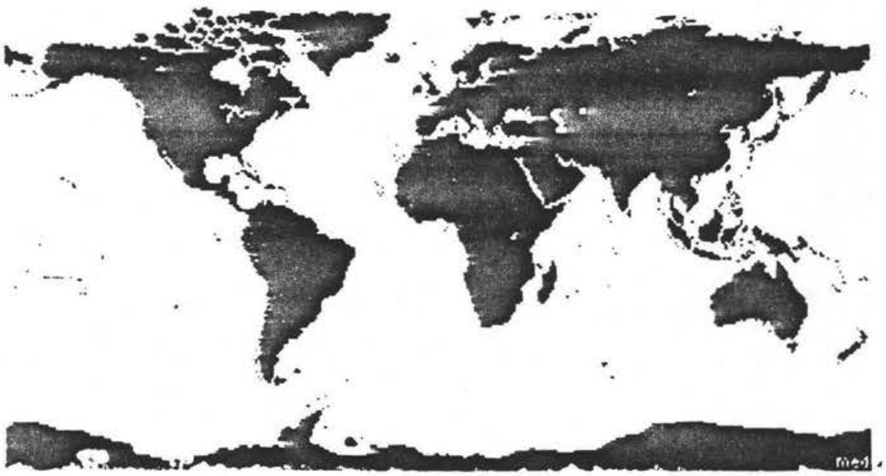
The World Bank, Washington, D.C.

JORDAN COUNTRY PAPER (DRAFT)



# WATER RESOURCES PLANNING AND DEVELOPMENT IN JORDAN

## Problems - Future Scenarios - Recommendations

Maher F. Abu Taleb
Jonathan P. Deason
Elias Salameh

June 1991

# Abstract

Pressured by the U.N. imposed Iraqi embargo, Jordan also faces the worst water crisis in the Middle East. Water availability is estimated at 240 cubic meters per capita per year vis-a-vis the generally recognized 1,000 cubic meter poverty line. To meet growing demand, Jordanians are overpumping groundwater aquifers causing adverse environmental impacts. Surface water resources are only 40% utilized, and further development is fraught with political and financial concerns. This paper places the water problems in Jordan and their socio-economic impacts in perspective. Future scenarios and recommended solutions are presented in an attempt to reconcile future water supply and demand imbalances. An integrated planning and management approach is proposed where optimal resource development opportunities can be identified to improve the overall well-being of the Nation. This approach could make significant contributions to the effectiveness and efficiency of the water resources systems in Jordan.

The opinions expressed in this paper are strictly those of the authors and do not necessarily represent the views of any government or organization.

## Table of Contents

*Chapter I*

# Introduction

In the semi-arid Middle East, water availability has become a major concern for regional policy makers. Water scarcity, coupled with unresolved conflicting uses (e.g., between irrigated agriculture and industry) is overshadowed by regional disagreements and is becoming a significant constraint to development. In Jordan, for example, the water management problem can be characterized by water shortages, environmental quality issues, and supply distribution concerns. The problem is currently exacerbated by high population growth rates and acute financial conditions, among other factors.

Jordan has a national water supply system that currently utilizes over 110% of its groundwater sources (pumping exceeds safe yields in many cases), and 40% of total surface runoff. Further development of surface sources is fraught with political and financial concerns. Over the years, Jordan has steadily developed its water supplies to meet ever increasing water demand. In 1990, total water utilization in Jordan reached 730 million cubic meters (MCM). Presently, the most prominent questions are: (1) how can water supply and demand be reconciled in an optimum manner, and (2) what development and planning approaches should the government employ to provide for the overall well-being of the Nation? The government, through laws enacted over the years, regulates water supply and consumption, and has set water use priorities for the different competing subsectors.

Numerous reviews and studies have appeared over the past decade addressing Middle Eastern water resources issues in general, and Jordan in particular, e.g., Al-Ibrahim (1990), Al-Momani (1987), Naff (1985), Naff and Matson (1984), Salameh (1990), Starr and Stoll (1987, 1988) and Wishart (1989). Most of these studies present a grim picture for Jordan, forecasting that water demand will exceed supply within a short time. Other studies express the need for comprehensive, integrated approaches to the water problems of developing countries (e.g., Munasinghe, 1988; Robinson, 1990; and World Bank, 1988). Although these may present insurmountable difficulties in many countries, the water resources management problems are not as complex or nebulous in Jordan as they are elsewhere. Thus, planning on a multisectoral basis in order for water resources to be optimally developed, appropriately priced, and efficiently utilized, is likely to yield valuable results.

This paper investigates the water problems in Jordan and evaluates the implications, in terms of socio-economic impacts, of various water management policies. Under this framework, the authors explore and analyze a variety of different future scenarios pertaining to water resources planning and development. One of the main ideas presented in this study is the need to optimize the use and development of scarce water supplies.

The organization of the paper is as follows: Chapter 2 provides a background description of the politics, history, demographics and economy of Jordan. The chapter also surveys the country's water resources and discusses the current and future forecasts of water demand and supply. Chapter 3 provides a summary of the institutional and political framework that exists in Jordan. In Chapter 4, a number of future policy scenarios and their likely impacts on water use in the country are described. This scenario development and analysis is regarded as an important step towards integrating water resources development and management as part of a comprehensive planning approach. Chapter 5 provides a summary description of the characteristics of the water problems in Jordan, followed by recommended solution approaches.

*Chapter 2*

# The National Setting

Prior to any attempt at formulating plans or methodologies for water management in Jordan, one needs to be aware of the descriptive trends and characteristics of the country. Figure 1 depicts the Hashemite Kingdom of Jordan as situated in a semi-landlocked region east of the Mediterranean Sea. One immediate consequence of its location is that the two most important surface water sources, the Jordan and Yarmouk Rivers, are shared with other riparians giving rise to immense political ramifications. The country has an area of 90,000 sq. km, and a population of 3.3 million (1991).

## 2.1 History and Politics

Jordan is a constitutional monarchy with two houses of parliament: the Senate, which is appointed by the King, and an elected House of Representatives, which consists of several political backgrounds. Under the founding constitution of 1952, the King and the two houses are vested with the highest legislative authority in the country. The prime minister is appointed by the King and the cabinet is formed upon further consultation. This cabinet is collectively responsible to the elected House of Representatives for gearing national policies to satisfy objectives of growth, development and equity, in a newly growing democratic atmosphere. Free speech, political parties and citizen participation in parliament are the main features of this "new" democracy. For more details on the new Jordanian political experience, the reader is referred to an article by Robins (1990), on the subject of political change in the Middle East.

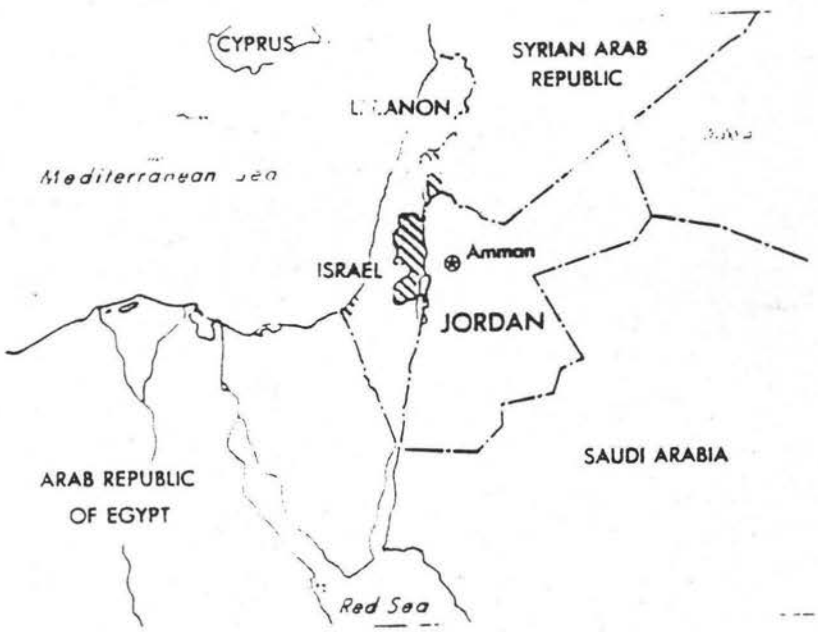



**Figure** 1. Location map of Jordan

Some brief dates in history are noteworthy. In 1946, Jordan gained its independence from Britain, after having been formed as a result of the First World War. King Hussein, the great grandson of Sharif Hussein Ibn Ali, was pronounced constitutional monarch in 1952. In 1945, Jordan became a became a founding member of the Arab League, and on December 14, 1955, the country became a U.N. member.

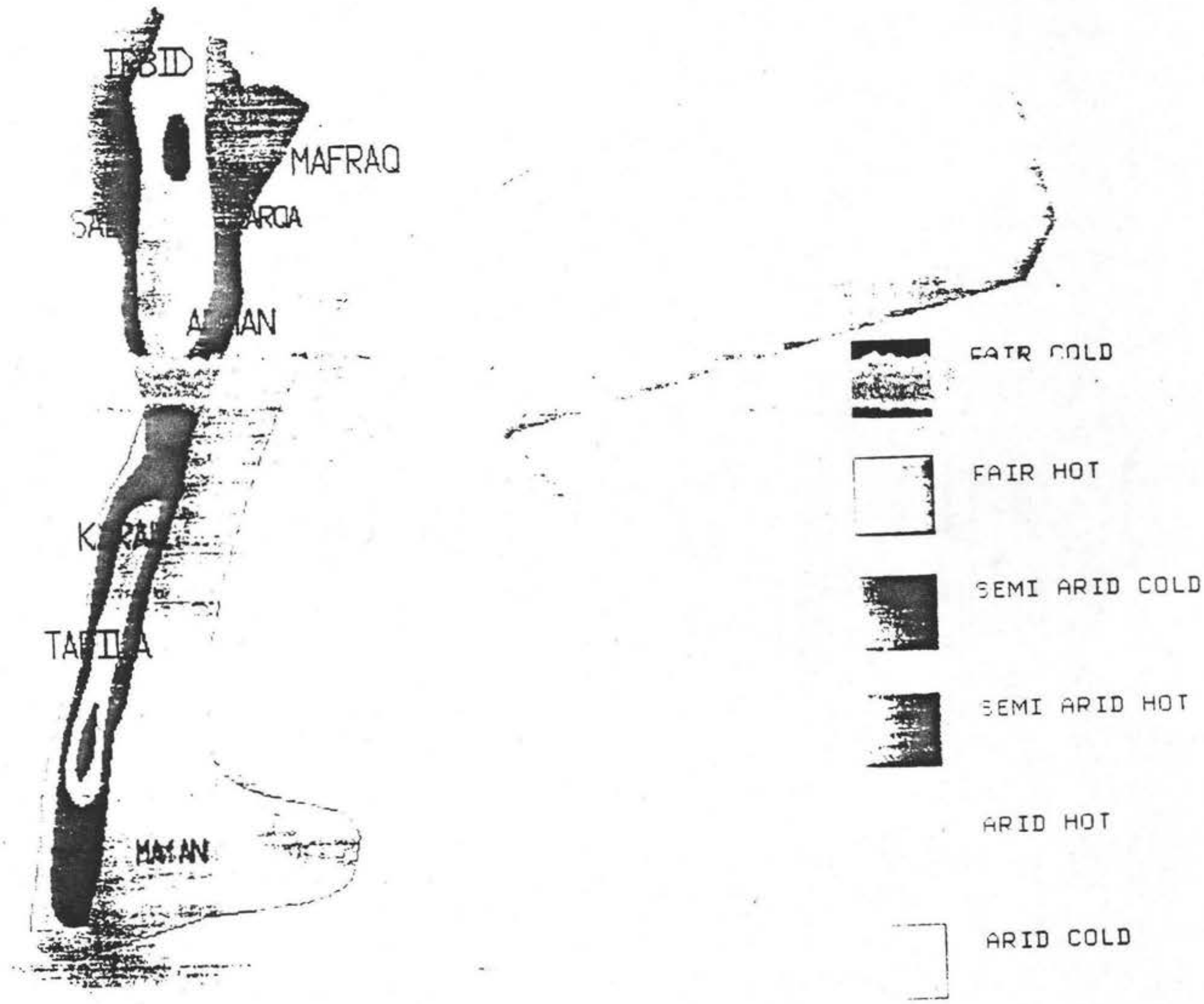
Over the years, living standards have continued to rise with the successful implementation of development programs initiated by the public sector under the guidance of His Royal Highness Crown Prince Hassan. Presently, Jordan has a high literacy rate, and a 1987 per capita Gross Domestic Product (GDP) of U.S. $1,560 per annum (World Development Report, 1989). This figure has declined in recent years, however, to less than U.S. $ 900 due to various economic disturbances (see "Economy" below).

## 2.2 Climate

The eastern regions of Jordan consist of a vast desert plateau while, in the western parts, mountaineous terrain predominates with altitudes exceeding 1,000 m. These mountains and hills slope westwards towards the north-south rift valley forming the Jordan River and the Dead Sea at a record depth of 400 m below mean sea level. The highest elevation is the peak of Rum Mountains at 1,754 meters.

The rift valley climate is warm to hot year round giving rise to rich and diverse agricultural production. The western highlands have gentler temperatures with averages ranging from 7 C in the winter to 33 C in the summer. The climatic regions of Jordan are presented in Figure 2.

Winds are predominantly western in direction and emanate from either the Mediterranean or North Africa. The former are moist in content whereas the latter are dry and blow across the southern regions of Jordan. The average annual precipitation in the northwest varies over a wide range (350-650mm/year, see Figure 3), occuring only in the winter months. Other


MAFRAQ
FAIR COLD
FAIR HOT
SEMI ARID COLD
SEMI ARID HOT
ARID HOT
ARID COLD

areas of the country, experience substantially lower precipitation, with 94% of the total area of Jordan receiving less than 200 mm (see Figure 3).

The dependence upon this endogenous supply of rainfall, which is highly irregular, contributes to the uncertainty involved in any overall water management plan. In fact, Naff and Matson (1984) point out that the rivers and streams in the region drain watersheds that lie within the same general rainfall belt, implying that the countries in the area cannot depend upon any exogenous supply emanating farther upstream due to heavier rainfalls.

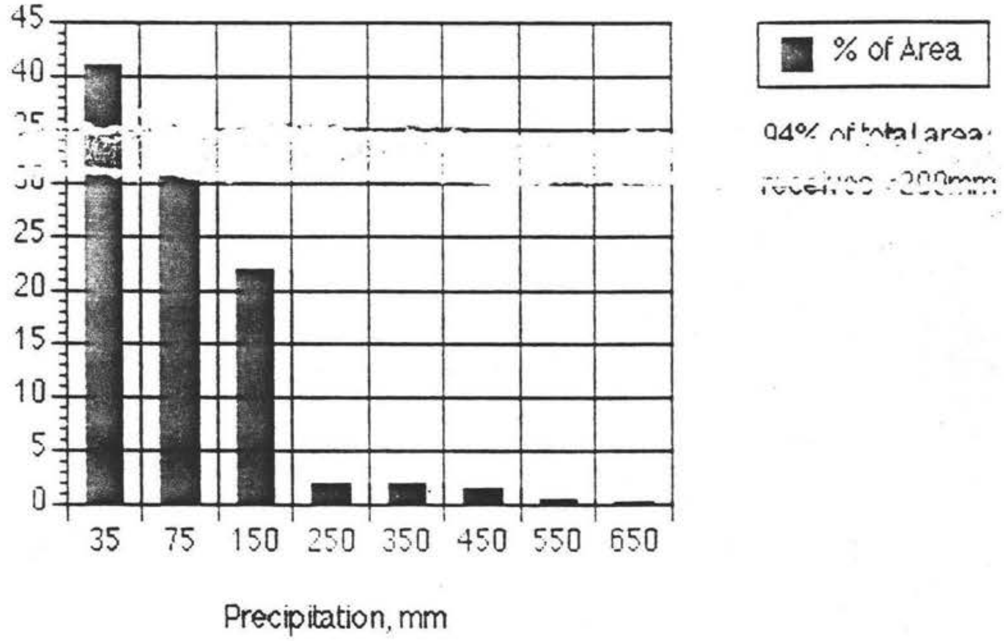
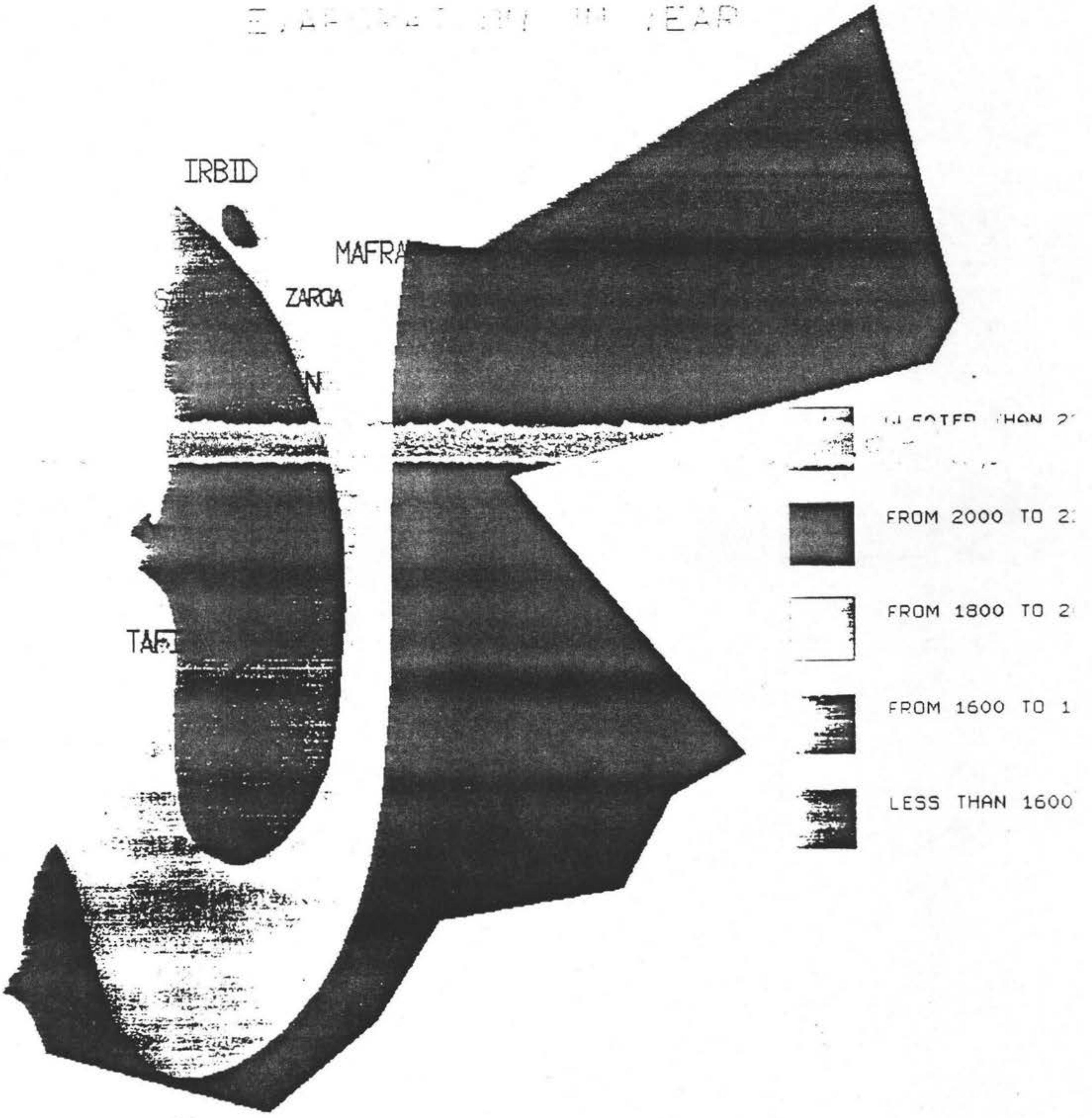



**Figure 3.** Rainfall coverage, 50 year average, 1937-1987
*(Source: Ministry of Water and Irrigation, MWI, 1991)*

Figure 4 provides an estimate of annual evaporation rates. Although high evaporation rates result in relatively low annual streamflows, the relatively high infiltration rates common to many areas of Jordan result in relatively high rates of groundwater recharge. A water balance chart for Jordan in the years 1986 and 1987 is presented in chapter 3.


IRBID
MAFRA
ZARQA
TAFI
FROM 2000 TO 2
FROM 1800 TO 2
FROM 1600 TO 1
LESS THAN 1600

## 2.3 Demographics

From a current total population of 3.3 million, over 90% live in the Northern Highlands and the Jordan Valley, and 75% are concentrated in the urban belt around Amman and Zarka. Figure 5 depicts the administrative boundaries within Jordan and identifies some of the major cities and towns.

In terms of the demographic structure, the Ministry of Planning estimates that 50% of the population are under 15 years old (Jordan Ministry of Planning, 1985). The country's population is increasing by 3.8% per year, which means that the population will double within roughly 20 years at present rates. In a recent article on overpopulation in the Middle East, Misch (1990), refers to a Population Reference Bureau figure indicating that the average woman in Jordan bears six children. Figure 6 illustrates population projections to 2015 in the governorates.

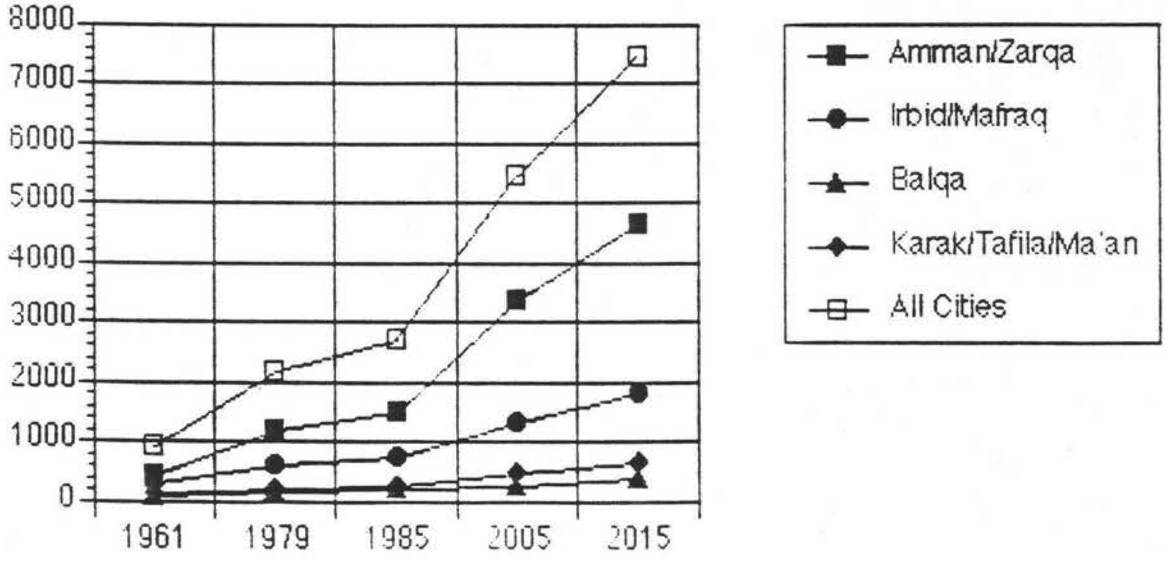
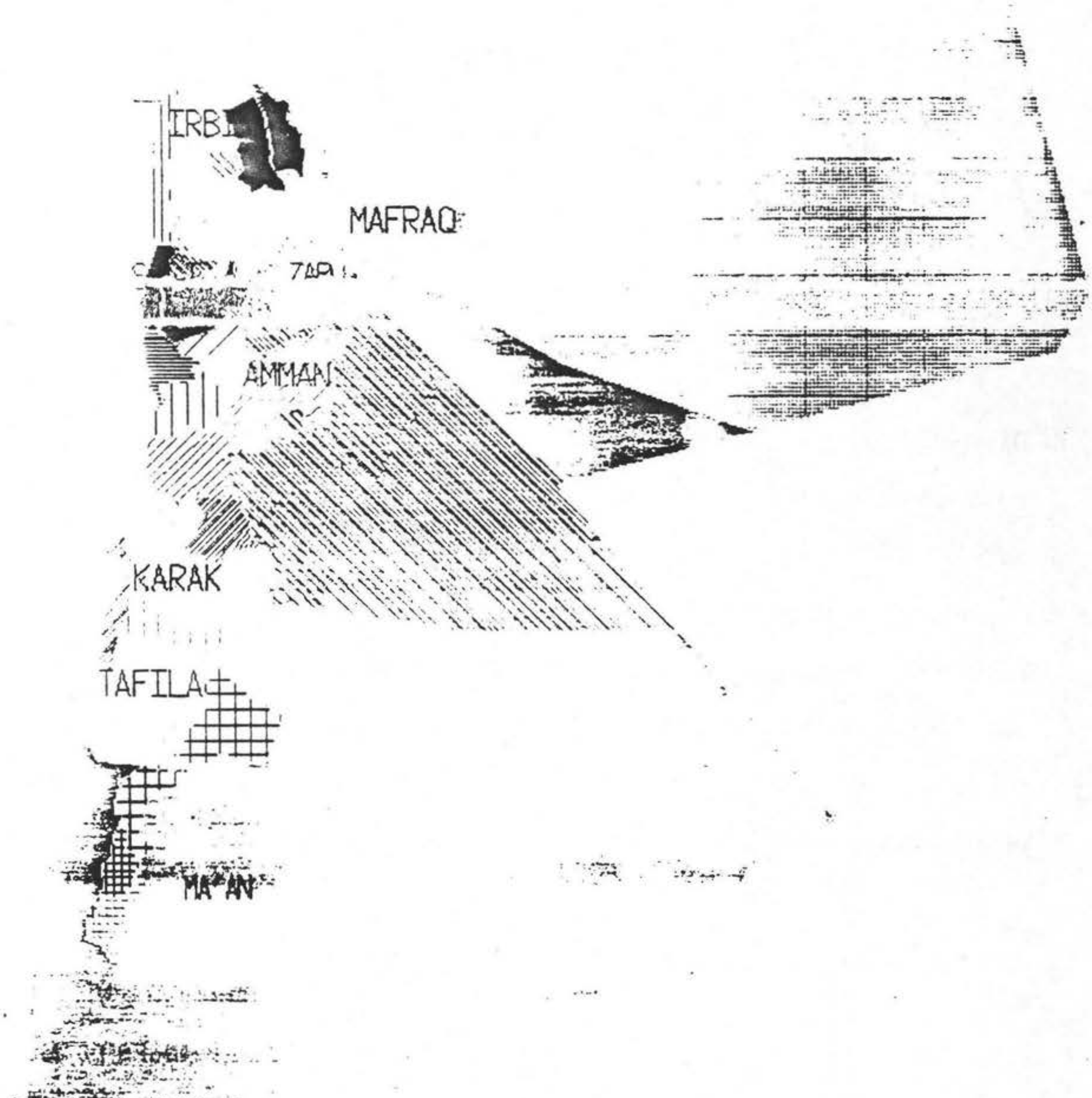



**Figure 6.** Population Distribution and Projections for Jordan Governorates, in thousands. (*Source: Dept. of Statistics, Jordan, and World Bank estimates, 1988*)


MAFRAQ
AMMAN
KARAK
TAFILA
MA'AN

Imran (1988) discusses the consequences of high population growth rates on the demand for water in Jordan and identifies this as a major problem. The demands by all sectors is likely to increase due to greater urbanization and the high population growth rate, potentially causing huge water deficits.

## 2.4 The Economy

An overview of the economic changes in Jordan over the last 20 years will provide a necessary backdrop to the subsequent discussion on water resources planning and management. For the purposes of this paper, the authors have classified the general economic trends in Jordan into three time periods based on major economic trends and events: 1970-1987; 1987-1990; and mid-1990 to the present time. Table 1 outlines this classification in terms of recent history.

Figure 7 illustrates the growth of GDP at constant 1980 prices in Jordan from 1975-1989 (World Bank, 1990). The data for the last two years are unofficial estimates. The growth exhibited in the 1970's and early 1980s was due mainly to a well educated population, political stability, strategic location, favorable external factors, and careful economic management. In the latter half of the 1980s (identified as the second phase in Table 1), this growth slowed considerably with unemployment growing to more than 10% and a sudden increase in the general price index. The main reason for this decline was the fall in oil prices which reduced the level of economic activity of the Arab Gulf States. This reduced three major sources of foreign earnings: (1) the size of the export market to those countries, (2) remittances to Jordan from expatriates working in the Gulf, and (3) economic aid from these countries. These recent declines demonstrated the extreme vulnerability of the economic base of Jordan.

**Table 1**. Economic Phases in Jordan

| Time Period | Remarks and key indicators |
|---|---|
| 1970-1987 | Real growth rate from 73-80 of 8.3%, 80-85, 4.2%; unemployment, inflation almost nonexistent; major growth in the construction, services sectors. Main reasons: well educated population, political stability, prudent economic management, availability of Arab and international aid. Per capita Income grew to U.S. $1560 in 1987. |
| 1987-1990 | Economic downturn. International aid and expatriate remitttances dwindled. High budget deficit; overall debt reached U.S.$8 billion. Devaluation of currency, trade reforms, and austerity measures were the main themes of an economic adjustment program formulated in cooperation with the World Bank and the IMF in 1989. This produced 2% growth in the first half of 1990 and lower unemployment. |
| Mid 1990- | U.N. embargo on Iraq and ensuing hostilities caused major economic problems. Jordan's losses are estimated at U.S.$1.544 billion in 1990, and U.S.$ 3.647 billionin 1991 (36% and 77% of GDP respectively). |

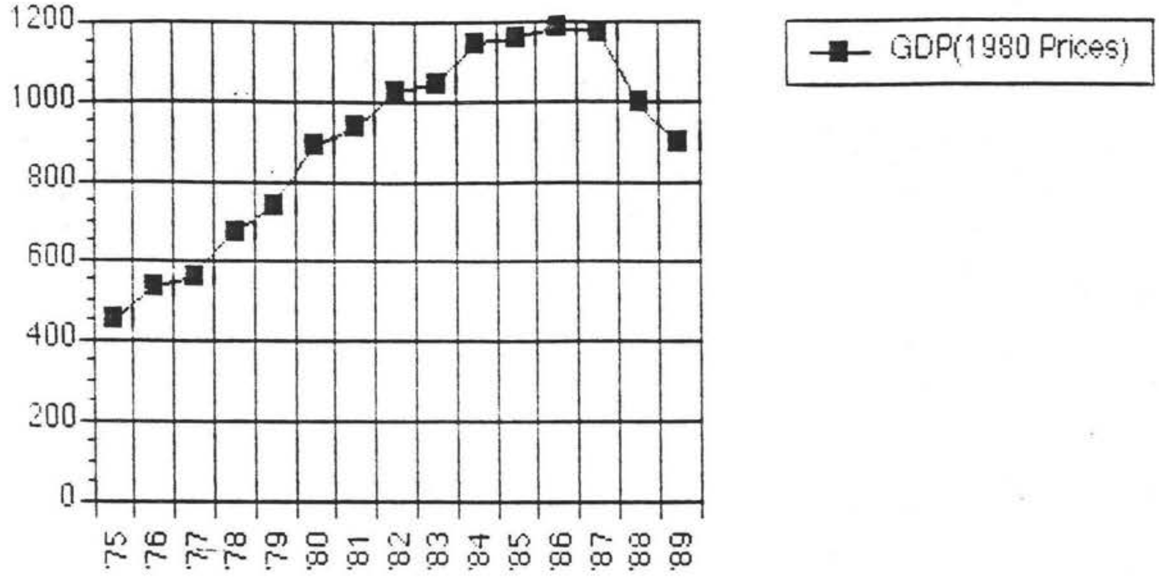



**Figure 7**. GDP at Constant 1980 Prices, in Millions JD

Jordan does not possess vast amounts of mineral wealth or other natural resources. The level of oil production from recent well discoveries has not proven to be very significant, although further oil drilling is expected. Phosphate production, on the other hand, is of significant importance to the economy. Jordan produced 4% of total world production in 1985 (Fantel *et al.*, 1989), bringing in a considerable amount of revenue and providing employment to a wide spectrum of the working population. For more information, the reader is referred to the detailed studies and surveys in Natural Resources Authority of Jordan (NRA), 1988.

The industrial sector (mining, manufacturing, electricity and water, and construction) contributed 30% to GDP in 1987 (Central Bank of Jordan Monthly Bulletin, Sept. 1987), and consumed about 10% of all water available. Figure 8 illustrates the major sectoral contributions to GDP in 1987. As can be seen, the economy is largely service oriented.

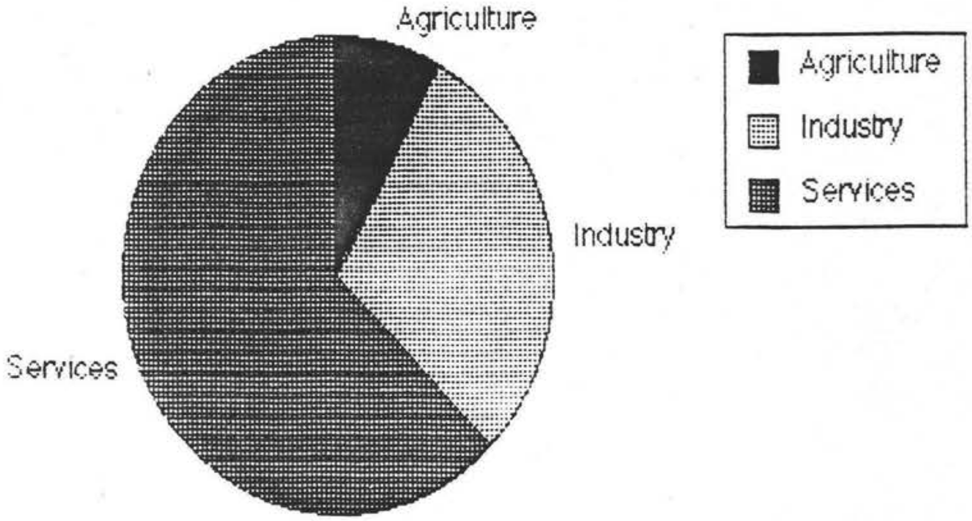



**Figure 8**. GDP by sector

Devaluation of the Jordanian Dinar (JD) by the government took place in late 1988, with the objective of making agricultural and industrial exports more competitive on the international markets (see Figure 9). This led to expectations of higher revenues and profits by farmers which, in turn, resulted in an immediate increase in the demand for irrigation water.

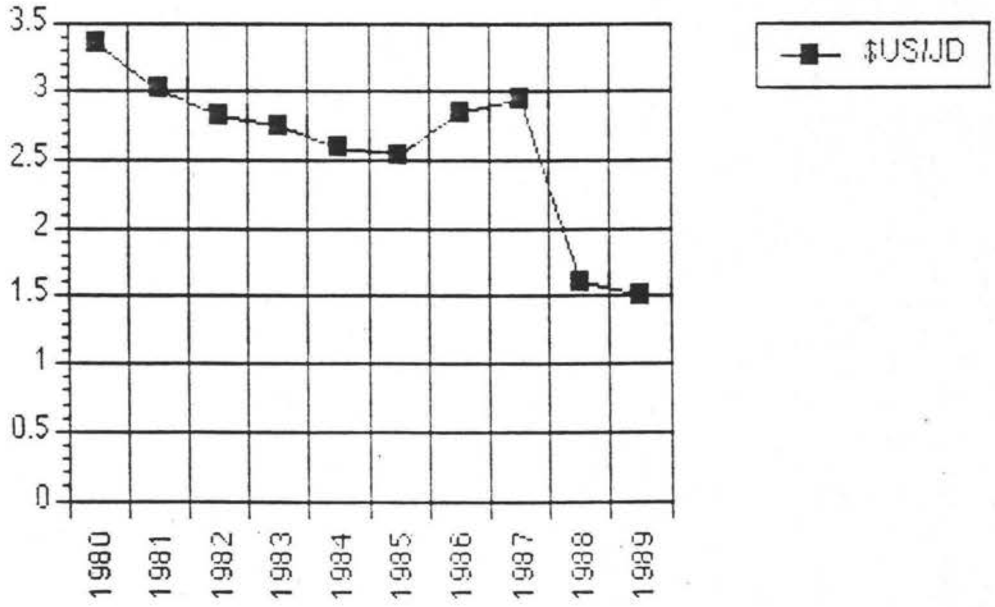



**Figure 9**. Currency Equivalents

Initiated from within the government, the economic adjustment began with the flotation of the currency and trade regime reforms. Subsequently, the Government, in collaboration with the World Bank and the International Monetary Fund (IMF), formulated an economic adjustment program for the period 1989-1993. In this program, monetary and fiscal policies promoted increased industrialization through tax breaks and lower interest rates on loans for new industries. By mid-1990, this program had resulted in significant export-led gains, and an estimated growth of 2% in the first half of 1990. For a review of effects before the outbreak of the Gulf War, the reader is referred to Jordan Information Bureau, JIB (1991); and Reed(1990).

However, in recent months the "Middle East Crisis" has placed considerable pressure on Jordan's economy (the third and continuing phase in Table 1). The loss to the economy due to the U.N. imposed embargo on Iraq, Jordan's major trading partner, and the subsequent arrival of over 1 million people, mostly refugees, into the country, are causing profound adverse effect on all facets of life. Sir Edward Heath, former Prime Minister of Britain, stated in an address to the Armed Services Committee of the U.S. Congress on December 20, 1990, that, according to international estimates, Jordan will probably lose over half of its GNP in 1991. More comprehensive U.N. report estimates place Jordan's financial losses due to the Gulf Crisis (mandatory sanctions against Iraq) and the ensuing hostilities at U.S.$ 1.544 billion in 1990, and U.S.$ 3.647 billion in 1991. These figures are equivalent to 36% and 77% of total GDP, respectively.

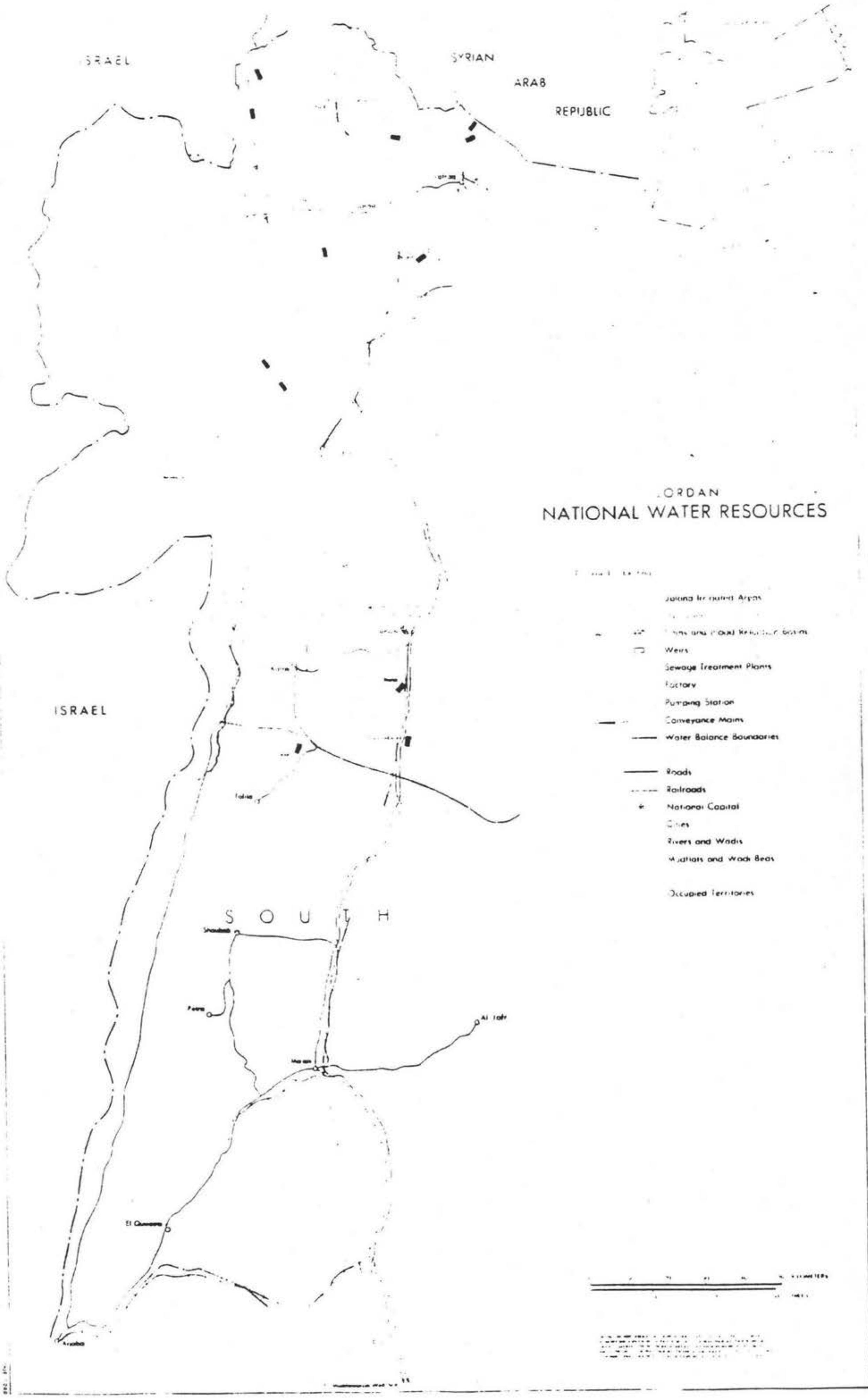
The financial losses to Jordan were mainly due to the impact of the crisis on exports, transit trade, remittances, official aid, tourism and the increased cost of oil imports. In addition, the number of Jordanian returnees from the Gulf region reached 200,000 people by the end of January, 1991.

## 2.5 Water Resources

In the following subsections, the existing water resources in Jordan are described. Water use is evaluated and allocations of water to the different competing subsectors is reviewed. Initially, an overview is presented in order to provide a broad understanding of the water sector.

### 2.5.1 Overview

Water available in Jordan is derived from surface water sources, groundwater sources, and wastewater reuse. Approximately 40% of the total surface water supplies available are presently being utilized. The most important development project by far is the proposed Al-Wehdah Dam on the Yarmouk River, which forms the border between Syria and Jordan. Groundwater resources on a nationwide basis are currently being extracted at a level of about 110% of the total available renewable supplies. The rates of withdrawal, in some cases, are greater than the natural recharge rates. Non-renewable groundwater is abundant in the south (e.g. the Disi Aquifer in the southern desert basin, see Figure 10, National Water Resources), but these sources are over 300 km from the major population centers in the North. Jordan is currently expanding its wastewater reuse system (see Jordan Ministry of Water and Irrigation, 1990).


ISRAEL
SYRIAN ARAB REPUBLIC
NATIONAL WATER RESOURCES
Weirs
Sewage Treatment Plants
Pumping Station
Conveyance Mains
Water Balance Boundaries
Roads
Railroads
National Capital
Rivers and Wadis
Occupied Territories
ISRAEL
SOUTH
Al Jafr
El Quweira
IBRD 19982

Unfortunately, increased supplies from these three sources are becoming very expensive to develop. For example, the price tag for the Al-Wehdah Dam is presently over U.S. $250 million. Transportation of water from the strategic Disi aquifer could also be very costly (2.53 JD/cubic meter provided per year). Overall, the World Bank (1988) estimates that the development of marginal sources of surface water could range between $6-$7 per cubic meter.

The total quantity of water consumed in Jordan in 1990 (730 MCM) was distributed in the following proportions: 175 MCM for residential use and 35 MCM for industrial use (both primarily from groundwater sources) and 520 MCM for agricultural purposes (60% of which was supplied from surface water sources).

To place these figures in perspective, consider a "water poverty line" of 1 MCM per 1,000 inhabitants per year to be defined as a line below which a country would be experiencing water scarcity. In that case, Jordan can be considered a water poor country, producing approximately 1 MCM per 4,200 inhabitants annually. This is reflected in severe water shortages at certain times of the year, which is more apparent in the municipal subsector than in others.

## 2.5.2 Historical Perspectives on Water Resources Development

Historically, water supplies in Jordan have been adequate and environmental degradation was not a serious concern because of low population densities and smaller agricultural and industrial outputs. In the past, water for residential use came from wells, natural springs or other sources located near points of use. Water for irrigation was obtained through diversion canals that conveyed water from flowing streams to individual properties. As such, water was regarded as a free good that was in plentiful supply. The situation now is quite different. Although most early population concentrations were near groundwater springs in Amman and other major towns, water supplies there are now insufficient for the expanding population. Water must be pumped to Amman and Zarqa from areas in the North and East and even from King Abdullah Canal (KAC).

Since the Jordan River system is essential to life in the area, riparian issues have been always at the forefront of concerns. In addition to normal conflicting uses, the Arab-Israeli conflict has overshadowed cooperative uses of the river system. Dating back to the beginning of the century, some schemes have been [illegible] and developed to estimate the needs of the local populations in neighboring areas. One such plan is called the Unified Johnston Plan of 1955, sponsored by the United States. The water allocations according to this plan for the Yarmouk River are compared with current allocations in Table 2.

**Table 2.** Allocation of Yarmouk River Water, MCM per year

| Riparian | Planned allocation, 1955 | Current use levels, 1990 |
|---|---|---|
| Jordan | 275 | 120 |
| Syria | 90 | 170 |
| Israel | 25 | 100 |

*Sources:* Naff and Matson (1984); Salameh (1990)

At the time of formulation of the Johnston Plan, Yarmouk River flow was estimated at 390 MCM, and the upper Jordan River Tributaries at 550 MCM. According to the plan, Jordan's share from the Yarmouk was 275 MCM, and its share from the Jordan River was fixed at 100 MCM to be stored in Lake Tiberias. This gave Jordan a total allocation of 375 MCM. However, Jordan only uses 120 MCM of this flow due to (1) other riparians using more than the planned allocation, (2) the fact that Jordan does not receive any of the 100 MCM potentially stored for it in Lake Tiberias, and (3) the fact there is no control of flood flow on the Yarmouk.

Jordan's East Ghor Canal (now called King Abdullah Canal, KAC), and the Israeli National Water Carrier, were completed in 1966 and 1964, respectively. The Israeli National Water Carrier was intended for development of the Negev desert area in southern Israel, while Jordan's KAC constituted the basic infrastructure necessary for agricultural development of the Jordan Valley.

Jordan would need the entire 375 MCM allocated in the Johnston Plan to develop and permanently irrigate the whole Jordan Valley, estimated at 36,000 ha. The developed area for irrigation by 1989 included 22,800 ha plus a new 6,000 ha addition at the southern end of KAC for a total 28,800 ha. The last addition of 6000 ha was intended to be irrigated during the winter months from stored flood waters of the Yarmouk. Due largely to the lack of availability of Jordan and Yarmouk River waters to Jordan, the area developed for irrigated agriculture in the Jordan Basin is severely underutilized. Furthermore, the Deir Alla to Amman pipeline is running at 1/3 capacity due to water shortage in KAC.

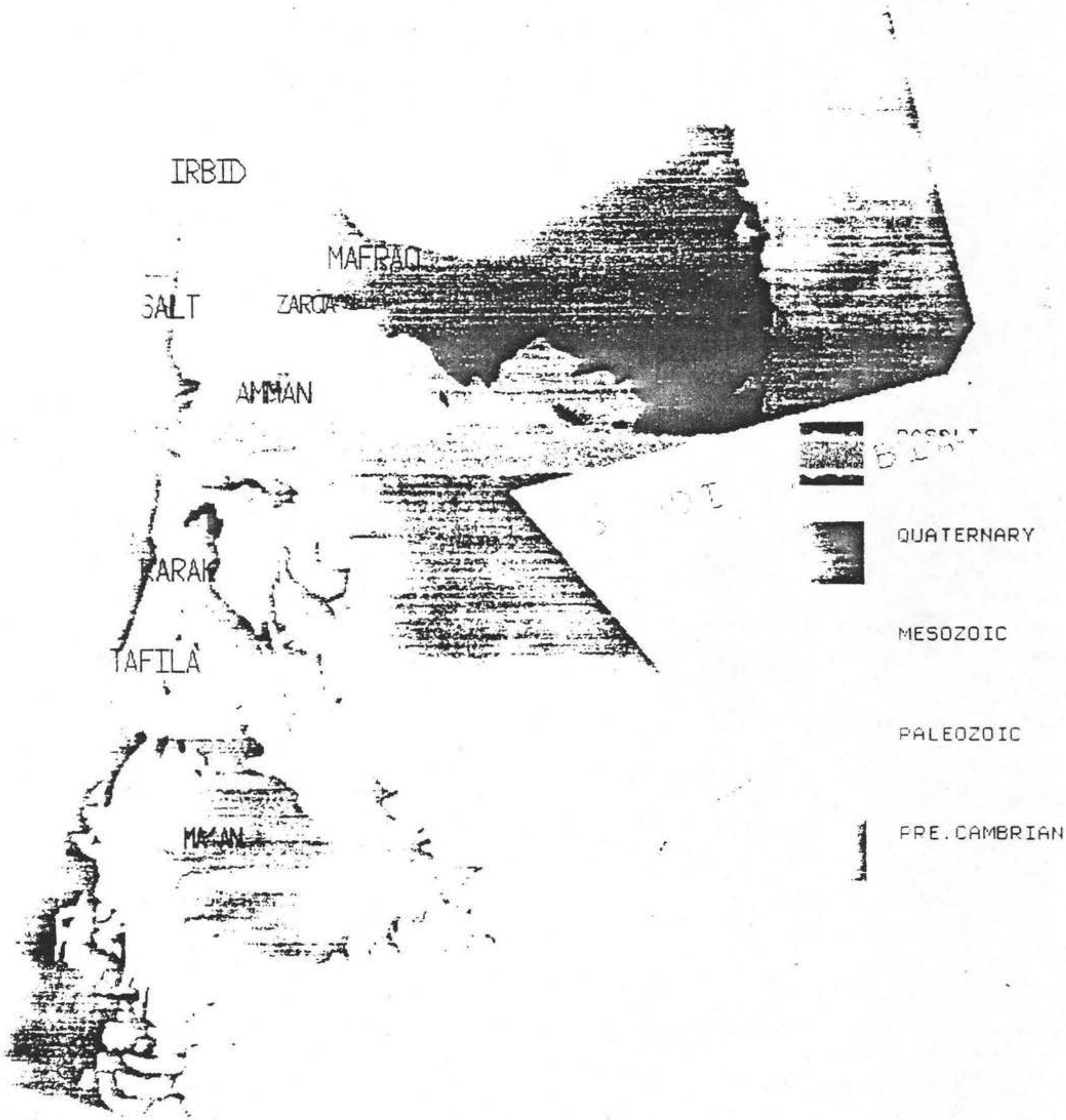
In recent history, water supplies in Jordan have been augmented to keep pace with demand as much as possible. With this expansion in water production and use, the volume of low quality return flows into the rivers has increased, causing concern for the quality of future water supplies and the overall environment (see "Environmental Considerations" below). Table 3 illustrates supply figures and public investments in the water sector over the past two decades. Most of the investment went into construction of dams, wastewater treatment facilities, water supply networks and irrigation works.

**Table 3**. Water Supply and Public Investments

| Period | Average Water Supply<br>MCM/year | Public Investments<br>in million JD | Investment as<br>% of Govt. budget |
|---|---|---|---|
| 1976-1980 | 550 | 520 | 16% |
| 1981-1985 | 625 | 245 | 10% |
| 1986-1990 | 678 | 280 (planned) | 9% |
| 1991- | 730 | | |

*Source:* Jordan Ministry of Planning.

In the 1980's, Jordanian water sector management was based upon the 1977 National Water Master Plan. In 1988, at the request of the Jordan Government, the World Bank undertook an extensive survey of the water sector and developed future forecasts and guidelines (World Bank, 1988). This survey has now become one of the cornerstones upon which decision makers' plans are predicated. Another important document appeared in 1989. In April of that year, the Jordan Ministry of Water and Irrigation


IRBID
MAFRAQ
SALT
ZARQA
AMMAN
TAFILA
QUATERNARY
MESOZOIC
PALEOZOIC
PRE.CAMBRIAN

(MWI) presented a working paper to the "Arab Countries Conference on Water Resources and their Strategic Importance." In the paper, the Ministry described the Jordanian experience of attempting to alleviate future water deficits and to cope with water scarcity.

In December, 1990, the Ministry of Water and Irrigation (MWI) presented a new water strategy for the period 1990-2005 to the House of Representatives. Although that strategy was based on a high degree of careful planning and analysis, the strategy was not based on a rigorous multisectoral, multiobjective framework. It appears that an improved strategy could be developed by using an integrated, comprehensive approach. This issue is adressed in later chapters of this paper.

### 2.5.3 Water Data Base

Jordan has a well conceived hydrogeological information base, which includes over 230 meteorological stations, some with records going as far back as 1923. Measured stream flows include data for the past 30 years. Groundwater potential is continually monitored and updated based upon the physical models developed for the 1977 National Water Master Plan. Data on soils, land classes and the geology of the region are well documented. Figure 11 provides an overview of the basic geology of Jordan.

Over the years, there have been coordinated, country wide water resources development plans. A wealth of general data on long term / short term objectives and development targets are available from those efforts. In addition, the statistical yearbooks of Jordan contain accurate and reliable macroeconomic and financial data for the whole country.

The most notable components of the existing water data base in Jordan include the following:

- National Water Master Plan, 1977
- Jordan Climatological Data Handbook, 1988
- Social and Economic Development Plan, 1986-1990
- Statistical Yearbooks (annual)
- Natural Resources in Jordan (Inventory, Evaluation and Development Program), 1989
- National Atlas of Jordan, parts I and II (Royal Geographic Center)
- Studu of Water Conveyance Systems for Southern Jordan, 1986
- Water Sector Study, World Bank, 1988
- Ministry of Water and Irrigation Water Studies, 1988-1991
- Agricultural Sector Strategy, World Bank, 1990
- A number of detailed physical models ralating to groundwater
- Environmental studies performed by the Royal Scientifc Society
- Hydrologic studies performed at the Water Research Center, University of Jordan.

It is important to note at this time that Jordan is not a "data poor" country. In fact, the available data gathering network is equal to that in developed countries. And as a matter of course, this data base has always been considered sufficient for planning purposes.

### 2.5.4 Survey of National Water Resources

This subsection describes the various water resources that exist across Jordan and summarizes estimates of the supplies they yield. Water sources are distributed very unevenly on a spatial basis, and some of these sources are shared by several countries. For the sake of simplicity, we divide these sources into the two major groups of surface and groundwater, which were mapped out in detail in the 1977 National Water Master Plan.

Since annual precipitation varies from 6,000-11,500 MCM/year, water availability from runoff into streams and for groundwater recharge purposes also varies widely on an annual basis. We will therefore provide figures for flood and base flows, analyze how the attempts that have been made to regulate base flows (e.g. storing winter floods for use in summer), and highlight the problem of groundwater mining in some regions.

Since surface and ground water sources are interlinked to a large extent, double counting of available water supplies presents a problem in many areas of the world. This does not appear to be a major difficulty in Jordan however, since detailed studies before and after the National Water Master Plan have recognized and addressed this problem.

Wastewater reuse is included in this section as a possible water source for the future, grouped together with other non-conventional sources of water.

#### *Surface Water*

Figure 12 provides an overview of the surface water sources, in terms of their base and flood flows. As can be seen, the North and Northwest regions have the lion's share of water. The major rivers are the Yarmouk, the Side Wadis (a wadi is a watercourse in a valley flowing in the winter months) and the Zarqa, all of which flow westwards into the Jordan River, and finally into the Dead Sea. The Dead Sea is a closed body of water, where the only avenue of water escape is through evaporation, estimated at a constant 1.6 meters per year. Water levels in the Dead Sea have declined from 392 m below sea level at the beginning of this century to 405 m at the present time (For details of Dead Sea levels and for information on the Mediterranean Dead Sea Canal, see Assaf, 1976; Weiner, 1980; Hochman et al., 1984; Salameh and Khawej, 1984; and Gross and Zahafi, 1985) . The decline in water levels is caused primarily by (1) increased diversions of water from all tributaries leading into the Jordan River system, and (2) increased industrial activity on both sides of the border, which withdraw [illegible] minerals in the [illegible] In addition to the decline in the surface water elevation at the Dead Sea these two factors have further secondary effects on the environment, as explained later.

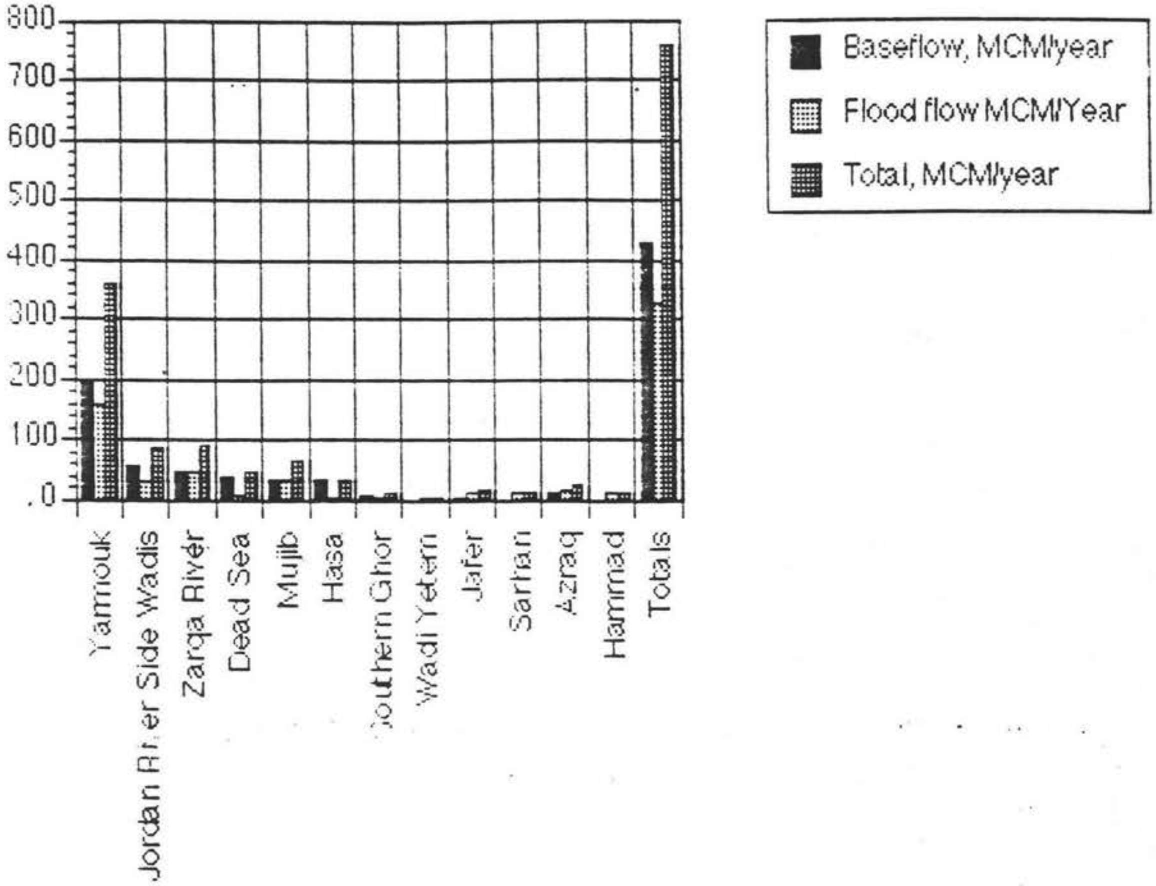



**Figure 12.** Surface water sources and annual flows (by basin)

For comparison purposes, the average annual discharges of several major rivers in the region are shown below. The Yarmouk, with its small discharge volume, would be of insignificant importance if it were located elsewhere in the world. However, in the semi-arid Middle East, any available quantity of water is precious and therefore invites exploitation.

**Table 4**. Average annual discharges of rivers in the Middle East

| River System | Discharge, MCM/ Year |
|---|---|
| Nile | 92,600 |
| Euphrates | 31, 830 |
| Tigris | 42, 230 |
| Jordan | 1,287 |
| Yarmouk | 400 |

*Sources:* Salameh (1991); Naff and Matson, eds. (1984).

Developments of surface water resources in the Jordan Valley have principally been for irrigation purposes. Table 5 lists the dams and reservoirs currently in use, and the dams that are proposed for further development. The table also identifies the major rivers and streams on which the dams are sited. The locations of these existing and proposed dams are illustrated in Figure 10.

The government is seeking to prioritize the development of all proposed projects according to yield, location, immediate needs, costs, and other factors. Steming from more recent feasibility studies, Jordan can potentially benefit from approximately 150 MCM of additional surface water bearing in mind that Jordan currently utilizes 120 MCM of Yarmouk water. These proposed projects substantially all of the surface water. resources remaining to be developed.

EXISTING DAMS IN JORDAN

| DAM NAME | RIVER OR WADI | YEAR COMPLETED | CAPACITY MCM | PURPOSE |
|---|---|---|---|---|
| KING TALAL | ZARQA | 1986 | 82.00 | IRRIGATION, POWER |
| WADI AL-ARAB | W.AL-ARAB | 1984 | 20.00 | STORAGE, POWER |
| KAFREIN | KAFREIN | 1976 | 4.80 | IRRIGATION |
| SHUIEB | SHUIEB | 1964 | 2.30 | G.W. RECHARGE |
| SHARHABEIL | ZIGLAB | 1964 | 4.30 | IRRIGATION |
| SULTANI | MUJIB | 1962 | 1.20 | IRRIGATION, LIVE STOCK |
| QATRANA | MUJIB | 1962 | 2.30 | G.W.RECHARGE,LIVE STOCK |
| LAHFI | DHULIEL | 1967 | 0.70 | LIVE STOCK WATERING |
| BUWEIDA | YARMOUK | 1967 | 0.70 | LIVE STOCK WATERING |
| GHADEIR AL-ABYAD | YARMOUK | 1967 | 0.70 | LIVE STOCK WATERING |
| SAMMA SIRHAN | YARMOUK | 1965 | 0.70 | LIVE STOCK WATERING |
| AGIB | DHULIEL | 1983 | 1.40 | G.W. RECHARGE |
| BURGU' | RUWEISHID | 1950 | 1.50 | LIVE STOCK WATERING |
| SHAL'AN | RUWEISHID | 1970 | 1.00 | IRRIGATION |
| DEIR AL-KAHF | DEIR AL-KAHF | 1950 | 1.50 | LIVE STOCK WATERING |

PROPOSED DAMS IN JORDAN

| DAM NAME | BASIN | STORAGE CAPACITY MCM | STUDY CONDITION | WATER USES |
|---|---|---|---|---|
| WEHDA | YARMOUK | 220 | FEASIBILITY | MULTIPURPOSE |
| KUFRINJA | J.V.SIDE WADIS | 5.2 | FEASIBILITY | IRRIGATION |
| W.YABIS | J.V.SIDE WADIS | 5.2 | FEASIBILITY | IRRIGATION |
| KARAMA | J.V.SIDE WADIS | 45 | FEASIBILITY | IRRIGATION & STORAGE |
| RUMIEL | WADI WALA | 25 | UNDER STUDY | IRRIGATION |
| HAMAM | WADI WALA | 3 | REFEASIBILITY | G.W.RECHARGE |
| NUKHILA | WADI MUJIB | 12 | UNDER STUDY | MULTIPURPOSE |
| AL-ABYAD | WADI MUJIB | 12 | REFEASIBILITY | IRRIGATION |
| SWAQA | WADI MUJIB | 2.8 | REFEASIBILITY | G.W.RECHARGE |
| TANNUR | WADI HASA | 14 | REFEASIBILITY | IRRIGATION |
| DABA'A | WADI MUJIB | 2.8 | REFEASIBILITY | MULTIPURPOSE |
| ZATARI | ZARQA RIVER | 2 | REFEASIBILITY | IRRIGATION |
| RUWEISHID | WADI RUWEISHID | 10.8 | UNDER STUDY | MULTIPURPOSE |
| ABU HAFNA | WADI RUWEISHID | 2.5 | UNDER STUDY | MULTIPURPOSE |
| RAJIL | AZRAQ | 2 | UNDER STUDY | G.W.RECHARGE |
| RATAM | AZRAQ | 2 | UNDER STUDY | G.W.RECHARGE |
| BUTUM | AZRAQ | 2 | UNDER STUDY | G.W.RECHARGE |
| ABU SAFAT | JAFR | 2.8 | UNDER STUDY | IRRIGATION |
| JURDHAN | JAFR | 4 | UNDER STUDY | MULTIPURPOSE |
| USHEISHAT | JAFR | 2.4 | PROPOSED | G.W.RECHARGE |
| MATHK | JAFR | 2 | PROPOSED | LIVE STOCK WATERING |
| FASSU'A | JAFR | 2 | PROPOSED | LIVE STOCK WATERING |
| ABYAD | JAFR | 2 | PROPOSED | LIVE STOCK WATERING |
| UQEIQA | JAFR | 2 | PROPOSED | LIVE STOCK WATERING |
| AL-JAHDANIYA | JAFR | 2 | PROPOSED | LIVE STOCK WATERING |

### *Groundwater*

Over the past two decades, extensive hydrogeological investigations covering the entire are of Jordan have been conducted. These have included studies on the evaluation, availability and suitability for utilization of groundwater resources. Various physical models have been developed based upon hydrogeologic surveys, such as the model developed for the Disi Aquifer in 1986 by Humphries for the Water Authority of Jordan. The World Bank (1988) and others have indicated that these investigations now provide Jordan with a resource information base that compares favorably with that in other countries. From this information base, we present below (Figure 14) the total yields available to Jordan from all groundwater aquifers combined.

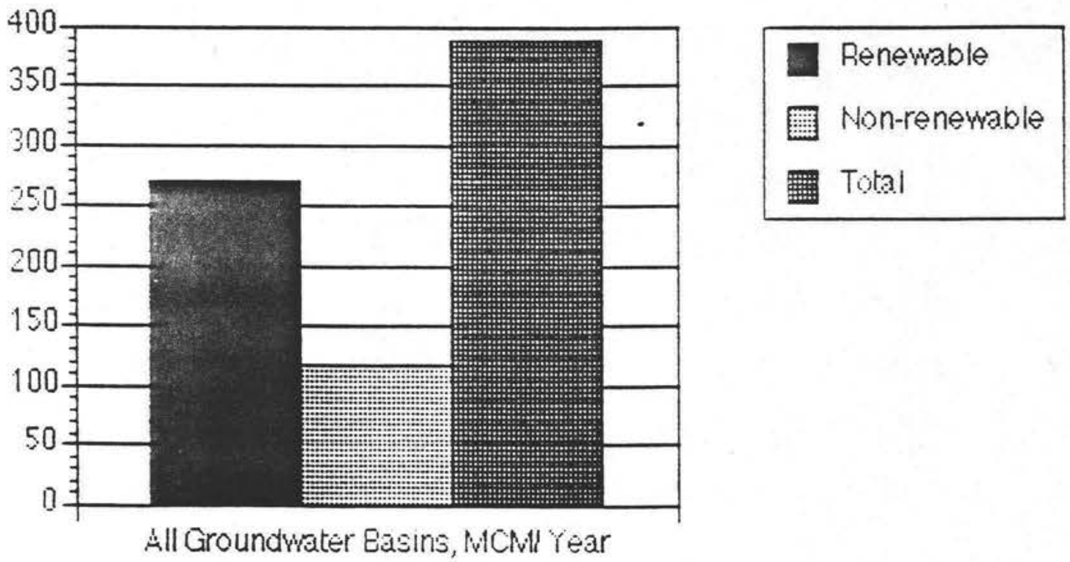
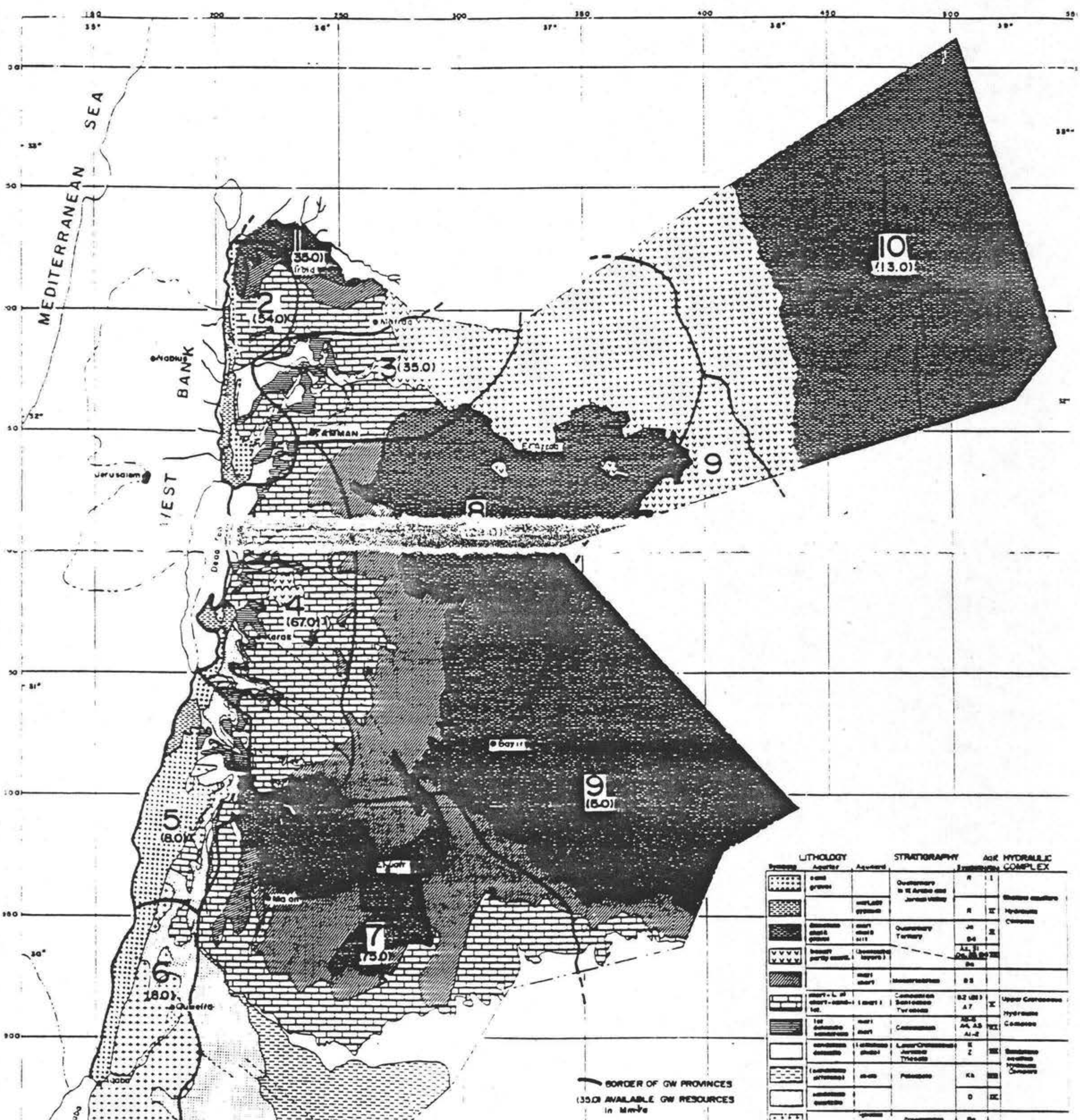



**Figure 14**. Groundwater yields

In Jordan, ten major groundwater basins are defined according to regional water divides, aquifer limits or important topographic features. These basins are illustrated in Figure 15, along with their associated safe yields. The MWI has stated that there are 1,503 licensed private water wells operating in these basins, extracting a total of 188 MCM per annum for irrigation purposes. Overall, safe yields from major renewable sources are being exceeded by an average of 32%, according to the MWI, by extractions from publicly and privately operated wells.

The World Bank (1988) in illustrating inter-regional water exchanges, defined four ground water regions, the North, Amman-Zarqa, Dead Sea-Azraq, and the South (refer back to Fig. 10). The discussion here lends itself primarily to the description of these four regions as given by the World Bank, tempered by recent data from the MWI and the Natural Resources Authority (NRA).

**Region 1**. The North: In this region, the Mukheiba and Wadi Al-Arab wells are the most prominent in terms of water supply. The former are mainly utilized for irrigation in the upper Jordan Valley (35 MCM) and the latter provide 12 MCM for municipal and industrial (M&I) demand. The exceedance of safe yield for the Wadi Al-Arab wells has reduced flows into the Wadi Al-Arab reservoir. This reservoir is now augmented by pumping water from the KAC. The World Bank suggests developing plans for using the Mukheiba well fields for M&I use in the future, due to its good quality waters. The use of the Mukhaiba well field directly for M&I use at the present time however, is not economically practical because it involves constructing a 100 km line to Amman. Flows from the Mukhaiba fields are presently diverted to the KAC to augment irrigation water supplies. In



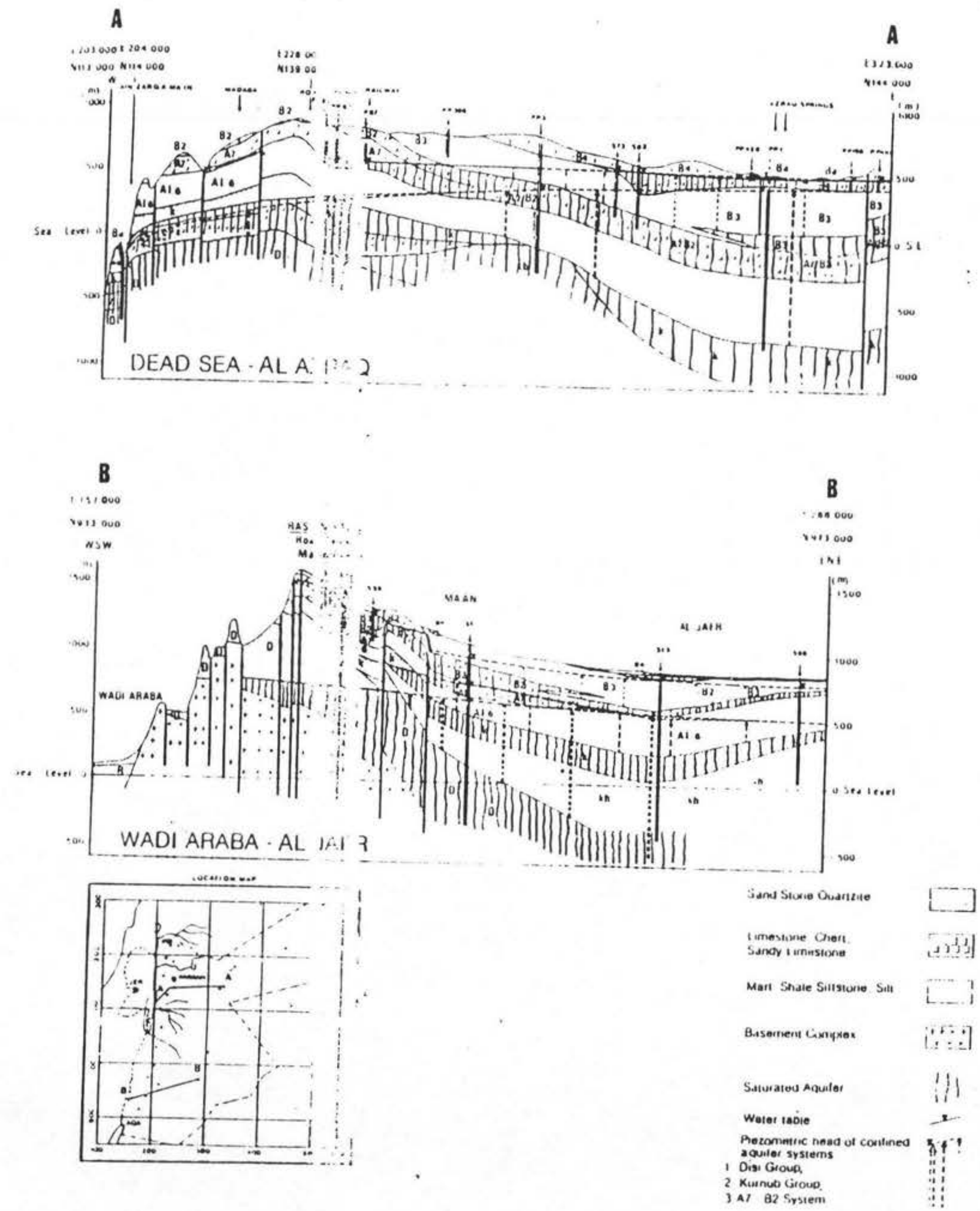
MEDITERRANEAN SEA
WEST BANK
1 (35.0) Irbid
2 (54.0)
3 (35.0)
4 (67.0)
5 (8.0)
6 (18.0)
7 (75.0)
8
9
9 (8.0)
10 (13.0)
AMMAN
Nablus
Jerusalem
Karak
Bayir
Qweira
Gulf of Aqaba
LITHOLOGY
STRATIGRAPHY
HYDRAULIC COMPLEX
BORDER OF GW PROVINCES
(35.0) AVAILABLE GW RESOURCES in Mm³/a
20 0 20 40 60 km

addition, KAC water, when available, is pupmped to Amman through the existing Deir Alla-Amman pipe line.

**Region 2.** Amman-Zarqa: This region supports a large concentration of the Jordanian population, and groundwater withdrawals already exceed safe yields. The main wellfields are the Wadi Seer (minicipal use), Wadi Ajib (municipal and agricultural use) and Wadi Dhuleil (mainly irrigation). These wellfields are subject to water quality problems due to over extraction, and in the case of the Wadi Seer/Amman aquifer, its overuse has caused the decline of water flows into the Zarqa River, reducing much needed freshwater dilution discharges into the river.

**Region 3.** Dead Sea-Azraq: The groundwater resources in this area have also been over extracted. The Azraq wells provide 15 MCM for Amman annually and about 5 MCM for local crop production. Safe yields are estimated at 20 MCM. Other ground water sources include Rumeil, which feeds Wadi Wala, and the Swaqa, Qastal and Katraneh which feed Wadi Mujib. Two simplified hydrogeological cross sections are presented in Figure 16 on the next page. The first cross section identifies water table depths and geologic sequences (A, B, K, etc.) from the Dead Sea to Al Azraq. The second cross section is discussed below.

**Region 4.** The South: The second cross section of Figure 16 depicts water levels and geologic formations from Wadi Araba to Al-Jafer. Although the natural recharge rate into the Al-Jafer basin is estimated at only 3.5 MCM per year, the stored volume of this aquifer is estimated at 17,000 MCM in the upper layers. Total dissolved solids (TDS) in the upper layers range from 600 to 4,000 ppm. The underlying aquifer stores an


A
A
B
B
DEAD SEA - AL AZRAQ
WADI ARABA - AL JAFR
Sea Level 0
WADI ARABA
MAAN
AL JAFR
WSW
ENE
LOCATION MAP
Sand Stone Quartzite
Limestone Chert, Sandy Limestone
Marl Shale Siltstone Silt
Basement Complex
Saturated Aquifer
Water table
Piezometric head of confined aquifer systems
1 Disi Group,
2 Kurnub Group,
3 A7 B2 System

estimated 40,000 MCM of slightly brackish, unexploited groundwater (TDS: 700-2,000 ppm). The Disi aquifer is another groundwater resource of extreme importance. Extraction rates are currently at a level of approximately 60 MCM per year. It has been estimated that an extraction rate of 110 MCM/year can be expected from this non-renewable aquifer for about 100 years without incurring excessive pumping lifts (NRA, 1988). The World Bank has suggested curtailing the use of this aquifer for desert agriculture (heavily subsidized by the government) and developing a plan for the use of its strategic reserves for much needed municipal supplies in the north, through conveyor systems currently under consideration by the MWI.

Future development of groundwater resources may take the form of extracting high [illegible] from deep aquifers. This would be very costly and water quality would be an issue of concern. In addition, artificial groundwater recharge is currently being studied by the MWI. The procedure would be to build a number of desert retention basins to collect flood flows and direct them to known groundwater basins for direct infiltration.

### *Non-Conventional Sources of water*

In general, most countries strive not to depend on non-conventional sources of water, because of the inherent high cost associated with them. The different types, employed in varying degrees over the world, include wastewater reuse, desalinization of seawater or brackish waters, cloud seeding, rainwater harvesting, and importation of water from abroad.

Jordan has some experiences with wastewater reuse (Batarseh *et al*, 1989). In the Khirbet Al-Samra wastewater treatment plant located near Amman, limited reuse has been applied to irrigate forest trees. Most of the effluent from this plant flows to King Talal Reservoir, whose waters irrigate parts of the Jordan Valley. According to the Ministry of Water and Irrigation, current treatment plants produce approximately 40 MCM of effluent annually, and this is expected to rise to 70 MCM in the year 2000 (Kefaya and Al-Alem, 1991). Because of this, various agencies in Jordan are studying the practicability and feasibility of using this effluent water for irrigation. In other parts of the world, effluent reuse has already been developed to a large scale. In Saudi Arabia, for example, an estimated 385 MCM of reclaimed wastewater was used in 1990 (Al-Ibrahim, 1990).

The possibilities for desalinization of seawater exist at Aqaba, the only seaport of Jordan. In this growing community, a large thermal power station is currently being built in stages. The heat generated from this power station could conceivably be used in a multistage flash distillation plant (Water Authority of Jordan, 1986). No detailed studies are available at this time, and desalinization of seawater is not seen as a viable alternative because the cost to the consumer would be approximately 1.5 JD/cubic meter (CM), as opposed to the average price of 0.25 JD/CM. However, desalting of brackish water could provide 145-220 MCM for municipal supplies per annum, according to the Ministry. This has not begun on any large scale yet.

Cloud seeding in Jordan was used for 3 years between 1986-1989. The results were not fully evaluated and research in this area is continuing. In general, the difficulties with cloud seeding stem from the imperfect knowledge of the physical processes causing precipitation, and from the physical constraints of using optimum amounts of silver iodide crystals at the right time and place (Kefaya, 1991).

The process of rainwater harvesting in Jordan would involve the collection of rainwater over large natural drainage areas. The runoff is collected in wadis, where low cost dams can provide storage. These small reservoirs would provide water for supplementary irrigation and for livestock requirements, as well as the potential for use in groundwater recharge.

Currently, the following innovative or non-conventional water resource practices are being utilized in Jordan:

(1) Large man-made lagoons are being used in a pilot project for cattle use and small scale agriculture in some areas of the Hamad basin in the North East.

(2) A study in Karak-Tafileh Governorates involves collection of rainwater using contour furrowing techniques. Several thousands of hectares have been identified that can be cultivated in this marginal area which receives between 100-200 mm of rain annually.

(3) The University of Jordan is implementing the first phase of a series of experiments on water harvesting at a 200 ha site 50 km southeast of Amman. Early results are encouraging.

Importation of water from abroad has also been considered for Jordan, especially diverting Euphrates water (estimated consumer price 2.0 JD/CM), and from the proposed peace pipeline from Turkey to the Gulf states. Both of these proposals have extreme political and economic ramifications and their feasibility studies for Jordan have been shelved at this time. To better prepare for the future, it is suggested that Jordan have a far reaching outlook on the issue of regional water resources.

### 2.5.5 Evaluation of Water Use and Supply

A water balance chart for Jordan is presented below. Table 6 combines data gathered from several sources which exhibited slight discrepancies. These have been smoothed out in order to gain a better understanding and feel for the overall situation, rather than to merely emphasize the numerics.

**Table 6**. Water Balance for Jordan

| Category | MCM/ 1986 | MCM/1987 |
|---|---|---|
| Precipitation | 7,200 | 8,000 |
| Evapotranspiration | 6,120 | 6,800 |
| Streamflow | 1,080 | 1,200 |
| Diversions | 678 | 709 |
| Irrigation | 518 | 539 |
| M&I | 160 | 170 |
| Consumption | 340 | 358 |
| Irrigation | 300 | 315 |
| M&I | 40 | 43 |
| Return Flow | 338 | 351 |
| Outflow | 740 | 849 |

*Sources:* Data adapted from Al-Momani(1987); World Bank (1988); and NRA (1988).

As depicted in Table 6, the share of water for agriculture is 76% of the total water available in the country, principally supplied from surface sources. The world average for agricultural water use is 70% (Postel, 1984). However, the important point to consider is that 58% of the water for agriculture is lost, that is, it is not directly returned to the "regional" hydrologic cycle. In the case of municipal use and industrial production, this loss proportion is approximately 25%. Thus, 75% of the water used for municipal and industrial purposes is returned to the cycle, albeit in an environmentally degraded form. The environmental impacts of these return flows will be discussed later.

*Water Supply*

For the purposes of this paper, estimates of water availability were collected from several sources. According to the Ministry of Water and Irrigation in Jordan (Jordan MWI, 1991), the total available flow in the surface basins (consisting of base flow and flood flow) is 750 MCM on an average annual basis. However, the maximum economically exploitable quantity available to Jordan, even after all dams including the Wehdah Dam are built, is only 474 MCM. This difference is due to the extensive use of the major river (Yarmouk) by others, and the lack of dams on the Yarmouk and major wadis. The MWI estimate of safe yield from the groundwater basins is approximately 388 MCM/year. World Bank estimates of these surface and groundwater resources are 878 MCM/year and 356 MCM/year, respectively. Other sources (Al-Momani, 1987, Naff and Matson, 1985) give estimates within that range. A more realistic total safe yield figure of 862 MCM/year (ground and surface combined, 388 + 474) will be used here. However, only 730 MCM out of this 862 MCM is presently being exploited and utilized annually to meet demand. It is only after the completion of the Al-Wahdeh Dam with a storage capacity of 200 MCM per annum (effective additional supply to Jordan of 200-125=75 MCM), and other supply augmentation projects, that the figure will approach the 862 MCM ceiling. The main sources of the water for 1990 are shown in Table 7 (*Source*: MWI).

**Table 7**. Sources of current water production

| Subsector | Water Production, MCM |
|---|---|
| **Municipal and Industrial (210 MCM)** | |
| Wadi El-Arab wells | 15-18 |
| [illegible] wells | 1-2 |
| Zaatari and Aqib wells | 18-22 |
| Dhuleil wells | 8-10 |
| Azraq wells | 18-20 |
| Jordan Valley wells | 8-10 |
| Baqaa wells | 2-3 |
| Swaqa, Qastal, Qatraneh wells | 16-18 |
| Sultani and Ghweir wells | 3-5 |
| Shawbak wells | 1-2 |
| Phosphates mines wells | 24-28 |
| Disi and Wadi Yutem wells | 9-11 |
| Deir Alla waters-Zai- Amman | 9-11 |
| Various springs and wells in governorates | 61-72 |
| **Irrigation (520 MCM)** | |
| King Abdullah Canal | 120-140 |
| Side Wadis, North Jordan Valley | 70-90 |
| Side Wadis, South Jordan Valley | 35-45 |
| Disi and Mudawarrah basin | 45-55 |
| Wastewater reuse | 28-32 |
| Private Sector wells | 180-200 |

The quantity of water produced is supplied to demand centers through a highly developed infrastructure, the efficiency of which remains questionable. This infrastructure consists of pumping stations, reservoirs and pipelines for municipal and industrial demand, storage facilities and canals for irrigation. In the case of residential supply, residents almost invariably have storage tanks on rooftops. These are used to regulate water flow, since the water authorities tend to shut off the supply a few times a week in the summer months. Therefore, residents generally have some water, albeit not in adequate quantities.

Over 85% of the urban population and about 20% of the rural population are served through house connections. Aggregating these figures for the whole country results in about 70% of the total population being served through direct house connections, the remainder having access to the water supply system through public standpipes (World Bank, 1988).

There are 14 wastewater treatment facilities of varying capacities in Jordan producing a total of 40 MCM of effluent annually. These plants serve approximately 75% of all buildings in Jordan (MWI, 1991). The remainder are served through local septic tanks or cesspools with effluent percolating into the ground. The resulting sludge is pumped out by tank trucks and dumped in approved areas.

### *Water Demand*

In terms of the demand for water, three main subsectors compete: the municipal, agricultural and industrial subsectors. Anticipated demand for each of these subsectors is presented below in Figure 17. The safe yield figure from all sources, fully developed, is 862 MCM / year.

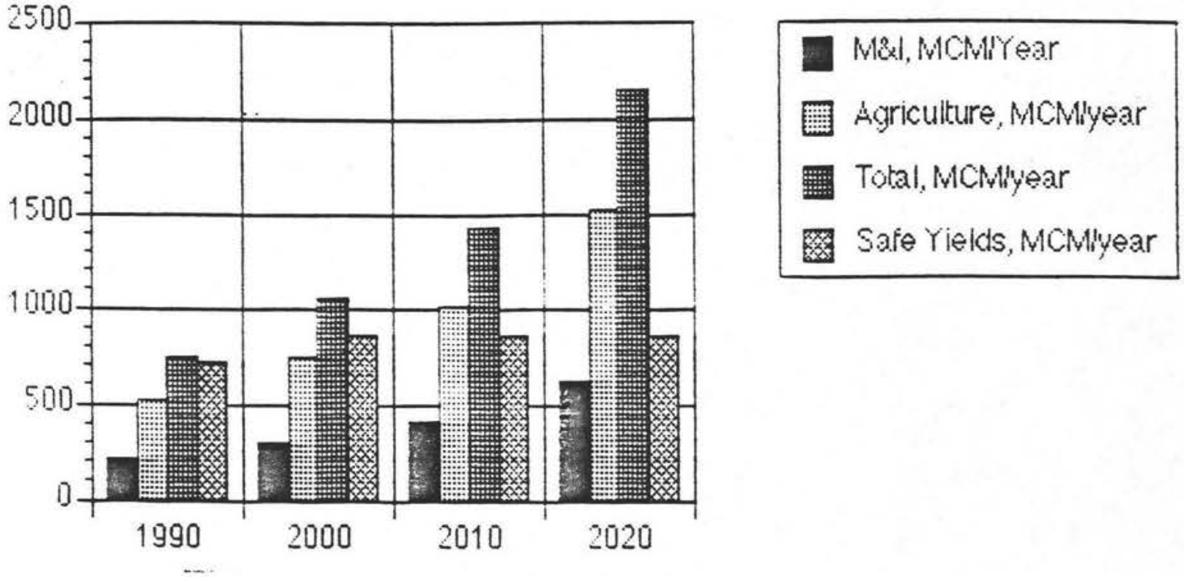



**Figure 17**. Projected water demand by each subsector

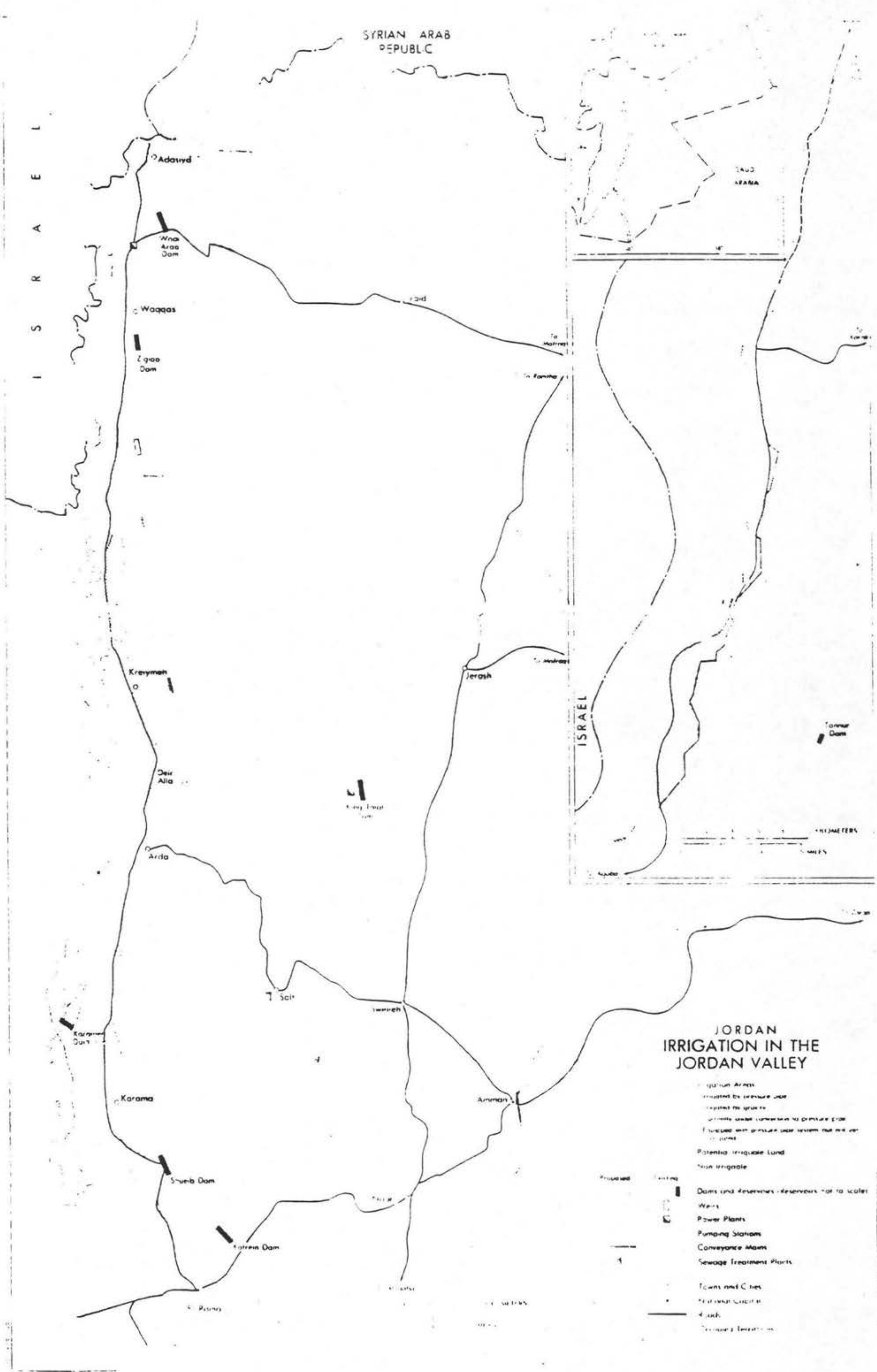
(a) Municipal Subsector

The municipal supply systems serve over 440,000 recorded residential, commercial and light industrial users and are plagued by huge losses. Some sources of inefficiencies are related to aging pressure pipes and inaccurate meters. In addition, illegal diversions of water to bypass meters is practiced on a significant scale, accounting for the remainder of the losses. In the municipal subsector, per capita consumption ranges from 50-300 liters per day (lpd) with an average of 150 lpd. The reliability of these estimates is questionable, however, due to the fact that a large amount of water is unaccounted. In fact, according to World Bank figures, 60 MCM of the water supplied was unaccounted in 1986. An estimated 11 MCM were unaccounted in 1982. Both figures were estimated from the difference between expected revenue and actual revenue received as payment for the water supplied in those years. These losses are the result of inefficiencies in operation, monitoring and maintenance.

In the municipal water subsector, inefficient operation and maintenance can have major consequences. For example, in 1986, surface water was used for the first time used in Jordan to satisfy municipal demand in Amman. The water supplied through a sub-system from King Abdullah Canal through Deir Alla was contaminated with raw sewage at a new treatment plant in Zai. All cross connections between polluted and fresh water were subsequently eliminated (at a higher total cost for the project) and the plant is now operational, albeit under conditions of water shortages in KAC.

(b) Agricultural Demand

In Jordan, agriculture provides 10% of nominal GDP, with crop production and livestock (sheep, poultry and goats) contributing 75% and 25%, respectively, of the value added in this subsector. However, the impact of agriculture is quite broad, and affects the industrial and service subsectors (World Bank, 1990). The total land area under irrigation is 55,000 hectares, mostly in the Jordan Valley and Southern Ghors. The King Abdullah Canal is the main lifeline for most irrigation projects in the area (see Figure 18, Irrigation in the Jordan Valley). Water supply to these areas is provided by surface gravity systems (45%) and pressure pipe systems (55%). It had been anticipated that irrigable land areas would be increased to 36,000 ha by the year 2000, after which water use for irrigation would level off. The anticipated increase in irrigable land area will mostly be in the Jordan Valley, since irrigation projects in the highlands utilize only groundwater supplies and therefore future land development there is very limited.



SYRIAN ARAB REPUBLIC
ISRAEL
Adasiyd
Wadi Arab Dam
Waqqas
Ziglab Dam
Kreiymeh
Deir Alla
Arda
Salt
Jerash
Karama
Shueib Dam
Kafrein Dam
Amman
JORDAN
IRRIGATION IN THE JORDAN VALLEY
Potential Irrigable Land
Non Irrigable
Proposed
Existing
Weirs
Power Plants
Pumping Stations
Conveyance Mains
Sewage Treatment Plants
Towns and Cities
Roads

In the agricultural subsector, irrigation efficiencies range from 38% for surface distribution systems to 70% for direct pipe distribution systems (World Bank, 1988). Many factors contributing to these inefficiencies are apparent. For example, even though a substantial investment in irrigation infrastructure is in place, evaporation rates from open irrigation canals in the Jordan Valley are high, and seepage losses from those same canals drain away considerable amounts of water. In addition, high subsidies to Jordan Valley farmers imply that more irrigation water is used than is necessary.

(c) Industrial Demand

The major industries in Jordan include the petrochemical refinery at Zarqa; cement industry at Fuheis and Rashadiyeh; the pharmaceutical industry at Salt; the phosphates industry in Hasa, Abyad and Shaidiyeh; potash plants at the southern tip of the Dead Sea; the glass factory in Maan; and the fertilizer industry in Aqaba. These major industries obtain their water from private groundwater wells. Smaller industries use municipal water supplied by the public sector. In all cases, efficient reutilization is encouraged by the licensing authorities at the MWI, as is the use of brackish water mixed with fresh water for cooling.

A number of studies have been applied to forecast water demand in Jordan for the next several decades. Al-Momani (1987), for example, employed ordinary least squares regresssion analysis to predict possible water use in the future. Two other studies (MWI, 1989; World Bank, 1988) were based on the Water Sector Master Plan of 1977. Figure 19 provides a perspective on these recently forecasted values of water demand from the three different sources.

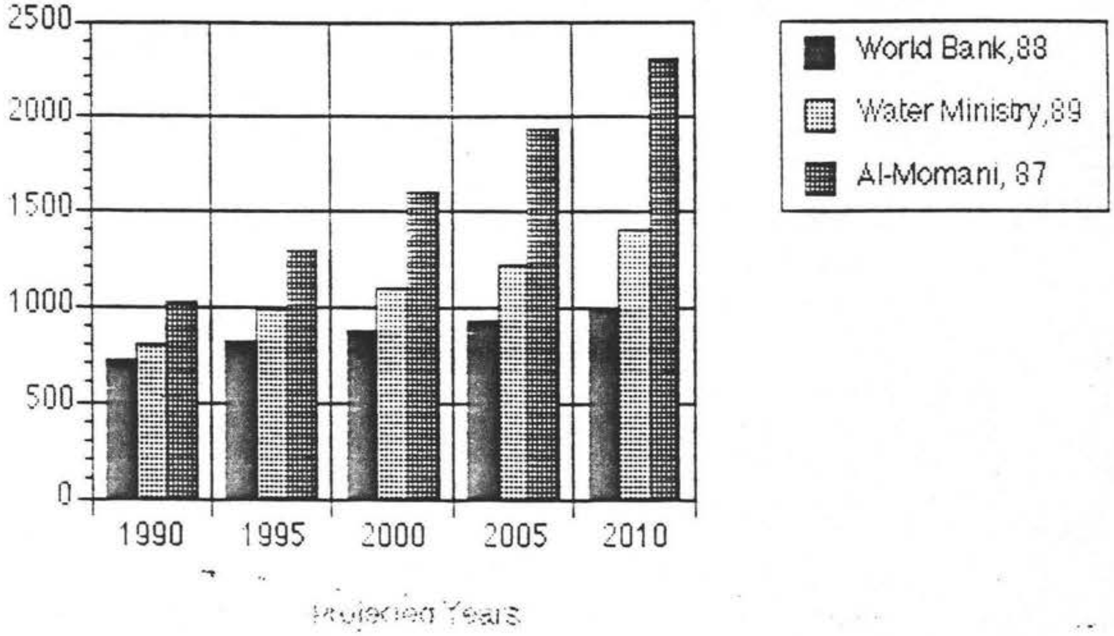



**Figure 19**. Forecasts of Total Water Demand, MCM per year

Some possible explanations for the discrepancies in demand forecasts are: (1) the use of different sources of input data, e.g., different population projection estimates; (2) the use of different theoretical assumptions, e.g., the assumption that agricultural water use would level off, and, (3) lack of a reliable historic data base on water supply and demand figures. Despite the discrepancies in forecasted water demand, the gap, or deficit, between supply and demand clearly is widening.

These studies also reveal that a substantial amount of current and historical water demand data are available. It appears that a sufficiently strong data base (regarding water availability and use) exists to support comprehensive water resources planning in Jordan to address the deficits.

The term "deficit" is a relative term and requires further elucidation. In the case of Jordan, a semi-arid country with scarce water supplies and a growing population, the general public realizes that they must conserve water. Thus, in light of the fact that demand per capita is relatively low, the question is how low would the government allow this demand level to reach, or, in other words what is an acceptable time frame in which new water supplies are required to keep pace with demand?

The government has placed residential demand as the first priority in water allocation decisions. An important consideration in water resources planning is the development of a lower limit, below which water supplies would not be allowed to fall. There is no easy way to do this. The most practical way is to use a ratio of accepted levels of water for each individual to maintain health, sanitation and hygiene. The Ministry of Water and Irrigation is considering a figure of 190 lpd per capita (including losses) to cover total demand in the country for municipal purposes. Any excess water would be allocated to the irrigation and industrial subsectors according to set quantities and proportions. Under this approach, total water demand can be calculated given adequate estimates of population growth. Then, these municipal demands (along with irrigation and industrial demands) can be compared with the supplies available within basins to determine future deficit projections.

Because of concern over impending deficits, the Jordan Government studied the situation in detail prior to the recent Gulf War. It outlined when the water deficit will occur and what it intends to do about it. According to the MWI, an estimated deficit of 143 MCM will be reached by the year 2005, assuming that historical levels of resource development continue to augment supplies. However, if the current financial squeeze continues for a significant period of time, expected development projects will not take place, causing deficits to occur earlier than expected and to increase thereafter. Possible courses af action envisioned by the government in 2005 include exploitation of deep water aquifers, initiation of conservation programs, controlling water supply losses, search for water sources outside the Kingdom, artificial recharge of groundwater aquifers, reclamation of wastewater for use in irrigation, and desalinization. The development and evaluation of alternative courses of action now, using proven integrated planning technologies, could be instrumental in enabling policy makers to deal with the situation in a more comprehensive and effective way than has been the case in the past.

Reasonable deficit projections are displayed in Table 8. These figures are estimates that the authors believe are representative of the actual situation, after reviewing the various available demand and supply projections, and considering the economic feasibility of various supply augmentation projects. They are based on an M&I demand of 190 lpd, and an irrigation demand of 1000 CM per year per 0.1 ha, assuming a constant population growth of 3.8% per annum for the period.

**Table 8.** Projections for the water deficit (1990-2005)

| | 1990 | 1995 | 2000 | 2005 |
|---|---|---|---|---|
| Water demand | 740 | 890 | 1045 | 1200 |
| Water supply | 730 | 862 | 862 | 862 |
| Net annual deficit | 10 | 28 | 183 | 338 |

### 2.5.6 Environmental Considerations

For Jordan, environmental problems are a direct externality of the supply-demand imbalances. Because of the generally low flows, surface streams have relatively low assimilative capacities. Treatment levels of wastewater is inadequate in view of the low assimilative capacities of receiving water bodies, and therefore, downstream uses are adversely affected. In the case of groundwater, overpumping (mining) to meet growing demand is degrading the quality of the remaining water in the basin. Although Jordan is well aware of the importance of environmental protection and has undertaken significant measures to face the problems facing its water supplies, much remains to be done.

The institutions involved in monitoring the chemical and biological constituents of water in Jordan are the WAJ, the Ministry of Health, the Royal Scientific Society (RSS), and the Water Research and Study Center. The RSS is a non-profit research institution established in 1970 to provide scientific and technical assistance to both the private and the public sector for development projects in Jordan. The Water Research and Study Center was founded in 1983 at the University of Jordan with the aim of contributing to the National effort in the field of developing water resources, and water conservation to protect against environmental impacts. Together, these institutions set the standards for wastewater, drinking water and irrigation water in accordance with World Health Organization specifications and U.S. Environmental Protection Agency standards.

### *Quality of Surface Water Resources*

The main rivers in Jordan are the Jordan, Yarmouk and the Zarqa. The waters of the Jordan River are highly saline for a number of reasons (Ahmad, 1989). It receives the return flows from irrigated fields on both sides of its banks, and now directly receives the flow of the saline springs that were diverted into the Jordan River by Israel. The diversion of these springs was undertaken unilaterally by Israel in order to conserve the quality of Lake Tiberias, which provides a substantial portion of Israeli water. This practice has made the Jordan River unsuitable for use in its present condition.

The Yarmouk River waters are of good quality at the present time. The Zarqa River, on the other hand, is an environmental disaster. Receiving industrial and municipal waste, it is very polluted. In the summer months, the flow of this river consists almost entirely of sewage effluent. The Zarqa flows to the King Talal Reservoir, where a number of studies by RSS have concluded that the water in the reservoir is acceptable only for "salt tolerant crops", with total dissolved solids at the outflow point averaging 891 mg/L (RSS study, 1989a) The study also concluded that because of the high concentration of sodium (133 mg/L), sprinklers should not be used since this will ultimately damage the plant leaves. Similar studies for Wadi El-Arab Dam reservoir revealed a TDS level of 509 mg/L and sodium levels of 101 mg/L at the outlets, with higher concentrations at the reservoir inlet. The same conclusions were reached, i.e., to use the water for irrigation of salt tolerant crops only, otherwise crop production may fall for non-tolerant crops (RSS, 1989b).

### *Quality of Groundwater Resources*

In the case of groundwater, which provides about 90% of municipal supplies, water quality is even more important. A detailed study of groundwater pollution can be found in Salameh (1989). That report indicated that the two main sources of groundwater contamination are water mining practices and seepage of wastes.

Contamination due to water mining refers to the general propensity of saline water to intrude into the higher levels of aquifers following extraction rates which are greater than the natural recharge of the aquifer. The first experience with saltwater intrusion in a groundwater basin occured in the Jafer region. In the 1960s and early 1970s, salinity levels escalated due to overextraction of water. To this day, salinity levels are not low enough to render this basin completely usable. In the Wadi Dhuleil well fields, mainly used for irrigation, salinity levels grew to such high levels that some investors and farmers were willing to sell to recoup some of their losses. In the Azraq basin, water is used for both irrigation in that area and for domestic supplies in Irbid and Amman. In that basin, water withdrawals began to exceed safe yields in 1982, and presently water levels have been lowered by 3-5 meters. Subsequent measurements of salinity revealed an increase from 500 mg/L to 700 mg/L in this basin. In the nonrenewable fields of the Disi aquifer, water levels have dropped by as much as 8m since the early 1980s.

Contamination of groundwater basins due to seepage of wastes has occured in the Amman area, where water quality is increasingly affected to the point that, in the near future, groundwater supplies in this area may not be adequate for human consumption. The main reason for this is the seepage from septic tanks in some parts of the city and the consequences of industrial activities. In Aqaba, wastewater near the coast is "filtered naturally" into the sands of the area. The general direction of movement within the aquifer is towards the coastline, implying that wastes could eventually reach the beaches. In the North, another wastewater plant operates under the so called natural stabilization method, and this has caused wastes to seep into groundwater systems that are connected to springs reaching the Yarmouk.

Future protection of groundwater basins is a matter of paramount importance. The following initiatives are considered to be high priorities by national policy makers: prevention of mining in groundwater basins; development of the wastewater infrastructure for a large part of the population and improvement of the operations of wastewater treatment plants; careful selection of landfill areas; monitoring of pesticide and fertilizer use in most areas; development of a sound industrial licensing policy and related laws and guidelines for the protection of the environment.

*Chapter 3*

# National Water Resources Management Policies

The challenge facing decision makers today is how to balance water demand and supply under conditions of limited resources and an increasing population, over the next 20-30 years. His Majesty King Hussein has said, "the balance between resources and population is the the main determinant for all facets of economic and social development. A continuing imbalance in this resource/population equation (namely in the case of water resources), constitutes the main limitation to achieving desired development levels. And it also slows the attainment of these desired levels." (A translated excerpt from the address made at a graduating ceremony for the University of Science and Technology in Irbid, 1989).

The main objectives of this chapter are to (1) discuss the current ~~institutional arrangements and economic policies of the Jordan government within the water sector~~, (2) taxonomize ~~the water resources problems and present an array of possible solutions~~, and (3) evaluate the current institutional and policy situation in terms of potential alleviations of future water shortages.

## 3.1 Institutional and Legislative Framework

Over the years, the Jordan government has established laws and guidelines regarding groundwater extractions, allocations of water for different uses, and effluent re-use. These have been reinforced as recently as October of 1987, with the reorganization and centralization of water sector institutional arrangements in a move considered essential to ensure integrated water resource management. The water sector now is controlled by the Ministry of Water and Irrigation, which consists of two major departments: the Water Authority of Jordan (WAJ), and the Jordan Valley Authority (JVA). Each of these authorities is headed by a board of directors reporting to the Minister. The Water Authority is solely responsible for providing water for municipal uses and for extracting groundwater to meet demands. The JVA, on the other hand, is responsible for the development and use of water resources in the Jordan Valley for the purpose of irrigated agriculture. JVA and WAJ are organized as illustrated in Figure 20.

Some level of knowledge of the historical background to the establishment of the MWI is important to an understanding of the current organizational arrangements controlling the water sector in Jordan. The organizational development of the water sector can be outlined within three major time periods: pre-1984; 1984-1987; and 1987-present time. In the first time period (pre-1984), the water sector was managed by a number of independent organizations including the Natural Resources Authority (NRA), the Water Supply Corporation, the Amman Water and Sewerage Authority, the Jordan Valley Authority, and local municipalities. The problems associated with this arrangement were primarily the inability to implement comprehensive development plans, and duplication of effort to a large extent.

## Ministry of Water and Irrigation

Organization and Breakdown of Activities

**Water Authority of Jordan**

- Administration of Water Resources
- Planning, Development and Information
- Administration of Projects
- Operation, Maintenance and Inspection
- Financial and Administrative Affairs

→ Responsible for water related activities in all areas of the Kingdom, except in the Jordan Valley. Responsibilities include planning, allocation and distribution of water to M&I and for irrigation in the uplands.

**Jordan Valley Authority**

- Operations, Maintenance and Mechanics
- Land Administration and Rural Development
- Soil and Land Reclamation and Drainage
- Dams, Watersheds and Irrigation Projects
- Administration and Finance

→ Responsible for planning and development of surface water resources in the Valley area, and for allocation of water for irrigation.

**Figure 20.** Institutional Organization of the water Sector

Beginning in 1984, the water sector was reorganized under the direction of two independent ministerial level authorities, the JVA and the WAJ. Although this new arrangement was an improvement over the previous one, the division between the JVA and the WAJ caused some major difficulties. For example, the conflicts in the water uses of the different subsectors were not addressed adequately, and the impracticality of employing comprehensive policies within this arrangement proved to be an obstacle for development (MWI, 1990). As a result, the two authorities were placed under the central control of the MWI, created in 1987.

It is worthwhile to consider the advantages and disadvantages of centralized control of the water sector in Jordan. One report (U.N., 1989) identified two approaches that developing country governments [illegible] the control of their water resources sectors. In the first approach, governments set guidelines and laws, which are enforced as part of their legal systems to guard and promote the public good. Under this approach, the responsibility for ensuring that water is allocated and used in an efficient and equitable manner is considered a task of the government. In the second approach, control is exerted by providing the capital and human resources necessary to plan and implement water development projects. Generally, these investments are so large that they can only be provided by the government.

Both of these factors are reflected in the Jordanian water sector. With a relatively small population to serve, scarcity of water resources to draw from, and significant economic difficulties to address, the government undertakes the planning, development and maintenance of all water related activities through its implementing agencies. Using its own financial resources and assisted by international lending organizations, it sets water use and development priorities and decides on the best allocation of water for competing uses. Unfortunately, the bureaucracies involved with this central control system causes changes to be implemented very slowly, which is a major disadvantage for a water poor country. However, such disadvantages are outweighed by the benefits derived from central control. The most prominent advantage of central control is the fact that integrated approaches which promote efficiency and equity can be implemented relatively easily in a country like Jordan, since in most instances, the scales of development and management are workable. In addition, the need to integrate the water resources sector with other sectors and functions of government can be addresssed effectively with the current organizational structure, since the governing boards of the JVA and the WAJ consist of a wide spectrum of high level officials from the Ministries of Planning; Agriculture; Municipal, Rural and Environmental Affairs; Health; Industry and Trade; Natural Resources Authority; and the General Manager of the Budget Department. Both of these boards are chaired by the Minister of Water and Irrigation.

The body of legislation in Jordan affecting the water sector provides a coherent legal base for the improvements in the future. The two main laws governing the sector are Law No. 18 of 1988 (WAJ), and Law No. 19 of 1988 (JVA). Both of these laws contain numerous articles and are quite lengthy. The main features of each of these laws are highlighted from the English translations in Ahmad (1989) below.

The laws delineate the responsibilities and duties of the two boards and regulate their financial affairs in accordance with accepted government practices. In doing so, development plans and policies are required to be presented to the Council of Ministers on an annual basis for approval. The laws also outline the penalties for committing unlawful acts, such as polluting water sources, or drilling wells without a license. Other related laws include the Organization of Natural Resources Affairs Law No. 12 of1968, and Agricultural Law No. 20 of 1973. These laws combined deal with the issue of water rights. The underlying premise is that water is a public good allocated by the government for the equitable dvelopment of the various regions in the country. In that sense, the drilling of wells may be licensed for irrigation of private lands greater than 50 dunums in area. A good example of licensed groundwater development for irrigation is the Wadi Dhuleil area near Zarqa. For industrial purposes, the Ministry isssues licenses to companies to use groundwater wells under specific conditions. The Ministry issued few licenses in 1990, and will most likely not issue any this year.

At the present time, the MWI is carrying out a project to better manage the water sector, and to assist decision makers in formulating water policies and related guidelines. The project is jointly sponsored by the United Nations Development Program (UNDP), the Arab Fund for Economic and Social Development, and the Jordan Government.

## 3.2 Economic and Financial Policies

The "economic" structure of the water sector includes important mechanisms that allow decisionmakers to formulate, analyze and compare alternative development plans. This section discusses water pricing and cost recovery, and introduces the role of future external assistance.

### *Water Pricing*

Presently, water prices to consumers in Jordan follow a progressive block rate system. As consumption exceeds certain block limits, the price of additional units increases. The old system of water tariffs included progressively higher prices for higher consumption, but with less delineation in block limits. The new system, adopted in 1990, added more blocks, with the result that revenues increased from 16 million JD to 25 million JD (WAJ figures for 1990). Table 9 presents the new block structure and the progressive rates by region for domestic uses. For agricultural use, the rate is 0.0065 JD/cubic meter.

Table 9. Domestic water pricing rates in Jordan, in JD

| Quantity of water, CM per quarter | Amman | Outside Amman | Jordan Valley |
|---|---|---|---|
| Up to 20 | 0.100 | 0.065 | 0.065 |
| 21-40 | 0.190 | 0.090 | 0.065 |
| 41-70 | 0.400 | 0.300 | 0.115 |
| 71-100 | 0.500 | 0.500 | 0.250 |
| >100 | 0.600 | 0.600 | 0.400 |

The rationale behind this new pricing system, according to the MWI, is that higher prices can encourage conservation by large users, while at the same time increasing revenue, but avoiding adverse impacts on the majority of the population. For example, records show that 12% of residential use is over 70 CM per quarter. Therefore, the water prices for this subsector were increased to promote conservation on the part of these high-use consumers and to increase revenue for the water sector, without increasing prices paid by more conservative users.

*Cost Recovery*

The MWI has recently required that any new investment plan for the water sector must address the following criteria as part of overall economic feasibility anlalyses:

1. Operating costs
2. Maintenance costs
3. Capital cost recovery
4. Benefits from new project
5. Maintenance of adequate levels of service

Detailed cost-benefit analyses are now required for all new projects, based upon the above framework. Although benchmark figures for cost recovery have not been explicitly specified as a cutoff point below which projects will not be implemented, the following cost information provides a contextual background in which such determinations are made. The average cost of a cubic meter of water for irrigation (amortized capital cost recovery + operation + maintenance) is 0.20 JD per year for a typical 50 year lifetime project at a zero interest rate. At an interest rate of 5%, this figure is 0.41 JD/CM (Backhit and Salameh, 1989). These types of costs are used for evaluations of proposed projects on a cost comparison basis.

Comparing these figures with the average price of irrigation water in the jordan Valley of 0.0065 JD/CM, it can be observed that the government is heavily subsidizing irrigation in that area. On average, this subsidy reaches 75% of farmer's costs in the Jordan Valley (World Bank, 1990). In the highlands, however, farmers have to pay all of their operating and investment costs, raising the issue of equity.

The economic value of water on the other hand is a much more difficult matter to estimate. In 1990, the World Bank presented the results of a detailed study on the long run marginal cost of irrigation water. The study concluded that "developing additional water supplies (Al-Wehdah Dam) remains an economically efficient investment."

### *External Assistance*

As is true with most developing countries, Jordan cannot merely depend on its own revenues for development of water supplies; external assistance in the form of loans and grants are important. This difficulty has been magnified by the effects of the U.N. sponsored Iraqi embargo and the ensuing hostilities. With the current state of the Jordanian economy, future financial investments from internal sources in the water sector are very unlikely. U.N. agencies, the European Community and others are being approached for financial assistance. By the end of 1990, Jordan had received *commitments* of U.S.$ 349 million in bilateral grants and loans from ten different countries. The substantial losses of U.S.$ 1.54 billion for 1990 are still to be recouped, however, because of the misunderstandings associated with Jordan's neutrality in the Gulf war. However, many financiers are still keen on providing Jordan with soft and commercial loans for the water sector, because they know the importance of water to the development process, and are aware of the future shortage in water supply in the years ahead.

## 3.3 Review of Current Planning Policies

The process of planning involves studying historic trends, forecasting probable events, and preparing for the future to meet targeted objectives. In Jordan, the planning process has evolved under numerous constraints such as regional political disputes, limited natural resources and financial sqeezes. Naturally, these constraints restrict the choices that can be made by policy makers. Notwithstanding the above, comprehensive plans have been implemented over the years with tangible benefits in terms of social and economic development.

At the national level, planning is mainly undertaken and implemented bu the Council of Ministers, who present their plans and budgetary requirements to the elected House of Representatives and the Senate for review and approval. As such, popular participation in the decision making process is guaranteed, albeit not in the implementation stages. At the sectorial, or Ministerial level, plans are formulated based on trends and the extent to which previous objectives have been achieved in each sector. Thus, new or modified programs are developed for each planning cycle (3-5 years) to satisfy specified objectives. The final decisions are made by high level officials based upon judgment and experience.

A recent comprehensive plan for the water sector was developed for the 1986-1990 period. The stated objectives at that time were to " (1) provide domestic and industrial water to all population clusters and establish wastewater networks for at least 65% of the population by the year 2000, and (2) to increase irrigable lands to the maximum extent which available water resources permit." The projected investment for the five year period amounted to 280 million JD, 56% of which was expected from foreign loans. The plan identified a target water supply figure of 705 MCM in 1990, beginning from a supply figure in 1985 of 520 MCM. In fact, a total of 730 MCM of water was utilized in that year (including significant groundwater mining) to satisfy demand. But since demand was estimated at 850 MCM, a shortage was felt in all subsectors

The most recent water policy has stated that the following regulations will be immediately adopted:

(1) Water supply cuts in the municipal and irrigation subsectors. As Munasinghe (1990) mentions, rotational cuts such as this can only be applied as a physical control in the short run. In the long run, cuts may be detrimental to public health and productivity.

(2) Suspension of new groundwater well license applications for this year, until further evaluation and monitoring is completed.

(3) Stringent monitoring of private sector groundwater extractions.

According to the MWI, the new policy is geared towards achieving national objectives and clear priorities. The highlights of the strategy presented by the Minister of Water and Irrigation to the Parliament on December 16, 1990 are summarized below.

***Main Features of the Water Strategy (1990-2005):***

(1) Increasing efficiency of water use through better management.

(2) Construction of the Al-Wehdah Dam.

(3) Construction of other main dams.

(4) Exploitation of new groundwater aquifers.

(5) Desalinization of seawater and brackish water.

(6) Reuse of treated wastewater in irrigation.

(7) Construction of water retention basins in the desert.

(8) Enhancement of environmental awareness and impact studies.

(9) Utilization of non-conventional sources of water.

(10) Price and subsidy modifications.

(11) Allocation of water to the municipal subsector as a priority.

Stemming from the current policy review as well as from knowledge of the predeeding sections, a characterization of the governmental policymaking process in the water sector is presented (see Table 10). This presentation (format adapted from Ascher and Healy, 1990) depicts the inherent weaknesses and strengths in the conventional planning process.

Table 10. Water resources policymaking in Jordan

| Characteristics of recent water policy making in Jordan | Generally accepted issues well*/not well~ served by characteristics |
|---|---|
| Long time horizon | * Emphasis on long term benefits<br>~ Realistic planning framework |
| Lack of financing information | ~ Flexibility of funding sources<br>~ Consolidating a viable financing plan for investments and costs |
| Inclusion of environmental impacts | * Multiobjective, integrated framework |
| Centralization | ~ Participation of beneficiaries<br>* Effective institutional framework |
| Setting objectives and priorities | * Prior articulation of targets<br>~ Analytical comprehensiveness |
| Fragmented pricing structure | ~ Equity considerations |

*Sources:* Ascher and Healy (1990), MWI (1991), Munasinghe (1990).

How can this policy be improved upon? First, the conventional planning process could be enhanced by use of an integrated framework of national objectives and strategies. For a country like Jordan, well endowed with research results and data, this is certainly feasible. Many international experts in the field of water resources have addressed the need for integrated approaches. Munasinghe (1990), for example, calls for an integrated approach that links the totality of sectors within the economy in order to produce the greatest beneficial impact and effectiveness. Munasinghe also identifies influential broad areas of concern to assist in the development of national objectives, a process he calls "a useful starting point for developing a national water supply strategy." Loucks and Somlyody (1985) argue for the use of the multiobjective methodology for water resources planning in developing countries. In a recent report, (U.N., 1989), systems analysis (including the field of multiobjective optimization) was advocated as a tool for water resources development and planning in developing countries. The methods of systems analysis, in various forms, have been used in the U.S. and other countries for the past 20 years.

Second, through the use of computer hardware and software currently available at the MWI, a decision support system (DSS) can be formulated to assist decision makers in viewing the broad consequences of their decisions. Future plans would thus be more responsive to national objectives, and would enhance the possibilities of attainment of those objectives.

## 3.4 Political Realities

In resolving international water rights issues of immediate concern to Jordan, the most pressing issue involves the Yarmouk River water allocations. The Yarmouk River, the main tributary of the Jordan River System, is shared by Jordan and Syria. The two countries ratified a plan in 1987 concerning construction of the Wehdah Dam and allocation of stored water in its reservoir. Actual use of the Yarmouk by Jordan had decreased from 130 MCM in the early 1980s to less than 110-125 MCM in 1990 (Salameh, 1990a).

Another major international issue related to conflicts in the region concerns the inability of Jordan to dredge the opening of the King Abdullah Canal (Naff and Matson, eds., 1984), whose inlet at the Yarmouk River has been partially filled with sediment. Israel has thus far made it difficult to perform much needed maintenance at the mouth of the Canal, with the result that water is flowing at low rates. In addition, the flow in the extension recently completed to irrigate the southern part of the Jordan Valley area from the KAC is at a trickle. The effects are devastating to that area of potential high agricultural productivity.

Over the years, numerous newspaper and magazine articles have attempted to portray the severity and consequences of the overall Middle East water crisis (see, for example, Cowell, 1989; Moffet, 1990; Murphy, 1990; Anderson, 1991; Mathews, 1991). As is often the case with publications directed to the general public, the political issues surrounding the main themes are the most popular. In the Middle East, political considerations are extremely important in deriving solutions to the water problems of the region. The Arab-Israeli conflict has impacts on the allocation of water from the Jordan River and its tributaries. Iraqi-Turkish relations are impacted every time the flows of the Tigris and Euphrates are adjusted by Turkey to meet its own demands. In addition, the current "Middle East Crisis," and the ensuing hostilities, may have major impacts still to be fully realized. We will not expand on the political writings in this field. We do, however, agree that alleviation of tensions could contribute enormously to the attainment of equitable, least cost solutions.

*Chapter 4*

# Future Water Policy Scenarios

The objectives of this chapter are to establish future scenarios in the water sector, and evaluate their impacts (or responses) on a number of relevant issues. This can be achieved, in an ideal situation, by adhering to the following requirements:

(1) Scenarios describe the water resources sector under various assumptions. These assumptions must be based upon a comprehensive knowledge of the water situation in Jordan.

(2) The objectives and intermediate targets should be feasible, given the current state of the institutional, technical and financial arrangements in Jordan.

(3) Evaluation of impacts should cover a broad spectrum of issues, or multiple criteria.

The next section defines the scenarios and summarizes their impacts in a less than ideal environment. It must be remembered that Jordan is undergoing critical financial pressures. The Prime Minister recently stated that Jordan requires U.S.$ 8 billion to recoup its losses from the effects of the Middle East Crisis and ensuing war. This serves to place greater uncertainty in projected scenarios and their impacts, and places an even higher level of uncertainty on the time frames for these scenarios. Nevertheless, these scenarios are valuable in qualitatively examining the broad ramifications of policy decisions.

## 4.1 Future Policy Scenarios

Four alternative scenarios are formulated, screened and finally compared on a heuristic basis. The first scenario involves the status quo with no development projects. The second focuses on providing the irrigation subsector with all of its water requirements. The third scenario involves providing an allocation preference to the municipal and Industrial subsectors. The fourth scenario involves the use of water with increased efficiency and water conservation policies and pricing structures. This last scenario will be studied in more detail than the others, and will be presented with a quantitaive foundation. In addition, environmental concerns will be considered within the scenarios.

### *Scenario No. I: The Status Quo*

For our purposes, the status quo refers to the continuation of present trends without any new development. This implies that the allocations of water will continue to the various subsectors through an enormously inefficient network, at an average of 132% of annual safe yields. Water quality deterioration will result, causing some aquifers to be damaged, consequently decreasing supply in the face of growing demand. The likely outcome of this scenario is a major water crisis in the next few years, with production levels falling and health standards gravely affected.

***Scenario No. 2: Irrigation Water Use Priority***

To allocate water to the irrigation subsector as a matter of priority does not require major changes in policy on behalf of the government. Most surface water development projects proposed by the MWI are irrigation oriented, primarily because of the low quality of the waters. Moreover, at least 10,000 ha can be further developed for agriculture in the Jordan Valley, which has the basic infrastructure it requires. In addition, irrigation in upland areas, [illegible] large amounts of ground water, can also expand. In the southern deserts, the Disi aquifer will solely be used to grow subsidized crops, and will leave only small amounts of water for Aqaba and surrounding towns. The net effect for agriculture, in this case, would be (1) more irrigated areas, (2) more production for internal as well as external consumption in the early years, but production will taper off and most likely will decline due to the increased deterioration in water quality, (3) more income to farmers, and agriculture related services in the early years, and (4) more foreign workers in the agricultural field.

The net effect on the industrial subsector is that expansion in production cannot take place, and current production will probably decline, negatively affecting the overall economy. The effects on the municipal subsector will consist of the harmful side effects of this policy in terms of health standards and the like.

To reconcile the problems stemming from this irrigation priority preference, the government could undertake measures to protect water resources from harmful return flows, and to prevent waterlogging. This would require substantial amounts of "environmental use" water, i.e., water needed to dilute low quality return water. This would cause an extra constraint on M&I water use. And in order to pursue this policy successfully, new sources would have to be found to supply water for municipal and industrial demand at cost, e.g., desalinization at Aqaba, and other supply projects to augment demand in the summer months.

The net effect of this scenario is that development projects such as the Al-Wehdah Dam would be required in order to expand the irrigated areas of the Valley, which would produce employment and equity benefits as identified by World Bank (1990). However, the costs of intensifying land use are less than the costs of expanding irrigable land in the valley. Therefore, these tradeoffs must be considered before any major decisions are made.

### *Scenario No. 3: M&I Water Use Priority*

In this case, agriculture would receive the residual water after municipal and industrial demand is satisfied. This is the recently stated policy of the government, which seems to be well timed, since M&I demand is expected to rise by over 200% in the next decade, while irrigation demand is expected to increase a modest 20% (Salameh, 1989a). Thus, reallocation from agricultural water supplies to M&I would be forthcoming in any case. This would curtail agricultural development to a significant extent, and without a program of efficiency enhancements, and conservation programs, many farmers would lose their means of livelihood.

### *Scenario No. 4: Increased Efficiency and Water Conservation*

In this paper, we have discussed the different ways in which operating inefficiencies have affected water supply. Inefficiencies in metering, maintenance programs, and other areas, contribute to water losses in the system. If the government can keep these losses down to a minimum by investing in the rehabilitation of supply networks, potential water savings could be as much as 100 MCM per year. Comparing this "rehabilitation project" to other supply augmentation projects, in terms of costs and benefits, would most likely lead to advantageous results in favor of this policy.

Water conservation in M&I and irrigation subsectors is a concept closely related to efficiency. For example, if water conservation can be applied in a direct way to the irrigation subsector without loss of yield, the whole country would benefit. Moore (1991) states that, in general, the potential benefits of irrigation water conservation programs are economic efficiency, improving environmental quality, and (in the case of Jordan), supplying unsatisfied municipal and industrial demand. Conservation would (1) imply use of water at near optimum rates, (2) result in fewer pollutants being created by irrigation return flows, and (3) leave more water for other uses.

Of the policy instruments mentioned by Moore (1991), the ones most applicable to Jordan are: quantity-based regulation, price-based regulation, and conservation subsidies. A discussion of each policy instrument and potential achievements are now presented.

Through quantity-based regulation, the MWI would simply reduce water deliveries to the Valley (or other areas) by a certain amount. Of course, the reduction would be announced to all affected farmers, and this would cause them to reduce irrigated lands, invest in water saving technologies, or change cropping patterns. In the "ideal" long run, this would rationalize water supply, improve environmental quality, and allow excess water to be used elsewhere. The extents of each of these favorable consequences could be determined by using economic models.

Through price-based regulations, price increases could have substantially the same effect. Again, detailed economic studies have to be performed before the MWI decides on a policy such as this.

Conservation subsidy programs would involve the MWI subsidizing water use reductions by farmers, making water available for other uses and improving environmental quality. As Moore (1991) mentions, these subsidies are offered only to induce water conservation, not to promote water conservation technologies, which may lead to expansion of irrigated lands without any decline in water use. Detailed studies for each agricultural area in Jordan should be undertaken to determine subsidy rates. This is a promising way in which MWI could approach some of the problems in irrigation.

The resulting effects of a water efficiency and conservation strategy on the "supply-demand balance" would be to delay the impending deficit by as much as 10 years. The cost associated with such water saving endeavors needs to be fully studied by the MWI. For this scenario, Table 11 illustrates the potential savings in water due to the adoption of an efficiency-conservation policy over a number of years. The quantity of water saved through the conjunctive use of increased efficiency with water conservation could be substantial but initial conservative estimates are as shown in Table 11. This number was calculated in the following way.

Water supply figures previously tabulated were for a per capita demand of 190 lpd including losses of 25% of total. If losses could be decreased to 10% in the M&I subsector, then a figure of 170 lpd could be used to estimate demand for M&I translating to a 10% reduction in overall M&I demand. In the irrigation subsector a conservative savings of 50 MCM per year is assumed based on estimates from the MWI. Our estimates were thus based upon the following simplifying assumptions:

(1) Population growth remains steady at 3.8%.

(2) The amount of annual savings in the irrigation subsector is constant over the next 20 years.

More refined economic models can relax these constraints and render the effort more dynamic and responsive to real world effects.

**Table 11.** Projections for the water deficit (1990-2005) in the efficiency-conservation scenario

| | 1990 | 1995 | 2000 | 2005 |
|---|---|---|---|---|
| Water demand* | 740 | 751 | 890 | 1030 |
| Water supply | 730 | 862 | 862 | 862 |
| Net annual deficit | 10** | 0 | 28 | 168 |

* Based on previous figures in Table 8, water demand was reduced by 10% for M&I considerations, and by 50 MCM per year for irrigation.

** Net annual deficit for the period 1990-1995 would remain positive until the efficiency-conservation policy has a full effect.

The effects of some of the other scenarios are depicted in Figure 21. The average pumpage per capita is the area between the two dashed lines. This is the desired level of supply by the government in an ideal situation, sufficient to maintain acceptable levels of public health, hygiene and sanitation. For the first scenario, with no development projects in sight, water supply will probably drop off below a generally accepted absolute minimum. For the M&I use priority scenario, per capita supply would have to increase then level off over time due to stabilization of population growth. The time dimension in the figure is used solely for illustrative purposes.

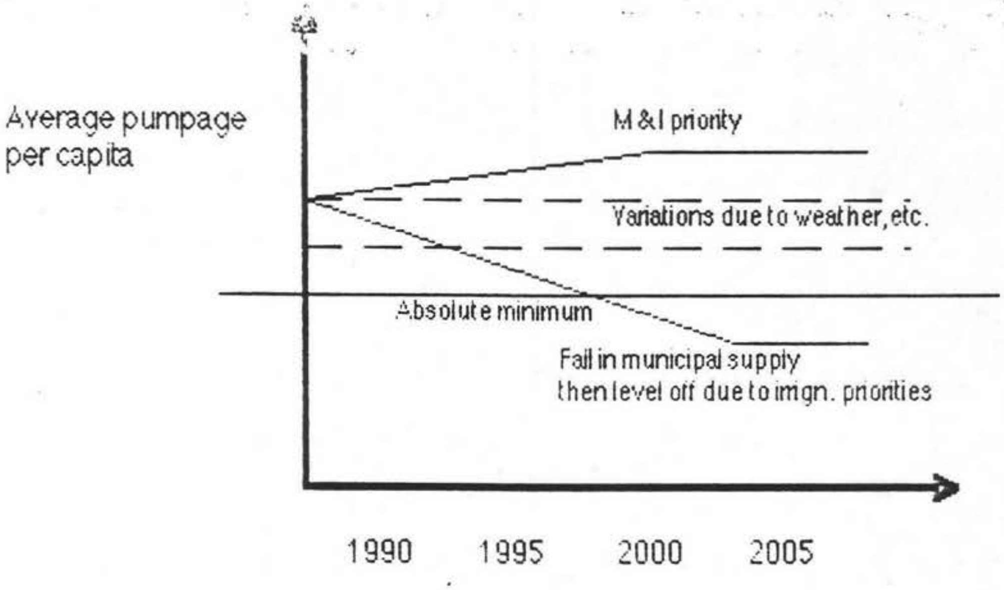



**Figure 21.** Illustrative sketch of municipal demand levels

## 4.3 Comparison of Scenarios

The scenarios above were developed using informed judgments. All the scenarios involve complex ideas and issues, however, and their comparison is not an easy matter. Decision aids such as the one outlined in the next chapter can assist in ranking and comparing alternatives. Moreover, the model described in the next chapter will have all of the "options" discussed in these scenarios as part of its internal data base. For now, however, the scenarios are compared on a purely heuristic basis.

To begin with, the **status quo scenario,** where no funding is available to undertake the necessary development and maintenance projects, would have impacts on the country that are extremely detrimental. The **irrigation water use priority scenario** leaves many questions unanswered. How could the government justify periodically shutting off municipal water supplies in the summer, while subsidized irrigation water is flowing freely in the Valley? Public forums may argue that the best quality irrigation water should be diverted to population centers where it is direly needed. The **M&I water use priority scenario** is a painful scenario for agriculture, but in the long run, M&I water use would be expected to level off to some extent, leaving the irrigation subsector some residuals from development projects. Food production may fall, and the issue of food security for the nation may be an issue of discussion in later years. The **increased efficiency scenario** may prove to be of importance if used in conjunction with a **water conservation scenario**, under conditions of international financial support. If this financial support were adequate, development projects such as Disi conveyor to Amman, and the Al-

Wehdah Dam, could be undertaken in conjunction with new efficiency enhancement projects and water conservation programs.

In sum, it would appear that if the economic situation in Jordan is boosted by international support, then the MWI can implement its projects based on a priority basis, and concurrently employ the efficiency and conservation policy. If the economic outlook remains grim, however, then reallocation of water form irrigation to M&I would be required sooner rather than later. The effects of this reallocation would be to cause a downward trend in all facets of economic and social development in the country.

*Chapter 5*

# Recommendations

The overall water situation in Jordan has reached critical proportions. The current financial squeeze is exacerbating the problem. If water supply and demand imbalances can be reconciled by using the latest in planning technologies, Jordan can better realize its economic and social development potential through sound renewed investments. But until then, sound management of existing water resources remains the only avenue for the government. If and when investments can take place, they will be analysed in an atmosphere of optimality and efficiency through an integrated multiobjective decision model which could make significant contributions to planning and policy formulation.

This chapter describes an approach by which that would be accomplished. It begins by providing an overview of the characteristics of the Jordanian water problems, followed by a discussion of proposed solution approaches.

## 5.1 Characterization of Water Resources Problems

This section presents a conceptual framework for the characterization of the water problems in Jordan, and their related socio-economic impacts. Of course, this diagnosis of the overall water situation does not, in itself, solve the problems, but it does serve to clarify them. Operational tools must be invoked to provide feasible and acceptable slutions. However, the identification of the components of the problems facing the water sector clearly is a necessary first step to the development of integrated and comprehensive solutions to be described later.

Table 12 identifies the major physical manifestations of the water resources problems in Jordan and presents their consequences as well as a qualitative statement of their associated levels of economic and social significance. The format follows largely from Bower and Hufschmidt (1984). An overall feature of this characterization is the inherent water supply-demand imbalances. In simple terms, these imbalances, if not alleviated, imply that Jordan can never realize its full potential for social and economic development.

**Table 12.** Characterization of Water Resources Problems in Terms of Social and Economic Significance

| **Physical Manifestation** | **Consequences** | **Economic and Social Significance** |
|---|---|---|
| 1. Semi-arid climate, low precipitation, high evap. rates. | Fluctuations in water supply; periodic droughts; naturally limited water resource base. | Planning, development targets plagued with uncertainty. |
| 2. High population growth rates. | Increased demand and competition for water; non-renewble ground water depletion; pollution. | Reduced living standards; health problems. |
| 3. Conflicting demands | Inequitable allocations and subsidies, regional price structures | Emergence of water lobbying |
| 4. Riparian conflicts | Critical supply augmentation projects cannot be undertaken. | Destabilizing to the economy. |
| 5. Absence of effective conservation program. | Waterlogging, environmental impacts, overall inefficiencies, losses. | Decline in productivity. |
| 6. Financial constraints. | Supply augmentation cannot meet demand requirements. | Increasing health problems, loss of productivity (chain reaction). |
| 7. Lack of integrated water policy. | Most of the above apply. | Low potential for social and economic development. |

## 5.2 Recommended Solutions

Based upon the information discussed above concerning of projected water deficits, and the problems and constraints outlined, it may be concluded that (1) demand will begin to exceed supply by 1995, even if all conventional sources have been developed, (2) there is a clear necessity for developing non-conventional water supplies, (3) there is a clear indication of the need for conservation and efficiency enhancement measures within the water sector, and (4) there is a clear need for overall integrated water resources planning, development, and operations.

On that basis, recommended solutions can be divided into four broad categories. The solutions include: (1) measures to increase supply from conventional sources, (2) measures to increase supply from non-conventional sources, (3) measures to promote greater efficiency and conservation, and (4) development of an integrated comprehensive planning and management framework.

Generally speaking, the first three categories have received a significant degree of attention in previous studies, reports and proposals. Conversely, the fourth category has heretofore received scant attention in Jordan, despite the fact that it represents an important approach to solving complex water resource quality and quantity problems in a number of more developed nations. Therefore, the first three categories will be addressed (in addition to the discussion of these subjects presented earlier in the paper) only briefly, while a higher level of attention will be devoted to the fourth category.

The first of the four categories (discussed in Chapter 2) involves increasing water supplies by 150 MCM annually, by constructing dams (e.g., Al-Wehdah, Karameh, Yabis, Al-Wala), fully utilizing side wadi flood flows, and developing the Disi, Al Jafer, and Hammad groundwater basins. The development of these groundwater basins could produce an additional quantity of 60-80 MCM per year for 100 years.

The second solution category (increasing supply from non-conventional water sources) was also discussed in Chapter 2 and will not be repeated here.

The third category of promoting greater efficiency and conservation involves the following related tasks:

(1) Reduction of physical losses from municipal water supply networks Losses are currently estimated at 25% of water supplies in these networks. Conceivably, these losses could be reduced to 10% by performing much needed maintenance work upon the identification of problem areas. In fact, a comprehensive study of system losses has been performed for the Greater Amman region by the WAJ, which is also planning to conduct the maintenance work in stages.

(2) Reduction of losses from irrigation canals Inefficiencies from the operation of major irrigation canals (including the KAC), and secondary delivery systems were discussed in Chapter 3. The quantity of savings could reach 50 MCM per year if losses are effectively reduced. Plans by the JVA are currently underway to increase the quantity of available water supplies by reducing these losses. Other measures in the irrigation area include the adoption of drip-irrigation in more areas than at present, decreasing evaporation losses, and planting crops with low water requirements.

(3) Reduction of water demand quantities by industries This could be accomplished through a comprehensive study on the current methods of industial water use and adopting water saving technologies in this field.

(4) Reduction of water demand by residential users A comprehensive study has been initiated by the RSS with support from the Ministry of Planning on the possibility of saving water by adopting simple household conservation measures. Potentially, tens of millions of cubic meters could be saved by changing personal consumption behavior.

(5) Reduction of adverse environmental impacts on water supplies A major move in this direction could be made by limiting groundwater extractions to [illegible] yields.

(6) Reduction of water demand by modifying water pricing policies Water prices should reflect actual cost to the whole population (with some subsidies for low income groups, and others), and should take into account population growth studies and the marginal costs of providing new supplies.

A wide variety of economic and political influences are presently molding the Jordaninan water sector. Management options are more important now than ever in the past, even though there are still development projects to undertake. Therefore, one of the most important recommendations that can be given at this time is that research into pricing, conservation subsidies and the like, be performed on a country wide basis. Such research will provide valuable results and provide the necessary input to a plan to proceed with a full fledged efficient management policy.

The fourth solution category for solving the water problems in Jordan involves the adoption of an integrated comprehensive planning and managment framework. It has been accepted practice for water resources development in developed countries for many years that socio-economic development can be measured in terms of the potential and actual contributions of development strategies to national objectives. In order to provide for the greatest achievement in terms of national objectives, at minimal cost, a method is needed to capture the connection between the desired objectives of the Nation and decision variables affecting water supply and demand. Such a method could be used not only to make decisions regarding investment opportunities, but could be used for policy analysis as well. That is, given specific actions by the planning and decision making bodies in Jordan, one can use the model to predict how much of the National Objectives could be attained by such actions.

The fundamentals of such an integrated planning approach for Jordan are now presented, based upon (1) the national objectives of Jordan, (2) the options and strategies available to it in the water sector, and (3) determination of which strategies contribute the most toward the national objectives at fixed investment levels. This planning approach ultimately could lead to the formulation of a comprehensive Decision Support System (DSS) to assist the Jordan Government in improving the planning and management processes in the water sector.

In order to explain this approach conceptually, we endeavor first to develop a hierarchical form of **national objectives**. In Jordan, these objectives have already been developed mostly by the Jordan Government as part of its planning policies over the past 20-30 years (e.g., Jordan Ministry of Planning, 1985). The objectives articulated in the recent report by the Jordan government are very detailed in nature, but they have not been specified in a manner conduicive to easy application of the technical methods envisaged. The section on objectives explains how they may be presented in a manner useful for multiobjective analysis.

Next, we link a number of disaggregated **options** (an option is defined as a single action to affect water management, eg., raising the height of a dam or applying water conservation subsidies) to form sets of coherent porfolios, called **strategies**. Under the proposed integrated approach recommended herein, the resulting strategies would be evaluated in terms of some feasibility criteria, in order to render each strategy sufficient in terms of its purpose as "a stand alone" policy. The feasibility criteria may include technical, environmental, financial, institutional and cost effectiveness considerations

Once these options, strategies and objectives have been formulated, the relative achievements of each option would be included in the data base files of the DSS, allowing the alternative strategies to be ranked using highly developed optimization routines (e.g., multi-criteria decision models). Ultimately the process would produce an optimal strategy for the future. Although the mathematical constructs involved in state-of-the-art multiobjective or multicriteria decision systems are generally complex, utilization of the system can be made very simple, so that a minimum amount of effort is required by decision makers to perform the analysis, even if the data base is modified frequently to add new information as it is developed. A brief description of how such a system could be developed for Jordan, using the framework of objectives, options, and strategies, is provided below.

### *Objectives*

Keeney and Raiffa (1976) have shown that the objectives in almost all complex problems can be structured into a hierarchy. At the top of the hierarchy is an all inclusive objective that takes into account all of the concerns of the policy makers. However, this broad is generally too vague to be of use in an integrated methodology. At each level of the objectives hierarchy, the objectives become progressively better defined but larger in number.

Keeney and Raiffa (1976) also address the question of how far to disaggregate an objectives hierarchy. They suggest that an appropriate set of objectives should represent that level of the hieararchy at which the number of objectives is as small as is [illegible] while still maintaining sufficient specificity that contributions of alternatives toward each objective can be measured. That is, the objectives must be both minimal and operational.

An example of an objectives set for Jordan was developed from an analysis of written Jordan Government policy statements, augmented by the collaboration of experts from the Ministry of Planning and the Water Research and Study Center at the University of Jordan. That objectives set is listed below.

**<u>National Objectives:</u>**

* Minimize groundwater extractions
* Minimize environmental impacts
* Maximize coverage of sanitation
* Maximize research and development
* Maximize supply of water
* maximize water conservation
* Minimize energy requirements
* Minimize initial costs

* Minimize operational and maintenance costs
* Minimize number of foreign labor
* Maximize number of hectares irrigated
* Maximize value of output
* Maximize efficiency
* Maximize cost recovery

Two important characteristics of the above objectives set that are fundamental to multiobjective analysis are that the objectives are conflicting (generally, additional contributions towards one objective results in reduced levels of contributions to other objectives at a fixed investment level), and non-commensurable (they are measured in non-comparable units, e.g., costs are measured in JD whereas environmental impacts are normally measured in nonmonetary units.

### *Options and Strategies*

The essence of multiobjective analysis is to determine which strategy provides the greatest level of contributions to the objectives, in terms of the decision maker's relative preferences among the objectives, at a fixed cost. To illustrate conceptually the manner in which this is achieved, a list of illustrative feasible options was developed by making use of recently avilable literature on the Jordan water situation augmented by collaboration with a number of agencies in Jordan. In Table 13, the classification employed by Walker and Veen (1988) is used to list some important options. The options are thus classified into those that affect water supply (technical and managerial) and those that affect water demand (pricing and regulation). Other important classification schemes exist, especially the one proposed by Munasinghe (1990), but the supply/demand classification below is adequate for the purposes of illustrating this technique.

A few general remarks concerning options to help solve the water problems are in order at this point. First, it can be seen from the classification of options that most are directed at the agricultural and municipal subsectors, the largest users of water. Second, options can be further classified spatially (by region) if required or in other manners. Third, if a larger set were generated for Jordan, a large portion of them would fall under the general framework of "management." This is the case because a thorough infrastructure already is in place, indicating that managerial type options are promising sources for future improvements. As such, [illegible] research and education, water conservation subsidies, and monitoring programs may ultimately constitute major features of water resources planning and management initiatives in Jordan.

It may appear that initially the objectives of minimizing costs and maximizing cost recovery may imply that some important strategies may never be selected as optimum (e.g., strategies including the Al-Wehdah Dam). Questions such as this relate to the chosen objectives set and preferences of the decision makers for contributions to the various objectives. For example, the objective of "minimize initial costs" could be disaggregated into sub-objectives such as "minimize costs to the Jordanian private sector," or "minimize costs to external parties." Or conversely, some objectives could be combined, such as combining cost objectives into a single "minimize net present value (or annualized) of all cost components," under a chosen discount rate.

**Table 13**. Some Water Resources Options for Jordan

Options Affecting Water
**Supply**

**1. Technical Options**
- construction of dams/ multipurpose reservoirs (see proposed dams)
- projects for reuse of marginal quality waters
- computerized system of water control in Jordan Valley irrigation
- exploitation of new wells, e.g., Wadi Seer aquifer, Wala Springs
- projects to increase urban runoff collection
- desalinization of brackish water at Azraq, Jordan Valley, Wadi Araba
- desalinization of seawater
- groundwater recharge projects. e.g.,
- subterranean drainage projects in Valley
- deep groundwater extraction
- rehabilitation of supply distribution networks in Amman, Irbid
- maintenance of KAC
- further development of Disi aquifer
- new wastewater networks (protect ground water wells)
- rehabilitation of polluted springs
- reroute industrial effluent further downstream in Zarqa River.
- computerized metering of groundwater wells.
- mixing of imported water and recycled water in Jordan Valley
- construction of private wells for rainfall interception
- conversion to drip irrigation
- construction of northern conveyer and develop Mukheiba wells

**2. Managerial Options**
- limit agricultural self sufficiency
- cease pumping from Qa-Disi aquifer
- research studies, e.g., simulation of all water movement in Jordan
- higher compensation for workers in control of diversions, inspections, etc.
- volumetric allocation of water on an annual basis
- incentives for recycling
- educational initiatives

Options Affecting Water
**Demand**

**3. Pricing Options**
- price water at cost
- subsidy modifications
- sewerage tariffs
- water conservation subsidies
- set prices for wastewater discharge for industries

**4. Regulatory Options**
- improve metering, billing and revenue collection
- monitoring extraction rates
- conservation programs
- change allocation procedures.

### *Optimization*

After a comprehensive set of feasible options is identified, contributions of each to each component of the objectives set are determined and various strategies (combinations or portfolios of options) are considered at various levels of investment. One of the most attractive features of a multiobjective decision support system, such as the one described here, is that the vast majority of the work is performed by the computer and the interactions between the decision makers and the computer are very straightforward. For example, a well designed computer based decision support system will automatically eliminate all strategies that are dominated by other strategies. That is, all strategies whose contributions to all national objectives are equaled or exceeded by at least one other strategy are removed from consideration. This is a very important feature because, even in a national or regional planning problem of moderate size, the total number of feasible strategies can be very large, effectively approaching infinity. This helps to explain why water resources planning problems are inherently so complex, and why so many past attempts to develop water resources without such sophisticated tools have not obtained optimal results, or have even been dismal failures.

From the remaining (relatively small) set of non-dominated strategies, the DSS employs one of a variety of techniques to interact with the decision maker to identify the most preferred strategy in terms of contributions to the objectives simultaneously. In addition, a typical water resources planning multiobjective DSS has many other useful features, such as the ability to conduct sensitivity analyses, and to determine which strategies are most susceptible to risks

## 5.3 Conclusion

This paper presented summary information concerning the water resources sector in Jordan. Within this framework, we proceeded to review the overall problems encountered in the sector. Some of these problems represent exogenous conditions, such as the state of weather patterns for certain years, and others were self imposed, e.g., state of riparian issues and high population growth rates. A number of scenarios were then developed, which verified the need for on-going economic and engineering research in the water resources sector. Categories of proposed solutions were described.

As a recent World Bank study of the Jordan water resources sector noted, an integrated decision model (such as the one proposed in Chapter 5) could make a significant contribution to water resources planning and policy formulation. This in turn, could contribute significantly to Jordanian growth prospects into the 21st century.

The technology outlined herein may also be favorably applied elsewhere in the Middle East region, where water resources constraints are similar to those of Jordan. Such a decision model could serve as a blueprint for model development in other Middle East countries. In such a context, the gains from improved water resources planning and management are likely to be large.

## REFERENCES

1 Walid Abedrabboh, "Multi-objective decision making applied for watershed development planning of Zarqa River basin in Jordan," Ph.D. dissertation, University of Arizona, 1988.

2 Maher F. Abu-Taleb and Jonathan P. Deason, "Identification of optimal investment strategies and policies affecting water resources development utilizing a multiobjective decision aiding model," seminar paper presented to the Agricultural and Rural Development Division, the World Bank, Washington, D.C., July 10, 1990.

3 Abdullah A. Ahmad, *Jordan Environmental Profile-Status and Abatement*, unpublished manuscript, 1989.

4 Abdulla Ali Al-Ibrahim, "Water use in Saudi Arabia: problems and policy implications," *Journal of Water Resources Planning and Management Division*, [illegible] 1990, pp. [illegible]

5 Ayman Hassan Al-Momani, "Modeling of future water demand and supply in Jordan- a tool for planning," Ph.D. dissertation, Oklahoma State University, 1987.

6 Ewan W. Anderson, "The source of power," *Geographical Magazine*, pp.10-14, Feb, 1991, and pp. 12-15, March 1991.

7 William Ascher and Robert Healy, *Natural Resource Policymaking in Developing Countries*, Duke University Press, Durham and London, 1990.

8 Mohammed A. Bakhit and Elias Salameh, editors, *Arab Conference on Water Resources and their Strategic Importance*, Jordan University, Amman, Jordan, 1990.

9 Layla I. Batarseh, Omar A. Rimawi and Elias Salameh, "Treated wastewater reuse in agriculture, part 1: Hussein Medical Center project," *Bulletin of the Jordan University Water Research and Study Center*,12, 1989.

10 Blair T. Bower and Maynard Hufshmidt, "A conceptual framework for analysis of water resources management in Asia," *Natural Resources Forum*, Vol 8, No 4 ,1984, pp. 343-356.

11 A. Cowell, "Next flashpoint in Middle East: water," *New York Times*, April 16, 1989.

12 Jonathan P. Deason, "A multiobjective decision support system for water project portfolio selections," Ph.D. dissertation, University of Virginia, 1984.

13 Jonathan P. Deason and K. P. White, Jr. "Specification of objectives by group processes in multiobjective water resources planning," *Water Resources Research*, Vol 20, No 2, February 1984, pp. 189-196.

14 John A. Dixon, Lee M. Talbot and Guy J.-M. Le Moigne, *Dams and the Environment-Considerations in World Bank Projects*, World Bank, Washington, D.C., 1989.

15 Daniel J. Hillel, *Out of the Earth- Civilization and the Life of the Soil*, The Free Press, A Division of Macmillan Inc. New York, 1991.

16 [illegible] "World phosphate supply," *Natural Resources Forum*, Vol 13, No 3, August 1989, pp. [illegible].

17 Abdul Rahim Imran, *Arab World Population, Present and Future*, U.N. Fund for Population Studies, New York, 1988. (In Arabic).

18 Jordan Central Bank, *Monthly Bulletin*, September, 1987.

19 *Jordan Information Bureau*, Jordan Issues and Perspectives, No. 3, February/March, 1991.

20 Jordan Meteorological Department, *Jordan Climatological Data Handbook*, Amman Jordan, 1988.

21 Jordan Ministry of Energy and Mineral Resources, *Natural Resources in Jordan: Inventory, Evaluation, Development Program*, December, 1988.

22 Jordan Ministry of Planning, *Five Year Plan for Economic and Social Development 1986-1990*, Amman Jordan, 1986.

23 Jordan Ministry of Water and Irrigation, "Water resources and uses in Jordan," paper presented at Arab Countries Conference on Water Resources and their Strategic Importance, Amman, Jordan, 1989.

24 Jordan Ministry of Water and Irrigation, *Water in Jordan : Challenges and Limitations*, Amman, Jordan, May 1990.

25 Jordan National Geographic Center, *National Atlas of Jordan, Part I: Climate and Agroclimatology*, Amman, Jordan, 1984.

26 Jordan National Geographic Center, *National Atlas of Jordan, Part II: Hydrology and Agrohydrology*, Amman, Jordan, 1986

27 Jordan Water Authority, *Study of water conveyance systems for Southern Jordan*, Published in association with Arabtech, Amman, Jordan, October, 1986.

28 R. L.--Keeney, and H. Raiffa, *Decisions with Multiple Objectives: Preferences and Value Tradeoffs*, John Wiley, New York, 1976.

29 Daniel P. Loucks and Laszlo Somlyody, "Multiobjective assessment of multipurpose water resources projects for developing countries," *Natural Resources Forum*, Vol 10, No 1, [illegible]

30 Jessica Mathews, "War and water in the Middle East," *The Washington Post*, April 28, 1991.

31 Ann Misch, "Purdah and overpopulation in the Middle East," *Worldwatch*, Vol 3, No 6, November-December, 1990.

32 George D. Moffet, "Middle East's cup runneth dry," *The Christian Science Monitor*, March, 8, 13, 14, 1990.

33 Michael R. Moore, "The Bureau of Reclamation's new mandate for irrigation water conservation: purposes and policy alternatives," *Water Resources Research*, Vol. 27, No. 2, pp. 145-155, February, 1991.

34 Mohan Munasinghe, "Water Supply Policies and Issues in Developing Countries," *Natural Resources Forum*, Vol 14, No 1, February 1990, pp. 33-48.

35 Caryl Murphy, "Middle East faces major water woes," *The Washington Post*, Saturday, March 10, 1990.

36 Thomas Naff, "Water : An emerging issue in the Middle East?" *The Annals of the American Academy of Political Scientists*, November, 1985.

37 Thomas Naff and Ruth C. Matson, *Water in the Middle East: Conflict or Cooperation?* Westview Press, Boulder, Colorado, 1984.

38 Sandra Postel, *Water: Rethinking Management in an Age of Scarcity*, Worldwatch Institute, Washington, D. C., December 1984.

39 Stanley Reed, "Jordan and the Gulf Crisis," *Foreign Affairs*, Vol 69, No 5, 1990, pp. 21-35.

40 Philip Robins, "Middle East I: Arabs eye Eastern Europe, warily," *The World Today*, August-September, 1990.

41 Brandon Robinson, "Collabrative Sector Analysis: A foreign assistance technique for improving LDC sector management," *World Development*, Vol 18, No 7, 1990, pp. 1015-1029.

42 Royal Scientific Society, *King Talal Reservoir monitoring project*, RSS, Amman, Jordan, September, 1989a.

43 Royal Scientific Society, *A study of the water quality in Wadi Arab Reservoir*, RSS, Amman, Jordan, November, 1989b.

44 Elias Salameh, "Groundwater contamination: causes, methods of protection, and examples from Jordan, " *Jordanian Geologist*, Amman, Jordan.

45 Elias Salameh, "Water resources in Jordan - current and future demands," paper presented at the Conference on the Disi Water Resource, Jordan University, Jan. 3, 1989a.

46 Elias Salameh, "Water resources of the Jordan River system and the surrounding countries," paper presented at the 3rd World Conference on Water Law and Administration, Alicante, Valencia, Spain, Dec.11-14, 1989b.

47 J. R. Starr, and D.C. Stoll, *U.S. Foreign Policy on Water Resources in the Middle East*, Center for Strategic and International Studies, Washington, D.C. Dec. 1987.

48 J. R. Starr and D. C. Stoll, *The Politics of Scarcity: Water in the Middle East*, Westview Press, Boulder, Colo., 1988.

49 Warren E. Walker and Meinaard A. Veen, "Screening tactics in a water management policy analysis for the Netherlands," *Water Resources Research*, Vol 23, No 7, July 1987, pp. 1145- 1151.

50 Jeremy J. Warford, "Economic development and environmental protection," *Natural Resources Forum*, Vol 13, No 3, August 1989, pp. 238-241.

51 David Wishart, "An economic approach to understanding Jordan Valley water disputes," *Middle East Review*, Summer, 1989, pp. 45-53.

52 World Bank, *Jordan: Water Sector Study Report*, 1988.

53 World Bank, *World Development Report 1990*, Oxford University Press, 1990.

54 World Bank, *Jordan: Towards an Agricultural Sector Strategy*, 1990.