
Cl "	1.20	1.85	0.72	0.89
HCO3 "	6.45	5.64	4.28	4.7
SO4 "	1.80	0.73	1.16	0.6
CO2 mg/l	50	60	0.0	0.0
NO3 mg/l	0.047	0.003	0.27	0.38
PO4 mg/l	0.06	0.01	0.10	0.08
Rn nCi/l	19.8	25	n.d.*	n.d.

* n.d.: not detected.

Recharge to the aquifers takes place along the highlands of Amman and Balqa (Salt) area.

The amount of available, renewable groundwater which does not appear as base flow is estimated at 10 MCM/year.

The lower lying aquifer, the Kurnub sandstone contains confined mineralized water. Wells drilled in Kafrain, Rama and Wadi Hisban areas produce artesian water with salinities up to a few thousand ppm.

Naturally the water in this aquifer flows upwards through the recent sediment cover to the earth surface and discharges along the lower reaches of the Jordan River side wadis.

The flowing wells drilled into this aquifer, which produce mineralized thermal water, are not used and are not controlled. Therefore, they are draining and depleting the aquifer which will certainly result in depriving the overlying Upper Cretaceous aquifers of their support system and hence lead to a continuous drop in their groundwater levels.

The unused water discharges of these flowing wells should be stopped as a conservation measure of the groundwater resources of the country.

The water of the Upper Cretaceous aquifers is of good quality and is suitable for different uses. But, since the catchment area is continuously becoming more urbanized, some signs of groundwater pollution are becoming evident. (Hisban and Wadi Sir Springs, Table 19).

The groundwater in the Lower Cretaceous aquifer is mineralized, thermal and artesian. It discharges CO2, H2S and radon gases in addition to its high iron contents which form a scale upon the water coming into contact with the atmospheric air.

In its natural state the groundwater of this aquifer can only be used to irrigate salt-tolerant crops. For any other use it should either be mixed with less saline water or be desalted.

3.3. Jordan Valley Floor Area:

The aquifer along the Jordan Valley floor consists of alluvial fans and other recent sediments inter-fingering with the salty, clayey deposits of the ancestors of the

Dead Sea, like the Lisan lake which tens of thousands of years ago extended northwards beyond the present shores of Lake Tiberias (Horowitz 1971). The groundwater flow is directed from the mountain foothills to the Jordan River course.

Recharge to this area takes place through lateral flows from aquifers extending to the east of the mountain foothills. Some direct infiltration takes place from precipitation water over the area where soil profiles are thin and rocks are porous and permeable.

Deep groundwater mainly in the Lower Cretaceous aquifer, is salty and under artesian conditions, and it seeps upwards through the recent sediments to the surface, forming saline springs (Wadi Mallaha).

The amount of available groundwater in this area ranges from 18 - 20 MCM/year (WAJ 1991, NWMP 1977). The water quality in the northern Jordan Valley area is generally good and suitable for irrigation; in certain parts it is even suitable for drinking purposes (Table 20). To the south, the water salinity increases due to the presence of saline formations and due to irrigation return flows. In certain parts there the water salinity goes up to a few ten thousand parts per million.

Locally, alluvial fans contain water with an excellent quality for all uses. The extensions of these fans towards the Jordan River contain increasingly brackish and salty water as a result of irrigation return flows and salty formation influences.

3.4. Amman Zerka Area:

Two main aquifers underline this area, namely, the deep A4 and the shallow complex consisting of B2 A7 or A7 alone or B2 A7 together with wadi fills and basalts. But the main aquifer consists of the A7 limestones.

Table (19)
Composition of Water in Area 2

		Rama Well Lower Cretaceous	Wadi Sir Well Upper Cretaceous
Date		15.03.1990	16.12.1990
T	C°	33.5	19.4
EC	µS/cm	4250	729
pH		6.39	7.03
Ca	meq/l	10.4	4.42
Mg	meq/l	6.2	1.75
Na	meq/l	35.0	1.11
K	meq/l	2.1	0.06
Cl	meq/l	28.18	1.57
SO4	meq/l	7.29	0.15
HCO3	meq/l	16.0	5.1
NO3	meq/l	0.03	0.59
CO2	mg/l	298	0.0
Fe	mg/l	2.31	0.01
Mn	mg/l	0.18	0.008
H2S	mg/l	0.3	0.0
PO4	mg/l	0.012	0.032
Rn	nCi/l	10.5	0.0

As in the Surface Water section, the Amman Zerka area can be divided into two parts; an eastern part extending to the northeast of Wadi Zerka and a western part extending to the west of Wadi Zerka. This division is important because of the different groundwater flow systems prevailing in the area. Wadi Zerka and Zerka River form the effluent stream of the area's

Table (20)
Water Quality in Area 3

	Abu Ziad Well Wadi Yabis	Princess Muna Farm South Shuneh
Date	5/1990	4/1990
T C°	25°	25.2°
EC μS/cm	917	1415
pH	8.1	7.86
Ca meq/l	5.6	3.75
Mg meq/l	3.2	5.3
Na meq/l	1.36	5.7
K meq/l	0.09	0.26
Cl meq/l	1.75	6.0
SO4 meq/l	1.40	3.46
HCO3 meq/l	6.82	5.51
NO3 meq/l	0.16	0.66

groundwater. Groundwater originating in the eastern part flows in a westerly direction, and that originating in the western highlands of Amman and its surroundings flows in an easterly direction. At the longitude of the Zerka River, in its north-south course, both groundwater currents converge and discharge in the form of springs.

The renewable groundwater amounts in the area average 88 MCM/year. Around 35 MCM/year return to the surface as base flow along the Zerka River, and the remaining 53 are pumped through wells distributed over the basin.

Over-pumping is already taking place along Wadi Zerka and in the eastern part of the area, such as in Dhuleil and Khalidiya subareas.

Recharge to the eastern parts of the area comes from precipitation falling over that area and partly from Jabel Druz. Flood waters flowing within the area

contribute to the groundwater recharge. Irrigation activities, especially in Dhuleil area, result in irrigation return flows which infiltrate back to the groundwater body underlying the entire area.

Recharge to the western part takes place along the highlands of Amman and its surroundings and along the wadi courses which discharge flood water. Return flows of domestic water used in houses and for commercial purposes form a non-negligible part of recharge.

In the Amman-Zerka area, leaking water supply nets and sewerage systems contribute also to the groundwater stock of the area.

Irrigation, industrial and domestic return flows contributions to the groundwater amount to 40 MCM/year.

Industrial effluent infiltration can be estimated at 5 MCM/year, whereas domestic cesspools leak around 25 MCM/year and irrigation return flows contribute an average of around 10 MCM/year.

The natural water system of the Amman-Zerka area is now highly disturbed by pumping water into the area. An annual average of about 40 MCM/year is brought into the area from outside and used there.

This fact is continuously bringing the water system of the area out of balance. In some parts of the area; along Wadi Dhuleil for example, a rise in the groundwater levels is registered since 1985, whereas in Dhuleil area the contrary is taking place. This is because of the infiltration of semi-treated waste water in the first case and over-pumping in the latter. Both badly reflect on the groundwater quality.

For Amman-Ruseifa area it is estimated that 30% of the naturally and artificially discharged water is recycled water, returning from leaking pipes, cesspools and other uncontrolled systems.

In Dhuleil area, return flows amount to several million cubic meters per year, which, during the last two decades, have gradually led to aquifer salinization. Along the course of Wadi Dhuleil downstream of Khirbet-es-Samra, a rise in the groundwater levels of up to 25m has been registered during the last 7 years, caused by the infiltrating treated and untreated waste waters from Khirbet es Samra treatment plant, which rendered the groundwater unsuitable for almost all uses including irrigation.

The groundwater qualities in the area represent a complex issue affected by various factors of recharge, discharge, inflows of waste waters, mixing of different water qualities, leaching of solid wastes and others. Therefore, no generalization concerning the water quality can be made for the whole catchment. But larger, major subareas can be delineated with features characterizing each of them.

Those subareas are:

* Amman - Ruseifa - Zerka subarea.
* Dhuleil subarea.
* Wadi Dhuleil subarea, downstream of Khirbet-es- Samra.

a. ***Amman - Ruseifa - Zerka subarea:***

This is the most densely populated area in Jordan, and is the site of more than 60% of the country's small and medium size industries. All these activities are taking place in an area almost devoid of a relevant soil cover. Permeable rocks leading into the aquifers form the ground of the area. Therefore, pollutants may easily reach the groundwater and contaminate it. Pollutants in Amman - Ruseifa - Zerka area originate from domestic and industrial waste waters and solid wastes.

The effects of domestic wastes and cesspools can be illustrated on the quality development of Rushdi es-Saudi well in Amman (Table 21).

Table (21)
Quality Changes in Rushdi es-Saudi well in Ras El-Ain area - Amman

		1965	1991
EC	µS/cm	480	1340
pH		8.3	7.1
Ca	mg/l	38	135
Mg	mg/l	24	30
Na	mg/l	34	122
K	mg/l	3	10.5
SO4	mg/l	36	65
HCO3	mg/l	145	302
NO3	mg/l	35	120
Cl	mg/l	51	215

In this well, from 1965 to 1991, the concentrations of calcium, sodium, chloride and nitrates increased nearly three-fold. Accordingly, the salinity of the water in 1991 was three times its value in 1965. This well shows at present faecal and total coliform contents, indicating the effect of cesspools and waste water contamination.

The effects of industrial pollution can be illustrated on the example of wells within the industrial zone along Wadi Zerka (Table 22).

The original salinity (TDS) of these wells was in the range of 500 - 600 mg/l, with sodium and chloride contents of less than 100 mg/l and a nitrate concentration of 15 to 20 mg/l.

Table (22)
Pollution indicators in wells in the industrial zone of Wadi Zerka (Gedeon 1991)
(values in mg/l)

Site	TDS	Na	Cl	NO3
Hussein Thermal Station well no. 1	2880	519	1115	50
Petroleum Refinary well no. 4	3072	553	1154	45
ICA Co. well	1632	266	593	121

Contamination by trace elements is rarely encountered and if so, only for a restricted area or well and for a limited time. The reasons behind that are:

1. Types of industries which do not process heavy elements or in which heavy elements are not used.
2. The ability of the aquifer to still absorb these elements.
3. The high throughput capacity of the aquifer.

b. ***Dhuleil area:***

Changes in the groundwater quality in Dhuleil area are attributed mainly to irrigation return flows and to salinization of aquifers as a result of overpumping.

Table (23) illustrates, with the example of well no. DP17 (coordinates E272, 236 N175, 165), the effects of overpumping and irrigation return flows. Available data on this well's water characteristics run from 1971 to 1990.

From 1971 until 1981, the period of heavy overpumping was characterised by increases in the concentrations of almost all parameters. But, overpumping does not result in an increase of the nitrate concentration, which can, in this case, be attributed to fertilizers and irrigation return flows. The nitrate concentration increased from a value of 9.6 mg/l in 1971 to 114 mg/l in 1981; after that, it decreased to around 60 mg/l until 1984 and then fluctuated around a value of 85 mg/l until 1990.

The salinity of the well increased from 500 μS/cm in 1971 to 4300 μS/cm in 1981, after that, it decreased slightly and continued to show a content of around 3000 μs/cm until 1990.

Salinity of this well increased from 500 μs/cm in 1971 to 4300 μs/cm in 1981, after which it decreased slightly and continued at a constant level of around 3000 μs/cm until 1990. Calcium, magnesium, sodium, potassium and chloride values reached their maximum during 1981. A slight drop in these values was encountered during 1982, and then the values remained at a nearly constant level. A drop in pH values in 1981 was matched by a drop in the level of bicarbonate; however, the bicarbonate levels remained constant after that.

c. *Wadi Dhuleil downstream of Khirbet-es-Samra*

Until 1985 this area was affected by overpumping of the aquifers. It showed the same pattern of concentration increases of the different parameters from 1974 until 1980, when the concentration of the different parameters started to level off. After 1985 -- the commission date of Khirbet-es-Samra waste water treatment plant -- drastic increases in the concentration of the different parameters have been taking place (Bannayan, 1991). For example, nitrate sulfate, potassium sodium, calcium and magnesium concentrations, which by 1984 levelled off to values of around 1.4, 2.4, 0.1, 5, 3.5 and 3.6 meq/l, increased in 1990 to values of 1.5, 5.6, 0.35, 11.13, 11.28 and 10.34 meq/l.

Table (24) illustrates the increase in the concentrations of the different parameters due to the infiltration of the semi-treated waste water of Khirbet-es-Samra into the aquifer.

3.5. Dead Sea area

This area lies to the east of the Dead Sea and extends some 50 kms eastwards. The ground water is found in two different aquifer complexes; the upper limestone aquifer complex and the lower sandstone aquifer complex. The groundwaters of the two complexes have totally different histories.

The upper aquifer receives precipitation water which infiltrates through the soil and rock covers and discharges in short time periods, measured in a few years. It is a renewable source of water. The total available groundwater amounts to around 87 MCM/year. Half of it discharges to the surface through springs along the upper reaches of the wadis of Zerka Ma'in, Wala, Mujib, Karak, Shaqiq, Ibn Hamad, etc. Groundwater is also artificially extracted from the aquifer through wells along the highlands in the areas of Madaba, Mujib, Katranah and Karak. It is used for domestic and irrigation purposes.

The lower aquifer (sandstone complex):

This aquifer does not receive any appreciable amounts of direct recharge by precipitation. The water in it originates from other areas. Due to its outcrop altitude, below sea level, and due to the presence of the graben and the Dead Sea which serves as an ultimate base level for all surface and ground water, the ground water in the different areas in Jordan is somehow attracted by gravity to flow to the Dead Sea. Because of the outcropping of the sandstone aquifer complex (which extends under the entire

area of Jordan) along the Dead Sea shores, the water in the different aquifers tends to flow to the Dead Sea area.

Table (23): **Annual Averages of Parameters of DP 17 well**

Date	EC µs/cm K meq/l NO_3 meq/l	pH-value Cl meq/l TDS g/l	Ca meq/l CO_3 "	Mg meq/l HCO_3 "	Na meq/l SO_4 "
1971	500 0.16 ---	8.1 2.14 0.32	0.7 0.177	1.5 1.09	2.43 1
1972	620 0.23 ---	8 2.85 0.4	1.1 0.177	1.92 1.61	2.91 1.56
1973	808 0.24 ---	8 4.62 0.52	1.58 0	2.38 1.47	3.87 1.74
1974	915 0.2	7.9 6.09 0.75	1.85 0.103	2.69 1.39 0.59	4.48 1.41
1975	1500 0.51 ---	7.4 9.72 0.96	3.3 0	5 1.16	4.91 2.13
1976	1688 0.37 0.65	7.5 11.6 1.08	4.5 0	5.6 1.58	5.78 2.48
1977	2250 0.41 0.65	6.6 15.49 1.44	5.6 0	7.92 1.3	6.61 3.25
1978	2700 0.41 0.65	7.8 19.35 1.73	6.35 0	9.67 1.16	8.09 3.19
1979	2930 0.56 1.13	7.8 22.33 1.88	7.05 0	12.58 1.1	8.7 4.04
1980	3372 0.52 1.36	7.7 27.35 2.16	8.77 0	14.57 1.08	10.54 4.96
1981	4368 0.59 1.9	7.8 35.61 2.8	12.06 0	18.56 0.97	13.86 6.9

Continued...

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Date	EC µs/cm K meq/l NO_3 meq/l	pH-value Cl meq/l TDS g/l	Ca meq/l CO_3 "	Mg meq/l HCO_3 "	Na meq/l SO_4 "
1982	3429 0.51 0.94	7.8 27.28 2.19	10.3 0	14.13 1.02	10.84 5.2
1983	2896 0.37 1.17	7.7 21.87 1.85	8.37 0	11.3 1.07	9.58 4
1984	2870 0.41 0.86	8 21.38 1.84	8.11 0	10.64 1.05	9.55 4.74
1985	3283 0.34 1.24	7.9 24.45 2.11	8.84 0	15.4 1.17	10.4 5.6
1986	3099 0.43 1.36	7.9 23.49 1.98	8.44 0.01	11.77 1.23	11.56 5.45
1987	3100 0.46 1.36	7.82 23.64 1.98	7.85 0	11.7 1.16	10.73 4.62
1988	3027 0.43 1.32	7.76 22.63 1.94	7.44 0	11.82 1.22	10.28 4.83
1989	2943 0.4 1.32	7.84 23.45 1.9	7.99 0	8.64 1.1	10.47 5.66
1990	3100 0.45 1.53	7.62 21.95 2.02	7.88 0	11.76 1.01	9.7 5.26

The water in the sandstone complex comes from different sources, like leakings from the upper aquifers, underground flows from Disi area, in addition to very limited direct recharge to outcrops.

Table (24): Average values of parameters per year for the Jordan Pipes Manufacturing well

(Cl, HCO3, Ca, SO4, Mg, NO3, Na, K in meq/l)

Year	EC µs/cm Cl	pH-value HCO3	Ca SO4	Mg NO3	Na TDS g/l	K
1974	810 3	7.8 3.2	1.65 1.68	2.33 0.27	4 0.52	0.17
1976	660 2.76	7.8 2.42	1.55 1.14	1.58 ---	3.26 0.42	0.14
1979	990 5.97	8 2	2.5 1.4	3 ---	4.26 0.63	0.12
1980	1125 6.28	7.85 2.71	2.73 2.52	3.25 0.47	5.04 0.72	0.14
1981	1130 6.32	7.8 2.28	3.08 2.42	3.2 0.46	4.97 0.72	0.14
1982	1200 7.5	7.6 2.29	4 2.1	3.4 0.45	4.91 0.77	0.1
1983	1240 7.69	7.9 2.34	3.5 2.41	3.61 0.45	5.3 0.79	0.1
1986	1658 10.24	7.77 2.39	4.52 2.54	4.75 0.81	6.52 ---	0.16
1987	1902 12.94	7.75 2.49	6.35 3.5	6 0.92	8.18 1.4	0.18
1988	2520 18.38	7.44 2.65	8.47 4.49	8.14 1.33	10.34 1.8	0.22
1989	2943 21	7.44 2.35	9.71 5.27	9.45 1.46	10.87 2.34	0.29
1990	3150 22.57	7.3 2.21	11.28 5.49	10.34 1.5	11.13 2.68	0.35

The total discharge from the lower aquifer complex east of the Dead Sea is around 90 MCM/year of mostly thermal, mineralized water (Salameh and Udluft 1985).

The water quality allows only for restricted uses like irrigating salt-semi-tolerant crops. But this thermal water can also be used for therapeutic purposes. Together with the climate prevailing in the area and the

Dead Sea water, the thermal spring water issuing from the sandstone aquifer complex represents a potential wealth element for the country. (The water quality in this aquifer is discussed under the surface water section Zerka-Ma'in and Zara areas).

The water quality of the upper aquifer ranges widely in the concentrations of the different parameters. Whereas, the concentrations are relatively small and within the acceptable standards for the different uses in the recharge areas, they increase rapidly along the groundwater flow directions and along some geologic lineaments because of mixing processes with piezometrically-rising, lower aquifer groundwaters. Table (25) shows two types of groundwater of the area; one with low salinity (No. 126) representing the vicinity of the recharge areas and another (No. 41) representing the mixed water.

The water of the second type can only be used for irrigating salt-semi-tolerant crops. The higher salinity is partly a result of overpumping and upconing of the lower aquifer groundwater.

Irrigation return flows and waste water seepages have not yet affected the aquifer, although some signs are indicating their effects, like slight increases in the nitrate and phosphate levels.

Table (25) <u>Water quality of the upper aquifer, Dead Sea Area</u>

		Well No. 126	Well No. 41
E.	coord.	241.4	252.6
N.	coord.	119.8	115.4
EC	µS/cm	690	2340
pH		7.32	6.72
Ca	meq/l	4.1	10.00
Mg	meq/l	2.46	3.20
Na	meq/l	1.64	9.54
K	meq/l	0.04	0.22
Cl	meq/l	1.66	10.30
NO3	meq/l	0.09	0.12
HCO3	meq/l	5.24	8.15
SO4	meq/l	1.76	3.7

3.6. Northern Wadi Araba:

The wadi floor is built up of alluvial sediments brought from the surrounding mountains in the east and west with thicknesses of thousands of meters. The water at greater depths is saline due to the effects of the Dead Sea interface and to the geologic history of the area and especially of former extensions of the Dead Sea.

The groundwater in the area is found in the fluviatile deposits, talus and alluvial fans with a total thickness of about 250m. The groundwater flows from the mountains in the east in a westerly direction, with a component towards the north; the Dead Sea. Generally, all the groundwater of this area discharges into the Dead Sea.

The throughput of water from this area into the Dead Sea was calculated to be around 22 MCM/year (Abu Zirr 1989). The fresh water renewable resources amount to some 8 to 10 MCM/year.

Generally, the water salinity increases in the direction of groundwater flow; from the areas adjacent to the recharge areas to the discharge areas (Table 26). In addition, irrigation return flows are gradually leading to groundwater quality deterioration. The increasing salinity, phosphate and nitrate contents are some indicators of that.

Table (26) **Groundwater qualities in northern Wadi-Araba**

		Sample close to the discharge area Well No. UM - 3	Sample close to the recharge area Well No. R - 10
EC	µS/cm	5300	1083
pH		6.63	7.50
Ca	meq/l	13.03	3.13
Mg	meq/l	9.19	2.83
Na	meq/l	16.12	3.71
K	meq/l	0.21	0.11
Cl	meq/l	29.83	3.16
SO4	meq/l	4.26	2.38
HCO3	meq/l	2.18	3.07
NO3	meq/l	0.109	0.16

The development of the groundwater resources of the area for irrigation purposes may be restricted by the salinity of the water which is already showing the effects of additional salinization due to irrigation return flows.

3.7. Southern Wadi Araba:

The wadi floor here is also composed of alluvial sediments brought from the surrounding mountains in the east and west. The thickness of the sediment fill is measured in kilometers, but the fresh and brackish groundwater is found in the uppermost portions of the aquifer.

The groundwater flow is directed from the north to the Red Sea in the south. Recharge comes from precipitation falling on the surrounding mountains in the east, and infiltrates there in the barren rocks and flows laterally into the fluviatile and alluvial deposits covering the wadi floor. A part of the recharge takes place along the wadi courses of the side wadis and wadi Araba itself.

The throughput of the aquifer is calculated to be around 10 MCM/year composed mostly of brackish water.

The source water quality resembles that of the northern part of Wadi Araba. Here again the salinity increases in the direction of groundwater flow; from north to south. In the southern Wadi Araba area there are almost no irrigation activities, and the effects of the Dead Sea and its ancestors have not affected the area there. Hence, the increase in water salinity is less expressed than in the northern part.

Table (27) **Water quality in the southern part of southern Wadi Araba**

		Well No. 2
EC	µS/cm	2190
pH		7.9
Ca	meq/l	7.5
Mg	meq/l	3.8
Na	meq/l	11.5
K	meq/l	0.2
Cl	meq/l	16.32
HCO3	meq/l	1.78
NO3	meq/l	0.8
SO4	meq/l	2.92

The analyses of the Palm Forest Well 2 (Table 27) indicate the less pronounced salinization of the southern part of Wadi Araba, although the well water quality here may be affected by inflows of the nearby Aqaba waste water treatment plant as indicated by the high nitrate concentrations.

3.8. Disi-Mudawwara area:

The Disi-Mudawwara aquifer system crops out in south Jordan and extends into Saudi Arabia and the underground of Jordan, where it overlies the Basement Complex, which consists of intrusive igneous rocks functioning as an aquiclude. This sequence of sandstones and shales underlies the entire area of Jordan at different depths, generally increasing in northerly and north-easterly directions. The Disi aquifer consists of medium-to fine-grained sandstones with a total thickness of about 1000 meters. The average precipitation over the area is around 80mm/year, with an average potential evaporation of 4000mm/year.

The groundwater in the Disi area is unconfined (Fig. 11) and lies at a depth of around 80 meters below the surface, whereas in the Mudawwara area, the water is confined and partly artesian. The groundwater flow is directed towards the north and north-east. The average permeability of the aquifer is 1.68 x 10^{-5} m/s with a gradient of 0.143%. Assuming a flow of 40 kilometers in width and a maximized saturation depth of 1000 meters, the throughput of the aquifer is calculated to be equal to: 1.68 x 10^{-5} x 1.43 x 10^{-3} x 40 x 10^{3} x 10^{3} x 30.5 x 10^{6} = 30.5 MCM/year.

This figure could be indicative of average recharge or the total flow as a result of fossil gradient adjustment.

The C^{14} ages of samples collected from that area range from 11,000 - 13,000 years. At present, it is generally accepted that the groundwater in Disi-Mudawwara area does not receive major replenishment. This means that the groundwater in the aquifer is fossil and that its extraction is at the expense of storage; in other words, this extraction is a mining process.

The groundwater in Disi has a very low salinity and is free of pollution signs of any type. Table (28) illustrates the excellent quality of that water. Since the aquifer is found in a non-industrialized area with a very low population density, industrial and urban types of pollutants are not to be expected to affect the groundwater on the long-term. But it is expected that irrigation in the area will lead to irrigation return flows infiltrating to the groundwater and hence to salinity increases and to pollution by agricultural pollutants such as fertilizers.

The Disi-Mudawwara aquifer, extending in the underground of the entire country, underlies all geologic units, and is, on a regional scale, hydraulically interconnected with the aquifers of the different units. This implies that any extraction from this aquifer at any location in Jordan is going to be reflected in lowering the water levels in the upper aquifers.

Table 28
Water quality of Disi Aquifer

	Min.		Max.	
EC	320	-	430	µS/cm
pH	7.4	-	835	
Ca	1.35	-	2.10	meq/l
Mg	0.2	-	1.15	meq/l
Na	0.52	-	1.40	meq/l
K	0.03	-	0.1	meq/l
Cl	0.65	-	1.8	meq/l
HCO3	1.46	-	2.05	meq/l
SO4	0.23	-	0.71	meq/l
NO3	0.08	-	0.20	meq/l
Fe	0.004	-	0.9	mg/l
Mn	0.001	-	0.4	mg/l
Zn	0.001	-	0.2	mg/l
F	0.08	-	0.18	mg/l

Extraction of water increased from 15 MCM/year in 1983 to 65 MCM/year in 1991. The total amount of extraction during this period was around 500 MCM, causing a nonrecoverable drawdown in water levels ranging from 1.85 to 12.11 meters. This nonrecoverable, irreversible decline is a major warning concerning the persistence of water resources.

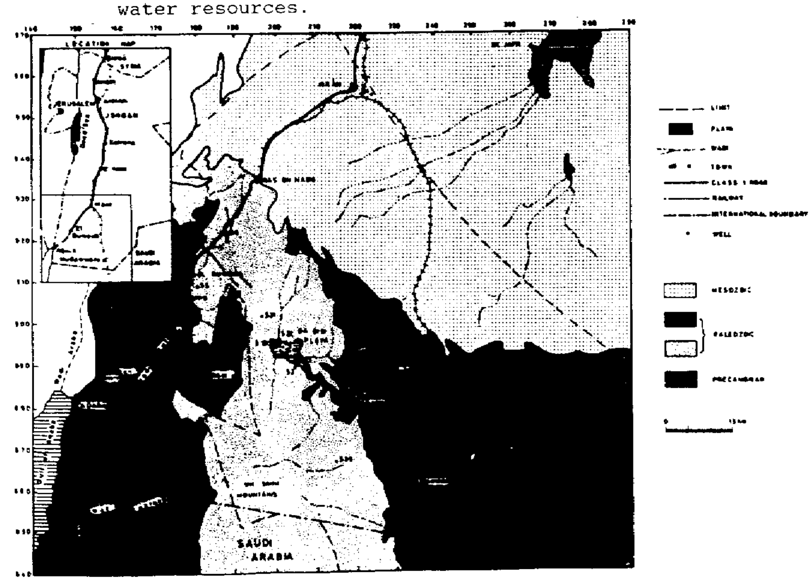

Figure (11): Location Map of Disi-Mudawwara Aquifer System

The final results of the hydrological studies on the Disi-Mudawwara aquifer can be summarized as follows:

* The groundwater is fossil and the recharge is estimated at 30 MCM/year. The age of the groundwater is measured to be more than 10,000 years.

* The total pumping of about 500 MCM in the last few years caused a drop in water level amounting to more that 12 meters in some areas.

* The groundwater body of Disi-Mudawwara underlies the entire area of Jordan and is, on a regional scale, hydraulically interconnected with all overlying aquifers. Hence, extraction from this water body will affect the groundwater resources in Jordan, as it lies in the upstream direction, and will ultimately cause a general drop in the water levels.

* There are indications that the water salinity has started to increase.

* The Disi-Mudawwara aquifer water is the only strategic water reserve of Jordan.

* This water is the only long-term source for the water supply of Aqaba.

3.9. <u>The Azraq Area:</u>

This area forms the northern part of an elongated geological depression known as Sirhan Depression. It functions as a base level for both surface and groundwater which collects there to form an oasis.

The groundwater in this area is found in different aquifer systems ranging from recent deposits to deep sandstone aquifer complexes.

In the shallow aquifer, consisting of recent deposits, basalts and partly the B4-formation, the water is renewable. In the intermediate aquifer complex consisting of Upper Cretaceous formations, the water is moving, but its main recharge areas lie far away in Jabel Druz and in the highlands of Amman - Madaba - Karak and Tafila. Therefore, it has relatively an old age -- hundreds to thousands of years.

In the lower sandstone aquifer complex the water also has a relatively old age, not because it was stored in the aquifer for a long time, but because it has, since hundreds to a few thousands of years, been underway from the source areas towards the underground of the Azraq area. The source areas are:

- The highlands of Amman - Madaba - Karak and Tafila, from which precipitation water infiltrates into Upper Createaceous rocks, flows in an easterly direction and percolates down to the lower aquifer complex.

- Disi-Mudawwara area where the groundwater flows with a component towards Azraq feeding the lower aquifer complex.

- The highlands of Sharaa mountains, where the precipitation water infiltrates into the exposed rocks consisting mainly of Cretaceous deposits and flows crossing the Jafr Basin in the underground towards Azraq.

All these components of groundwater join in the underground of Azraq Depression and flow in a westerly direction towards the Dead Sea to be discharged there as mineralized thermal groundwater (compare area 5).

The groundwater in the different aquifers, from the shallow one to the deep complex, is hydraulically interconnected with the following movement directions:

- In the shallow aquifer all the groundwater flows towards the oasis with only a lateral component.

- In the intermediate aquifer the groundwater flows from west, north and south towards the Azraq Oasis. Some of that groundwater seeps upwards to the shallow aquifer and some downwards to the sandstone aquifer complex. Another portion flows further eastwards to Saudi Arabia.

- In the sandstone aquifer complex, the downward leakage of the overlying aquifers, as well as the groundwater flowing laterally from the south and eventually the east, flows in westerly and eventually northwesterly directions to the Dead Sea and probably to the Jordan Valley areas.

The amount of groundwater available in the shallow aquifer is calculated to be 20 to 24 MCM/year.

Due to overpumping, the water levels in the surroundings of the oasis have in recent years, dropped by a few meters, which has resulted in ceasing the discharges of Qaysiya and Soda springs feeding the oasis, and in increasing groundwater salinities.

The water of the basalt aquifer is of a very good quality for different uses. Table (29) gives the result of ASWA well No. 1 of the Water Authority well field area in Azraq.

Table (29) Water quality of the basalt aquifer in Azraq area

ASWA Well No. 1		
Date: 19..06.1990		
EC	µs/cm	539
pH		8.12
Ca	meq/l	1.28
Mg	meq/l	0.78
Na	meq/l	3.59
K	meq/l	0.13
Cl	meq/l	2.7
SO4	meq/l	0.86
HCO3	meq/l	1.7
NO3	meq/l	0.11

The water quality of the intermediate aquifer depends on the depth and site of collection. A well drilled in the Azraq area (AZ1), producing artesian water from the intermediate aquifer, has the composition given in Table (30).

The well also produces carbon dioxide, hydrogen sulfide and radon gases, indicating the confined nature of the aquifer in that area, which leads to the upward and downward leakages of the aquifer water to the overlying shallow and underlying deep aquifers.

Table (30) Water quality of Azraq well No. 1 producing from the intermediate aquifer

EC	µs/cm	1428
T	C°	39
pH		7.14
Ca	meq/l	4.02
Mg	meq/l	2.74
Na	meq/l	7.25
K	meq/l	0.30
Cl	meq/l	7.43
SO4	meq/l	3.90
HCO3	meq/l	3.78
NO3	meq/l	0.01

No analyses of the water of the deep aquifer in Azraq area is available, but the same water is discharged along the eastern Dead Sea shore from the thermal springs there. From hydrodynamic and hydrochemical points of view it is justifiable to assume that the discharged, thermal, mineralized water at the Dead Sea eastern shores resembles in its quality the deep aquifer water underlying Azraq (for water analyses see Dead Sea Area).

3.10. Jafr Area:

The main groundwater aquifer in the area is B4 - Formation of the Balqa group, consisting of thin beds of chert, limestones, clays and marls with a total thickness of 20 - 25 meters.

The B2A7 and the Kurnub and Disi sandstones form the deeper aquifers which are separated from each other by thick aquitards. The different aquifers are weakly interconnected. The groundwater flow in the B4 aquifer is generally directed from west to east. In the lower aquifers, the groundwater flows in a general northerly direction with components towards the northeast and northwest. The groundwater of the deeper aquifers represent a support and backbone of other groundwater bodies found north-west and south of Jafr Basin. Hence, extracting the water of the deeper aquifers would undermine other resources.

Recharge to the B4 aquifer takes place in the mountainous highlands of Shoubak lying to the west of the Jafr Basin. Direct recharge by precipitation is negligible because the surface area of the playa, where floodwater collects, is covered by very fine sediments which do not allow for rapid infiltration and groundwater recharge.

The total recharge to the B4 aquifer is around 7 MCM/year (Parker 1979). Because of over-exploitation, the groundwater resources started to deteriorate in the late sixties, after only a few years of extraction. The salinity increased rapidly from 600 to 700mg/l in the early sixties in the different wells, to values between 700 and 2800mg/l in the early seventies.

Since that time, no major changes have taken place in the water quality. Although some water salinities increased beyond their values of the early seventies (Table 31).

Jafr Basin was the first main groundwater area in Jordan to suffer from over-exploitation, resulting in groundwater resources depletion and salinization. Nonetheless, experiments with over-extraction have continued and have led, during the last two decades, other groundwater areas to depletion and salinisation.

Table 31
Water quality of Jafr Prison Well

Date:		11/1992
EC	µS/cm	1080
pH	meq/l	7.8
Ca	meq/l	3.53
Mg	meq/l	3.00
Na	meq/l	3.98
K	meq/l	0.03
Cl	meq/l	4.33
SO4	meq/l	2.05
HCO3	meq/l	4.16
NO3	mg/l	9.96

3.11. Sirhan and Hamad areas:

The groundwater in these areas is found in a shallow aquifer consisting of Upper Cretaceous and Tertiary rocks and recent sediments of wadifills, basalts and alluvial deposits.

The general groundwater flow direction is oriented towards the local base level of Sirhan Depression extending in a southeasterly - northwesterly direction.

The permeabilities of rocks underlying both areas are very small. Rocks which extend from the highlands of Jordan towards the east show a general decrease in grain size and a general increase in siltation and cementation. Therefore, aquifers are not well developed and the water movement through the rocks is very slow. This results in small yields of aquifers and hence wells, and in longer intensive interactions of water with rocks, which are viable for dissolution, resulting in higher salinities of the water.

The estimated available groundwater resources for the Sirhan and Hamad areas are 5 - 10 MCM/year. Due to the large extents of those areas the groundwater is considered as sparsely available and can only be used for restricted local development (ACSAD 1980).

The groundwater, in addition to its scarcity, suffers from a salinity problem. The water is generally

brackish and needs certain technologies to be made suitable for relevant uses.

The salinity of the water ranges from around 1000 µs/cm up to 4500 µs/cm. The majority of sources has a salinity of about 2000 µs/cm.

The analysis below (Table 32) shows an example of the water quality of wells in the area. The groundwater is far away from pollution sources, but the high nitrate concentration is attributed to contamination in the immediate vicinity of the well.

Table 32
Water quality of Shalan well No. 1

Date:		1991
EC	µs/cm	1750
pH		7.2
Ca	meq/l	8.4
Mg	meq/l	4.3
Na	meq/l	6.7
K	meq/l	0.18
Cl	meq/l	7.00
SO4	meq/l	7.90
NO3	meq/l	0.4
HCO3	meq/l	5.91

IV

Waste Water Treatment and Reuse

1. Introduction to Waste Water Treatment (WWT):

1.1. The need for wastewater treatment:

Wastewater is essentially water that has been fouled by communities through its use in the various daily activities such as cooking and washing. Domestic sewage is mainly composed of human body wastes and sullage. Industrial sewage comprises numerous and various chemicals including those toxic to humans and nature. Sewage is extremely hazardous in content mainly because of the number of disease-causing organisms and toxic matter that it contains.

The proper treatment and safe disposal of sewage into a receiving watercourse is of utmost importance for two major reasons:

a. The removal of pathogens and hence the spread of communicable diseases.
b. The oxidation of the organic matter it contains and prevention of pollution of surface and ground water.

In many water-blessed countries sewage is treated before disposal into the nearest watercourse, where it is not used directly for any specific purpose. The case is different in some parts of the developing world where water resources are scarce, population density is high and continuously growing, and health and hygiene awareness are minimal.

In countries where water is not readily available and agriculture is predominant, treated wastewater could be used to irrigate relatively large areas of cropped land.

Jordan's desperate need for water imposed a necessity for the reuse of treated wastewater in agriculture. To meet this end, several wastewater treatment plants were constructed to treat sewage from major cities in Jordan. It has been estimated that some 18 million m^3/year of water could be retrieved from sewage treatment plants, and these are enough to cultivate at least around 36,000 dunums with alfalfa and various trees such as olive and apple.

If proper and efficient treatment of wastewater could be

achieved, the effluent -- rich in nutrients -- would even be suitable for aqua culture.

1.2. Methods of wastewaters treatment:

Various methods for wastewater treatment have been developed over the past years. Many are conventional, such as activated sludge and biofilters, and others slightly less conventional, such as oxidation ditches, aerated lagoons and natural treatment such as waste stabilization ponds.

1.3. Conventional wastewater treatment:

This method is usually used in temperate climates. It comprises the following stages of treatment:

a. Preliminary treatment: which is the physical removal of large suspended solid particles usually through screening, or the physical shredding and taring of such particles through communication.

b. Primary treatment (sedimentation): which is the gravitational separation of a suspension into its component solid and liquid phases. At this stage the aim is to clarify the liquid from the solids it contains, and thus reduce the load on the secondary treatment phase.

c. Secondary or biological treatment (biofiltration or activated sludge): where the liquid from the primary sedimentation tanks is treated in either a biofilter (also known as the percolating trickling filters) or through an activated sludge process.

In the first case, settled sewage is distributed over a 1.8m deep bed of coarse aggregates. The sewage trickles down over the surface of the aggregates, where a microbial film develops and the bacteria, which constitute most of the film, oxidize the sewage as it flows past.

In activated sludge, the settled sewage is led to an aeration tank, where oxygen is supplied either by mechanical agitation or by diffused aeration. The bacteria which grow on the settled sewage are removed in a second tank.

d. Sludge treatment, sludge from primary and secondary sedimentation tanks, are anaerobically digested and re-used as fertilizers.

Although conventional treatments are most commonly used in temperate climates, they are also used in hot climates. They can achieve high BOD removal at very short retention times which makes them very efficient when large areas of land are not available and where the high temperature of the surroundings may cause a large amount of water loss through evaporation.

Conversely, they are heavily mechanized and require high construction and maintenance costs, as well as several skilled operators. In spite of their high efficiency in BOD removal, the rate of pathogen removal is very low, consequently, chlorination activity is a must, which may cause a hazard in trihalomethane formation.

1.4. Less conventional methods of wastewater treatment:

a. *Oxidation ditches:*

The oxidation ditch is a modification of the conventional activated process. It receives screened raw sewage and provides long retention times; the hydraulic retention time is commonly 0.5 - 1.5 days, and for solids it is 20 - 30 days. Mechanical roters are needed to aerate sewage, and BOD5 removals are consistently more than 95%.

b. *Aerated Lagoons:*

Aerated lagoons are activated sludge units operated without sludge return. They were developed from waste stabilization ponds, by introducing mechanical aeration to supplement the algal oxygen supply. It was found that instead, the algae disappeared and the microbial flora resembled that of activated sludge. Aerated lagoons achieve BOD5 removal greater than 90% at comparatively long retention times (2 - 6 days).

Both oxidation ditches and aerated lagoons require further pathogen removal treatment depending on the intended end use of the effluent.

c. *Waste Stabilization Ponds:*

These are large relatively shallow basins enclosed by earthen embankments. The raw sewage enters the first pond and follows continuous treatment in successive ponds. The process is natural and is carried out by the action of algae and bacteria. There are three basic types of ponds: anaerobic, facultative and maturation ponds.

d. *Anaerobic ponds:*

They are relatively deep ponds, 2 -5 m, and considered as pre-treatment ponds where the sewage received is of high organic loading (100 - 400g $BOD5/m^3/day$) and contains high amounts of suspended

solids (> 300mg/l). The organic loading is so high that they are devoid of dissolved oxygen - hence the name anaerobic.

The solids settle to the bottom where they are digested anaerobically and the supernatant is discharged into further ponds. The efficient operation of the ponds depends on the balance between acid - forming bacteria and methanogenic bacteria; i.e. a temperature > 15c° and pH > 6 are required.

e. *Facultative ponds:*

These ponds are designed to receive either raw sewage or effluent from anaerobic ponds and septic tanks. They are usually 1 -2m deep, with a mixture of anaerobic activity in the lower layer of the pond and aerobic activity towards the upper layer of the pond.

Some of the oxygen required to keep the upper layer aerobic is due to surface aeration, but most of it is produced by photosynthetic algae which grow naturally in the ponds. The bacteria present utilize the oxygen to oxidize the organic waste and release carbon dioxide as one of its major end products. Carbon dioxide is readily utilized by the algae during photosynthesis. Therefore, there exists a symbiotic relationship between pond algae and the pond bacteria.

f. *Maturation Ponds:*

Maturation ponds are designed to receive treated effluent from facultative ponds. The removal of BOD5 in these ponds is small, and two ponds in series with a retention time of 7 days are usually needed. They are relatively shallow 1- 1.5m and are aerobic.

The primary function of maturation ponds is the destruction of pathogens. Faecal bacteria and viruses die off because of the unfavorable environment in the maturation ponds. The rate of die-off increases with rise in temperature. Ultraviolet light penetration, high dissolved oxygen concentrations and the release of algal toxins have been suggested as direct causes of faecal coliform die-off in maturation ponds. It has been proved that a high pH > 9, as a result of rapid algal photosynthesis, is mainly responsible for faecal coliform die-off and that of bacterial pathogens. The eggs of helminths and the protozoan cysts have a relative density of about 1.1, and with the long retention times in these ponds, they settle to the bottom.

The method of treatment using WSP is natural. No mechanical aerators are needed to produce oxygen, but rather oxygen is symbiotically produced by algae. No sludge recycling is needed. It was found that in spite of the long retention time needed, ponds will, under the appropriate conditions, produce a very good effluent quality with a BOD5 removal > 95% and up to $6\log^{10}$ cycle reduction in faecal coliforms.

2. Wastewater Treatment in Jordan:

The population in Amman has increased from 50,000 inhabitants in 1940 to 800,000 in 1986. Today, with the returnees from the Gulf and the high growth rate, it may exceed one million inhabitants. This has placed an immense strain on the existing infrasawucture, especially water consumption and wastewater disposal.

Prior to 1969, cesspools and septic tanks provided the sole wastewater disposal option in Amman. Such practice resulted in ground water pollution, which posed a severe threat to the city's drinking water supply.

To revive the situation, the concerned governmental agencies put forward a plan to connect houses in the Amman area through a network of sewers to a conventional wastewater treatment plant. Accordingly, in 1969 the Ain Ghazal treatment plant (AGTP) was completed to handle wastewater at an average flow of 60,000m^3/day and a BOD loading of 180,000 kg/day. The AGTP consisted of conventional (bubble aerated) activated sludge treatment and anaerobic sludge digesters.

In spite of the presence of such a plant, the continuous improvement on the Amman sewerage schemes increased the inflow to the treatment plant from 15,600 m^3/d in 1979 to 50,000m^3/day in 1985.

By 1980, although the average inflow was well below design capacity at only 19,300m^3/d, the high influent BOD concentration of 960mg/l resulted in organic overloading, which necessitated remedial measures.

The Water Authority of Jordan (WAJ) calculated the savings that could be achieved by integrating the treatment of sewage from various communities in the Zarka River Basin. This would provide treatment for the wastewater from the cities of Amman, Zarqa and Ruseifa (Fig. 12); which comprise 40% of the country's increasing population. Such a retrial project was considered to be more desirable than enlarging the AGTP or constructing two smaller plants.

For this purpose, waste water stabilization ponds (WSP) were considered most suitable since land was available at low cost and the area is characterized by a warm climate and high

levels of solar radiation. Disadvantages of such a system would include seepage into groundwater, evaporation losses and possible odour formation.

A decision was made to locate the ponds at Khirbet As-Samra at an elevation of 101m below that of AGTP, thus permitting the flow of wastewater under gravity and eliminating pumping costs.

A pipeline conveying the wastewater from the standard AGTP to the new WSP site had to be constructed.

The pipeline was 38.6 km long and had a diameter of 1.2 m and connected between AGTP at an elevation of 668m above sea level and WSP at 580m above sea level. The pipeline is an inverted siphon with it's lowest point at an elevation of 460m above sea level. The pressure at this point is approximately 25 bars.

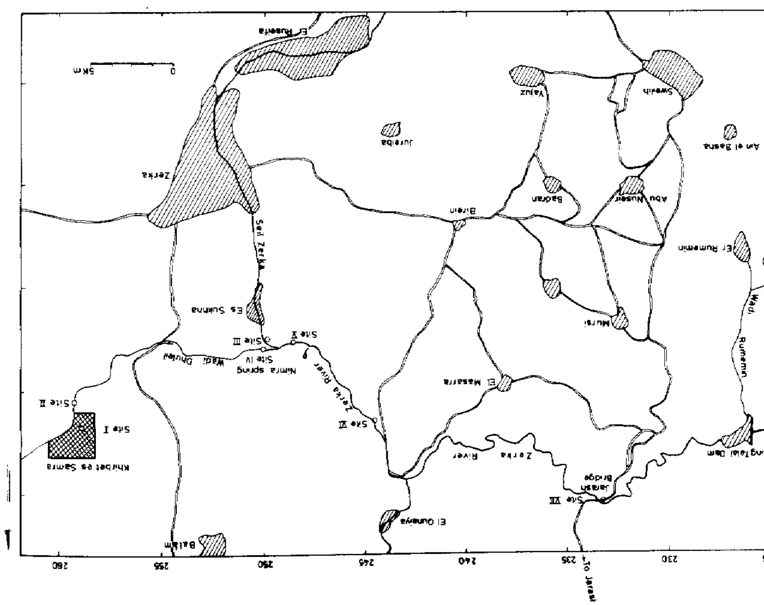

Figure (12): Location of Khirbet-es-Samra Waste Water Treatment Plant

2.1. Khirbet-es-Samra WSP:

The ponds system consists of 3 parallel trains; each a series of 2 anaerobic ponds, followed by 4 consecutive facultative ponds which empty into the first of 4 maturation ponds. The ponds were designed to handle loads projected for the year 2000:

Average Dry Weather Flow	=	68,000 m^3/d
Peak Wet Weather Flow	=	148,000 m^3/d
BOD5 Loading	=	45,750 kg/d
BOD5 of Raw Sewage	=	526,000 mg/l
Suspended Solids Loading	=	42,000 kg/d

The Jordanian health authorities require a residual free chlorine of 2mg/l in the final effluent of the ponds. Therefore, chlorine gas is dosed into the final effluent at a rate of 10 - 15 mg/l.

2.1.1. Critique of Khirbet-es-Samra pond design:

Anaerobic Ponds: It was assumed that a BOD5 reduction of 30 - 40% would be achieved in the 1st anaerobic pond during winter, and a conservative estimate of 40% during summer. This removal is equal to that expected from sedimentation of solids. A further 10% reduction in BOD5 is expected to occur in the 2nd anaerobic pond.

Therefore, according to the design value of 526mg/l, the effluent from the 1st and 2nd anaerobic ponds would be 316mg/l and 284mg/l respectively.

Facultative and Maturation Ponds: In the design of such ponds, first order kinetics are used:

$$Le = \frac{Li}{1 + k_1 t^*} \quad \text{..........................(1)}$$

where:

Le and Li are the effluent and influent organic loads in mg/l

t* is the retention in (d)

$$K^1 = \frac{K_{35}}{\theta^{(35-T)}} \quad \text{..........................(2)}$$

where:

K_{35} = breakdown rate at 35°c (K_{35} - 1.2)
K_1 = breakdown rate at temperature T, C°.
θ = temperature reaction coefficient (1.085)
T = temperature, C° (T = 12.5 C°).

Using the McGarry and Pescod formula for maximum allowable surface loading:

$$\delta s = 11.2\ (1.054)^T \quad \text{............(3)}$$

where
T in F° = (54.5 F°)
δ s = 197 kg/ha/day.

The load from the 2nd anaerobic pond = 19,800 kg/day, which means that an area of 96.6 ha is needed.

However, the combined area of the existing four facultative ponds is 87ha, which is less than the minimum recommended area for such ponds(*1). Taking into consideration that these ponds were constructed in series rather than in parallel, it is clear that the 1st and possibly the 2nd ponds are highly overloaded, which affects the facultative treatment as the ponds may become devoid of oxygen and turn anaerobic.

BOD reduction in these ponds was taken as 80% during winter and after 23 days retention time, the influent BOD5 to the 2nd maturation pond is 54mg/l, i.e. a surface loading of 196kg/ha/day. This means that the 2nd maturation pond is receiving sewage that should be discharged into a facultative pond.

Again using 1st order kinetics, the BOD5 of the effluent from the 2nd, 3rd and 4th maturation ponds were 32, 19 and 12mg/l. Hence it was agreed that even if the 2nd maturation pond was in effect acting as facultative, the pond system still produced the desired effluent quality according to international standards.

2.1.2. Performance of Khirbet As-Samra: (KS)

The flow into KS exceeded 73,000 cu.m/d in 1987, with a BOD5 loading of more than 730mg/l. In 1992, both the hydraulic flow and organic loading were much higher. Other parameters such as TSS, TOC and COD were also very high at the inlet and accordingly at the outlet (Table 33).

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*1 = The designers added the area of the 1st maturation pond to those of the facultive to become 105.75ha with a retention time of 23/days.

Table (33)
Actual and design BOD5 loading and removal (1986 -1987)

Pond	Actual BOD5 (mg/l)	Design BOD5 (mg/l)	Reduction %	Accumulative Reduction (%)
Raw Sewage	730	526	---	----
Effluent of:				
Anaerobic 1	357	316	51	51
Anaerobic 2	283	284	20.7	61
Facultative 1	240	---	15.2	67
Facultative 2	216	128	10	70.4
Facultative 3	184	79	14.8	74.8
Facultative 4	173	49	6	76.3
Maturation 1	153	34	11.56	79
Maturation 2	147	24	3.92	79.9
Maturation 3	133	17	9.52	81.8
Maturation 4	124	12	6.8	83

It can be concluded that the plant is already over loaded and would in no way withstand the projected loads for the year 2000. Moreover, this method of natural treatment is not recognized as suitable for dry, arid or semi-arid regions.

Not only is the plant handling very high organic and hydraulic loadings, but the sludge accumulation at the bottom of the ponds leaves us with even less effective depths and therefore less retention time and less treatment efficiency.

The BOD5 of the effluent was around 125mg/l which was much higher than the 30mg/l value set by the guidelines. Suspend solids in the effluent were above 185mg/l, again more than three-fold the value of 50mg/l set by the guidelines. COD leaving the plant exceeded 400mg/l. The number of faecal coliforms leaving the plant varied between 34,000 and 1000/100ml, depending on the extent and effectiveness of chlorination taking place at the outlet of the pond system. The values of TOC, PO4 and NH4 were also high in the effluent, which shows that treatment at KS is incomplete. The fact that NH4 was appearing in the effluent shows that no nitrification was taking place in the ponds. Purple sulphur bacteria were appearing throughout the stages of treatment,

which suggests that anaerobic conditions were prevailing along the pond system as a result of overloading.

The designers of KS anticipated that further tertiary treatment would surely take place along Wadi Dhuleil and in King Talal Dam; the course of water discharged from the ponds. When comparing pollution parameters of KS effluent with the flow in Wadi Zarka some 12km downstream of KS plant, it can be seen that there are some increases in these pollutants, Table (34).

Table (34)
Concentration of pollutants at KS outlet and 12km downstream

Parameter	Annual Average KS outlet	Concentration at 12km downstream
BOD5 mg/l	115	92
COD mg/l	406	330
TOC mg/l	140	123
TSS mg/l	183	283
Total Coliform Count/100ml	2976	8443
Faecal Coliform Count/100ml	217	1143

The water table in Wadi Dhuleil area is close to the surface, and the surface aquifer is unconfined and consists in its upper portions of highly permeable wadi deposits. The surface water feeds the underground water. Consequently, the water table has risen some 20m in the immediate surroundings of KS, as a result of the formation of this recharge mouth. This rise dies off gradually in a radial way. The groundwater quality along Seil Al-Zarka has greatly retarded due to this recharge with polluted water from KS plant and from the seepage of irrigation water used in KS area.

This continual seepage into the underground may reverse the direction of underground water flow and thus negatively affect the entire Zarka area, Khaou, Al-Sukhneh and the area along Seil Al-Zarka (Fig. 13). Organic amounts have greatly increased along the Zarka River course, and the amount of oxygen has decreased until the Jerash bridge.

The groundwater quality along Seil Al-Zarka has been negatively affected since the start of KS plant. Also, the water quality of King Talal Dam -- the recipient water body of KS effluent -- has become increasingly low, to an extent that it is no longer suitable for unrestricted irrigation.

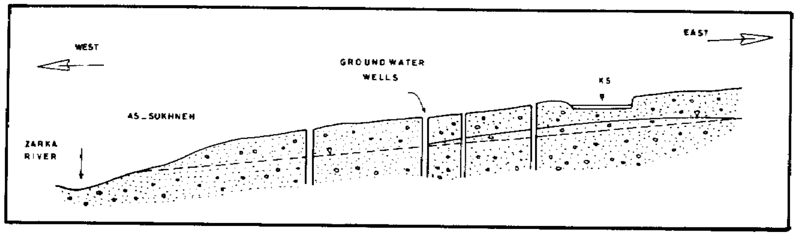


Figure (13) Groundwater flow downstream of Khirbet-es -Samra

Hence, the government issued a defence decree prohibiting the irrigation of edible vegetables with this water.

Comparison of the quality of groundwater in Zarka area with that of Wadi Dhuleil is shown in Table (35). The great increase in the amount of pollutants in Wadi Dhuleil can be readily seen, and this is primarily due to the discharge of KS effluent into Wadi Dhuleil. The dramatic change in Wadi Dhuleil water quality can also be seen when comparing prior to 1985 results (the commencement of KS plant) with those after 1985.

2.1.3. Proof of the effect of KS effluent quality on groundwater:

Some 2km to the west of KS, a series of productive wells are situated. The closest, the Tillawi well, produces water from the upper unconfined aquifer. Until the year 1987 - 1988, the well water was used for domestic purposes and to irrigate around 40 ha of vegetable- producing land. In 1986, the well owner started to complain about the quality of the water in the well. The crops of 1987 - 1988 were so bad that the land was ascribed zero productivity. The level of the well water rose by some 19m after the operation of KS plant; which was higher than any historic level for this well. Results are presented in (Table 36).

Many other wells were shut down for the same reason. A study was carried out during 1990 to compare the results of wells downstream of KS plant with those upstream of it. The study showed a sudden increase in the concentration of pollutants after 1985 in those wells downstream of KS, while those lying upstream were unaffected. Figure 14 (GP1-GP7) show the jump around 1985 - 1986 in the pipes factory well, downstream of KS. Figure 15 (GD1 -GD7) shows no sudden change in DP17 well, upstream of KS, concentrations of pollutant but rather a mild decreasing slope, around 1985 - 1986, due to the high amounts of recorded precipitation during those years.

Table (35)
Average chemical parameter values for groundwater in Wadi Dhuleil and Zarka areas

Parameter	Zarka area	Wadi Dhuleil Area prior to 1985	Wadi Dhuleil Area post 1985
EC μs/cm	1700	1706	3359
pH - value	7.25	7.56	7.34
Ca meq/l	5.55	6.08	11.15
Mg meq/l	3.9	4.64	10.04
Na meq/l	7.57	6.74	14.13
K meq/l	0.157	0.163	0.22
HCO3 meq/l	4.35	3.5	3.08
SO4 meq/l	2.2	4.67	7.34
Cl meq/l	9.66	9.2	21.88
Br mg/l	3.303		8.51
I mg/l	1.141		3.02
PO4 mg/l	0.266		0.38
TOC mg/l	4.86		7.82
COD mg/l	2.46		16.19

2.1.4. Suggestions for reviving the deteriorating situation in the area:

It is clear that the ponds at KS are not functioning as designed. This is because of overloading of the ponds, the unsuitability of such a system in such an area, as well as the improper design and construction of such ponds.

(a) Review of Khirbet-es-Samra Pond Design:
Considering the actual flow of 73000 cu m/day and a BOD loading of 730 mg/l, it is better to keep the anaerobic ponds as they are, since they have proved to be very efficient in removing ≈ 61% of the organic loads.

The influent to the 1st facultative pond has a BOD of 284mg/l. Using the McGarry and Pescod formula, the maximum permissible surface loading to be applied is 200 kg/ha/day, which suggests that a minimum surface area of 103.7 ha is required for the facultative ponds. Such an area, with a depth of 1.5m, gives a retention time = 21.3 days at the current flow rate.

Using the K1 value given by equation (2) = 0.191 and substituting in equation (1);

Le = 56mg/l, which is the amount of BOD5 inflowing to the maturation ponds.

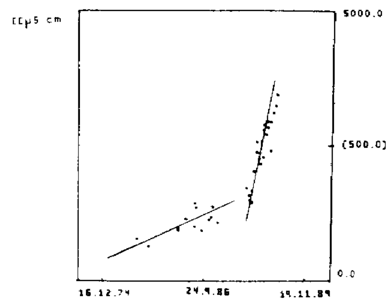
Using 1st order kinetics again for the design of maturation pond and requiring a final effluent BOD of 20mg/l. Substituting in equation (1). The retention time is 9.5 days. At a depth of 1.25m, a surface area of 55 ha is required for the maturation ponds to achieve the effluent quality set by the guidelines. Therefore, the way the ponds are interconnected, in parallel rather than in series, affects the loading amount on the successive ponds and hence the treatment of such sewage.

(b) The situation could be revived partially by using the abandoned AGTP to its limits and diverting the excess flow into KS plant.

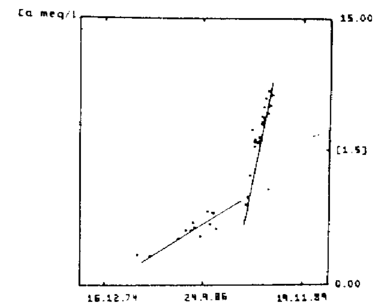
(c) Alternatively, AGTP could be upgraded and extended to accommodate the inflowing loads. This activated sludge method has proved more efficient in treating the substantial BOD5 concentration in sewage received at the works.

(d) In order to limit groundwater pollution -- groundwater being the main source of drinking water in Jordan -- effluent from sewage treatment works - which is evidently of extremely poor quality, it is in fact the quality of incoming wastewater in countries with adequate water resources -- should be carried in lined channels or pipes. What is the point in collecting wastewater from houses instead of disposing of the waste into cesspools, then allowing it to penetrate into long stretch of land "Wadi Dhuleil" until it reaches its' destination "King Talal Dam".

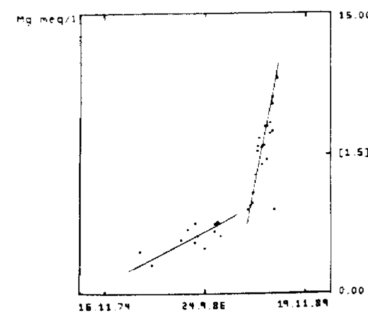
(e) Reusing the effluent from the plants to irrigate nearby land would not only lower the risk of pollution, but would be more economical as the amount of evaporation would be limited.



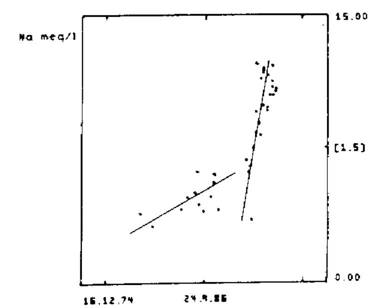
(FIG.14) GP1: ELECTRICAL CONDUCTIVITY AGAINST TIME FOR THE PIPES FACTORY WELL



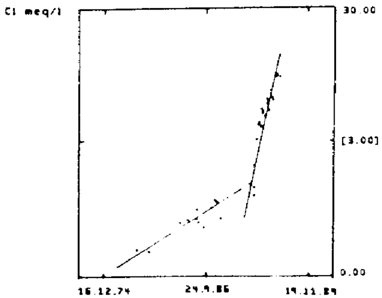
(FIG.14) GP2: CALCIUM CONCENTATION AGAINST TIME FOR THE PIPES FACTORY WELL



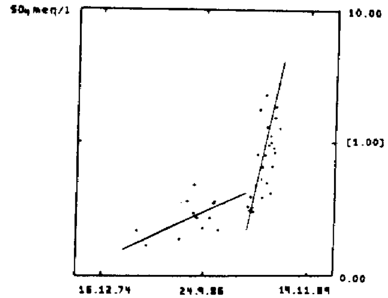
(FIG.14) GP3: MAGNESIUM CONCENTRATION AGAINST TIME FOR THE PIPES FACTORY WELL



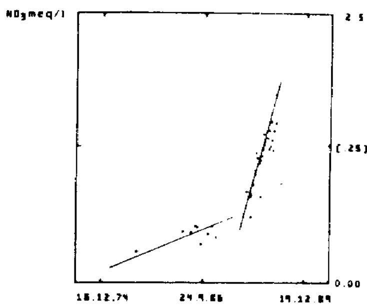
(FIG.14) GP4: SODIUM CONCENTRATION AGAINST TIME FOR THE PIPES FACTORY WELL



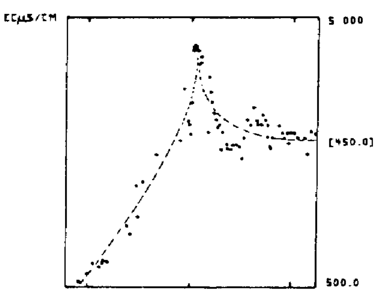
(FIG.14) GP5: CHLORIDE CONCENTRATION AGAINST TIME WELL FOR THE PIPES FACTORY WELL



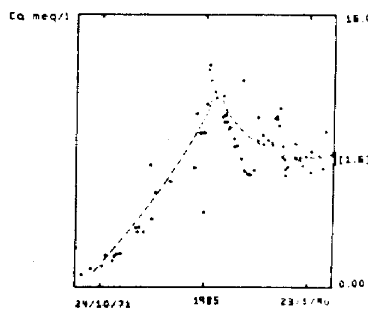
(FIG.14) GP6: SULPHATE CONCENTRATION AGAINST TIME FOR THE PIPES FACTORY



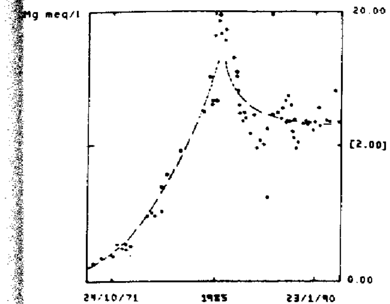
(FIG.14) GP7: NITRATE CONCENTRATION AGAINST TIME FOR PIPES FACTORY WELL



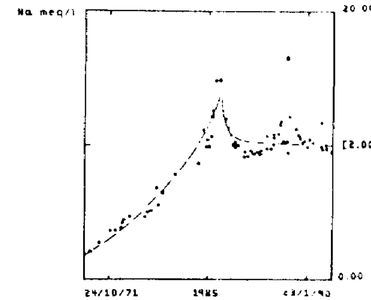
(FIG.15) GD1: ELECTRICAL CONDUCTIVITY IN µS/CM OVER TIME FOR DP17 WELL



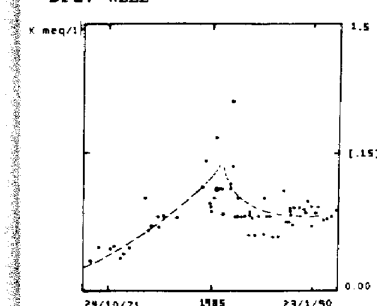
(FIG.15) GD2: CALCIUM CONCENTRATION IN MEQ/L OVER TIME FOR DP17 WELL



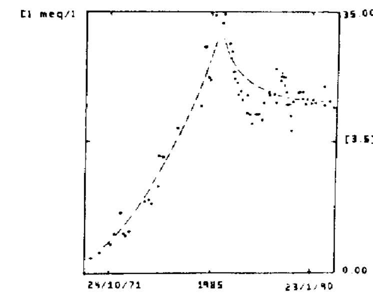
(FIG.15) GD3: MAGNESIUM CONCENTRATION IN MEQ/L FOR DP17 WELL



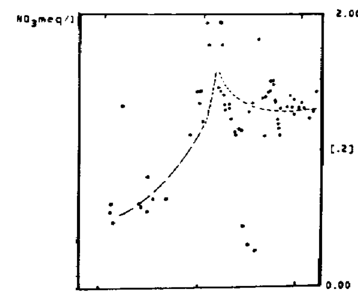
(FIG.15) GD4: SODIUM CONCENTRATION IN MEQ/L OVER TIME FOR DP17 WELL



(FIG.15) GD5: POTASSIUM CONCENTRATION IN MEQ/L OVER TIME FOR DP17 WELL



(FIG.15) GD6: CHLORIDE CONCENTRATION IN MEQ/L OVER TIME FOR DP17 WELL



(FIG.15) GD7: NITRATE CONCENTRATION IN MEQ/L OVER TIME FOR DP17 WELL

Table (36)
Water quality of Tillawi well

(K, Cl, HCO3, Ca, Mg, SO4, Na, NO3 in meq/l)

Date	ECμs/cm K	pH-Value Cl	Ca HCO_3	Mg SO_4	Na NO_3
07.86	7140 0.4	7.24 70.6	40.5 2.07	36.5 9.46	8.32 2.58
07.86	8060 0.44	7.35 77.75	43 2.15	40 10	9.47 2.9
09.86	9520 0.49	7.25 105	63 1.3	54 20.6	12.9 3.38
10.86	10060 0.43	7.17 109.5	65.6 1.22	55.8 20.29	13.39 3.22
12.86	10520 0.58	7.47 114	70.38 1.94	65.28 24.76	18.89 4.75
01.87	9500 0.62	7.3 100	56.5 1.74	50.1 20	19.09 4.1
03.87	10490 0.64	7.14 121.38	71.7 1.75	54.55 26.29	19.53 2.3
04.87	8720 0.68	7.16 97.83	-- 1.86	77.7 34.43	27.14 4.77
05.87	10150 0.33	7.13 110.74	69.5 2.28	52.5 30.77	25.7 4.49
09.87	11190 0.5	7.11 117.6	71.6 2.6	62.4 32.52	24.49 --
11.87	10440 0.52	7.25 115.8	68.48 1.92	64.06 26.52	15.87 4.16
02.89	10110 1.10	7.39 103	59.5 2.91	50.5 16.69	35.48 7.1
04.89	12020 0.84	7.51 120	73 2.91	65 20.06	45.26 7.7

2.2. Al-Mafraq WSP:

Following the construction of KS plant, numerous WSP were hastily constructed across the Kingdom, before reaching a consensus on the adaptation of this imported technology to the socio-economic situation in Jordan.

The waste stabilization ponds at Al-Mafraq were designed to serve a population of more than 23,000 inhabitants, with an estimated flow of 1800m^3/d and an organic load of 1500 kg/d expected by the year 1995. The treatment works consist of two trains in parallel, each consisting of one anaerobic pond,

three facultative ponds connected in series followed by two maturation ponds also connected in series. It was anticipated that the ponds will achieve an effluent quality in accordance with the Engelberg guidelines:

average BOD5 = 30 mg/l
average S.S = 20 mg/l
average F.C count ≤ 1000/100ml

2.2.1. Critique of the ponds performance:

During 1988, the flow into the ponds was only 800m^3/d, serving only 11,000 inhabitants. The flow increased slightly during 1989 and 1990 to reach a maximum of 1100m^3/d during September 1990. Water losses throughout the ponds were as high as 42% at times. Organic loads fluctuated considerably from one month to another, with a minimum BOD5 of 440 mg/l and a maximum of 1088 mg/l reaching a value of 3693 mg/l during August 1991. No apparent trend could be attached to these fluctuations. The oxygen consuming substances expressed in BOD5 in the effluent range between 100mg/l and 340mg/l; i.e., three to ten-fold the acceptable value of 30mg/l set by the standard envisaged in the design criteria.

The average rate of BOD5 removal at the treatment plant was 71.8% during 1989, it decreased to 67.2% in 1990 and to 62.5% during the first half of 1991.

The chemical oxygen demad (COD) followed a similar fluctuating behavior as that of the BOD, ranging between 2125mg/l and 890 mg/l, reaching as high as 6000 mg/l at times. The efficiency of COD removal ranged between 30% and 75%. However, it is clear that the effluent contained very high COD, nearly the same as what could be considered as raw sewage.

The values of suspended solids in the effluent were more than 100 mg/l reaching 350mg/l at times. Surprisingly ammonia was present in the effluent of the ponds at an average concentration of 177mg/l, which means that no nitrification was taking place within the ponds. This is attributed to a number of possible reasons, such as the strength of the received sewage and the unavailability of enough oxygen.

Although WSP are renowned for their excellent microbial removal, the ponds at Al-Mafraq were not able to achieve the desired removal of such pathogens. Chlorophyll concentrations at the facultative ponds were very low, which reflect minimal algal production, thus affecting the metabolic processes in the system such as nitrification and BOD5 removal.

2.2.2. Critique of the ponds design:

According to the available data, only 54.7% BOD5 removal is achieved within the 1st two ponds, namely the anaerobic and 1st facultative. Table (37), shows the BOD5 removal in the pond system during 1989 - 1991. It is clear that at times, hardly any removal was taking place within the ponds, and in fact the ponds were exerting some organic load especially within the third facultative pond. This could be due to algal die-off and a clear indication of possible failure of the treatment process. The values of COD and suspended solids (S.S.) followed similar ambiguous behavior.

It might be worthwhile at this stage to look into the original design and design criteria of the ponds.

WAJ documents show that the ponds have the following dimensions:

Pond Type	Area (ha)	Depth (m)
Anaerobic	0.58	4
Facultative	2.05	2.1
Maturation	1.04	1.5

According to the recommended design of ponds, Mara 1976, and Metcalf and Eddy 1979, the facultative ponds should not exceed 1.5m in depth and the maturation should be 0.75m to 1.2m.

(a) Anaerobic Ponds:

In the design of such ponds, BOD5 removal of 60 - 70% at 2.5 - 5 days retention time is expected. At Al-Mafraq ponds only 54% removal is achieved within the anaerobic ponds and the 1st facultative ponds, i.e., after 7 - 8 days retention time.

(b) Facultative Ponds:

At the present state of the ponds, the influent BOD5 to the facultative ponds is around 440mg/l, while the absolute maximum allowed, according to the McGarry and Pescod formula, is 200kg/ha/day, which means that the minimum area needed for these ponds is 4 ha. Using a more conservative design an area of 6 ha would be needed.

(c) Maturation Ponds:

The average BOD5 inflowing to the maturation ponds is around 300mg/l, thus imposing a surface load of 520 kg/ha/day. Even at this final stage

Table (37)
BOD5 loadings and rate of removal in the ponds during winter 1989 up till spring 1991

POND TYPE	INLET	FIRST FACULTATIVE		SECOND FACULTATIVE		THIRD FACULTATIVE		FIRST MATURATION		SECOND MATURATION	
Date	BOD5	BOD5	% removal	BOD5	% removal	BOD5	% removal	BOD5	% removal	BOD5	% removal
Winter 89	1151	638	44.5%	494	23.0%	485	1.8%	507	- 5.0%	246	51.0%
Spring 89	829	488	41.0%	---	----	378	---	375	0.0%	266	30.0%
Summer 89	550	165	88.0%	162	0.0%	212	- 31.0%	176	16.0%	147	16.0%
Autumn 89	540	263	51.0%	281	- 6.8%	159	43.0%	114	28.0%	127	- 11.0%
Winter 90	927	374	60.0%	302	19.5%	280	7.0%	268	4.0%	184	31.0%
Spring 90	635	---	----	---	----	---	---	---	---	---	----
Summer 90	570	---	----	---	----	---	---	---	---	349	----
Autumn 90	462	184	60.0%	120	34.0%	212	- 77.0%	174	18.0%	140	20.0%
Winter 91	588	443	25.0%	394	11.0%	435	- 10.0%	364	16.0%	316	13.0%
Spring 91	857	337	60.0%	375	- 11.0%	366	2.4%	396	- 8.0%	227	43.0%
Average			53.7%								

of treatment the ponds are loaded as anaerobic. If the facultative ponds were enough to produce an effluent BOD5 of 75mg/l which is the maximum to flow into the maturation ponds, then two ponds with seven days retention time would be adequate to produce the acceptable final effluent quality. Table (38) shows the differences between the original and proposed design:

Table (38)
Summary of Original and Proposed Design

Pond Type	Area (ha)		Depth (m)		Surface loading (mg/l)	
	Orig.	Prop.	Orig.	Prop.	Orig.	Prop.
Anaerobic	0.58	1.28	4	4	---	---
Facultative	2.04	4	2.1	1.5	565	200
Maturation	1.04	2.52	1.5	1	520	75
Total Area	3.66	7.80				

Already, some 42% of the flow is lost in the ponds due to evaporation and seepage. Therefore, if the new design is implemented, then 61% of the inflow/year will evaporate.

It is clear that this method of wastewater treatment, especially at such high amounts of BOD and such weather conditions, is not recommended, as seen from the performance of this treatment plant.

It might be useful to reconsider sewage treatment using other methods such as activated sludge or a combined treatment system adaptive to indigenous characteristics of climatic conditions, organic loads and patterns of lifestyle in Jordan.

2.3. Baqaa Treatment Plant

This treatment plant treats the extremely concentrated sewage of Al-Baqaa refugee camp, Suweileh city, Safout area and Ein El-Bashah. The treatment works are situated north of Baqaa camp on the west side of the Amman-Jerash highway

The plant comprises: an automatic and manual screen, followed by a grit removing chamber, three primary sedimentation tanks, and two trickling filters filled with plastic media. Each trickling filter is connected to two secondary sedimentation tanks. There are two solid contact channels, two polishing ponds and two chlorine contact basins.

The wastewater flowing to the plant is screened, passed through a grit chamber and then to the primary sedimentation tanks. The sewage passes through the primary filters and into the secondary sedimentation tank after being flocculated by air diffusers (Fig. 16). The effluent of secondary sedimentation tank flows to two polishing ponds working in series. The final effluent is disinfected in the chlorine contact basin. The chlorinated effluent is carried by a closed pipe to a deep wadi leading to King Talal Dam where it is discharged.

The sludge from the secondary sedimentation tanks of both filters is continuously pumped to the headworks where it is mixed with the primary sludge and settled in the primary sedimentation tanks. The mixed sludge is pumped to the thickners. The supernatant is drawn off and pumped back to the head works.

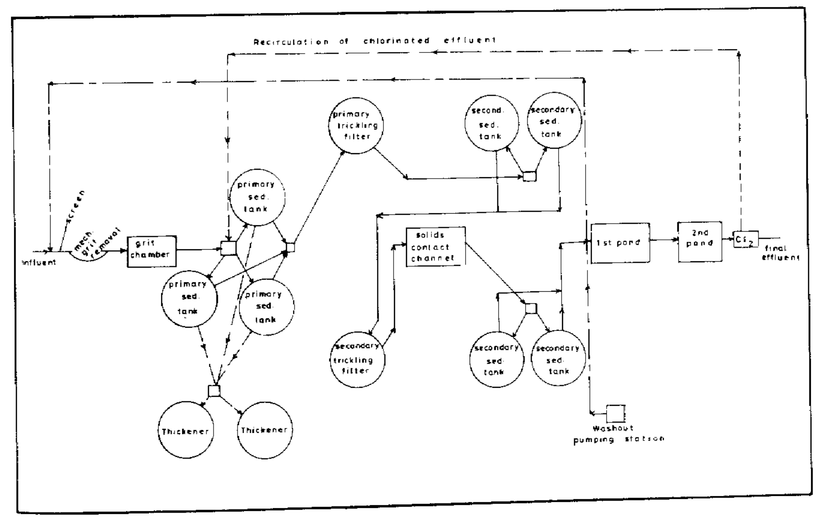


Figure 16: Process flow diagram (Baqaa WWTP)

The plant was designed to treat an average flow of 6000m^3/d with a BOD5 of 900mg/l and suspended solids content of 1000 mg/l.

Retentions time in the primary and secondary sedimentation tanks are around 5 hours each with a surface loading of $34m^3/m^2d$. The BOD5 loading on the primary and secondary filters are $1.81kg/m^3$ d and $0.63kg/m^3d$ respectively. Retention time in the two polishing ponds is around 2.3 days.

2.3.1. Performance of the Baqaa plant:

The inflow is around $3500m^3/d$. The BOD content exceeds 1200 mg/l and that of TSS is around 1000 mg/l. The effluent however does satisfy the set guidelines.

Odour has been a problem in this plant, and is possibly attributable to the sludge thickners or the concentration of the influent sewage.

Chlorine addition at the end of the works produces large amounts of trihalomethanes which affect the water in the wadi and at King Talal Dam.

This method of treatment is quite efficient, and the effluent quality is suitable for irrigation. The plant has protected the area from pollution if the sewage was to be disposed of into cesspools.

2.4. <u>Jerash Treatment Plant</u>

The city of Jerash is located about 45 kms north of Amman. The climate is moderate and the wastewater temperature ranges between 18 and 25°C. The treatment plant was constructed in 1982 with a design capacity of $1155m^3/d$, and a BOD5 concentration of 924mg/l. The method used in the plant is the extended aeration process method. The wastewaters, after passing through screens and a grit removal unit, flow directly to an aeration tank without primary settling treatment. The water flows over a secondary settlement tank to a chlorination basin before being discharged to the wadi. The aeration basin has a volume of $2300m^3$ and is aerated through six cylindrical rotors of 30 KW each.

Wadi Jerash, where the effluent of wastewater treatment plant flows, is nearly dry in high summer. In rainy seasons the wadi can carry considerable quantities of water.

Due to the increase in population, the treatment works have reached the maximum limit and therefore need upgrading.

In 1989, the flow exceeded $1100m^3/d$, and the inflowing BOD5 averaged 986mg/l. The outflowing BOD5, however, was within the set guidelines. The wastewater should not be allowed to flow into the wadi, as it will affect the groundwater in the area. The waste could be carried in lined channels to their final destination.

2.5. <u>Aqaba Treatment Plant</u>

The city of Aqaba, some 320 km south of the capital Amman, is Jordan's sole outlet to the sea. It is known for its nearly all year round beautiful weather and lovely beaches which attract tourists from all over the world.

In 1987, a waste stabilization treatment plant was constructed north of Aqaba some 2km from the bay, to treat a waste flow of $900m^3/d$. The inflowing BOD5 was estimated at 465 mg/l with faecal coliform counts up to 1×10^9 /100ml. A series of two facultative ponds followed by a maturation pond were constructed.

A retention time of 33 days was estimated from such a design. Initially the inflow was little, it evaporated and seeped through to the underground, hardly any effluent was reclaimed at the outlet works.

During 1988, the average inflow was $2984m^3/d$, this increased in 1989 to $4122m^3/d$. Evaporation losses were around $1402m^3/d$ and losses due to seepage were high at an average of $968m^3/d$. Therefore, an average of $1752m^3/d$ were reclaimed at the outlet, i.e., 58% losses. During summer, the losses are substantially increased due to the season's high temperatures.

In pond samples taken regularly by the concerned authorities, show definite increase in all pollution parameters along the treatment works, (Table 39).

High levels of ammonia are always present at the effluent which shows that no nitrification processes are taking place within the ponds. Even faecal coliform counts, which should decrease dramatically because of the long retention time and the high ambient temperature, are high in the waste effluent and do not satisfy the set guideline requirement of <1000/100ml.

It has been measured, that the water table in the area of the ponds has risen because of the continuous seepage of the wastewater into the underground. Samples from wells around the area have shown a rise in the water table and a definite deterioration in their water quality. Ammonia and faecal coliform were detected in these samples, which suggests that the source of pollution is that of domestic waste.

The flow of underground water is towards the beach, which suggests that if the source of pollution is not improved dramatically, fowling of the beaches would result.

In a hot city, such as Aqaba, stabilization pond treatment might not be the ultimate method of treatment, especially with such high evaporation and seepage losses.

To revive the situation, an anaerobic pond might be constructed at the inlet, this will reduce the area needed for treatment and hence reduce evaporation losses.

However, a more conventional method of treatment such as activated sludge might be better suited in this case, were retention losses are minimized, and the effluent quality effectively improved.

2.6. Irbid Treatment Plant

The city of Irbid, is the primary urban center of northern Jordan. It is the third largest city in Jordan and is a proposed center for future development.

Irbid is the major city in the area, dominated by rainfed agriculture. The city has had a dramatic increase in population during the past 20 years. In 1987, a sewage treatment plant was constructed, it was composed of trickling filters and activated sludge systems.

The plant was designed to handle an influent average flow of $11023m^3/d$ with a BOD5 load of 805mg/l and total suspended solids of 920mg/l.

The treatment works consist of a grit chamber, two primary clarifiers, two trickling filters, two aeration tanks, and two floculation clarifies. Sludge is carried into a sludge thickner and digester, and deposited onto nine drying beds. Chlorine is added at the end of the works in the chlorine contact basin, then the effluent flows into the wadi, to reach Wadi Al-Arab Dam.

The flow so far has not reached half the design flow; the influent however has had high BOD values, reaching in 1990 around 800mg/l. Fifty percent of BOD5 removal is carried out in the primary settling tanks. Continuous BOD5 removal is carried out in the aeration and secondary settling tanks. The final effluent quality complies with the recommended values set by the guidelines. COD values however are much higher than recommended, high levels of ammonia are also present in the final effluent. Coliforms are greatly reduced by the chlorine addition.

It is noticed that large quantities of sand are washed into the inlet works, and these have to be removed manually. Oil and grease are also carried into the treatment plant, affecting its performance. Sludge

Table (39)
Quality of the waste water during the different treatment steps in Aqaba waste water treatment plant and that of the Palm Forest well

Source	Date	Temp	E.C	pH	Ca	Mg	Na	K	Cl	HCO3	SO4	NO3	PO4	TOC	COD	Color	Turbid	TDS	BOD
In-let	6.6.89	30.4	1430	7.50	1.80	2.0	2.58	0.610	0.200	8.08	0.531	0.18	1.62	320	1463	78	130	0.55	853
F1	6.6.89	31.8	1940	7.80	2.90	3.10	8.54	0.71	0.300	8.80	2.97	0.55	1.79	294	1063	136	186	1.01	680
M1 N	6.6.89	31.6	2366	8.67	3.20	3.80	10.90	0.87	10.40	7.47	5.33	0.39	1.30	290.9	811	150	75	1.27	482
M2 S	6.6.89	31.5	2320	8.23	3.20	3.30	10.71	0.87	10.2	7.76	4.22	0.40	1.45	286.7	787	64	100	1.19	460
Outlet	6.6.89	25.0	2330	8.43	3.30	3.70	10.73	0.81	10.15	7.27	5.73	0.29	1.19	248.9	523	44	100	0.94	396
Palm Forest	6.6.89	29.9	3010	7.45	9.40	4.10	12.38	0.13	19.85	2.02	5.36	0.500	1.43	0.603	13	136	186	1.01	10

drying beds are covered with a layer of fine sand which does not allow for seepage.

The effluent flowing into the wadi gets polluted by other sources of water such as that flowing from the slaughterhouse in Irbid and the untreated sewage from Irbid camp, as well as the solid wastes from the stock farms along the wadi.

This water then feeds the underground water in many areas and causes pollution of wells such as Kufr Assad Well.

Although, so far the groundwater in Wadi Arab is not greatly polluted, something has to be done to prevent the polluted water and solid wastes from being dumped into the wadi.

V

Water Projects

During the last few decades development of water resources represented a major field of activity and a major concern for the different governments in Jordan. The rapidly increasing population -- whether because of natural multiplication or refugee waves -- the improving living standards, the development of irrigation projects and the introduction of industries required in accelerating steps more and more water. Therefore, projects were defined, implemented and commissioned swiftly to satisfy the multiplying demand. Following is a brief mention of the major projects which have been implemented since the early sixties.

1. Domestic Water:

All towns and villages in Jordan have been supplied with piped drinking water. At present 96% of the population is served by piped networks (Bilbeisi 1992). The remaining 4% who get their water from cisterns, wells, springs or have it transported by trucks can hardly be served by pipes because of their scattering all over the country in very small communities or due to their nomadic life style.

For domestic uses mainly groundwater is extracted. Only the Deir Alla scheme, which pumps water from King Abdullah Canal to Amman, uses surface water during the winter or during other seasons in preciption-rich years.

To satisfy the needs of the urban population, water has to be conveyed from distant sources. Therefore, expensive water conveyance facilities have been constructed. Among those are the following supply systems:

* Azraq - Amman, capacity: 20 MCM/year.
* Deir Alla - Amman, capacity 45 MCM/year, average pumping amounts (1986 - 1993) around 11 MCM/year.
* Wadi Arab - Irbid, capacity: 20 MCM/year.
* Swaqa/Qastal - Amman, capacity: 15 MCM/year.
* Za'tari - Mafraq, capacity: 30 MCM/year.
* Sultani - Karak, capacity: 17 MCM/year.
* Za'atari - Dhuleil - Khaw: 30 MCM/year.

Some of these schemes were extremely expensive considering the amount of water they produce; e.g., Deir Alla - Amman project cost around million US$ 250 million producing until now an average of 11 MCM/year, although its design capacity is 45 MCM/year.

2. Irrigation Water:

To collect and convey irrigation water, dams, canals and distribution systems were constructed.

The main targets of development by the government have been the Jordan Valley and the southern Ghors. The private sector development of water resources has taken place mainly in the highland areas.

Dams: Irrigation uses:

King Talal Dam,	capacity 89 MCM.
Wadi-El-Arab Dam,	capacity 20 MCM.
Ziqlab Dam	capacity 4.3 MCM.
Shueib Dam	capacity 2.3 MCM.
Kafrain Dam	capacity 3.8 MCM.

Other small desert dams have also been constructed for local uses such as animal husbandry, irrigation and artificial groundwater recharge.

Canals:

* King Abdullah Canal, concrete, length 110 km, capacity 300 MCM/year, irrigation of 280,000 dunums.

* Ghor Safi chain of canals to irrigate 47,000 dunums.

* Irrigation networks, pressure pipes, and other technologies to maximize water conveyance and distribution efficiency.

* Springs were captured and developed.

* Water saving technologies, piped nets, drip irrigation, plastic houses etc.. were introduced and are now widely used.

3. Waste water treatment as a means to protect the environment and to increase available resources:

Fourteen municipal wastewater treatment plants now operate in Jordan. In addition, the majority of industrial plants, hospitals, universities, army units, airports, etc., possess their own waste water treatment facilities. The effluents of the treatment plants are used directly or indirectly, after mixing in irrigation.

The cities and towns equipped with wastewater treatment plants are the following:
Amman - Ruseifa - Zerka, Irbid, Karak, Tafila, Ma'an, Madaba, Salt, Abu Nusseir, Mafraq, Ramtha, Aqaba, Jerash, Baqa'a, Kufranja.

VI

Water Consumption: Present and Future Demands

1. Water Use:

1.1. Domestic Uses:

A total of 180 MCM/year are presently used in Jordan to satisfy domestic uses. The water supply network suffers from corrosion and damage which leads to losses estimated at 30% of all the supplied water.

Calculating the per capita domestic water use in Jordan shows that it averages around 85 l/day. Compared to the domestic uses in Europe of 250-350 l/c.d., to those of Israel of 280-300 l/c.d., to the Gulf States of 280-350 l/c.d., and to Iraq, Syria and Egypt of 130 l/c.d., it can be said that Jordanians are using the least of all, not only because they are extremely concerned about water use, but also because water is much less available. Concerning domestic water use, especially during summer, 85% of Jordanians live at the hygienic brink. Less water would mean public health detriments.

1.2. Industrial Uses:

Industries in Jordan use at present around 45 MCM/year of water. The large part of this amount is consumed by the phosphate mining, potash and fertilizer industries.

Almost all industries in Jordan suffered from water shortages which led them to recycle their wastewater wherever and whenever it was possible. One of the major concerns of new industries is how and from where to obtain water.

Water availability forms also a limiting factor for the establishment and expansion of certain water-consuming industries like paper, steel, oil shale extraction, etc.

1.3. Agricultural Uses:

Irrigated agriculture is an important factor in the economy of Jordan. Irrigation in Jordan dates back to its development by ancient civilizations in this part of the world.

The major water amounts used in Jordan are those consumed by irrigation. Animal husbandry and fish farming consume only negligible amounts of water.

The consumed amounts in this sector depend on the availability of resources; amounts of water stored in dams, yield of springs, discharges of wastewater treatment plants and others. At present around 650 mcm/year, are used in agricultural purposes, part of which is fossil, non-renewable water. As a result of governmental and private sector development, the irrigated cropping area reached 60,900 hectars in 1991.

Perhaps farmers of few countries in the world share with Jordanian farmers their awareness of the importance of water. Despite the high cost of implementing drip irrigation instead of the traditional irrigation methods (surface), farmers have been installing these new techniques.

Also, an external factor affecting the amount of water used in irrigation is how much is allowed to enter Jordan's territories from the regional water resources such as the Yarmouk. This amount has been monotonously declining for about 8 years, which has reflected badly on the production of crops and land productivity in the Jordan Valley area.

1.4. Total Uses:

The total water uses differ from year to year and depend on the available resources. In 1991, the total uses added up to about 875 mcm. In 1992 it was expected that this amount would rise to more than 900 mcm because of the extremely wet year 1991/1992 and accordingly the availability of additional resources.

2. Water Balance: Resources Versus Consumption:

The demand for water in Jordan exceeds the available resources, and with the passage of time, the gap between both demand and supply is widening.

The surface water resources have been developed to a large degree to be mainly used in irrigation. Dams, canals and advanced irrigation systems were introduced to make the best use of the available resources. The water sources which have not yet been developed are very limited and are expensive to make available. As an example, there are plans to construct 5 dams on Hidan, Wala, Mujib, Kerak and Hasa Wadis with total additional captured water amounts of 60 MCM/year; some of which is water with relatively high salinity. The construction cost of such dams exceeds JD 2.60 / m^3 or US$ 3.8 / m^3 of water.

Nonetheless, the government of Jordan is planning to construct these dams to assist in alleviating the severe water shortage in the country.

The Unity Dam, planned for construction on the Yarmouk River, is supposed to supply Jordan with an additional 100 mcm/year of good quality water, which may moderately alleviate the water shortage problem in Jordan. But since the construction of the dam has not started yet, it is expected that by the time the dam is completed the gap between demand and supply will have doubled. Hence, the Unity Dam will, by the time of its completion, only alleviate a small portion of the water shortage problem.

Desert wadis are presently developed by constructing weirs to collect floodwater (water harvesting) for both agricultural uses and groundwater recharge. But even the development of all the desert wadis will mean a small addition of around 30 MCM/year to Jordan's water resources.

The groundwater resources of the country are overexploited at a rate of around 120 MCM/year (1991). Some groundwater basins like Jafr and Dhuleil were depleted in the seventies and eighties. Others like Azraq, Disi and Agib are showing signs of depletion, such as declining groundwater levels and increasing salinity. If the present overexploitation continues at the same rate, these groundwater resources are expected to be exhausted within the coming decades.

3. Future Water Demand: (Table 40)

3.1. Domestic Uses:

Increasing demand for domestic purposes in Jordan is caused by the following factors:

- Natural growth of population of 3.6% per year.
- Improving living standards.
- Waves of refugees settling in Jordan.

The present amount of water supplied for domestic uses is around 180 mcm/year; serving 3.7 (1992) million inhabitants, expected to increase to 4.7 and 6.8 million in the years 2000 and 2010 Table (41) .

If supply rates per capita remain as low as they are at present, 235 mcm/year and 340 mcm/year will be needed by the years 2000 and 2010 to cover domestic supply.

Jordan's inhabitants consume in domestic uses an average of 85 l/day per capita, which, for the living standards and development state of the country, is considered the minimum to sustain the health situation of the population. An average of 110-130 l/c.d. can be considered adequate to satisfy the population's needs. If 120 l/c.d. are consumed and if the natural population growth for the years 2000 and 2010 are considered, Jordan will need 332 MCM/year and 480 mcm/year respectively to cover domestic water demand.

In addition, improving living standards and styles of life may cause an increase in domestic demand by an additional 10%.

Table (40)

Water use, demand by sector (MCM/year) and population growth (million)

	Present Uses	Present demand 1993 120 l/c.d.
Domestic	180	250
Industrial	45	45
Irrigation	650	700*
Population		3.7 Million

* Increases are due to increasing wastewater production, treatment and reuse in irrigation.

* Increases are due to increasing wastewater production, treatment and reuse in irrigation.

Migration and refugees' needs cannot be estimated or taken
into consideration. But refugees and immigrants to Jordan will reflect catastrophically on the water sector.

Table (41)
Water demand and population growth by different per capita use

	Year 2000 85 L/c.d.	Year 2000 120 L/c.d.	Year 2010 85 L/c.d.	Year 2010 120 L/c.d.
Domestic	235	332	340	480
Industrial	85	85	120	120
Irrigation	688*	756*	760*	860*
Population	4.7	4.7	6.8	6.8

Jordan received three waves of refugees since 1948, and the last wave of 1990/1991 increased the population of the Kingdom by 12%.

3.2. Industrial Uses:

At present, medium and large industries consume around 45 mcm/year of water. The planned and expected development in this sector estimates the demand by the years 2000 and 2010 to be 85 mcm and 120 mcm/year. The main increase is expected to be caused by the Dead Sea chemical industries and oil shale extraction and processing.

3.3. Agricultural Uses:

The used amounts of water in irrigation depend on the availability of resources. This sector consumes at present some 650 mcm/year. But if new resources are not going to be developed, this amount is expected to decrease because some of the currently used water is extracted from non-renewable resources. The agricultural sector under the present resources availability is not expected to be allocated more than 550 mcm/year after the year 2000.

4. Water Sources to Cover the Demand:

Jordan is currently overexploiting its groundwater resources by around 120 MCM/year. Generally, water levels are dropping, fossil water resources are under mining, salinization of aquifers is increasing, salt water intrusions can hardly be avoided, irrigated soils in different areas of the country are showing salinization phenomena and the population's domestic water supply does not satisfy the hygienic and living

standard's demands.

In conclusion, Jordan is experiencing an escalating water crisis. Water shortages are already chronic.

The options of alleviating the water deficiency can be classified under different titles such as:

- Increasing supply from:
  * Internal sources
  * External sources
- Decreasing demand.

4.1. Options of Increasing the Supply:

a. *Internal sources.*

The Unity Dam:

During the last four decades different dam plans have been advanced to collect the Yarmouk River water, like Mukheiba Dam with a capacity of 200 MCM, the Maqarin Dam with a capacity of 350 MCM and the Unity Dam with a capacity of 200 MCM.

Because of political complications with the other riparians especially Israel, Jordan was unable to construct any of these dams.

The latest agreement signed with Syria in 1987 called for the construction of the Unity Dam (Wahda Dam) on the Yarmouk River to regulate its flow and to increase the water amounts flowing into Jordan by around 80 MCM/year. In this case the total intake of Jordan would be around 180 MCM/year, far below its share of the river, according to the Johnston Plan (1955) of 377 MCM/year.

The diversion tunnel of the Unity Dam was completed in 1989, but since that time no works were carried out on the dam site.

The Unity Dam will bring an additional 80 MCM/year of water, which is supposed to alleviate the water shortages of the Jordan Valley area and partly relieve the increasing domestic water deficiencies.

Jordan Valley side wadis:

Different small wadis on the eastern flank of the Jordan Valley are still pouring their flood waters into the Jordan River, like Wadi Kufranja, Yabis, Hisban, Jurum and Rajib. The total discharge of all these wadis is around 28 MCM/year, half of which consists of baseflow, already utilized for domestic and irrigation uses.

The intercatchments of wadis, which are very difficult to control and regulate, discharge about 18 MCM/year of water. Such areas need intensive and expensive constructions to make use of their water. Dam projects on the small wadis are being prepared at present. But, all these projects together will only partly alleviate the irrigation water shortage in the areas lying at the mountain foothills east of King Abdallah Canal, because the additional amounts of water which can be collected are not expected to exceed 20 MCM/year.

Dead Sea eastern shores:

The water resources of this area: Zerka-Ma'in, Ibn Hamad, Mujib, Karak and Hasa have not yet been developed to their full extent. The reasons for that are:

- A very rough terrain and environment which makes the selection of dam sites highly complicated.

- Unavailability of irrigable lands downstream of the wadis like Zerka Mai'n, Mujib and Ibn Hamad.

- The salinity of the baseflow which mainly consists of lower aquifer discharges reaches values of some 4500μs/cm, making the water use conditional.

- Water constructions, dams, canals, etc., are expensive to establish because of the rough terrain and sparce infrastructure.

These factors together make the utilization of the limited water resources complicated and expensive. Still, plans are underway to develop and make use of them. The additional water resources which can be gained from these projects amount to 100 MCM/year. Partly, the collected water requires treatment to be made useful even for irrigational uses.

Disi Mudawwara - Sahl-es-Swan:

Advanced technologies in waste water treatment and reuse offer new opportunities for semi-arid and arid countries. They allow for the use of the same water more than once. That domestic water uses are only partly (70 - 75%) consumptive should be utilized to the full extent in arid areas.

The present situation in Disi-Mudawwara - Sahl-es-Swan area (henceforth Disi area) is that 70 - 80% of the groundwater is extracted and used in irrigation which is a consumptive water use.

One can think of transferring the water currently used in irrigation in Disi area to the urban centers in Jordan to be first used for domestic uses, then collecting the waste water, treating it adequately and reusing it in irrigation. The gains of such a project are the following:

1. Putting an end to the water shortage of the urban center for at least one decade.

2. Saving evaporation water during the use in irrigation. A dunum (1000m^2) of land in Disi area requires at least 1220m^3 of water to produce one crop, whereas a dunum of land in the highlands or even in the Jordan Valley requires only 600 - 800m^3 of water. This means that of what is lost of the water because of its use in domestic purposes, 25 - 30% of the pumped water can be gained again by using the water for irrigation in areas with less potential evaporation.

3. The Disi water has an excellent quality for the use in domestic purposes, but it lacks fertilizing agents like phosphates and nitrates. Those will be added to the water if it is first used for domestic purposes.

4. The present irrigation projects in Disi area will ultimately result in causing deterioration of the groundwater qualities underlying that area, because of the infiltration of irrigation water which is loaded with salts, fertilizers and eventually biocides. Transferring the water from that area and using it in domestic purposes and irrigation after treatment will conserve the groundwater quality of Disi.

5. Agricultural projects are more economical and will produce cheaper products if they lie closer to consumers, whereas Disi lies 300km to the south of the main urban centers of Jordan.

Transferring Disi water to the urban center for domestic uses, treating the produced wastewater and using it in irrigation will set an end to the domestic water shortage for a decade and will represent a technical and economic advancement for the country.

Water Harvesting:

This technique incorporates the collection of floodwaters of desert wadis discharging relatively small amounts of water, where the collection in large dams is prohibited by the high ratio of reservoir area to the collected volume of water. The technique serves in saving the water from reaching the salt pans and becoming saline, and from evaporation, by allowing its infiltration to the groundwater.

If this technique is applied it will add 30 - 50 MCM/year more to the present water resources the country.

The shortcoming of the whole technique is that the collected water is widely distributed along the wadi course and the surface water can only be used for local irrigation. Therefore, this water will not alleviate the present water situation in Jordan because the amount is small and only a portion of it recharges the groundwater resources. But it will lead to an increase in agricultural production.

Pilot projects are being carried out in Jordan in Muwaqer area, 40km southeast of Amman, in El-Hamad area, northeast of Jordan and in Karak and Tafila areas. The obtained results until now are encouraging (Kifaya 1991).

Waste water treatment and reuse:

Increasing domestic and industrial water consumption result in additional production of wastewater which, after proper treatment, can be used for irrigation. At present the quantity of treated wastewater amounts to 45 MCM/year and it is expected to increase with time, proportional to the amounts of domestic and industrial water supplies and to the percentage of connected houses to the sewerage system.

This technique will add a few tens of million cubic meters to the water currently used in the irrigation sector.

Brackish Water:

Because of the prevailing climate in Jordan and the hydrodynamic system governing the groundwater evolution, Jordan possesses brackish water resources. The salinities of these brackish waters range from 1500 ppm up to 4500 ppm, which makes their use in irrigation salt-semitolerant and tolerant crops possible.

The area which produces the largest amounts of brackish water without affecting other water bodies is located along the slopes overlooking the Dead Sea (Zerka Ma'in, Mujib, Ibn Hamad, etc.). The brackish water amounts are estimated at 70 - 90 MCM/year, which if desalinated may add a potential source for domestic water supplies.

Not to be recommended is pumping brackish groundwater from areas like Azraq or deep aquifers to be desalinated for the different uses, because such brackish groundwater builds, in most cases in Jordan, the support system for fresh water bodies. In contrast, the brackish water along the eastern slopes of the Dead Sea
discharges naturally out of springs, and its utilization, whether in its present state or after desalination, should become a priority for the water sector in Jordan, especially because its use does not cause any injury to other surface or groundwater resources. Desalination of brackish water like that mentioned above may very well prove to be economically feasible, even for irrigation uses.

Desalination of Sea Water:

Sea water desalination is still an expensive technique: US$ 1-2/m^3 of water. In addition, the only place to practice sea water desalination in Jordan is Aqaba, where there is absolutely no need for additional water in the coming decades if Disi water is reasonably used.

Desalination at Aqaba and pumping the water to other areas in Jordan may cost as much as US$ 3-5/m^3, which is a very high price even for the rich who use it at home.

Cloud Seeding:

This technique is applied to enhance precipitation of super-cooled clouds by seeding the clouds with crystallization nuclei to allow them to form droplets that fall to the surface of the earth.

Cloud seeding was practiced in Jordan in the years 1986 -1990, without a clear result about its efficiency. It seems that much effort could have been saved had a better scientific approach been established for each seeding experiment. But, the subject still deserves more study and evaluation.

If successfully applied, cloud seeding may add tens of million cubic meters of water to the present water resources of the country.

Cloud seeding may be more effective and economically feasible if it is used to guarantee more precipitation for dry farming areas, especially at the end of the rainy season when in certain years plants still need water, but no precipitation takes place. In such cases crops can be rescued by adding 10 - 30mm of precipitation.

Other measures and techniques:

Measures like limiting and preventing water pollution, minimizing evaporation and increasing water collection from rooftops may increase the available water by a few tens of million cubic meters per year. This would alleviate local water shortages.

Also limiting the use of domestic water for irrigation purposes on farm scales, especially in Mafraq and Ma'an governorates, may alleviate other areas' domestic water shortages and allow for more wastewater to be treated and reused in irrigation.

b. External Sources:

- Euphrates project
- Peace pipeline

Euphrates project:

The scheme of the Euphrates project incorporates importing water from the Iraqi section on the Euphrates River to Jordan. A study was carried out in the early eighties concerning the technical and financial feasibility of the project and it was found that the project is technically feasible, but economically it cannot be justified because the water will have a pumping head of around 1400m from its intake on the Euphrates to the main urban centers in Jordan.

The study considered pumping of 80 MCM/year in the first phase and another 80 MCM/year in the second.

The peace pipelines:

In 1987, the peace pipelines project was suggested by then Turkish Prime Minister Turgut Ozal. The project would include conveying water from the two rivers Seyhan and Ceyhan, which originate in Turkey and discharge into the Mediterranean Sea, to be used in the countries lying to the south of Turkey.

Two pipeline branches were suggested to supply the different countries lying to the south of Turkey with water; an eastern line running through Iraq to supply Kuwait, the other Gulf states and Saudi Arabia, and the western line running through Syria and supplying Jordan, Palestine and Saudi Arabia.

The cost of the project was estimated at US$ 21 billion which is extremely expensive considering the amount of water it supplies.

The other major objection to the project is its political complications. Making some countries dependent for such a vital commodity on others while no peace treaties are in place.

4.2. <u>Decreasing Demand:</u>

A variety of conservation measures can still be applied in Jordan to increase the available amounts of water. These include:

1. Reducing losses from irrigation canals:
   The main target of this action is the King Abdallah Canal with estimated yearly losses of around 50 MCM of water.

2. Expanding drip irrigation and cultivating plants requiring less water:

   These measures may save a few tens of million cubic meters of water per year, especially in the Jordan Valley area where in certain reaches of the King Abdallah Canal more water is used in irrigation than is required by the plants.

3. Reducing losses from the domestic water supply networks, which are estimated at 25% of the pumped water. Worth mentioning is that the leaked water is not entirely lost because part of it infiltrates back to the groundwater and is then pumped again into the water net.

4.3. Economic Restructuring:

It is now a well-established fact that with the present available water resources and technologies, one cannot let deserts bloom. One has also to be realistic and practical and to try to substitute for the lack of water resources, knowing that 72% of Jordan's waters are used in irrigation to produce food and create jobs for the explosively increasing population.

Food production in the world increased in the last decades, and in terms of the world food production, what Jordan produces is negligible and can easily be substituted by other areas production.

Job opportunities can be created in agriculture (which further development is prohibitive in the case of Jordan), in industry and services, like tourism and trade.

Agriculture and Services:

The potential in Jordan for more workers in agriculture is negligible. Tourism and trade development is limited by the present political situation in the Middle East. Their future development has only a certain limited potential and they cannot create enough jobs to serve the population needs in Jordan.

Industry:

Jordan has a relatively small domestic market, therefore, the choice for industrialization is outward oriented which narrows the range of product lines.

Also, the public financial resources are limited and the government's allocations of investment resources were, until now, directed to building up basic industries such as cement, chemical fertilizers, oil refinery, phosphate mining, etc. At the same time, the private sector has been hesitating to invest its money in long-term investments. The private sector wants mainly to deal with secure short-term investments and to avoid the more risky long-term ones.

One of the reasons for that is the political arena in the area, burdened with insecurities concerning investments.

Industrialization requires basic infrastructure, markets, know-how, technologies, political stability, security and sustainability.

Jordan has already developed its basic infrastructure to a satisfactory degree to allow industrialization. Roads, electricity, telecommunications are fairly

available. Also Jordan has developed a large number of well-educated manpower both in technical and administrative aspects.

Also, the investment atmosphere and institutional environment are characterized by stability and security. But it seems to be very essential to create still more secure environments for investment. Of great importance is the need to ease regulations and instructions for industrial investments and to elaborate on more suitable practices and procedures dealing with investments, imports and exports.

Marketing skills should also be developed. Markets in the Middle East and in the surrounding countries are believed to be capable of absorbing industrial products, if the range of products is well chosen.

Restructuring of the economy of Jordan to absorb the unemployed work force and to bring about a shift from an agrarian economy to an industrialized one, may require an investment of a few billion US dollars. Such a small investment measured in terms of industrialized countries and a significant large investment considering Jordan's economy, can be a part of the solution, not only of the water problem of Jordan, but also of the Middle East problem.

Industrial countries should look at the economic restructuring of Jordan as a cheap means for partially solving the Middle East conflict.

It should also be the interest of oil-rich countries to allocate such a small investment in their terms to stabilize the area politically and to look at non-oil producing Jordan as a partner, especially for the future when the present oil resources are depleted.

Jordan, so far, has made its achievements under extremely difficult conditions. But, it is now recognizing its limitations in the midst of a powerful external environment: more of its people have been foreed to return to the country; there have been large cut-backs in foreign financial assistance; and the priparian states' pumping practices are depriving Jordan of part of its water resources.

VII
WATER POLLUTION

Generally, water resources are exposed to pollution factors which affect their qualities; these include human activities like the disposal of solid and liquid wastes of urban and industrial areas, the use of biocides and fertilizers in agriculture, the return flows to surface and groundwater resources from irrigation water, as well as the overexploitation of groundwater resources.

1. Pollution Sources:

For the case of Jordan, Table (42) shows the pollution producers, the sites, the affected environmental element and the affected group.

The drastic increase in Jordan's population and the improving living standards demanded an increase in water supplies, which produced increasing amounts of wastewater, irrigation return flows, and led to the total use of all available surface water resources and to overexploitation of aquifers. The results were deteriorating surface and groundwater qualities.

Following is a discussion of the major polluted areas and the causes of water quality deterioration.

1.1. Wastewater treatment plants (WWTP)

The first WWTP was constructed in Jordan in 1945 to serve the town of Salt (Fig. 17), where cesspits were the form of wastewater deposition. Naturally the fouled water used to seep both to the surface and groundwater, negatively affecting the water quality in the area as well as transmitting various diseases. The springs supplying the town with drinking water were also polluted from the cesspool seepages.

The WWTP of extended areation type, served its purposes and cesspools were abandond, hence, the springs and wadi water qualities improved. The good quality of the treatment plant effluent allowed for its unrestricted use in irrigation along wadi Shueib without any environmental or health hazards.

The case of Salt repeated itself in Amman, Irbid and other towns and cities in Jordan. Treatment plants were then constructed, in sequence, especially from the eighties onward.

The first generation of WWTP of trickling filter and activated sludge types functioned properly without any major problems except for becoming over-loaded with time (Table 43).

Table (42)
Water Polution in Jordan
(major producers, sites, affected environmental element and affected group)

POLLUTION PRODUCER	WASTE WATER TREATMENT PLANTS	CESSPOOLS	INDUSTRIAL WASTES	IRRIGATION RETURN FLOWS	PESTICIDES INSECTICIDES	SOLID WASTE DISPOSAL SITES	SALT WATER INTRUSIONS	OVERPUMPING & OVER-EXPLOITATION
SITE	KHIRBET ES-SAMRA, MAFRAQ, RAMTHA, BAQAA, IRBID, JERASH, KERAK, SALT, TAFILA, AQABA	IRBID, AZRAQ, ZERKA, RUSEIFA	AMNAN, ZERKA, RUSEIFA, BAQAA	JORDAN VALLEY, DHULEIL, AZRAQ, SHOUBAK, AQIB	JORDAN VALLEY, AZRAQ, DHULEIL, AQIB, SHOUBAK	SE-AMMAN, UKHEIDER, SALT, MADABA	AZRAQ	AZRAQ, DHULEIL, SHOUBAK, N-BADIA, DISI, AQIB, JAFR
AFFECTED ENVIRON-MENTAL ELEMENT	SURFACE WATER GROUNDWATER	GROUNDWATER	SURFACE WATER & GROUNDWATER	GROUNDWATER & SOILS	GROUNDWATER	GROUNDWATER & SURFACE WATER	GROUNDWATER	GROUNDWATER
AFFECTED GROUP	HUMAN AND ANIMAL HEALTH	HUMAN HEALTH	HUMAN AND ANIMALS WELL BEING	DECREASING SOIL PRODUCTIVITY	HUMAN AND ANIMAL HEALTH	HUMAN AND ANIMAL HEALTH & DETERIORATING SOILS	DECREASING SOIL PRODUCTIVITY AND SOURCE DAMAGE	SOURCE DAMAGE & DECREASING SOIL PRODUCTIVITY

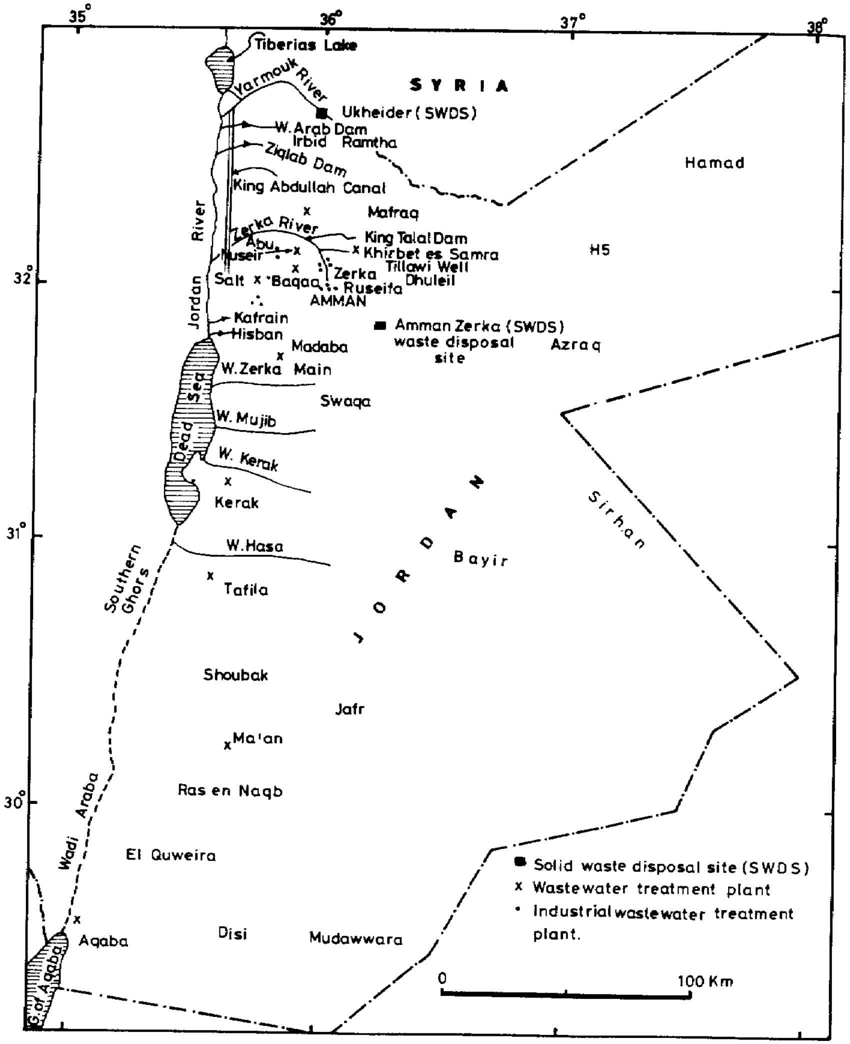


Figure 17: Location map of waste water treatment plants

In 1985 waste water stabilization ponds were introduced into Jordan. Khirbet es Samra (KS) was constructed around 35 km northeast of Amman to serve Amman, Ruseifa, and Zarka cities. But soon after operation it was recognised that this type of WWTP showed the following shortcomings.

Table 43
Average Municipal Wastewater Influent/effluent Quality, by Treatment Plant, 1991 (Files of WAJ)

Treatment Plant	Flow m^3/d	BOD-In mg/l	BOD-Out mg/l	COD-In mg/l	COD-Out mg/l	TSS-In mg/l	TSS-Out mg/l	Type of Treatment
As Samra	97,471	703	104	1,574	316	640	172	S
Mafraq	1,394	960	225	1,246	592	540	251	S
Aqaba	3,883	330	68	698	127	330	140	S
Ramtha	671	919	162	2,000	505	931	262	S
Abu Nuseir	1,316	711	24	1,172	79	709	25	A
Baqa'a	4,998	1,080	100	2,087	382	1,029	100	T
Salt	3,322	859	14	1,755	78	974	23	E
Irbid	6,175	1,139	25	3,622	101	1,585	30	TA
Jarash	1,316	1,128	9	2,285	90	1,064	17	O
Karak	718	624	62	1,427	208	661	89	TI
Tafila	537	1,014	49	1,939	163	1,100	42	TI
Madaba	1,234	1,290	212	2,422	602	1,231	229	S
Ma'an	914	798	79	1,520	283	703	191	S
Koufranja	516	1,115	25	1,956	125	1,321	32	TI

S = Stabilization ponds
T = Trickling filter
O = Oxidation ditch
E = Extended aeration
A = Activated sludge
I = Imhof tank

Areas served with wastewater treatment suffered less surface and groundwater contamination. The WWTP effluents were also efficiently used in irrigation without any negative effects on public health.

In 1985 waste water stabilization ponds were introduced into Jordan. Khirbet es Samra (KS) was constructed around 35 km northeast of Amman to serve Amman, Ruseifa, and Zarka cities. But soon after operation it was recognized that this type of WWTP showed the following shortcomings.

- Large surface areas of pools resulted in very high evaporation rates under the semi-arid climatic conditions prevailing in the country.

- The effluent of the treatment plant still contained high values of BOD5, faecal coliform, suspended solids and numerous other pollutants.

- The treatment during cold weather and hot weather was incomplete.

KS, planned to serve the area and its expansion until the year 2010, was already overloaded in 1986 (one year after its operation) due to improper and inaccurate design. Since that time, many attempts have been carried out to improve its efficiency, but with very moderate success. The problem now requires a radical solution. Surface and groundwater qualities underlying the area and lying downstream of it are suffering from severe pollution because of the bad quality of KS effluent. Along Wadi Dhuleil and Zarka River foul odour prevails, especially during warm weather. Many farmers, who depended for irrigation on the area's groundwater resources, had to abandon their farms because the groundwater in certain areas became so polluted that it was no longer suitable for irrigation (Table 36).

The case of KS was also repeated in Aqaba, Ramtha, Mafraq and Madaba areas, where stabilization ponds were built. The same deficiencies in this type of treatment appeared in all these plants, which led to surface and groundwater pollution and turned the wadis along which the effluents flow into breeding sites for insects and diseases.

At present, all WWTP working as stabilization ponds need radical and immediate improvement; involving redesign and probably the addition of polishing ponds, etc. Nonetheless, all these additional steps and improvements are expected to cause an increase in evaporation amounts now estimated at 30-45% of the incoming wastewater quantities in a country characterised by its scarce water resources. Nowadays 15-20 MCM/year of water are lost by evaporation from stabilization ponds, which in

itself represents an enormous water loss for the country. On the other hand, the dissolved salt concentrations increase in the remaining water after evaporation by 50-100%, making the use of the effluent more difficult and conditional even for irrigation purposes.

Other types of WWTP -- trickling filters extended aeration, and activated sludge -- are functioning adequately in Jordan. Examples are Irbid, Jarash, Karak, Abu Nuseir and airport treatment plants.

In certain areas, improper discharge and use of effluents is causing deterioration of other natural elements such as surface and groundwater, air and soil. But with suitable implementation of reuse techniques, environmental inadequacies can be overcome.

1.2. Cesspools

Before the construction of WWTP, each house in Jordan possessed a cesspool or a cesspit, which either leached to the groundwater, or unobserved, gradually to the nearby slopes or wadis. Non-leaky cesspools were emptied during floods into the nearby wadis. But, since floodflows were not collected in dams or other types of constructions, and they used to reach their destination undisturbed, pollution did not surface.

The increasing population, and accordingly the number of cesspools and the amount of wastewater, led to surface and groundwater pollution and to odourous streets and town quarters. In later stages, streets and free areas became breeding grounds for insects, and the wastewaters affected drinking water pipes, attacked and leaked into them, contaminating the drinking water of various communities (Karak, Irbid, Salt, Amman, etc.).

The construction of sewerage systems and WWTP allowed surface and groundwater resources in towns and their surroundings to recover (Amman, Aqaba, Ramtha, Jarash, Karak, Salt, etc). Towns not served adequately with sewerage systems continue to suffer from problems; these include Ruseifa, Azraq and, partls of Irbid, etc.

In such communities surface and groundwater resources are still exposed to quality deterioration (Table 44). In addition, emptying cesspool contents into wadis and streets during floods is now negatively affecting the water qualities of downstream dams like King Talal and Wadi el Arab.

1.3. Industrial Wastewater

During the last two decades development was also concentrated on industrialising the country; where both the private and the public sectors were actively involved in the industrialisation processes.

Many small and medium types of industries were mainly established in Amman-Zerka area (Fig. 17). Heavy and large industries have been located in areas of natural resources or closest to the required services: phosphate mining developed in Ruseifa, El-Hasa, and Shidiya areas; potash at the shores of the Dead Sea; fertilizers in Aqaba; and an oil refinery and power station in Zerka.

With each newly established industry an increasing quantity of wastewater was introduced into the environment, resulting in polluting water resources and rendering some of them unsuitable for their former uses.

Table (44)
Ruseifa Spring analyses 1991
Cesspool effects on groundwater resources

Date		02.11.1991
T°C		18
EC	µS/cm	1020
pH		7.43
NO_3	meq/l	0.83
HCO_3	meq/l	5.61
CO_3	meq/l	0.0
Cl	meq/l	3.33
SO_4	meq/l	0.437
Mg	meq/l	1.98
Na	meq/l	3.43
K	meq/l	0.14
TOC	meq/l	6.51
COD	meq/l	0.00
Li	mg/l	0.11
PO_4	mg/l	0.434
I	mg/l	0.094
B	mg/l	1.12
F	mg/l	0.367
Total Coliform	1.1×10^3	
Fecal Coliform	1.1×10^3	

In the early eighties the government issued instructions that each individual industrial plant had to treat its wastewater to a satisfactory degree before discharging it into the environment. A time limit was also assigned for the industries to implement the instructions. Subsequently all industries, whether big or small, producing trace and heavy elements or household type wastewater installed WWTP. But because of the lack of experience and in the rush to fulfill the government instructions on time, many of the established treatment plants proved to be insufficient, inefficient and/or even non-specific for the produced wastewater. The action remained only partly successful. Soon after, the industries found ways to circumvent the government instructions (Table 45).

With time the industries recognised that they had to adequately treat the wastewater in the interest of the society and therefore, they exchanged, improved and upgraded their treatment facilities and methods.

In Amman-Zerka and Baqaa areas, industries dealing with heavy metals or using them in processing their products, and industries producing heavy organic loads still cause water resources to deteriorate (Gedeon, 1991). This problem is currently under study and it is expected to improve the situation, especially because the majority of these industries are willing to cooperate in alleviating the problems.

1.4. Irrigation Return Flows

The aridity characterizing Jordan forces the use of flood and spring water to irrigate lands for food production. Since water by this practice is spread over a large area and because of the high evaporation potential, relatively high salt concentrations are left behind accumulating in the soils. Continual irrigation allows the salts to seep down below the capillary fringe and to reach the groundwater or to seep again to the earth's surface and reach the surface water. The high salt content of the filtrate causes an increase in the salt concentrations of the surface and groundwaters which may, with time, render them unsuitable for certain uses or may lower their crop productivity.

Table (45)
Mean values for organic loads of industrial effluent*
(January 1990 - July 1990)
(Gedeon 1991)

Designation**	Flow m^3/d	pH	TDS kg/d	SS kg/d	COD kg/d	BOD kg/d
Jordan Yeast Co.	350	6.6	7000	6975	11690	5309
Arab Detergent Mfg.	40	10.3	4	64	89	28
ICA Co. (INTAJ)	120	7.5	4256	303	580	177
Mineral Exploration	100	7.7	142	93	7.2	1.1
Overall Co. (oven mfg)	125	8.4	315	32.4	57	23
Chem. Polymers Co.	4	6.3	92	153	372	39
Jordan Tiles Co.	55	12.1	187	84	2.5	0.3
Imperial Underwear	50	7.8	92	17.5	32.3	8.4
Textile Co. (TBAKHI)	20	7.9	23	6.7	14.4	5.3
Tent & Blanket Fact.	80	8.0	65	8.2	21.4	6.7
Pupl and Mill Mfg.	2000	7.6	2672	252	760	306
Jordan Ceramics Co.	85	7.7	243	60.2	11	3.3
Chemical Ind. Co.	1	11.2	14	0.2	1.6	0.5
Intermed. Petrochem.	2	7.9	3	0.3	14.8	0.4
Hussein Iron & Steel Ind.	50	8.2	333	31.2	16.5	3.9
Jordan Matches Mfg. Co.	4	7.0	43	8.0	17.2	6.3
Jordan Sulphochem. Co.	30	9.2	717	345.5	44.7	14
Warehouse Mfg.Co.(Refrig)	10	8.3	8	0.5	1.1	0.3
Rock Wool Factory	1	8.0	2	0.2	0.1	0.0
Jordan Petroleum Refinery	1600	7.5	3749	117	282	74
Hussein Thermal Station	1700	7	2733	56	102	34
Arab Iron & Steel Co.	300	8.8	452	32.4	16	2.4
Jordan Hygienic Paper Co.	100	7.3	224	197	164	60

The phenomena of irrigation return flows have already affected different areas in Jordan; In Dhuleil area the salinity of the water increased twice or three times its original value. The groundwater in that area contains residues of fertilizers like phosphates and nitrates (Rimawi, 1985). In certain portions of the aquifer, the water became so saline, as a result of irrigation return flows and overpumping, that it could no longer be used for irrigating normal crops. (Table 46).

Table (46)
Annual averages of parameters of DP17 well
(Water quality development due to overpumping and irrigation return flows)
(K, NO3, Cl, Ca, CO3, Mg, HCO3, Na, SO4 in meq/l)

Date	ECμS/cm K NO_3	pH-value Cl TDS g/l	Ca CO_3	Mg HCO_3	Na SO_4
1971	500 0.16 ---	8.1 2.14 0.32	0.7 0.18	1.5 1.09	2.43 1
1972	620 0.23 ---	8 2.85 0.4	1.1 0.18	1.92 1.61	2.91 1.56
1973	808 0.24 ---	8 4.62 0.52	1.58 0	2.38 1.47	3.87 1.74
1974	915 0.2	7.9 6.09 0.75	1.85 0.103	2.69 1.39 0.59	4.48 1.41
1975	1500 0.51 ----	7.4 9.72 0.96	3.3 0	5 1.16	4.91 2.13
1976	1688 0.37 0.65	7.5 11.6 1.08	4.5 0	5.6 1.58	5.78 2.48
1977	2250 0.41 0.65	6.6 15.49 1.44	5.6 0	7.92 1.3	6.61 3.25
1978	2700 0.41 0.65	7.8 19.35 1.73	6.35 0	9.67 1.16	8.09 3.19
1979	2930 0.56 1.13	7.8 22.33 1.88	7.05 0	12.58 1.1	8.7 8.04
1980	3372 0.52 1.36	7.7 27.35 2.16	8.77 0	14.57 1.08	10.54 4.96
1981	4368 0.59 1.9	7.8 35.61 2.8	12.06 0	18.56 0.97	13.86 6.9
1982	3429 0.51 0.94	7.8 27.28 2.19	10.3 0	14.13 1.02	10.84 5.2
1983	2896 0.37 1.17	7.7 21.87 1.85	8.37 0	11.3 1.07	9.58 4 Cont.

cont. tbl.46

1984	2870 0.41 0.86	8 21.38 1.84	8.11 0	10.64 1.05	9.55 4
1985	3283 0.34 1.24	7.9 24.45 2.11	8.84 0	15.4 1.17	10.4 5.6
1986	3099 0.43 1.36	7.9 23.49 1.98	8.44 0.01	11.77 1.23	11.56 5.45
1987	3100 0.46 1.36	7.82 23.64 1.98	7.85 0	11.7 1.16	10.73 4.62
1988	3027 0.43 1.32	7.76 22.63 1.94	7.44 0	11.82 1.22	10.28 4.83
1989	2943 0.4 1.32	7.84 23.45 1.9	7.99 0	8.64 1.1	10.47 5.66
1990	3100 0.45 1.53	7.62 21.95 2.02	7.88 0	11.76 1.01	9.7 5.26

In Azraq and Shoubak areas, the groundwater quality started to deteriorate as a result of irrigation return flows. The salinity of some springs fed by the same groundwater systems deteriorated and were of doubtful quality for domestic uses (Salameh 1991).

In Disi area, problems associated with irrigation return flows have not yet surfaced, because the overlying aquifer consists of medium to fine grained sandstones, where the infiltrating water needs years to reach the groundwater table. Tests carried out on pits in the irrigated areas indicate a downward moving salt water front. It is only a matter of time until the groundwater shows the same phenomena of increasing fertilizer and salt concentrations, (Salameh 1991).

Along the Jordan Valley, irrigation return flows affect two areas; In one of them the irrigation water seeps to already saline groundwater bodies within the saline Lisan Formation regime which seeps to the Jordan River course. In the other, the irrigation water seeps to the sparce water resources, especially in the northern parts of the Jordan Valley and along the extents of alluvial fans. (Naqa 1989, Hawi, 1989).

1.5. Solid waste disposals

Solid waste disposal sites represent a potential threat to surface and groundwater resources. Highly mineralized and with organic matter, loaded leachates of landfills may reach surface and groundwater resources and contaminate them.

The solid waste disposal site of Amman, in Wadi El-Kattar area where industrial and domestic solid wastes are deposited is now leaching to the surface and groundwater resources of that area. The groundwater in the surroundings of the site is increasingly showing higher concentrations of organic matter, trace elements like iron, cadmium, lead, manganese, etc., and other chemical constituents such as calcium, magnesium, potassium, sodium, chloride, sulfates and nitrates.

The groundwater loaded with the pollutants flows in a northeasterly direction where it is then pumped for domestic and industrial purposes. Here industrial water pumped from the area does not only function as a process water, but it enters the food chain through the processed foods and beverages.

The leachates which join the surface drainage system end up in King Talal Dam reservoir and add to its pollution.

The solid waste disposal site of Irbid, Al-Ukheider, lies at the slopes to the Yarmouk River. The bottom of the site consists of a thick aquiclude which does not allow leachates to easily reach the groundwater underlying the area. But the surface leachates together with other liquid wastes emptied in the same area by wastewater trucks flow along the tributaries to the Yarmouk River. Along the tributary wadis, the liquids infiltrate and reach the groundwater body there. The portion of the liquid wastes which does not infiltrate flows to the Yarmouk River directly or dries out during the hot season to be flushed to the river by flood waters.

Smaller solid waste disposal sites like those in Salt, Madaba, Karak, Mafraq, Jarash, etc., have the same impacts on surface and ground water resources. But since in these sites only solid wastes of domestic origin are deposited, only organic pollutants and increases in the salt contents of the waters are encountered.

1.6. Over-exploitation, resources depletion and aquifer salinization

If the extracted amount of a groundwater body exceeds the average recharge in a series of years, and if it is practically not expected that under the normal climatic conditions very wet years may compensate for the extracted amounts, the water body is considered to be over-exploited. In this case the groundwater levels or piezometric heads drop monotonously, although with some seasonal or secular fluctuations.

This situation is affecting Jafr, Azraq, Dhuleil, Shoubak, Wadi Arab, northern Badia, Amman-Zerka and Disi areas (Fig. 17). In all these areas water levels are continuously declining and wells drilled in Dhuleil, Azraq and Amman-Zerka have to be deepend and pumps sunk in accordance with continuously dropping water levels.

Dropping water levels result in coning up of underlying water bodies which contain generally higher salinities. Hence, their upconing causes salination of water bodies under use. In Dhuleil and Badia areas, increasing salinities due to upconing are affecting the aquifers under exploitation.

Salty water is also found at the surface of and underlying playas and certain desert oases. Oases area generally fed by surface and/or groundwater, where the water evaporates and salts accumulate or remain dissolved in the rest of the water.

Jafr basin

In the early sixties the Jafr groundwater basin was developed to provide water for both domestic and irrigation uses. After a few years of water extraction, groundwater levels started to rapidly drop and the water quality began to deteriorate. Therefore, part of the investment in that area was lost because of the worsening water quality which became unsuitable, even for irrigational use. Water levels dropped also to uneconomic levels.

Table (47) shows a comparison of the water quality in well No. 17 in that area and illustrates the gradual salinization of the aquifer's water.

Table (47)
salinity increase in Jafr well No. 17. (Files of WAJ).

Analysis date		27.6.1965	17.9.73	11.8.92
EC	µS/cm	909	3.100	4.400
pH		7.5	7.2	7.10
Ca	mg/l	82	164	289.4
Rg	mg/l	40	100	140.4
Na	mg/l	85	287	438.2
K	mg/l	7.5	16	20.2
Cl	mg/l	99	768	1201.0
SO_4	mg/l	145	240	350
NO_3	mg/l	10	19	25.9
HCO_3	mg/l	321	256	240

Dhuleil area

The water resources of Dhuleil area were developed in the early seventies. At that time the water quality of the aquifer was excellent for the different uses. In rapid steps increasing numbers of wells were licenced and drilled. The water found its use in agriculture. By the end of the seventies the aquifer water increasing salinities forced some farmers to excessively irrigate their fields. Gradually, in the eighties more and more land was laid fallow. The results of this development were salinization of the aquifer due to overpumping, salinization of soils due to the use of brackish water and fertilizers, and as a result, further salinization of the aquifer's water due to irrigation return flows.

Table (48) shows the development of the groundwater quality on the example of well AL 1109, Wasfi Al-Tal.

Table (48)
Water quality development of well No. AL 1109 from 1970 - 1990

Date		1.4.70	22.4.1979	14.6.90
EC	µS/cm	440	1060	2940
pH		8.1	7.8	7.5
Ca	mg/l	12	51	181.2
Mg	mg/l	16	42	132.4
Na	mg/l	53	103	221.3
K	mg/l	4.7	9.0	16.5
Cl	mg/l	61	272	784
SO_4	mg/l	29	71	263.0
HCO_3	mg/l	128	82	75
NO_3	mg/l	15	23.0	120

The salinization of the aquifer's water can be deduced from the rapid increase of Na, Cl, SO_4, Ca and Mg concentrations. Irrigation return flows were indicated by the increase in the nitrate value from 15 mg/l in 1970 to 120 mg/l in 1990. Also this well showed high concentrations of phosphates in 1990, which can be attributed to fertilizers used in agriculture. Rimawi (1985) studied the groundwater resources of the area and concluded that both over-exploitation and irrigation return flows were leading to the rapid deterioration of the water quality.

Azraq area

Since 1982, water produced from a series of wells located to the north of Azraq has been pumped to Amman to alleviate increasing demand. The amount of water pumped to Amman ranged from 12-16 MCM/year. By 1986 the drawdown in the groundwater table reached three metres.

At present the general drawdown is around seven metres. The spring discharges in South Azraq stopped, and those of Qaysiya and Soda springs decreased rapidly. The total groundwater discharge of 16 MCM/year, measured by Arsalan in 1973, decreased because of overpumping to 10 MCM/year in 1983, to 6 MCM/year in 1986, and to less than 1 MCM/yr. in the past two years (Figure 18).

Tritium, which has a half-life of 12.3 years, has never been detected in Azraq well water, indicating that no recent recharge to the groundwater is taking place. C^{14}-age determinations gave a recharge age of 5,000 to 12,000 years (Rimawi 1985, Balthazar et.al. 1991), which indicates that the pumped water is of very ancient recharge.

The salinity of Aura pool and Qaysiya springs has increased rapidly during the last few years, too, and is now in the range of brackish water.

At present the groundwater level in the well field area and its surroundings lies two to three metres below the level of the pool's surface in North and South Azraq. It is now feared that water will start moving from the salty marshes, which are located between North and South Azraq and east of the line connecting them, to the well field area.

The problem of saltwater intrusions did not surface until now because of the periodic seasonal pumping of the aquifer. Generally, water is not pumped during the winter, when the groundwater is able to recover.

The results of such practices are the following:

* If a proper balance between the seasonally pumped amounts and the recovery of water levels is maintained, only the oasis will dry, and no salt intrusions are expected to occur.

* If pumping goes beyond its present amounts, but with the same seasonality, the water levels in the area will drop further, making recovery more difficult and resulting in saltwater intrusions.

* If pumping is practiced, whether at the present rates (same amount, but distributed throughout the year) or at an increased rate, salt water will start moving towards the well field, leading to the salinization of the groundwater.

1.7. Other areas

The groundwater well fields of Shoubak, Agib, the northern Badia and Disi are all suffering from dropping water levels.

For example, extracting around 500 MCM from the Disi aquifer in the last 7 years resulted in nonrecoverable drawdown in water levels ranging from 1.2 up to 11 meters.

This nonrecoverable, irreversible decline is a major warning concerning the persistence of water resources.

The same behavior of aquifers is also observed in Shoubak, Agib and northern Badia areas, with the difference that the groundwater in Disi is nonrenewable, whereas that in the other areas is renewable but is extracted at a faster rate than it is replenished.

1.8. Sea water

In the Gulf of Aqaba area various human activities have been developed during the last two decades. They include a thermal power plant fueled with oil, a fertilizer industry, urbanisation, tourism, an oil harbour, storing and loading of phosphates and common purpose harbour which does not only serve Jordan, but also the surrounding countries. These continuously increasing activities are putting additional pressure on the environmental elements, especially water, in the semi-opened Gulf area.

Dust and gases produced by the industries, especially the phosphate loading harbour, precipitate in the water and cause negative effects on the aquatic community. Water pollution is also caused by oil spills from navigational activities, power plants,

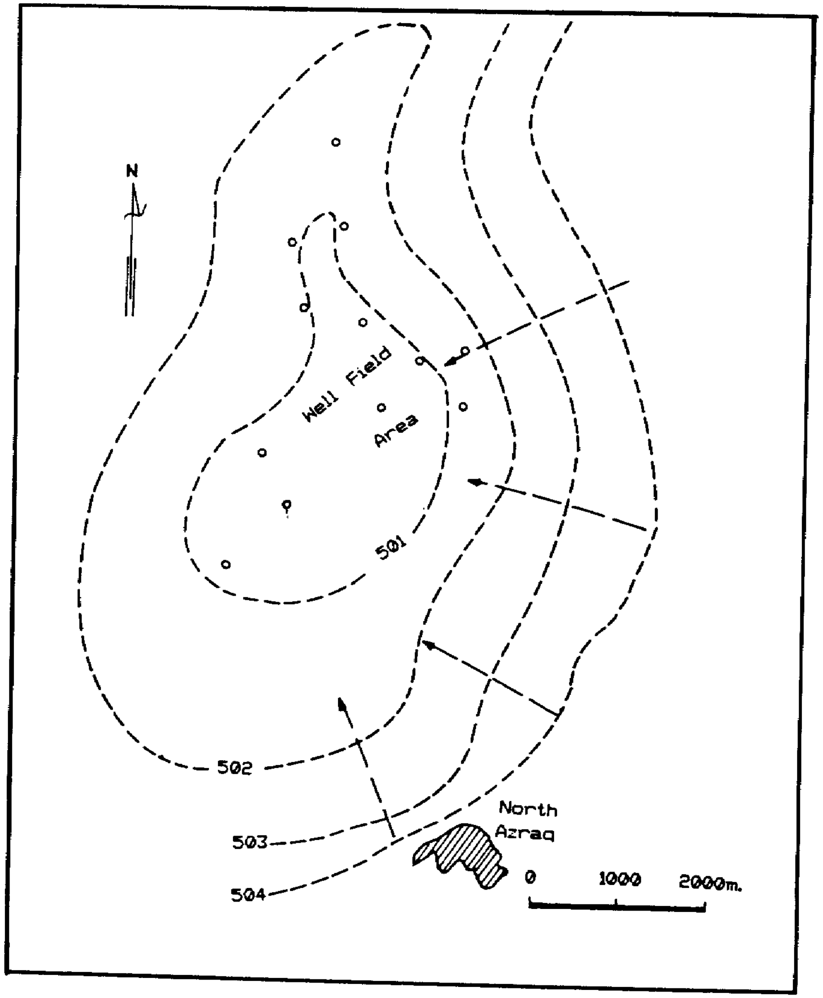


Figure 18: Water levels in 1989, Azraq well field

liquid wastes from chemical industries and thermal pollution produced by the Aqaba thermal power plant.

Pollution is increasingly causing a shift in the delicate balance of Aqaba Gulf aquatic species; more algal production

to the disadvantage of the corals. Coral survival and multiplication are also suffering from decreasing light intensities due to turbidity resulting from dust deposition.

Currently, it is also feared that the effluents of the wastewater treatment plant of Aqaba will seep to the Gulf waters and cause deterioration in their qualities.

2. Discussion on the water pollution situation:

It can be concluded that water pollution sources are continuing to increase in type, quality and quantity. At the same time, actions and measures are actively implemented to alleviate the pollution problems and to eliminate pollution at its sources. Therefore, domestic wastewater treatment plants were constructed to serve all cities and towns. Even some hospitals, universities, and military camps, for instance, were equipped with wastewater treatment plants. This has, in the last two decades, lowered the environmental load by far. But, at the same time some of the wastewater treatment plants have not been functioning properly, because they are not suitable for the type of climate and water situation of the country. In addition, the effluents of the treatment plants, even of those functioning properly, present an environmental detriment, because of misplanning and mismanagement of their reuses.

Waste water treatment plants have been constructed without studying their or their effluents' enviromental impacts on the natural elements and human life. Hence, no planning of proper, environmentally sound effluent use was conducted. After the commission and operation of each waste water treatment plant, a new problem arose which is how and where to use the effluents to avoid their detrimental environmental impacts. It seems that problems were only shifted from cesspools polluting surface and groundwater resources within towns, to wastewater treatment plant effluents polluting water resources downstream of their locations.

Industrial waste water treatment plants were also constructed for each individual industry. But due to the improper installation of these plants, only very few of them were specifically designed to take care of the respective waste water quality. The majority of industrial waste water treatment plants extract organic pollutants to a certain degree, very few if any, treat trace and heavy metals, which continue to pollute the environment. Oils and fuel rests are not extracted from the waste water. Thermal pollution is affecting the Gulf of Aqaba and Zerka River waters.

Irrigation of arid lands overlying groundwater resources with percolation possibilities are continuously leading to groundwater quality deterioration. Not only soils are salinized in this case, but also the underlying groundwaters due to the percolation of irrigation return flows. Years may pass before these leachates reach the groundwater table, but it is certain they will.

Since Jordan is a semiarid country, short in water resources, soils can not be washed and accumulating salts cannot be flushed. It should also be considered that the only ultimate fate of salt accumulated in the highland soils of Jordan is a "drainage" and leakage to the groundwater.

Unless properly designed and implemented, irrigation projects overlying groundwater resources certainly result in the damage of the latter.

Solid wastes are disposed of without further treatment in the environment as landfills. After deposition, landfills start to leach and to emit liquids and gases polluting surface and groundwaters and the atmospheric air.

Developed countries are now excavating and repairing old solid waste disposal sites and treating their contents to minimize their detrimental impacts on the environment. Here in Jordan, solid wastes are still being dumped in a primitive and inadequate way, leaving the problems to future generations to deal with.

Overpumping of aquifers is continuously leading to a lowering in groundwater levels, salt water intrusions and salt water upconing. Continuing along this same line means depletion and salinization of aquifers -- actions considered deadly to groundwater resources, because decontaminating and sweetening are very difficult and complicated tasks. In certain areas in Jordan the case is still in our hands, but immediate actions based on the safe yield concepts are urgently needed. Otherwise, soon we will witness one aquifer after another becoming salinized, depleted and of no use; rendering investments useless.

The sea water at Aqaba is continuously deteriorating, thermal, organic, dust and oil pollutants are emited and discharged into the air and water, causing a shift in the balance of aquatic species. Here also immediate actions are urgently required, otherwise the whole ecosystem will be destroyed and the waters of the Gulf will become perilous for living organisms.

3. Conclusions about the Pollution Situation of Water Resources:

Jordan is a developing semiarid country with very scarce water resources or natural resources to compensate for water shortages. Population growth whether due to multiplication or to refugee waves is putting increasing pressure on the scarce water resources.

Scarcity requires creative management of both resources quality and quantity. If Jordan, with its present population, industrialization and agricultural activities had at its disposal twice the amount of water it has now, Jordan would be considered an advanced country in water management. But water scarcity is putting more use and pollution loads on each available water unit than elsewhere in the world.

The per capita annual water resources in Jordan are 250 - 300 m^3 compared to 4500 - 5500 m^3 in Sudan, Syria and Iraq, more than 1700 m^3 in Lebanon and 1200 m^3 in Egypt. With this amount of water and with only less than 2,5% of the country's total area viable for dry farming, Jordan produces only about 50% of its food needs. The available water resources are exposed to pollution which will make them unsuitable for certain uses further depriving the country of vital resources.

Jordan, now needs immediate actions to lower the extent and alleviate the effects of its water resources pollution. Of utmost importance is keeping a balance of aquifer's safe yields and extractions. Improving wastewater-treatment effluents qualities and lessening their adverse impacts on the environment by proper planning of discharge and reuse projects is an urgent necessity for the sustainability of water resources. Also proper treatment and reuse of industrial wastes is becoming a pressing issue in water resources management.

The handling of solid wastes should be improved because leaving over the problems of landfills to the next generations is accompanied by continuous degradation of underlying and surrounding water bodies. In this context also immediate action is becoming increasingly urgent.

Irrigating areas overlying important aquifers is known to result in groundwater quality deterioration and damage, especially in semiarid areas where there is not enough water to flush salts. Therefore any project aiming at irrigating lands overlying unprotected aquifers should underly strict environmental impact assessment. Present projects should be restudied and reevaluated considering their potential threats to the groundwater resources in terms of depletion and pollution.

VIII

Special Characteristics of the Groundwater System in Jordan

1. System Characteristics and its Development:

The groundwater flow system in Jordan exhibits very specia: features of recharge, flow, discharge, quality genesis, radioactivity and salt-fresh water interface configuration. These features deserve further elaboration to illustrate the sensitivity of the groundwater system to any human activity like pollution, artificial groundwater extraction and lowering or raising the Dead Sea level. The hydrodynamics here have also had great impacts on oil and gas accumulation and flushing. Therefore, the special features of the groundwater system will be discussed in some detail.

The precipitation water falling over the highlands infiltrates into the exposed rocks and flows either to the west, the Rift Valley, or to the east, the Azraq - Sirhan depression. In the exposed Upper Cretaceous aquifers a groundwater divide lying along a line 20-30km to the east of the Dead Sea separates the easterly from the westerly directed groundwater flow. The westerly directed groundwater flow in the upper aquifer complex (Upper Cretaceous) discharges along the slopes overlooking the Dead Sea as cold water springs (Fig. 19). The easterly oriented groundwater flow in the upper aquifer complex infiltrates through the aquitards of this complex down to the lower aquifer sandstone complex (Lower Cretaceous and older rocks). The infiltration processes take place along both the primary and the secondary porosity of the upper complex. As soon as the infiltrating water reaches the lower aquifer complex it changes its flow direction to westerly because of the presence of the ultimate base level, namely the Dead Sea (about 400 m below sea level).

This groundwater recharge, infiltration, flow and discharge system is the result of the development of the Jordan Graben. Whether the latter is an outcome of a sinistral movement along the Graben (Seidlitz 1931) or of differential uplift movements (Picard 1943) is of little significance to the groundwater system itself.

The history of the graben relevant to the hydrogeological development can be summarized as follows:

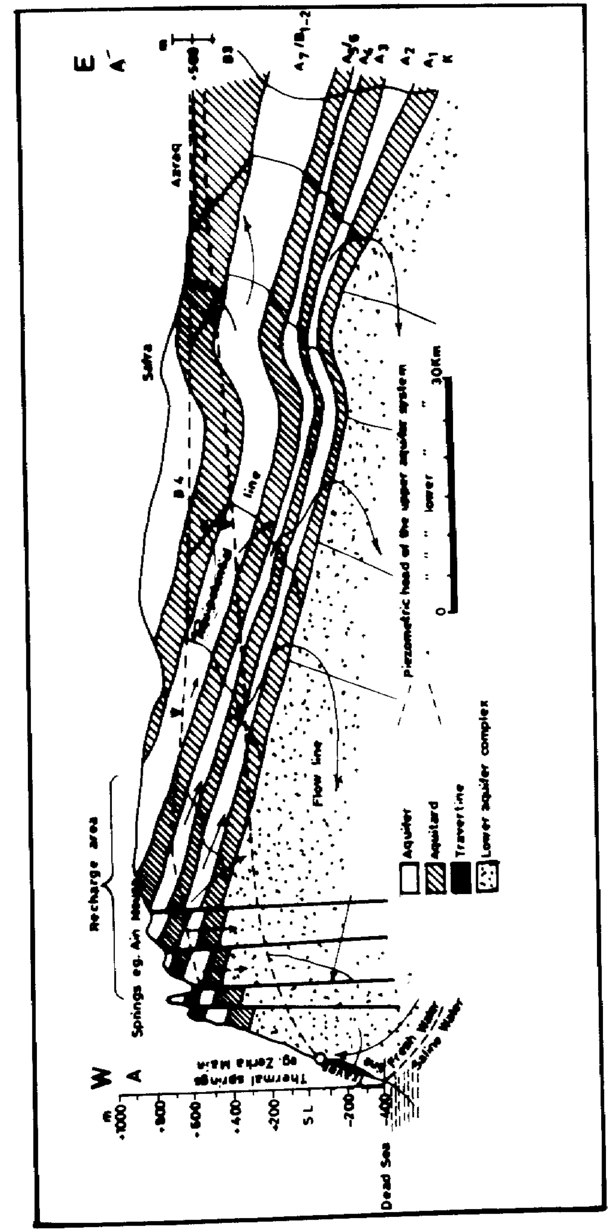


Figure 19: Hydrodynamic pattern of the central part of Jordan (after Salameh & Udluft 1985)

Stage of uplifting

According to Horowitz (1979), the recent uplift movement started in the late Miocene. The area was uplifted along an old geosuture line (Bender 1968), and an anticlinal bending started to form. At the end of this stage, slight down faulting movements affected the central part of the anticlinal bending along its axis, forming an initial shallow graben.

Salt Unit stage (Neev & Emery 1967)

The formation of the initial graben led to a new local base level for surface and groundwater. This base level could have had temporary connections to the Mediterranean Sea (Neev & Emery 1967) with a base level elevation of ± 0 m. During this stage of Plio-Pleistocene age, thick salt deposits were precipitated. The precipitation continued also after the major faulting until 100,000 years ago.

Lisan Lake stage

This stage started some 100,000 years ago as the level of the water in the lake dropped to -180 m. The deposition of Lisan Marls began about 65 - 70,000 years ago (Neev & Emery 1967, Bender 1968). The bottom of the Lisan Lake has an elevation of -750 m. According to the above authors, this stage ended some 23,000 years ago. At its end, the base level dropped to -400 m.

Dead Sea stage

Downfaulting accompanied with a shrinkage of the Lisan Lake resulted 23,000 years ago in the formation of the Dead Sea stage with a base level elevation corresponding to the present sea level of about 400 m below mean sea level.

2. Hydrogeological Development:

The sedimentary sequence, as previously mentioned, can be divided into two main complexes relevant to the present elaborations.

The Upper Cretaceous limestone and marlstone sequence (upper aquifer complex) consists of alternating aquifers and aquitards with a total thickness of about 680 m. The groundwater in this complex moves toward the East (Salameh & Udluft 1983). Only in the vicinity of the graben, the groundwater moves to the west (Fig. 19).

The Lower Cretaceous sandstone and older units sequence (lower aquifer complex) consist mainly of thick sandstone formations interrupted by relatively thin marl and limestone beds with negligible regional hydrogeological relevance. The thickness of this complex increases from south to north and from west to east. For our purpose, a thickness of 600 m is considered.

The aquifer parts which lie below these 600 m are irrelevant to the present study. The aquifer complex contains several hundred billion cubic meters of mostly confined water which flows in the area under consideration in a westerly direction and discharges to the graben (Fig. 19).

The paleomorphological and paleohydrological configuration of the upper and lower aquifer complexes can be concluded from the structural development of the area and particularly from the development of the Jordan graben itself.

Formation waters should have been saturating all units at the end of the regression of the Eocene transgression. The outcrops of the geological units were, at that time, and still are at present, exposed in the southern area south of Ras en Naqb escarpment. The area represented the only possible place for infiltration of precipitation water and recharge of the aquifers. The formation waters saturating the aquifers at that time had two ways to flow out; either to flow to the NNW and discharge into the Mediterranean, or to flow to the NNE, to Sirhan Depression and later to the Arabian Gulf.

After the late Miocene uplift along the geosuture (Bender 1968) the anticlinal bending of the uplift formed a new recharge area. The former groundwater flow pattern was superimposed by a new E-W component which increasingly overweighed the recharge in the southern areas (Fig. 20). At this stage no changes in the base level took place; they remained the Mediterranean Sea in the west and the Sirhan Depression in the east. Only the gradients changed, and a stronger E-W component affected the groundwater flow (Fig. 21a).

In Plio-Pleistocene, the central part along the anticlinal bending was slightly downfaulted forming a graben and creating a new base level. This graben was invaded by Mediterranean Sea water through the NW-SE trending morphotectonic valley of Bet Shean (Gvirtzman 1970). During the Salt Unit stage, the upper aquifer complex of the elevated graben sides, east and west of the graben, was phreatic. New groundwater gradients were established and the phreatic water of both elevated belts started to move to the graben itself, which formed the new base level (Fig. 21b).

The flow system in the layers within the graben lying beneath the Mediterranean water level (water level in the graben coincided with that of the Mediterranean) should not have been affected, because at that time no new outlets to the graben were available (Fig. 21b).

After the Salt Unit stage downfaulting movements continued and the temporary connection to the Mediterranean Sea was interrupted. The water level in the graben dropped to-180 m and formed the Lisan Lake some 100,000 years ago.

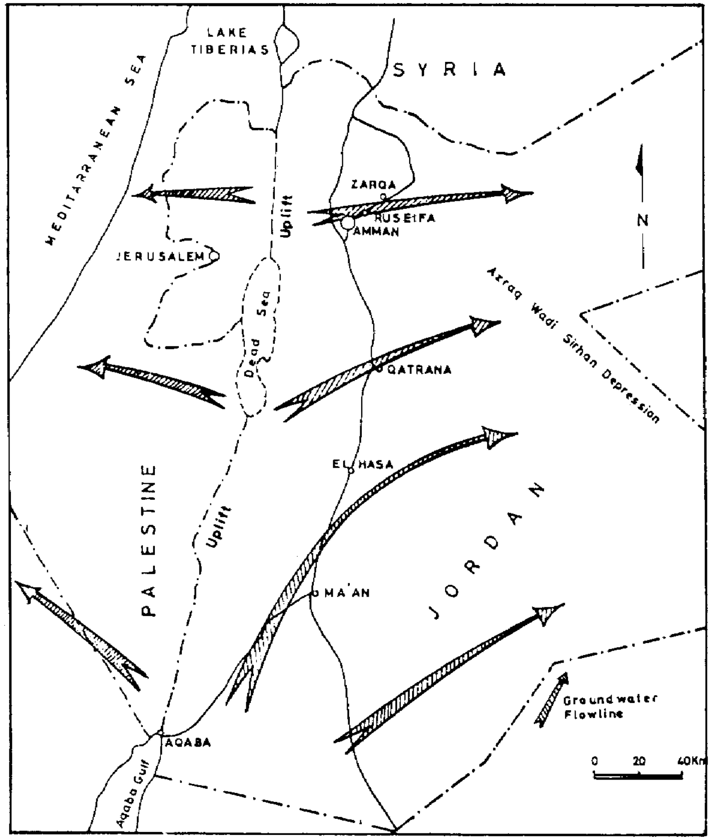


Figure 20: Groundwater flow lines after the Late Miocene uplift along the geosuture: The formerly NNW and NNE oriented groundwater flow was superimposed by a new E-W component which increasingly overweighted the recharge in the southern highlands.

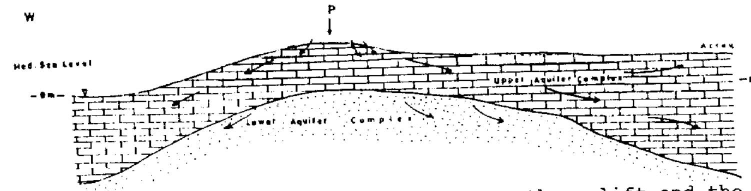


Figure **a**: The new recharge area along the uplift and the corresponding groundwater flow pattern along an E-W cross section.

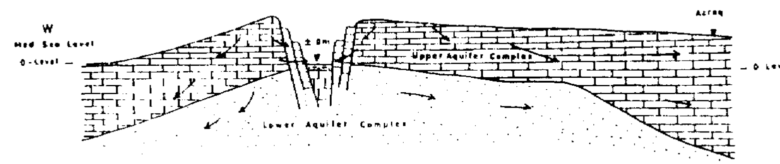


Figure **b**: Due to downfaulting a new base level for both surface and groundwater was created. The water level of the Salt Unit stage corresponded to Mediterranean Sea level.

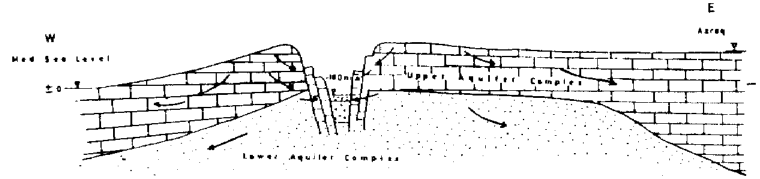


Figure **c**: During the Lisan stage the water level in the graben dropped to -180 m. Larger portions of the aquifers were drained toward the graben.

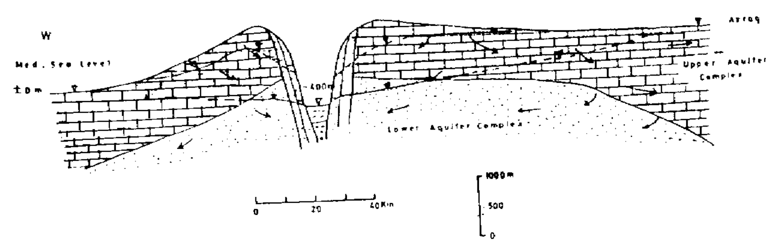


Figure **d**: Present situation.

Figure 21: The development of the hydrodynamic system since late Miocene

Deeper groundwaters were increasingly affected by the new ultimate base level of -180 m. The groundwater divide at the eastern side of the graben moved increasingly eastward (Fig. 21c).

The bottom of the Lisan Lake had an elevation of -370 m, which lies deeper than the outcrops of the lower aquifer complex at the eastern side of the graben. Because of the presence of the ultimate base level of -180 m, the groundwater in the lower aquifer complex, which has a higher elevation, should also have started to move to the Lisan Lake (Fig. 21c).

Starting some 70,000 years ago at the beginning of the Lisan marl deposition, gradual lowering of the Lisan Lake level, due to tectonic movements and climatic changes, resulted in the recent base level of about -400 m and a sea bottom of about -750 m some 23,000 years ago (Fig. 21d). (Neev and Emery).

The gradual drop in the ultimate base level from -180 to -400 m resulted in higher groundwater gradients. The groundwater shed of the lower aquifer complex moved further to the east where it now exists in the Azraq Sirhan Depression (Fig. 19).

3. Development of Groundwater Gradients and Flow Directions

The present easterly oriented average groundwater gradient of the upper aquifer complex equals 0.18% (distance Amman - Azraq = 80 km, difference in groundwater levels 650 - 505 m).

The groundwater gradient in the lower aquifer complex, which had until the beginning of the Salt Unit stage coincided with that of the upper aquifer complex, could not have exceeded the present average gradient of the upper aquifer complex of 0.18% because the area at the eastern flank of the gaben has since then been moving upwards.

The present day, westerly oriented, average gradient of groundwater in the lower aquifer complex equals 0.75% (distance Dead Sea - Azraq = 120 km, difference in groundwater elevations = + 505 - (-400) =900 m).

In the Salt Unit stage with a base level elevation in the invaded graben equaling the Mediterranean Sea level, the groundwater gradient in the lower aquifer complex must have been 0.42 % towards west (difference in elevation 505 - 0). During this stage the groundwater flow direction changed from eastward, towards Azraq and Sirhan local base levels to the newly created ultimate base level in the graben, lying in the west.

At the beginning of the Lisan Lake stage the westerly oriented groundwater gradient increased, and at a lake level or -180 m it should have been equal to (505 - (-180) = 0.57 %.

During the Lisan Lake stage the water level dropped from -180 m at the beginning to -400 m at the end of the stage, 23,000 years ago, at which point the gradient reached its present average value of 0.75 %.

The creation of a new base level for surface and groundwater of the eastern side of the Jordan Graben caused a reversal in the flow direction of both surface (partially) and groundwater. The groundwater gradient in the lower aquifer complex changed from 0.18% towards east gradually to 0.75% towards west. The change and increase of the gradient was accompanied with an increase of the aquifer throughput and hence discharge to the Dead Sea.

During the Pleistocene time, the water level in the Azraq Oasis had been higher than at present. It had an elevation of 525 m ASL and the surface area of the Oasis was 600 km^2 (Arsalan 1976). The drop in water level has always been attributed to climatic changes (Bender 1968, Arsalan 1976). Considering the above explanations this shrinkage can also be attributed to two other effective factors, namely, the increase of the throughput capacity of the aquifers underlying the area which increasingly drained the water to the Dead Sea, and reversals of river courses which formerly discharged into Azraq and at present discharge into the Dead Sea. This fact can be evidenced in the example of the Zerka River which, during the Pleistocene, had been flowing in an easterly direction through Zerka area, Wadi Dhuleil, Qa Khanna and from there to Azraq. Headward erosions of a westerly water course (now called lower Zerka River) intersected the ancient course of Zarka River at Zerka and turned its course towards the Dead Sea. Also Wadi Dhuleil behaved in the same way and the whole catchment area until Qa Khanna in the east is now drained westward to the Dead Sea.

The different terraces of clay gypsum layers in Azraq could most probably be correlated with the large-scale, long-term fluctuations in Dead Sea levels and changes of throughput capacities of the underlying aquifers.

Other parameters which could also be directly associated with the Dead Sea level are the former sites of discharge of thermal water along the graben. In Zarka Main area, old travertine deposits as high as 100 m ASL are present. They show former discharge sites of thermal water (Khoury, Salameh & Udluft 1984). These travertine deposits correlate with former Dead Sea levels, most probably with that of the Lisan Lake of -180 m.

4. Oil and Gas Exploration:

Concerning the exploration for oil and gas in the study area, it is worth mentioning that even if any accumulation of oil and gas had been structurally entrapped in large structures of the aquifer complex under a NNE-directed, gentle groundwater gradient in Pre-Miocene times, then these accumulations must have been flushed under the new, westerly oriented, larger hydrodynamic gradient. This fact should be strongly emphasized because the lower aquifer complex must at least have been flushed three times since the proper end of the Lisan Lake stage and at least twelve times since the beginning of Lisan Lake stage (a flushing period requires around 7,000 years, Salameh & Udluft 1985).

The flushing of oil can be evidenced by the asphalt blocks which float from time to time to the surface of the Dead Sea in the area of the mouth of Wadi-ei-Mujib.

Therefore, it is not terribly surprising that all the wells drilled in the flush area between the Jordan Graben and Azraq base level (Safra, Suweilih, WG, WR, etc.) have only encountered rests of dry, thick asphalt but no oil or gas.

The indication should not mean that Jordan is totally devoid of oil and gas. But exploration should be concentrated on the areas east and northeast of Azraq. In the area under discussion oil and gas could be found in small structural traps or in oriented combined stratigraphic, structural and hydrodynamic traps at depths of more than 2000 meters.

According to the hydrodynamic development, older rock units underlying the Rift Valley are also promising sites for oil and gas accumulations.

The hydrodynamics of the area should therefore play a key role in oil and gas exploration.

5. Hydrochemistry and Evolution of Water Types

The hydrochemistry of the groundwater of the different aquifers shows different types of waters indicating the processes of water-rock interaction geochemistry leading to their formation.

The precipitation water recharging the upper aquifer complex and interacting with it shows ionic rations of:-

$Ca>Mg>Na;HCO_3>CI>SO_4;$

$HCO^3>Ca$, and Na/Cl
this water is saturated with oxygen (Table 49).

Generally, Ca and Mg represent more than 70% of the total cations, while HCO3 represents more than 55% of the total anions. This water type resembles precipitation water chemistry (Table 49) of the area (Salameh and Rimawi, 1987), with little changes in ionic ratios, but higher concentrations indicating evaporation.

Further interaction of the above water type with the rock matrix of the upper aquifer complex, which consists of limestones, marls and shales containing evaporitic minerals, renders the water to another type, with:

$Na>Ca>Mg;Cl>HCO_3>SO_4;HCO_3+SO_4>Ca+Mg$ and $Na/Cl>1$ (Table 49)

Table 49
Development of water parameters' concentration
from the recharge to the discharge area

Source → Parameter ↓	Precipi-tation water	Hisban Spring	Deep Upper aquifer complex	Azraq well	Thermal Spring Zarka Ma'in
EC µS/cm	46	553	1220	1460	3190
pH	7.3	7.6	7.5	6.8	6.50
TC°	6.4	19	25	39	57.9
Ca mg/l	5.63	56	98	84	180
Mg mg/l	0.99	22.8	42.7	39	64
Na mg/l	2.71	21.0	136.2	213	340
K mg/l	0.87	2.4	6.8	15	52
Cl mg/l	5.73	36.8	203	244	680
SO_4 mg/l	5.19	18.3	188	195	250
NO_3 mg/l	1.76	29.0	10	0.0	0.0
HCO_3 mg/l	11.68	236	273	341	365
pH equil.	10.7	7.65	7.28	7.04	6.96
SI	-2.77	-0.05	+0.22	-0.24	-0.91
DO mg/l	9.3	6.5	0.0	0.0	0.0
H_2S mg/l	0.0	0.0	very minor	small	0.04
CO_2 mg/l	1.28	22.1	58.2	123	470
Fe mg/l	n.d	0.02	n.d	0.16	0.5
Mn mg/l	n.d	0.00	n.d	0.08	0.65
Bq/l	0.0	0.01	0.1	30	79

In this stage of the water type evolution, the average sodium content represents up to 70% of the total cations, whereas chloride represents about 52% of the total anions. The oxygen saturation is less than that of the origional precipitation. Whereas the precipitation water percolation into the upper reaches of the upper aquifer complex (recharge areas) contains nitrates in concentrations of 20 to more than 100 mg/1, the groundwater in this stage contains not more than 50mg/1 of nitrates.

By further flow and interaction with the upper aquifer rock matrix, the chloride and sulfate represent more than 80% of the total anions, while alkalines and earth alkalines are almost equal.

This water is depleted of oxygen, and the maximum nitrate concentration is around 10mg/1.

In a later stage, the water enters the lower aquifer complex, where it changes to sodium-chloride water. Its temperature rises to more than 50 C and the dissolved oxygen content dereases to zero. Also, all the nitrate is completely reduced and the water contains H_2S, N_2 and CO_2 gases as byproducts of the oxidation/reduction processes of the organic matter within the groundwater system.

No major changes take place in the water quality thereafter, except an increase in the total dissolved solids due to evaporite dissolution. Carbon dioxide and H_2S gases lower the pH-value of the water, initiating therefore the dissolution of heavy metals oxides present in the sandstone matrix. The discharged water from the springs contains consequently iron and manganese and other trace metals. These precipitate as hydoroxides as soon as the water comes into contact with the atmospheric oxygen. The dissolved uranium salts produce within the disintegration series radium226 and radon222, which are also discharged with the water causing its radioactivity.

The above explanations show that the free oxygen content of the water decreases from the recharge areas to the lower portions of the upper aquifer complex, where it reaches zero at the base of the latter.

Denitrification processes reduce the nitrate and produce N_2 and CO_2. The water of the lower aquifer complex contains no nitrates. The further oxidation of the organic matter goes on the account of sulfate reduction, hence producing H_2S and CO_2 gases (Freeze and Cherry, 1979).

6. Hydrothermometry:

The water discharged from springs and wells in the lower aquifer complex has higher temperatures than the ambient temperature. They range from 30° to 63°C. SiO_2 geothermometers were applied to calculate the reservoir temperatures. Table 50 shows the discharge temperature of the water and the calculated reservior temperatures.

The calculated average geothermal gradients between the water producing horizons and the earth surface range from 3.8° to 7.5°C/100 m. In the thermal spring area bordering the Dead Sea, the geothermal gradient is calculated to a distance comprising the depth from the ground surface to the interface of the fresh and saline Dead Sea waters.

The origin of heat has not yet been clarified, hence the following discussion is an attempt at trying to attribute the elevated reservoir temperatures to a relevant cause.

Table 50
Reservoir temperatures of wells and springs
(Salameh & Rimawi, 1987)

Source	Discharge Temperature	SiO_2 mg/1	Reservoir temperature
N-Shunah	56°C	29.75	79°C
Rama	34	26.47	74
Afra I	45	27.7	76
Afra II	46	27.7	76
Afra III	46	27.4	75
Burbatah	45	36.42	96
Zara No.22	55	27.6	76
Zara No.27	54	28.3	77
Zara No.30	43.5	29.4	78.6
Zara No.41	63	32.1	82.2
Ma'in No.8	62.3	29	78
Ma'in No.47	57.8	28.6	77.5
Ma'in No.55	47	25.6	73
Ma'in No.6	53.3	29.7	79
Azraq well I	39	28	76.5
E. Madaba	33	25	72

The elevated temperature in the lower aquifer complex can be attributed to one or more of three models; these are:

1. Abnormal regional heat flow originating from the lower crust and mantle.

2. Normal regional heat flow superimposed by either:

   a. Volcanic and tectonic activity of rifting along the Dead Sea Jordan Graben, or
   b. Heat production due to radiogenic activity.

3. Presence of heat storing layers in the underground or a combination of exclusive reasons.

A model explaining the elevated temperature in the lower aquifer complex should account for the following findings:-

1. The lower aquifer complex consisting of sandstone contains water with temperatures of 72°C.

2. The overlying upper aquifer complex consisting of shales, marls, claystones and limestone contains in its permeable portions water with a temperature of up to 40°C.

3. Thermal water is also encountered in wells penetrating the lower aquifer complex in places where no direct volcanic contributions are probable (Safra well, Azraq well).

4. The groundwater of deep wells in Azraq and of springs along the Rift Valley are chemically of the same type.

5. The average geothermal gradient from the lower aquifer complex to the surface in Azraq Well is

$$\frac{72 - 22}{1300} \times 100 = 3.85° \text{ C/100 m.}$$

In Zarqa Ma'in and Zara areas the geothermal gradient is calculated to be 3.88°C/100m (Salameh and Khudier 1986). This values show that the average geothermal gradient is only weakly elevated and hence, the regional heat flow is most probably normal.

Some wells and springs like those of Kafrain, Hisban, North Shunah, Azraq, and Safra produce thermal water in areas with no evidence of any volcanic activity. This fact, together with the consistency of the hydrochemical type of the thermal water along some 100 km, contradicts a model of local volcanic activity superimposing a normal geothermal gradient.

The above discussion, in addition to the clarification of the hydrodynamic pattern of recharge, flow and discharge in the central part of Jordan (Fig. 19, Salameh and Udluft, 1985), as well as the detection of radioactivity in the thermal

waters of the lower aquifer complex, encouraged considering radiogenic activity as a heat source instead of volcanic activity.

The production and decay rate of radon222 should in an enclosed system be in equilibrium with the whole decay series of U238. The long distance and times of flow up to 100 km and thousands of years, and the confined nature of the water in the lower aquifer complex indicate the enclosed nature and conditions for radioactive decay. Hence, the amount of Rn in the water is a very good measure of the amount of uranium in that water.

The half-lifetime of Rn222 of 3.825 days indicates also that no special accumulation of Rn is possible in the above-mentioned groundwater aquifer with a permeability of about 5 X 10^{-3} m/s.

The energy produced by U238-decay series can be calculated, since, in an equilibrium, the number of disintegrating atoms of each nuclide is equal. With an average activity of Rn222 of 3.6 μCi/1, the energy produced in each liter of water due to U238 disintegration equals 2.4 E - 4 Mev.

If this is taken as an average for a saturated aquifer with a total porosity of 15% and a thickness of 500m, the heat production of a cross-sectional area of 1 cm^2 equals 5.1 x 10-3 μcal/cm^2.

Compared with a worldwide heat flow average of 1.4μ cal/cm^2s (Buntebarth 1980) and of 0.3 to 11 μ cal/cm^2s for Palestine, the heat flow produced by the radioactivity of the water in the sandstone is in fact negligible. There remains only the possibility of heat storage as an explanation for the high temperature in the lower aquifer complex.

The heat conductivity of saturated sandstone is twice or more than that of dry or weakly wetted sandstone and that of shales and marls topping the saturated sandstone (12.5 and 12:7 respectively, Haalck 1958, Bentz 1979 and Buntebarth 1980). This fact implies that the nonsaturated portion of the sandstone such as the overlying shales and marls function as heat isolating layers. Since the heat flux is a constant along the path of heat, the temperature difference along a flow path should be a function of conductivity. Therefore, and to obtain a constant heat flow, temperature differences between both faces of a low conductivity layer should rise to a limit to compensate for the conductivity.

The heat flow equation can be written in the form:

Q _ k grad. T

where

Q is heat flux
K is heat conductivity

T is temperature
Q is a constant along a flow path and hence, K grad T should be a constant.

Since K of a saturated sandstone is about twice of dry sandstone and shale, the grad. T within the latter should be about twice that of saturated sandstone for the same flux value.

The measured geothermal gradient in the dry sandstone is 7.6°C/100m (Rimawi and Salameh, 1988). Also, the geothermal gradient in the shales and marls overlying the sandstone equals:

$$\frac{72°C - 40°C}{400m} = 8°C/100\ m.$$

The average geothermal gradient for the whole sequence is 3.85°C/100m. This value shows that the elevated temperature in the lower aquifer complex is only a result of the poor heat conductance of the dry portions of the sandstone and of the marls and shales overlying the saturated sandstones.

7. The Interface Configuration, Fresh and Dead Sea Waters:

Generally, the interface configuration of salt and fresh water starts at shores or beneath the sea water with a relatively high gradient of inclination (Fig. 22). The interface then

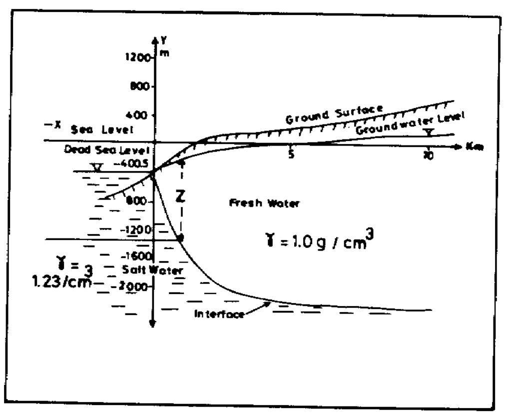


Figure 22: Present configuration of the interface between Dead Sea water and fresh water at Wadi Zerka Main latitude. (After Salameh 1985).

flattens out landward where it tends to become horizontal, or to end at an equiclude. The nearly horizontal interface is the depth to which precipitation water percolates and mixes within the dispersion zone with intruding sea water. The interface configuration is a function of the densities of the two fluid phases (sea water and fresh groundwater), the inland distance from the shorelines and the hydraulic gradient, as well as the amount of discharged groundwater (Ghyben-Herzberg, 1888; Glover, 1959; and Bear, 1972).

Compared with fresh-oceanic water interface, the fresh-Dead Sea water interface is closer to the surface because of the larger density difference of the latter of 0.225 g/cm^3. Hence, the interface of fresh-Dead Sea water is more flat and extends further landwards.

The groundwater which flows to the Dead Sea area is either discharged along the slopes over the Dead Sea directly from the water table or it ascends to the surface along the N-S faults due to clogging of emergence sites by the deposition of travertine.

The densities of the Dead Sea water and fresh water, and the fresh water levels at certain distances from the Dead Sea shores are already known (Neev and Emery, 1967; and Salameh and Khudier, 1986). The hydraulic gradient within the Zarka-Ma'in area and along its longitude is 4% (Salameh and Udluft, 1985). To the west it increases gradually to give the pattern in Figure 22.

The amount of fresh groundwater, which flows to the Dead Sea and its hydraulic equilibrium with the Dead Sea water is calculated to be 6 m^3/s (Salameh and Udluft, 1985).

The interface configuration was approximated by Glover and Kremer (1959) for the dynamic case. This approximation is given in the following equation (Langguth & Voigt, 1980).

$$Z = \sqrt{\frac{2qX}{(\delta s - \delta f)K} + \frac{q^2}{(\delta s - \delta f)^2 K^2}}$$

where: Z = the depth of the interface in a landward lying point (X) in respect to water level.
q = the quantity of fresh groundwater flowing to the sea per unit length unit time (m^{2}s).
K = the permeability of the aquifer for fresh water(m/s)
δs = density of the Dead Sea water.
δf = density of fresh water.

The intersection of the interface with the sea bottom occurs at point X_o which is given by the following:

$$X_o = \frac{q}{2(\delta a - \delta f)K}$$

At the shoreline, X = O, the depth of the interface equals

$$Z_o = \frac{q}{2(\delta a - \delta f)K}$$

The application of this equation results in the fresh-Dead Sea water interface configuration given in Figure 22.

Since the commissioning of various water projects in the catchment area of the Dead Sea in 1964, increasingly less and less water has been reaching the Dead Sea. Hence, the equilibrium between incoming water and outgoing water (evaporation) has been greatly distorted and the result was a declining Dead Sea level from 392m below sea level in the early sixties to around 405m below sea level in the early nineties.

The drop in the level of the Dead Sea means a lower salt water pressure along the interface between the Dead Sea water and the fresh groundwater. The reaction of the interface to the drop in sea level is a seaward movement of the interface accompanied with a movement of the fresh groundwater resources towards the Dead Sea to occupy the evacuated regions of saline water.

The final result on the fresh groundwater resources is a drop in their levels in all parts of the Dead Sea groundwater catchments for which the Dead Sea forms the ultimate base level.

The amount of drop in the fresh groundwater levels is not the same amount of drop in sea level or its equivalent hydrostatic pressure, according to the communicating vessels principle, but a multiple (maybe 5 times) of that because of geomorphologic and hydrodynamic pecularities, not to be mentioned here since they are beyond the scape of the present elaborations.

The drop of fresh groundwater levels will result in drying up of springs with time, especially thermal springs along the eastern slopes of the Dead Sea, like Zerka-Ma'in and Zara thermal springs.

Therefore, it is essential to re-raise the Dead Sea level to its former elevation of the early sixties of -392m by either transferring water from the Red Sea or the Mediterranean Sea.

Such a project will not only restore the fresh groundwater bodies, but, it will also have the following outcomes:

- Produce hydroelectric energy due to the level differences between the open sea and the Dead Sea of around 400 m.
- Save pumping energy for the potash company.
- Save a unique national and international treasure from drying up.
- Larger Dead Sea area will also positively affect the climate by increasing evaporation by around 50 m^3/second.
- Save tourist facilities and optimize their use, because the further the Dead Sea level drops, the farther they become from the shoreline.

If the Red Sea-Dead Sea canal is chosen, then fish farms can be established along Wadi Araba; the shoreline of Jordan on the Red Sea water will be enlarged and it will increase the attractions to international and national tourism.

8. Radioactivity

The thermal water discharged as springs or through wells produces gases consisting mainly of CO_2 and $H2_S$. In addition, a radioactive gas was identified as radon^{222} using δ - spectroscopy.

The δ - activity of the thermal water was then measured by EDA-equipment (RD 200 provided with ZnS (Ag) sensor). The instrument was calibrated with a radium^{222} -standard after equilibrium with its daughter element of radon^{222}.

Table 51 lists the activities of the discharged water in μ Ci/I. Radon^{222} is a daughter element of U^{238}. Its presence indicates decay and leaching of uranium^{238} minerals which are known to occur in the different sandstones of the lower complex.

The evolution of the different water types leads to CO_2 and H_2S production, which lowers the pH-value of the water, hence increasing the solubility of uranium minerals which then move in a soluble form with the groundwater to the discharge sites.

The precipitated hydroxides and carbonates which take place at the discharge sites of springs and wells and along the water courses at the surfaces of the ground give α-radiation which was detected to be a result of U^{238} decay.

Table (51)

Radon concentration in Zarka Ma'in-Zara area

Spring No.	Rn-concentration
Zara - 22	3.6 μCi/I
Zara - 27	7.3 μCi/I
Zara - 41	7.4 μCi/I
Zarka-Ma'in - 47	0.9 μCi/I
Zarka-Ma'in - 8	4.7 μCi/I
Zarka-Ma'in - 55	4.7 μCi/l
Mukheiba Wells	8.4 μCi/l
Wadi El-Arab Wells	6.6 μCi/l
N-Shuna Well	7.7 μCi/l
Rama Well	10.0 μCi/l
Hima	3.4 μCi/l
Azraq Deep Well	4.0 μCi/I

IX

Water Price, Alternative Uses for Sustainable Development and Social Impacts of Pricing Policies and Some Water Projects

1. Water Pricing:

The main objective of water pricing is to facilitate a better water use policy. The value assigned to a water source depends on different factors such as its yields, the technology to convey it to consumers, the demand for it and the alternative uses.

If water is abundant and accessible it may not be essential to assign an economic value to it. But if it is scarce its value increases and can only be determined by the interaction of the competitive uses. Therefore, it is essential to develop a mechanism which allows the best use of water in socio-economic and environmental aspects. Pricing water may be an effective instrument in achieving a better use strategy.

Assessing the economic value of water is a difficult task because it incorporates a socio-economic component consisting of benefits and costs, in terms of social, environmental, health, economic and political impacts that result from the use of water. But, nonetheless the criteria for price setting may differ from one area to another and from one water use sector to another.

In Jordan, water is a very scarce resource, and for many users it is still regarded as a "free good", which is the worst possible position from which the management of this scarce resource can be approached.

Still, the government of Jordan assigned tariffs for water use. These tariffs are reconsidered from time to time, taking into consideration cost recovery, consumer ability to pay and the social and health effects of raising or lowering water prices.

1.1. Price of Domestic Water:

Currently, the price of domestic water increases with increasing consumption. It follows a block system of water use to which definite progressive prices are assigned. Prices increase as the consumption exceeds a block limit. Table (52) lists the current water prices with their block limits.

Table (52)
Domestic water tariffs (fils/m^3) for the consumed amounts in a quarter year (Q/3 months)

Q/3 months (m^3)	Amman	Jordan Valley	All other areas
0 - 20	100	65	65
21 - 40	190		90
41 - 70	400	11.5	300
71 - 100	500	250	500
101 - 150	600	400	600
over 150		600	

The records of the Ministry of Water and Irrigation show that only around 30% of the meters register a consumption of more than 100 m^3/quarter. This group includes companies, small industries, institutions of different sizes, hotels, etc. Otherwise, the consumption remains modest in the majority of houses and at the hygiene brink in the poor population areas.

Domestic water consumption can hardly be decreased any further, since 85 l/c.d., the average consumption in Jordan, is very low and the population is living at the hygiene brink. Domestic water supply should increase to cover the demand which, considering the living standards in Jordan, should be around 120 l/c.d. at present.

This would mean that using higher tariffs as an instrument to save water will be ineffective and will have only a limited impact on high-use consumers.

Wastewater has its own tariffs which are added to the water bills of consumers. The tariffs follow the same progressive block rates of domestic water and are collected for the consumed water amounts and not the produced waste water. Table (53) lists the wastewater tariffs valid for all towns where wastewater treatment plants are operating.

Cost of domestic water:

The cost incurred in making water available to consumers can be subdivided in different units such as:

- the value of the water in the source (cost)
- exploration and source development (cost)
- water treatment (cost)
- transport and storage (cost)
- waste water treatment (cost)
- waste water reuse (revenues)
- waste water disposal; environmental effects (cost)
- reducing the country's natural resources in the case of fossil-water mining; depriving future generations of resources (cost).

Table (53)
Wastewater tariffs (fils/m^3) considering the consumed water amounts in a quarter year m^3/3 months

Water consumption m^3/3 months	Tariff fils/m^3
0 - 20	130
21 - 40	230
41 - 70	500
71 - 100	700
over 101	850

The above units can be categorized in:

- capital cost
- operation cost
- country deprivation or enrichment of resources

Until 1991, the capital cost of all domestic water projects totalled around J.D. 420 million. By considering an average lifetime of 50 years (some projects have been operative for about 15 years) and an interest rate of 5%, the capital cost can be estimated at around 450 fils/m^3.

In 1988, the World Bank calculated an operation cost of 217 fils/m^3 of water. But since that time the expenditures of WAJ increased from J.D. 37 million to J.D. 61 million in 1991, and the produced water amounts increased from 135 MCM/year to 182 MCM/year in 1991.

The expenses of WAJ are not detailed and subdivided in capital and operation costs, therefore, it is difficult to reach at an exact figure for the operation cost.

But, by using the same ratio of operation cost to the total expenses for the years 1988 through 1991 and by using the figure of the World Bank for the operation cost in 1988 of 217 fils/m^3, the operation cost in 1991 would amount to 265 fils/m^3.

The revenues of WAJ were J.D. 24 million in 1991, which cover only around 50% of the operation cost.

At this stage, it is worth mentioning that 56% of the water produced by WAJ is unaccounted for and hence not billed (GTZ, Schlenker 1992). This loss is attributable to corroded and defective networks, illegal connections, inaccurate or inoperative water meters and billing errors.

According to the Pride Study 1992, metering and billing errors result in revenue losses of J.D. 8.15 million/year.

If leaks are reduced to around 25% and the saved water reaches paying consumers, the revenues of WAJ would increase by some J.D. 12 million/year.

The cost incured to the country and its future generations by the mining of fossil water resources or because of the over-exploitation of renewable aquifers or by the disposal of treated and untreated waste water, requires detailed, comprehensive studies which are beyond the scope of this book. Nonetheless, this type of cost should be addressed soon because it is believed that it will be no small cost for future generation to pay.

The above details indicate that if the efficiency of the Water Authority is increased, the losses in the delivery system are minimized and the illegal connections are stopped, the water revenues may cover the cost.

1.2. Price of Irrigation Water:

The first tariff for irrigation water in Jordan was issued in 1961.

Irrigation water was first charged by the government in 1961 when a water price of 1 fils/m^3 was assigned to the water used in irrigation in the Jordan Valley area. Any amount exceeding 1800m^3/month was charged at 2 fils/m^3 (Ohlmeyer 1991). In 1974 the price was raised to 3 fils/m^3 regardless of consumption. Again in 1989 the price was raised to 6 fils/m^3.

At present, the capital and running cost of JVA irrigation projects in the Jordan Valley and in the

southern Ghor areas are, according to Ohlmeyer (1991), 37.6 and 57.4 fils/m^3 for interests rates of 3% and 5% respectively. Considering the amounts of water sold to the farmers, which differ from one year to another, the range of capital and running costs fluctuate between 37.6 and 60 fils/m^3 for an interest rate of 3%, and between 57.4 and 90.2 fils/m^3 for an interest rate of 5% (Ohlmeyer 1991).

Also, according to Ohlmeyer, the operation and maintenance costs range, according to the sold amounts of water, between 9.9 and 17.4 fils/m^3.

Using an interest rate of 3% and the average sold water amounts in the Jordan Valley and southern Ghor areas, the water price of 6 fils/m^3 covers only about 12% of the capital, operation and maintenance costs and around 40% of the operation and maintenance costs alone. This shows that the government is heavily subsidizing irrigation in both above-mentioned areas.

In the highlands, farmers themselves have to cover all the capital, operation and maintenance costs for their water supply, which is generally extracted by pumping from groundwater wells driven within the farm area or its neighborhood. The cost for such water ranges from 40 fils/m^3 for shallow wells to about 100 fils/m^3 for deep wells.

1.3. Industrial water prices:

Industries supplied with water by the Water Authority pay for the consumed amounts the same progressive prices valid for domestic uses. But these industries and commercial activities consume only around 15 MCM/year of the industrial water currently used in Jordan.

The majority of large and medium-size industries such as potash, phosphate, oil refinery, thermal power station, beverage, and aluminum concerns, as well as some universities, army units and governmental organizations possess their own groundwater wells to cover their needs. They pay nothing for the consumed water and they are free to extract from the groundwater as much as they like, with no control from the concerned governmental agencies. The only costs they pay are the capital and operation costs of their own equipment.

This policy, has had until now, two main results:

* The groundwater resources have been depleting at an accelerating rate because there is no control, such as metering of the extracted amounts.

* In order to abide by the instructions of waste water disposal, factories possessing waste water treatments plants have been pumping more groundwater to dilute their effluents so as to keep within the guidelines requiring that the effluents are suitable for disposal along wadis or generally to the environment.

The outcomes of such a policy are:

* a more rapid depletion of the groundwater resources of the country.
* less revenues to the Water Authority and less compensation for the nation.
* degradation of the environmental elements by diluting the pollutants instead of removing them.

2. Alternative uses for sustainable development and impacts of pricing policies:

Neither farmers in the Jordan Valley and southern Ghors, nor those in the highlands or industries possessing their own groundwater wells pay any compensation to the nation for extracting water, which, because of its scarcity in Jordan, can be considered as a national resource. At the same time water extractions in the highlands are not metered, and farmers or industrialists from those areas can pump as much groundwater as they please.

The principle of returns to water used in irrigation and industry is useful in that it focuses attention on this scarce resource and can assist policy and decision makers when allocating funds to water-using sectors, water-using activities, and to certain crops which bring varying returns.

Until now, planners, engineers and economists in Jordan have not satisfactorily incorporated water management and sustainable development principles in calculating the opportunity cost of water resources. If applied, this may result in future constraints on resources uses if they prove economically and environmentally unsound. But, if water resources are optimally used according to economic and environmental sustainability principles, they may give better yields and reach better present and future socio-economic developmental objectives.

It is generally difficult to quantify water cost and benefits, but in Jordan, with its scarce water resources, the opportunity cost and benefits are easier to determine, especially if the future needs are not to be compromised.

As long as the water resource is renewable it is not conditionally important to set a price for the water at the source, unless the different use sectors and users compete for that source.

In the Jordan Valley area and southern Ghors the competition among the water use sectors is very limited, but is high among users in irrigation. Therefore, it is necessary to set the price of water at its capital and operation cost and to allocate some of it for the domestic sector uses.

At the same time, it is not recommended that the water amounts allocated to irrigation be curtailed in order to provide additional domestic supplies, because the resultant impact on the labour market will mean increased unemployment. Such a measure will result also in decreased food production and hence less domestic coverage, which will require compensation through imports and more expenditure on foreign currency. Unemployment and less food production may result in social unrest in the country.

Nonetheless, increasing water use efficiency may result in increasing the available water amounts, hence covering the domestic water shortages and at the same time increasing food production.

Currently, the efficiency of water use in irrigation is still low and can be raised significantly. According to Pride (1992) the overall water use efficiency (on farm and conveyance) in the northern Jordan Valley is 42%. In the middle and southern Ghors, where pressurized pipe systems are used, it rises to 65%.

If the overall efficiency of irrigation in the Jordan Valley can be raised to the acceptable limit of 85%, an additional 20,000 hectares can be irrigated with the same amount of water produced at present.

Pricing water at its cost may represent a very good instrument and incentive for farmers and for the Jordan Valley Authority (JVA) to increase efficiency. Farmers will be interested in saving the cost of water and the JVA will be interested in earning more revenues to cover its expenditures.

Even in the highlands where there is significant competition among the water use sectors, the on-farm efficiency ranges from 68% to 94% and the delivery efficiency from 68% to 93% (Pride 1992). If the overall efficiency here is increased to 85%, an additional 5600 hectares can be irrigated with the same amount of water.

Increasing on-farm efficiency alone in the Jordan Valley and southern Ghor areas would allow irrigating an additional 3500 hectares or saving 40 MCM of water per year.

To achieve a better overall efficiency, farmers and JVA have to convert to pressure pipe systems and repair the canal linings. At the same time, the excessive manpower in the JVA has to decline, because farmers will not be willing to pay for excessive manpower whose salaries form a part of the operation cost of the water projects.

Provided that this is a mechanism which enables a realistic price to be charged to water use in irrigation, then the market may play a considerably useful role in that mechanism.

Generally, increased water prices compete with the incomes of farmers. Therefore, assigning prices to irrigation water can be considered under the socio-economic issues influencing decision makers. But, there is always an optimal way to allocate water resources and assign prices if considering the real cost to a society. This results from using and protecting a certain source of water for other uses to produce other crops.

From the point of view of more efficient water use, according to economic, technical and environmental requirements, a more balanced irrigation water pricing system, targeting recovering costs, should be implemented in the near future in Jordan. Such policies should not be affected by those in the agriculture sector who have a significant constituency and can strongly influence the political leadership through the concerned officials.

Farmers benefiting from the current allocation and pricing practices will not want to yield such benefits. The principle of equitable use of water may contradict current allocation practices, and any attempt to change water allocation and prices may create strong reactions on the part of the water users in irrigation. But such a pricing policy should be implemented in order to secure the resources for the coming generations.

Since the use for domestic purposes is life-essential and from a health point of view irreplacable, water should be allocated to consumers at a very low price to cover their basic needs of hygiene and not to cover their luxurious uses such as gardening, car washing, swimming pools, etc...

Therefore, subsidies of domestic water should only address specific target groups to cover those hygienic needs. Any used water amount beyond a certain amount per person per time unit should be charged at a cost which should also compensate for the cheap water used to cover the basic needs. Hence it was necessary in Jordan to set progressive prices for increasing consumption, otherwise there would not have been any incentive for water saving and conservation. Most Jordanians live now at the hygiene brink as long as domestic water use is concerned. Hence any pricing policy aiming at increasing water prices will not lead to savings but to health deterioration among the poor.

The average water price in Jordan of about 220 fils per m^3 is not much different from the production cost. The higher expenditure of WAJ and the lower revenues it collects, are attributable to the supply system losses and inadequate management.

The development of a reliable water supply system greatly depends on the cost recovery principles. But to convince people to accept that principle the operation technologies, maintenance, preventive maintenance and the management of the water supply should be optimal, otherwise consumers will not be willing to accept the principle of cost recovery. For example, no consumer would appreciate an overstaffed water supply institution or an inefficient one. According to the World Bank study of 1988 and to Pride (1992) the Ministry of Water and Irrigation is overstaffed and positions are not always occupied by the proper persons. If the consumer has to pay the total cost of water, then the WAJ should minimize its cost and maximize its output.

In this context, it is worth mentioning that waste water should be adequately treated for use in irrigation and it should also be sold to the private sector. The cost incurred to highland farmers to pump groundwater to the surface of 40 - 100 fils/m^3 can serve as an indicator price for effluents.

If 60 fils/m^3 are charged the revenues of WAJ may increase by some J.D. 3 million/year.

To farmers, effluents of waste water treatment plants are a reliable source of water in its quality and it contains the necessary nutrients for plants such as PO4, NO3, K, etc.

To encourage water recycling in industries, effluent fees have to be set for discharging the waste water whether treated or untreated to the environment.

This fee should take into consideration the quantity of the discharged water and its loads on the environment. This will lead the different industries to adequately treat their waste water and reuse it wherever possible in the same industry because pumping additional groundwater and discharging treated water would increase the cost.

3. Examples of socio-economic impacts of water projects:

3.1 Disi Projects:

As an example, the extraction of fossil water in Disi-Sahl es Swan - Mudawwara (henceforth, Disi) area has not undergone economic and environmental considerations on a national scale. The irrigation projects there are fulfilling only a certain economic objective which brought social and economic benefits to a small sector of the society while it is creating a significant cost for the Jordanian society at large.

Looking at Disi irrigation project from an economic perspective, the following points may be raised:

* The potential evaporation in the area is around 4000 mm/year which is the highest in Jordan. Considering an irrigation period of 3 months per crop results in an evapotranspiration of at least 1000 mm.

* To produce one ton of wheat, an average irrigated area of 2500 m^2 is required (production per 1000 m^2 ranges from 250 kg up to 600).

* To irrigate 2500 m^2 for the duration of 3 months (cropping period 4 months at least), 2500 m^3 of water are required.

Therefore, to produce one kilogram of wheat, 2.5 m^3 of the non-renewable, precious and best quality groundwater in Jordan are used.

The present cost of imported wheat C&F Aqaba is $0.15/kg. Selling the water needed to produce one kilogram of wheat in Aqaba means a revenue of around $0.5.

The government buys the wheat from producers for a subsidized price of J.D. 147 ≡ $216 per ton whereas, the imported wheat C&F Aqaba costs $150/ton.

According to the producers, the cost of wheat production (fuel, seeds machinery, spare parts, fertilizers, biocides, laborers ... etc) amounts to some J.D. 110/ton, 80% of which are imported facilities. This means that to produce wheat, Jordan has to import production facilities for around J.D. 88/ton ($130/ton), whereas importing wheat itself would cost J.D. 108/ton ($150/ton).

The gains of the project can be summarized as follows:

* saving around $20/ton of wheat in hard currency.
* a gain for the producer of around J.D. 36/ton ($53/ton).
* covering 5 - 10% of the country's wheat consumption, which does not mean much in terms of food security.

The losses incurred can be illustrated as follows:

* Loosing 2500 m^3 of the precious, non-renewable, best quality groundwater per ton of produced wheat. This water, because of its non-renewable nature, may be an asset for future generations and should not be exhausted for wheat production as long as wheat is cheaply available on the world market.

* For the government (tax payers) the project means a loss of around J.D. 47/ton ($69/ton), because imported wheat is cheaper.

* Since the only available future supply of Aqaba is Disi, exhausting its water resources would mean that sea water has to be desalinated to guarantee the continuous supply of water to the city. But desalination of one cubic meter of water costs at present a minimum of $2.00, which would mean that producing one ton of wheat deprives the country of $5000, to be paid in water desalination; the major portion of which will be spent in hard currency for imported fuel and machinery for desalination.

* Irrigating land results in irrigation - water return flows to the groundwater carrying high salt concentrations due to evaporation, fertilizers, biocides and other contaminants which, on the medium-term, would lead to deteriorating groundwater qualities rendering them less suitable for present uses.

Wheat subsidies were thought of in Jordan to encourage farmers of rain-fed areas not to lay their lands fallow (which meant enormous losses to the country) and not to subsidize the irrigated wheat production of farmers which exhausts natural resources and strategic water reserves of the country as well as the future generations' sources of drinking water.

The fossil groundwater resources in Disi aquifer and the overexploited groundwater resources in other parts of the country need to undergo analyses aiming at their sustainable development, which must include the protection of future generations and their environment and deal with the present economic and environmental concerns of the population. Therefore, it is essential to conduct studies on:

* economic analyses, cost-benefits for the nation.
* financial sustainability and alternative uses.
* economic feasibility, short and long-term economic costs, alternative programs.
* importance of source for future generations and in terms of national security.
* socio-economic analyses of irrigation projects and their implications on local population, culture and environment.

Non-renewable water resources in Jordan should only be exploited under strict, detailed consideration of:

* Their impacts on the quality of life for the population and future generations.

* The range of policy choices available to the government to achieve a country-wide sustainable development.

3.2. Khirbet-es-Samra:

Another example of economic impacts of water projects can be illustrated by Khirbet es Samra waste water treatment plants (KSTP). As explained in chapter IV and chapter VII, KSTP does not produce an effluent with which the environment can cope. The impacts of KSTP have numerous economic dimensions such as:

* evaporation losses
* deteriorating groundwater qualities
* deteriorating surface water qualities along Wadi Dhuleil and Zerka River down to King Talal Reservoir and finally in the Jordan Valley, where the water is used for irrigation.
* health detriments to the population living in the surroundings of KSTP (up to 10km in diameter) and along Wadi Dhuleil and Zerka River.
* health impacts on the livestock drinking the effluent or feeding on plants irrigated by the effluents.

Of the above-mentioned impacts, only the first three can be approached in economic terms.

Evaporation losses:

According to the WAJ files and reports, the evaporation from the stabilization ponds ranges from 15-30% of the incoming water, which is measured to equal 110,000m^3/day. Taking a conservative evaporation rate of 20%, the total evaporation per year would equal 7.8 MCM. If this water can be saved by using conventional mechanical treatment plants instead of stabilization ponds, the following results can be achieved:

* 7.8 MCM/year can be used to irrigate around 11000 dunums, which will increase agricultural production by around US$ 17 million.

* Farmers in the surrounding areas spend around US$ 0.16 to pump one cubic meter of groundwater. Hence, saving 7.8 MCM/year of surface water would mean saving US$ 1.25 of pumping cost.

* Allowing 20% of the water to evaporate results in salt concentrations in the remaing water of 25%. With the already relatively high salinity of the water of 1500 mg/l, this would mean 15 - 25% losses in crop production.

Deteriorating Groundwater Qualities:

As explained in chapters IV and VII, KSTP and its effluents caused a deterioration in the groundwater quality and rendered the groundwater in a strip 3 km in width and 7km in length unsuitable even for irrigation. The estimated amount of damaged groundwater is around 70 MCM, with a natural discharge rate of 7 - 8 MCM/year. This means that 7 - 8 MCM of good quality groundwater per year are made useless because of KSTP. The crop productivity of this water if used in irrigation will be some US$ 16 million a year.

Since the groundwater is not more in use because of severe quality deterioration its flow to the surface in the form of base flow causes also a deterioration in the surface water quality of Zerka River and King Talal Reservoir.

Some wells within the groundwater regime affected by KSTP which were formerly used as a drinking water source, have been abandoned because their water became polluted and the water salinity rose very high for drinking uses. To substitute the drinking water, new projects and new water sources had to be planned and developed, which also meant large investments for the public and private sectors.

Deteriorating Surface Water Qualities:

The effluent of KSTP is discharged into Wadi Dhuleil which joins the Zerka River at Sukhna. The base flow of Zerka River is very small, 1 - 1.5 m^3/s, which is equivalent to the present effluent of KSTP. This mixing ratio of 1:1 does not cause a major dilution to the semi-treated effluent. Therefore, the Zerka River salinity increased from an average of around 700mg/l for the base flow to an average of 1150 mg/l for the mixture of base flow and KSTP effluent. Such an increase in water salinity brings about 10 - 20% crop production losses. Considering a conservative water amount of 30 MCM/year (50% effluent and 50% base flow) and an average of crop losses due to salinity of 15%, the crop production losses would amount to US$ 14.5 million.

In addition, the surface water is affecting animal life and health and is functioning as a breeding site for insects.

Summarization of Khirbet es Samra Impacts Assessment:

The quantifiable losses due to the negative impacts of KSTP can be estimated at US$ 50 million per year, which, for a country like Jordan, is a considerable amount of money.

The non-quantifiable effects are health impacts, animal lives, bad odour, declining job opportunities and their implications on the socio-economics of the population.

This waste water treatment plant in Khirbet es Samra, thought of as an immediate relief to the then overloaded Ain Ghazal waste water treatment plant, has proved during the last 8 years to be an environmental and economic disgrace to the country.

The above two examples of Disi projects and Khirbet es Samra treatment plant imply that unsound water management may threaten the environment, the economy and the security of a country by degrading the quality of life and narrowing the choices of manoeuvering. Therefore, water management in Jordan should soon enter the security consideration, since it may threaten the basis of existence of the population and that of future generations.

Water and its sustainable development appear to be a security issue for Jordan and should be accordingly managed.

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CONCLUSIONS

The history of man in Jordan throughout the last three to four millennia has been determined and shaped largely by one major infrastructural element, water. This essential resource has great influence over human life when it is scarce. In Jordan the lifestyles of people, their socio-economics and their conflicts have all been determined by this basic factor.

Agriculture developed when the amount of rain was sufficient to support plant life. Irrigated agriculture was practiced along water courses such as the Jordan, Yarmouk and Zerka Rivers and a number of springs pouring into the Jordan Valley as well as around the few oases in the eastern part of the country.

In the past, availability of water and the technologies used for its exploitation not only determined lifestyles and socio-economics but also limited the population to the number who could be supported by the amount of food produced. In the last few decades the population growth rate has been very high, not only due to natural growth but as a result of the waves of refugees coming into Jordan, mainly from Palestine.

The whole of Jordan's development has been concentrated in agriculture, mainly irrigated agriculture, which entails developing water resources to be used for irrigation. Irrigated agriculture created job opportunities through less expensive investments for both Jordanians and refugees. This averted the potential catastrophes of poverty and hunger, and fostered domestic peace in Jordan. But, with the sharp increase in population and agricultural development, as well as the establishment of many small, medium-sized and even heavy industries (potash, phosphate and fertilizers), the available water resources were insufficient to meet development aspirations, especially because the spectrum of water uses has widened and the intensity of water needs has increased. Population growth, higher standards of living, industrialization and other activities accelerated the exhaustion of available resources.

Despite the implementation of intensive water projects and reservation measures, water shortage is the major obstacle to Jordan's development. This puts specialists and politicians under severe stress concerning the future of the country's economic growth, especially by considering the water problems of the country (Table 54).

Table (54): Water problems in Jordan

INSUFFICIENT RESOURCES	WATER RIGHTS OF INTERNATIONAL WATER NOT BOLD	WATER POLLUTION	OVEREXPLOITATION OF RESOURCES	WATER LOSSES LEAKS AND ILLEGAL CONNECTIONS	USE OF DOMESTIC WATER IN IRRIGATION	UNCLEAR, CHANGING STRATEGY AND POLICY
MEAGER PRECEPITATION	SOURCES OUTSIDE THE COUNTRY	INADEQUATE NATURAL QUALITY	MISMANAGEMENT	INADEQUATE NETWORKS	FREE WATER IN THE CASE OF ILLEGAL CONNECTIONS	UNCLEAR IMPORTANCE FOR POLICY MAKERS
HIGH POPULATION	NON-EXISTENCE OF VALID AGREEMENTS	INDUST- RIALIZATION	INSUFFICIENT INFORMATION	INADEQUATE IMPLEMENTATION OF PROJECTS	NONAPPLICATION OF BY-LAWS AND INSTRUCTIONS	SHORT-TERM PLANNING DUE TO SHORT-TERMS APPOINTMENT OF KEY PERSONS, URGENT NEEDS
INDUSTRIALIZATION	DOWNSTREAM POSITION OF JORDAN	IRRIGATION RETURN FLOWS	IGNORANCE OF RESEARCH RESULTS	INSUFFICIENT MAINTENANCE AND CONTROL	ECONOMIC GREED	SOCIAL FACTORS AND PRESENT WATER USES INHIBTS LONG-TERM PLANNING
INTENSIVE AGRICULTURAL DEVELOPMENT	MILITARY STRENGTH COMPONENT	INSUFFICIENT MONITORING AND CONTROL	INSUFFICIENT RESEARCH AND RESEARCH INTERESTS	SELECTION OF CHEAP MATERIALS	INSUFFICIENT OTHER RESOURCES	
IMPROVING LIVING STANDARDS	POLITICAL COMPLICATATIONS	INADEQUATE WASTE WATER TREATMENT	COMMERCIAL INTERESTS	INTERRUPTED PUMPING	MISMANAGEMENT	
RESOURCES USE BY OTHER RIPARIANS	INDIFFERENT PEACE WAR SITUATION	MISUSE OF RESOURCES	SUPERFICIAL CONSULTANCIES	USE OF DIFFERENT WATER QUALITIES MIXED IN PIPES WITHOUT EQUILIBRIATION	INADEQUATE SOLIDARITY AND COMMUNITY FEELINGS	
LOCAL IRRIGATION WATER SUBSIDIES	INADEQUACY OF INTERNATIONAL LAWS			NON-APPLICATION OF BY-LAWS AND INSTRUCTIONS		

The prevailing climate in Jordan is semi-arid. Only the highlands in the west and northwest can be characterized as Mediterranean. Jordan receives an average yearly amount of precipitation ranging from 30 mm in the southeast and east to about 600 mm in the northwest.

The evaporation force of the climate in Jordan is very high: in the cooler north-western areas, it is about 1800 mm per year; in the southeast it goes up to 4200. This is respectively, three and 140 times the amount of average annual precipitation.

Perennial water in Jordan is found mainly in the rivers and wadis of Yarmouk, Zerka, Mujib, Zerka-Ma'in and Hasa. These discharge water during all seasons into the Jordan River, the Dead Sea and Wadi Araba, but its ultimate destination is the Dead Sea. In addition to rivers and wadis, the Azraq Oasis, situated 100 km to the east of Amman, holds water in all seasons. These sources, excluding the jointly-owned Yarmouk River, discharge approximately 160 million cubic meters annually, less than the average discharge of the Nile in one day and less than that of the Euphrates in two.

The groundwater resources of the country are of two origins: 1) recent and renewable and 2) fossil, which receives no or only a very small amount of recharge. The latter are non-renewable in technical terms and their exploitation is equivalent to a mining process. The fossil ground-water resources are mainly found in the southern and eastern parts of the country. They infiltrated into the aquifers tens of thousands of years ago, when the prevailing climate was more humid. Such water can be considered a reserve for dry years.

The renewable groundwater resources of Jordan without the Yarmouk, amount to about 340 MCM/year. They suffice for the greater part of domestic and industrial, as well as highlands agricultural needs.

As mentioned above, water-resources development is of great concern and forms a major target for the country. Dams were constructed, irrigation canals were built, domestic water supplies were extended to serve 96 percent of the inhabitants including the remote and sparsely populated areas of the country. Even in areas where the source of water lies tens of kilometers away from the settlement, water was brought to the inhabitants through pipe connections. Fourteen cities and towns (60 percent of Jordan's population) are now served by sanitary sewage systems and wastewater treatment facilities.

In the Jordan Valley area, the King Abdullah Canal (formerly the East Ghor Canal) was constructed along the eastern bank of the Jordan River. It extends some 110 km and irrigates 170,000 dunums. Other irrigation projects were implemented in the southern area of the Dead Sea, putting around 46,000 dunums to use. In addition, the lands of the Jordan Valley lying above the reaches of the canal were irrigated using the waters of the side wadis and some groundwater, bringing the total irrigated land in the Jordan Valley to around 280,000 dunums. In the highland areas irrigation projects dependent on pumping groundwater were implemented to cultivate another 250,000 dunums.

Concerning domestic water supplies, expensive projects proved to be necessary in order to serve the population centers, which generally lie removed from potential water resources. For example, the capital city of Amman gets its domestic water from various sources extending 100 km to the east (Azraq) and 55 km to the west (Jordan Valley area), with pumping heads of up to 650 and 1400 meters respectively, in addition to friction heads. This is, for a non-oil-producing country, a very expensive affair.

The population of Jordan is growing at the high rate of 3.6 percent per year and is not expected to decrease during the next one to two decades. Accordingly, the population of Jordan is expected to grow to 4.7 million by the year 2000 and to 6.4 million by the 2010, i.e., doubling in 20 years. If living standards and population structure remain at their present state, domestic water use will also double in the same time period. Any rise in living standards or social-structure order will result in higher demands, which will exceed double the present daily consumption.

The present per capita daily water use is 85 liters. Of the present total amount of water pumped to consumers; 180 MCM/year, one quarter is lost through corroded leaky pipes, another quarter is used illegally (not being paid for), and a fraction is used by small-scale industries.

The planned industries are also expected to consume more water. The demand is calculated to rise from 45 MCM/year at present to 85 MCM/year by the year 2000 and to 125 MCM/year in 2010.

Around 650 MCM/year of water were used for irrigation during the last few years, distributed between surface and groundwater resources.

Added to domestic and industrial consumption, the total water use comes to 875 MCM/year. The total extractable and renewable water resources of the country are around 896 MCM/year. It is worth mentioning at this point that some of the resources are overexploited, such as Dhuleil Azraq, Disi, and Wadi Arab, whereas other resources are still underutilized - Mujib, Zerka Ma'in and Yarmouk. But in general, the water resources still to be developed are very meager and are partly shared with other countries.

Even if the amount of water used for irrigation is limited to its present level, and if water projects and extractions are redistributed to achieve the safe-yield concept, Jordan will be using all its available and renewable resources by the year 2000.

The increasing demand for water led planners to develop the most accessible sources, concentrated in certain areas, while others remained unexploited. For example, in the Jordan Valley 75 percent of the water resources are used, very close to the maximum possible rate of 85 percent. On the other hand, only eight percent of the water resources of the eastern slopes overlooking the Dead Sea are used. Other less optimal water resources have been developed, e.g., water from Azraq was piped 100 km to Amman, causing the groundwater level in that area to drop by many meters within a few years. This resulted in salt-water intrusions from deeper saline aquifers and the drying up of a unique oasis, thus damaging the natural habitat of the area.

Not only were renewable water resources used, but extractions were expanded to include the fossil-water resources which have been stored underground for thousands of years. Some of these resources have been exhausted because their replenishment rates can not cover the extraction rate. This is the case in Dhuleil and Jafr, and the Azraq and Disi areas are now threatened.

Failure to plan water projects carefully has resulted in exhaustion or damage to some sources; others are still untapped.

During the last three decades small and medium-sized industries have been established in Jordan, concentrated mainly in the Amman-Zerka area. Effluents from these industries are only partly treated and are directly discharged either into the nearby wadis or into the sewerage system, causing the deterioration of surface and groundwater quality. This type of pollution is limited in its distribution and extent, and major steps were taken to alleviate its effects. The major pollution problems are the result of inadequate treatment of domestic wastewater, inefficient treatment plants and the choice of inferior wastewater treatment plants and methods.

Jordan's scarce water resources, lack of perennial flows, hot climate and relatively low per-capita use of water result in a dense wastewater with highly concentrated pollution parameters, which renders the current unsuitably chosen treatment plants and technologies inadequate. The insufficiently treated effluents are not diluted, due to the scarcity of perennial water such as rivers. The toxicity of effluents and the hot climate accelerate eutrophication processes in surface-water bodies, rendering the main reservoirs highly eutrophic (ageing lakes). The effects of treatment-plant effluents are also damaging to the groundwater resources, especially the effluents of waste stabilization ponds in the Khirbet es Samra (Amman-Zerka area), Mafraq, Aqaba and Ramtha areas. Waste-stabilization ponds have proved to be unsuitable for countries with poor water resources, where sewage is very concentrated, evaporation rates are high, and no dilution takes place, added to the problem of the extremely unwise choice of treatment sites. Also, the wrong choice of solid-waste disposal sites and methods has led to deterioration of both surface and groundwater in their areas.

The riparians of the Jordan River are Jordan, Syria, Lebanon, Palestine and Israel. Its tributary, the Yarmouk River, is shared among Jordan, Syria and Palestine. In the last few decades both rivers have played a remarkable role in Middle East politics. One of the major reasons for the 1967 war is strongly believed to be the complications concerning the utilization of the Jordan River water. The construction of a dam on the Yarmouk River was postponed, then abandoned; its site was shifted three or four times within the last two decades because of the non-existence of a peace treaty.

At present, Syria extracts 160 - 170 MCM/year from the headwaters of the Yarmouk River, although its share according to the Johnston plan is only 90 MCM/year. Israel also extracts around 100 MCM/year from the Yarmouk, although only 25 MCM/year were allocated to irrigate the Yarmouk Triangle, now lying in Israel. Jordan extracts 100 - 110 MCM/year from the Yarmouk River through the King Abdallah Canal.

If Jordan is allowed to take its share of 100 MCM/year from the Jordan River and the additional 175 MCM/year from the Yarmouk, Jordan's water problems will be shifted and their urgency will be postponed for another 20 years. By then, it is expected that population growth will decline to a moderate rate, and that solar desalinization and nuclear-fusion technologies will be at the world's disposal.

The choices for increasing water resources within Jordan are limited to sea-water desalinization at Aqaba and treated wastewater reuse. The first choice is very expensive and can hardly be accommodated within the economy of the country since fuel has to be imported. The second choice has been discussed above. Another alternative to be considered is importing water from other countries. A feasibility of the Euphrates River was carried out, but no further action was taken because of the riparian rights of that river and the high cost of implementing the project. Another proposal, advanced by the Turkish government, is the construction of two pipelines to supply the Middle Eastern countries in Asia and the Gulf states with water from two unutilized rivers in Turkey. The project, "Peace Pipeline", would cost approximately $21 billion. The name of the project suggests the connection between peace and integrated development in the area. This project will have a good chance of implementation after certain political advances are made and if it proves economically feasible.

Only expensive projects to utilize water resources can postpone Jordan's crisis a little longer. But even limiting agricultural uses at their present water-consumption rate, allowing domestic demand to cover only the natural increase of population without any rise in living standards or in per-capita consumption and letting planned industries obtain minimal amounts of their needed water, using all the available resources and developing them to safe yield limits, will only satisfy this restricted demand until the year 2000.

The present shortage in water resources and the expected sharpening of demand should give rise to water policies involving more efficient conservation systems rather than the traditional search for new resources. The challenge facing us is to develop and introduce the necessary technologies for water and wastewater systems. The increase in population makes this challenge more difficult. The traditional policy of developing new resources to satisfy needs is, in the case of Jordan, almost exhausted. Now is the time to formulate new policies and change management strategies. Investment in leakage detection and maintenance is a more economical way to increase the efficiency of water supply. Water leaking from pipes represents a great loss since, although it has been collected, purified, pumped and distributed, it does not reach the consumer to pay for it.

It is now necessary for wastewater treatment and reuse to become an integral part of water services. Although wastewater is polluted, proper treatment can make its application in irrigation quite safe. It also has advantages over fresh water: wastewater contains the nutrients necessary to support plant growth.

The government of Jordan pays the capital cost of all the large irrigation projects. Although it is expected that farmers would irrigate their crops more efficiently if irrigation water prices reflected the actual cost, subsidizing irrigation water is still government policy. Pricing this water artificially low has led to the inability to satisfy the demand. Users of fossil-water resources for irrigation in Azraq, Dhuleil, Disi and other areas pay only for the pumping costs, but not for exhausting these non-renewable national resources. Current practice in this area will certainly lead to the depletion and the loss of the nation's future water and food security. Paying a certain cost now might lead to saving and conserving at least part of the water and maybe to reconsideration of the economic feasibility of projects.

In the coming decade high-cost projects, environmental hazards and tightened budgets will make large water projects unattractive and difficult to implement. Therefore, policymakers should change their strategies to lower the demand for and increase the efficiency of water instead of increasing the supply.

The increasing demand for water, as a result of population growth and improvements in the standards of living, is gradually leading to competition for the water resources. Projects of additional supplies are becoming more and more expensive and very scarce because of the unavailability of additional resources. Such a situation is expected to gradually lead to economic consideration of water supply and allocation practices.

In the past four decades social and political issues determined the water use allocations in the country. But the scarcity of water and the expenses of allocating new resources require new thinking and new management procedures.

Water allocations for certain agricultural activities may have to be curtailed, which may in turn cause difficult socio-economic and political problems (more expenditure on foreign currency, increasing unemployment, less food production and eventually social unrest).

The increasing demand for water and the competition among water use sectors will make the present management and development of the water sector through the policy of project-by-project, area-by-area or users group-by-users group planning insufficient. The country should develop a water strategy with adequate dynamic instruments in it to enable comprehensive planning.

Ad hoc decisions in water management are never in place because water development and allocation decisions have generally long term effects on the human activities relying on the water, on the socio-economic and socio-cultural state of the population and on other environmental elements. The only guarantee to consider all these aspects in water management is the development of a dynamic, comprehensive water strategy based on economic efficiency objectives, while taking into consideration the socio-economic and socio-political components.

The change to an efficient water economy will not be an easy task. But such a change should start and continue. The technologies are available. Therefore, allocating more funds to improving the efficiency of water systems will make unnecessary some expensive, environmentally unsound projects, such as some of those carried out during the last decade.

Economic restructuring from irrigated agricultural to industrial is the way of the future for a country like Jordan, poor in water resources rich in its talents and people and enjoying security.

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This book is partly based on the proceedings of the two conferences held in Amman in 1990 and 1991 with the following contents:

A. Contents of the proceedings of the Conference on Water Pollution in Jordan - causes and effects, FES, El-Kutba Publ. Co., Amman, 1991.

1. Impacts of liquid wastes on surface and groundwater resources and their elimination through proper treatment and reuse
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2. The inadequacy of stabilization ponds treatment as manifested by the effects of Khirbet es-Samra effluent on the groundwater quality of the surrounding area
   Helen Bannayan

3. The potential impacts of industrial wastes on water resources in Amman-Zarqa basin
   Raja Gedeon

4. Impacts of urbanization and industrialization on water reservoirs: King Talal Reservoir, a case study
   Murad Bino

5. Over-exploitation and salinization of groundwater resources and accompanying saltwater intrusions
   Elias Salameh

6. Solid waste disposal sites and their effects on ground and surface water
   Samir Hijazin

7. Impact of biocides on ground and surface water pollution in Jordan
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8. Protective measures of water resources in the Federal Republic of Germany
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