Water Quality Degradation in Jordan

(Impacts on Environment, Economy and Future Generations Resources Base)

By
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ROYAL SOCIETY
FOR THE
CONSERVATION
OF NATURE

Class No.	363.73
Author	Elias Salameh
Title	Water Quality Degradation in Jordan (impacts on environment, economy and future generations resources base)
Subject Heading	Water - Jordan
Deposit No.	(1134/8/1996)
Notes	The Higher Council of Science and Technology

Prepared by The National Library

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Foreword
FES

In their widely acclaimed *Water Wars - Coming Conflicts in the Middle East*, Adel Darwish and John Bulloch quoted Elias Salameh as saying, "Water will determine the future of the Middle East." Darwish and Bulloch expand on this message: "Israelis and Arabs alike face vital questions over water, which will determine the future of their countries and their peoples. Both sides in the forty-year old core conflict of the region know that finite resources and burgeoning populations, accompanied by urbanization and industrialization, are bound to lead to growing competition for the available water, if agreement cannot be reached.

To some people such a martial outlook may seem exaggerated, but the truth is that the conflicting demands for sufficient shares of scarce water resources are basic obstacles to the already threatened peace process in the Middle East. However, if the most intimately involved parties - Jordan, Palestine, Israel, Syria, and Lebanon - would strengthen their commitment to settle the water conflict, such an exercise in regional cooperation could encourage them to overcome other, more ideologically-based differences as well.

This prospect was highlighted - although unfortunately only for a brief period - by the Middle East North Africa (MENA) Economic Summit held in late 1995 in Amman, with the water problem enjoying a prominent place on the agenda Emphasizing the problem's structural core, Percy Barnevic, President of ABB and a key speaker at the summit, said that improved regional water cooperation after the peace process would certainly help, and that the cost of poor water management in the form of paying damages later would be enormous.

A 1995 study entitled "Water Disputes in the Jordan Basin Region and their Role in the Resolution of the Arab-Israeli Conflict" concludes that a solution of the water disputes is certainly not a sufficient condition for a lasting peace in the region, but is nevertheless indispensable. The study, published by Swiss Peace Foundation Berne and written by Stephan Libiszewski, pointed out that in Israel, Jordan, and the Occupied Palestinian Territories, the ratio of water consumption to total supply is around or even above 100 percent. The study also says that the overuse of existing resources seriously endangers the long-term stock. For us in Jordan, this means that the long overdue implementation of the water chapter of the Wadi Araba Peace Treaty between Jordan and Israel would relieve water scarcity but not climinate it.

The other side of the problem - namely excessive water consumption - deserves equal attention. Independent of whatever opportunities there may be to receive water from surplus countries such as Turkey, it seems that Jordan has no choice but to take all possible steps to protect its limited resources, make the water supply system more efficient, avoid water pollution, and stop all wasteful consumption.

The present publication, which focuses on water quality and pollution of water resource, is part of a series of publications on water issues which has been supported by Friedrich Ebert Foundation in Amman. Elias Salameh was the co-author of two of these books - *Water Pollution in Jordan: Causes and Effects* (1991) and *Water Resources of Jordan: Present Status and Future Potentials* (1993). In this present volume, he aims at illustrating the current situation with regard to water quality and at delineating the likely outcome if the necessary measures are not soon and adequately addressed.

In supporting this publication, Friedrich Ebert Foundation aims to contribute to a direly needed continuation of the dialogue on water in Jordan. It is hoped that this effort may encourage other attempts to improve Jordan's water supply situation.

Amman
October 1996

Manfred Haack
Friedrich Ebert Stiftung

Foreword

RSCN

Two thirds of the Earth's surface is covered by water. Huge amounts of water flow in rivers, collect in seas and oceans, or are frozen in the polar ice caps or even stored in aquifers. Nevertheless, available fresh water resources can hardly satisfy human needs in most countries of the world.

Water scarcity is now emerging as the most detrimental issue afflicting the population of the Middle East. Unfortunately, however, the problem is becoming more and more alarming each year due to dramatic population growth, the ever-increasing per capital use and the requirements of the industrial and agricultural sectors. This scarcity is aggravated by water disputes and the fact that water which flows in one country and originates from another is difficult to control. All and above, the misuse of water and the pollution of existing resources are bad omens for the future, not to mention the environmental and public health hazards they impose.

Against this backdrop, Professor Elias Salameh's efforts in dealing with water problems are all the more timely and appreciated. Upgrading water quality and diminishing the depletion of water resources are now needed more than ever. Likewise, wise planning of current water supplies and the application of new technologies are now high on the agenda of priorities of all nations and they deserve the attention of officials and policy makers.

Each and every member of society should be made aware of the need to save this precious resource and to spare no effort in protecting it from pollution. Regional agreements for cooperation should be reached with regard to reaching a formula of better comprehension and understanding on water-related issues, taking into consideration the legal rights of each country and the need to avoid possible conflicts and probably wars, now that politicians predict that any future war in the area is likely to be over water rights.

Dr. Salameh's book sheds light on threats posed to water resources in the county. It also delineates the proper way of handling, treating and utilizing these resources with a view to ensuring optimum utilisation and management of available water for the benefit and welfare of the people of the region.

Furthermore, the book is an important addition to a series of valuable works on the same topic by the author.

On behalf of The Royal Society for the Conservation of Nature, and on my own behalf, I would like to convey my appreciation to Dr. Salameh's commendable efforts. It is hoped that researchers, scholars, and policy makers would make use of the data and information included in this book in their future research. It is also hoped that the contemporary serious research would solve water and other problems in the region, and would contribute to the national effort in protecting this generation and the coming generations from any possible threats or harms.

Dr. Anis Mu'asher
President
The Royal Society for the Conservation of Nature
Amman, October 1996

Water Quality Degradation in Jordan (impacts on environment, economy and future generations resources base)

Preface

It is not the water quantity, but its worsening quality that will bring us to our knees.

One thing is becoming clearer with every passing day; that the quality of our water resources is degrading rapidly, not only because of active pollution introduced by liquid or solid wastes, but also, and in increasing steps, by passive degradation due to salinization as a result of overpumping and depletion of our groundwater resources base.

Water quality deterioration problems are exacerbating and sharpening the severe water shortage of the country perceived under the prevailing economic, social, scientific and technological situations.

This book is designed to include information about the water quality situation in Jordan and its development in the last few decades of rapid socio-economic achievements. For those purposes chapters I and II are intended to illustrate the water resources availability of the country.

Chapter III discusses the water quality issue. It includes information on original water qualities in the different parts of the country and their development as a result of pollution such as cesspools, treated and untreated wastewater, industrial wastewater, solidwastes, irrigation return flows, salt water intrusions and the coning up of salt water bodies.

Chapter IV is an attempt to quantify the cost of polluting and depleting water resources in physical terms, such as loss of resources, declines or losses in water productivities, developing additional resources to substitute polluted ones and cost to coming generations. It also touches on the social cost; the cost incurred by the society as a result of water pollution and depletion.

Chapter V discusses the issues of water resources, pollution, depletion and economic issues and attempts to indicate the managerial, technological and pricing policies the country should envisage to achieve a sustainable water resources base taking into consideration intergeneration equities as one of quality degradation and over exploitation limiting factors.

The information in this book about water resources and their quantities are mainly derived from the Ministry of Water and Irrigation. Information about water quality degradation and overexploitation are taken from a variety of sources listed in the references list, but mainly from reports and files of the Ministry of Water and Irrigation, the University of Jordan and the Royal Scientific Society.

The author highly appreciates the support and help granted by Freidrich-Ebert-Foundation (FES) and the Royal Society for the Conservation of Nature (RSCN).

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

I, the author, hope this book contributes to a better understanding of the water quality degradation situation and its economic implications on the country's present and future generations and that the responsible agencies and persons look at water quality and resources degradation as a vital issue for the society in Jordan and its economic achievements.

Prof. Dr. Elias Salameh

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I

Introduction

The naturally imposed semi-aridity of Jordan entails the country is limited amounts of rainfall and hence limited surface and groundwater resources.

The water shortage perceived is a straightforward population induced scarcity of resources aggravated by quality deterioration and resources misallocation, processes which in themselves negatively reflect on the availability of the naturally scarce resources.

During the last few decades population growth, industrialization, irrigation projects and improving standards of living not only have led to increasing water use and overexploitation, but also to deteriorating water qualities as a result of the various human activities.

These facts initiated many activities at research institutes, especially the University of Jordan which together with Friedrich-Ebert-Foundation (FES) in the years 1989-1991 organized three seminars on water pollution and water resources. The proceedings of these seminars are:

Water Pollution in Jordan - Causes and Effects - FES - Amman 1991 and

Jordan's Water Resources and their Future Potentials (eds. Gärber and Salameh), FES - Amman 1992.

were highly appreciated and received by concerned individuals and were ordered by universities, scientists, research centers, national, regional and international organisations from inside Jordan and abroad.

In 1993 both proceedings were out-of-print, and Friedrich-Ebert-Foundation, in cooperation with the Royal Society for the Conservation of Nature, sponsored the publication of a book on "Water Resources of Jordan - Present Status and Future Potentials - Salameh and Bannayan (1993 reprinted in 1994) Amman, FES and RSCN."

Since the issuing of these publications new information, analyses, facts and methodologies were made available. They require documentation and interpretation to illustrate the present water situation in the country, especially concerning quality degradation overexploitation and their socio-economic impacts. Therefore, again FES and RSCN are sponsoring this publication intended to serve all concerned individuals, especially policy-makers and institutions.

1. Country Profile

Area: 89.900 km^2, (Fig. 1).
Population (1994) = 4.1 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, manpower, 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 south-north 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 80km to the north. From there it drops gradually to about 400km 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 375km, is about 30km wide in the area of Wadi Araba and narrows to around 4km 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 Balqa and to more than 1200m ASL in Shoubak and Ras El Naqab areas. The width of this zone ranges from 30 to 50kms 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 northeast. 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, discharges into desert playas or qaas forming extended shallow lakes in winter and dry mud flats in summer.

The northeastern part of the country "the pan handle" is a flat plateau with a very smooth topography which rises from 500m in Azraq area to about 900m at the Jordan-Iraq borders. It is interrupted by volcanic mountains which rise to about 150m above the plateau level.

The southern desert forms also a flat area intersected by partly deep incised wadis. The topography rises in its south western parts to more than 1500m ASL (Aqaba mountains).

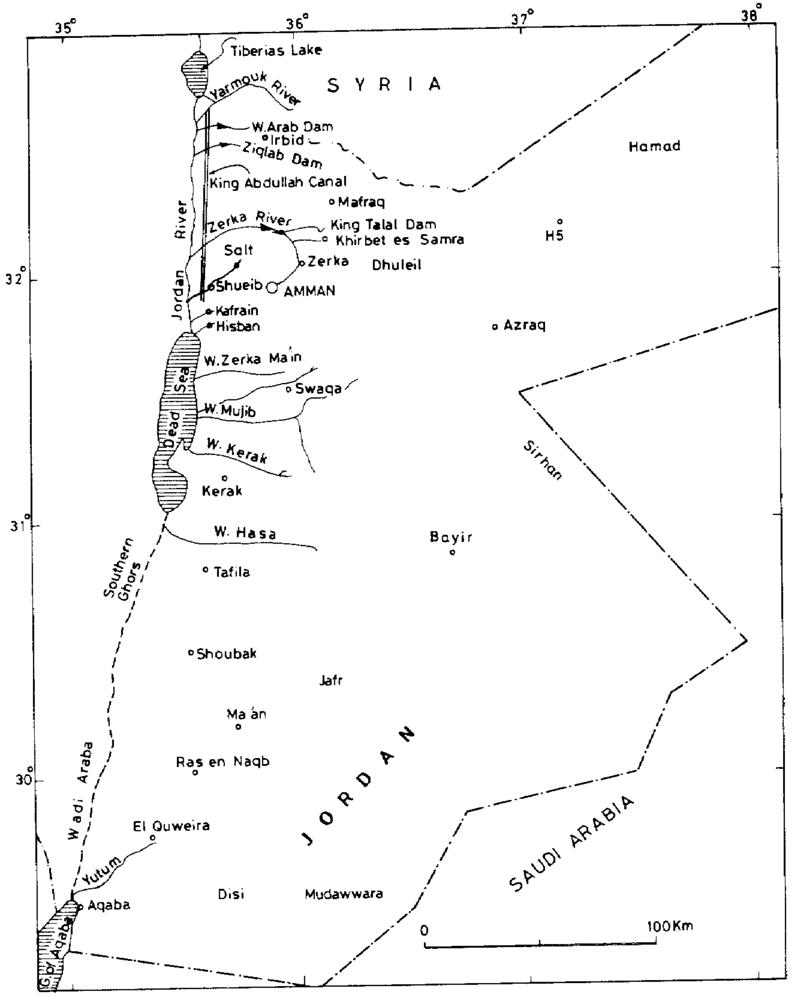

Fig. (1): Location map

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 a different geology consisting of sandstones and a granitic basement complex. The elevation of the area is around 900m ASL, with a north-south width of around 100kms. This part of the country is sometimes referred to as the southern desert. It is strongly disected by wadis with very rough topography in the western part and smooth topography in the eastern part.

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 300km, 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 humidity 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).

The highest rates of ppt fall over the highlands of Ajlun, Balqa, 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. 3), e.g., it decreases from an average of 600mm/year in Ajlun to 250mm/year in the Jordan Valley within a distance of 10kms 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 50mm/year some 30kms east of the town.

Generally, the following facts can be stated 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 receives an average annual ppt of more than 500 mm, only 1.8% between 300 and 500 mm, 3.8% between 200 and 300 mm, 12.5% between 100 and 200 mm and the rest, 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.

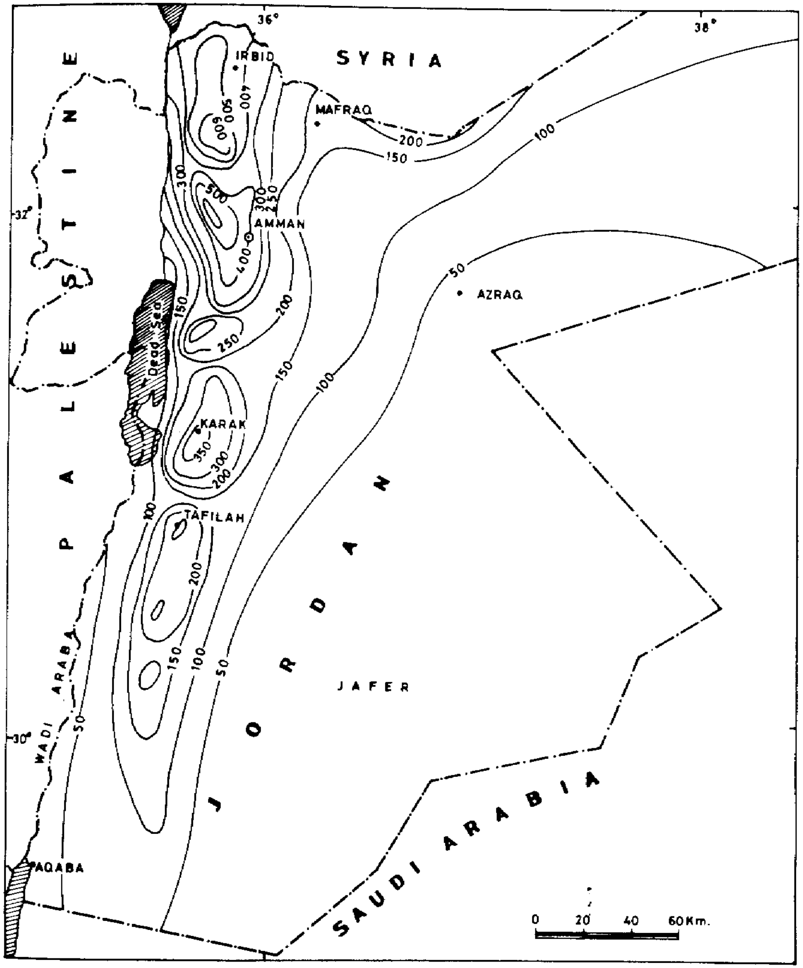

Fig. (2): Rainfall Distribution in Jordan mm/yr. (50-Years Average).

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.

The dry climate, the atmospheric dust and the low intensity of precipitation affects also the quality of precipitation water, generally reflected in increasing salt contents.

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 1600mm/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 receive.

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 rates are 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 content and hence, not allowing for the development of plants.

The high evaporation rates and the low precipitation amounts lead generally to salt concentrations of the water which increases the salinity of infiltrating, and in dam-stored water.

II

Water Resources

1. 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. Even this river is a very small 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 flood flow wadis in the different parts of the country (Fig. 3).

1.1 The Jordan River Area

1.1.1 Jordan River

The surface catchment area of the Jordan River measures 18.194 Km^2, of which 2833 Km^2 lie upstream of the Lake Tiberias outlet. The eastern catchment area, downstream of Tiberias, measures 13.027 Km^2, and the western, 2344 Km^2.

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. 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.

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.

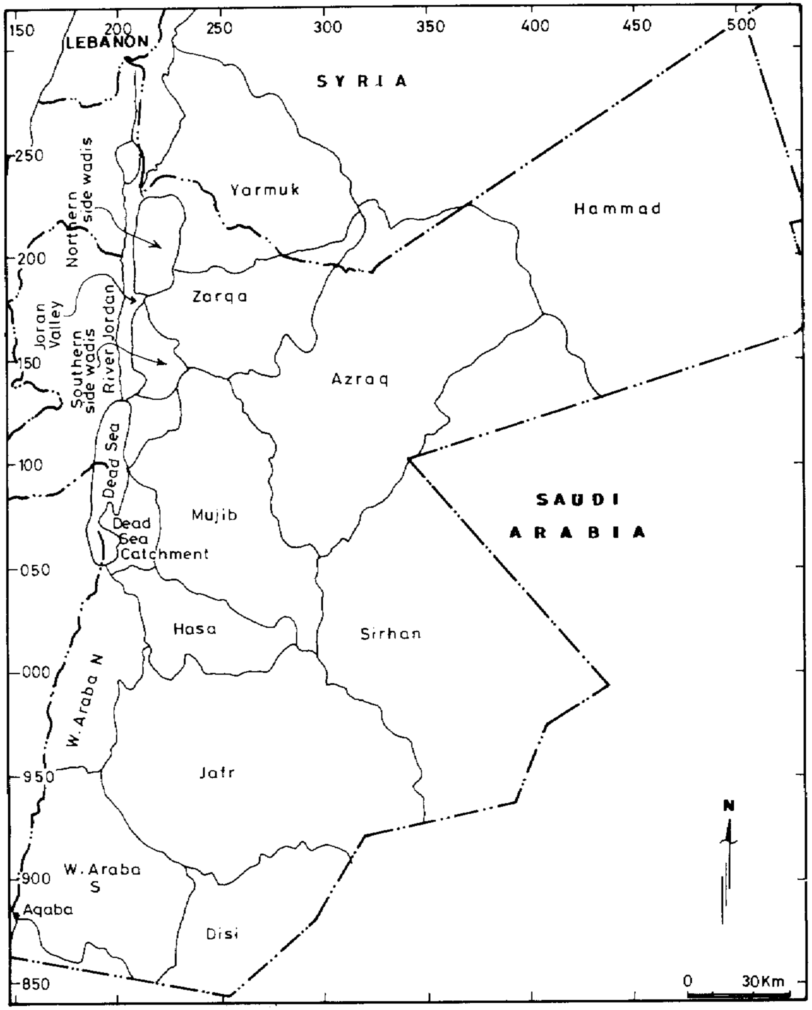

Fig. (3): Surface Water Catchments.

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 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.

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. 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.

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 waste water 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.

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. (1927-1964). 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 (Salameh 1993).

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.

1.3 Zerka River

This Zerka River is the second largest in Jordan in the area of its drainage basin and its mean annual discharge. The catchment area measures 4025 Km^2 and extends from the foothills of Jabel Druz to the Jordan River.

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 Zerka River. Naturally, the eastern branch drains only flood flows as a result of precipitation, whereas the western branch drains flood and base flows.

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 waste water 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 397mm/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 such as construction of 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 the 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 the 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 demand, effluents reaching the dam are expected to fill it almost yearly.

At present, the domestic and industrial waste water 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 waste water, the quality during floods remains acceptable for most uses.

1.1.4 Wadi El-Arab

The catchment area of Wadi El-Arab borders the Yarmouk catchment and measures $267km^2$.

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 waste water 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 ten years the drop in the ground water levels in Wadi El-Arab wells exceeded 25m -- 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.

1.1.5 Wadi Ziqlab

The catchment area of Wadi Ziqlab measures $106km^2$ and extends from the Jordan Valley eastwards into the highlands. Its eastern parts receive an average amount of precipitation of 500mm/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 5MCM/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 with 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.

1.1.6 Wadi Shueib

Wadi Shueib drains an area of approximately $180km^2$ lying to the west of Suweileh at elevations of 1200m down to below sea level. 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 3.9MCM/year as baseflow. In addition the effluent of the Salt town waste water 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 with 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 waste water treatment plant.

1.1.7 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. 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 Centre 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. It is now being raised to a capacity of 7 MCM.

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 waste water treatment plants.

1.1.8 Other wadis discharging into the Jordan Valley

These wadis are not dammed and include Yabis, Kufranja, Jurum, Rajib, Hisban and other small catchments.

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 2700mm/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.

1.2 Dead Sea Wadis

1.2.1 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. 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 2400mm/year in the west at the shores of the Dead Sea.

Zerka Ma'in discharges directly into the Dead Sea an average amount of 23MCM/year, of which only around 3 MCM/year as flood flows and 20MCM/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.

1.2.2 Wadi Mujib (including Hidan)

The catchment area of Wadi Mujib measures 6.596 km² and ranges in elevation from 1100m BSL. 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 100mm/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.

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.

1.2.3 Wadi El-Karak

The catchment area of Wadi El-Karak measures 190 km² and lies at elevations ranging from 1000m ASL to 400m BSL. 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.

1.2.4 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 catchment areas and 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.

1.2.5 Wadis between the major Dead Sea catchments

Different small areas between the major Dead Sea catchments discharge directly into the Dead Sea.
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.

1.3 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.

1.3.1 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 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 26MCM/year.

The flood flows which reach Wadi Araba infiltrate rapidly into the course-grained alluvium deposits 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 Tafilah 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 Tafilah 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).

1.3.2 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. 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.

1.4 Wadi Yutum Catchment

Wadi Yutum catchment drains an extensive area in southwest Jordan, east of Aqaba into the Red Sea. The extent of the catchment is 4.400 km². Precipitation over the area falls in the form of rainfall and ranges from 150mm/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.

1.5 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. 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 10MCM/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.

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.

1.6 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.

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 15MCM/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.

Few dispersed urban centers and industries are found in the catchment area.

1.7 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 19.270km.

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 10MCM/year.

2. Groundwater

2.1 Groundwater Aquifers

The groundwater aquifers of Jordan are divided into three main complexes, (Fig. 4).

Deep Sandstone Aquifer Complex.

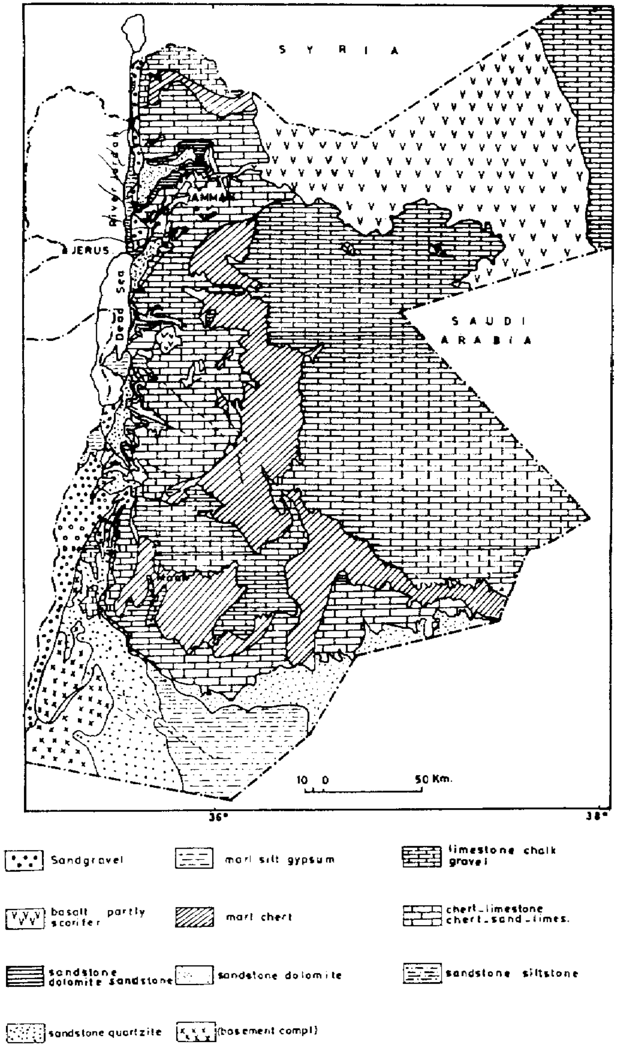

Fig (4): Surface extension of groundwater aquifer systems in Jordan (NWMP)

Upper Cretaceous Aquifer Complex.
Shallow Aquifer Complex.

2.1.1 Deep Sandstone Aquifer Complex

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-Mudawwara 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 Rum area separates a small southern region where the groundwater moves towards the west and south.

B. Kurnub and Zerka Group of Jurrassic-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 Zerka 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 - Zerka aquifer system is being exploited mainly in the lower Zerka 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 and Udluft, 1985).

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

2.1.2 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 A7-B2, 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.

2.1.3 Shallow Aquifers Hydraulic Complex

It consists of two main systems:

A. Basalt Aquifer:

Basalts extend from the Syrian Jabel Druz 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 Druz. From there the groundwater moves radially to all directions. Geological structures favored the formation of three main discharge zones namely, the upper Yarmouk River basin, the Wadi Zerka 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.

2. 2 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. 5) 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-Mudawwara:

1. Yarmouk basin.
2. Northern escarpment to the Jordan Valley.
3. Jordan Valley floor.
4. Zerka 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-Mudawwara.

2.2.1 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 B2/A7 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

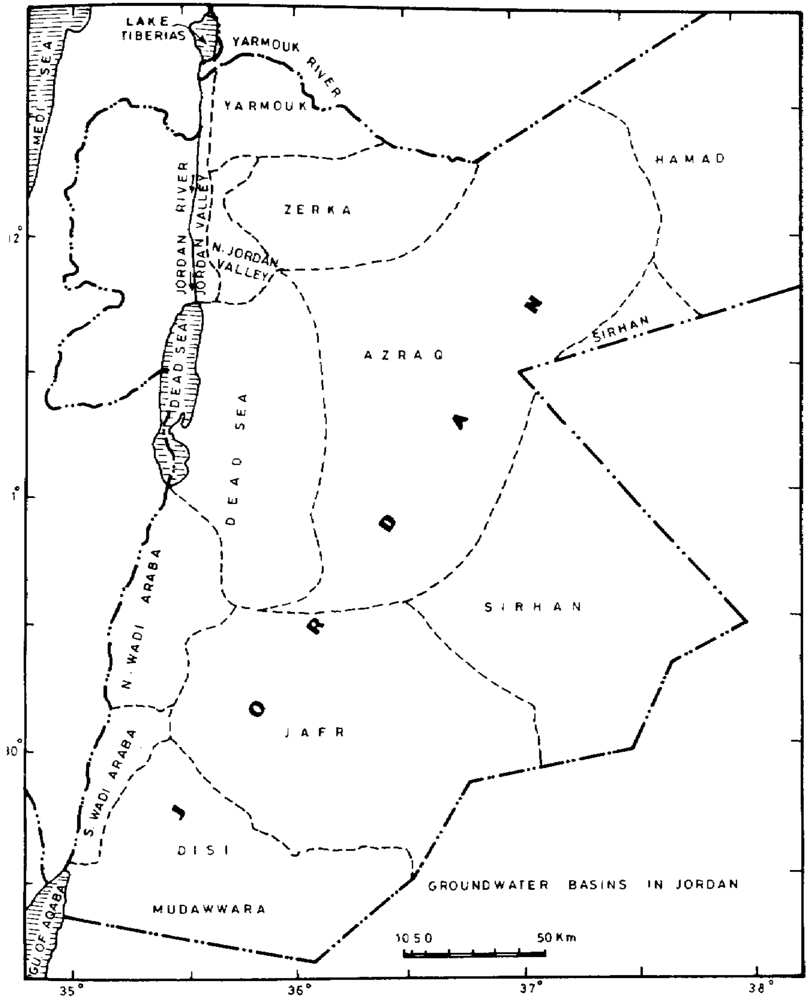

Fig. (5): Groundwater basins in Jordan.

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.

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 an 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 the different uses.

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 network.

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 Mukeiba and Wadi El-Arab wells make the water treatment essential to rid drinking water of this carcinogenic agent.

2.2.2 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.

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).

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.

2.2.3 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. 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 (Wadi Mallaha).

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.

2.2.4 Amman Zerka Area:

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

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 groundwater. Groundwater originating in the eastern part flows in a westerly direction, and that origination in the western highlands of Amman and its surroundings flows in an easterly direction. At the longitude of the Zerka River, in its south-north 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 networks and sewerage systems contribute also to the groundwater stock of the area.

Irrigation, industrial and domestic return flows contributions to the groundwater amount to about 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 65 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-Rusaifa 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 10 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 solidwastes 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. (See chapter on pollution).

2.2.5 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 groundwater 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.

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.

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 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.

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

2.2.6 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 250mm. 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. In addition, irrigation return flows are gradually leading to groundwater quality deterioration. The increasing salinity, phosphate and nitrate contents are some indicators of that.

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.

2.2.7 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, it 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.

The analyses of the Palm Forest Well 2 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 their high nitrate concentrations.

2.2.8 Disi-Mudawwara Area

The Disi-Mudawwara aquifer system crops out in south Jordan and extends southwards into Saudi Arabia and northwards in 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 shells 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 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 1.68×10^{-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: $1.68 \times 10^{-5} \times 1.43 \times 10^{-3} \times 40 \times 10^{3} \times 10^{3} \times 30.5 \times 10^{6} = 30.5$ 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. 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 in the long-term. But it is expected that irrigation in the area will lead to irrigation return flows infiltrating to the groundwater 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 level in the upper aquifers.

Extraction of water increased from 15 MCM/year in 1983 to 85 MCM/year in 1995. The total amount of extraction during this period was around 850 MCM, causing a nonrecoverable drawdown in water levels ranging from 3 to 20 meters. This nonrecoverable, irreversible decline is a major warning concerning the persistence of water resources.

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 850 MCM in the last few years caused a drop in water level amounting to more than 20 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 upgradient direction, and will ultimately cause a general drop in the water levels.

* There are indications that the water salinity has started to increase due to salt releases from the overlying Khreim confining unit.
* 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.

2.2.9 The Azraq Area

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 Tafilah. 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 Tafilah, from which precipitation water infiltrates into Upper Cretaceous 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, to a few tens of meters which has resulted in ceasing the discharge of Qaysiya, Soda and other springs feeding the oasis, and in increasing groundwater salinities.

The water of the basalt aquifer is of a very good quality for different uses.

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 a salinity of 1500 µs/cm.

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.

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.

The upper aquifer is now under heavy over exploitation with some 600 producing wells with dropping water levels by 10s of meters and rapidly rising salinities.

2.2.10 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 B2 A7 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.

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 salinization.

2.2.11 Sirhan and Hammad 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.

3. Patterns of Water Use

3.1 Water Use

3.1.1 Domestic Uses

A total of 216 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 150-250 l/c.d., to those of Israel of 280-300 l/c.d., to the Gulf States of 280-450 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 (Table 1). Concerning domestic water use, especially during summer, 85% of Jordanians live at the hygienic brink. Less water would mean public health detriments.

3.1.2 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 waste water 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.

Table (1): Water use, demand by sector (MCM/year) and population growth (million)

	Present Uses	Present demand 1995 120 l/c.d.
Domestic	216	314
Industrial	45	45
Irrigation	650	720*
Population		4.2 Million

3.1.3 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 waste water treatment plants and others. At present around 650 MCM/year, are used for agricultural purposes, part of which is fossil, non-renewable water. As a result of governmental and private sector development, the irrigated cropping area reached 61.000 hectars in 1994.

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.

3.1.4 Total Uses

The total water uses differ from year to year and depend on the available resources. In 1994, the total uses added up to about 910 MCM.

3.2 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, Karak 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/m³ 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 220 MCM/year (1995). 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.

3.3 Future Water Demand: (Table 2)

3.3.1 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 216 MCM/year; serving 4.2 (1995) million inhabitants, expected to increase to 4.7 and 6.8 million in the years 2000 and 2010 (Table 2).

If supply rates per capita remain as low as they are at present, and if the leaky network is not repaired and leakages stopped, 241 MCM/year and 350 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 the natural population growth for the years 2000 and 2010 are considered, and the leakages continue, Jordan will need 341 MCM/year and 493 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%.

* Increases are due to increasing waste water 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 (2): 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	341	341	350	493
Industrial	55	55	80	80
Irrigation	688*	756*	760*	860*
Population	4.7	4.7	6.8	6.8

In 1995 Jordan started to rehabilitate its leaky water network. If this rehabilitation continues and is completed by the year 2000, the domestic water demand will be as shown in the Table 3 below (allowing for system leakages of 20% instead of the present unaccounted for water of more than 50%).

Table (3): Domestic water demand and population by different per capita use after water network rehabilitation allowing for 20% unaccounted water of the supplied amounts.

	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 demand MCM/year	160	210	215	300

As a condition, to reach the above figures, domestic water uses for irrigating farms should be totally stopped, especially in certain areas such as in Ma'an and Mafraq governorates.

3.3.2 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 55 MCM and 80 MCM/year. The main increase is expected to be caused by the Dead Sea chemical industries and oil shale extraction and processing.

3.3.3 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.

III
Water Pollution

Two issues should be clearly and strictly separated from each other when considering the quality of a water source.

1. Natural water quality: water characteristics as affected by natural conditions.
2. Water quality as affected by human activities: changes on the original water qualities due to human activities of urbanization, industrialization, agriculture and building of structures.

For any type of water use the water quality issue is as vital as the water quantity or availability itself.

Any water source can have only a limited number of uses according to its quality. Most water resources can serve as sources of raw water, which can be treated and manufactured to serve uses demanding certain criteria of physical, chemical or biological characteristics.

One other fact is that any water, whatever quality it has, can be treated to produce water with certain characteristics required to serve specific objectives, but the cross-cutting problem in this case is the cost of treatment.

The principle objective is whenever and wherever possible to use water sources without putting much effort and expenses in treatment to achieve? at a desired quality for a certain use. Water treatment and purification are expensive issues and involve in many cases complicated technical processes, especially if the source experiences continuous quality changes. Water quality matters are highly affected by economic and financial issues. The questions are generally, how much finances can be afforded to make a water source usable for a certain use, what other alternative resources are available, and is it worth investing in that specific treatment? Such questions are valid for the original water qualities and their treatability.

The economic equations which describe and address pollution and changes in the original water quality of a source making it unsuitable for its original uses are more difficult to judge, because their reuse and impacts have social, environmental and health aspects; issues which cannot be easily quantified.

1. Natural Water Qualities

Naturally, some water sources cannot be used for a certain or all common uses (household, irrigation, or industrial), because their quality is impaired by one or more chemical constituents or biological content or physical property. This fact leads us to characterize the different water qualities at the source, under natural conditions (unaffected by human activities) according to their suitability for the common uses.

1.1 Precipitation

In the rift valley area where the amounts of precipitation range from 400mm/year in the north Yarmouk River, to 30 mm/year in the south, Aqaba. The EC of the water ranges from 40 to 500 µs/cm and the pH from 6.6 to 8.2. The pH values decrease with increasing precipitation amount and with the progress of time in each precipitation event.

The non-availability of enough acid-producing gases with pH values of less than 5.5, such as NO_x and SO_2, explain the relatively high pH values.

In the highlands extending from Irbid in the north to Ras-en-Naqab in the south the annual precipitation ranges from 250 to 650 mm/year. The EC of precipitation in this area ranges from 150 to 436 µs/cm and the pH from 6.39 to 8.8. For partial sampling of precipitation events the pH ranges from 4.85 to 9, where the 4.85 value was measured at the end of very heavy rains of cold western fronts. In Amman the lead concentration of 0.021 mg/l reflects the traffic density and the leaded fuel used in Jordan.

In the eastern plateau, the precipitation rates range from 250 mm/year to 30 mm/year. The EC of precipitation water ranges from 100 to 642 µs/cm and the pH value, from 6.5 to 8.8.

Generally, the precipitation water in Jordan has a pH value of more than 5.6: which is the biogenic pH value. This means that the country is not affected by any type of acid rain. The precipitation water contains high concentrations of dissolved substances as a result of dust in the atmosphere which also neutralizes any acidic, low pH gases.

In the rift valley area and on the plateau both the salt contents and the pH values of precipitation are higher than those of the highlands.

This indicates that even precipitation water in Jordan as a semi arid country contains higher salt contents which are then reflected in higher salinities of surface and groundwater resources.

Pollution in precipitation water is only found in Amman, (traffic), in Zerka (industry), in Hashimiya (refinery and thermal power station), in Fuheis (cement factory, dust), in Hasa (phosphate dust).

1.2 Floodflows

All over the country floodwaters, which have generally only short contact times with the country rocks, contain small concentrations of chemical components, their physical properties; pH-values, temperatures, dissolved oxygen and electric conductivities and their biological contents indicate natural conditions. Therefore, they can be used for all common uses with very minor treatment aiming at turbidity settlement and eventual chlorination as a precaution measure in the case of household uses.

Table (4 a,b) shows the characteristics of flood flows in wadis in the different parts of the country.

The floodwater salinities expressed in EC units range from 123 to 530 µs/cm, depending on a variety of factors such as precipitation water quality, rock and soil types covering the catchment areas, their topographic features, rainfall, ground surface temperatures, and land use.

All the parameters listed in Table (4) indicate a water quality allowing use for all common purposes, household industry and irrigation without any restrictions except filtration to remove the suspended load and chlorination as a precautionary measure for household uses.

1.3 Baseflows and Groundwater

The baseflow of a water course consists of spring discharges and other seepages within the catchment area of that water course. Hence, its characteristics reflect, to a certain degree, the qualities of the groundwater underlying the drainage area.

Table (4a): Floodflow composition along wadis in Jordan

Parameter	Yarmouk River	Yabis	Kufranja	Abdoun Ras El-Ain	Zerka River Jarash Br.	Hisban	Zerka Ma'in	Mujib	Karak	Hasa
EC µs/cm	530	430	307	160	392	235	182	183	165	301
pH	7.91	8.37	8.05	8.42	8.01	7.97	8.36	7.78	7.98	8.38
Ca meq/l	1.9	2.87	2.46	1.6	2.36	1.58	1.00	1.02	1.16	1.60
Mg "	1.4	1.43	0.59	0.2	0.32	0.29	0.40	0.42	1.57	0.20
Na "	1.70	0.95	1.03	0.29	1.22	0.53	0.59	0.58	1.12	1.02
K "	0.15	0.17	0.41	0.08	0.16	0.10	0.13	0.10	0.22	0.09
Cl "	1.58	1.10	0.4	0.25	1.20	0.50	0.23	0.27	0.78	0.39
SO_4 "	0.85	0.84	0.63	0.41	0.74	0.16	0.13	0.16	1.04	2.04
HCO_3 "	2.97	2.91	2.99	1.42	2.04	1.72	1.73	1.82	2.66	2.04
NO_3 mg/l	18.5	18.2	13.4	5.3	18.0	9.2	4.80	5.8	4.2	6.6
PO_4 "	0.73	0.12	1.37	0.55	0.53	0.38	0.84	0.252	0.24	0.87

Table (4b): Floodflow composition along the plateau wadis

Parameter	Daba	Qastal	Zizya	Rweished	Safawi	Khalidiya	Mafraq	Muwaqqar	Azraq	Yutum	Shidiya
EC µs/cm	123	212	233	229	218	291	220	186	214	135	130
pH	8.55	8.53	8.55	8.25	8.43	7.76	7.8	8.48	7.7	8.21	8.27
Ca meq/l	1.2	1.53	1.73	1.9	1.28	1.8	0.59	1.1	1.18	0.74	1.30
Mg "	0.4	0.69	0.72	0.4	0.19	0.26	0.45	0.2	0.20	0.13	0.35
Na "	0.27	0.92	0.41	0.31	0.75	0.92	1.08	0.93	0.94	0.25	0.62
K "	0.22	0.05	0.05	0.09	0.05	0.18	0.13	0.11	0.13	0.01	0.16
Cl "	0.15	0.4	0.60	0.4	0.35	0.22	0.2	0.23	0.4	0.35	0.60
SO_4 "	0.35	0.39	0.94	0.41	0.24	0.2	0.23	0.25	0.34	0.10	0.38
HCO_3 "	1.55	1.82	1.46	1.91	1.35	2.45	1.57	1.94	1.65	0.76	1.52
NO_3 mg/l	0.54	10.2	13.8	2.1	4.2	4.8	16.2	6.8	7.2	2.4	3.2
PO_4 "	2.8	0.92	0.62	0.16	0.09	0.96	0.61	0.72	0.81	0.00	0.62

According to their quality characteristics different groups of base flows are found in Jordan.

Group I: baseflows and groundwater suitable for all common uses.

Such groundwaters are discharged from springs all over the country generally at elevations of 100m ASL and higher. The water flows then along the different wadis in the area extending from the Yarmouk in the north to Ras-en-Naqab in the south. Recharge by precipitation and floodwater takes place along the highlands extending from Irbid area to Ras-en-Naqab area with an east-west extension of 20-30km. The recharged water discharges along the slopes overlooking the rift valley and along the wadis draining completely or partly to the east.

All springs along the Yarmouk River, Wadi El-Arab, Ziqlab, Kufranja, Rajib, Yabis, Zerka River, upstream of King Talal Dam, Shueib Dam, Kafrain Dam and Hisban diversion dam, Udheimi, Zerka Ma'in, Shqiq, Mujib, Wala, Hasa upstream of the thermal spring discharges, Tafilah, Shoubak, Finan and Gharandal discharge a base flow with a natural quality suitable for all common uses.

Wadis and wadi systems draining completely or only their upper reaches eastward such as Zerka, Mujib, Jafr, Wala, Shallala, and those springs of Azraq discharge or they formerly discharged water with a quality compatible with all common uses.

Table (5) shows some examples of spring and baseflow discharges of waters suitable for all common uses. Generally, the EC is less than 1500 µS/cm, none of the other parameters has a higher concentration than recommended by the WHO or by Jordanian standards for drinking water. Slightly elevated nitrate, calcium, chloride and phosphate concentrations indicate some type of domestic pollution.

Group 2: Water with high salinities and or high temperatures

Such waters are found naturally in Jordan. According to their salinities and other properties such as temperature, pH, presence of certain gases (carbon dioxide, radon, hydrogen sulfide) or certain elements at a high concentration, e.g., iron, manganese and others, these waters are differentiated into several subgroups:

Table (5): Spring and baseflow discharges along the upper reaches of wadis, unaffected or very slightly affected by domestic type of pollution

Parameter	Yarmouk River	W. El-Arab	W. Ziqlab	W. Yabis	Ras El-Ain* Zerka R.	Zerka Ma'in**	Hisban	Bahhath	Mujib	Karak	Hasa
EC µs/cm	980	820	665	844	780	618	540	530	712	784	1424
pH	8.15	7.8	7.72	8.57	7.7	7.3	7.50	7.45	8.40	7.97	8.49
Ca meq/l	3.06	5.0	2.9	2.66	5.02	3.9	3.66	2.97	3.50	1.96	3.35
Mg "	2.56	2.6	2.6	2.56	0.75	1.7	2.08	1.29	2.10	1.68	5.71
Na "	4.10	2.28	1.13	3.60	1.22	1.00	0.76	0.67	2.40	4.1	5.52
K "	0.17	0.10	0.02	0.10	0.10	0.04	0.05	0.04	0.18	0.24	0.13
Cl "	3.10	2.15	6.65	2.7	1.87	1.72	0.98	1.23	2.08	3.85	6.0
SO_4 "	1.64	1.6	0.57	1.75	0.12	0.6	0.23	0.19	1.23	1.84	2.65
HCO_3 "	4.38	5.11	4.2	3.60	6.01	3.52	4.79	3.06	3.78	1.96	4.72
NO_3 mg/l	23	21	12	11.8	20	28	24	27	15.0	13.5	11
PO_4 "	0.35	0.38	0.11	0.17	0.32	0.17	0.27	0.03	0.025	0.86	0.016

* Ras El-Ain/Zerka River 1964
** Zerka Mai'n Upper Reaches

a. **Waters with high salinities**

Examples of that are the discharges of the Jordan River, Wadi Mallaha. Azraq area, and generally, the deep groundwater in the country. These waters`. according to their salinities, have only a limited range of uses. If their salinity is low enough, 1500 μs/cm up to 4000 μs/cm, they can be used to irrigate salt semi-tolerant or tolerant crops. But, if their salinities are higher, then they cannot even be used for those purposes. Nonetheless, they can serve as a source of raw water to be desalinated or mixed with fresh water to be used for different purposes.

Table (6) shows the examples of the composition of such water.

The salinity of brackish and saline water ranges from the upper limit of fresh water salinity of ca. 1500 μs/cm up to 18000 μs/cm in Wadi Mallaha. The major constituents such as Ca, Mg, Na, Cl, and SO_4 are the main parameters contributing to salinity.

In Wadi Mallaha and Karameh Society well, both in the Jordan Valley, and in Sumaya Spring (Zerka River), irrigation return flows or domestic type of pollution or both can be concluded from the higher nitrate contents.

This type of water can partly be used to irrigate salt-tolerant crops, or it can be mixed with fresh water for general irrigation purposes, or it can serve as a source of raw water for desalination.

b. **Water with high salinity and elevated temperature**

This type of water results from deep percolation of infiltration water and from very long contact times with the aquifer matrix, undergoing oxidation/reduction processes.

Such water, due to its temperature of more than 5°C above the ambient temperature can be classified as curative water. It is generally found along the slopes overlooking the rift valley.

Examples of this type of water are the springs of Zerka Ma'in, Zara, Mujib, Deir-Allah, Abu Thableh and the wells of Hisban, and Abu Ziad.

Table (6): Chemical analyses of waters with high salinities in the different parts of the country

Parameter	Jordan River*	Wadi Mallaha	Wadi Araba UM-3	Sumaya Spring Zerka River	Omari Well 2 Azraq	Jafr Well 17	Reasheh No. 2 Hamad	Karameh Society J. Valley
EC μs/cm	8810	18100	5300	2250	2430	5790	4330	4100
pH	8.26	7.62	6.63	7.00	8.0	7.8	7.4	7.4
Ca meq/l	28.10	34.0	13.03	5.81	7.15	16.7	12.05	9.1
Mg "	12.28	50.0	9.19	8.28	7.75	17.5	14.0	13.0
Na "	42.7	117.2	16.12	9.70	9.48	23.69	20.17	17.70
K "	2.39	5.54	0.21	0.36	0.3	0.5	0.3	0.55
Cl "	73.75	147	29.84	14.39	12.57	46.86	19.68	31.94
SO_4 "	6.94	59.6	4.255	3.08	7.85	8.10	26.67	3.40
HCO_3 "	4.02	3.96	1.0	5.02	3.75	3.32	7.13	4.20
NO_3 mg/l	24	60	6.5	75	3.5	20	2.1	42

* Jordan River, King Hussein Bridge. Dry Season.

Table (7) gives the composition of such waters and some of their therapeutic agents.

Generally, these waters have salinities of more than 1500 µs/cm, a temperature of more than 33°C. Gases such as CO_2, H_2S and radon are discharged with the water.

These characteristics and composition allow the water to be classified as thermal-mineralized water with therapeutic properties.

This type of water can easily serve as a raw water source to be mixed with fresh water for the various uses or for desalination. Due to its high discharge temperature it could also be used for heating homes and green houses during the cold season.

c. **Water with low salinity and high temperatures**

Thermal water discharges are not restricted to saline or brackish springs. Many springs along the slopes overlooking the rift valley discharge fresh thermal water. The temperature may reach more than 50°C, but the salinity remains less than 1500 µs/cm.

Such water presents a soūrce for all common uses after some cooling and areation. Table (8) shows the composition of thermal water springs and wells with low salinities.

Radon and H_2S gases can easily be removed by areation, which makes the water potable.

In summary the natural water resources quality can be described as follows:

1. All floodwater resources in Jordan have qualities which allow them to be used for all common purposes. For domestic and certain industrial uses they may require filtration to remove silt particles and chlorination as a precautionary measure.

2. All renewable water resources (in their natural states) along the highlands and on the plateau are also suitable from a qualitative point of view for all common uses.

Table (7): Composition of the thermal water with high salinity

Parameter	Zerka Ma'in Shallala	Zara Sp. 40	Hisban Thermal Well	Deir-'Alla Spring	Abu Thaleb Spring	Abu Ziad Well
EC µs/cm	3050	1786	4190	3440	1928	2300
pH	6.8	6.3	6.37	6.5	6.82	6.9
Ca meq/l	7.39	4.58	11.84	12.5	7.6	7.25
Mg "	2.82	1.90	8.87	8.81	4.3	4.17
Na "	14.13	7.86	29.02	13.61	7.74	10.96
K "	1.30	0.63	2.40	0.75	0.38	0.40
Cl "	19.07	9.26	28.05	18.45	9.30	11.71
SO_4 "	4.31	2.77	7.37	12.10	4.03	4.4
HCO_3 "	3.00	2.84	13.10	6.58	7.65	6.33
NO_3 mg/l	0.00	0.00	2.5	0.0	0.00	0.02
T c°	55.0	53.5	33	36	36.8	50.2
Rn nci/l	14.25	25.5	4.3	1.7	15.65	17.3
H_2S mg/l	0.18	0.04	smell	smell	smell	0.5

Table (8): Composition of thermal water with low salinities

Parameter	Afra Springs	Weidaa Spring	Ibn Hammad Upper	Himma Spring Yarmouk River	North Shuna Therm. Spring	Manshiya Well 2
EC µs/cm	545	610	847	1320	863	735
pH	6.96	6.5	6.8	6.98	7.06	6.34
Ca meq/l	2.17	3.80	4.2	6.21	4.08	3.4
Mg "	1.40	1.21	2.42	2.7	3.66	3.25
Na "	1.48	1.68	2.57	5.87	3.31	0.91
K "	0.02	0.21	0.10	0.44	0.21	0.06
Cl "	1.68	2.48	4.51	6.03	2.81	1.03
SO_4 "	1.35	1.77	2.44	3.45	1.76	0.90
HCO_3 "	1.98	3.00	3.05	5.54	6.38	7.33
NO_3 mg/l	0.00	0.0	0.0	3.10	1.24	0.0
T C°	45.9	33	37	41.4	52.7	54.3
Rn nci/l	7.38	2.86	5.9	31.46	2	16.5
H_2S	0.0	0.0	0.0	2.8	5.83	0.2

3. The natural groundwater qualities in the intermediate and deep aquifers with a free water table are suitable for all common uses, without any treatment except chlorination as a precautionary measure.

4. The natural groundwater qualities in the Jordan Valley are also suitable for all common uses except when they are in contact with the salty deposits in the valley, especially the Lisan Formation.

5. The confined deep aquifer and the confined B2/A7 and A4 portions contain water with high salt concentrations, CO_2, H_2S and radon gases and have temperatures exceeding the ambient temperature by more than 5°C reaching a maximum of 64°C. Hence, this water is generally not suitable for common uses, except after treatment which may incorporate desalination.

6. The slowly rechargeable aquifers of northeast Jordan, Sirhan, Hamad, and Azraq basins contain generally high salt concentrations; 1500 to 5000 µs/cm which classifies them as brackish water. They are only conditionally suitable for the common uses after certain treatment.

2. Water Quality as Affected by Human Activities

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.

Pollution Sources:

For the case of Jordan, Table (9) 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 and industrialization demanded an increase in water supplies, which produced increasing amounts of waste water, 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.

Table (9): Water Pollution in Jordan
(major producers, sites, affected environmental element)

POLLUTION PRODUCER	WASTE WATER TREATMENT PLANTS	CESSPOOLS	INDUSTRIAL WASTES	IRRIGATION RETURN FLOWS	PESTICIDES INSECTICIDES	SOLID WASTE DISPOSAL SITES	SALT WATER INTRUSIONS & MOBILIZATION	OVERPUMPING & OVER-EXPLOITATION
Site	Khirbet es-Samra, Mafraq, Ramtha, Baqaa, Irbid, Jerash, Kerak, Salt, Tafila, Aqaba, Madaba	Irbid, Azraq, Zerka, Ruseifa, Hartha	Amman, Zerka, Ruseifa, Baqaa, Mafraq	Jordan Valley, Dhuleil, Azraq, Shoubak, Aqib, Disi	Jordan Valley, Azraq, Dhuleil, Aqib, Shoubak	Se-Amman, Ukheider, Salt, Madaba	Azraq, Mudawwara, Jafr	Azraq, Dhuleil, Shoubak, N-Badia, Disi, Aqib, Jafr
Affected Environmental Element	Surface Water Groundwater	Groundwater	Surface Water & Groundwater	Groundwater & Soils	Groundwater	Groundwater & Surface Water	Groundwater	Groundwater

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

2.1 Domestic Wastes

* The wastes produced in households consist of waste water, solidwastes and gases emitted into the atmosphere. In Jordan, the two main waste types which result in water pollution are waste water and solidwastes.

Domestic waste water

The waste water of households is disposed of in two ways:

* Cesspools and septic tanks.
* Collection via sewerage systems and treatment in waste water treatment plants.

Each of them has its impacts on the local surface and groundwater resources.

Human sewage contains organisms that cause a variety of diseases such as cholera, typhoid, dysentery. It also has relatively higher concentrations of nitrates, phosphates and higher salinity than the supply waters. If not handled properly it leads to diseases and eventual death, it contaminates surface and groundwater resources, produces odour and may pollute soils, threaten the health of cattle and contaminate crops. Therefore, it represents a significant problem for all communities and countries, because abating their impacts requires relatively large investments, know-how and safe reuse schemes.

Generally, waste water contains higher dissolved salt concentrations than those used to supply water. The increases in salt contents result from use, evaporation and addition of chemicals and are a function of the per capita water consumption. The less it is the higher the concentration of salts. Waste water treatment can remove a variety of pollutants and substances but salts can only be removed by very expensive techniques, such as desalination. Hence, they are not removed from the waste water during treatment.

Crops grown in Jordan; vegetables and fruit trees produce the largest yields per unit of land if the salinity of the water is less than 1200 µs/cm. If salinity increases beyond that, the result is a reduction in crops. Therefore, the use of treated waste water may result in crop reductions and productivity declines (Fig. 6).

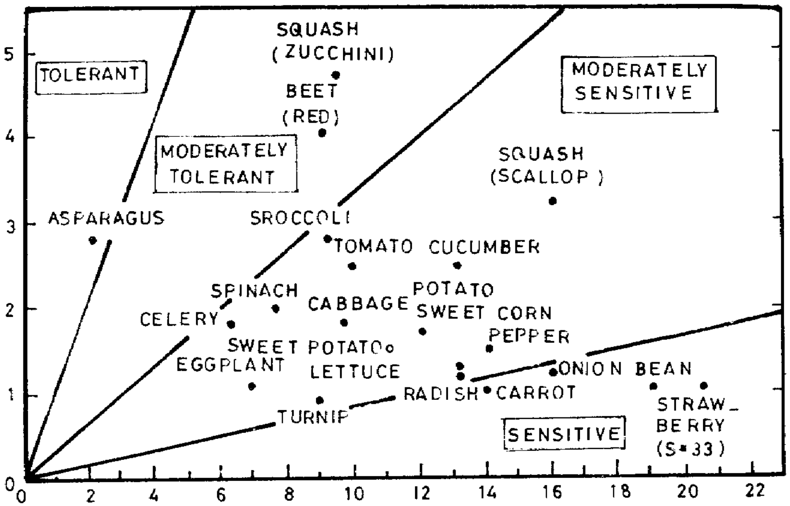

Fig. (6) Rate of Yield Reduction (S), % Per ms/cm (After Shalhevet) Baqa'a area

2.1.1 Cesspools

Many towns, villages, settlements, higher education centers, military camps... etc. are still not connected to sewerage systems and waste water treatment plants. Even in sewered towns there are households still using cesspools. In addition sewere pipes are not totally tight, therefore, untreated waste water leaks from them.

Generally, cesspools are not designed to hold the waste water to be trucked later on to a waste water treatment plant. The bottoms and walls of cesspools are normally permeable, especially in those types of rocks generally found in the highlands, such as karstic limestones, fractured cherts and silicified limestones, sandstones or disintegrated shales.

These conditions allow the infiltrated sewage water to reach the underlying water bodies, especially those phreatic ones.

In the following, examples of local pollution caused by infiltrating waste waters are given.

a. Amman area

Although Amman possesses a sewerage system and a sewage treatment plant, some of its outskirts still lack the connection to a waste water treatment plant. In addition, sewerage pipes are not very tight, therefore they leak into the surrounding soils and rocks. The city is built on limestone, cherts and silicified limestone, all of them highly permeable and build aquifers in the area. The waste water collected in cesspools and that which leaks from the sewers infiltrate into the rocks and reach the groundwater bodies resulting in their pollution. Examples of that are Ras-el-Ain and Rusaifa springs. The pollution of waste water is reflected in the nitrate contents of the springs of 72 and 60 mg/l (Table 10) compared to a natural concentration in such phreatic aquifers of 15-20 mg/l. Already in 1966 Ras-el-Ain spring had a nitrate concentration of 30 mg/l, almost double the natural concentration. The rapid increases in the concentrations of sodium and chlorides indicate also the effects of waste water. Worthmentioning here is that, in the upgradient areas of these spring, industrial and irrigation activities are absent, which excludes them as causing the pollution.

b. Zerka-Marka area

Also this area possesses a sewerage system and numerous industrial waste water treatment plants. The rocks underlying the area consist of cherts, phosphates, limestones, all of them are permeable and form the areas' aquifers. Leaky cesspools and sewers resulted also in increases in salinity, sodium, chloride and especially nitrate concentrations.

The EC original values ranged formerly from 500-700 µs/cm, now they are two to two and a half fold of that value. The strong increase is in the nitrate

Table (10): Examples on the pollution resulting from domestic waste water infiltration from cesspools and sewer systems into the aquifers

Well or Spring name	Amman Ras-El-Ain Spring		Rusaifa Spring	Pepsi Well	Zerka Munici Well	Baqa'a El-Shami Ibr.		Naur Sp.	Karak Sara Sp	Salt Jadour Sp.	Irbid Kufr Assad Well	Irbid Nuaymeh Mun. Well		Hertha Um Irshed Spr.
	1966	1995	1995	1995	1995	1981	1995	1995	1995	1995	1995	1975	1995	1996
EC µs/cm	520	950	915	1120	1780	600	740	1160	706	830	1350	590	630	770
Ca meq/l	3.71	5.95	2.5	5.4	5.2	3.4	4.0	6.26	3.8	4.51	8.80	3.2	3.5	4.65
Mg "	1.15	1.45	1.7	1.75	1.25	1.9	2.13	1.94	1.40	2.21	2.55	1.9	2.0	2.41
Na "	0.3	2.09	2.47	3.70	8.70	1.13	1.12	3.1	1.75	1.81	2.95	0.91	0.91	2.1
K "	0.06	0.12	0.10	0.10	0.12	0.1	0.19	0.26	0.5	0.61	0.15	0.04	0.06	2.23
Cl "	0.67	2.54	3.84	4.0	9.83	1.16	1.30	3.49	0.5	1.65	3.22	0.89	1.19	3.29
SO_4 "	0.75	0.52	0.42	0.37	3.02	0.71	0.65	0.46	0.52	1.21	3.80	0.14	0.18	1.07
HCO_3 "	4.22	5.4	1.82	4.54	5.02	4.42	4.20	5.5	3.70	4.62	6.20	4.57	4.57	3.77
NO_3 mg/l	30	72	60	58	67	13	78	87	55	94	70	20	48	198

content; 3-4 times of the natural concentration. Zerka Municipality well can only be safely used for municipal supply after mixing with better quality water to lessen its salt content and nitrate concentration to cope with the Jordanian drinking water guidelines.

Baqa'a Refugee Camp and the surrounding villages possess a sewerage system and a waste water treatment plant. But many houses constructed on the surrounding mountains possess only cesspools. The aquifer underlying the area is the Kurnub Sandstone, which is phreatic with a water table of up to 100 m below ground level. The surrounding mountains are built of highly fractured disintegrated limestones and shales which allow infiltration into the underlying sandstone aquifer. Therefore, infiltrating sewage water reaches the groundwater body and pollutes it. An example on that is El-Shami Ibrahim well originally (1981) with a nitrate concentration of 13 mg/l and EC value of 600 µs/cm increasing to 78 mg/l and 740 µs/cm in 1995. The six fold increase in the nitrate concentration compared to the very slight increase in salinity indicate at sewage type of pollution. The further surroundings of the well area especially its upgradient parts are devoid of any major industry or agricultural activity, hence excluding these as sources of pollution.

The highland towns; Naur, Karak, Salt, Irbid and Hartha.

Karak, Salt and parts of Irbid possess sewerage systems and waste water treatment plants. Nevertheless, cesspools and leaky sewers still leak through the karstic aquifers building up the highlands to the groundwater bodies. Limestones, silicified limestones, cherts and shales are the surface rocks underlying these towns. In Salt, Karak and Hartha the limestones of the Upper Cretaceous and Lower Tertiary are highly karstified. Cesspool contents of waste water infiltrate rapidly to the groundwater bodies. Some of the cesspools especially in Hartha area are not able to hold any water.

The original water quality in all these areas showed EC values of 500-700 µs/cm and nitrate contents of 15-20 mg/l. Table (10) shows the moderate increases in the EC valves compared to 3-10 - fold increases in the nitrate contents. These areas are devoid of any major industry or intensive agricultural activity. Hence, pollution is related to household types of waste water.

2.1.2 Waste Water Treatment

Introduction to Waste Water Treatment (WWT)

The need for waste water treatment

Waste water 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 sludge. 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 groundwater.

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 waste water 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 waste water in agriculture. To meet this end, several waste water treatment plants were constructed to treat sewage from major cities in Jordan. It has been estimated that some 60 million m^3/year of water could be retrieved from sewage treatment plants, and these are enough to cultivate at least around 120,000 dunums with alfalfa and various trees such as olive and apple.

If proper and efficient treatment of waste water could be achieved, the effluent -- rich in nutrients -- would even be suitable for aqua culture.

Methods of waste water treatment

Various methods for waste water treatment have been developed over the past decades. 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.

Conventional waste water 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.

Less conventional methods of waste water 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 rotors 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).

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.

* Anaerobic ponds:
They are relatively deep ponds, 2 - 5m, 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.

* 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 pond bacteria.

* 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 mg/l, 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.

The first WWTP was constructed in Jordan in 1945 to serve the town of Salt, where cesspits were the form of waste water 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 abandoned, 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 (Fig. 7).

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.

In 1985 waste water stabilization ponds were introduced into Jordan, Khirbet-es-Samra was constructed around 35 km northeast of Amman to serve Amman, Rusaifa and Zerka cities.

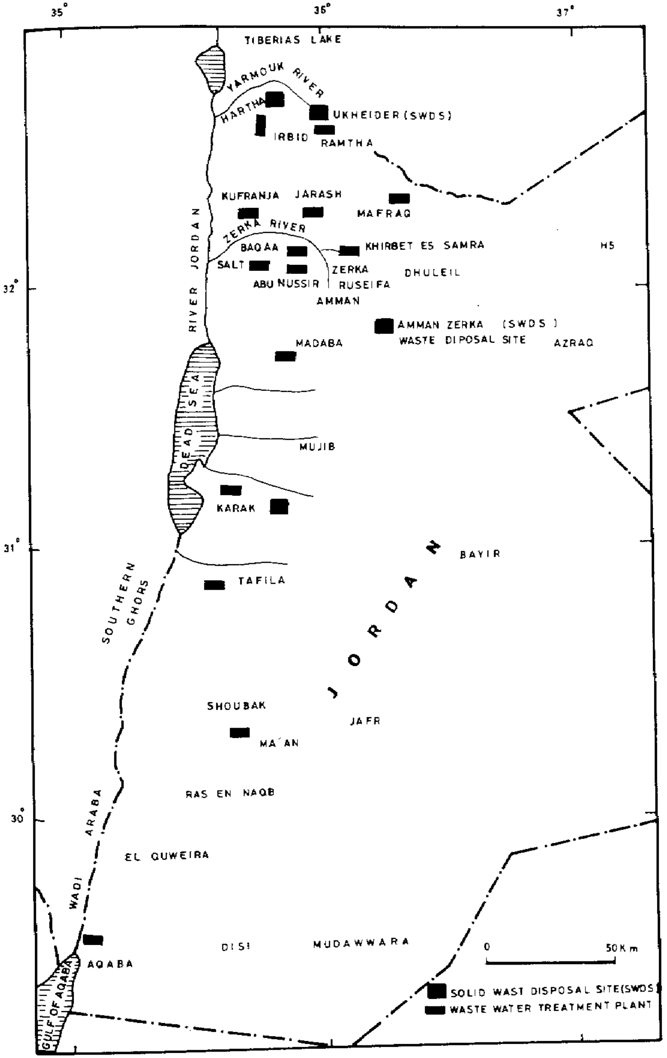

Fig. (7): **Location sites of solidwaste disposal sites and wastewater treatment plants**

2.1.2.1 Amman - Zerka Area, Khirbet-es-Samra WWTP

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 infrastructure, especially on water consumption and waste water disposal.

Prior to 1969, cesspools and septic tanks provided the sole waste water disposal option in Amman. Such a practice resulted in groundwater 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 waste water treatment plant. Accordingly, in 1969 the Ain Ghazal treatment plant (AGTP) was completed to handle waste water 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/day in 1979 to 50,000 m^3/day in 1985.

By 1980, although the average inflow was well below design capacity at only 19,300 m^3/day, the high influent BOD concentration of 960 mg/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 Zerka River Basin. This would provide treatment for the waste water from the cities of Amman, Zerka and Rusaifa (Fig. 8); 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.

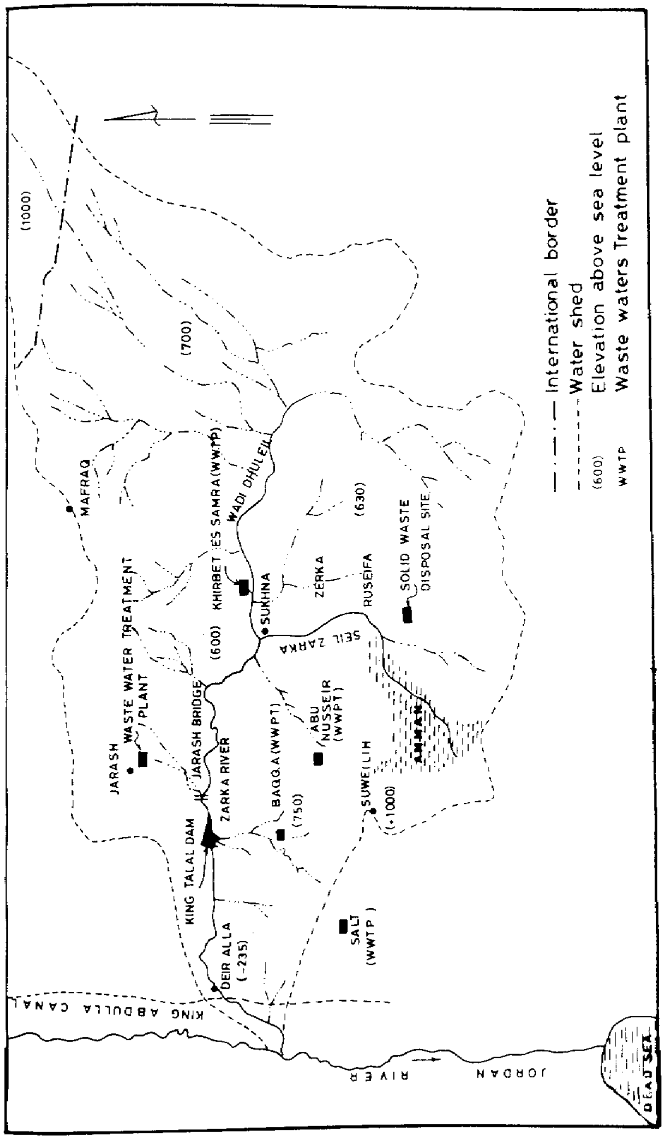

Fig. (8): Location of Khirbet-es-Samra Waste Water Treatment Plant.

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

A pipeline conveying the waste water 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 668 m above sea level and WSP at 580 m above sea level. The pipeline is an inverted siphon with it's lowest point at an elevation of 460 m above sea level. The pressure at this point is approximately 25 bars.

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 2010:

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/l

The Jordanian health authorities require a residual free chlorine of 2 mg/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.

The flow into Khirbet-es-Samra (KS) exceeded 73,000 cu.m/d in 1987, with a BOD5 loading of more than 730 mg/l. In 1995, 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 11).

Table (11): Khirbet-es-Samra waste water treatment plant, in flow and out flow (1995) - concentration of pollution and salinity indicators

		Year's average	Month's average	
			Minimum	Maximum
In flow	m^3/d	143440	135000	153100
Out flow	"	120260	110600	133200
TDS in	mg/l	1100	616	1252
out	"	1220	974	1438
TSS in	"	422	298	682
out	"	126	62	167
BOD5 in	"	609	308	706
out	"	144	56	229
COD in	"	1260	970	1545
out	"	356	273	439
NH_4 in	"	68	40	86
out	"	80	39	93

From this table it can be concluded that the plant is severely overloaded and would in no way withstand the projected loads for the year 2010. 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 in 1995 around 144 mg/l, which was much higher than the 30 mg/l value set by the guidelines. Suspend solids in the effluent were above 126 mg/l, again more than two-fold the value of 50 mg/l set by the guidelines. COD leaving the plant exceeded 356 mg/l. The number of faecal coliforms leaving the plant varied between very high, tens of thousand/100 ml and 1000/100 ml, depending on the extent and effectiveness of chlorination taking place at the outlet of the pond system. The values of TOC, PO_4 and NH_4 were also high in the effluent, which shows that treatment at KS is incomplete. The fact that NH_4 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 Zerka some 12 km downstream of KS plant, it can be seen that there are some increases in these pollutants, Table (12).

Table (12): Concentration of pollutants at KS outlet and 12 km downstream (1995)

Parameter		Annual Average KS outlet	Concentration at 12 km downstream
BOD5	mg/l	144	60
COD	"	356	294
TOC	"	128	115
TSS	"	126	125
Total Coliform count/100 ml		40000000	15000

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 undergroundwater. Consequently, the water table has risen some 20 m in the immediate surrounding of KS, as a result of the formation of this recharge mouth (KS). This rise dies off gradually in a radial way. The groundwater quality along Seel el-Zerka 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 undergroundwater flow and thus negatively affect the entire Zerka area, Khaou, el-Sukhneh and the area along Seel el-Zerka (Fig. 9). Organic amounts have greatly increased along the Zerka River course, and the amount of oxygen has decreased until the Jerash bridge.

The groundwater quality along Seel el-Zerka 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 gradually deteriorated, to an extent that it is no longer suitable for unrestricted irrigation.

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

Comparison of the quality of groundwater in Zerka area with that of Wadi Dhuleil is shown in Table (13). 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.

Some 2 km 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 1985 - 1986, the well water was used for domestic purposes and to irrigate around 40ha 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 19 m after the operation of KS plant; which was higher than any historic level for this well.

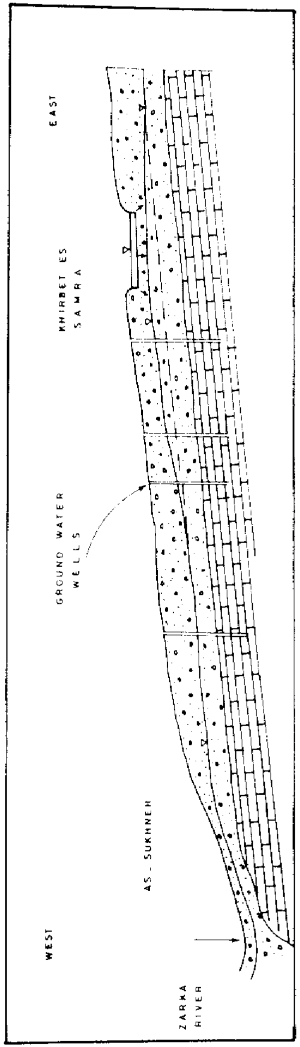

Fig. (9): Groundwater flow in Khirbet-es-Samra area.

Table (13): Average chemical parameter values for groundwater in Wadi Dhuleil and Zerka areas

Parameter		Zerka area	Wadi Dhuleil Area	
			Prior to 1985	Post 1985
EC	µs/cm	1700	1706	3359
pH	-	7.25	7.56	7.34
Ca	meq/l	5.55	6.08	11.15
Mg	"	3.9	4.64	10.04
Na	"	7.57	6.74	14.13
K	"	0.157	0.163	0.22
HCO_3	"	4.35	3.5	3.08
SO_4	"	2.2	4.67	7.34
Cl	"	9.66	9.2	21.88
Br	mg/l	3.303		8.51
I	"	1.141		3.02
PO_4	"	0.266		0.38
TOC	"	4.86		7.82
COD	"	2.46		16.19

Table (14) shows a comparison of well water qualities for 4 wells, two lying upgradient of Khirbet-es-Samra Moasher E.2 and DP 17 and two lying downgradient of it (Pipes and Paper). The drastic increases in the nitrate and salinity parameters of the downgradient wells can only be attributed to KS effluents. Whereas the slight increases in the upgradient wells can be attributed to over pumping and pollution. The recharge mouth created by KS and along Wadi Dhuleil may have partly reversed the local groundwater flow regime. Because the aquifer in the upgradient area is suffering overexploitation, the groundwater depression in that area may gradually attract the recharged water of KS to reach the upgradient wells and pollute them.

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 the ponds.

Table (14): Comparison of the water composition for wells in the upgradient and downgradient area of Khirbet-es-Samra waste water treatment plant for the time before its operation, 1984, and after 10 years of operation, 1995.

Source		Up-Gradient				Down-Gradient			
		Moasher Elias well-2		DP 17 well	Al 1023 well	Pipes well		Paper well	
		1984	1995	1984	1995	1984	1995	1984	1995
EC	µs/cm	1008	1350	3200	4088	1100	5342	1260	3938
pH		7.70	7.00	7.90	7.65	7.80	7.33	7.30	7.63
Ca	mg/l	42	57	169	270	62	402	91	306
Mg	"	30	35	152	237	38	248	31	182
Na	"	131	141	244	281	97	494	117	358
K	"	7.8	10.7	12	27	3.9	24	7.6	20
SO_4	"	85	111	301	397	81	801	52	507
Cl	"	234	277	804	1258	230	1469	234	1046
HCO_3	"	99	101	79	63	137	157	253	223
NO_3	"	25	30.10	70	108	26	190	35	120

Effects on King Talal Dam Water Quality:

After the operation of Khirbet-es-Samra WWTP radical changes started taking place on the environmental situation along Wadi Dhuleil, Wadi Zerka, King Talal Dam reservoir and on the areas in the Jordan Valley irrigated with water coming from King Talal reservoir.

The inflows into KTD show increases in both pollution and salinity parameters. Table (15) shows some of these changes as averages for the years 1984 (before operation of KS) 1988, 1991 and 1994 (after operation).

Table (15): Average pollution and salinity parameters in the Zerka River inflows into King Talal reservoir (1984, the era before Khirbet-es-Samra) 1988, 1991 and 1994 (after the operation of Khirbet-es-Samra) and the gradual increase of their concentrations (RSS and WAJ files).

Time	1984	1988	1991	1994
BOD5 mg/l	8	24	25	45
COD mg/l	57	77	97	114
Phosphorous mg/l	1.5	4.2	7.6	10
NO_3 mg/l	9.5	27	31	45
EC µs/cm	1060	1499	1910	1950
Na mg/l	175	245	226	205
SO_4	62	111	118	135
Cl	205	290	361	355

It is very clear that the pollution parameters of BOD5, COD, phosphorus and nitrate concentrations increased very drastically in that period by 5, 2, 7 and 5- folds respectively. This organic load changed the reservoir water body from mesotrophic to eutrophic from 1977 to 1984/85 and to hypertrophic after that.

The hypertrophic processes lead to excessive algal growth and die off, where the remains of algae settle to the bottom of the lake and disintegrate consuming all the dissolved oxygen. The bottom layer of water becomes anaerobic, enriched in H_2S and CO_2. Therefore the pH value drops and allows dissolution of sediments and trace elements at the reservoir bottom and release them into the water body (Table 16).

Table (16): Trace element concentration in the outflow of King Talal Dam for the years 1992- 1995. (RSS, WAJ files and author's results).

Time	1992	1993	1994	1995
Fe mg/l	0.12	0.072	0.75	0.081
Mn mg/l	0.18	0.13	0.15	0.18
Zn mg/l	0.38	0.25	0.26	0.88
Cd mg/l	0.01	0.009	0.013	0.006
Cr mg/l	0.07	0.06	0.08	0.065
Pb mg/l	0.03	0.025	0.036	0.015

The table also shows the increases in the concentrations of the salinity parameters expressed in the EC values, Cl, Na and SO_4 concentrations. A salinity of around 2000 µS/cm has already a detrimental effect on soils and crops, knowing that the productivity of crops and soils decreases exponentially with increasing irrigation water salinity.

For crops irrigated in the Jordan Valley area the productivity of water with a salinity of 2000 µS/cm is less by about 20% of a water with a salinity of 1000 µS/cm by using the same amounts of irrigation water per land unit.

Early in 1991 the salinity of the water in KTD reached a value of 2900 µS/cm. The water flowing out of the dam was heavily loaded with organic matter, contained relatively high concentrations of trace elements and was depleted of oxygen. Upon using that water in the Jordan Valley for irrigation via a pressurized pipe system, 6 thousand hectars of crops were damaged with an estimated loss of 30-60 million JDs.

The lesson learned is that a combination of salinity, hypertrophic conditions, depletion of oxygen, richness in organic matter and trace elements with H_2S and CO_2 gases may lead to crop losses, especially if the water is transported in a closed system to the farms, using drip irrigation techniques.

2.1.2.2 Al-Mafraq WWTP

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 865mg/l BOD5. 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

During 1988, the flow into the ponds was only 800m^3/d, serving only 11,000 inhabitants. It increased gradually to reach an average of 1300m^3/d during 1995 (Table 17). 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 460 mg/l and a maximum of 1600 mg/l during December 1995. No apparent trend could be attached to these fluctuations. The oxygen-consuming substances expressed in BOD5 in the effluent range between 135mg/l and 437mg/l; i.e., four to fifteen-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 68.7% in 1995.

The chemical oxygen demand (COD) followed a similar fluctuating behavior as that of the BOD, ranging between 3964mg/l and 85 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 of 432 mg/l.

The values of suspended solids in the effluent were more than 180 mg/l reaching 235mg/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.

Table (17) Mafraq Waste water treatment plant; inflow and outflow (1995) concentrations of pollution and salinity indicators

Time Period			Year's Average	Month's Average Minimum	Month's Average Maximum
Inflow average		m^3/d	1297	1174	1431
TDS	in	mg/l	1054	840	1536
	out	"	1029	300*	1395
TSS	in	mg/l	967	206	2947
	out	"	181	87	236
BOD5	in	mg/l	868	459	1600
	out	"	272	135	437
COD	in	mg/l	1760	851	3964
	out	"	432	355	786
NH^4	out	mg/l	177	69	235

* Strongly diluted by floodwater

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.

It is clear that this method of waste water 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.

The effluent of Mafraq treatment plant can only very conditionally be used to irrigate certain crops or trees. The water is still heavily loaded with organic matter. It might have a slight salinity hazard on soils and crops. It is not recommended to allow the water to infiltrate into aquifers or to join any surface water body whether in dams or along wadis and rivers.

2.1.2.3 Baqa'a WWTP

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

The plant constructed in 1988 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 waste water flowing to the plant is screened, passed through a 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. The effluent of the 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 thickeners. The supernatant is drawn off and pumped back to the headworks.

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

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

The inflow in 1995 was around 6900m^3/d (Table 18). The BOD content exceeded 1300mg/l, and that of TSS was around 1200 mg/l. The effluent however did not satisfy the set guidelines.

Table (18) Baqa'a waste water treatment plant, inflow and outflow (1995), concentration of pollution and salinity indicators

Time Period		Year's Average	Month's average	
			Minimum	Maximum
Inflow	m^3/d	6918	5243	9943
Outflow	"	6133		6722
TDS in	mg/l	1436	1038	2456
out	"	1277	1036	1556
TSS in	"	1230	458	2200
out	"	170	120	269
BOD5 in	"	1323	86	1908
out	"	297	196	400
COD in	"	2494	1542	3357
out	"	575	429	724

Odour has also been a problem in this plant, and is possibly attributable to the sludge thickness 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, but the plant is hydraulically and organically overloaded. The effluent quality is suitable only for restricted irrigation.

The effluent which reaches King Talal reservoir negatively affects its water quality and assists in the hypertrophication processes of that water body.

2.1.2.4 Jerash WWTP

The city of Jerash is located about 45 kms north of Amman. The climate is moderate and the waste water 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 waste waters, 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 waste water 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 1995, the flow was 1387m^3/d, and the inflowing BOD5 averaged 1062 mg/l (Table 19). The outflowing BOD5 of 28 mg/l, however, was within the set guidelines. The treatment plant was expanded in 1993 to treat 3500 m^3/day. The COD and TSS concentrations in the effluent indicate a well functioning treatment plant. The waste water should not be allowed to flow into the wadi, as it will affect the groundwater in the area. The waste water could be carried in lined channels to its final destination. The effluent may have a slight salinity (year's average, 1082 mg/l) hazard especially during the summer months (summer average, TDS = 1474 mg/l).

Table (19): Jerash waste water treatment plant, inflow and outflow (1994), concentration of pollution and salinity indicators

Time Period			Year's Average	Month's average	
				Minimum	Maximum
Inflow		m^3/d	1387	1240	1539
Outflow		"	1329	1224	1500
TDS	in	mg/l	1082	774	1474
	out	"	1007	722	1257
TSS	in	"	1124	671	2286
	out	"	51	17	97
BOD5	in	"	1062	689	1469
	out	"	28	11	55
COD	in	"	2194	1700	3014
	out	"	124	72	226
NH_4	out	"	47	15	79

2.1.2.5 Aqaba WWTP

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 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 2 km from the bay, to treat a waste flow of 9000m^3/d. The inflowing BOD5 was estimated at 465 mg/l with faecal coliform counts up to 1 X 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 1995 to 6014m^3/d (Table 20). Evaporation losses were around 1733m^3/d and losses due to seepage were high at an average of 550m^3/d. Therefore, an average of 3000m^3/d were reclaimed at the outlet, i.e., 50% losses. During summer, the losses are substantially increased due to the season's high temperatures.

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 waste water 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 undergroundwater is towards the beach, which suggests that if the quality of 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.

Table (20): Aqaba waste water treatment plant, inflow and outflow (1995), concentrations of pollution and salinity parameters

Time Period			Year's Average	Month's average	
				Minimum	Maximum
Inflow		m^3/d	6014	5176	6665
Outflow		"	3672	3256	4073
TDS	in	mg/l	770	699	883
	out	"	915	842	1154
TSS	in	"	333	213	527
	out	"	3	106	530
BOD5	in	"	411	278	542
	out	"	74	53	96
COD	in	"	882	661	1150
	out	"	323	231	480
NH_4	out	"	29	14	59

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, where retention losses are minimized, and the effluent quality effectively improved.

The effluent of Aqaba treatment plant has a relatively low salinity of 770mg/l, but high BOD5 and very high COD and ammonia concentrations. It could be used for irrigation but not for aquifer recharge if the groundwater is to be used for household purposes. The eutrophication potential of the effluent is very high, hence if the water reaches the bay of Aqaba it may strongly enhance eutrophication processes in the Gulf water itself.

2.1.2.6 Irbid WWTP

The city of Irbid is the primary urban center of northern Jordan. It is the third largest city in the country 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 920 mg/l.

The treatment works consist of a grit chamber, two primary clarifiers, two trickling filters, two aeration tanks, and two flocculation clarifiers. Sludge is carried into a sludge thickener 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, where a bypass conduit diverts it into the Jordan Valley.

The flow so far has only reached 70% of the design flow; the influent however has had high BOD values, reaching in 1995 around 1341mg/l (Table 21). Fifty percent of the BOD5 removal is carried out in 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. The 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 drying beds are covered with a layer of fine sand which does not allow for seepage.

The effluent of this treatment plant can be used for irrigating most of the crops grown in the Jordan Valley area. The salinity of the water (960 mg/l) has a slight salinity hazard on crops and soils especially during the dry season (TDS = 1260 mg/l). But, excess irrigation; using more water per unit land can compensate for the elevated salinity.

Table (21): Irbid waste water treatment plant, inflow and outflow (1995), concentrations of pollution and salinity indicators

Time Period			Year's Average	Month's average	
				Minimum	Maximum
Inflow		m^3/d	7620	6950	8050
Outflow		"	7444	7000	7890
TDS	out	mg/l	960	804	1260
TSS	in	"	1337	908	2744
	out	"	105	35	678
BOD5	in	"	1341	984	1940
	out	"	35	15	76
COD	in	"	3933	2852	5583
	out	"	203	135	335
NH_4	out	"	132	22	168

It is not advisable to store the water in weirs or to allow it to join the water collected in Wadi El Arab Dam, because of the very high eutrophication potentials of the effluent. It should also be avoided to let the effluent infiltrate and recharge the shallow aquifers in the surrounding areas, especially the B2/A7 out of which, part of Irbid governorate water supply is covered.

2.1.2.7 Tafilah WWTP

The principle of this treatment plant is trickling filter/Imhof tank. The plant was constructed in 1989 with a design capacity of 1600 m^3/day and a BOD5 of 1050 mg/l. The inflow in 1994 averaged 935 m^3/day with a BOD5 of 840 mg/l (Table 22). The plant is neither hydraulically nor organically fully loaded. The effluent has average values of BOD5, TSS and COD of 43, 59 and 181 mg/l which can be regarded as acceptable.

The effluent can be used for irrigation, and because it is chlorinated before release from the treatment plant it can be used for unrestricted irrigation. The wadi where the effluent flows is influent. But, downstream water resources are limited and are only used for irrigation. Nonetheless from a scientific point of view the effluent will negatively affect down gradient groundwater resources. The effects are expected to appear after a few additional years when the contribution of the effluent to infiltration increases.

Table (22): Tafilah waste water treatment plant inflow and out flow (1994), concentration of pollution and salinity indicators

Time Period			Year's Average	Month's average	
				Minimum	Maximum
Inflow		m^3/d	935	825	1122
Outflow		"	not measured	minimal losses	
TDS	in	mg/l	863	619	1144
	out	"	871	637	1386
TSS	in	"	659	312	982
	out	"	59	23	99
BOD5	in	"	840	452	1147
	out	"	43	7	71
COD	in	"	1690	1079	2233
	out	"	181	84	333

2.1.2.8 Ma'an WWTP

This is a stabilization pond type of treatment plant, constructed in 1989 to serve the town of Ma'an with a design capacity of 1590 m^3/day and a design BOD5 of 970 mg/l. In 1995 the plant was slightly underloaded hydraulically with an inflow of 1530 m^3/day and slightly overloaded organically with 1047 mg/l BOD5 (Table 23). But the effluent shows high averages of BOD5, COD

Table (23): Ma'an waste water treatment plant, inflow and outflow (1990), concentration of pollution and salinity indicators

Time Period			Year's Average	Month's average	
				Minimum	Maximum
Inflow		m^3/d	1530	1249	1711
Outflow		"	1042	282	1556
TDS	in	mg/l	1056	904	1332
	out	"	1130	878	1495
TSS	in	"	703	423	1121
	out	"	211	100	360
BOD5	in	"	1047	756	1492
	out	"	170	90	288
COD	in	"	1837	1158	2694
	out	"	353	241	438
NH_4	out	"	74	42	120

and TSS of 170, 353 and 211 mg/l. The effluent has also a high concentration of ammonia, which indicates that the treatment is incomplete and that the effluent is still highly polluted. The treatment plant and its effluent course are influent in hydrogeologic terms. Hence it represents a great threat to the groundwater resources of the area.

The water is not even suitable for irrigation and has a medium salinity hazard. The odour of the plant is highly objectionable and it could be noticed kilometers away from the treatment plant itself.

2.1.2.9 Kufranja WWTP

This treatment plant was constructed in 1989 to serve different towns and villages in Ajlun such as Kufranja, Anjara and Ajlun. The design capacity of this plant is 1920 m^3/day and 850 mg/l BOD5. The plant in 1995 was still hydraulically and organically underloaded with an average inflow of 730 m^3 and a BOD5 of 747 mg/l. The effluent of this trickling filter-Imhof tank treatment plant has an average BOD5 of 29/mg/l and a COD of 156 mg/l, Table (24). The COD of the effluent is high. Also high is the average effluent ammonia concentration of 55 mg/l (1994). The effluent can be used for irrigation without any restrictions, especially because it is chlorinated before discharge along Wadi Kufranja.

Table (24): Kufranja waste water treatment plant, inflow and outflow (1995), concentration of pollution and salinity indicators

Time Period			Year's Average	Month's average	
				Minimum	Maximum
Inflow		m^3/d	730	610	845
Outflow		"	301	22	600
TDS	in	mg/l	887	----	952
	out	"	981	----	1078
BOD5	in	"	747	535	1035
	out	"	29	17	46
COD	in	"	1370	1000	1640
	out	"	156	54	240
NH_4	out	" (1994)	55	7	89

2.1.2.10 Abu-Nusseir WWTP

This is an activated sludge treatment plant with a design capacity of 4000 m^3/day and a BOD5 load of 680 mg/l. The plant is both hydraulically and organically fairly underloaded. The incoming amounts averaged in 1995, 1497m^3/day with a BOD5 value of 533 mg/l (Table 25). The effluent has an average BOD5 value of 19 mg/l, an average TSS of 20mg/l and an average COD of 76.

Table (25): Abu Nusseir waste water treatment plant, inflow and out flow (1995), concentrations of pollution and salinity indicators

Time Period			Year's Average	Month's average	
				Minimum	Maximum
Inflow		m^3/d	1497	1421	1593
Outflow		"	not measured, but no major losses		
TDS	in	mg/l	1141	1040	1350
	out		650	630	877
TSS	in	"	518	220*	570
	out	"	20	18	25
BOD5	in	"	533	500	580
	out	"	19	18	22
COD	in	"	1002	910	1116
	out	"	76	67	86

* affected by floods in February.

Since the effluents are chlorinated it can be used to irrigate all types of crops. The wadi along which the treated waste water flows before it joins the Zerka River (Wadi Bireen) is influent. Hence, there is a very high potential of infiltration and with time a high danger of groundwater quality deterioration and pollution. The groundwater may become unsuitable for human consumption with time. The wadi possesses a high self-cleaning potential, but infiltration takes place along its upper reaches where flow distances do not allow adequate self-purification.

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consumption with time. The wadi possesses a high self-cleaning potential, but infiltration takes place along its upper reaches where flow distances do not allow adequate self-purification.

2.1.2.11 Ramtha WWTP

This is a stabilization pond type of treatment constructed in 1988 to serve the town of Ramtha. The design capacity is 1920 m^3/day and the design BOD5 is 860 mg/l. The treatment plant is hydraulically loaded to 75% of its capacity and organically overloaded by 150% with an average inflow of 1431 m^3/day and a BOD5 of 1305 mg/l in 1995 (Table 26). The effluent has average concentrations of BOD5, TSS and COD of 290 mg/l, 160 mg/l and 595 mg/l. The effluent ammonia concentration has an average of 137 mg/l which indicates that no nitrification is taking place during treatment. The effluent composition shows also that the treatment is very inadequate and that the effluent is still highly polluted. It represents a threat to the total environment of surface and groundwater, soils, crops, human health and aesthetic values. The effluent flows along the nearby wadi and is partly reused in an infiltration area. Hence, it started polluting the groundwater in the wells lying down gradient of the plant. The effluent has also an intermediate salinity hazard on plants. Evaporation losses exceed 35% of the incoming water which represents a large economic and water supply loss to the country.

Table (26): Ramtha waste water treatment plant, inflow and outflow (1995), concentration of pollution and salinity indicators

Time Period			Year's Average	Month's average	
				Minimum	Maximum
Inflow		m^3/d	1431	1380	1484
Outflow		"	1147	1035	1367
TDS	in	mg/l	1274	1006	1612
	out	"	1312	878*	1877
TSS	in	"	940	283	1501
	out	"	160	101	296
BOD5	in	"	1305	609	2400
	out	"	290	110	417
COD	in	"	2229	1295	3336
	out	"	595	374	730
NH_4	out	"	137	115	220

* dilution by floodwater in the rainy season

2.1.2.12 Karak WWTP

This treatment plant was constructed in 1988 after the severe effects of cesspools on Sara spring water quality peaked and the nitrate concentration in the spring water reached a value of 140-150 mg/l. The design capacity of this trickling-filter-maturation pond treatment is 786 m^3/day with a BOD5 of 1080 mg/l. The treatment plant was, in 1995, hydraulically overloaded with an average inflow of 1165 m^3/day and organically underloaded with an inflow BOD5 of 830 mg/l (Table 27). The effluent shows slightly elevated BOD5, TSS and COD - averages of 45, 93 and 157 mg/l. Of some concern is also the relatively high ammonia concentration in the effluent. The effluent can be used for unrestricted irrigation, especially because it is chlorinated before discharge. The mixing of the effluent with Wadi Karak water allows its quality to gradually improve in a downstream direction.

Wadi Karak is an effluent of the area's groundwater resources. Hence infiltration is not a major question there, and the potentials of groundwater pollution are very small except further downstream once the water enters the Ghor; the Dead Sea area.

Table (27): Karak waste water treatment plant, inflow and outflow (1995), concentration of pollution and salinity indicators

Time Period			Year's Average	Month's average	
				Minimum	Maximum
Inflow		m^3/d	1165	950	1948
Outflow		"	877	650	1400
TDS	in	mg/l	928	828	1242
	out		914	748	1109
TSS	in	"	576	407	693
	out	"	93	47	272
BOD5	in	"	830	638	1351
	out	"	45	15	102
COD	in	"	1377	937	1819
	out	"	157	89	223
NH_4	out	"	50	18	81

2.1.2.13 Madaba WWTP

This treatment plant was constructed in 1989 to serve the town of Madaba. It lies 5 km southeast of Madaba and discharges its effluents along a tributary of Wadi Zerka Ma'in. It is a stabilization pond type of treatment. The design capacity is 2000 m^3/day and the design BOD5 is 850 mg/l. The plant is overloaded both hydraulically and organically with an average inflow in 1995 of 2437 m^3/day and an average BOD5 of 1339 mg/l (Table 28). Accordingly, and due to the proven inadequacy of stabilization ponds for Jordan's climate, the effluent of the treatment is still highly polluted with an average BOD5 of 329 mg/l, an average TSS of 239 mg/l and an average COD5 of 614 mg/l. The ammonia concentration in the effluent is very high with an average of 104 mg/l.

Table (28): Madaba waste water treatment plant, inflow and outflow (1995), concentration of pollution and salinity indicators

Time Period			Year's Average	Month's average	
				Minimum	Maximum
Inflow		m^3/d	2437	2269	2604
Outflow		"	1490	1000	1843
TDS	in	mg/l	1420	758	1811
	out		1411	1175	1905
TSS	in	"	1163	800	1516
	out	"	239	159	350
BOD5	in	"	1339	1069	1663
	out	"	329	204	474
COD	in	"	2742	1796	3747
	out	"	614	498	747
NH_4	out	"	104	57	210

The effluent of this treatment plant resembles in its pollution contents the raw sewage of European cities.

The water can not and should not be used, not even for restricted irrigation. Evaporation losses from the ponds exceed 40% of the inflow which means an increasing effluent salinity. The water has a relatively high salinity hazard

on soils and crops. Parts of the effluent infiltrate along Wadi Nitl and are expected to gradually threaten the groundwater resources of the area, especially because that wadi is influent along the reaches where the effluents of treatment flow.

The odour produced by that treatment plant can be noticed kilometers away from the plant following wind direction.

This treatment plant is like all other stabilization pond treatment plants in Jordan; Khirbet-Es-Samra, Mafraq, Ramtha, Aqaba and Ma'an which are not functioning properly, whether underloaded or overloaded. They represent catastrophies for the water supply situation of the country because of the evaporation losses exceeding 35% of the total inflows and for the environmental situation of Jordan with great threat to surface and groundwater resources as soil, public health, crops and because of their highly objectionable odour.

2.1.2.14 Salt waste water treatment plant

This is the oldest WWTP in Jordan, first constructed in 1945 and expanded in 1994/95 to treat 7600 m^3/day of waste water with a design BOD5 of 1090. The plant is hydraulically and organically underloaded. The extended areation type of treatment is producing an effluent with a BOD5 (average, 1995) of 30 mg/l (Table 29). The COD and TSS concentrations in the effluent are also relatively low, 131 and 79 mg/l and indicate a well functioning treatment.

The effluent can be used for irrigation, especially along Wadi Shueib where additional base flow joins the effluent and dilutes it. Along Wadi Shueib self-purification takes place and the rest of the water which reaches Shueib dam can be stored in the dam's without major impacts on the dams water quality, which is used downstream, in the Jordan Valley area for irrigation. Wadi Shueib discharges base flow all year-round, hence infiltration of effluents along its course to join the groundwater is of very low potential.

Table (29): Salt waste water treatment plant inflow and outflow (1995, concentration of pollution and salinity indicators

Time Period			Year's Average	Month's Average	
				Minimum	Maximum
Inflow		m^3/d	3868	3113	4253
Outflow		"	3787	3037	4132
TDS	in	mg/l	889	772	1096
	out		787	672	952
TSS	in	"	724	454	1004
	out	"	79	34	167
BOD5	in	"	841	610	1102
	out	"	30	10	62
COD	in	"	1622	1204	1942
	out	"	113	53	237

2.1.2.15 A Summary on Domestic Waste Water Treatment Plants

From Table (30) it can be concluded that Khirbet-es-Samra, Mafraq, Ramtha, Baqa'a, Madaba and Ma'an WWTP produce an effluent with BOD5 concentrations of more than 144 mg/l. All of them work as stabilization ponds except Baqa'a which is a trickling filter waste water treatment plant. Different guidelines are given in the literature concerning the effluent of treatment plants; They generally depend on the environmental conditions in the downstream areas, the next use and the environmental impacts of their discharges especially on the recipient water bodies. In Middle Europe, 30 mg/l BOD5 are recommended as an upper limit. Elsewhere this concentration can go up to 100 mg/l if environmental conditions allow it.

For Jordan, with its extreme water scarcity and high value of water, a BOD5 concentration of 30 mg/l should be targeted, especially because experience with these treatment plants' effluents indicate severe environmental impacts on surface and groundwater, and the odour can even be detected at a distance of more than 10 kms away from the treatment plant itself or from the river course along which the effluents are discharged. Khirbet-es-Samra with an average effluent BOD5 of 144 mg/l is just one example of that, let alone Madaba plant with a BOD5 of 329 mg/l.

Table (30): Average Municipal waste water influent/effluent quality by treatment plant, 1995 (Files of WAJ)

Treatment plant MCM/yr	Outflow MCM/yr	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*
Khirbet-es-Samra	43.68	609	144	1259	356	422	126	S
Mafraq	0.315	868	272	1759	432	967	181	S
Aqaba	1.34	411	74	882	323	333	301	S
Ramtha	0.35	1305	290	2229	595	940	160	S
Abu Nusseir	0.53	533	19	1002	76	518	20	A
Baqa'a	2.24	1332	297	2494	575	1230	170	T
Salt	1.38	841	30	1622	113	724	79	E
Irbid	2.72	1341	35	2852	135	1337	105	TA
Jarash	0.47	1062	28	2194	124	1124	51	O
Karak	0.41	830	45	1377	157	575	93	TI
Tafilah	0.37	840	43	1690	181	659	59	TI
Madaba	0.266	1393	329	2742	614	1163	239	S
Ma'an	0.38	1047	170	1837	353	-	-	S
Kufranja	0.12	747	29	1370	156	1287	71	TI

* S : Stabilization ponds.
T : Trickling Filter.
O : Oxidation Ditch.
E : Extended Aeration.
A : Activated Sludge.
I : Imhof-Tank.

The other treatment plants, working on mechanical principles, produce an effluent with a BOD5 concentrations of less than 74 mg/l. The treatment in these plants involve mechanical components, trickling/areation, activated sludge ... etc. Only Aqaba, which works on the stabilization pond principles, produces an effluent with a BOD5 of 74 mg/l. But that should not be surprising since the inflow to the plant contains an average BOD5 concentration of 411 mg/l compared to a weighted average of around 625 mg/l for all treatment plants in Jordan.

If, in the inflowing water to Aqaba waste water treatment plant the BOD5 concentration were like the average for Jordan, then the effluent BOD5 would be 113 mg/l which is also a relatively high value considering the next use (intended irrigation, unintended groundwater recharge). The other parameters, COD and TSS reflect also the efficiency of treatment. They correlate with the BOD5 concentrations for both the incoming and outgoing water.

The only mechanical treatment plant producing an effluent with a BOD5 concentration of more than 100 mg/l is Baqa'a with an average BOD5 concentration of 297, although this treatment plant is underloaded by 10% of the amount of waste water it treats and overloaded by 47% of the design BOD5 concentration. But this does not explain the inefficiency. It seems that other factors are reducing its efficiency, such as the presence of trace elements, insecticides or pesticides or mineral oils in the inflowing water.

Effluents with a bad quality, not coping with the downstream environmental conditions, like those of Khirbet-es-Samra, Mafraq, Ramtha, Baqa'a, Madaba and Ma'an, represent a threat to the environment. They are polluting surface and groundwater resources and forming breeding sites for insects in addition to their objectionable odour, not only that which comes from the treatment plant itself but that which develops along the wadis where the effluents flow.

2.1.3 Solidwaste Disposal

The impacts of solidwaste disposal on surface and groundwater resources are well recognized and documented in the literature (Farquhar 1989). The problem is that once these impacts are recognised in the composition of a groundwater body manifested in the detection of pollutants, the repair becomes very difficult or even impossible.

Generally, municipal solidwastes contain only limited numbers and amounts of dangerous chemicals. But, in certain cases where separation of wastes is not practiced, even dangerous chemicals, such as insecticides, pesticides, all types of medicaments, batteries, paints, mineral oils among others, reach the solidwaste disposal sites, become dissolved and leak to ground and surface water bodies.

Of concern here in Jordan are the solidwaste disposal sites distributed all over the country (Fig. 7). The sites of Amman, Zerka, Salt, Madaba, Ukheider, Karak, Hartha, and Aqaba among others were not exposed to sophisticated environmental impact assessment in advance. Hence, they do not fulfil present-day environmental criteria.

In addition most of the sites are located along wadis or depressions of abandoned quarries or karst holes, forming therefore a direct threat to the ground and surface water resources.

Solidwaste in Jordan consists of about 49.5% foodwaste 25.9% carton, 6.5% plastics, 3.3% glass, 2.5% metals and the rest of natural materials: wood, earth, stones, construction refuse ...etc, (El-Natour, 1993).

In Amman solidwaste disposal site, the waste is brought by trucks. Unseparated, it is deposited, consolidated and covered by a few centimeters of soil. Such a procedure only reduces the entry of air, prohibits immediate burning and combustion and improves the view of the landscape, compared to open uncovered dumping sites.

Wells in the upstream area (Fig. 10) of the solidwaste disposal site (no AL 2106, Fig. 11) show relatively constant concentrations of the different parameters. Wells lying down gradient of the site show, contrary to that, increases in the concentrations of the different parameters (AL 1326, Fig. 12). Further down gradient wells: AL 1303, AL 1318 and AL 1302 (Fig. 13) show less expressed increases in the concentration of the different parameters as a result of the divergence of the pollution plumes.

The composition of the leachates originating from the solidwaste disposal site of Amman is given in Table (31). The table shows also the composition of the liquid waste pool in Wadi El-Kattar in the immediate neighborhood of the solidwaste site.

In practice, many years may elapse before the solidwaste disposal site reaches field capacity to generate leachate, which are almost entirely; 98% composed of calcium, magnesium, sodium chloride, sulfates, nitrogen compounds (as ammonia, nitrate and nitrite) and bicarbonates. Also time is required before peak concentrations of the various parameters are reached. However, once this peak is reached, it continues at the same level for tens or hundreds of years after the disposal is stopped.

Poorly biodegradable, low-solubility contaminants appear and reach peaks way after the normal chemical constituents mentioned above. Hence, they persist longer and affect the water resources for long periods of times, tens to hundreds of years, (Farquhar, 1989).

In the other areas of Jordan solidwaste disposal sites are not better off than the one in Amman. Serious impacts on the surface and groundwater resources are unavoidable if not already there.

2.2 Industrial Effluents

Waste water effluents of industries in Jordan can be categorizied concerning treatment into the following:

a) Treated effluents.
b) Untreated effluents.
c) Semi-treated effluents.

The majority of industries in Jordan (>90%) possess waste water treatment plants. Some of them produce effluents which comply with regulation and standards, many do not, and most of them produce semi-treated waste water.

Considering the way of effluent disposal, industrial waste water can be categorized into:

a) Connected to a domestic waste water treatment plant, especially Khirbet-es-Samra.
b) Discharging into the nearby wadis.
c) Used for irrigation in the surrounding of the effluent-producing industry.
d) Transported to a collection pool or allowed to infiltrate and/or evaporate in a spreading basin.

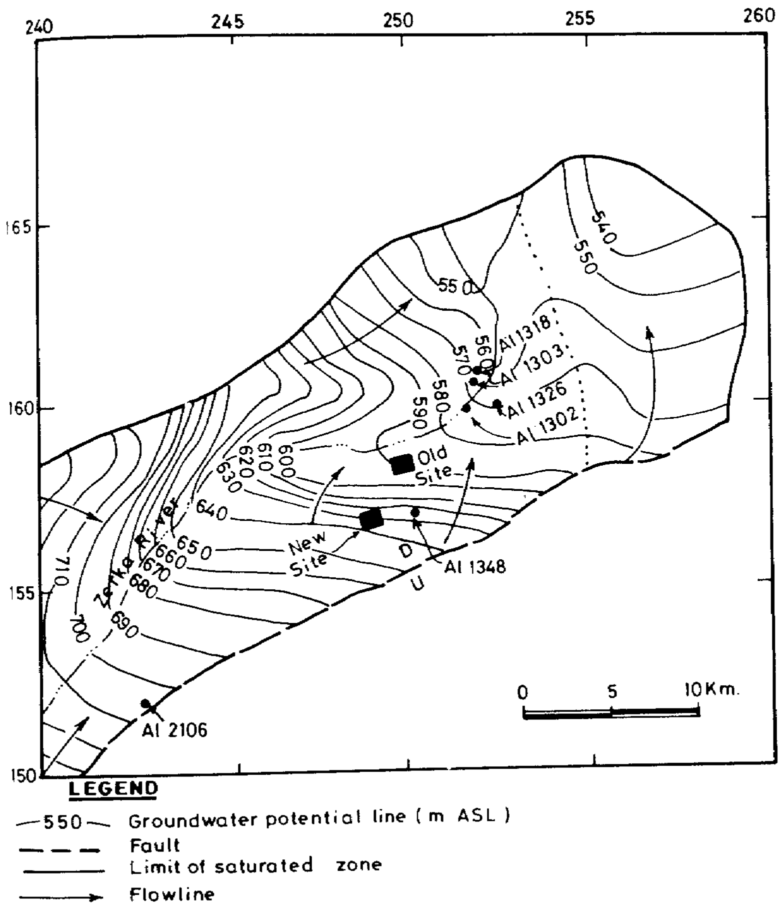
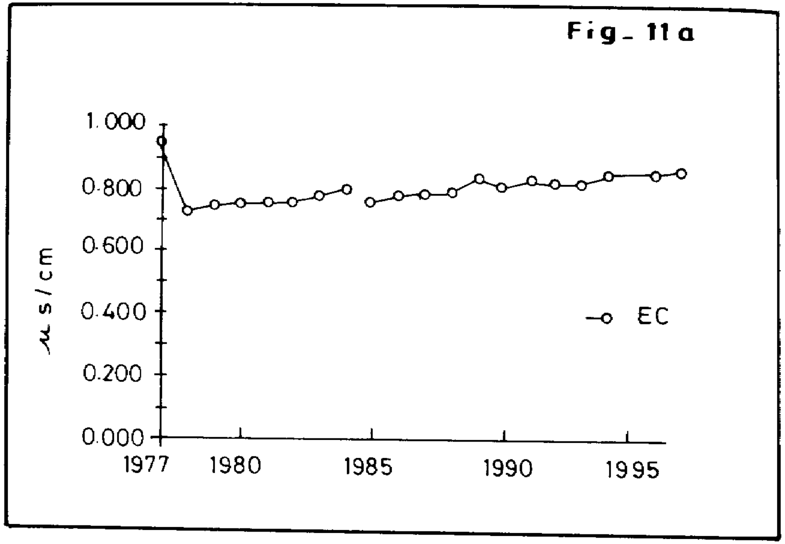
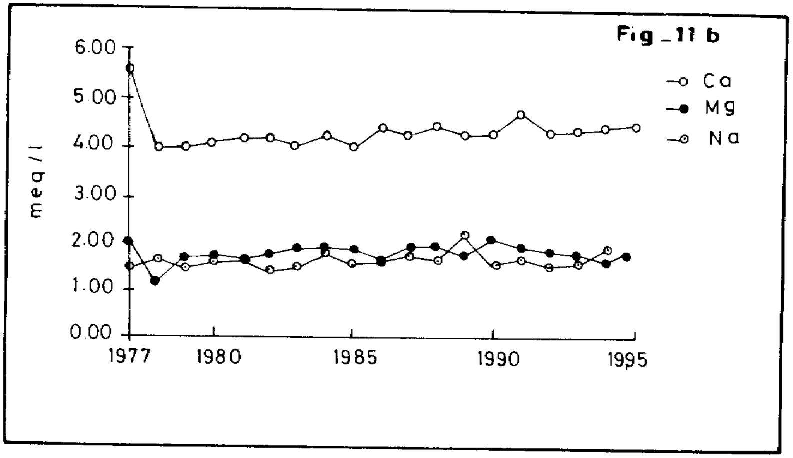


Fig. (10): Groundwater potential lines in the surroundings of Amman solid waste disposal site.





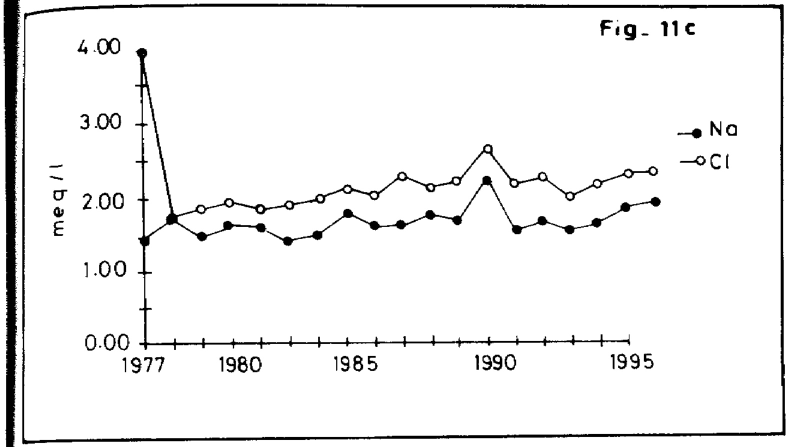
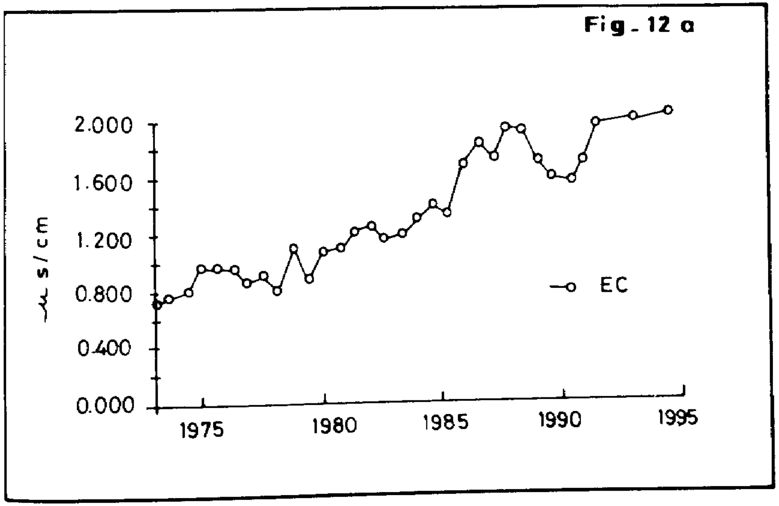
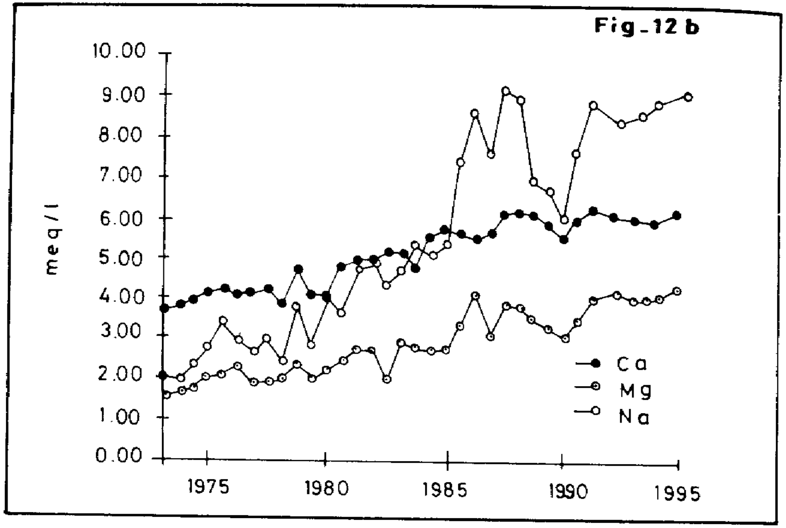


Fig. (11a, b, c): Temporal changes in the EC, Ca, Mg, Na and Cl concentrations in well Al 2106.





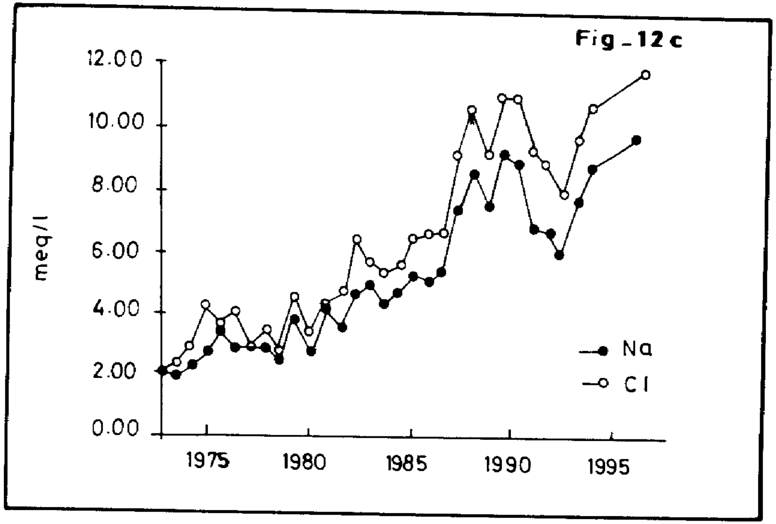


Fig. (12a, b, c): Temporal changes in the Ec, Ca, Mg, Na and Cl concentrations in well Al 1326.

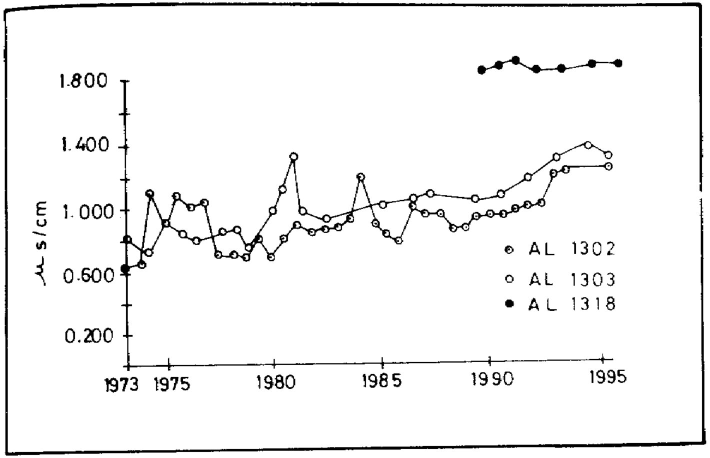


Fig. (13): Temporal changes in the EC values in wells Al 1302 Al 1303 and Al 1318.

Table (31): Analyses of the solidwastes leachates, and the liquid waste pool, southeast of Amman

Parameter	Old dump	Newdump	Wastepool
Temp. C°	14.6	14.4	15.6
mmoh/cm EC	138.000	5.500	18.560
pH	8.46	8.10	8.68
meq/l NO_3	12.09	0.062	89
meq/l HCO_3	6.09	4.48	3.50
meq/l CO_3	0	0	0
meq/l SO_4	11.5	1.9	4.88
meq/l Cl	150	34.1	158.9
meq/l Ca	7.3	2.4	7.71
mrq/l Mg	8.6	3.2	9.77
meq/l Na	142	37.6	154.3
meq/l K	23.22	1.18	2.65

Around 44% of the industries discharge their pretreated effluents to domestic waste water treatment plants. Others are not allowed to do that because their effluents contain substances which pose great threat to the treatment processes of domestic WWTP. They discharge their effluents to the nearby wadis. Some industries, such as yeast, partly the refinery and others use the effluents in local irrigation.

Some industries with effluents of a few cubic meters per day transport their waste water by trucks to pools and spreading basins where they infiltrate or evaporate.

According to the quality degradation parameters contained in industrial effluents, they can be classified into the following:

a) High salinity effluents.
b) High organic loads effluents.
c) High trace elements effluents.
d) High contents of other specific substances such as phosphates and ABS.
e) A combination of any group of a) to d).

The majority of industries have effluents with high salinity or high organic load or both. A few of them have high trace element concentrations, and very few have high concentrations of specific parameters.

Trace Elements

High concentrations of trace elements are found in the effluents of some industries (Table 32). These effluents end up in the surface and groundwater bodies and in the soils. Locally, they may threaten surface and groundwater bodies and may, if connected to domestic waste water treatment plants, kill the active bacteria and algae and hence stop the biological activities involved in waste water treatment.

The destination of these trace elements in the Amman/Zerka area is King Talal Dam (KTD). Therefore, the inflows to KTD whether, the base or the floodflows, contain some trace elements dissolved in the water itself and attached to or bound into the suspended particles which are transported by the water. In KTD the particles settle to the bottom of the reservoir, but they partially become released into the water again due to the eutrophication processes, taking place there. Afterwards they are discharged along Wadi Zerka with the water used for irrigation in the Jordan Valley area.

Table (32): Examples of Industries with high trace element concentrations in their treated effluents (mg/l).

	Av. Discharge m^3/d	Concentration of:								
		Fe	**Mn**	**Zn**	**Cu**	**Cd**	**Cr**	**Ni**	**Pb**	**Hg**
Tanning	370	0.43	0.16	0.32	0.120	0.052	1.92	0.25	0.25	0.001
Yeast	330	4.20	2.00	0.18	0.072	0.020	0.08	0.23	0.072	0.0008
Battery	12	16.30	6.50	0.45	0.620	0.020	0.08	0.25	6.32	0.005
Chemical Ind. (Detergents)	8	0.50	0.32	0.21	0.09	0.090	0.21	0.26	0.32	0.15
Sulpho-chemicals	62	3.50	1.40	0.16	0.090	0.700	0.23	0.25	0.35	0.0009

Until now these trace elements did not represent a threat to downstream irrigational uses. But, a combination of factors such as less irrigation water per unit land, water depletion of oxygen and high water salinity may activate these trace elements and make them available to plants which would weaken the resistivity of these plants to diseases and may end up in crop failure.

The total loads of trace elements to the whole water system in the most industrialized area in Jordan, the Amman - Zerka area, is relatively small and it does not represent any threat on the system as a whole. But on a local scale some trace elements such as lead (battery industry) or mercury (chemical Industries or chlorine filling plants) represent an acute danger to surface and groundwater resources. Therefore, these industries should treat these trace elements adequately before any waste water releases to the surroundings. The outlet water of KTD contain some high concentrations of trace elements such as lead, 15-40 µg/l (1994) nickel, 50-100 mg/l. chromium, 50-62 mg/l, cadmium, 0-20 mg/l, zinc, 70-88 mg/l, Cu, 2-12 mg/l, manganese, 120-180 mg/l and iron 70-80 mg/l. This water is generally mixed with other less polluted water in irrigation in the Jordan Valley area.

Trace elements are also found in the effluents of, other industries.

Iron: Eagle Distilleries of 3.68 mg/l, United Distilleries of 4.82 mg/l. Oven Manufacturing 1.82 mg/l.

Nickle: Warehouse Manufacturing 0.32 mg/l, and Hussein Thermal Station 0.21 mg/l.

Zinc: Arab Brewery 0.41 mg/l, Hussein Thermal Station 0.43 mg/l. Hussein Iron & Steel 0.23 mg/l, Arab Co. for Commerce and Food Industries 0.432 mg/l, United Industries 0.31 mg/l, Warehouse Manufacturing Co. 0.532 mg/l, Oven Manufacturing 0.2 mg/l and Jordan Matches 0.72 mg/l.

Lead: National Industrial Co. (Tissue Paper) 0.045 mg/l.

Organic Loads

The majority of industries (food, drinks, paper, yeast, polymers, detergents ... etc) produce effluents with high organic loads expressed in their BOD5

contents (Table 33). The BOD5 values exceeded in those effluents 100 mg/l and reached a value of 8120 mg/l in the Yeast Co. effluent.

The weighted average of BOD5 for the effluents of industries listed in Table (33) is 1961 mg/l which is almost double the value for raw domestic waste water in Jordan.

Organic loads such as those contained in the effluents of the industries listed in Table (33) above are degradable under natural conditions. But, they add to the pollution of surface and groundwater resources along the wadis where they flow or in dams where they collect. They enhance also eutrophication processes.

Table (33): Examples of Industries with High Organic Load in their Effluents

Type of Industry	BOD5 mg/l	Flow m^3/d
National Industries (Tissue Paper)	156	104
Sulphochemicals	805	62
United Industries (Distillery)	132	35
Arab Co. for Commerce and Food Ind.	850	85
Chemical Industries Co. (Detergents)	613	8
Yeast Co.	8120	330
Eagle Distilleries	3212	130
Tanning Industry	134	370
Arab Brewery	890	45
Jordan Hygiene Paper	612	105
Jordan Matches	1500	4.3
Textile Co.	280	21
Imperial Underwear	170	52
Chemical Polymers	1090	4.1

High Salinity

High salinity waste water is produced by the industries listed in Table (34). Some of them do not only produce brackish water with a few thousand µs/cm, EC values but saline water with EC values of more than 10000 µs/cm. such as Tanning with an average EC of 17650 µs/cm. Battery 15150 µs/cm. Chemical Industries Detergents 42160 µs/cm and Sulphochemicals 11150 µs/cm.

In a country with scarce water resources and generally higher salt contents in its natural water resources industrial effluents with high salinities have severe consequences on its surface and groundwater resources.

For example, to make the effluent of the Tanning Industry suitable for irrigation (1500 µs/cm) from a salinity point of view 8500 m^3/d of a normal water source with an EC value of 800 µs/cm is needed. This means a dilution of about 1:25.

To make the waste water produced by the industries mentioned in Table suitable for irrigation (1500 µs/cm) by dilution from a normal source (800 µs/cm), 30000 m^3/d, or 11 million cubic meter per year of water are required. This calculation indicates that the problem of industrial water in Jordan is mainly a salinity problem and to a lesser extent a trace metal problem or an organic load problem.

Table (34): Example for Industries with high salinity concentration in their effleunts:

	EC Value (µs/cm)	Flow (m^3/d)
Tanning Industry	17650	370
Eagle Distilleries	2515	130
Yeast Co.	7750	330
Battery Industry	15150	12
Iron & Steel Co.	5130	265
Chemicals Industries Co. (Detergents)	42160	8
National Industries (Tissue Paper)	3876	104
Petroleum Refinery	3655	4600
Hygiene Paper	3240	105
Sulphochemicals	11150	62
Jordan Tiles	5325	57

Other Industrial Pollutants

The waste water effluents of some industries contain specific substances which may negatively affect the environment. Examples of that are the phosphates discharged with the effluents of ICA (Intag) with a concentration of 560 mg/l and the Warehouse Manufacturing with 62 mg/l, compared to domestic waste water treatment plants' effluents of up to 50 mg/l.

Phosphates in water enhance the eutrophication processes in surface water bodies and lead to ageing lakes.

Also the ABS values of ICA (Intag) and Arab Detergents effluents are 720 mg/l and 1250 mg/l compared to effluents of mechanical waste water treatment plants of domestic origin with up to 10 mg/l or to stabilization ponds with 5-45 mg/l.

2.3 Biocides

Biocides are sets of chemical compounds used to control plant diseases, mosquitoes, flies, fleas, lice and others.

Applying these chemicals to fields, stagnant water bodies and other insect breeding sites, allows these chemicals to be transported by water, air, dust and soil particles to surface and groundwater bodies.

In the same way in which biocides harm and kill mosquitoes, flies, plant diseases-causing organisms ... etc., they also affect and may cause death to human beings and other living creatures. The difference is the doses which a body of a certain size and weight receives and can tolerate. But biocides are generally persistent, they need a few years to disintegrate to 80-90% of their original activity. Some of them require for that tens of years.

Therefore, their effects are cumulative. This is to say that taking a small dose (more than a body can assimilate) for a long time causes illness and may be lethal.

Now it is generally recognised that the application of biocides is for human beings not a safe interference in natural processes but a risky one.
If biocides reach surface and/or groundwater bodies the water becomes contaminated, and depending on their concentrations even unsuitable for human consumption or fish farming or other similar uses.

The pathways of biocides to surface water bodies are:

* direct application to stagnant or flowing waters to control mosquitoes, flies ... etc.
* direct deposition from the atmosphere or via dust particles, plants.
* washed from soils and plant remains by runoffs due to excess irrigation and precipitation events.

The pathways to the groundwater bodies are:

* infiltration of contaminated precipitation water (from dust, atmosphere).
* leaching of contaminated soils by irrigation water or infiltration precipitation.
* infiltration of contaminated water along wadi courses or from surface water bodies; reservoirs, waste water treatment plants ... etc.

In Jordan only a limited number of surface and groundwater resources were analysed on their biocide contents. The analyses show that their concentrations are generally still below the recommended guidelines for the specific use of the analysed water sources.

But, the presence of these biocides in some surface and groundwater resources indicates that they and other not examined sources may represent a potential danger for the water uses.

The values listed in Table (35) indicate an increase in the concentrations of certain biocides with time, such as the HCH concentration in King Talal Dam which increased from <3 mg/l in 1988 Thames Water Authority (TWA) to 14 mg/l in 1994 Royal Scientific Society (RRS) and in Zerka River from <3 mg/l in 1988 (TWA) to 18-30 mg/l in 1994 (RSS).

Also in King Abdullah Canal the HCH total concentration increased from 15 mg/l in 1988 (TWA) to a max. of 40 mg/l in 1996 (Kuisi).

The number of analyses is so small that it does not allow a comprehensive judgement about the biocide contents of water bodies. But biocides have wide uses in agriculture, to control flies and mosquitoes and even at home, to control flies, mosquitoes, ants ... etc.

Table (35): Biocide concentrations and concentration changes for selected sites in Jordan

King Abdullah Canal					
Hexachlorohexa-misomers	Σ HCH		< 15	mg/l	(TWA, 1988)
	Σ HCH		up to 40	"	(Kuisi, 1996)
	Deldrin		< 10	"	(TWA, 1988)
	Chlordane		< 2	"	" "
	Oxamyl		< 200	"	(Kuisi, 1996)
	Dinethoate		< 90	"	" "
	Monocrotophos		< 20	"	" "
King Talal Dam					
Σ HCH			< 3	mg/l	TWA, 1988
Σ		outlet	12	"	(RSS 1994)
		inlet	360	"	" "
		reservoir	14	"	" "
Dimethsate		outlet	160	"	" "
		inlet	940	"	" "
		reservoir	130	"	" "
Chlordane		outlet	0.4	"	(Shoreiki 1992)
		inlet	0.34	"	" "
Zerka River					
Σ HCH			< 3	mg/l	(TWA 1988)
			18-30	"	(RSS 1994)
Dimethoate			Ca 1600	g/l	" "
Groundwater					
Jordan Valley area, Middle part					
Σ HCH (av. 20 samples)			8 mg/l		(Kuisi 1996)
Dimethoate			23 mg/l		" "
Irrigation Drainage water Jordan Valley, Middle part					
Σ HCH (av. 13 samples)			13 mg/l		(Kuisi 1996)
		max.	30 mg/l		" "

They are afterwards washed and find their ways to surface and groundwater resources via sewerage systems, soils, wadi courses ... etc.

2.4 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 almost all areas in Jordan; Jafr, Azraq, Dhuleil, Shoubak, Agib, Qastal, Qatranah, Wadi Arab, Northern Badia, Amman-Zerka and Disi areas. In all these areas water levels are continuously declining, and wells drilled in Dhuleil, Azraq and Amman-Zerka have to be deepened 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.

2.4.1 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 (36) shows a comparison of the water quality in well No. 17 in that area and illustrates the gradual salinization of the aquifer's water.

Figure 14 shows the continuous decline of the water level in observation well (G 1346) from 1988 to 1994 with an average drop in water level of 1.5 m/yr.

Table (36): Salinity increase in Jafr well No. 17. (Files of WAJ)

Analysis date		27.6.1965	17.9.1973	7.7.1994
EC	µs/cm	909	3.100	3760
pH		7.5	7.2	7.58
Ca	mg/l	82	164	233.6
Mg	"	40	100	122.2
Na	"	85	287	364.4
K	"	7.5	16	20.0
Cl	"	99	768	933
SO_4	"	145	240	333
NO_3	"	10	19	11.8
HCO_3	"	321	256	217

2.4.2 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.

Fig. (14): Dobservation well G 1346-Abu Makhtub No. 2
PGE 206200 PGN 985700 ALT: 1430m TD: 162m Aquifer: A7/B2

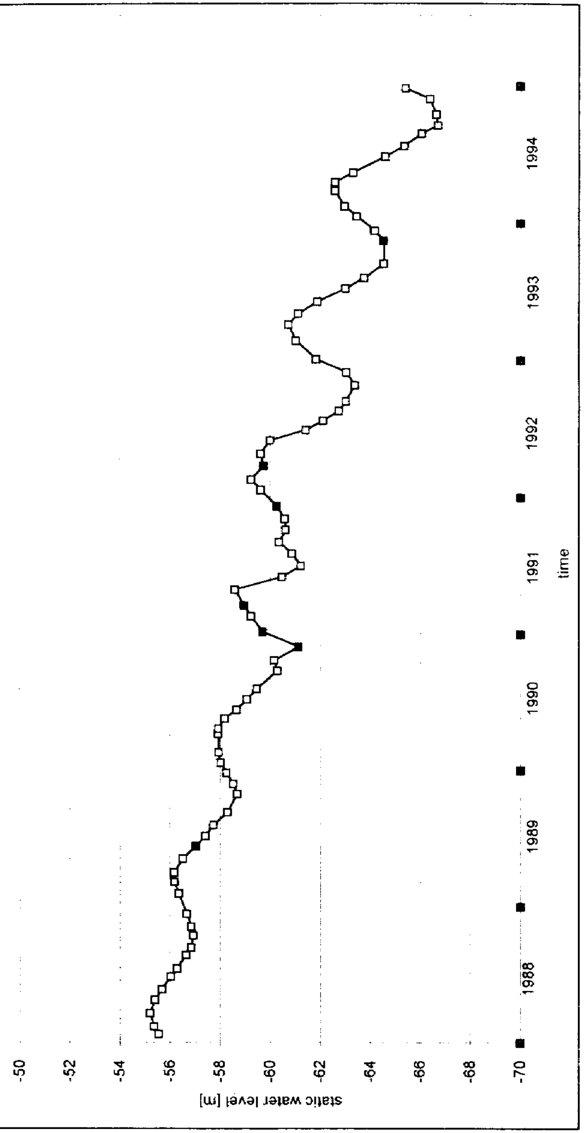


Table (37) shows the development of the groundwater quality on the example of well Al 1109, Wasfi Al- Tal.

Table (37): Water quality development of well No. Al 1109 from 1970 - 1995

Analysis date		1.4.1970	22.4.1979	1995
EC	µs/cm	440	1060	2700
pH		8.1	7.8	
Ca	mg/l	12	51	159.3
Mg	"	16	42	115.5
Na	"	53	103	180.7
K	"	4.7	9.0	18
Cl	"	61	272	695
SO_4	"	29	71	126.3
NO_3	"	128	82	72.6
HCO_3	"	15	23	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 1995. Also this well showed high concentrations of phosphates in 1995, 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.

The drop in water levels is illustrated on the examples of wells No. 5. Al 2698 (Hallabat observation well 1) and Al 1040, TW 5. The average declines in water table from 1980-1988 in well Al 1040 was around 25 cm/year. After that it increased to around 85 cm/year in both wells (Fig. 15).

2.4.3 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.

Fig. (15a): Observation well Al 2698 - Hallabat obs. Well No. 1
PGE 281000 PGN 169100 ALT: 585m TD: 120m Aquifer: A7/B2 Recprd

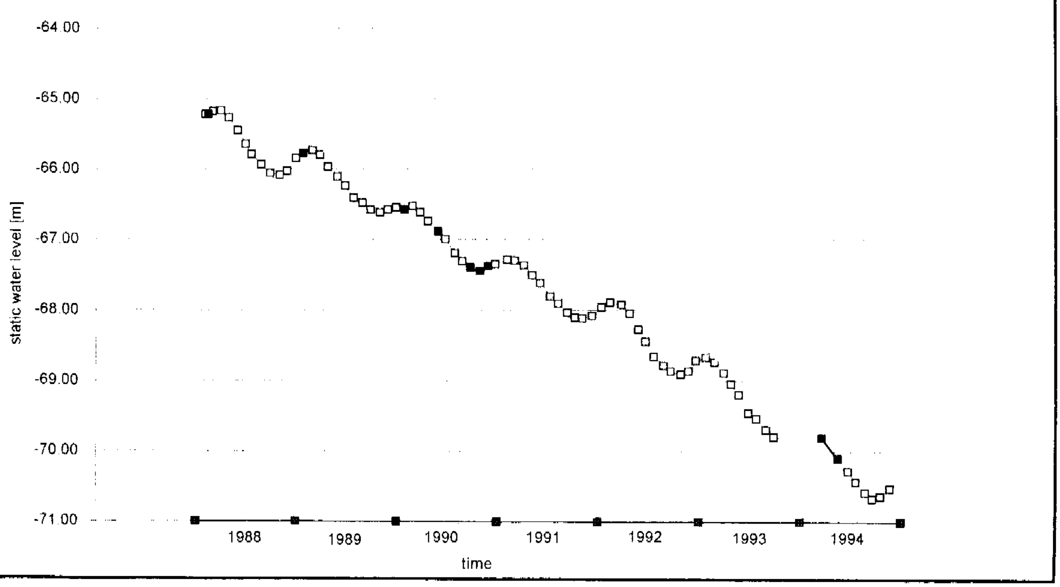
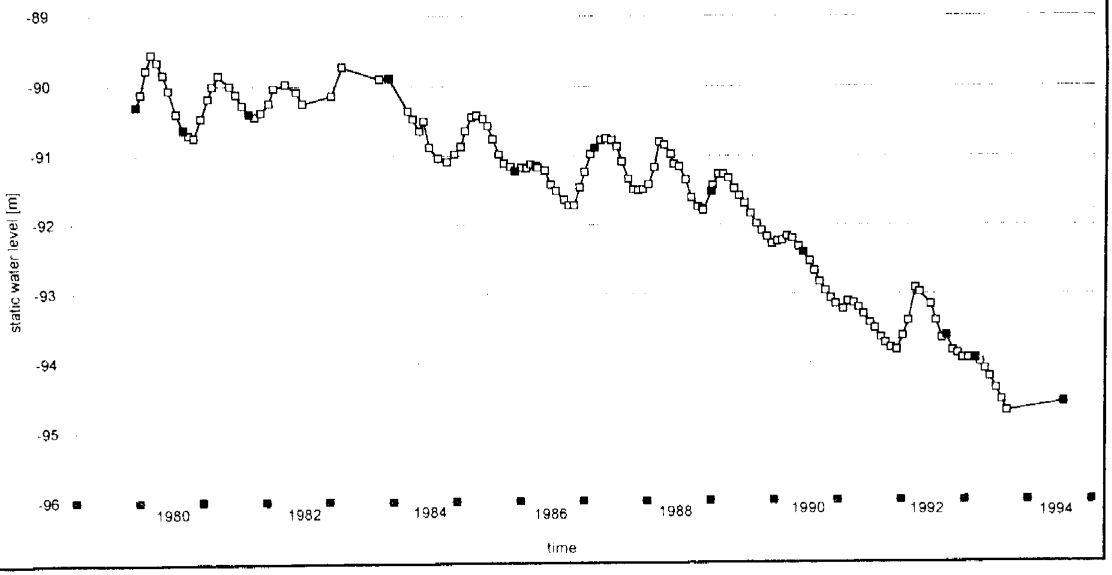


Fig. (15b): Observation well Al 1040 - TW 5 (PP157)
PGE 271278 PGN 177834 ALT 596m TD 165m Aqifer: A7 Recorder



At present the general drawdown is 8-9 metres. The spring discharges in South Azraq, and those of Qaysiya and Soda springs stopped in 1993. The total groundwater natural discharge of 16 MCM/year, measured by Arsalan in 1973, decreased because of overpumping to 10 MCM/year in 1983, and to zero in the past 4 years.

The drop in water level is illustrated on the examples of wells F 1043 (Azraq) and F 1280 (observation AWSA-2) with an average decline in the water table of 50-60 cm/year. (Fig. 16).

Well drilling activities in Azraq area intensified in the late 80s and first few years of the 90s. The results of salinization of water and drop in water levels extended to affect the whole basin.

In 1994/1995 a decision was taken to pump around 0.5 MCM of fresh water produced from the Water Authority wells (AWSA wells) into the oasis which fell dry in 1993. This action was initiated by a Global Environmental Facility (GEF) - UNDP project, Rasmer, to somehow restore the oasis functions with the assistance of the Ministry of Water and Irrigation. But, the impacts of such an action on the groundwater resources may be horrible in light of the hydrogeologic situation prevailing in the area.

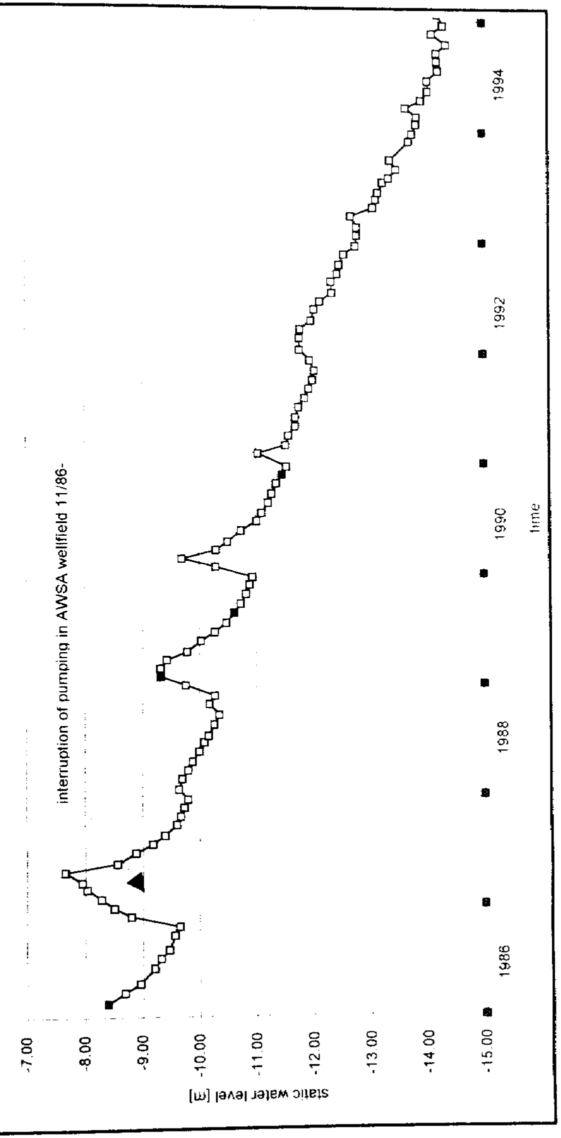
The oasis is an exitless evaporation pan. Before the recent developments during the last 15 years the water system of the oasis functioned in the following pattern:

* Floodwater originating within the catchment area collected in the marsh land area of a few square kilometers.

* The shallow aquifer B4, the Basalt or the composite aquifer of B4-Basalt and recent sediments discharged their groundwater directly into the oasis pools through a few springs such as Ora, Mustadima, Soda, Qaysiya and others.

* The groundwater in the deeper aquifer the B2/A7, is pressurized with a piezometric head exceeding that of the shallow aquifers basalt-B4- recent deposits and that of the deep Kurnub aquifer. Therefore it leaks upwards through the overlying B3 into the shallow aquifers and from there into the oasis, and downwards through a series of aquifuges into the Kurnub (Fig. 17a).

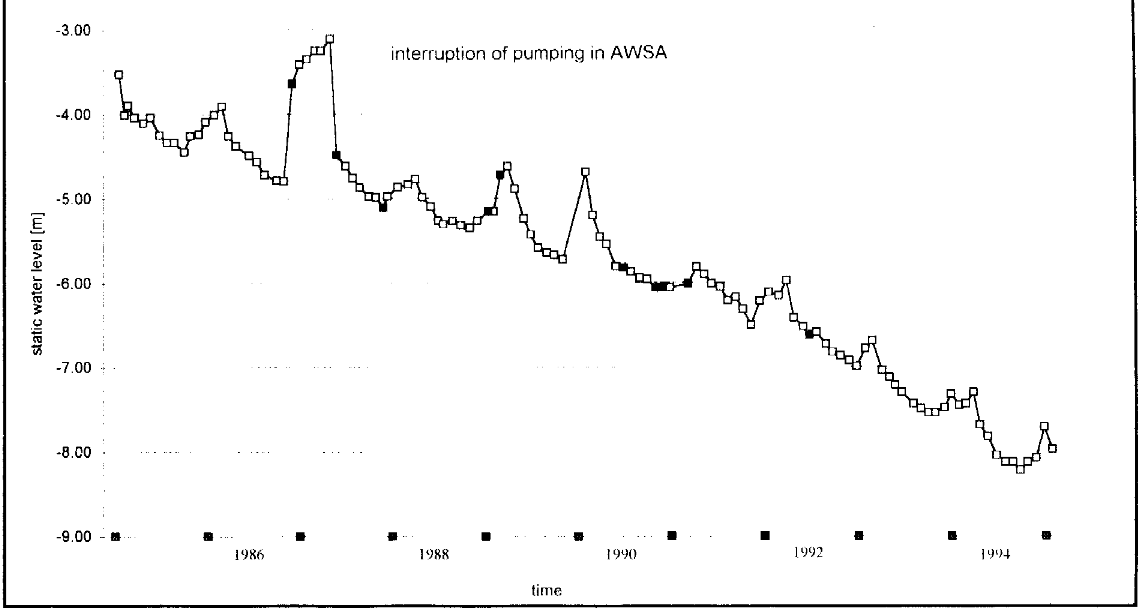
Fig. (16a): Observation well F 1043 - AZ 12
PGE 322395 PGN 149404 ALT: 517m TD: 255m Aquifer: BS+B4/B5 Recorder



German Jordanian Technical Cooperation

Fig. (16b): Observation well F 1280 - AWSA No. 2

PGE 323783 PGN 147863 ALT: 514m TD: 195m Aquifer: BS+B4/B5 Recorder



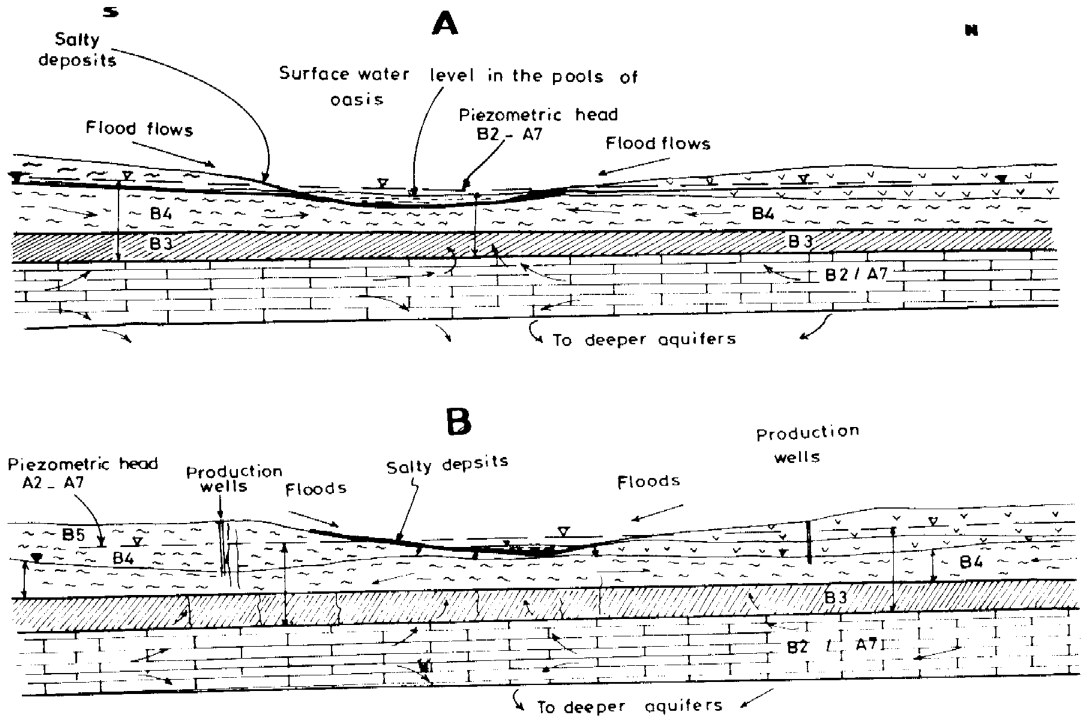


Fig. (17a. b): Changes in the groundwater flow system in Azraq Oasis area and the effects of filling the Oasis with fresh water

All the water which used to flow into the oasis and marshes evaporated and left behind the salts.

Gradually, the increasing pumping out of the aquifer has led to the following:

- Floodwater, is still reaching the marsh land although with decreasing quantities.
- The shallow aquifer water levels dropped and springs stopped feeding the Oasis.

The deeper groundwater still leaks upwards into the shallow aquifers but its water is not appearing at the surface (Fig. 17b).

The marsh lands surrounding the Azraq pools are built up of silt and clay with gypsum and halite. The salt concentration in the ditches dug in the area to extract table salt reach sometimes 70 g/l of water. These marshes extend to the pool areas and border them.

But, since the water table in the area had dropped by 8-9 m (1982-1994), the areas underlying the pools and marshes turned into unsaturated zones. Filling the pools with water will cause the water to infiltrate to the groundwater table taking with it the dissolved salts increasing herewith the groundwater salinity. Now since the pools will function as a recharge mouth. the water levels beneath them will rise and the groundwater flow direction will be reversed towards the production wells. This will result in increasing salinities of production wells in the surrounding of the oasis including those wells of AWSA.

Therefore, it is expected the Azraq project (UNDP/Rasmer) will cause an increase in the groundwater salinity, and if it continues for the coming few years some well waters will become unsuitable for domestic water supply.

It is somehow surprising that the GEF through the UNDP-Azraq project (Rasmer) is enhancing an action which will certainly lead to salinization processes of vital groundwater resources of the country.

2.4.4 Disi-Mudawwara-Sahl-es-Siwwan Area

The sandstone aquifer in this area contains water with a recharge age of 2000-1100 years, hence it can be classified as a fossil water. Major development in the unconfined parts of the aquifer (Disi) and the confined

parts (Mudawwara) started in 1985 to 1987. From that time on, increasing groundwater amounts have been pumped out of the aquifer. The present extraction rates for the water supply of Aqaba town and for the local irrigation projects amount to some 85 MCM/year.

From 1985-1987 on, water levels in the area started to drop (Fig. 18). The average drop in levels ranged from 0.2 m/yr in Disi to 1.2 m/yr in Khreim and Mneisheer. This drop in groundwater levels compared to the very scarce rainfall in the area with an average of 30 cm/yr indicate the aquifer is experiencing a mining process, which means that the aquifer is being emptied; overexploited.

Until now no changes in the water quality have taken place, but irrigation return flows will certainly reach the groundwater in the unconfined portions of the aquifer (Disi) which may lead to increasing salinities and increasing fertilizer concentrations such as nitrates, phosphates, potassium ... etc.

In the confined portions of the aquifer the salt water found in the Khreim confining layer may upon pressure releases due to water level declines lead to salt releases from the Khreim unit into the underlying Disi aquifer. Some signs of that are seen in Mudawwara wells.

2.4.5 The Northwestern Parts of the Highlands (Sama Sirhan, Mafraq, Wadi Arab, Mukheiba)

The main aquifer in this area is the B2/A7. Extraction of water from the unconfined eastern part of the aquifer (east of Irbid to Mafraq) was very limited until the beginning of the 80s. After that intensive well-drilling activities were carried out and hundreds of new wells were put under production to supply water for irrigation. Wells were also drilled in the confined, western part of the aquifer (Mukheiba, Wadi el Arab, Waqqas, Abu Ziad and others). The results of the extensive water extraction were dropping water levels and declining water table. The parts of the confined aquifer west of Irbid become free water table aquifers. Figures 19 and 20 show the drawdown in water levels in the area. On average for the last 8-20 years the declines in water levels for the different wells ranged from 0.55 cm/yr in Ilyan Migbel well in the unconfined part of the aquifer to 3.2 m/yr in Kufr Assad well in the confined part of it.

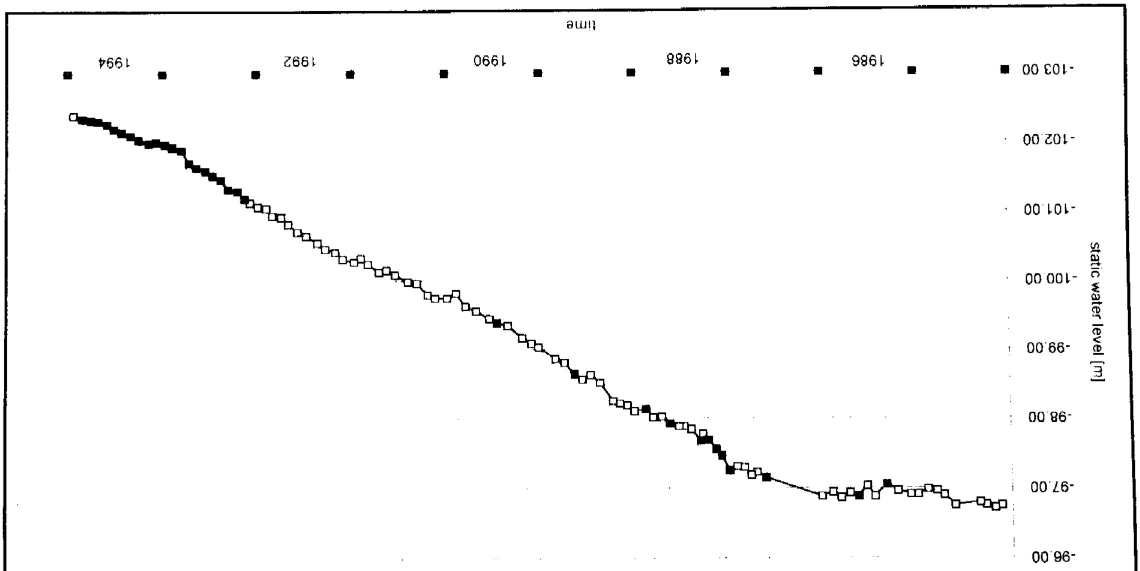


Fig. (18b): Observation well ED 1328 - Q'aa Khreim (S 28)
PGE 223820 PGN 877860 ALT: 840m TD: 543m Aquifer: Disi Recorder

BGR - WAJ

Fig. (18a): Observation well ED 1303 - Sahl es Suwwan (S3)
PGE 217470 PGN 884340 ALT: 828.6m TD: 163m Aquifer: Disi Recorder

BGR - WAJ

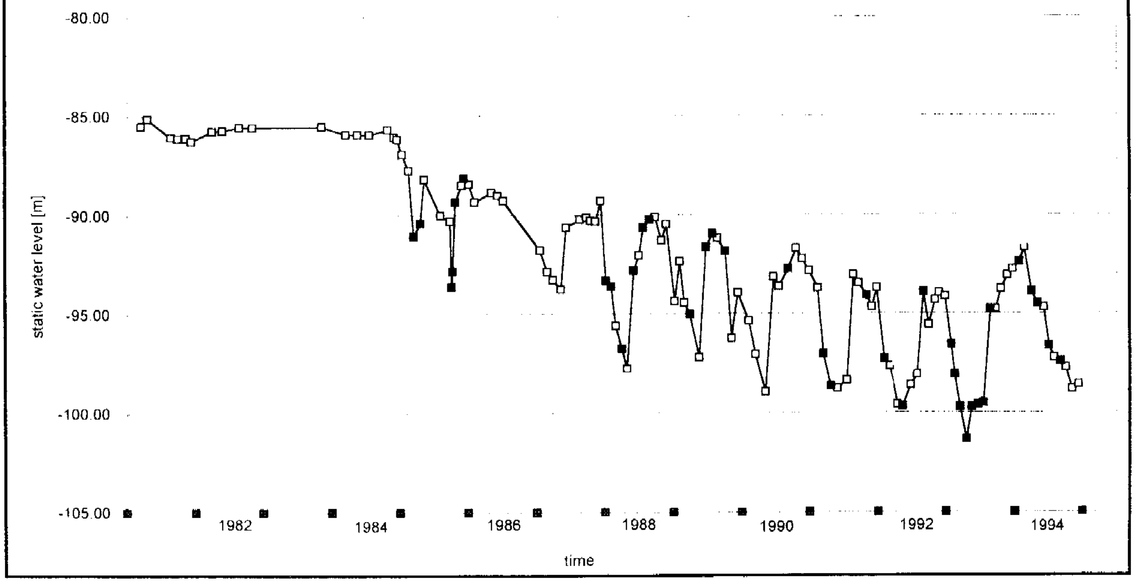


Fig. (18c): Observation well ED 1202 - Mneisheer MW-2
PGE 206050 PGN 895540 ALT: 802m TD: 300m Aquifer: Disi Recorder

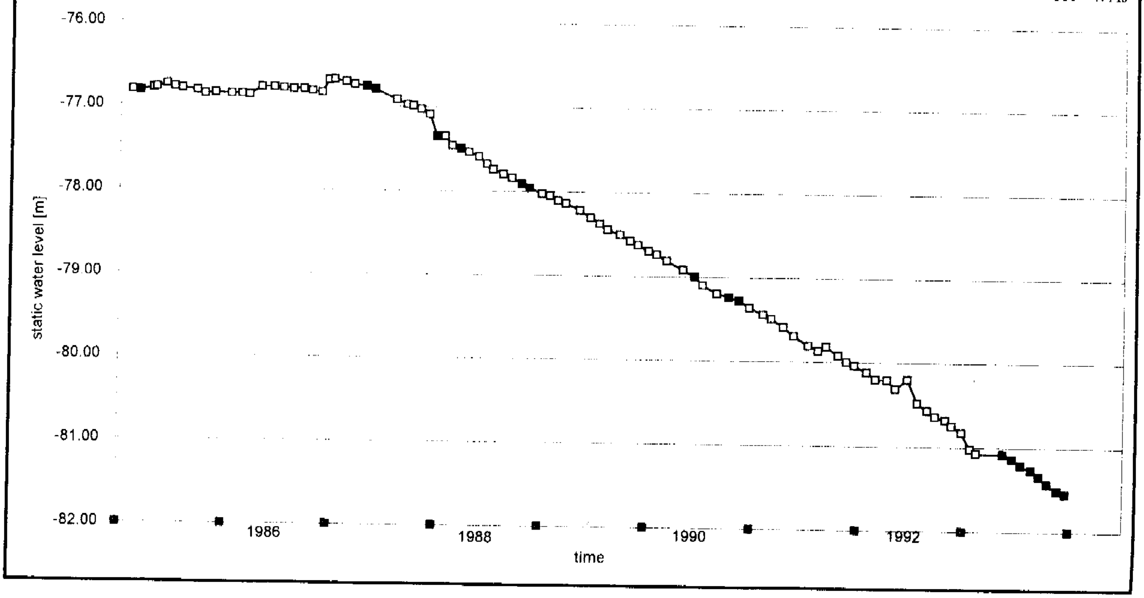


Fig. (19a): Observation well AD 1276 - Mukhaiba well No. JRV. 1
PGE 214700 PGN 234500 ALT: -70m TD: 1238m Aquifer: A7/B2+A1/A6 (Recorder)/Discontinued

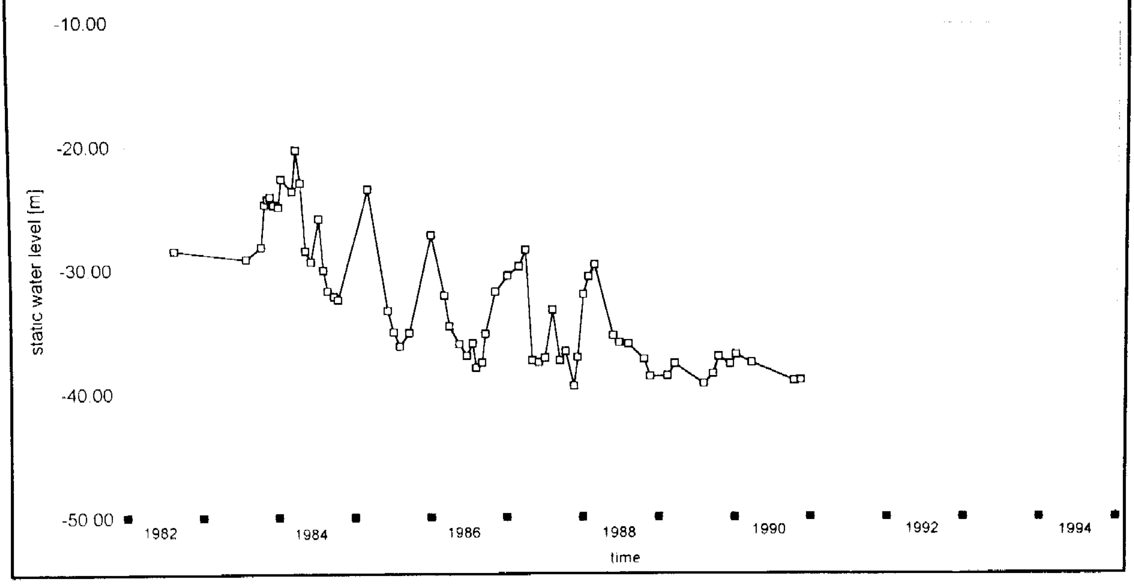


Fig. (19b): Observation well AD 1148 - Ilayan Miqbel obs. Well, Somaya No. 1
PGE 264360 PGN 204060 ALT: 622m Aquifer: A7/B2 Recorder

BGR - WAJ

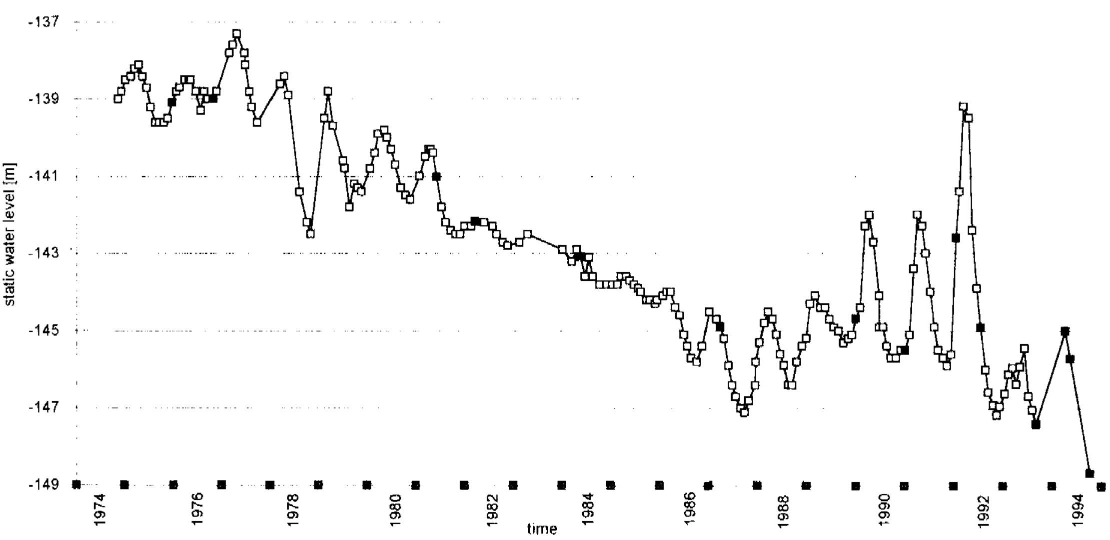
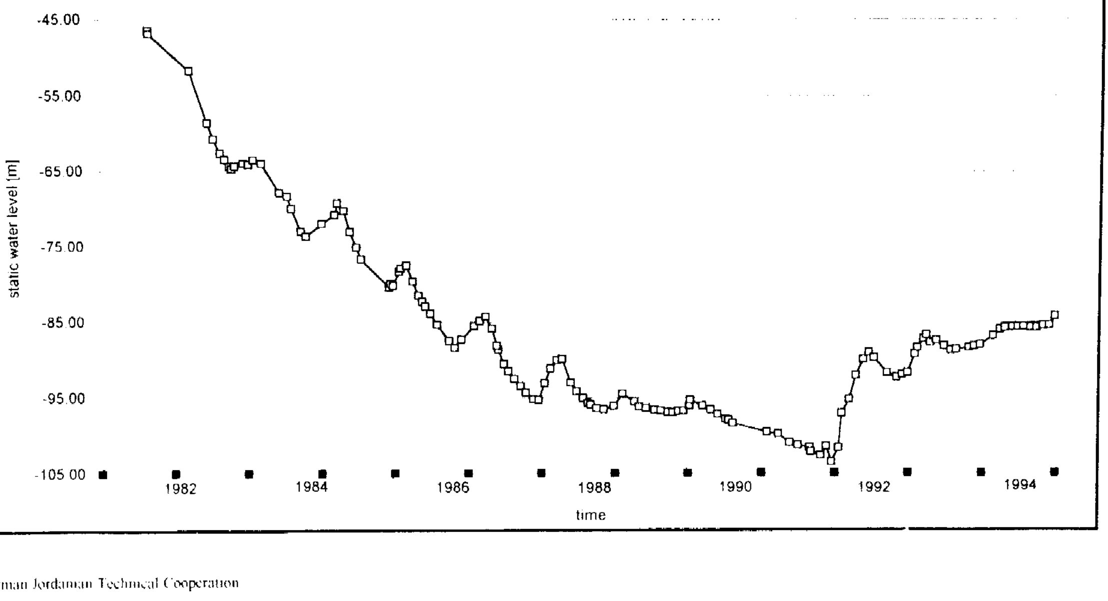


Fig. (20a): Observation well AE 1003 - Kufr Asad
PGE 217025 PGN 225750 ALT: 105m TD: 263m Aquifer: A7/B2 Recorder

BGR - WAJ



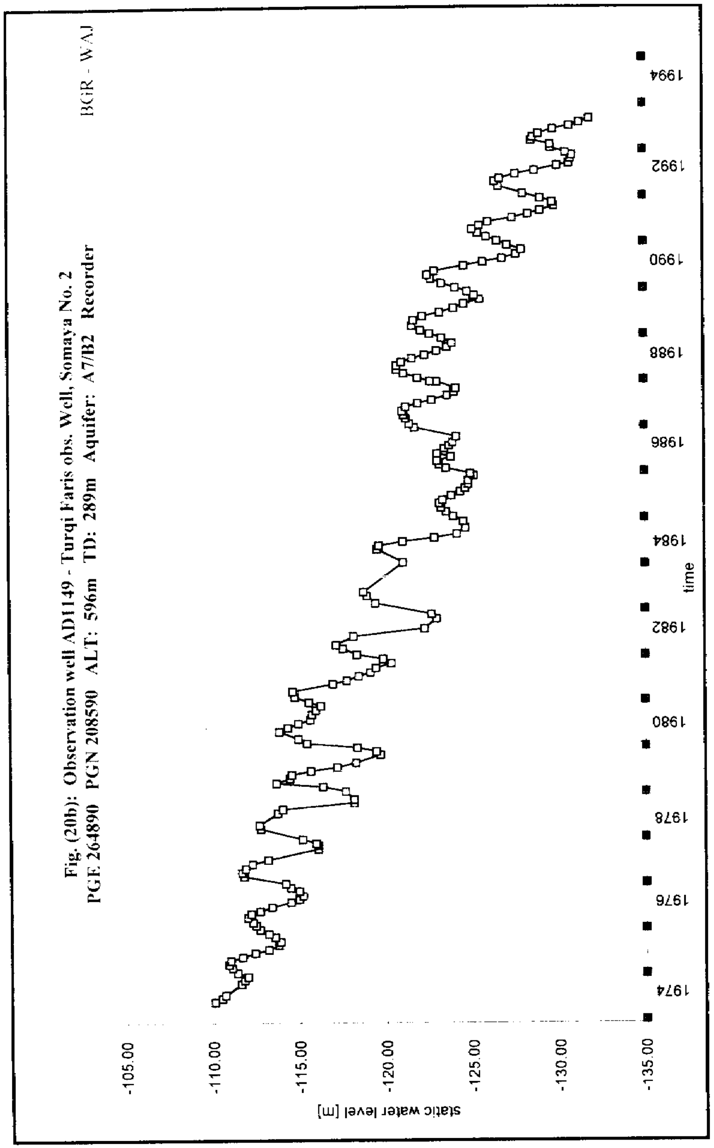


Fig. (20b): Observation well AD1149 - Turqi Faris obs. Well, Somaya No. 2
PGE 264890 PGN 208590 ALT: 596m TD: 289m Aquifer: A7/B2 Recorder

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No major changes in the composition of the groundwater were registered in the western confined and unconfined parts of the aquifer: Wadi Arab wells, Mukheiba wells, Nuayma and Yarmouk University wells.

In the eastern parts, irrigation return flows seem to affect the chemistry of the water, but there are no signs of salinization due to overpumping.

2.4.6 Qatranah area

Under this area Qastal, Siwaqa Qatranah Sultani and Hasa are understood. The number of wells in the area is around 250 including some 70 governmental wells. Governmental wells in Sultani supply Karak city with municipal water, whereas Qastal, Siwaqa and Qatranah are connected to the water supply of greater Amman.

The major drilling and extraction activity started in 1984/85. At present around 35 MCM/yr are extracted from the B2/A7 aquifer extending from Hasa to Qastal. The result of this extraction can be seen from Figures 21 and 22 which illustrate the drawdown in observation wells nos. Qatranah 10, Siwaqa 2 Dabaa (S 70) and Wala 14. The drop in water levels in these wells ranged from 70 cm/yr to 2 m/yr.

Looking at the chemical composition of the groundwater no major changes seem to have taken place in the last decade although water levels are rapidly dropping. The reason for that could be the presence of a thick aquiclude underlying the B2/A7 aquifer from the saltier deep groundwater bodies.

Only in a few wells sudden rapid increases in salinities take place. But these increases are temporary and the salinity drops again after aquifer releases. It seems that this phenomenon is restricted to wells close to faults or fault zones where drawdowns in wells due to pumping cause temporary upconing of saltier water along these faults.

2.5 Wasted Groundwater Resources and their Impacts

The Jordan Valley Authority drilled in the nineties and nineties numerous wells along the Jordan part of the rift valley, especially in the area close to the foothills (Hisban, Kafrain, Rama, North-Shuna, Ghor Haditha and other places). These wells produce artesian, salty thermal water from a variety of

Fig. (21a): Observation well CD 1106 - Qatrana No. 10
PGE 247900 PGN 77440 ALT: 793m TD: 226m Aquifer: A7/B2

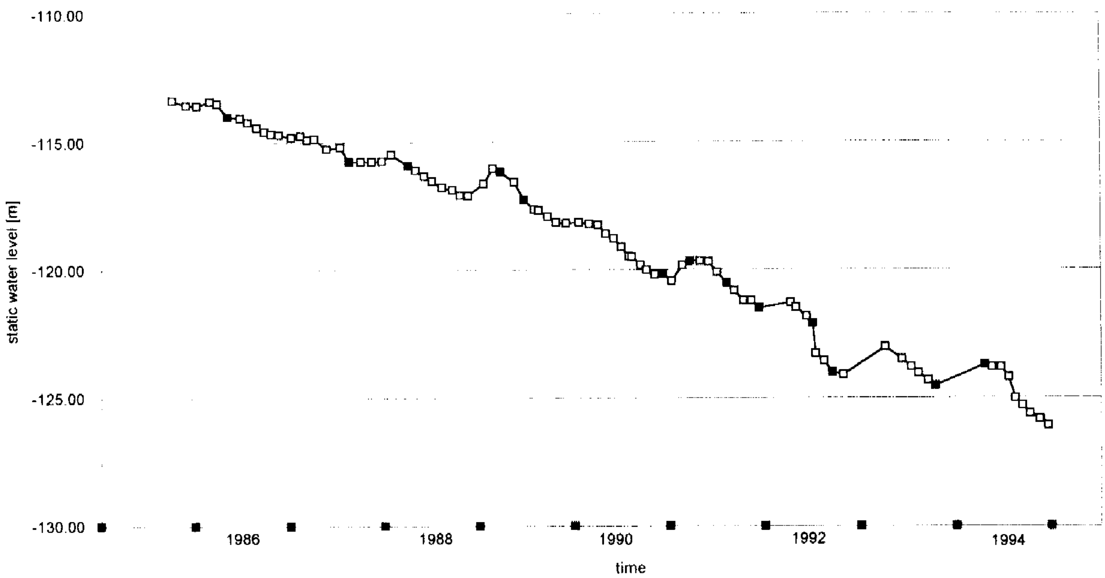


Fig. (21b): Observation well CD 1132 - Siwaqa Oss. No. 2
PGE 254350 PGN 86200 ALT: 736m TD: 400m Aquifer: A7/B2 (Recorder)/Manual

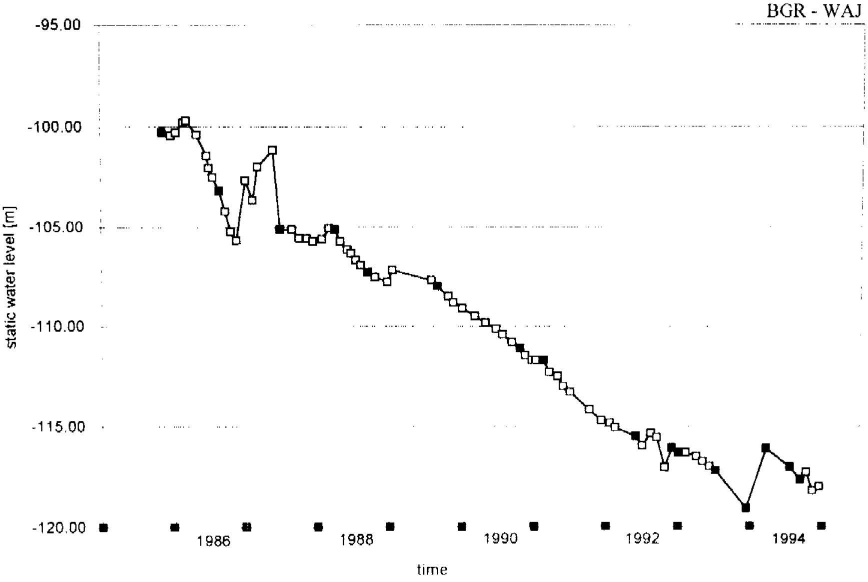


Fig. (22a): Observation well CD 1136 - Dabba (S 70)
PGE 249800 PGN 104060 ALT: 740m TD: 201m Aquifer: A7/B2 Recorder

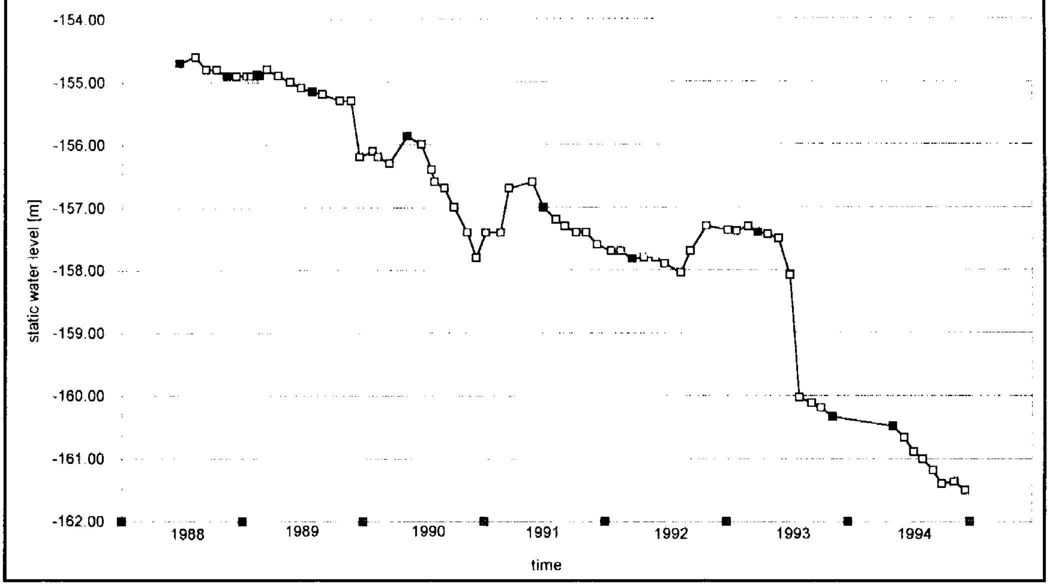
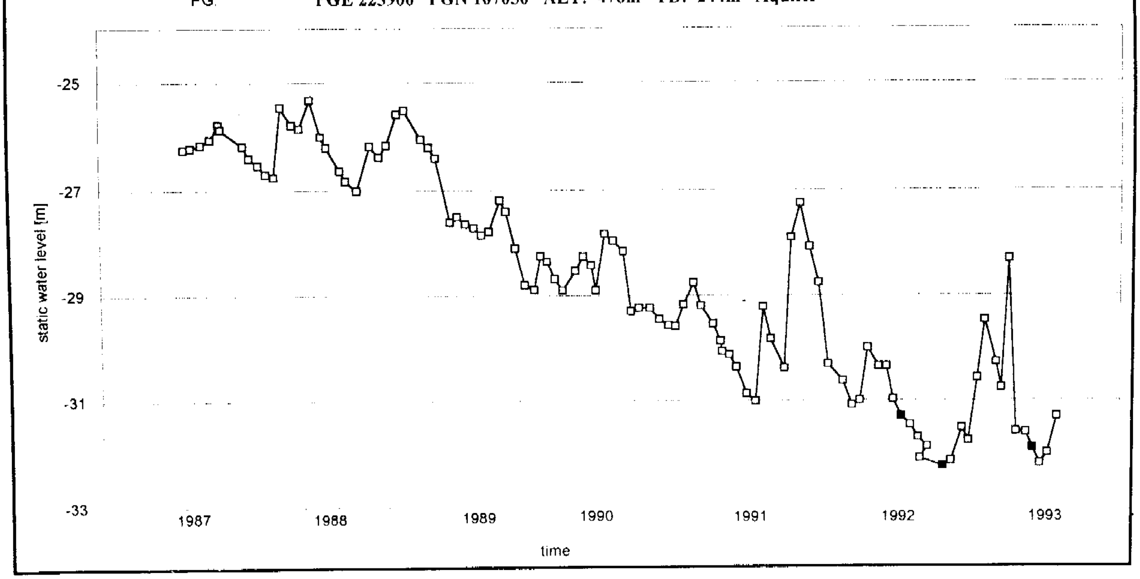


Fig. (22b): Observation well CD 1100 - Al Wallah No. 14
PGE 223900 PGN 107050 ALT: 476m TD: 244m Aquifer



aquifers (Kurnub, Zerka, B2/A7, B4 and combinations of them) covered by confining rocks (B3, B1, A5, 6, A1, 2, 3 and recent marly deposits).

The high salinity of these wells did not allow any relevant use. Also, because they are artesian they continued to flow (to discharge water) since the early to middle eighties without the appropriate efforts of the responsible agency to close these wells and stop their wasted discharges (no use) in the interest of the country's water supply.

Concerning that, two facts are worth mentioning here:

1- Although the water flowing from these wells is salty, the water bodies from which they produce extend in an easterly direction and contain there fresh water, e.g., B2/A7 of North Shuna corresponds to the B2/A7 of Wadi Arab wells and to the municipal and irrigation wells east of Irbid, Nuayma, Yarmouk University ... etc; Rama wells produce from the same Kurnub-Zerka Aquifer complex producing fresh water in Baqa'a and west of Mahis.

2- The eastern extensions of the water producing aquifers and the water contained in them build the backbone of the overlying fresh water bodies which form irreplaceable sources for the water supply of the country.

The conclusion is now that the salty water flowing out of the wells in the Jordan Valley area belongs to the same water bodies producing fresh water in the highlands. Therefore, not stopping the useless discharges of these wells will have the result of partly emptying the aquifers or draining the water bodies with the following consequences:

1- The fresh water in the eastern extension of the water bodies will move faster westward, down-the-gradient to the well's areas where the aquifer matrices are salty causing the salinity of the fresh water to strongly rise.

2- Generally, the eastern extensions of the water bodies from which the above mentioned wells produce build the basis water body over which all shallower groundwater bodies rest in a hydrodynamic equilibrium. The draining of these underlying groundwater bodies means that the overlying ones will have to substitute any water deficit arising in the lower groundwater bodies. This leads to declining water levels and salinization of the fresh water introduced into the salt water confined aquifer.

Allowing the wells to flow uncontrolled and the water unused during the last 10-15 years is depriving the country of vital groundwater resources and undermining its water supply base.

Such actions and projects leading to depletion and salinization of water resources without any benefit to anybody whether intended or unintended can be considered as an "act of terror" against the interests of the nation and its resources base. Hence, it should be stopped immediately.

IV
Water Pollution Management and Cost

1. Management and Cost

Water pollution management efficiency can be measured by its performance. A sound management is in place when water resources use is efficient. Misuse of water resources, water pollution, overutilization or not respecting sustainability principles and intergeneration equity indicate unsound water resources management. In this context it should never be accepted that the cause of development is used as a reason to sacrifice the water resources whether quantitatively or qualitatively. Because doing so will bring the whole issue of development into a vicious circle, in which degradation of water resources as a vital element of the environment may in turn negatively impact the development itself.

Therefore, development should be compatible with the water resources issues, especially their pollution and sustainability in countries with scarce or poor water resources. Accordingly, appropriate management of water resources incorporates also the management of their environmental aspects, altogether within the framework of sound economics.

Therefore, any project generating degradation of water resources without the mechanisms and economic instruments to repair that degradation can be regarded as a misallocation and misuse of water resources.

This implies that any water development plan whether for urban, industrial or agricultural use should include an economic feasibility aiming at objectives beneficial to the society. But, if the environmental aspects of water resources development use, disposal of waste water and reuse are not fully included in that feasibility, the benefits to the society remain partial or even only apparent. In this case the whole development is, in reality, on the long-run detrimental to the society and not beneficial.

Therefore. the objectives or water resources development and use are obvious and aim at serving the society. But, the main objectives of water pollution prevention should be explicitly expressed here. They are:

- achieving sustained use of water resources taking into consideration intergeneration equity.
- satisfying the basic needs of the population on a clean, adequate water supply, without destroying the resources base.
- reaching an environmentally healthy situation in all that concerns water extraction, use, treatment of waste water and its reuse.

This leads us to state that, developing water resources should be addressed within a comprehensive framework of quantity and quality aspects and within the context of the environmental assimilation capacity, intergeneration equity and economic soundness.

Our concern is now, how to address water degradation, and depletion issues in economic terms in order to achieve an environmentally relevant water management conditioned by intergeneration equity and economic feasibility.

The main objective of economically evaluating water resources pollution and damage is to facilitate a better understanding of the human impacts on these resources. The value assigned to a water source depends on several factors such as its use, its relative scarcity, the demand for it, and its socio-economic relevance. But, assessing the economic value of a water source 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. Nevertheless the criteria for price setting may differ from one area to another and from one water use sector to another.

Degradation of water resources whether quantitatively or qualitatively can also be economically approached by evaluating the economic losses due to degradation of water resources or their complete loss. In this case one can approach valuing water degradation by two means:

1. Calculating the cost of degradation abatement; this the cost incurred to reduce or eliminate the degradation causes, e.g., adequately treat pollution at source.

2. Calculating the cost of damage due to degradation of water resources (e.g., decreasing productivity of irrigation water due to increasing water salinity).

Pollution and degradation reduce the value of the affected resources whether water, soil, crops ... etc. which are common goods of the society. For. in restoring the affected environmental elements cost is involved.

Sometimes its is essential to compare both costs of 1 and 2 above just to illustrate the severity of the problem once degradation is spread from a limited place and defined amounts into larger area extents and increasing damage.

If practically, the cause of degradation can be eliminated at a certain cost. then not spending this cost can be considered as the cause of degradation.

Also the principle that polluters have to bear all the cost of the repair of any water resources or environmental damage for the welfare of the society indicates that water resources and environmental degradation are economic problems.

Not included in the cost mentioned above is the social cost which accounts for detrimental consequences of water resources degradation to the physical and mental well-being of the members of the society (e.g., social cost of odorous waste water treatment plants). Therefore any valuation of degradation of resources can only be sketchy, because any damage involves significant psychological elements, such as loss of pleasure owing to the pollution of a surface water body say a lake (no swimming, no fishing, bad smell) or visual pollution or pain or suffering.

2. Examples of Degradation Cost

2.1 Waste water treatment

As mentioned in the chapter about "Pollution", waste water treatment in Jordan is achieved by a variety of methods with different effluent qualities and different costs. Table (38) shows the cost of treatment for the different domestic waste water plants in Jordan for the years 1993-1995.

This table indicates the following facts:

1- The treatment in stabilization ponds (S) is cheaper than in mechanical treatment plants (M). It costs only about half of mechanical plants.

2- Within stabilization ponds the treatment cost ranges from around 13 fils/m^3 in Khirbet-es-Samra up to 55 fils/m^3 in Mafraq WWTP.

3- The cheapest cost per m^3 in a mechanical treatment plant is 68.5 fils in Salt and the highest in Abu Nusseir with 163 fils.

At first glance, stabilization ponds seem to be a very attractive option for waste water treatment from a cost point of view. But, if the effluent qualities of these stabilization ponds and their environmental impacts are considered the whole picture may change. The impacts of these WWTP have numerous economic dimensions such as:

Table (38): Waste water treatment operation cost (fils/m^3)

Year	1993	1994	1995	Average	Type of plant
Kh. es-Samra	12.4	12.6	13	12.65	S
Aqaba	33.1	31.2	35.4	33.2	S
Madaba	35.4	47	53.7	45.4	S
Mafraq	47	47	70	55.3	S
Ramtha	55.8	54.7	52	54.2	S
Ma'an	42.8	----	41.7	42.3	S
Irbid	----	----	82.2	82.2	M
Jarash	82.2	94	114	96.7	M
Kufranja	165	----	105	135	M
Baqa'a	94.8	98	94	95.6	M
Abu Nusseir	165	164	160	163	M
Salt	69.6	61	75	68.5	M
Karak	136	----	114	125	M
Tafilah	135	144	123	134	M

- High evaporation losses.
- Degrading qualities of groundwater bodies underlying the treatment plant and along wadis where effluents are discharged.
- Deterioration of surface water qualities along wadis and river courses, in surface water reservoirs and finally in areas where the water is reused in irrigation.

- Health detriments to the population living in the surroundings of these plants and along the effluent courses.
- Deterioration of the quality of life for the affected population groups.
- Health impacts on the livestock drinking the effluents or feeding on plants irrigated by these effluents.

Of the above mentioned impacts only the first three can be adequately approached in economic terms.

Table (39) gives in some details the running cost distribution of treatment: (salaries, electricity and fuel and others such as chlorination, spare parts ... etc.) and the BOD5 loading in relation to design BOD5 and the hydraulic loading compared to design, in addition to the effluent BOD5 as a measure of efficiency. This table shows the following:

1- All stabilization ponds produce an effluent with a BOD5 concentration of more than 144 mg/l with the exception of Aqaba WWTP with an effluent BOD5 of 74 mg/l which is hydraulically loaded by only 50% of its design capacity and by 65% of its design organic load; BOD5.

2- All mechanical treatment plants produce an effluent with a BOD5 load of less than 45 mg/l, except Baqa'a WWTP with an effluent BOD5 of 297 mg/l. (underloaded hydraulically 90%, overloaded organically 147%).

3- The salaries paid for WWT range from 3.9 fils/m^3 in Khirbet es Samra up to 98 fils/m^3 in Karak WWTP. Salaries in stabilization ponds range from 3.9 fils/m^3 in Khirbet-es-Samra to 50 fils/m^3 in Mafraq. For mechanical WWTPs it ranges from 27 fils/m^3 in Salt up to 98 fils/m^3 in Karak. Such discrepancies indicate the state of overstaffing in most WWTPs. They should hence not be taken seriously in the treatment calculation cost.

   Mafraq, Ramtha, Madaba and Ma'an stabilization pond treatment plants are surely overstaffed. Also very strongly overstaffed are Karak, Abu Nusseir, Tafilah and Jarash mechanical treatment plants.

4- If salaries are ignored then the cost of treatment ranges for stabilization ponds from 3.7 fils/m^3 in Ramtha to 20 fils/m^3 in Mafraq, and for mechanical WWTPs it ranges from 16 fils/m^3 in Karak to 75 fils/m^3 in Kufranja.

Table (39): Cost, load and evaporation for waste water treatment plants

	Type of Treat-ment	Salary fils/m^3	Electricity + fuel fils/m^3	Cost without salary fils/m^3	Total cost fils/m^3	Hydraulic to design load	Actual to design BOD5	BOD5 in effluent mg/l	Evaporation % of incoming water	Potential evaporation rates mm/yr
Kh. es Samra	S	3	3.5	9	13	190%	110%	144	18%	2900
Aqaba	S	22	8.1	13.3	35.4	50%	65%	74	30%	4000
Madaba	S	41	8.1	12.7	53.7	100%	180%	329	38%	2700
Mafraq	S	50	9.3	20	70	68%	80%	272	33%	2850
Ramtha	S	46	5.6	6	52	65%	126%	290	34%	2800
Ma'an	S	38	2.8	3.7	41.7	75%	90%	170	35%	3700
Irbid	M	43	16	39	82.2	67%	186%	35	~3%	2300
Jarash	M	66	36	48	114	125%	125%	28	4%	2300
Kufranaja	M	30	26	75	105	40%	100%	29	2%	2200
Baqa'a	M	33	21	61	94	90%	147%	297	<2%	2600
Abu Nusseir	M	92	34	68	160	30%	95%	19	~2%	2500
Salt	M	27	33	48	75	158%	83%	30	2.5%	2500
Karak	M	98	2.7	16	114	110%	62%	45	<3%	3000
Tafilah	M	91	20	32	123	50%	82%	43	2.5%	3050

S= stabilization ponds, M= mechanical treatment

5- The cheaper treatment in stabilization ponds is strongly reflected in the bad effluent quality.

For retention times ranging from 28 to 40 days and evaporation rates r... from 2800mm in Ramtha to 4000mm in Aqaba evaporation losses ... stabilization ponds range from 18% to 38% of the inflowing amounts into these treatment plants compared to 2-3% in mechanical WWTP.

The weighted average evaporation losses of all stabilization ponds amount to 25% of the incoming water, which means a loss of water resources of 13 MCM/year with a value of 1 million JD if that lost water were made available to farmers in the highlands (average running and capital cost of groundwater extraction is 80 fils/m^3. But, if the productivity of the water in irrigation is considered (1 JD/m^3, Pride 1992, Dietz 1987, Salam 1995) the loss for the nation equals 13 million JD/year. The other result of evaporation loss is the salinity concentration in the remaining water which equals, in the case at hand 30% increase over the original salt concentration of around 1500 µS/cm.

For the different stabilization ponds the effluent salt concentration is 22% to 70% more than the inflow concentration.

Such an increase means further deterioration of water qualities. The reduction in the productivity of such water when used for irrigation compared to it at normal salinity ranges between 10% and 30% for those crops normally produced in Jordan Fig (6). The average productivity reduction is around 20%. Even if the water is diluted by a better quality water in a ratio of 1:2 (better to treated) the result will still be a reduction in crop productivity of around 15% of original productivity of the mixed water. But because effluents are not always diluted and dilution water is not always available, it is estimated that losses are in the range of 18% of the original productivity for the main crops in Jordan.

If the average productivity of 1 JD/m^3 of water is reduced by 18%, the average productivity losses of the 53 MCM/year of stabilization ponds effluents amount to 9.5 million JD per year.

The waste water in the stabilization ponds infiltrate through their unsealed bottoms to the groundwater bodies. Also the effluents flowing along the downstream wadis infiltrate and recharge the groundwater. Because of their high organic and salt contents, and due to their ability to react with rocks (aggressively) infiltrating waste waters and effluents become saltier, and cause therefore rapid increases in groundwater salinities and organic matter contents (Wadi Dhuleil, Hashimiya area, Aqaba, Ramtha, Madaba and Mafraq).

The amount of deteriorated groundwater in those areas is 9-11 MCM/year which means losses of their productivity or of the water bodies themselves.

Many wells and springs along Wadi Dhuleil, Wadi Ramtha and generally down gradient areas of stabilizaition ponds (see chapter on pollution) suffered severe quality deterioration due to pollution and salinity and salinity increases. Many of the wells and springs have been abandoned. New projects and new water resources had to be planned and developed which meant large investments for the public and private sectors. The estimated operation cost of the new projects is 1.5 to 2 million JD/year with a capital cost of 15-20 million JD.

In addition to the physical losses of water due to evaporation, to quality deterioration and to productivity losses the incurred costs to the society (the social cost) such as the physical and mental well-being sufferings of the society members caused by odour or loss of pleasure, or visual pollution has to be taken into consideration when calculating the economic impacts. But, it is very difficult to quantify these losses in monitory terms. Nonetheless, they should be kept in mind.

Now the degradation abatement costs incurred during a more efficient treatment of waste water than that achieved in stabilization ponds can be compared with the cost of damage resulting from the present situation due to stabilization pond effluents.

To treat the water properly in a mechanical WWTP such as Salt, Irbid, Jarash, Karak or Tafilah, the treatment cost excluding salaries is 16-48 fils/m^3 with weighted average of 36 fils/m^3 compared to 10 fils/m^3 in stabilization ponds. The additional running cost of treating the water (53 MCM/year) properly in mechanical WWTP instead of stabilization ponds amounts to 1.4 million JD/year which means that the degradation abatement cost is merely

1.4 million JD/year. T'.. present degradation losses of the physical damages of stabilization ponds effluents at present are as follows:

* 13 MCM/year evaporation losses with a productivity value in agriculture of 13 million JD/year. (To produce 13 MCM/year from groundwater cost 1 million JD).
* a loss of effluent productivity due to increasing salinities as a result of evaporation amounting to 9.5 million JD/year.
* damage to the local groundwater resources of 1.5 million JD/year to substitute them, or 9-11 (say 10) million JD to account for their productivity in irrigation. Hence, the total losses add to 24 million JD/year or to 34 million JD/year to account for productivity.

Comparing the degradation abatement cost of 1.4 million JD/year to the actual damage of 24 million JD/year or to productivity detriments of 34 million JD/year shows that stabilization ponds are damaging to the water resources of the country and its economy.

During the last 10 years, since the establishment of the first stabilization pond treatment in Jordan in Khirbet es Samra, this type of treatment proved to be an environmental and economic disgrace to the country and its people.

2.2 Cost of Aquifer Overexploitation and Depletion

Groundwater from all major aquifers in Jordan is extracted for municipal water supply. From most aquifers irrigation water is produced, and in some defined areas, groundwater is extracted for industrial uses.

The main areas producing groundwater for municipal uses are:

* Disi for Aqaba
* Azraq for Azraq and Amman
* Swaqa - Sultani - Qatranah for Amman
* Madaba, Karak, Qatranah...etc.
* Amman-Zerka for Amman-Zerka areas
* Za'atari-Mafraq for Mafraq governorate
* Yarmouk and Wadi El Arab groundwater basin for Irbid governorate and Ramtha
* Shoubak for Shoubak
* Jafr for Ma'an
* Jordan Valley aquifers for Jordan Valley domestic supply.

As elaborated on in the section on "Pollution" all the aquifers underlying the highlands are suffering from overexploitation (depletion) and salinization.

Within Jordan, there are no appreciable aquifers to be developed in addition to those under use. Therefore, no substitution for any of these groundwater resources serving domestic supply are to be found in the country. This implies that the country from within its territories is not able to continue supplying any city, town or settlement, even not with the present supply amounts if the groundwater aquifers in use now deplete or suffer quality deterioration, such as salinization, which prohibits the use for household purposes.

From this it can be concluded that for the country's municipal water supply two options remain open:

a- Cutting agriculture in the highlands to stop groundwater depletion and salinization and allow the aquifers to recover.
b- Desalination of sea water or import of water from water-rich countries.

Even the supply to cover the immediate needs of the country's growing population can never be covered from the present sources unless one or both of the above mentioned options are implemented.

Cutting agriculture does not imply that the saved amounts of water can be allocated for domestic supply because the aquifers are now overexploited, and the total annual depletion exceeds the safe yields by some 300 MCM/year. This is to say that irrigational water use in the highlands should be cut by 300 MCM/year, in order that no further drop in water levels takes place.

Another fact is, that around 235 MCM/year out of around 270 MCM/year used for domestic and industrial water supplies are taken from the highland aquifers. This amount of 235 MCM/year approximately resembles the renewable groundwater amounts in Jordan of some 275 MCM/year.

As a consequence of that, all irrigated agriculture in the highlands has to immediately be stopped just to arrive at an equilibrium between extractions for domestic and industrial supplies on one hand and renewable groundwater amounts (safe yield concept) on the other. But even such an action will not allow aquifers to recover.

If water use priorities are listed then supplying household water seems to have a first priority because it has unreplacable benefits to the society in general and to each individual consuming this water. Making a certain minimum level of water supply to the population is a merit and hence it is not surprising that the government of Jordan subsidize water and that the water issue receive much political attention. Such a priority cannot be assigned to the other main use sectors; industry and irrigation. Although prioritization here is also somehow necessary, the fact that industrial water uses amount to only 5% and irrigation uses to 70% of the total uses and the other fact that water productivity in the industrial sector (m^3/JD output) is 20 to 30 times of productivity in irrigated agriculture indicate that the competition between the two is not to be feared on the long run nation-wide. On a local scale (industrial plant versus irrigation) prioritization may turn to be an economic problem; who can pay more or pay the other or industry use the water first, treat it properly to be reused in irrigation.

The growing population requires additional amounts of domestic water which implies that even if irrigated agriculture with fresh groundwater in the highlands were immediately stopped increasing domestic and industrial water supplies would not come from the present groundwater resources, if safe yield and supply continuity principles are to be respected.

The above discussion shows that the option of curtailing or even stopping irrigated agriculture using freshwater in the highlands does not mean saving water for other uses. Hence, the only option for Jordan to sustain and increase its municipal water supply would be to desalinate sea water, or to import water from water rich countries.

The desalination cost, amounts to $US/1-1.5 per cubic meter at sea shore. Transportation and distribution cost depend on the supplied area. To supply Amman, for example, from water desalinated at Aqaba transportation and distribution cost may amount to $US 0.5/$m^3$.

This indicates that the option of making desalinated water available in Amman would cost something between $US 1.5 and 2.0/$m^3$. Here, it is considered in between $US 1.75/$m^3$.

At present, making water available at Amman from a variety of groundwater sources cost around $US 0.33/$m^3$.

This shows that each cubic meter of groundwater which was and which is being now used in irrigation in the highlands is (1.75 - 0.33) $US 1.42/m^3.

Hence, assigning an adequate price to the groundwater resources to include them in the process of economic development means that each cubic meter of groundwater in the highlands has a value of $US 1.42.

Therefore, and because no options are there for the municipal water supply of the major cities in Jordan other than desalination, the overexploitation of the groundwater resources of the highlands by 300 MCM/year for irrigation means depriving the country (present and future generations) of $US 426 million per year, which by far exceeds the total productivity of water in the irrigated sector.

2.3 Discussion on Regulation and Scarcity Price of Water Resources and Water Quality Deterioration

If water resources are to continue yielding adequate amounts of water with suitable qualities, government interventions in the form of regulation, environmental laws, and pollution control standards become preconditional. Therefore, any consideration of water resources pollution should involve a fair judgement about the level of pollution which can reasonably be tolerated and accepted by the society without compensation. But one important issue in pollution control is the legal acceptance of the principle that an activity could be restricted by governmental actions, if, it is presumed (not proven) to be harmful.

This implies that polluters must obtain from the government a "permission to pollute". Otherwise they should not be allowed to cause any pollution. The permission should specify the quantity and concentration of the effluents allowed to be discharged. In such a case the government takes into consideration effects on downstream areas. Failing to meet the conditions laid down in the permission or to pollute without permission should be dealt with as a criminal offence.

As have been elaborated on in the case of waste water treatment in stabilization ponds, abatement cost of pollution at source is the least costly among all pollution reduction costs and hence it should be always targeted as a first choice option for pollution minimization. Therefore, pollution costs

should be incurred by the polluters themselves at the place of pollution; a company, firm...etc or by the taxpayer in the case of municipal waste water treatment and safe disposal of solid-wastes. But, in order to avoid pollution, polluters should be instructed about the environmental damage (both physical and social) which their pollution may produce compared to the abatement cost of pollution at source. It should be clear to them that it is in the interest of the nation that pollution sources should be treated at source before they inflate. This requires development of market prices for the water.

In general water polluters do not pollute in order to intentionally or unintentionally harm and impose cost on others but, only to avoid the cost of stopping the pollution at its source.

Firms pursue the objectives of increasing their profits and maximizing their revenues by reducing their production costs, but controlling and treating their waste water incurs further costs of production. Therefore, they try by all means to ignore any pollution control instructions, especially if penalties on pollution are less than the cost of abating it at the source.

Unless pollution is controlled and abated at source, pollution abatement cost can be considered as an additional benefit or revenue to the polluter.

In order to sustain the scarce water resources of the country and to conserve their qualities by avoiding overexploitation and water quality deterioration, the overall effects on the water itself and on the produced goods in industry or agriculture will be price increases. However, the major impact of undervaluing the scarcity value of the country's scarce water resources is that goods produced remain underpriced compared to goods which involve economic considerations of water use and its environmental impacts. Therefore, market prices should not only reflect the scarcity of water but also its uselessness resulting from quality degradation.

Water quality degradation and overexploitation are not only undermining the current status of welfare of the material base of the nation, but it will affect the future generation is resources base. Hence water quality degradation and over-exploitation under general water scarcity conditions should urge the responsible authorities to regard water as a national security issue. For each individual of us it should be considered a security problem.

If intergeneration equities are to be addressed, the enhancement of the water scarcity by social and institutional factors such as, inequitable extraction rights, antisocial water resources distribution, ineffective pricing policies, inadequate effluent pollution charges and in general inefficient water resources management should be also regarded and dealt with as a criminal offence on present and coming generations. Therefore, water protection measures in the context of environmental and economic soundness and intergeneration equity should be regarded as a means of achieving the wider objectives of sustainable economic and social growth.

It must also be stated that the willingness and ability of the government to take unpopular measures will largely determine whether the depletion and degradation of water resources will continue to threaten and to damage the socio-economic growth and the well-being of the population. A substantial commitment from the government is required to make decisions that may adversely affect powerful interests.

In addition to the impacts mentioned above of water pollution and depletion other impacts are only partly understood until now. Therefore, levels of pollution are judged according to the present status of knowledge, about effects and impacts, mainly on man and not on the other species sharing the same environmental source. Therefore, it is justifiable and fair to consider any level of pollution or depletion as a potential problem.

V
Conclusions and Recommendations

1. Resources

The history of humans 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-economic status 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, irrigation 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 numerous water problems of the country: such as increasing demand, limited resources, depleting resources, overexploitation, exhaustion of non-renewable resources and pollution.

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 30mm in the southeast and east to about 600mm in the northwest.

The evaporation force of the climate in Jordan is very high: in the cooler north-western areas, it is about 1800mm 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.

2. Projects

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 waste water 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.

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.

3. Water use and Resources Development

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; 220 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 around 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 915 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, suffer from salinity or 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 is now using all its available and renewable resources.

The increasing demand for water led planners to develop the most accessible sources, concentrated in certain areas, while others remain 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.

4. Pollution and Overexploitation

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 wastewater treatment plants, the choice of inferior waste water treatment plants and inappropriate reuse schemes.

Cesspools and sewers are leaking to the groundwater causing their pollution. Cross-connections with the leaky water supply net is also leading to contamination of municipal water supplies.

Jordan's scarce water resources, lack of perennial flows, hot climate and relatively low per-capita use of water result in a dense waste water 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 stabilizaiton ponds in the Khirbet es Samra (Amman-Zerka area), Mafraq, Aqaba, Madaba, 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.

Overexploitation of aquifers on the account of the country's reserves of non-renewable and fossil water is gradually leading to aquifer depletion and exhaustion.

In certain areas, Dhuleil Jafr, Azraq and others overexploitation is also leading to aquifer salinization by the mobilization of salt water bodies which are in contact with the fresh water resources.

The safe yield of all groundwater aquifers of the country can now hardly cover the municipal and industrial demand, nonetheless these groundwater resources are overexploited at a rate of something like 300 MCM/year, mainly used in irrigation along the highlands.

Even if no groundwater were allowed to be used for irrigation and if groundwater quality deterioration were stopped immediately, the groundwater stock of Jordan would not recover. The incurred damage during the last two decades is irreparable, and irreversible if groundwater bodies are not allowed to recover by a policy aiming at extracting amounts less than the safe yields.

Most landfill sites in Jordan were chosen at times when the potential environmental impacts of solid water disposal were locally not fully taken into consideration or not well understood. Therefore, pollution-preventive measures in the design of the landfill areas or disposal practices were not even thought of. Other preventive measures such as separation of solidwaste were also not considered.

The pollution caused by the solidwaste disposal sites and/or their pollution potentials show that approaches and management of municipal solidwaste disposal must undergo radical changes, including separation of wastes, reuse, recycling and better protection precautions of surface and groundwater resources by a set of sophisticated measures which should be applied on the disposal site before operating it. Provision for sophisticated leak detection and reduction are of great importance for the protection of the water resources and for sustaining the environment.

5. Additional Resources

The choices for increasing water resources within Jordan are limited to sea-water desalinization at Aqaba and treated waste water 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 waste water 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 waste water treatment and reuse to become an integral part of water services. Although waste water is polluted, proper treatment can make its application in irrigation quite safe. It also has advantages over fresh water: waste water 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 may be 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.

6. Pollution Control, Management and Cost

Like all other material resources, water in Jordan should be considered as a resource having the value of a common good. An adequate water supply in quantity and quality offers to the people facilities to enjoy health and a pleasant life.

A clean water supply and healthy water resources base are like a satisfactory level of nutrition, a good desired by all human beings. Thus societies try to endeavour to promote measures leading to a clean water supply and water resources base. The competition of the different use sectors for this scarce resource; water, in Jordan puts more and more pressure towards a compromise of tolerable water pollution situation and economic development especially because the other use sectors, irrigation and industry produce other goods desired by the society.

Hence, it seems that the resolution of water pollution and resources depletion problems is in itself a resolution of a conflict of interests. Therefore, measures to reduce water pollution levels, to stop resources depletion and to reverse it will positively affect the resources as a common good and hence the society at large, but at the same time these measures will impose costs to the pollution producers and lead to curtailing certain economic activities (irrigation in the highlands). This cost is then effectively carried by the society itself especially in a country like Jordan where water rights (use or property) and pollution control laws are not yet well developed. Worth mentioning is that the legitimate uses of property are, in the case of water, not yet well defined, although that is one of the main functions of the legal system. The fact that the ownership of a property is essentially the ownership of the rights to some, but not all the services that property can offer has not yet been rooted in the thinking of the public of Jordan.

Also the absence of carefully defined responsibilities for a functioning water resources agency enabling to maintain quality and water property rights lead to unlimited use (e.g., in irrigation, or private wells of industry) and to eventual conflicts between different types of use. At the same time unrestricted access (in quantity and quality) to water resources by certain groups (farmers, industrialists) leads to overexploitation and damage of resources as illustrated in the section on pollution.

At this point an aggressive type of management should be implemented in order to limit the damage and restore the resources quantitatively and qualitatively.

In order not to risk irreparable damage, early preventive actions are required, even in advance of clear-cut scientific evidence of relating between water extraction, disposal of waste water or solidwastes on the one hand, depletion of water resources and their quality degradation on the other.

Therefore, in the case of Jordan, the policy of looking at water degradation issues as being less important, and giving greater priority to economic development should be rapidly abandoned in the interest of present and future generations and water resources sustainability. Here, it should be emphasized that water resources can not always be regarded as an externality

in the production process, but as an inherent part of the production and consumption process and that sustainability principles must address that adequately, especially in what concerns water pricing and pollution charges. If because of any reason, such as institutional, administrative, tribal, influential groups of beneficiaries ...etc. water resources have to bear a zero price or a symbolic price, then other regulations and behavioural rules have to be superimposed to reduce and counteract the social cost versus private cost discrepancies.

Such regulations and behavioural rules may contain appropriate environmental standards, taxes on pollution and other policy instruments.

Intergeneration equities in quantitative and qualitative terms have to be one of the major instruments which should govern water developmental policies. They should not be allowed to irreversibly pollute or overexploit a water resource unless the revenues of that are invested for the benefits of future generations to substitute the damage or the depletion of resources, especially those which are non-renewable or fossil.

Protection, enhancement and restoration of water quality and abatement of water pollution should be the major component of any water development program because preservation of the resources base is very vital for sustainable development. This is especially valid when knowing that water pollution and resources depletion abatement costs are for less than the damage cost (compare chapter on pollution).

For that it is very essential to enable policy makers to judge the effects of depletion and degradation of water quality by valuating pollution damage based on the magnitude of the damage in physical terms (m^3 of water) and an agreed upon means of converting that into a common unit of measurements in monetary terms.

A water polluter is likely to ignore the consequences of his activities for others if those affected groups of the society are not quite aware of the magnitude and impact of pollution or if they for any reason (being employed by the polluter, or paid by him, or socially linked to him) suppers their sufferings and the damages their water resources are experiencing. Even governmental agencies try to ignore the consequences of their activities if the affected groups do not oppose or if there is no directly affected group such as depleting aquifers in the Jordan Valley (flowing wells of brackish water) damaging the resources base. Against such damage only NGO's can raise voices in the interest of the society and future generations.

Sewage treatment plants should be designed to accommodate organic and hydraulic loads for the expected population and discharges after 30 years. In Jordan all the waste water treatment plants designed and implemented in the second half of the eighties were overloaded hydraulically or organically after a few years. In all the standards this indicates incompetence, short sightedness and the wish to underdesign to make projects attractive to the government. Those same designers and implementors of such projects thus keep themselves busy because they have to redesign and reimplement after a few years to accommodate the additional loads. (It is a continuous flow of income to them).

Groundwater extraction should be limited to aquifer safe yields; it should have no adverse effects on the groundwater quality or quantity.

If non-renewable groundwater resources have to be exploited (mined) then the revenues of their use (even that of domestic uses) should be able to cover their substitution or they should be invested to enable future generations to substitute them from other resources or by using other technologies (Disi, Azraq, ...etc).

Preventive protection measures against groundwater pollution by the infiltration of lower quality water, such as treated or untreated waste water: irrigation return flows and others, should be well designed and implemented before initiating projects. This requires that cross-sectoral issues related to water extraction. use and discharge such as land use, industrial and agricultural activities should be part of the all over approach to water management. In the case of Jordan, repair of damage to groundwater proved to be inefficient, costly and partly impossible (Dhuleil, Jafr, Azraq, Wadi Dhuleil).

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