MODELING OF FUTURE WATER DEMAND AND SUPPLY IN JORDAN - A TOOL FOR PLANNING

By

AYMAN HASSAN AL-MOMANI

Master of Science in Engineering
Leningrad Institute of Civil Engineering
Leningrad, USSR
1983

Master of Science
University of Oklahoma
Norman, Oklahoma
1985

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
DOCTOR OF PHILOSOPHY
May, 1988

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Thesis Approved:

George W. Reid (deceased)

Thesis Adviser

Dean of the Graduate College

DEDICATION

This dissertation is dedicated to my parents who have taught me the most important things in life, the loyalty to work, serve and study the needs of Jordan communities, to promote social progress, and better standards of living for a brighter future.

ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation and gratitude to his dissertation advisor, Professor George W. Reid, for the advice and guidance throughout the study period at Oklahoma University and in the preparation of this dissertation. Also, he would like to extend his sincere appreciation and gratitude to his Academic Advisor, Dr. Bennett Basore, for his encouragement, suggestions and constructive criticism during the preparation of this dissertation.

Many sincere thanks to Dr. Marcia Bates for reviewing the manuscript and providing guidance and suggestions. Unlimited gratitude and appreciation to Dr. Richard N. Devries for his academic guidance and research ideas given in the course works and preparation of this study. A special note of gratitude to Dr. Hamed Kamal Eldin for his continual support and hours spent on the research problem and data analysis, and providing the computer programs for investigating the proposed problem.

This work would not have been possible without the generous support and assistance of many institutions, colleagues and friends. The help of the members of the Ministry of Municipalities & Rural Affairs & Environment, Royal Scientific Research Society, Jordan Valley Authority, Department of Statistics, Natural Resources Authority, Water Supply Corp. is gratefully acknowledged. Special thanks to Yousef Zurigat, Ute Conly, and Daleene Caldwell for their help in this research.

Special thanks to my father, mother, brothers and sisters for their patience, encouragement and many sacrifices through my studies.

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CHAPTER I

INTRODUCTION

Water is very important to mankind, plants, and animals. Where water is available, civilizations flourish, settlements are created, and stability is attained. This importance increases in the arid areas where water is scarce and very valuable, especially in a country like Jordan. In Jordan, like many other developing countries, the major constraint in national economic development is the removal of hunger and diseases. Water is the major resource in the elimination of hunger by farm irrigation and the elimination of diseases through safe and adequate public water supplies. It is unfortunate that less than 10 percent of the population in developing countries is presently supplied with piped water. Even where such supplies exist, their safety is impaired by the intermittent nature of the service and the lack of supervision of quality.

The most important benefit from improving the quality and quantity of water supplies is an improvement in public health. Numerous studies have identified the transmission of typhoid, cholera and other diseases by contaminated water. The effect of water supply on the community health depends on the level of use of the supply, and service provided. If the water supply is insufficient for proper personal hygiene, the diseases cannot be controlled. Also improving water supply is an essential step in industrial and agricultural development and productivity. Further, meeting the demands imposed by population increase should take place, otherwise, intermittent supply and emptying of pipes specially in the areas of wastewater infiltration would turn the water distribution system into a transmission source of many diseases (Saunders, and Warford, 1976).

Statement of the Problem

The problem of this study arises from the need for a reliable study of potential water resources in Jordan and reliable estimate of future water demands. Population and economic activity have increased without sufficient regard for the availability of water. The population of Jordan doubled in size because of the forced immigration from the West Bank to the East Bank of Jordan, and major industrial complexes like the iron and steel works and petrochemical works have been established even though water resources are far from abundant.

An additional complicating factor is the strong emphasis placed on national and local-sufficiency in agriculture. The result is the high priority attached to agriculture especially irrigated farming. Agriculture, of course, is the single largest user of water accounting for 80 percent of consumption nationally.

Under ordinary circumstances there would be a deficiency between the supply and demand. However per capita residential usage is now very low (60 liters per day). If the economy develops as expected this could double by the year 2000 while population also continues to increase at a very modest rate. Therefore, substantial additional supply will be needed unless other factors change.

A continued deficiency of water supply in Jordan may have a disastrous effect on future health and development. Adequate and potable water supply is an essential and basic factor in economic development and public health. Quality of life is enhanced by availability of adequate potable water, when and where people need it. Healthy citizens can effectively function under conditions of ample water supply and disease-free environment. Further, water supplies for industry are usually met through community or public systems. In Jordan reliable water supply service can play an important role in supporting the development of industry.

Among water supplies problems in Jordan are the limited financial resources, inadequate management, lack of qualified manpower, inaccurate rainfall data, unavailability of past water consumption and future water demand data, inadequate data of water resources particularly in relation to water quality, and scarcity of engineering personnel for constructing and maintaining water and waste water systems, inadequate feasibility studies, political and legal problems, and arbitrary selection of plan targets.

Water shortages are often not caused by a lack of water but a lack of water resources development, poor utilization, unsuitable forecasts, neglect of scientific multidisciplinary approach for the water supplies, neglect of existing socio-economic and socio-political factors, inefficient institutions and the use of outdated management techniques.

In Jordan, the rapid urban growth of the last twenty years has occurred without a comparable expansion of utilities, including water supply. Growing disparities between the effective supply and demand for water have reached very serious proportions and constitute a danger to national development. The mismatches between the supply and demand of water are growing. Combating these deficiencies constitutes a major and fundamental task.

The rapid increase in population, irrigated land, education expansion, urbanization, industrialization, technological, and environmental development will augment the municipal, industrial and agricultural water demands. Further, the increase of population is imposing an additional burden to existing natural resources, particularly waste handling and treatment, and air pollution. The expansion of water supply and distribution systems has resulted in deterioration of sanitary conditions and increase in health hazards, affecting the safety and availability of water.

A national strategy of environmental protection requires a better understanding of the environmental, technical, legal and economic complexities arising when dealing with water resources. Better coordination of existing regulatory programs and a better understanding of the impact of all new regulatory actions on natural resources are necessary. Regulatory programs need to reflect the close relationship between air, land, ground water and surface water.

Scope and Objectives

Over the last few years, the Jordanian government has become concerned about environmental problems, that is, lack of adequate water supplies and proper waste disposal, air and water pollution, traffic congestion and transportation deficiencies, noise and odor troubles, land erosion, and salinity intrusion.

All the environmental problems have worsened because of the lack of comprehensive governmental programs dealing with environmental problems, that is, natural resources protection, management, absence of water policy, overlapping and duplication of functions and responsibilities among institutions which causes loss of money, and low efficiency and productivity.

The growing demand for water in Jordan, calls for the development of a mathematical model to forecast the water demand for municipal, industrial, and agricultural uses. The main objective of this study is to develop the following models:

1. Municipal Water Demand Model.
2. Industrial Water Demand Model.
3. Agricultural Water Demand Model.

The secondary objective is to forecast the water demand and the variables of the models by category for the year 2020.

The third objective is to evaluate the water resources availability in the country; surface water, ground water and waste water, to determine its reliability for meeting the water demands.

Finally, the objective is to amass information which may be useful to the government concerning environmental problems, and to suggest solutions to these problems.

Method of Approach

The problem analysis includes the following steps:

1. Data gathering on the present water resources' conditions in Jordan. This includes physiographical, geological, and climatological conditions. The data were obtained from several governmental agencies, i.e., Ministry of Municipalities and Rural Affairs and Environment, Jordan Valley Authority, Natural Resources Authority, Department of

Statistics, Water Supply Corporation, Amman Water and Sewerage Authority, Royal Scientific Research Society, Ministry of Industry and Commerce, United Nations and World Bank (see Chapters II and III).

2. Literature review and selection of the factors affecting the unit use of water as applied to Jordan. These factors were classified as meteorological, socio-economic, and technical (see Chapter IV).

3. Analysis of the methods available in the literature for estimating the unit use of water. Four methods were identified to be applicable to Jordan. The most suitable method among these methods was adopted in this study and is described in detail in Chapter V along with the discussion of the other methods.

4. Development of the mathematical models for the prediction of water demand patterns in Jordan. The stepwise multiple regression analysis constituted the heart of the models developed in this study (see Chapter VI).

5. Application of the mathematical models and forecasting water demand in Jordan in the next 30 years, i.e., to the year 2020 (see Chapter VI).

6. Recommendations for water resources planning, development, conservation, and utilization are drawn based on step 5 above and listed in Chapter VII. The recommendations should be helpful to government agencies in planning and development of water resources and in developing regulatory policies regarding water supplies in Jordan.

Regression Analysis

The main objective of this study is to develop Municipal, Agricultural and Industrial water demand models and to forecast the demand of water in Jordan. The use of multiple regression analysis permits one to gain an understanding of the interrelations between variables, also it is used to establish a quantitative relationship between variables that are useful for making predictions. In regression analysis, the relationship between variables is expressed in a general form as follows:

$$Y = b_o + \sum_{i=1}^{n} b_i X_i$$

where:

Y = dependent variable

X_i = independent variables

b_i = regression coefficient

b_o = intercept

In the developed model few assumptions were made on growth of population, cultivated land, urban and rural population and industrial productions. The discussion and evaluation of the developed models are included in Chapter VI.

CHAPTER II

PHYSIOGRAPHY, GEOLOGY, AND CLIMATE IN JORDAN

Jordan, situated near the Southeastern coast of the Mediterranean, lies between the longitudes 34 - 39^{o} East and latitudes 29 - 33^{o} to the North. The total area is 96,199 square kilometers (36,832 square miles). The population of Jordan is 2,798,760 (East Bank only) consisting of:

Urban population	62 percent
Rural population	35 percent
Nomadic population	3 percent

The population growth is 3.4 percent annually.

Jordan is bordered with: Syria to the North, Iraq to the East, Saudi Arabia to the East and South, the Gulf at Aqaba and the Red Sea to the South, and since its establishment by the United Nations Armistice Agreement of 1949, Israel to the West. See Figure 1.

The country's major river is the Jordan river, whose discharge is derived from springs located on the western and southern slopes of Mount Hermon (Jabal esh-sheikh) in Syria. The longest spring is the Dan Spring, which represents 50 percent of the discharge of the upper Jordan and collects the waters from the Yarmouk River which originates on the eastern margin of the Rift Valley. The Jordan flows to the south through the deepest subaerial portion of the Rift Valley to enter the Dead Sea at 398 m (1306 ft) below the sea level, the lowest point on the

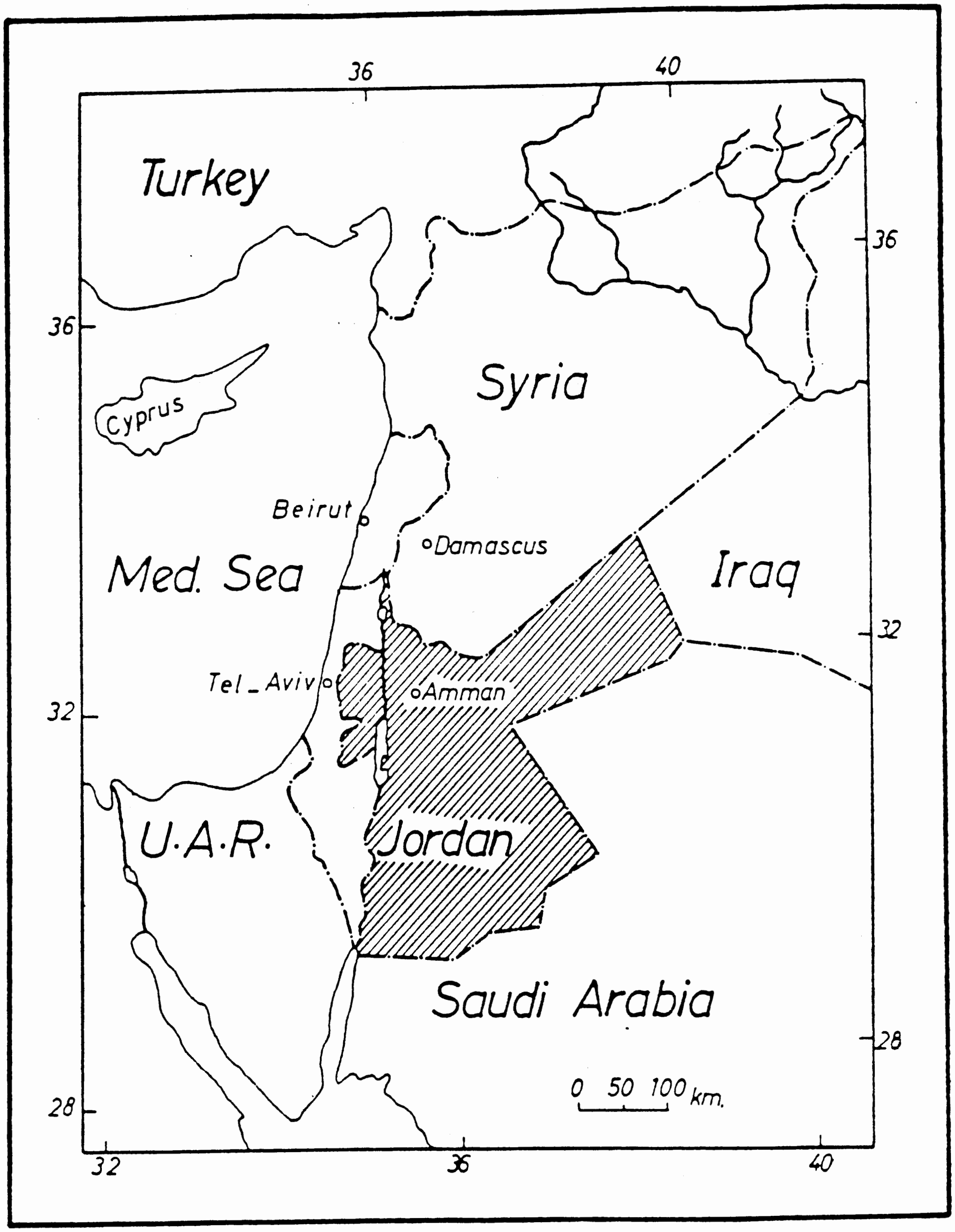


Figure 1. Location Map of Jordan

earth's surface.

The Jordan Rift Valley extends for 375 kilometers (233 miles) in a north-south direction, from the Southern shores of the lake Tiberias to the Gulf of Aqaba. Lake Tiberias is at -212 meters (-696 ft) below sea level, and the Dead Sea at -392 meters (-1286 ft) below sea level. The width of the valley increases southward until it reaches about 15 Km (9.3 mile), where the Jordan River enters the Dead Sea. South at the Dead Sea at 96 Km (60 mile), there is a divide in Wadi Araba at Ghor Al-Ajaram, where the Rift rises to 240 m (788 ft) above the sea level. Then it falls down to sea level at the Gulf of Aqaba. The Wadi has a total length of 170 Km (106 mile), and it varies in width from 10 - 20 Kms (6.2 - 12.4 mile). See Figure 2 and Figure 3.

From Deraa in Syria to Adasseiya in the Jordan Valley the Yarmouk River is deeply incised into volcanic rock. The chalk cliffs are capped by basalts which are the aquifers bringing ground water from the North to Mzeirib and Tell Shihab Springs in Syria. East at Deraa, the elevation is around 500 m (1640 ft) and the territory, lying on basalt, swings to the Southeast and rises to the Jabal Druse Mountains at 1800 m (5906 ft), then slopes to the South to reach just 1250 m (4100 ft). The basalts continue south toward Azrag and extends south to Saudi Arabia.

Most of the Eastern Plateau slopes toward the East to Wadi Sarhan. Under hydrostatic pressure this slope brings the spring water and surface run-off to the Wadi. At 200 Km (124 miles) from Azraq, the Wadi Sarhan turns Southeast into the Saudi Arabian territory, turns west toward El-Mudawwara in Jordanian territory and extends toward Aqaba, where it passes the Southern Desert. The highlands extend from the

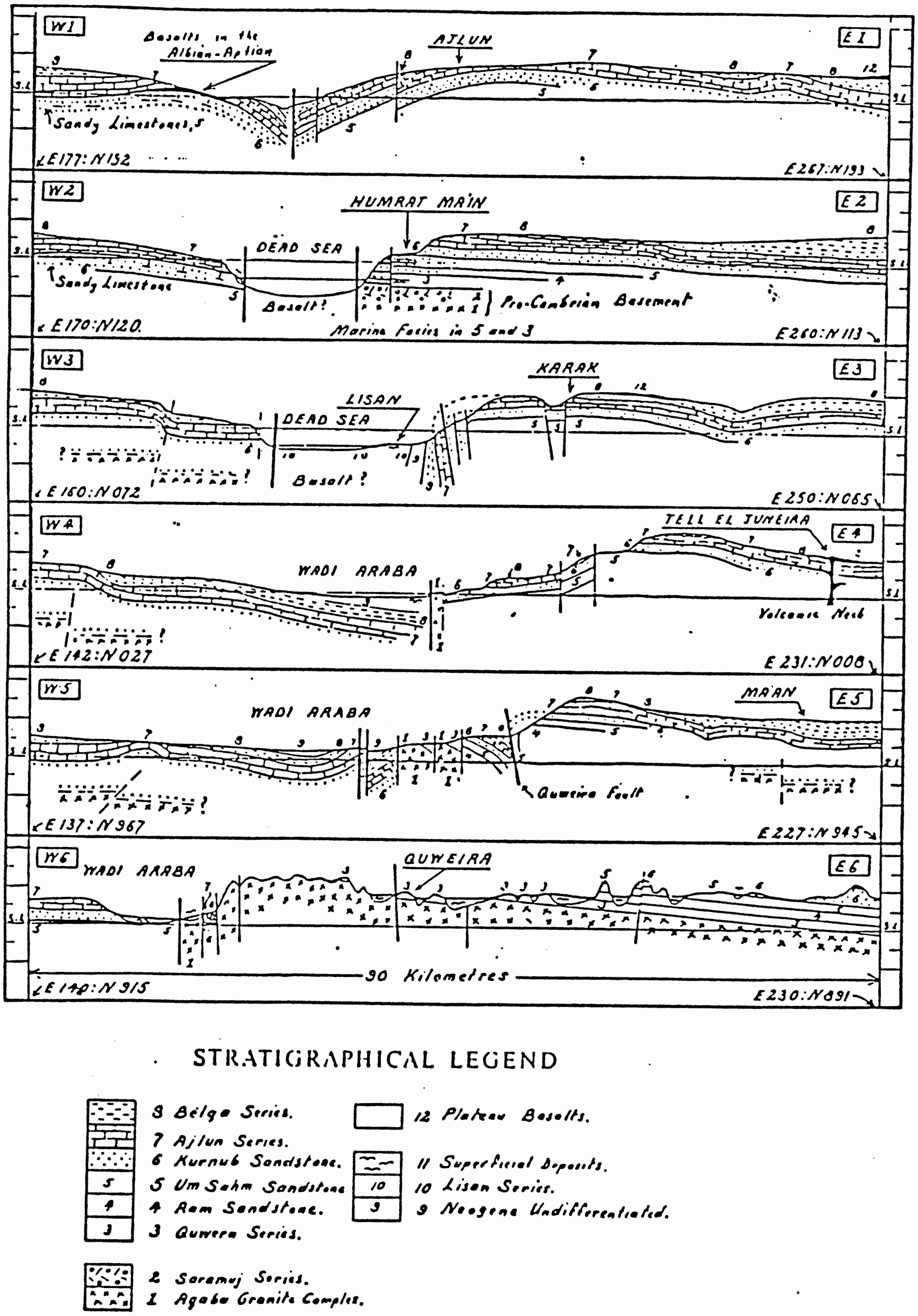


Figure 2. Six West to East Vertical Geological Sections, With a Vertical Scale Which is Four Times the Horizontal Scale.

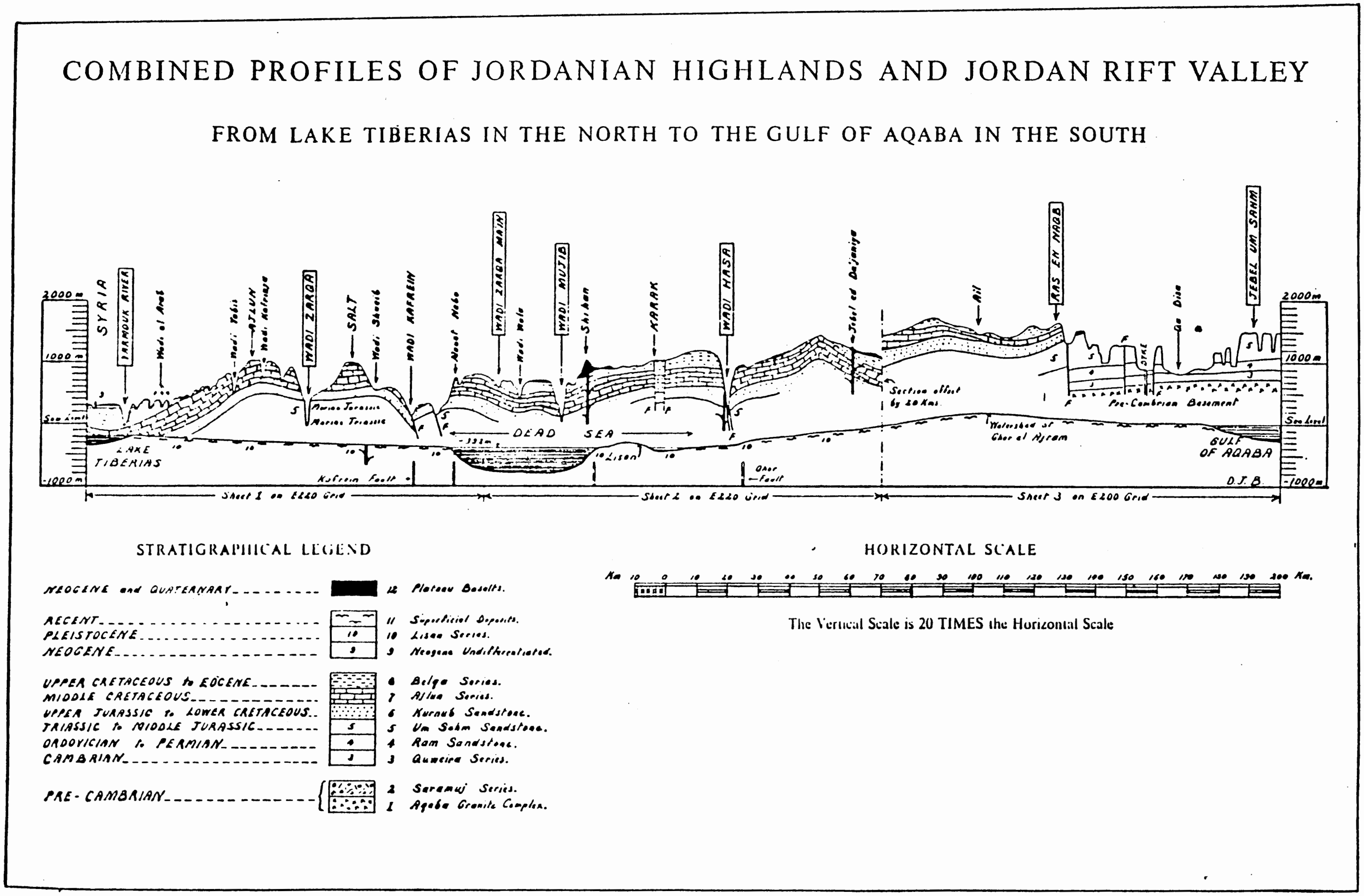


Figure 3. North-South Section, Showing the Topographical and Geological Relationships Between the Jordan Rift Valley From Lake Tiberias to the Gulf of Aqaba and the Higlands Which Border it on the East.

Syrian border on the North to the Gulf of Aqaba in the South, forming a hill region of limestone, sandstone, chalks and flints. The Southern Desert is an area of outcrops of sandstones and granite.

Climate

The climate is influenced by the location and physiography of Jordan. As mentioned earlier, Jordan is located on the northern edge of the desert and on the southern edge of the Mediterranean climate. The influence of the Mediterranean is covered by the highlands on the west side of the country. The Dead Sea and Gulf of Aqaba have small influence on the climate. The minimum temperature in winter increases from the western highlands to the East, from 11^{o} to 17^{o}C (52 - 63^{o} F). Areas influenced by the sea have higher minimum temperatures. But the minimum temperature decreases in the eastern highlands and desert, as shown in Figure 4.

Generally speaking, there is a contrast in the temperatures over a relatively short distance at any given time. In the summer season, the temperatures start at 22^{o}C (72 F) in the highlands and increases to 30^{o}C (86 F) in Rift Valley. The average maximum temperature in the desert areas is about 28^{o}C (83 F). The Gulf of Aqaba has a very mild winter and a very hot summer conditions when it exceeds the temperature of the desert and the Rift Valley, as shown in Figure 5.

Precipitation

Precipitation is highly seasonal, and the amounts are related to two major factors: the moisture sources of the Mediterranean and the altitude. In general, two types of climate prevail in Jordan. The

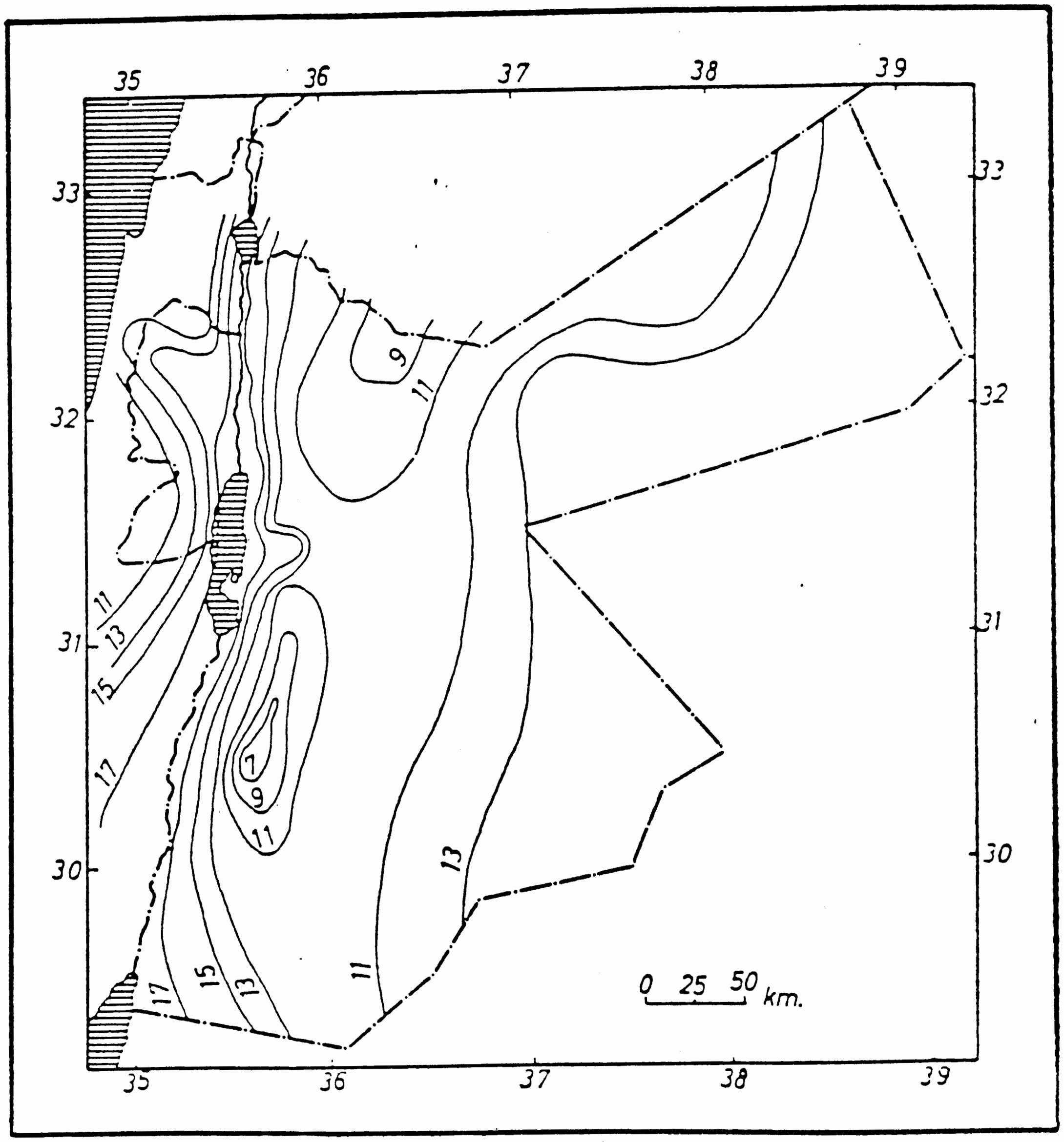


Figure 4. Average Minimum Temperature

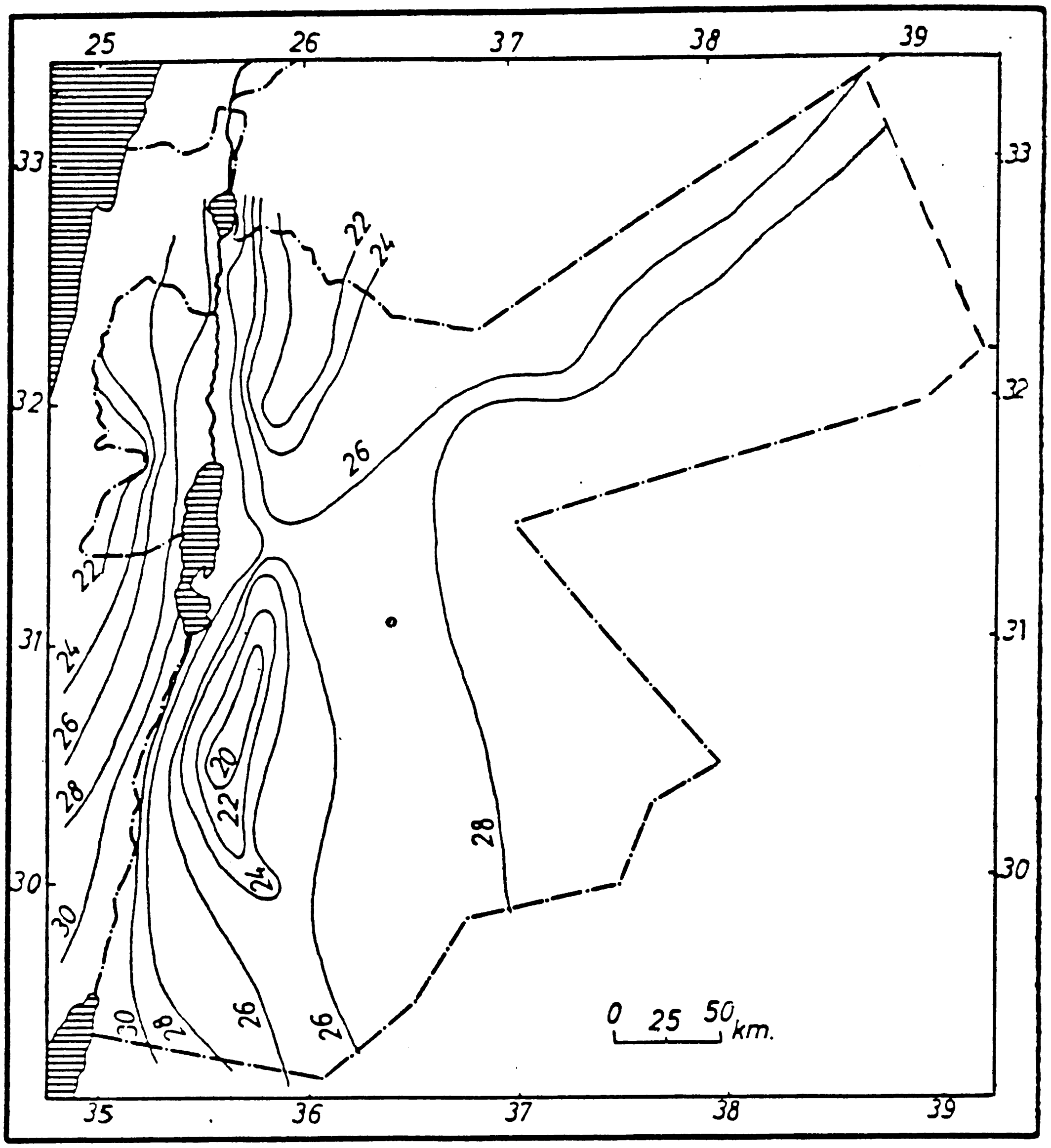


Figure 5. Average Maximum Temperature

Mediterranean in the west deposits its moisture content over the western and northeastern highlands of Jordan. The southeastern highland receives less moisture because of the wind coming from North Africa contains only small amounts of moisture. The second type is a climate of low latitude and desert area which comprises the eastern part of the country. Figure 6 shows the rainfall distribution.

The highest quantities of rainfall is 700 mm in the Western highlands, while the lowest is less than 150 mm in the Eastern Desert. A few short showers occur during September, and a heavier rainfall occurs from November to March. In general, precipitation in Jordan is too small in amount, too low in intensity, and too restricted in some areas, to permit large infiltration to the aquifers.

Evaporation

In any climate, temperature and precipitation data do not provide a clear picture of the moisture conditions as experienced by plants. To obtain this information, the climatological data have been recorded by NRA (National Resources Authority) and the Meteorological Department through a network of meteorological stations. Since 1962, the mean monthly figures on precipitation, cloudiness, wind speed, pressure, temperature, humidity, sunshine hours, and solar radiation were recorded. These records show that the annual potential evaporation in Jordan varies from 1984 mm (78.1 inch) in the North to 4323 mm (170.2 in) in the South. The variation between actual and average monthly evaporation is generally very small. Humidity is 75 percent in winter, and 35 percent in summer. In the Jordan Valley, it is 70 percent in winter and 40 percent in summer.

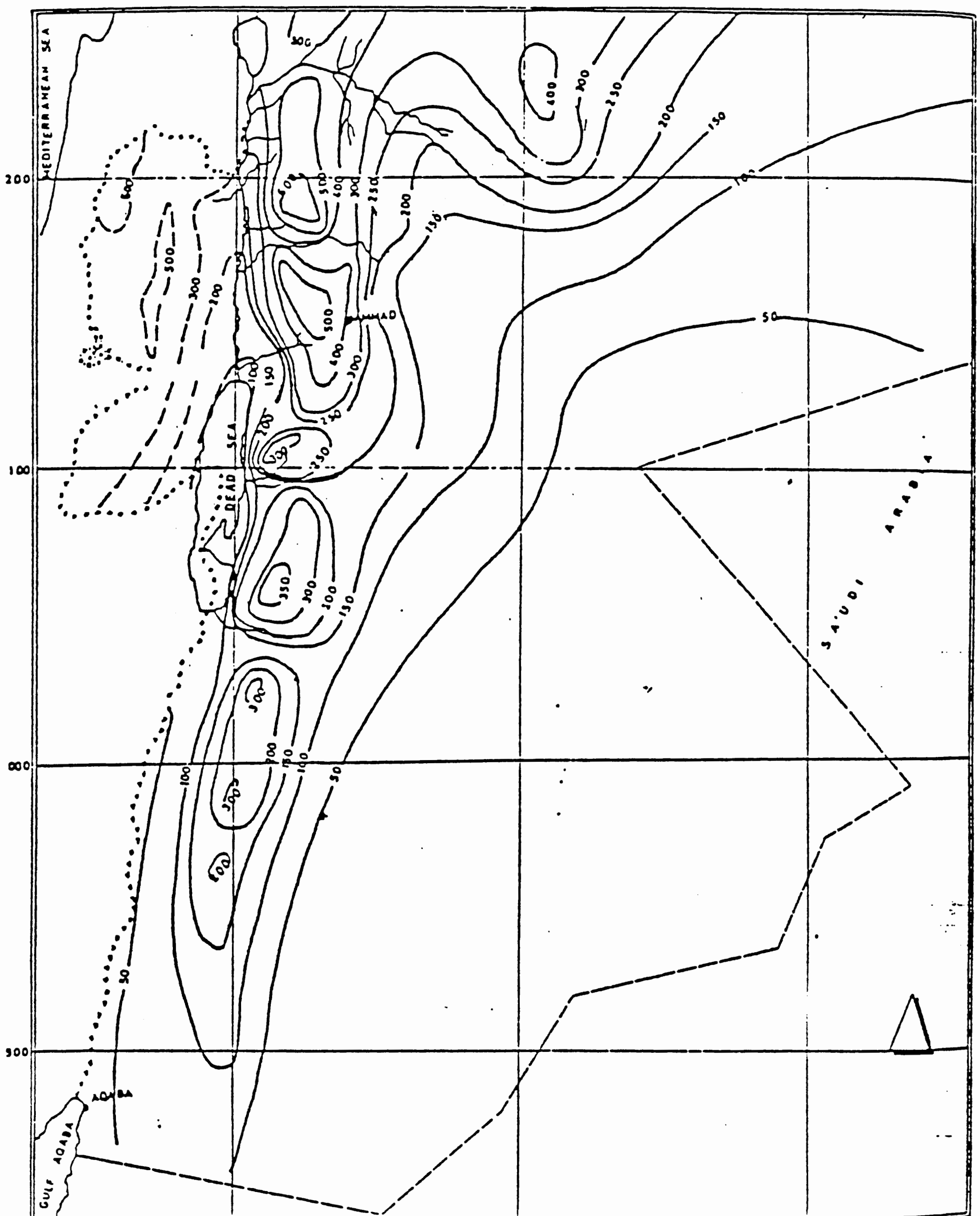


Figure 6. Rainfall Distribution in Jordan

Soil

Jordan soil is classified in the following Great Soil Groups:

1. Grey Desert Soils (Sierozem), developed under desertic conditions which cover some 50 percent of East Jordan. This kind of soil shows a very weak development due to unfavorable climatical-vegetational conditions for soil development and erosion removes the soil. This kind of soil is found in the areas where the rainfall is less than 150 mm (6 in) a year.
2. Yellow soils: They are found in the steep lands where the rainfall is between 100 - 200 mm (4 - 8 in). Yellow soil is related to the Brown soil which contains a higher percentage of limestone.
3. Red and Yellow Mediterranean soils: They are found in the areas with a higher rainfall. The yellow type is found from 250 - 350 mm (10 - 14 in) rainfall, while the Red soils are at above 350 mm (14 in). The Yellow Mediterranean soil is located between the cultivated highlands and the steep area with yellow soils. It also occurs on the slope near the Rift Valley and has a high limestone content. The Red Mediterranean soil develops on limestone and basalt, found in the areas where the rainfall exceed 350 mm (14 in). This type of soil extends to 120 cm (47.3 in) deep. It has a considerable capacity for storing moisture, and is rich with potassium, as found in the Irbid and Madaba regions. Figure 7 shows the soil categories in Jordan. Figure 8 shows the schematical cross section representing different soils in relation to parent material and topography.

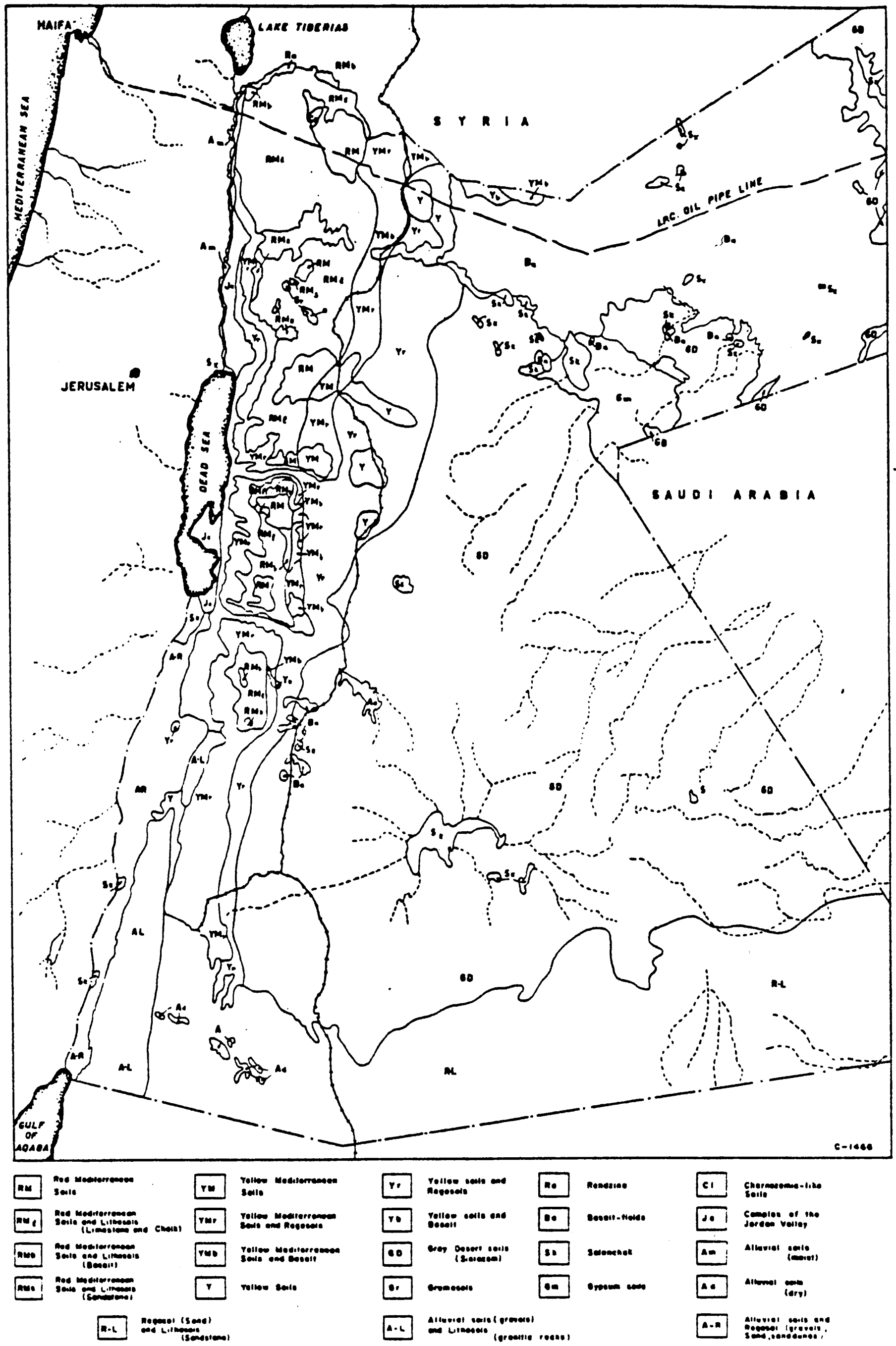


Figure 7. General Soil Map of Eastern Jordan

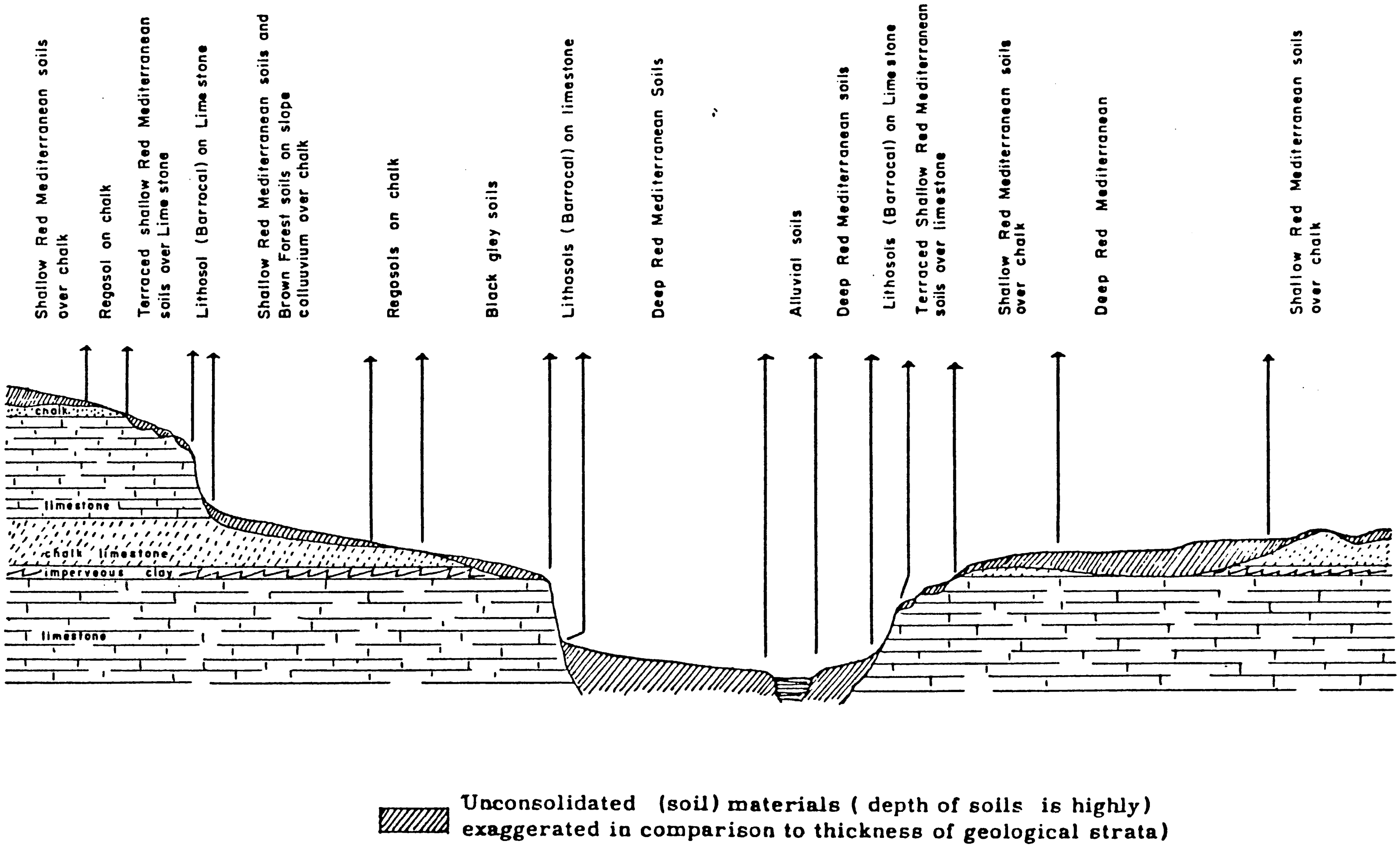


Figure 8. Schematical Cross Section Representing Different Soils in Relation to Parent Material and Topography

CHAPTER III

WATER RESOURCES IN JORDAN

Basically, the water supply in Jordan depends on past and present rainfalls. During precipitation, some of the moisture will evaporate back to the atmosphere through transpiration of plants and the evaporation process of rivers and lakes. Most of the moisture percolates down into the soil to become part of the groundwater, and only a small quantity runs off to form the rivers and streams. Most of the water which falls on Jordan as rain is from water vapor which originates through evaporation from the surface of Mediterranean Sea. A minor supplement of water vapor comes from the surface of fresh water lakes, streams, Dead and Red Sea, moist earth and the leaves of plants. The rainfall is not distributed evenly. The wettest areas reach 700 mm (28 inches) per annum, while the least wet do not reach 150 mm (6 inches). Generally speaking, to describe the features of the country with regard to its rainfall it is divided into the following geographical zones:

Western Highlands:	precipitation 300 - 700 mm (12 - 28 inches), and snow.
Eastern Highlands:	precipitation 300 - 700 mm (12 - 28 inches).
Jordan Valley:	(Irrigated area) 300 - 600 mm (12 - 24 inches).
Southern Desert:	rainfall less than 250 mm (10 inches).
Eastern Desert:	rainfall less than 150 mm (6 inches).

The amount of precipitation is estimated to be 7880 million cubic meters (6388316 ac-ft) per annum of which 80 percent is lost by evaporation, and the rest flows in the valleys, rivers or seeps underground to collect in aquifers to supply the baseflow of rivers or to be welled. The mechanism of such water movement varies widely from one place to another depending on topographical, geological, pedological and vegetational characteristics which are affected by human activities and the seasonal changes.

A major issue in Jordan is the shortage of municipal water supply. To overcome this problem, the Jordanian government established plans and strategies for developing new water resources for the country by raising old dams, building new dams in dry highland, reusing wastewater for irrigation purposes and exploiting ground water in different regions of the country.

A German consulting firm prepared a national water plan for Jordan. According to their studies, the average annual volume of water resources is 1,197 MCM of which 789 MCM surface water and 408 MCM ground water.

Water resources in Jordan can be divided into two categories: surface water and ground water.

Surface Water

One of the most important aspects of water resources development in Jordan is the control and utilization of surface water. Because surface water, in the streams, rivers and lakes, is usually more accessible and plentiful than ground water, it is the first option to fulfill the demands of municipalities, industries and agriculture.

Surface water consists of rivers, wadis and streams, lakes, springs and floods caused by rainfall on the four major hydrological regions. The Eastern Jordan Valley Area, the Dead Sea Basin, the Wadi Araba Basin, and desert Basins. The total area of these regions is 97,332 sq. Km (37579 sq. mile).

The average quantity of rain for the different regions of the country is as follows:

Desert area:	3,400 MCM/yr	(2,756,406 Ac-ft)
Eastern Highlands:	2,530 MCM/yr	(2,051,090 Ac-ft)
Jordan Valley:	440 MCM/yr	(356,711 Ac-ft)
West Bank:	2,130 MCM/yr	(1,726,807 Ac-ft)
TOTAL	8,500 MCM/yr	(6,891,016 Ac-ft)

About 80 percent (6800 MCM/yr) is lost through evaporation and the remainder is dispensed in the underground and as surface run-off. Table I summarizes mean annual surface water discharge from rivers and wadis. It was only after the independence of Jordan that it was possible to attempt a clear evaluation of national resources, or a definition of growth and production targets. Intensive effort was devoted to drawing up an inventory of resources, defining growth objectives, formulating methods, and determining planning strategies. In fact, the development of water resources, and agricultural production were the main goals of Jordanian National development plans. The major project was East Ghor Canal, which was started in 1952 and completed in 1965. The length of this canal is 70 Km (44 mile) constructed from Al-Adassiyeh in the North to the Wadi Zarga in the South. Eight additional canal lengths were constructed in 1968. This project resulted in a very considerable improvement in agricultural production and quality.

The need for comprehensive long-term planning in the development of

TABLE I

MEAN ANNUAL SURFACE WATER DISCHARGE FROM RIVERS AND WADIS

	Catchment Area Km^2 (Mile sq)		Average Annual baseflow MCM (CFS)		Average Annual Total Flow MCM (CFS)	
Yarmouk River	6,805	(2,627)	218	(244.10)	438	(490.56)
Zarga River	3,440	(1,328)	54	(60.48)	85	(95.2)0
Arab	254	(98)	33	(36.96)	35	(39.20)
Ziglab	131	(51)	12	(13.44)	13	(14.56)
Jurum	119	(46)	13	(14.56)	13	(14.56)
Yabis	102	(41)	5	(5.60)	6	(6.72)
Kufrinja	27	(11)	6	(6.72)	12	(13.44)
Rajib	80	(31)	4	(4.48)	4	(4.48)
Shueib	187	(72)	9	(10.08)	11	(12.32)
Kufrein	161	(62)	11	(12.32)	12	(13.44)
Hisham	90	(35)	5	(5.60)	6	(6.72)
Wala	1,800	(695)	5	(5.60)	20	(22.40)
Mujib	6,570	(2,537)	50	(56)	23	(81.76)
Karak	200	(77)	6	(6.72)	9	(10.08)
Hasa	2,500	(965)	25	(28)	55	(61.60)
Zarga Ma'in	300	(116)	15	(16.80)	19	(21.28)
TOTAL	22,772	(8,792)	471	(527.52)	811	(908.32)

Source: Wael Kannaan, Yousef Attich, Jordan Agricultural Development irrigation was recognized with consideration of water scarcity, shortages of capital, time and data. In 1972, Crown Prince Hassan established the Jordan Valley Authority (JVA) to concentrate on the valley's economic and social development. JVA prepared a seven year plan for the development of the Jordan Valley for the period 1975-1982. At the same time, the Jordanian government published the five year plan for the period 1976-1980, for development projects throughout the country. These plans had the following objectives:

1. Increase the irrigated lands.
2. Create new jobs for agricultural workers and other supporting services.
3. Supply the local market with agricultural products.
4. Increase the Agricultural sector by 40 percent and the Industrial sector by 220 percent.

To achieve these objectives the following projects were undertaken:

1. Kafrein-Husban project: the purpose of this project is to irrigate 15500 Dunums (3828.5 acres) by a sprinkling system which started in 1976 and was completed in the end of 1977 at a cost of 1.4 million JD ($3.64 million).
2. Zarga River project: building of a dam (King Talal Dam) to store 48 MCM (38913.6 ac-ft) which was started in 1972 and finished in 1977, at a cost of 10.5 million JD ($28.3 million)
3. East Ghor Canal extension: to irrigate 35,000 Dunnum (8645 acres) by a sprinkling irrigation system. The project was begun in 1975 and completed in 1976 at a cost of 4.5 million JD ($12.15 million).
4. Zarga Triangle: to irrigate 15,200 Dunnum (3754.4 acres). The

project was started in 1975 and finished in 1977 at a cost of 1.9 million JD ($5.13 million).

5. Wadi Al-Arab project: to irrigate 27600 Dunnum (6817.2 acres) and building two dams (Al-Arab and Al-Jurun Dams), started in 1976 and completed in 1977, at a cost of 3.7 million JD ($10 million).

6. Al-Mujeb and Al-Ghor South: to increase the water resources potential, and increase the storage capacity of flood control in the area and irrigate 62,000 Dunnum (15314 acres). It was completed in 1981 at a cost of 12 million JD ($32.4 million).

7. Irrigation of highlands and desert areas: to increase the irrigated land by exploiting the groundwater. These projects are as follows:

Projects	Irrigated Areas Dunnum (acres)
Abu-lusin	1170 (289)
Wahida	1710 (423)
Abu-Makhtub	2100 (519)
Athruh	1500 (371)
Al-Green	1400 (346)
Sawaga	2700 (667)
Gatrana	6500 (1606)
Sultani	2700 (667)
Wahite Wadi	4500 (1112)
Tal Burma	3000 (741)
Al-Gueir/Ader	2000 (494)

the estimated cost was 2,100,000 JD ($6 million).

8. Building Magarin Dam project: with a capacity of 350 MCM (283745 ac-ft). The purpose of this project is diverting the Yarmouk water in a 24 Km (15 miles) canal to the East Ghor to irrigate 125,000 dunums (30875 acres). This project also includes two power plants to provide 46 million Kwh/yr.

After the design of the Magarin Dam had been completed, and the finances were secured, this project was suspended because of political differences with Syria. Obviously, a shortfall of such magnitude in Jordan's water supply is of great consequence to Jordan's economic growth.

Jordan has had continuous water problems. In order to overcome the water shortages, the Jordanian government selected a German consulting firm (Bundesanstalt fur Geowissenshaften Und Rohstoffe) in 1976 to conduct a water supply investigation and produce a master plan that would assess the overall situation and make short- and long-range recommendations. The Master Plan was established in 1977. The findings of the studies indicate that water resources development projects will have to be implemented in line with the appropriate water allocation strategies, urgent attention to water conservation measures, necessity for pollution control, and implementation of sanitary sewage treatment facilities to allow the recycling and reuse of the water resources, and increasing the storage capacities of the existing dams to achieve the national development targets of Jordan. Table II shows the existing dams in Jordan and their capacity and purposes.

One of the major water system projects in this National development plan (1981-1985) is a new water system for the capital. Water will be diverted from the east Ghor Canal at an elevation of 230 m (755 ft)

TABLE II

EXISTING DAMS IN JORDAN

Name	Capacity MCM (ac-ft)		Purpose
King Talal	82	(66,477.40)	Irrigation, Power Generation
Kafrein	4.8	(3,891.36)	Irrigation
Shueib	2.3	(1,864.61)	Irrigation
Ziglab	4.3	(3,486.01)	Irrigation
Sultani	1.2	(972.84)	Irrigation, Drinking for Livestock
Gatrani	4.2	(3,404.94)	Irrigation
Luhfi	0.7	(567.49)	Irrigation, Drinking for Livestock
Buweida	0.7	(567.49)	Irrigation, Drinking for Livestock
Um Jimal	1.8	(1,459.26)	Irrigation, Drinking for Livestock
Gahadier Abyad	0.7	(567.49)	Irrigation, Drinking for Livestock
Sama Sirhan	1.7	(1.378.19)	Irrigation, Drinking for Livestock
Al-Ageb	1.4	(1,134.98)	Recharging Ground Water Aquifer
Wadi Al-Arab	20	(16,214)	Irrigation and Drinking
TOTAL	125.8	(101,986.00)	

below sea level and pumped through four pumping stations to a treatment plant near the city at an elevation of 1040 m (3412 ft) above the sea level, with a total lift of 1270 m (4167 ft). Another pump station provides the final lift to the terminal reservoir near Suweilih. From the terminal reservoir the water flows by gravity to a reservoir at Amman.

The new system has a capacity of 45 x 10^6 m^3/year or 85 m^3/min (22500 gpm) or 32 mgd. The total cost of this project is $107 million, and the water supply is at a cost of $0.80/ m^3, which is higher than the cost of existing ground water sources. The project was completed in 1985, and there is a study to extend this project to the nearby communities, Zarga, Jarash, Salt, and Madaba. Fig. 9 shows the schematic water supply system and the layout.

The National Development plan for the period from 1976 to 1980 was followed by another five year plan (1981 - 1985) which had similar objectives, i.e. increase the agricultural sector by 43.6 percent and increase the manufacturing and mining sector by 127.3 percent, provide Jordan with additional sources of water, and increase the irrigated land.

During this plan's period, small attention was given to wastewater networks, treatment facilities and storm networks, but in the next National Development Plan, 1986 - 1990, more attention is expected.

The conservation of surface run-off is of considerable importance to economic development. As Jordan reached dead end with the Magarin Dam, the Jordanian government issued the five year National Development Plan for the period 1986-1990, attempting to construct water catchments that will preserve water through the dry season. At present, these

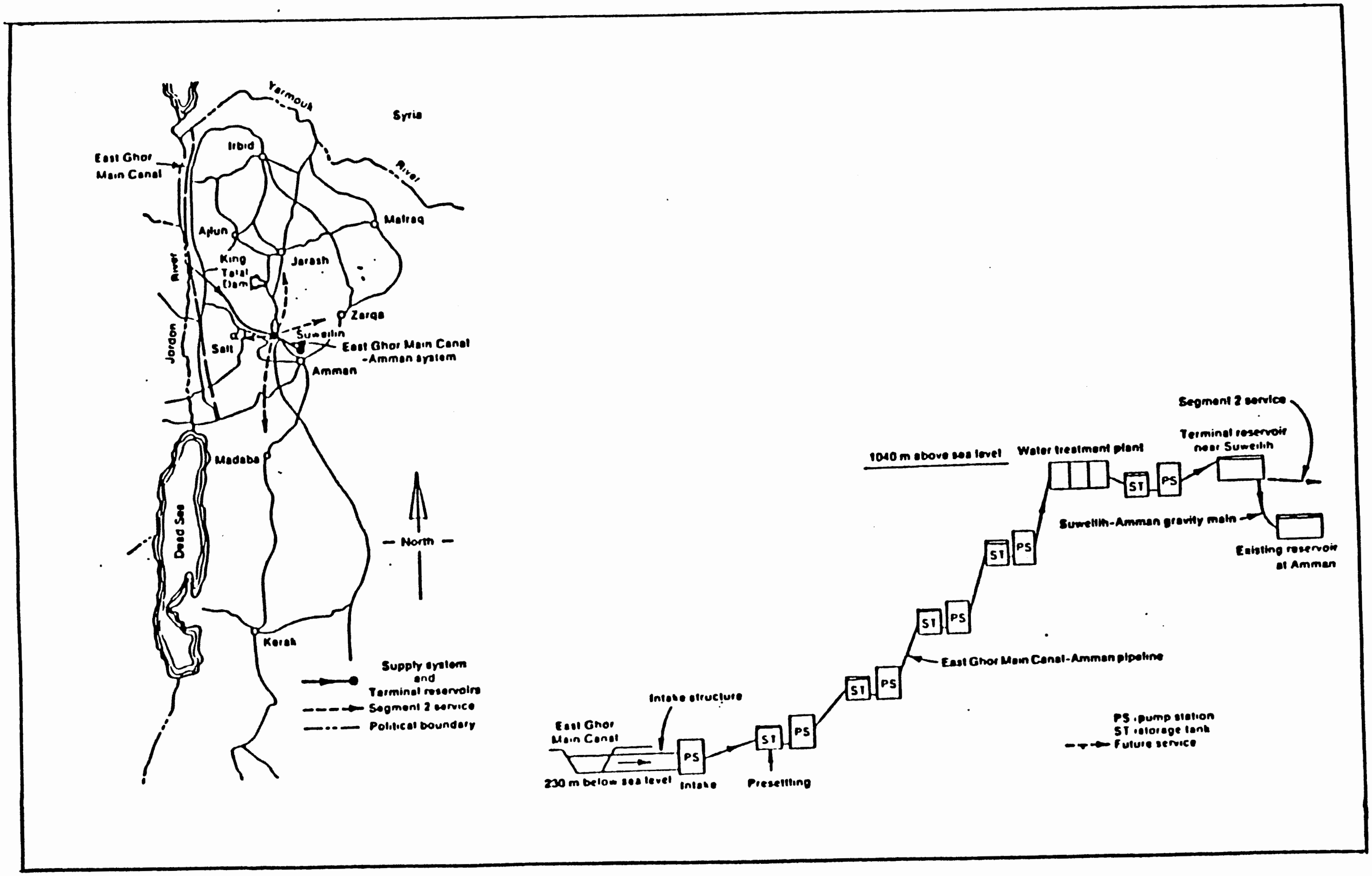


Figure 9. Jordan Valley Water Supply System (First Segment) and the Layout

projects are under study. Table III shows the proposed projects and their capacities.

To expand the water supply in Jordan, United Kingdom Consultant Howard Humphreys is carrying out technical studies and financial assessments to pipe water from the Euphrates River in Iraq. This will supply Jordan with 160 MCM/year (1,2976 ac-ft). The length of pipeline is 650 Km (406 miles) and the pipe size is 1.5 m (59 inches) in diameter. The water will be pumped in three stages through a total head of 1000 m (3281 ft) which requires a large amount of power. The estimated cost will exceed $1,000 Million. This project faces two criticisms: the high cost of the project which will result in a cost increase of water, and the more important is the water source would be in the hands of another country, which might result in holding up any development in Jordan due to possible changes in relations between Jordan and Iraq. In light of the problems with the Magarin Dam project, this second criticism carries a lot of weight with Jordanian officials.

It is obvious that the surface water in Jordan is very limited. Only a very small part of this supply is being used. However, due to the population growth, agricultural expansion and industrial development, it is possible that more water will be needed to fulfill the demands of industry, agriculture and municipalities. Also, in viewing the location of Jordan, any plan for development along these watersheds must include consideration of the right of neighboring states. A compact agreement with neighboring Syria and Iraq to allocate the water becomes increasingly important as the need for water increases. Unfortunately, these agreements are slow to be reached but they should be consummated within the near future.

TABLE III

PROPOSED DAMS IN JORDAN

Name	Capacity MCM	(ac-ft)	Purpose
Maqarin	350	(283,745)	Irrigation, Drinking, Power Generation
Khalid	200	(162,140)	Irrigation, Power Generation
Tanur	16.5	(13,376.6)	Irrigation, Flood Control
Rimail	53	(42,967.1)	Irrigation, Drinking, Flood Control
Nakhilah	5	(4,053.5)	Irrigation
White Wadi	12	(9,728.4)	Irrigation, Recharging Ground Water Aquifer
Suaga	2.8	(2,270)	Irrigation, Recharging Ground Water Aquifer
Al-Yabis	2.8	(2,270)	Irrigation
Al-Jurm	2.3	(1,864.6)	Power Generation
Kufrinja	2.5	(2,027)	Irrigation
Zarga	3	(2,432)	Irrigation
Milaha	45	(36,481)	Irrigation
Al-Rueshid	7	(5,675)	Irrigation
TOTAL	702	(569,111.4)	

Ground Water

Jordan has large quantities of ground water, but it is not equally distributed throughout the country. Ground water originates from moisture that falls on the surface of the land and percolates down into the waterbearing strata. Under favorable conditions, about 15 percent of the water that falls on the surface soaks down into the ground. This water cannot be classified as true ground water until it enters the zone of complete saturation. Some water in the soil remains, but only a few days or a few months until summer brings its water consuming plants and drying sun and wind.

Ground water represents a very important source of water for all purposes. The importance of this source increases in the regions where surface water is limited or nonexistent.

Large quantities of ground water are found in underground sand or gravel, fractured rock, or rock such as limestone which is full of holes caused by the chemical action of water. Such underground formations are called aquifers. Three kinds of aquifers have been recognized in Jordan:

1. Alluvial deposits: sand, gravel and clay deposited by streams. These deposits contain a large quantity of water, because of their thickness and high permeability. Such aquifers are found in the Jordan Valley area.
2. Fractured rocks: this type of aquifer has three kinds of rocks:

    -Basaltic rock: covers north and northeast of Jordan. This kind has a good capacity for yielding aquifers.

    -Chert chalk rocks: covers different parts of the country.

-Limestone rocks: covers central and northern Jordan.

3. Sandstone rocks: covers most of the southern desert and is considered of good potential.

Ground water basins in Jordan: There are three major groundwater basins in Jordan.

1. Dead Sea Basin
   - Jordan Valley Basin
     - Yarmouk Basin
     - Zarga Basin
     - Wadi Dhuliel
   - Mujeb and South Shuneh
   - Wadi Araba North
2. Desert Basin
   - Azrag Basin
   - Al-Hammad
   - Al-Jafer
   - Al-Disi and Wadi Sarhan
3. Red Sea Basin
   - South Wadi Araba Basin
   - Wadi Al-Utum Basin

Figure 10 shows the major ground water basins in Jordan.

In addition to the mentioned ground water resources, there is an investigation for additional sources in East Jordan being carried out by United Kingdom Consultant Howard Humphrey to help solve Jordan's water supply problems. Table IV lists the ground water resources in Jordan.

In the western part of the Rift Valley there are 60 large springs,

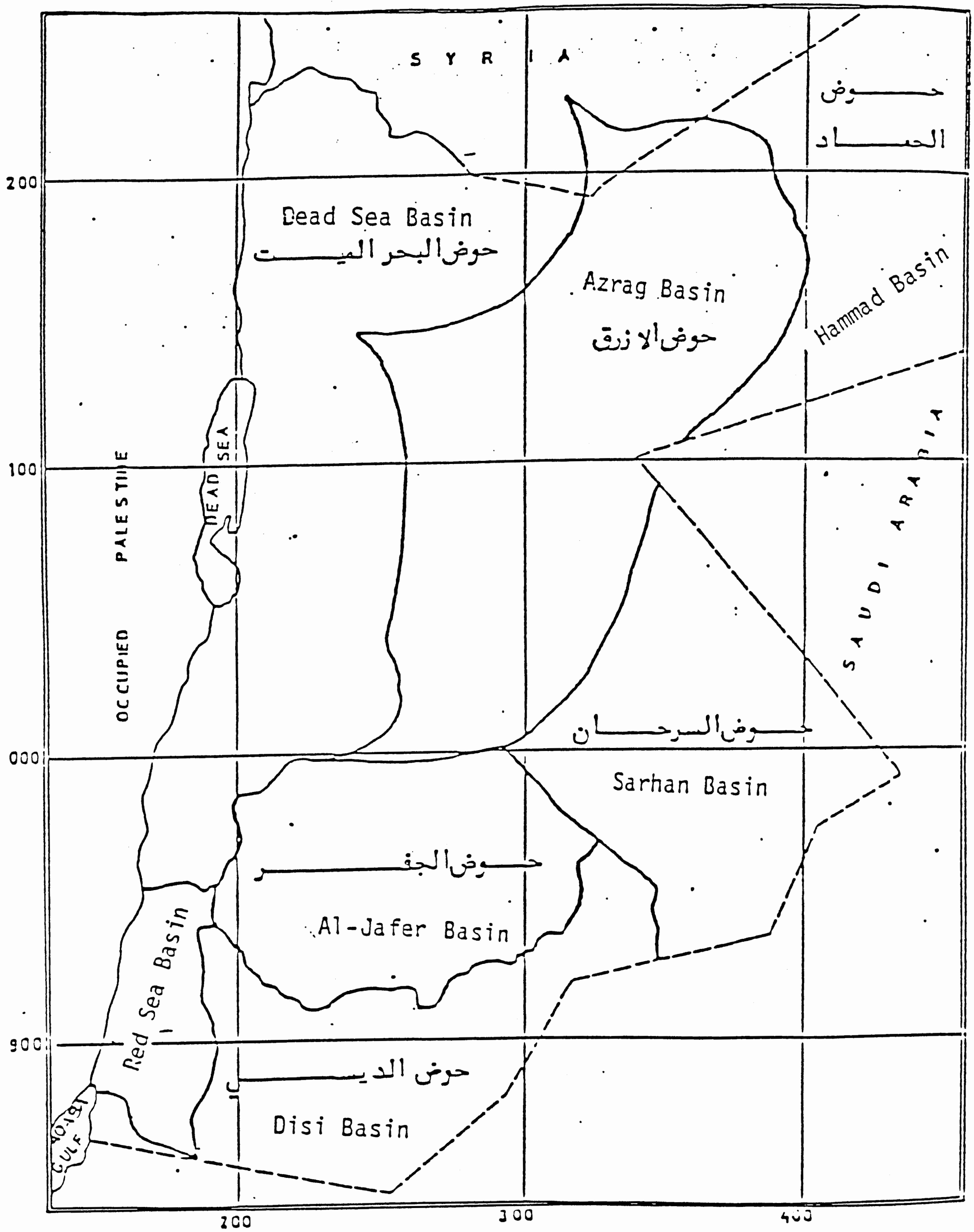


Figure 10. Ground Water Basins in Jordan

TABLE IV

GROUND WATER RESOURCES IN JORDAN

Basin	MCM/yr (ac-ft)	Quality of Water, ppm	Average Depth of wells, m (ft)	Depth to surface water, m
Yarmouk	80 (64,856)	300-800	150-350 (492-1,148)	100-280 (328-919)
Zarga	30 (24,321)	350-1,200	150-400 (492-1,312)	20-250 (65-820)
Azrag	20 (16,214)	290-360	25-250 (82-820)	5-75 (16-246)
Jordan Valley	54 (43,778)	500-2,500	100-300 (328-984)	25-80 (82-262)
Dead Sea	60 (48,642)	500-1,000	200-250 (656-820)	50-100 (164-328)
Wadi Araba & South Shuneh	23 (18,646)	800-3,000	50-300 (164-984)	25-80 (82-262)
Wadi Araba Hills	12 (9,728)	---	---	---
Disi and Mudora	50 (40,535)	250-300	300-450 (984-1476)	70-90 (230-295)
Jafer	20 (16,214)	500-3,500	100-600 (328-1,312)	40-100 (131-328)
Wadi Sarhan & Hammad	27 (21,889)	100-2,500	250-350 (820-1,148)	100-200 (328-656)
North Badiah	32 (25,942)	500-1,000	300-400 (984-1,312)	150-250 (492-820)
TOTAL	408 (330,766)			

utilized for irrigation and domestic consumption; the average annual output of these springs is 40 - 50 MCM. Also, there are 300 small springs in the West Bank, fed by local aquifers of limited capacity, with an average annual output of 50 - 60 MCM. In addition to these sources, there are 314 wells owned by Arabs and 17 wells owned by Jewish settlements. The total amount of water pumped from these wells is 97 MCM per year (25,600 million gallons) used mainly for irrigation and domestic purposes.

The amount of water in the West Bank is insufficient to support the Arab land. Therefore, the municipalities of Arab towns and villages are facing a shortage of water supply. To avoid this problem, many Arab municipalities and Arab civilian applied for drilling of new wells in their land, but Israeli authorities restricted any new drilling or even improving the capacity of the existing wells. If the present situation and occupation policies and practices continue on the Arab land, water resources will become more scarce.

It can be seen that in some areas ground water is not readily available. In some parts potential aquifers lie at a considerable depth, and can be reached only by a very expensive drilling operation. In other parts, potential aquifers have not been identified. Also the ground water resources are inadequately documented and attempts to quantify the resources are inaccurate due to the absence of basic data on aquifer parameters. A small amount of hydrological and hydrogeological data has been collected and was not evenly distributed for all water resources. Therefore, a survey of ground water availability, water quality, data collection and analysis should be undertaken to provide accurate quantitative information required for good planning and management.

Waste Water

Reusing water can greatly lower the overall demand for water resources. Wastewater can be used for irrigation, industry, recharging ground water and municipal uses if properly treated. With good planning, industrial and agricultural demands can be met by using purified wastewater, and making the fresh water available for human consumption.

Wastewater is considered a very important source of water. Most water resources are non-renewable and the requirement for water is usually more than the available supply. Also the reclamation of wastewater helps to reduce pollution and enhances water conservation. However, improvement of water supply and distribution has resulted in deterioration of sanitary conditions and increase in health hazards. Sewage systems in Jordan are inadequate. Only five sewage treatment plants are now in operation, in Salt, Zarga, Russeifa, Aqaba and Amman. In many areas, pollution of the soil is the common method of disposal.

The provision of safe and secure water supply has been of primary concern to the government for a long time, a concern related to the close association among water, health, and rural and urban development. During the previous plan period, 1981 - 1985, only a small provision or attention was given to sewage treatment and disposal, and the necessity for sewage system is extremely important. In the development plan 1986 - 1990, the Jordanian government is aiming at building twenty-three sewage disposal plants to serve thirty-four cities and towns and to treat 81 MCM (65667 ac-ft) of wastewater in the year

2000. The treated waste will flow to the Jordan Valley by gravity where it will be diverted into the irrigation systems.

Plans for new water supply systems must be made in conjunction with plans for adequate sewage disposal systems to cover all the cities and towns in the country, so that these places can perform their roles in the national development effort. This is also important in avoiding the danger of contamination and pollution of water resources with waste. However, as the population grows and the industry develops more domestic and industrial waste is produced. Therefore, more attention must be placed on the sewage collection, treatment and disposal.

Quality of Water

Generally, water in Jordan is of a good quality with reasonably low salinity. Table V shows the salinity of water coming from the rivers and wells. These amounts are acceptable for domestic, industrial and agricultural uses.

Surface water quality. The Zarga River is considered as the second river in importance because of its location and river flow. There is, however, one problem area, and that is the water quality of the Zarga River. It originates in Amman, Russeifa and the Zarga area. From there it flows down to Jarash, Deir Alla and then enters the Jordan river. The total area of the Zarga basin is 3468 Km square (1399 sq. miles). The flow of the Zarga River is supplemented by springs and streams and reaches 83 MCM (67,288 Ac-ft) at Deir-Alla. In 1977, King Talal Dam was completed at a cost of $46 million to store 82 MCM (66,478 Ac-ft) of Zarga River water. This water is used by the Amman and Zarga areas which have a total population of 1,100,000 people. It is important to

TABLE V

SALINITY LEVELS

Name of Water Source	Salinity (ppm)
Yarmouk River	100
Zarga River	1,000
Wadi Araba	500
Wadi Ziglab	500
Wadi Jurn	500
Jordan River	
at South of Lake Tiberias	340
at Allenby Bridge near Jericho	2,500
Dead Sea	250,000
Sammaya (upper Yarmouk Basin)	750
Dhuleil (Zarga Basin)	400
Azrag	500-1000
Disi	250-300
Jafer	500-3,500
Wadi Sarhan	100-2,500
Badia Al-Shamalieha	500-1,000

mention that 90 percent of Jordanian industry is located in this area.

In 1982 the Royal Scientific Research Society has carried out a study on the Zarga River in order to provide an over-all evaluation of general water quality and to assess the impact of numerous natural and man-made factors. The result of these studies showed that this river is polluted with industrial, domestic and agricultural wastes, which impair the quality of Zarga River and the ground water supply located in the area.

Degradation of the chemical, physical, and biological quality, resulting from hydrologic, geologic, and man-induced sources is evident as the streams progress downward to their lower reaches. Factors affecting the quality of water for various uses include: temperature, total dissolved solids, sediment, dissolved oxygen, sulfates, nutrients, heavy metals, pesticides, and biological agents. Future conditions in the river depend on the amount of waste disposed in the river. Measures to clean up the water at the Zarga River are currently being undertaken.

Ground water quality. The ground water quality is good in the outcrop areas, and suitable for municipal, industrial and irrigation uses. Also it varies with respect to the properties of the water-bearing rocks and geographic location within the country.

There are many actual and potential sources of ground water pollution. Poor quality may result from several sources. These sources are natural pollution, oil field, brines, over-pumping, irrigation return flows, solid waste, animal wastes, accidental spills of hazardous materials, septic tanks and municipal landfills.

In the Rift Valley and Azrag area, the use of irrigation for dry land farming is considered the most important cause of saline water seepage into the underground water system. Irrigation water is usually heavily laden with dissolved solids. As plants take up irrigation water most of the dissolved minerals are left behind in the form of salts which builds up in the root zone, and moves into the ground water systems from irrigation channels and return flows. Also a serious problem with irrigation water is the deterioration in water quality because of fertilizers and pesticides. This has contributed significantly to the deterioration in raw water quality especially in the Rift Valley.

The chemical quality of ground water depends on the chemical composition of the materials where the water percolates and contacts the soil and rocks where it dissolves the minerals in its movement through the basin. The amount and kinds of minerals in ground water depend on the types available and duration of contact.

More study is needed on the quality of surface and ground water resources. It is in the interest of industrial development and public health to have priority programs on waste treatment, conservation of stream quality and the adoption of a pollution control program.

Problems Associated With Water Resources Planning

Water resources development and planning are not fully developed in Jordan. Advanced techniques in forecasting and planning are still lacking. The past three-year and five-year plans always fell far short of achieving the target goals, primarily because of a lack of profound multidisciplinary scientific approach in both planning and operational phases of these projects. Reliable forecasting and estimations along with proper funding and experienced institutions are the key factors in tackling problems of national importance. In determining the targets and size of the plan it is necessary to adopt a practical approach to the planning problems by basing the ultimate attained objective on the availability of resources.

The development of water supply system resulted in a very cumbersome and inefficient administrative situation. There are several organizations responsible for water production and water distribution. Some municipalities are responsible for water sources and distribution, while on the regional and/or national level are controlled by the following authorities:

1. The National Resources Authority (NRA).
2. The Water Supply Corporation (WSC).
3. The Jordan Valley Authority (JVA).
4. The Amman Water and Sewerage Authority (AWSA).

Administrative problems have been a major obstacle to water resources planning. The decision-making process follows a series of steps through administrative levels, where they are routed to all interested officials, most of the time at the same level, then the decisions are made only at or near the top level. This problem is prevalent in the planning as well as the operation phase.

Political and legal problems are also associated with water resource planning in Jordan. There have been many political and legal problems over the Jordan River when Israel, in a series of military strikes, hit the East Ghor Canal on June 23, 1969 and August 10, 1969. Another conflict is over the Yarmouk River with neighboring Syria which resulted in suspension of Magarin Dam, due to the political differences between the two countries. The lack of stability might spell out the downfall of any project developments in the region.

The lack of financing to handle water resources projects is a serious problem facing the government. This problem cannot be solved by local banks because of the high risk involved. Foreign banks also need assurances which cannot be granted under the present conditions of political instability in the region.

As previously stated, Jordan faces serious problems in ensuring an adequate water supply. These problems are due to a complexity of interrelated constraints including limitation of natural resources, poor water management, uncontrolled ground water extraction, lack of hydrological and hydrogeological data, lack of reassessment of the water resources and water supply-demand relationship, absence of techniques involving reduction of evaporation from water and soil surfaces, absence of urban and municipal systems for sewage collection, treatment and disposal, inadequate development of an institutional framework to facilitate the formation of water policies at the highest policy-making level. Absence of boards or commissions for international drainage basins which insures the legal rights at the basins at the regional and international levels. All these problems must be resolved for advance future planning and development in Jordan.

The provision of safe, potable water and sanitary disposal of wastewater is extremely important for health and progress of Jordan. Less than one-tenth of the population in developing countries have these facilities. Most of Jordanian population live in areas where the conventional practices in environmental hygiene need to be changed. Most of the problems involved in providing adequate water supplies and sewage systems can be solved through mutual cooperation between resident, local administration, and government. Since gaining independence in 1946, the government initiated a number of improvement programs, but little has been achieved and it will be long before satisfactory levels of development are attained.

CHAPTER IV

LITERATURE REVIEW

Municipal Water Demand Models

An important responsibility of any government is the provision of adequate amounts of safe water for its citizens. This was recognized by the United Nations when they set safe water goals for the Second Development Decade (1971 - 1980) (World Bank, 1976). At the Water Supply Conference (Mar del Plata, Argentina) the United Nations has declared the 1980's as Drinking Water Supply and Sanitation Decade, to provide all the world's population with adequate domestic water supplies by 1990 (Feachem, 1978).

In order to plan water supply systems, it is necessary to forecast future water demand. Total water demand can be subdivided into three major components: agricultural, industrial and municipal. Municipal demand includes domestic use, commercial and light industrial uses, public uses and losses (Linsley and Franzini, 1972).

One of the most widely used models for forecasting water demand is of the form

$$\text{Water Demand} = \text{Population} \times \text{Unit Use}$$

$$WD = P_i \times WC$$

where:

WD = Water demand

P_i = Population in year i

WC = Average per capita consumption in year i

This equation can be used for either total or municipal demand. In either case, the appropriate unit use factor must be applied. To use this model, both population and unit use must be forecast. Population levels and trends have been well studied for most countries. Unfortunately, the same is not true of unit use. In the past, planners have used a fixed unit use value or have assumed a nominal increase per year. However, this ignores variations in the factors which affect unit use. Even today, it appears that many of these factors are still not considered in depth by some planners (Linsley, 1979).

Another approach is carried out by Robert Saunder (1969), conducted at West Virginia University. The overall objective is to develop a rational method to forecast water usage in several urban areas in any given year in the future. In his study, he derived a method of forecasting which takes into consideration changes in population, economic activity, and water-related technology, and then he suggests modifications of requirement forecast based on changes in price.

The data were collected from three samples. The first one was derived from 140 cities located in North-East-Central region of the United States (Ohio, West Virginia, Indiana, Illinois and Michigan). For the second sample, data were collected for the 92 largest United States' cities. The third set of data of water sales were collected for 32 billing districts in Louisville, Kentucky.

The general approach of his study is to isolate the important factors and eliminate all other factors which are not associated with water usage. Then the remaining variables are introduced into a least squares regression analysis. Through the regression analysis, the attempt was made to measure the association between the urban area size and income as fundamental factors associated with water usage. In other words, factors analysis was used to reduce the 65 variables to two significant variables.

The resulting daily-water-usage estimates were derived in the following formula:

$$E_{75i} = (W_{60i} \times 1.19 \times \frac{Y_{75i} - Y_{60i}}{Y_{60i}} + W_{60i})P_{75i}$$

For i = 1, 2, 3, ... 141.

where:

E_{75i} = Projected amount of water in 1975

W_{60i} = Gallons per capita use

Y_{60i} = Per capita income

Y_{75i} = Estimated per capita income

P_{75i} = Estimated population.

Reid and Muiga (1976), developed a model that predicts, for planning purposes, the municipal, agricultural and industrial water requirements for Africa, Asia and Latin America. They used the stepwise multiple regression analysis to relate solid-economic, environmental and technological parameters to the water demand in the developing countries. The equations to forecast water demand are as follows:

$$D_{W.af} = 22.0341 + 0.0973\ X_2$$

$$R^2 = 0.953$$

$$D_{W.af} = 12.7200 + 0.0682\ X_2 + 0.0142\ X_6$$

$$R^2 = 0.968$$

$$D_{W.as} = 7.1476 + 0.0827\ X_2$$

$R^2 = 0.902$

$$D_{W.as} = 6.6817 + 0.04597\ X_2 + 0.2204\ X_5 + 0.0263\ X_6$$

$R^2 = 0.968$

$$D_{W.La} = 15.3981 + 0.0663\ X_2$$

$R^2 = 0.81$

$$D_{W.La} = 13.7401 + 0.0645\ X_2 + 0.0682\ X_5 + 0.0330\ X_6$$

$R^2 = 0.897$

where:

$D_{W.af}$ = Water demand in Africa in gallons per capita per day (gpcd).

$D_{W.as}$ = Water demand in Asia (gpcd)

$D_{W.La}$ = Water demand in Latin America (gpcd)

X_2 = Population of the community served by water supply in thousands, where $X_2 \geq 1{,}000$.

X_5 = Percentage of homes connected to water supply systems

X_6 = Average national per capita annual income in U.S. Dollars.

Reid (1971) has developed a model for predicting the demand of water, by using economic, population and life style sub-models. The predictive equation is as follows:

$$WD_t = (POP_t)\ UU\ \left(\frac{PPt_t}{PPt_s}\right)^x \left(\frac{INC_t}{INC_s}\right)^y \left(\frac{POP_t}{POP_s}\right)^z$$

where:

WD = Water demand at time t

UU = Unit use

POP_t = Population at time t

PPt_t = Precipitation at time t

INC_t = Income at time t.

Grima (1972) carried out a study on residential water demand in Ontario, Canada. His aim was to find methods by which the large and growing capital costs of water supply infrastructure in municipalities could be reduced. In particular, the research focused on the economic nature of residential water demands and the efficacy of using water pricing to decrease these demands.

Grima examined the pricing structures in the study area, located in and around Metropolitan Toronto, and found that the pricing structures fit into two types: a flat rate structure and block rate structure. In the flat rate structure, charges are unrelated to the amount of water used in the residence, and most often this amount is unmetered. In the block rate structure, the amount of water used is metered, and unit charges decline as more water is used, leading to wasteful water use.

Grima used the multiple regression analysis. The equations were calculated for three dependent variables: average annual water use per day per dwelling, average summer water use per day per dwelling and average water use per day per dwelling. The independent variables used were: the assessed value of the residence, lot size, the number of persons in the residence, the price of water, the amount of daily water use and the amount of the fixed (i.e. minimum) bill for one billing period. Both linear and non-linear (logarithmic) forms of the regression equation were used in the analysis, and the data were collected on both single and multiple family dwellings. The equations are as follows:

1. For single family dwelling:

$$\log WU_a = 2.78 + 0.56 \log V^{**} + 0.59 \log N_p^{**} - 0.93 \log p^{**}$$

$- 0.31 \log F^{**}$

$R^2 = 0.56$ S.E. = 0.15 F-value = 27.5**

$$\log WU_s = 3.24 + 0.51 \log V^{**} + 0.63 \log N_p^{**} - 1.07 \log p^{**} - 0.35 \log F^{**}$$

$R^2 = 0.55$ S.E. = 0.16 F-value = 26.45**

$$\log WU_w = 2.45 + 0.48 \log V^{**} + 0.62 \log N_p^{**} - 0.75 \log P^{**} - 0.24 \log F$$

$R^2 = 0.49$ S.E. = 0.16 F-value = 20.38**

2. Multiple family (town house) dwellings.

$$\log WU_a = 0.34 + 0.71 \log V^{**} + 0.49 \log N_p^{*}$$

$R^2 = 0.27$ S.E. = 0.08 F-value = 6.54**

$$\log WU_s = 0.3 + 0.7 \log V^{**} + 0.62 \log N_p^{**}$$

$R^2 = 27$ S.E. = 0.78 F-value = 6.55**

$$\log WU_w = 0.12 + 0.81 \log V^{**} + 0.44 \log N_p$$

$R^2 = 0.23$ S.E. = 0.1 F-value = 5.8**

* Significant at 95% level

** Significant at 99% level.

Where:

WU_a = water use in gallons/day/dwelling unit (annual average).

WU_s = water use in gallons/day/dwelling unit (summer period average).

UW_w = water use in gallons/day/dwelling unit (winter period average).

V = the assessed sales value of residence in hundreds of dollars.

N_p = the number of persons in the dwelling units.

P = the variable price of residential water in cents/1000 gallons.

F = the fixed bill for one billing period in cents.

The analysis showed that the logarithmic form of the regression explained more of the total variance in annual summer and winter water demand (49% to 56% of R^2) than did the normal form (46% to 52%) for metered single family dwellings. The variables found to be significant at 95% level of explanation, and the variable price in annual, summer and winter cases were found significant at the 99% level. In unmetered residences, the number of persons living in the residence and the residence value were found significant at 95% level for the annual and summer cases. For the winter case only residence value was significant at this level. The variance ranged between 23% and 27%, but in the logarithmic form was found preferable.

Another study is carried out by Willsie and Pratt (1974) for the Seattle region. The purpose of their study is to quantify past, present and future water demands for residential, industrial, commercial and public uses, and to study the factors affecting water use. In their study they used multiple linear regression to calculate water use for 23 years of water consumption records. The developed equation is as follows:

$$Y = -184.71 - 133.72\ X_1 + 0.000136\ X_2 + 3.27\ X_3$$

where:

Y = Average water use in mgd

X_1 = Average inches of precipitation per day

X_2 = Population

X_3 = Average daily temperature

The next step in their study is the residential water use relationships. Four relationships were studied:

1. Single-family residential, dry season

   $Y_{11} = f(X_1, X_2)$

2. Single-family residential, wet season

   $Y_{12} = f(X_1)$

3. Multi-family residential, dry season

   $Y_{21} = f(X_1)$

4. Multi-family residential, wet season

   $Y_{22} = f(X_1)$

where:

Y_{ij} = water use per person by type of residence during the season

X_1 = average income per person per year

X_2 = average lot size per person for single family residences in square feet.

A study carried out by Grunewald, Haan Debertin and Carey (1976) on rural residential water demand in Kentucky. They propose that the demand management through pricing policy can be used with supply management to solve water supply problems. In their study, the demand is a function of price, economic and social status of an individual and physical need. Data obtained were used in an econometric analysis. The general form of the model is as follows:

$$Q_d = f(P, I, V, E, N, u)$$

Where:

Q_d = quantity of water used in thousands of gallons per year per dwelling unit.

P = average water bill in dollars per 1000 gallons.

I = mean income in thousands of dollars per year per household.

V = value of dwelling unit in thousands of dollars.

E = pan evaporation in inches.

N = number of persons per household.

u = stochastic error.

The data were subject to both linear and log-linear models. The results of the linear demand function is as follows:

$$Q_d = 12.97 - 12.37P + 1.71I - 0.85V + 1.62E + 10.78N$$

This relationship was inadequate because of the standard errors of the regression coefficients. The result of the log-linear demand function is as follows:

$$Q_d = 24.53P^{-0.92}\ E^{0.29}\ N^{0.33}\ V^{0.14}\ I^{-0.14}$$

From their study, it is concluded that rural residential water demand is a decreasing function of price.

Headley (1963) has carried out a study on the relationship between water demand and income in the San Francisco-Oakland Metropolitan area of California. He used income flow as a measure of income level and he has two cross-sectional models and a time series model for each municipality.

He considered the precipitation, the temperature and price of water to be constant over the area and focused on the income level. The developed model is as follows:

$X_o = -30.24 + 2.16\ X_1$ for 1950

$r^2 = 0.81$

$X_0 = -18.77 + 1.27\ X_1$ for 1959

$r^2 = 0.8$

where:

X_0 = gallons/capita/day purchased

X_1 = The median family income per year in $100.

In general, an increase in income will result in increased water use. Also, the variation in family income is not related to any other variable, such as price, number of persons in residence and lot size.

Sasaki and Sasaki (1972) developed a model for Tokyo, Japan. They used four factors to develop the model: population, personal income, industrial production and sales of goods. The equation developed is as follows:

$$I = 0.5674\ X_1 + 0.1606\ X_2 + 0.1149\ X_3 + 0.1571\ X_4$$

where:

I = Water demand in gallons per capita per day

X_1 = Population

X_2 = Personal Income

X_3 = Industrial production

X_4 = Sales of goods.

Lee (1969) carried out a study on thirteen sites in Calcutta and New Delhi attempting to find the relationship between water supply and economic development and the components of the demand function for domestic water supply. He suggested that the following factors are influencing water use:

1. The distance of water source (or availability of water)

2. Income

3. Education

4. Religion

5. Housing.

Then he divided the population into two groups, the first group is the household with water connection inside the house while the second group is dependent upon public water sources outside the house.

In this study, he concluded without giving any predictive equations, that domestic water supply is a function of accessibility to water, housing conditions, level of income and water use habits. The most important factor in the water consumption appears to be the accessibility of water supplies.

Linaweaver, Geyer and Wolff (1968) carried out intensive studies for water demands using several variables for domestic demand. The researchers used special demand meters over two years and gathered the data from sixteen water utilities. The developed models are as follows:

1. In metered and public sewer areas:

   $q_{ad} = 206 + 3.47v - 1.3P_w$

2. In flat rate apartment areas with public sewers:

   $q_{ad} = 28.9 + 4.39v + 33.6d_p$

3. In metered areas with septic tanks:

   $q_{ad} = 30.2 + 39.5\ d_p$

4. In metered areas with public sewers:

   $q^*_{ss} = 1.09 + 2.07(W_s = 0.6r_s)^* = 1.12\ P^*_s + 0.662\ V^*$

5. In metered areas and public sewer in arid regions:

   $q^*_{ss} = 3.053 - 0.203P^*_s + 0.429\ V$

6. In humid regions:

$q^*_{ss} = 0.784 - 0.793\ b^* + 2.93\ (W_s - 0.6\ r_s)^* - 1.57\ P^*_s + 1.45V^*$

7. In flat rate areas with public sewers:

$q_{ss} = 2.00 + 0.783\ V^*$

where:

q_{ad} = average annual quantity for domestic purposes in gallons per dwelling unit (pgd/du).

v = market value of dwelling in $1,000.

d_p = number of persons per dwelling unit

P_w = sum of marginal water and sewer charges

qss = average summer sprinkling demand (gpd/du)

b = irrigable area per dwelling unit

w_s = summer potential evapotranspiration in inches

r_s = summer precipitation in inches

P_s = marginal commodity charge applied to average summer rate use

*variables are logs to the base 10.

White, Bradely, and White (1972) carried out a study in East Africa (Kenya, Tanzania, and Uganda) on domestic water use. In this study, they used several variables: per capita income, educational levels, family size, source of available water, cost, culture and natural environment. From this study it was found that daily per capita usage ranges from 1.4 liters in rural areas to 660 liters in suburb of Moshi, Tanzania. Also it shows that there is a difference in per capita use for piped supplies and unpiped supplies. Generally speaking, the per capita use in piped supplies is a function of costs, income level, family size and education, while the per capita use in unpiped supplies is a function of income level, urban versus rural situations, and the family size. This study shows that the price is of measurable significance. Predictive equations were not given.

Hanke (1971) performed an analysis based on time series data for Boulder, Colorado. The time series compared a flat rate to a metered rate through time with the utility. The hypothesis was that the actual sprinkling consumption (q_t) is linearly related to ideal springkling consumption (Q_t) based on the evapotranspiration rates, and after meters were installed, there was a downward shift in the function:

$Q_t = a_1 + B_1Q_1$ flat rate period

$Q_t = a_2 + B_2Q_2$ metered rate period

where

a_1 is greater than a_2

B_1 is equal to B_2

These estimates were made from both periods and combined into a single relation:

$Q_t = a_1 + a_2X_2 + B_1Q_t + B_2Z$

where:

$Z = X_2Q_2$

where

$X_2 = 0$, in each month during the flat rate period

$X_2 = 1$, in each month during the metered rate period.

Therefore:

$Q_t = a_1 + BQ_t$ as the flat rate

$Q_t = (a_1 + a_2) + (B_1 + B_2)Q$ as the metered rate.

Martin, Ingram, Lancy and Griffin (1984) developed a residential water demand model for Tucson, Arizona. The researchers used multiple-regression analysis. In their model they assumed that the demanded water is a function of the price, the family's income, the family's life style, rain, and temperature. The developed equation is as follows:

$$\log_{10}Q = 0.820737 - 0.00375P + 0.040471(EVT - R_t) + 0.000005\ FCV$$

$$R^2 = 0.102$$

where:

Q_{it} = the quantity of water delivered to a single-family residence i in the month t, in 100 ft^3 per month

P_{it} = the marginal price of water, measured in cents per 100 ft^3

$EVT\text{-}R_t$ = evapotranspiration minus rain for month t, in inches

FCV_i = the full cash flow of the single-family residence i.

Darr, Feldman and Kamen (1976) carried out a study on residential water consumption in Israel. Their study was based on two levels of analysis: the spatial and the behavioral.

On the spatial level, tests were performed to determine the significance of variables on consumption among twenty eight towns. On the behavioral level, the study was made on 1892 households in Jerusalem, Kaifer, Beersheva and Tel Aviv.

In the first study the purpose was to determine the relationship of water usage to price and to the income. The relationships were stated mathematically as

$$Q = f(P, I)$$

where:

Q = the quantity of water per capita per annum (cubic meters)

P = price of water (per cubic meter)

I = income per capita

The developed equation is:

$$Q = 1.35 + 0.659I \quad \text{(logs to the base 10)}$$

In the second study (behavioral analysis), the objective was to obtain consumption data for various segments of the population. The hypothesized equation is as follows:

$$\left.\begin{matrix} Q_d \\ Q_a \\ Q_s \end{matrix}\right. = f(I_c, N_p, N_r, A, C, E, S)$$

where:

Q_d = quantity of water per capita not including water for gardening (cubic meter per annum).

Q_a = quantity of water per capita, including water for gardening (cubic meters per annum).

Q_s = quantity of water per capita for gardening purposes only (cubic meters per annum)

I_c = monthly income per capita

N_p = number of persons per dwelling unit

N_r = number of rooms per dwelling unit

A = age of the head of household

C = cultural factor determining water use preferences

S = settlement, area, or municipality which the dwelling is located

E = education of the head of household

The developed equations for Q_a and Q_d, by non-metered dwelling units are as follows:

1. $Q_a = f(N_p, A, C, E)$

   $Q_a = 2.139 - 0.7952\ N_p$

2. $Q_a = f(N_r, I_c, A, C)$

   $Q_a = 1.1651 - 0.2161\ N_r + 0.2315\ I_c + 0.1704A - 0.0827\ C$

3. $Q_d = f(N_p, A, C, E)$

$Q_d = 2.1025 - 0.7653\ N_p$

4. $Q_d = f(N_r, I_c, A, C)$

$Q_d = 0.8946 + 0.3301\ I_c$

The equations for Q_a and Q_d for the metered dwelling units:

5. $Q_a = f(N_p, A, C, E)$

$Q_a = 1.8021 - 0.5133N_p + 0.1035A + 0.0816E$

6. $Q_a = f(N_r, I_c, A, C,)$

$Q_a = 0.7848 + 0.3085I_c + 0.1910A$

7. $Q_d = f(N_p, A, C, E)$

$Q_d = 1.8015 - 0.4766N_p$

8. $Q_d = f(N_r, I_c, A, C,)$

$Q_d = 1.1395 + 0.1477I_c + 0.1105A - 0.0888C$

All the equations are in logarithmic form to the base 10.

Industrial Water Demand Models

Water is one of the largest raw materials used by industry for many purposes and requirements. The uses of water in industry are: boiler water, cooling water, fire protection, processing, sanitary facilities, air conditioning and cleaning. The amount of water used in industries varies dependent on the industrial group and its size. Table VI shows the major groups of industry and their daily water consumption for some selected industries in Jordan obtained from the Royal Scientific Research Society in 1981, and Jordan Master Plan.

Bower (1966) developed a model for forecasting industrial water demands. In his model, he assumed that the industrial water demand is a function of the nature of the production process, the nature of raw materials used, product output mix operating level, physical layout of

TABLE VI

DAILY WATER CONSUMPTION FOR SELECTED INDUSTRIES IN JORDAN WITH INDEPENDENT WATER SUPPLY

Name	Type of Industry	Location	Annual Water Consumption 10^3 m^3
Jordan Ice and Aerated Water Co. Ltd.	Soft Drinks	Amman	550
Rainbow	Poultry	Amman	25
Jordanian Electric Power Co.	Electrical Works	Amman	220
United Industry Corp	Batteries	Amman	140
Army Factory	Textiles	Awajan	70
Jordan Paper and Cardboard Factory	Paper	Awajan	300
7-Up Company	Soft Drinks	Ruseifah	400
Transjordan Minerals Co.	Mining	Ruseifah	300
Jordan Tanning Co. Ltd.	Tannery	Awajan	400
Jordan Worsted Mills Company	Textiles	Ruseifah	150
Oil Refinery	Oil	Zarga	2,100
Ceramic Factory	Ceramics	Awajan	300
Jordan Dairy Co. Ltd.	Milk	Ruseifah	130
J. C. A. Co. Ltd.	Various	Ruseifah	750
Port	--	Agaba	267
Timber Plant and Various Industries	Various	Agaba	312
Fertilizer Plant	Fertilizers	Agaba	5,000
Refinery	Oil	Agaba	2,000

TABLE VI (Continued)

Name	Type of Industry	Location	Annual Water Consumption 10^3 m^3
Soap	Soap	Amman, Zarga and Irbid	240
Phosphate Mines	Phosphate	Ruseifah	4,000
Phosphate Mines	Phosphate	Al-Hassa	6,500
Phosphate Mines	Phosphate	El-Shiddiyya	4,200
Cement Factory	Cement	Fuheis	600
Arab Potash Company	Potash	Dead Sea	9,000
Copper	--	Finan-Wadi Araba	9,000
Iron & Steel	Steel	Zarga	458
Chemical Production	Various	Zarga	175
Beer			
-Heninger		Ruseifah	53
-Amestil			89
Arak Star		Ruseifah	12
Paint		Zarga	4
Methylated Spirit	Spirit	Zarga	15
Vegetable Oil		Ruseifa-Zarga	55

Sources: AGRAR-UND HYDROTECHNIK CMBM, "Domestic and Industrial Water Demand," National Water Master Plan of Jordan, Vol. VI. 1977, p. 49.
Royal Scientific Research Society, "Study of Pollution on Zarga River," Industrial Chemistry Department, 1981. (Arabic). and
Authors survey on Industrial Water Consumption in Jordan.

the plant, and controls on gaseous and liquid waste discharges. The joint function is:

$$Q_I + U + Q_E + W_D + W_E = f(C_I, PP\text{-}PM, RM, OR, R, MR, BP, CE)$$

where:

$Q_I + U + Q_E + W_D + W_E$ equal the time pattern of water intake, consumptive use, final effluent, waste load generated, and waste load in the final effluent respectively.

C_I = cost of intake water, which is a function of the time pattern of quantity and quality of water available and of the cost of water treatment.

PP-PM = combination of production process-product mix.

RM = nature of raw materials used.

OR = operating rate.

R = degree of recirculation which is a function of the cost of recirculation - which, in turn, is a function of the physical layout of the plant and the production process-product mix, the cost of waste treatment, the cost of input water treatment, and quality specifications for the final product outputs

MR = possibilities for materials recovery

BP = possibilities for by-product production

C_E = cost of handling and disposing of the final effluent, which in turn, is a function of the controls imposed on liquid and gaseous waste discharges, the availability of places for disposal of wastes, and the production process-product mix.

The developed model is an economic base study, and five steps were followed to forecast industrial water demand:

1. Classify existing plants by process, region, product mix, and size.
2. Forecast trends in production processes, product mix, and regional location patterns, i.e., forecasting technology (a forecast of market).
3. Relate the production process-product mix combinations to gross water applied and waste loads generated.
4. Analyze the alternative internal water utilization patterns and costs thereof, considering the impacts of in-plant water quality requirements in relation to product quality and the costs of other factor inputs such as fuel and heat exchangers.
5. Forecast political decisions relating to pricing policy for water at the intakes and policies relating to waste discharge.

Then the water demand can be forecasted.

Reid and Muiga (1976) developed a forecasting model for (ECWA) region. They identified the factors affecting industrial water usage and used the stepwise multiple regression analysis. The developed model is as follows:

$$I_{n,t} = 0.7587 + 0.0018NP_{n,t} + 0.1373GNP_{n,t} + 789.8WF_{n,t}$$

where:

$I_{n,t}$ = industrial water demand for country n at year t.

$GNP_{n,t}$ = Gross national product in U.S. dollars for country n at year t.

$NP_{n,t}$ = national population in thousands of country n at year t.

$WF_{n,t}$ = percentage ratio of $X_1/X_2/X_3$ of work force of country n in year t.

X_1 = percentage of national work force which is professionals

X_2 = percentage of national work force which is skilled.

X_3 = percentage of national work force which is unskilled.

Brown (1968) developed a mathematical model for forecasting water requirement for pulping industries. In his model the total water use is a function of quantity of product and average of water use. The developed model is as follows:

$$I_t = \left(\sum_{i=1}^{n} P_{it}W_i + (1+i)^s \sum_{j=1}^{n} Q_{jt}W_j \right) \left(\frac{r_o + 1}{r_t + 1} \right)$$

where:

I_t = total water use in period t.

P_{it} = quantity of pulp produced by pulping process i in period t in tons.

W_i, W_j = average water use per ton of process i or product j.

Q_{jt} = quantity of product j produced in period t.

r_t = rate of water reuse in period t

S = length of projection period

i = rate of product quality improvement.

Robert H. Stewart and Ivan Metzger (1971) developed a model for forecasting industrial water demand. They presented a formula using ratios as the input factors. The factors are as follows:

E = The ratio of future employment in manufacturing to the present employment in such industries.

O = The ratio of future output per employee to the present value.

R = The ratio of future recirculation to present recirculation.

T = The ratio of present gross water requirements per unit of production (including recirculated water) to the future gross water requirement.

These factors are combined in the following equation:

$$F = \frac{E \times O}{R \times T}$$

where:

F = The ratio of future to present industrial water needs.

Agricultural Water Demand Models

Water is the most important input factor in agricultural production. Irrigation has played a key role in opening up new agricultural lands. The UN Food and Agriculture Organization (1977) estimated that 88 percent of the water used throughout the world is for irrigation and 30-40 percent of the world's food is dependent on irrigation. Also, it has estimated that $100 billion investment program in irrigation projects will be required to keep up with population growth and the demand for food.

The most difficult analysis of the agriculture water demand is the water used in irrigation. Forecasting for irrigation is done on two bases: the predicted variables are a function of other variables, and the forecasts are obtained by extrapolating past trends. Recently, more emphasis has been placed on the first approach.

In the UN Economic Commission for Europe draft for the Compilation of Balance of Water Resources and Needs (1971) it states that the common practice in Europe for determining the net water requirements for irrigation is to compile a balance of water in the soil. In this manual, various formulas are presented to determine the element of an equation for determining the consumption per plant. The final formula which determines the quantity of water is as follows:

$$V_o = \frac{S}{K_a K_s} m \qquad m^3/\text{ha/month}$$

where:

S = The area under irrigation in hectare.

m = consumption per plant.

K_s = The coefficient of irrigation efficiency.

K_a = The output of the irrigation system.

Bartone (1970) developed and equation for agriculture water demand in each county of the state of Oklahoma. The basic assumption in this model was that the ratio of county's irrigated acres to the state's will remain constant in the future. The developed equation is as follows:

$$A_j^t = (1 + 28.5 \frac{t - t_o}{A_s^{t_o}}) A_j^{t_o}$$

where:

A_j^t = thousands of irrigated acres in the j^{th} county at time t.

$A_j^{t_o}$ = thousands of irrigated acres in the j^{th} county during the base year t_o.

$A_s^{t_o}$ = total Oklahoma irrigated acres in thousands during the base year t_o.

Reid and Muiga (1976) developed a model to estimate the required water for irrigation for the (ECWA) region, by using the stepwise multiple regression technique. The developed equation is as follows:

$$IR_{n,t} = 0.15 + 0.0007NP_{n,t} + 0.5051IC_{n,t}$$

where:

$IR_{n,t}$ = irrigation unit water demand for county n at year t.

$NP_{n,t}$ = national population in thousands of county n at year t.

$IC_{n,t}$ = national percentage ratio of irrigated to cultivated land of county n at year t.

The first step of this study was to identify all the factors that affect unit use of water. The literature reviewed included both general references and case studies. Unfortunately, few of the case studies involved Jordan.

Before discussing factors which affect water demand, it is appropriate to differentiate between water use and water demand. When water supply is adequate, it is assumed that water use equals water demand. On the other hand, if supply is limited, use is adjusted downward. In communities where water use has been limited by drastic shortages or lack of a public supply, extrapolation of historical trends may be inappropriate. This is because water use patterns will change with increased water availability, all else being equal.

Factors Affecting Water Demand

Factors affecting water demand are divided into three main groups: climate, socio-economic and other factors.

Climate

Unit use tends to be higher in warm, dry climates than in humid climates. This has been attributed to increased bathing, lawn watering, etc. (Linsley and Franzini, 1972; Lee 1969). However, the current trend in Jordan, Fig. 11 and Fig. 12 indicate that the consumers respond to the climatological changes in the high temperature season (May - October) by carrying out their municipal sprinkling and personal uses.

The trend of higher unit use in warm dry climates is not an unbounded one. It holds only where supplies are adequate to satisfy demand. In arid regions, water use is governed by limited supplies, rather than potential demand. When this occurs, users often resort to segregated use. That is, good quality water is reserved for drinking and cooking, while water of lesser quality is used for bathing and washing.

Several examples of this phenomenon exist. In Kuwait, desalinated water is used for drinking and cooking, and slightly brackish ground water supplies other needs. In 1968, when only a few homes had water connections, the per capita use was 52 gallons per day (gpd). This consisted of 20 gpd desalinated water and 32 gpd ground water. By 1972, with all homes connected to the supply system, this per capita use was expected to have risen to 107 gpd (35 gpd disalinated and 72 gpd ground water) (Al-Awadi, 1968).

In Savanna Region, Nigeria, water shortages are prevalent during the dry season. The people of this area are aware of water quality, and use water from different sources for different purposes. They sometimes spend many hours per day fetching potable water from a distant source (Akintola, Acho-Chi and Mark, 1980).

The rationale here is that water use in the dry season is controlled by availability. When users perceive that water is available,

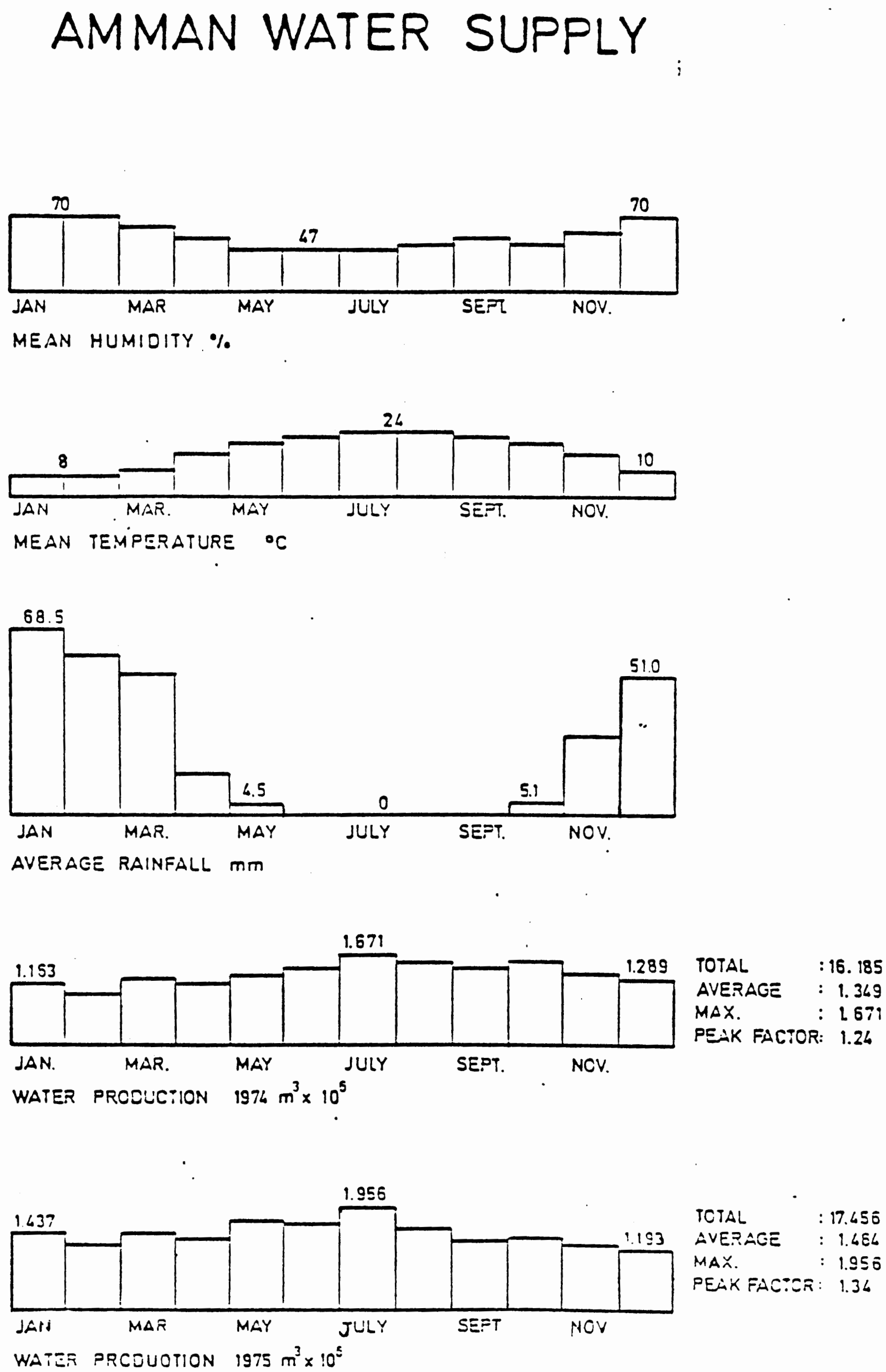


Figure 11. Monthly Water Production and Monthly Climatic Parameters.

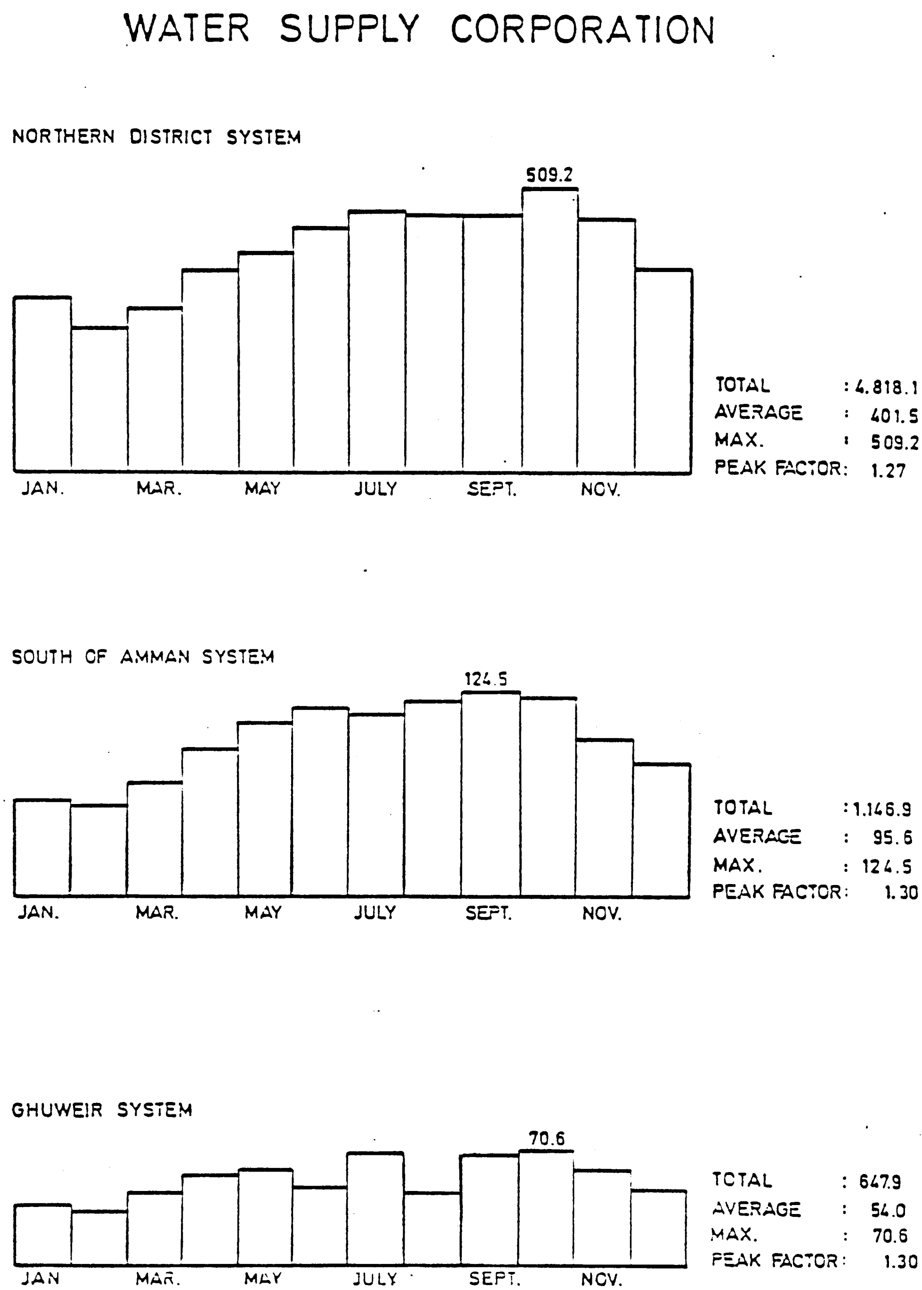


Figure 12. Monthly Water Production in Jordan

as with a public supply, demand increases during the dry spell. However, when the supply is limited, as with rain water, use is reduced to ensure that supplies last until the rains come.

Socio-Economic Factors

Socio-economic factors have the greatest effect on unit use. In spite of this, these factors remain the least understood. There are several reasons for this phenomena. Traditionally, the social scientists have been largely excluded from the water field (Linsley, 1979). There is a large array of social theory but it is not in a form that can be readily applied to forecasting. This is because the training of social scientists is geared towards observing and commenting after the fact (Widstrand, 1978).

Community Characteristics

In the developed countries, especially in the United States, unit use of water tends to be higher in large cities than in small communities. This trend is due to increased demand for water in the areas of commercial and public use, industrial use, and losses in water supply systems (Linsley and Franzini, 1972).

A study of water consumption carried out in Santa Clara County, California, suggests that the population density has a large effect on unit use of water. Figure 13 shows that as the population density increased from 3 persons per acre to 30 persons per acre the indoor water use declined from 100 gallons per capita per day to 70 gallons per capita per day. Also the graph shows that the outdoor water use declined from 200 gallons per capita per day at 3 persons per acre

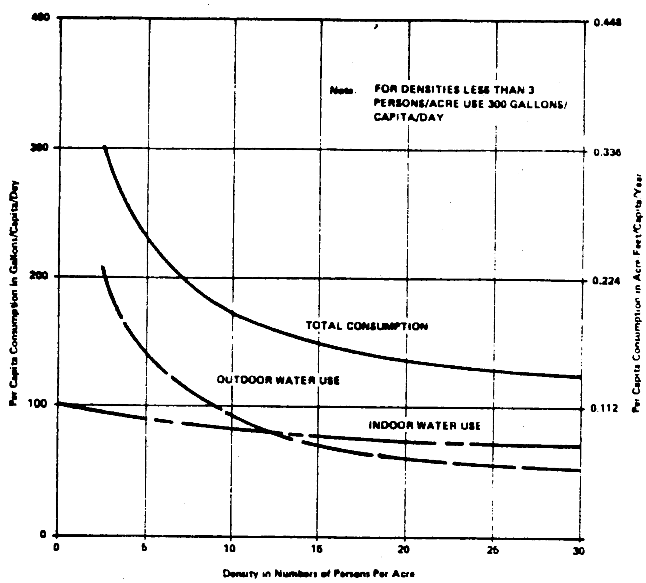


Figure 13. Residential Per Capita Water Consumption as a Function of Population Density

density to 50 gallons per capita per day at a population density of 30 persons per acre. (See Figure 13). The outdoor water use decrease is attributed to a smaller area of landscaped yard per dwelling unit. It should be noted that the water used to sprinkle landscape yards in Jordan is not a major factor since it is restricted to a limited number of neighborhoods in large cities, namely those with high income levels.

Another community characteristic that affects the unit use of water is the economic conditions of the community. Urban communities have a greater demand for municipal and industrial water than rural areas. Thus, it can be concluded that the degree of urbanization causes greater demand for municipal and industrial water. Continued economic and social growth is anticipated to increase the unit use of water. Table VII shows the per capita water consumption in different cities in Jordan.

Life Style

In addition to the community characteristics, pesonal life style also affects the unit use of water. These factors include household size, income per capita, country of origin of the consumer, house appliances and education. A large number persons per dwelling unit have lower water use per captia. In a study conducted on five regions in Jerusalem, Tel Aviv, the Tel Aviv Suburbs, Haifa and Beersheva, Israel the family size and income per capita were found to be the principal factors influence the water consumption. Family size has a greater effect upon water consumption than income (Darr, Feldman and Kamen, 1976). The same relationship between family size and unit use was noted in India. However, this factor was not a very important one, and it was

TABLE VII

WATER CONSUMPTION FROM MUNICIPAL WATER SUPPLY SYSTEMS, 1975

System	Operated by	Raw water sources: deep wells	Raw water sources: springs	Population served x 10^3	Consumption l/c/d
Amman	AWSA	x	x	606.6	37.0
Zerqa	M	x		184.0	27.8
Ruseifah	M	x		43.0	20.7
Salt	M	x	x	29.0	33.9
Aqaba	WSC	x		16.1	80.9
Souf	M		x	15.0	14.0
Wadi Sir	M		x	15.0	67.5
Suweileh	M		x	15.0	71.0
Ma'an	M	x		12.0	45.2
Karak	M		x	12.0	54.2
Jarash	M		x	11.0	59.2
Ajlun	M		x	4.0	65.0
Northern District	WSC	x	x		
- Irbid				119.1	20.0
- Mafraq				17.0	50.4
- Ramtha				25.4	28.0
- El Husn				10.0	31.3
- Other communities				195.2	20.0
Tafileh	WSC	x		20.0	71.4
South of Amman with Madaba	WSC	x		96.5	23.7
Ghuweir	WSC	x		62.2	17.7
Tannour	WSC	x		28.0	23.3
Shaubak	WSC	x		10.0	16.5
Wadi Rajib	WSC	x		6.9	25.0
Ain Deek	WSC		x	5.2	26.3
Total				1,558.2	

Note: M = Municipality and WSC = Water Supply Corporation often masked by other factors such as community affluence (Lee, 1969).

Personal affluence is another factor which affects the unit use of water. Most of the studies show that per capita use increased with income level. This is not a direct relationship. Income affects use indirectly through other factors such as types of appliances, and sewerage.

The trend of steadily increasing water use has been attributed to the use of appliances such as air conditioners, automatic washing machines and dishwashers, and home garbage disposal units (Linsley and Franzini, 1972). The Jordanians are only now entering the stage of consumerism which swept the U.S.A. in the 1950's and early 1960's. Thus, a dramatic increase in water demand can be expected within the next decade.

A person's educational attainment was found to affect water use in Israel (Darr, Feldman and Kamen, 1976). ¶A similar phenomenon can be observed in Jordan. In many developing countries there is a strong correlation between education and economic status. As a result, education affects water use but may correlate strongly with higher economic status.

Other Factors

The final group of factors are those which relate to the technical aspects of water supply. These include metering and pricing, regularity of supply, type of supply and water conservation.

There are two methods of billing for water consumed. The first method consists of charging the consumer based on the actual water use (metering system). The second method is levying a flat rate which is independent of actual use. In the flat rate billing system, price discrimination is frequently encountered and is based on property value or geographical area.

In the flat rate method of billing an incentive to conserve water does not exist. Rates based on property value are independent of total use. As a result, unit use of water tends to be higher than with the metered billing system (Linsley and Franzini, 1972).

There are different levels of metering. One meter may be used to moniter several dwelling units, for example, a block of appartments, or an individual house. It has been found that the most effective means of reducing unit use is the metering on an individual house level. This implies that the per capita use of water is less in individually-metered apartments than the block-metered apartments. A number of studies have confirmed this conclusion, for example, Linaweaver (1968), Darr, Feldman and Kamen, (1976) and Hanke (1971).

A number of studies have been made to determine the effect of price on demanded quantities of water (Hanke and Baland, 1971; Chiogioji and Chiogioji , 1973; Gysi, 1972; Hanke and Davis, 1971). The issue of pricing water is still subject to debate. Some authorities believe that water use does not respond to price changes, while others see the pricing is not an effective means of controlling water consumption. In this context water use can be divided into two parts. The first part is the water requirement for essential needs, i.e., drinking water, cooking and sanitiation, which is viewed by some workers as price inelastic. The second component is the non-essential water use which is price elastic and includes car washing, swimming pools, and lawn sprinkling. Flack (1981) noted in his study on Denver, Colorado that water use experiences moderate change with price, while sprinkling use changse at a considerable rate. Lee (1971) and Hanke and Davis (1971) also suggested pricing as a means of optimizing water use practices.

In many studies conducted on water supply, it has been noted that consumers use more water under intermittent water supply than those with constant supply (Lee, 1969). Users consume more water when shortages in supply are expected. This can be avoided by installing a storage tank and connecting it to the household plumbing system. This practice is in widespread use in Jordan.

Water supply can be a direct house connnection, private standpipes serving one household or public standpipes serving many households. A worldwide survey conducted by World Health Organization (WHO) indicates that there are great variations in the amount of wter consumed with rural and urban public standpipes. Consumers supplied with standpipes always consume much less water than those supplied with household connections. Table VIII compares unit use for different types of water supply in several countries. In all cases, consumers with household connections used significantly more water per capita than those served with public standpipes.

Water conservation is a factor which lowers water use. This approach is only now gaining recognition in the United States of America and other industrialized nations. This is because water is no longer abundantly available at low prices in these countries.

Flack (1981) listed various means of conserving residential water. These are:

- Water saving household devices, such as plumbing fixtures and water saving appliances.

TABLE VIII

DAILY WATER CONSUMPTION FROM COMMUNITY WATER SUPPLIES
(LITERS PER CAPITA)

World Health Organization region	Urban				Rural	
	House connections		Public standposts			
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Africa	65	290	20	45	15	35
Central and South America	160	380	25	50	70	190
Eastern Mediterranean	95	245	30	60	70	85
Algeria, Morocco, Turkey	65	210	25	40	20	65
Southeast Asia	75	165	25	50	30	70
Western Pacific	85	365	30	95	30	95
Average	90	280	25	55	35	90

Note: Average daily consumption rounded to nearest 5 liters.
Source: (Saunders and Warford, 1976)

- Structural methods, such as metering, flow control devices and recycling systems.
- Operational methods, which are primarily detection and repair of leaks in the distribution system.
- Economic methods, including pricing policies, incentives and penalties.
- Socio-political methods, which are basically public education.

In developing countries where resource constraints are tighter and demand growth is faster, adaption of water conservation methods should be adopted as part of new supply systems in order to extend the usefulness of these supplies. From the literature reviewed numerous residential and municipal water demand studies conducted to date have shown that the quantities of water consumption increases significantly with income and decreases with the price.

Demand studies are carried out widely by using cross-section or time series data and, often include variables that describe the climatic, economic and technical characteristics of the study area. Most of these studies are carried out in the United States and other industrialized countries. Unfortunately, little is known about the demand for water in developing countries, especially in Jordan.

CHAPTER V

ESTIMATION TECHNIQUES

This chapter summarizes several methods of forecasting which have been used and are useful for estimating unit use of water. These methods do not form an exhaustive list. Instead, they are those which may be applicable for Jordan. Five methods were considered: trend analysis, surrogate approach, expert-opinion methods, systems dynamics, and multiple regression analysis. The basic principles of each model are presented with applications and limitations. The final section of this chapter will present the adopted model for this study in more detail.

Forecasting Approaches

Forecasting by definition is a process which has as its objective the prediction of future events or conditions including any change that may accompany them. Forecasting techniques are not limited to a certain discipline but are incorporated into every aspect of our lives. Forecasting relates to people, economics and natural resources.

Forecasting techniques can be categorized into three groups The first group is called qualitative (Delphi method, Market research and Historical analogy), where all information and judgment relating to an item are used to forecast the items demand. This technique is often used when little or no demand history is available.

The second group is called Causal (Regression, Econometric, input-output models), where a cause and effect type relation is sought. The forecaster seeks a relation between an items demand and other factors, such as business, industrial, and national indices. The relationship is used to forecast the future demands of the item.

The third group is called time-series analysis, where a statistical analysis on past demand is used to generate the forecasts. A basic assumption is that the underlying trends of the past will continue into the future. The Box-Jenkins, moving average, and Exponential smoothing methods belong to this group.

Trend Analysis

"Trend extrapolation is the general name for a variety of mathematical forecasting methods all of which determine future values for a single variable through some process of identifying a relationship valid for the past values of the variables and a solution for future values." (Institute for Water Resources, 1975).

As the above suggests, trend analyses are forecasts. They use past data to develop a trend which is assumed to continue into the future direction and at the same rate as in the past. Trend analysis is the simplest and most widely used method of forecasting. This is attributed to the fact that a relationship is developed between the variables of interest and some other indicator variable. Trend analysis is widely used in many areas in physical, biological, behavioral and social sciences, marketing, and finance. The Corps of Engineers used this method for population estimates, recreation projections, flood damages and water demand.

The major limitation of this type of analysis is that only quantifiable data can be used and the mobility to deal with unforseeable changes in the trend. Since trend analysis is based on the concept of the data leading the planner, limitations and difficulties arise from the availability, reliability and validity of the data. Technical data is often scarce in developing countries (Printz, 1981). In addition, financial and technical resources required to generate needed data is often in short supply (Munn, 1982). In the specific case of water supply, data availability is a much greater problem in developing countries than industrialized ones. This is because a large portion of water supply projects in the developed countries are expansions rather than new supplies. Thus, is it possible to analyze past records in the area to be served. In developing countries water systems are generally new and hence historical water use records do not exist (Muiga, 1975).

Data must be available over a long period to clearly define its trend. The main problems with data collected over long periods are changes in its definition, and methods and standards of acquisition and recording. Validity requires the appropriate application of available data. Data forced to fit a preconceived trend can be very misleading. In fact, such an approach may conceal much more than it reveals. (Institute for Water Resources, 1975).

Surrogate Approach

One of the problems identifed in the last section is the unavailability of data in developing countries. In such a situation it is desirable, where possible to apply trends from one community to another. This method was attempted in South Africa (Van den Berg, 1980).

A total of 104 South African towns with adequate water consumption records were available. The technique used was to multiply the population of the town of interest by unit consumption rates of another town with similar climate, size, standard of living and water availability. This study showed several problems associated with the use of surrogates. In the first place there was wide variation in unit use between towns (with record) that were classified as similar. Secondly, even the 104 towns in the study proved to be too small a sample from which to obtain a generalized pattern. This is an important observation because the number of towns in Jordan that have adequate records is far less than 100. The authors of the South African study advised extreme caution when using the surrogate approach.

Expert-Opinion Methods

Expert-opinion methods are most useful when data is unavailable and when inputs are subjective. These methods are based on the underlying assumption that persons with training and expertise in a particular field can make reasonably accurate intuitive predictions of changes, within their sphere of knowledge. The key to success in these methods is the experts themselves. They must be persons who are currently employed in the field of interest, who are conversant with the state-of-the-art in that field, and who can conceptualize the nature of the changes to be predicted. When a suitable expert, or preferably a panel of experts, has been selected, one of several expert-opinion methods can be used. Two techniques will be discussed in this section: panel discussions, and the Delphi technique.

The panel discussion. In this method, the group of experts is brought together and asked to discuss the problem and come to a conclusion. Panels may be formal or informal, and may meet once or several times. However, it is important that the members have in common an exceptional degree of knowledge or opinion about the topic in question. (Institute for Water Resources, 1975).

The major benefit of panel discussions is that a consensus may be reached in a relatively short time. Note, though, that a consensus is not always reached. There are cases where a minority opinion persists even after lengthy discussions. In spite of this it is normally possible to issue a majority opinion after the panel's work is done. This then serves as the estimate or prediction upon which future action is planned.

Some of the drawbacks of panel discussions include inconvenience, cost, "noise", dominance and conformity (Linstone and Turoff, 1975). Panels are inconvenient because it is difficult to find a common time when the whole panel is available and willing to assemble in one place. They incur the cost of travel and accommodation, as well as the cost of expert's time. "Noise" is the many unnecessary side discussions which accompany the main debate. It also includes incessant repetition of one idea by the person who proposes it. Studies have shown that such repetition can sway a group's opinion, simply by attrition. By virtue of their position or personality, some people can dominate others during face to face interactions. Thus, the views of dominant individuals may become those of the group. Finally, most people will assume a moderate sounding position in order to avoid being labelled "radical." The Delphi technique is one way to reduce or eliminate these drawbacks.

<u>The Delphi technique</u>. The objective of this technique is to arrive

at the most reliable consensus of opinion of an expert panel. This is done using anonymity, statistical analysis and controlled feedback (Dalkey and Helmer, 1963). The technique itself is relatively simple, as described below.

In the first round of a Delphi, the panelists are asked to consider a problem and provide an estimate. This is done on an individual basis without consultation and discussion. The panel's collective response is statistically analyzed, and a summary is returned to each expert. This summary shows majority and minority opinions for descriptive answers, and maximum, minimum, mean and quartiles for numerical answers. No indication is given as to which panelist gave a particular response.

In the second round, panelists are asked to "Challenge their own opinions" (Coates, 1975). They are asked to study the results of the first round and reconsider their own position. These new opinions form the second round response and these are again analyzed statistically.

Other rounds have the same form as round two. In each case the previous round's response is studied and opinions are reconsidered. There is usually convergence of opinion with each successive round. The number of rounds required varies from one study to another. In many cases, responses stabilize after three rounds (Helmer, 1966). Because of this, it is advisable to conduct at least four rounds. This will give minority opinions an opportunity to convince the rest of the panel. (Toussaint, 1975).

The Delphi technique is more convenient and less expensive than the panel discussion. Delphi's are usually conducted by mail or telephone, eliminating the need to assemble the panel. The anonymity in the technique eliminates dominance and conformity. The questionaire format precludes noise.

The major disadvantages of the Delphi are the length of time required and low response rate. Delphi's can take several weeks or months to complete because of the number of rounds and the time taken to receive and analyze responses from each round. In addition, the entire panel does not respond and some responses are received after the cut-off date.

Systems Dynamics

This model was developed by professor Jay Forrester at Massachusetts Institute of Technology in 1960. The initial development of this model was from the military appalication, and expanded to the industrial and to its final application to the public sector. The model evolved into a comprehensive look at all the interactants at one time using inductive followed by deductive reasoning or feedback. The model used to understand, design, predict, evaluate, and forecast. It is a symbolic representation of a real life situation. (Reid, 1970).

System dynamics model has many applications. It has been used in water supply and water quality, where it relates to broad considerations of population, life style, employment and investment. Dynamic models have a short and long span of forecast and require large amounts of data, resources, time, skills, and the necessary use of computers to carry out the computations of the simulation, which limits the use of this model in Jordan at the present time.

The institute for Water Resources (1975) stated that the general procedure for a dynamic model forecast has the following phase:

1. Formulate the problem:
    a. Urban-rural migration
    b. Changes in the economy toward services
    c. Allocation of water to recreation.
    d. Pollution control policies.
2. Identify system components:
    a. The capital sector
        - industry
        - services
        - agriculture
    b. Population sector
        - rural population
        - urban population
        - intra and interregional migration
3. Identify feedback loops:
    a. Positive loop: amplify changes in the system
    b. Negative loop: attenuate changes in the system
4. Quantify and validate:
    a. Requirement of specific numerical values for the parameters in the system structure, for the quantification
    b. Verification of the model by the experts
5. Simulate future values on the computer by using the Dynamo computer program
6. Evaluate the output by applying to different planning horizons
    a. Short-range planning
    b. Long-range planning

Other Methods

In some situations, the forecasting of future demands based on past trends is inappropriate. This is due to past patterns that are biased in some manner. For example, a community may adjust its life style to a perpetual water shortage. Extrapolation of water use records for such a community will result in unit use projections which are lower than the demand if adequate water supply were available. Another case in question is the country or community that has had no public water supply system. In this case, there are no historic data.

The final two methods to be addressed in this section can be used to estimate an appropriate value where these extreme conditions exist. The first method is based on setting water supply goals for a particular community depending on their available resources. Feachem (1975) suggests a set of possible goals for a water supply development in a low-income community in a developing country. It was claimed that high-grade water service is unattainable for the majority of the population of developing countries because its immediate goals are high quality, abundant quantity, complete availability and total reliability. According to Feachem, some combination of improvements in quality, quantity, availability and reliability must be decided upon for the purpose of planning and design. Table IX gives Feachem's goals for projects backed by varying stages of resources. The unit use of water will depend on the level of improvement which is decided upon. Substantial work is still required in order to determine actual values of unit use which would correspond to each level of supply.

In the second method, the municipal water demand is broken down into its principal components, hence the name Principal Component

TABLE IX

POTENTIAL BENEFITS OF WATER SUPPLY IMPROVEMENTS
(FEACHEM, 1975)

Immediate Aims	Stage I Benefits	Stage II Benefits	Stage III Benefits
Improve: Water quality, Water quantity, Water availability, and Water reliability	Save time, Save energy, and Improve health.	Labor release, Crop innovation, Crop improvements, Animal husbandry innovation, and Animal husbandry improvement.	Higher cash incomes, Increased and more reliable subsistence, Improved health, and Increased leisure.

Analysis. Each component is then estimated. All components are then summed to give the municipal water demand. One way of subdividing municipal use is into domestic use, commercial use and industrial use. Domestic unit use is estimated on the basis of an average household. Table X shows daily water use for a family of four in the United States.

Commercial and industrial water use are not usually estimated in a per capita form with this method. As a result, this method is more suitable to finding total municipal use rather than unit use. One of the disadvantages of Principal Components Analysis is that demand tends to be over-estimated.

Choice of Methods

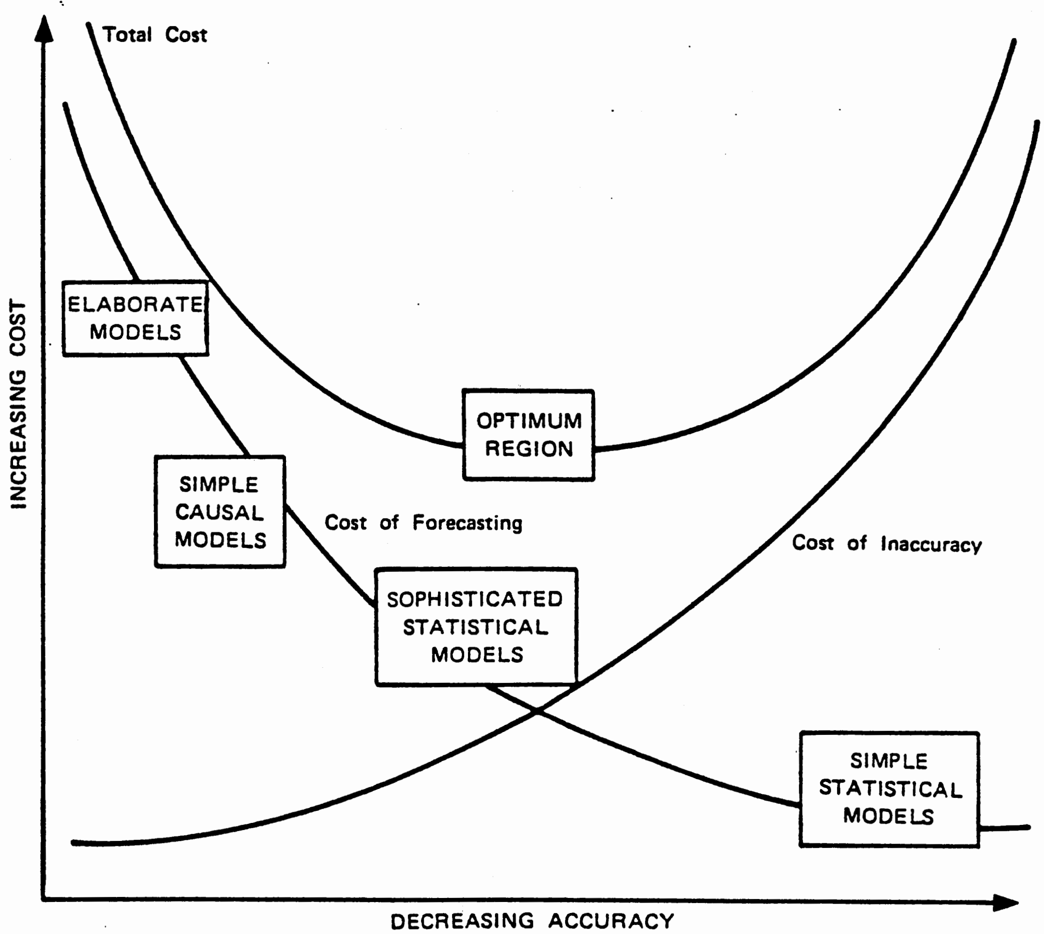
The choice of a method of estimated unit use is essentially a trade off between the cost of an elaborate model and the cost of inaccuracy. The technologist must assess the available data and expertise as well as the cost of generating additional data. He must also consider the cost which would be incurred if his estimate is off target. This concept is displayed graphically in Figure 14. The cost of forecasting includes the cost of data, expertise, and computing methods. Of these, the first is usually the largest. The cost of inaccuracy is less clearly defined. It also varies from one project to another. When unit use is over-estimated the cost of inaccuracy is the cost of over-design. Where per capita use is under-estimated the cost of inaccuracy is the social cost of water shortages.

Of the techniques discussed in this chapter, expert-opinion methods tend to be the least accurate. Hence, while the cost of using this method is low, the cost of inaccuracy may make the total cost high.

TABLE X

DAILY WATER USE FOR A FAMILY OF FOUR IN THE UNITED STATES

Function	Use in the United States	
	From Reid, 1982	From Flack, 1981
Toilet	96 gallons	100 gallons
Bath/Shower	80	80
Laundry	34	40
Dishwasher	15	12
Drinking, food, etc.	8	24
Garbage disposal	3	
Total In-house	236	256
Unit Use (In-house)	59	64
Lawn Sprinkling	100	125
Car	5	
Total	341	381
Unit Use	85.25	95.25



SOURCE: "How to Choose the Right Forecasting Technique" by John C. Chambers, Satinder K. Mullick, and Donald D. Smith, Harvard Business Review, July-August 1971, pp. 45-74.

Figure 14. Cost of Forecast Versus Cost of Inaccuracy

Multiple regression analysis is more expensive to use than expert-opinion methods. However, the reduction in cost of inaccuracy generally puts the total cost in the optimum region. Simple causal models and elaborate dynamic models are among the most accurate. Unfortunately, these are expensive because they require large amounts of data, high technology and great expertise to develop and use. For Jordan the development of a model using regression analysis appears to be the best approach.

Regression Analysis

Simple and multiple regression uses statistical methods to define the trend between variables. In the case of simple regression, a relationship between two variables are defined using a least squares method. In multiple regression, the relationship between the variable of interest and all important factors or dependent variables is sought. The relationship is linearized in the process. In other words, the method seeks a linear relationship between the main variable and a set of independent variables. This method is fairly popular in forecasting future water requirements and some applications of it will be discussed.

The multiple regression model will be used in this study. The general equation for multiple regression has the following form:

$$Y_i = B_0 + B_1X_1 + \ldots + B_iX_i + E$$

or

$$Y_i = B_0 + \sum_{i=1}^{K} B_iX_i$$

where:

Y_i = the value of the dependent variable in the i^{th} trial.

B_0 = constant or Y-intercept.

B_1, B_2 = net regression coefficients.

X_1, X_2 = the values of the independent variable in the i^{th} trial.

E = the random variable that is normally distributed around zero (the mean of E), and has a variance of V_E.

Given a set of data the regression analysis then is used to compute the regression coefficient, B_i. With the constants or coefficients established, the equation, thus in effect, provides a quantitive means by which one can describe the relationship between the dependent and independent variables. The operation of the regression analysis is based on the principle of least square.

There are four basic assumptions which should be made each time multiple regression is used in practice. An understanding of these assumptions and the conditions necessary to meet them is important in order that regression analysis may be used wisely and accurately. When these assumptions are not met, the results can be misleading and inaccurate. The first assumption inherent in the application of the method of least squares is that of linearity. This assumption states that the dependent variable is linearly related to each of the independent variables. Thus, this restriction is not nearly so binding in practice as it may appear on the surface. The second basic assumption in regression analysis is that of constant variance of the errors. This is often referred to by the technical name, homoscedasiticity. This assumption is simply that the variance and the amount of variation do not change over the range of observations. The lack of constant variance can also be inferred when patterns in the residuals exist. The third basic assumption inherent in regression is that the residuals are independent of one another. This means that each residual value is independent of those values coming before and after it. In technical terms, when this assumption is not met, it is said that serial correlation exists among successive residual values. Another limitation on the application of multiple regression that should be mentioned is the problem of multicollinearity. Multicollinearity is a computational problem that develops when two or more of the independent variables are highly correlated. Technically the result is a near singular or close to zero matrix which has the same effect as trying to divide a number by an extremely small number. Since there is always randomness present, the existence of multicollinearity does not normally result in an answer of infinity but can give a result that is extremely large and cannot be handled by the computer. For sample data, the model is defined as:

$$Y_i = b_0 + b_1X_{1i} + b_2X_{2i} + e_i$$

$$= \hat{Y} + e_i$$

$$Y = \text{is an estimate of } Y.$$

Rewriting the error term (residual), which represents the difference of an observed value of the dependent variable from the value predicted by the estimated linear relationship. We have:

$$e_i = Y_i - \hat{Y}_i$$

To find the minimum sum of squares of these errors, we use the least squares method as follows:

$$\text{minimize} = \sum_{i=1}^{n} e_i^2$$

$$= \sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2$$

$$= \sum_{i=1}^{n} (Y_i - b_0 - b_1X_1 - b_2X_2)^2$$

for computing the correlation coefficient, we use the following formula:

$$r_{XY} = \frac{n\,\Sigma XY - (\Sigma X)(\Sigma Y)}{(n\Sigma X^2 - (\Sigma X)^2)^{1/2}\,(n\Sigma Y^2 - (\Sigma Y)^2)^{1/2}}$$

$$= \frac{COV_{XY}}{(Var_X)^{1/2}\,(Var_Y)^{1/2}}$$

Coefficient of determination (R^2). The coefficient of determination, denoted by R^2, is the ratio of explained variation to the total variation. The value of R^2 ranges from 0 to 1 with latter representing a condition where all the variation is explained. A small R^2 can mean that one or more important variable(s) is not included in the regression model. The coefficient of determination is computed as:

$$R^2 = \frac{\Sigma(\hat{Y}_i - \bar{Y})^2}{\Sigma(Y_i - \bar{Y})^2} = \frac{\text{explained SS}}{\text{total SS}}$$

where:

$\hat{Y}$ = predicted value

$$\overline{Y} = \frac{1}{n} \sum_{i=1}^{n} Y_i$$

Y = observed value of the dependent variable.

For example, an R^2 value of 0.8760 is interpreted as 87.60% of the variation in the dependent variable Y can be explained by the combined variation in the independent variables in the equation.

Analysis of variance (F-test): The analysis of variance, or F-test, is a valuable tool in using the regression analysis for it provides a mean by which one can judge the significance of the regression model created.

For any Y_i the total deviation shows the difference between Y_i and $\overline{Y}$, which is equal to both explained and unexplained error or deviation, as seen in Figure 15.

Total deviation = Unexplained deviation + Explained deviation

$$(Y_i - \overline{Y}) = (Y_i - \hat{Y}_i) + (\hat{Y}_i - \overline{Y})$$

Summing the squares of the total devation:

$$\Sigma(Y_i - \overline{Y})^2 = \Sigma(Y_i - \hat{Y}_i) + (\hat{Y}_i - \overline{Y})^{2}$$

$$= \Sigma(Y_i - \hat{Y})^2 + \Sigma(\hat{Y}_i - \overline{Y})^2$$

$$+ 2\Sigma(Y_i - \hat{Y}_i)(\hat{Y}_i - \overline{Y})$$

Since we have

$$Y_i = a + bX_i$$

$$Y = a + b\overline{X} \quad \text{and}$$

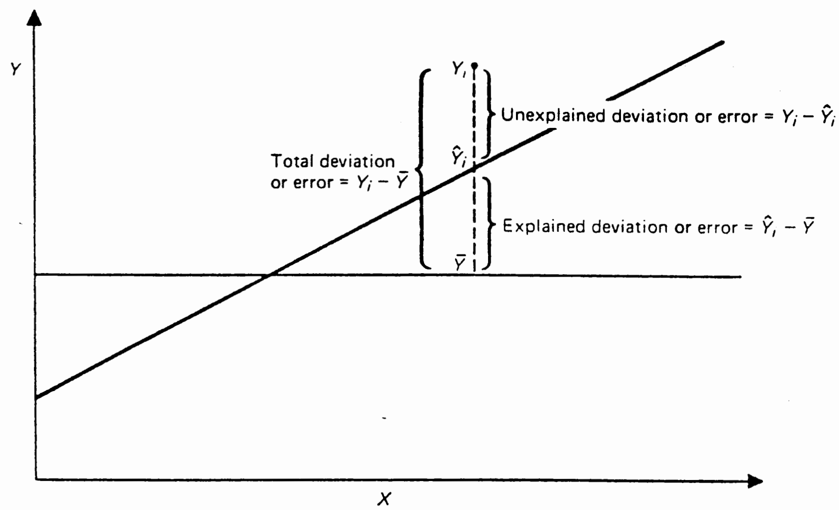


Figure 15. Explanation of the Partitioning of Total Deviation into Explained and Unexplained Deviations

$$(X_i - \overline{X}) = 0$$

then

$$\Sigma(Y_i - \hat{Y})(\hat{Y}_i - \overline{Y}) = \Sigma(Y_i - a - bX_i)(bX_i - b\overline{X})$$

$$= b\Sigma Y_i X_i - Y_i\overline{X} - a(X_i - \overline{X}) - bX_i^2 + b\overline{X}X_i$$

$$= b\Sigma(X_i Y_i - \frac{\Sigma X_i \; \Sigma Y_i}{n} + 0 - b\;\Sigma X_i^2 - \frac{(\Sigma X_i)^2}{n})$$

$$= b\left[nC_{XY} - \frac{C_{XY}}{C_{XX}}(nC_{XX})\right]$$

$$= 0$$

where

C_{XY} = Covariance between X and Y

C_{XX} = Variance of X

b = C_{XY}/C_{XY}

Thus we have

$$\Sigma(Y_i - \overline{Y})^2 = \Sigma(Y_i - \hat{Y})^2 + \Sigma(\hat{Y}_i - \overline{Y})^2$$

Total SS = Unexplained SS + Explained SS

Furthermore, the degrees of freedom for this partition satisfy the relation

$$df_{total} = df_{unexplained} + df_{explained}$$

For the K regressor, X_1 through X_K, there is K + 1 coefficients for b_o through b_K. The degrees of freedom are as follows:

$$df_{total} = N-1$$

$$df_{explained} = (K + 1) -1$$

$$df_{unexplained} = N - (K + 1)$$

Since the F statistic is the ratio of two variances, we convert sums of square to mean square:

$$MS_{total} = SS_{total}/(N - 1)$$

$$MS_{explained} = SS_{explained}/K$$

$$MS_{unexplained} = SS_{unexplained}/(N - K - 1)$$

Then the F-ratio is as follows:

$$F = \frac{MS_{explained}}{MS_{unexplained}}$$

$$F = \frac{\Sigma(\hat{Y} - \overline{Y})^2/K}{\Sigma(Y - \hat{Y})^2/(N-K-1)}$$

where:

K = number of variables

N = number of observations.

There is a greater relationship between R^2 and F, so when R^2 is computed, F-tests value may also be computed as:

$$F = \frac{R^2/K}{(1 - R^2)/(N - K - 1)}$$

Multiple regression can be expressed in a matrix form:

$$Y = xb + e$$

$$Y = \begin{bmatrix} Y_1 \\ Y_2 \\ Y_3 \\ \vdots \\ Y_n \end{bmatrix}$$

$$X = \begin{bmatrix} 1 \\ 1 \\ 1 \\ \vdots \\ 1 \end{bmatrix} \begin{bmatrix} X_{21} & X_{31} & \cdots & X_{K1} \\ X_{22} & X_{32} & \cdots & X_{K2} \\ X_{23} & X_{33} & \cdots & X_{K3} \\ \vdots & \vdots & & \vdots \\ X_{2n} & X_{3n} & \cdots & X_{Kn} \end{bmatrix}$$

$$b = \begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ \vdots \\ b_K \end{bmatrix} \qquad e = \begin{bmatrix} e_1 \\ e_2 \\ e_3 \\ \vdots \\ e_n \end{bmatrix}$$

$$Y = Xb + e$$

$$\begin{bmatrix} Y_1 \\ Y_2 \\ Y_3 \\ \vdots \\ Y_n \end{bmatrix} = \begin{bmatrix} 1 & X_{21} & X_{31} & \cdots & X_{K1} \\ 1 & X_{22} & X_{32} & \cdots & X_{K2} \\ 1 & X_{23} & X_{33} & \cdots & X_{K3} \\ \vdots & \vdots & \vdots & & \vdots \\ 1 & X_{2n} & X_{3n} & \cdots & X_{Kn} \end{bmatrix} \begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ \vdots \\ b_K \end{bmatrix} + \begin{bmatrix} e_1 \\ e_2 \\ e_3 \\ \vdots \\ e_n \end{bmatrix}$$

where:

Y = vector of observations of the dependent variable

X = matrix of constants of independent variable

b = vector of explanatory parameters

e = vector of random errors.

The use of matrixes is convenient since the computations increase tremendously as the number of variables and observations increase. The use of a digital computer is essential if investigation of many possible predictive equations is desirable.

Suppose Y to be an n by 1 vector of observations at a dependent variable; X to be an n by K matrix at independent variables which explains the dependent variable's value; b to be an n by 1 vector at unknown parameters to be estimated, and e to be an n by 1 vector of residuals. The intercept term, b_1 dictates that each of the elements of the first column of the matrix X, (X_{11}, X_{12}, ..., X_{1n}) equal one.

The least-square hyperplane minimizes the sum of the squared residuals e'e in matrix form or $\sum_{i=1}^{n} e_i^2$

$$e_i^2 = e'e = (Y - Xb)'(Y - Xb)$$

where

$$e' = (Y - Xb)'$$

$$e'e = (Y' - b'X')(Y - Xb)$$

$$= Y'Y - Y'Xb - b'X'Y + b'X'Xb$$

$$= Y'Y - 2b'X'Y + b'X'Xb$$

since b'X'Y is scalar and equal to its transpose Y'Xb then:

$$\frac{\partial e'e}{\partial b} = -2X'Y + 2X'Xb = 0$$

$$X'Y = X'Xb$$

$$b = (X'X)^{-1}X'Y$$

A modified stepwise regression procedure is employed in this study. Typical stepwise regression uses a simple correlation matrix for the selection of the first independent variable, which chooses the independent variable with the largest absolute value at the correlation coefficient with the dependent variable. The selection of subsequent variables in the typical stepwise regression is made by the selecting from the independent variables the variable having the highest partial correlation coefficient with the response. The decision of acceptance or rejection of each newly added variable is based on the results of an overall and a partial F-test. Then stepwise regression examines the contribution the previously added variables would have made if the newly added variable had been enterd first. A variable once accepted into the regression equation may later be rejected by this method.

Selection of Best Equation. The square of the multiple correlation coefficient or the coefficient of multiple determination (R^2), which is the ratio of the sum of squares due to the regression to the total sum of squares, is one possible criterion for selection of the best equation.

The standard error of estimates, defined as the square root of the residual mean square, has incorporated into it consideration of the degrees of freedom of the residual and, therefore, is also a usable indice for evaluating alternative regression equations.

The simple F-test, a ratio of the regression mean square to the residual mean square, is not necessarily a measure of the equation's usefulness as a predictor. A significant F-value means only that the regression coefficients explain more of the variation in the data than would be expected by chance, under similar conditions, a specified percentage of the time. So it must also be used cautiously. The sequential F-test was used to determine if the addition of a new variable into the regression equation explained more of the variation than would be expected by chance. A fifteen percent level of significance is used in this study. The sequential or partial F-test as it is sometimes called is the ratio of the regression sum of the squares explained by the addition of the new variable divided by the residual mean square.

CHAPTER VI

THE DEVELOPED WATER DEMAND MODELS

This chapter is a presentation of the water demand models developed for Jordan. It is thought that using causal forecasting models to forecast the demand of water would be an appropriate method because of the nature of the product, the nature of the Jordanian economy and other nations' experience. The dynamic nature and the rapid growth of Jordan's economy makes the use of other forecasting methods less effective and the role that the government plays in the country's economy makes macroeconomic approaches to forecast the demand for water more effective.

Some countries like the U.S.A. and some European countries using causal methods, particularly regression techniques, have achieved better results than those nations which are not using causal forecasting. Therefore, the method adopted in this study is to determine the relationship between the annual total water demand and the progress of various macroeconomic factors of Jordanian economy. Regression analysis is used to establish the degree of this relationship.

In order to forecast the water demand it is necessary to rely on a model which explains changes in water demand in terms and change in other variables. Thus, water demand forecasts require forecasts for the explanatory variables. These variables may be chosen from the available forecasts for the explanatory variables.

There are four major phases in development and application of causal variables regression models:

1. Designing the form of the models, that is, deciding what variables to include and what form of relationship to use.
2. Evaluating the constants in the models using available historical data.
3. Selecting from these models the model or models that seem to be the most appropriate.
4. Using the derived models to prepare forecasts and estimate the range of expected error.

Municipal, Industrial, and Agricultural Uses of Water

Water is very important in any society. Its uses cover a wide range of applications: domestic, agricultural, industrial, recreational, power, navigation and fishing. In this study coverage will be limited to municipal, industrial and agricultural uses. The many uses of water in the municipal, industrial and agricultural categories are as follows:

1. Municipal water uses:

    Domestic: drinking, washing, bathing, toilet, and fire protection.

    Commercial: hospitals, restaurants, schools, shopping centers and street washing.

    Industrial: light industry which obtains the needed water from municipal systems.

2. <u>Agricultural water uses</u>:

   Refers to irrigation of farms and maintaining livestock.

3. <u>Industrial water uses</u>:

   Self-supplied industries, such as paper manufacturing, petroleum and coal products, chemical and allied products, lumber and wood products, food and kindred products, glass production, cement production, metals and fabrication, machinery and clothing production.

Water uses are summarized in Figure 16.

Municipal Water Demand Model

The purpose of this section is to develop a model to project the water demand for domestic, commercial and industrial uses. In 1975 about 80 percent of the country's population (1,951,968 inhabitants), living in 800 communities, was served by public water systems, while the remainder depended on nearby springs or cisterns. Table XI indicates the domestic water supply situation with regard to the population.

The percentage of unpiped systems has been decreasing since 1975. In 1980 the average percentage was less than 11 percent (10.83), which means 222,300 inhabitants were without piped systems. According to the National Development Plan 1986-1990, all communities in Jordan will be supplied by piped systems by the end of 1987.

In order to develop the municipal water demand model, seven independent variables were considered. The historical data were collected from the department of Statistics, Ministry of Municipalities and Rural Affairs and Environment, Amman Water and Sewage Authority, and Water Supply Corporation, from the year 1970 to the year 1986.

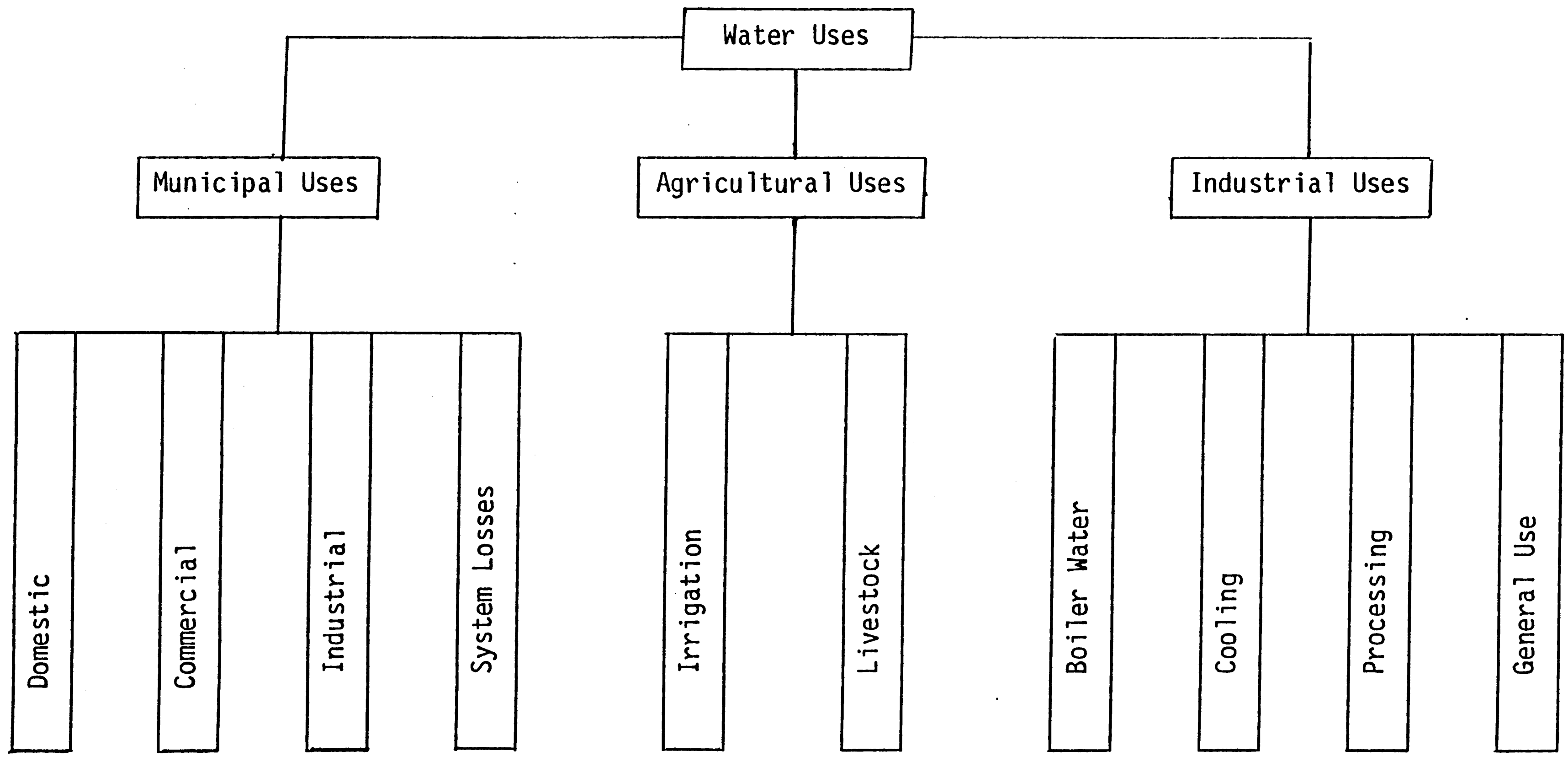


Figure 16. Water Uses

TABLE XI

POPULATION SERVED BY WATER SUPPLY SYSTEMS

Number of Community	Number of Inhabitants per Community	Total Population in 1975 No. x 10^3	Percent	Population Served by Piped System No. x 10^3	Percent	Unpiped System No. x 10^3	Percent
3	more than 100,000	910	47	910	100	0	0
14	10,000 - 100,000	269	13	250	93	19	7
71	3,000 - 10,000	305	16	162.7	47	167.3	53
712	less than 3,000	468	24	239	52	229	48
800		1,952	100	1,541.7	80	410.3	20

From the above discussion the municipal water demand can be hypothesized mathematically as:

$$Y_m = f(X_1, X_2, \ldots X_7)$$

where:

Y_m = Municipal water use in Jordan in MCM per year.

X_1 = Total population in Jordan in thousands.

X_2 = Per capita income in \$1000.

X_3 = Gross domestic product in million JD.

X_4 = Number of college and university students in thousands.

X_5 = Non-agricultural employment in thousands.

X_6 = Number of tourists in thousands.

X_7 = Annual temperature.

There are several trials made to develop the best multiple regression equation. Applying the stepwise multiple regression program, the following model equation was developed:

$$\hat{Y}_m = -149.0517 + 0.1059X_1 + 0.0959X_2 \qquad (6.1)$$

$R^2 = 0.9878$

$SE = 0.003$

$F_{statistic} = 1.26$ at 15%

$F_c = 564.50$

The population, X_1, has the highest influence on the municipal water use, while the per capita has less significance.

The developed model can be tested by comparing the actual consumed municipal water quantities, Y_m, with that predicted, i.e., $\hat{Y}$, and by studying various statistics which are used to measure the reliability of the regression equation (for example, the error in the prediction, $Y - \hat{Y}$).

In addition to statistical tests, the model can also be subjected to the test of reasonableness. The output of the model, $\hat{Y}_m$, must be compatible with the forecast for the determinants, X_1 and X_2, of municipal water projection. The equation was solved by substituting values of X_1 and X_2 from the appropriate columns of Appendix A. Thus the predicted number was 147.4. The reported (actual) water consumption for the same period was 146.4. The error $(Y - \hat{Y})$ was within 0.1 percent. Based on this analysis and the statistical test analysis which follows, it was concluded that the model yielded projections with good accuracy.

The first statistical test is the coefficient of determination, R^2, which is the square of the multiple correlation coefficient, R. R^2 is equal to the percentage of total variation accounted for by the independent variables X_1 and X_2. For example, the R^2 of 0.9878 means that the independent variables used in this equation satisfactorily explain 98.78 percent of the total influence of all possible variables.

Also, the standard error of estimate is a measure of the degree that the data varies from the regression line. In other words, this amount of error is to be expected (standard) when predicting the dependent variable, $\hat{Y}$, from the information known about the independent variables X_1 and X_2. In this analysis, the actual error is less than the standard error.

The Fisher Statistic determines the statistical significance of the coefficients of the independent variables in the total equation. In comparing the values of F_c and $F_{statistic}$, the hypothesis, H_o, is rejected if $F_c > F_s$. The developed model meets this condition and, therefore, it can be concluded that there is a statistically significant relationship between the independent and dependent variables. All the independent variables have the appropriate sign and passed the sequential F-test.

The developed model shows that the per capita income is a significant factor in determining the water use compared to the rejected independent variables. This has been attributed to the use of appliances such as washing machines, dishwashers, garbage disposals, air conditioners, car washing, lawns, gardens and and swimming pools. Thus, the municipal water demand depends on the total number of consumers (population) and their income level. In the next chapter, the developed model will be used to forecast the water usage rate in Jordan.

Agricultural Water Demand Model

The agricultural water use is influenced to a high degree by population, land under irrigation, and livestock. Forecasting irrigation water use is a very complex task involving product demand and marketing, and an economic unit which examines the quantities of products, and income. This information is used for analysis in conjunction with data on rainfall, temperature, and evaporation, to give an estimate for the agricultural water demand.

In order to develop the agricultural water demand model, historical data were collected on the agricultural water use and the related independent variables, from the year 1970 through the year 1986. From the above discussion the agricultural water demand can be hypothesized by the multiple regression equation as follows:

$$Y_A = f(X_1, X_2, \ldots, X_9)$$

where:

Y_A = Agricultural water use in Jordan in MCM per year.

X_1 = Total population in thousands

X_2 = Agricultural production in thousand tons.

X_3 = Total irrigated land in thousand dunums.

X_4 = Total number livestock in thousands.

X_5 = Afforestation and forest production in thousands.

X_6 = Agricultural income in millions of JD.

X_7 = Annual temperature.

X_8 = Mean annual precipitation in mm.

X_9 = Evapotraspiration.

The developed model for the agricultural water demand is as follows:

$$\hat{Y}_A = -333.4895 + 0.2486X_1 + 0.3047X_3 + 0.0278X_4 \qquad (6.2)$$

$$R^2 = 0.9960$$

$$SE = 0.068$$

$$F_c = 1083.23$$

where:

X_1 = Population in thousands.

X_3 = Irrigated land in thousands of dunums.

X_4 = Total number of livestock in thousands.

The developed model is a satisfactory model for its high value of R^2 and the sequential F-test. It seems that the population, X_1, land under irrigation, X_3, and livestock, X_4, are the factors with the highest influence on agricultural water use. The sample correlation coefficient of agricultural water use variable, $\hat{Y}_A$, is 0.9979. The missing variables (X_2, X_5, X_6, X_7, X_8, X_9) have a low sample correlation coefficients with the dependent variable, $\hat{Y}_A$. All the signs of the model are correct.

To check the validity of the developed model, the correlation matrix was examined to show the coefficients of correlation for the dependent and independent variables. However, it seems reasonable to assume that the independent variables are significant to the agricultural water use.

In order to examine the appropriateness of the linearity of the regression function, two steps were followed: comparison of predicted and observed values, and checking residuals for scatter. In comparison of predicted and observed values the predicted values ($YHAT_i$) fall near the observed Y_i values, which proves that the choice of the final model is related to the observation data. In checking residuals for random scatter the residuals are plotted against the independent variables X. The residuals fall randomly within the reference line centered around 0. Based on the established validity of the regression, a plot of calculated data (YHAT) against the original data (A) was made, and it has been found that the slope is of unity and it passes through the origin.

The developed model (4.2) will be used in the next chapter to forecast the water requirement for the agricultural sector in Jordan.

Industrial Water Demand Model

The purpose of this section is to develop a model to project the water demand for industral use in Jordan. All large industries use water from their own water sources, mainly deep wells in the vicinity of their plants. Light industries are supplied by the public water systems in Amman, Zarga, and other major cities. Their water demand is included in the Municipal Demand Model. It is important to mention that in most industries there is recirculation of water, and the industrial water requirements can be estimated by the following model:

$$D_{I_i} = P_i \times W_i \tag{6.3}$$

D_{I_i} = Industrial water requirement for product i.

P_i = Production quantities of product i.

W_i = Water use per unit of product i.

Thus, the total water requirement is as follows:

$$\sum_{i=1}^{i=n} DI_i$$

Technological changes have a large impact on water demand. New and sophisticated technology can result in a decrease in water use. This includes water recycling techniques, more efficient process equipment, and the implementation of automatic controls on water utilization. Howe, Charles W. (1971) and his colleagues from Resources for the Future, Inc., summarized the possible impact of technological changes on water use as follows:

> Technological change can have an important impact on the patterns of water use. General production processes as well as technologies relating specifically to water intake, treatment, and wastewater discharge all will affect future water demand. Account must be taken of technological change in planning future water developments and establishing policies relating to water use and supply. The principal national and regional forecasts of future water supply and demand have given little consideration to the kinds of technological change which may occur.

From the above discussion, it seems reasonable to assume that the decrease in water use will take place in Jordan. Thus, the developed model does not seem to be correct when a constant amount of water is used to produce a unit of production, therefore, the developed model should be modified by introducing a reduction factor to the water use in the industrial sector. The modified model should be as follows:

$$D_{I_i} = P_i \; W_i \; \alpha_i \qquad (6.4)$$

Where:

D_{I_i} = Industrial water requirement for product i.

P_i = Production quantities of product i.

W_i = Water use per unit of product i.

α_i = Conservation factor in year i.

Due to the technological changes in manufacturing there are two factors governing the water use. One factor is the recycling rate which is obtained by dividing gross water use by intake, while the other is the changes in gross water consumption resulting from the recycling process.

The author conducted a survey for the industrial water consumption in Jordan. From this survey it has been found that thirty industries account for 90 percent of all manufacturing water requirements. Also, these industries are classified by industrial water use: processing, and noncontact cooling.

Processing uses of water is used in many industries. In this process the water contacts the materials being processed or waste products, or is incorporated in the product. This category includes the following: boiler feedwater, paper forming, bleaching, dissolving, food, and beverages.

The noncontact cooling is widely used in the manufacturing sector. Here the water is used as a heat removal medium. This use is on a large scale in the steam-electric power generating industry and air conditioning.

Although the use of water in industries varies, cooling exceeds all other water uses. Table XII shows the industries, location, and their water use in Jordan based on the survey conducted by the author. Table XIII shows the annual water consumption for the industries that did not respond to the survey, the sources of this data is from the Jordan Master Plan and a study conducted on the Zarga River by the Royal Scientific Research Society.

In these tables, it is important to recognize the differences between the parameters of water use, the water intake and gross water consumption. Intake is the quantities of water taken into the plant to substitute for the water loss in the processing, evaporation and leaks in the system. The gross water use is the quantities of water required to run the plant which is the sum of total quantities of intake water plus the reused water.

Water recycling has a great effect on industrial water withdrawals. Kollar and Brewer (1975) listed the factors influencing the recirculation rate:

1. Cost and availability of water to the plant.
2. Quality of raw water.
3. Plant technology and processes.
4. Recovery of materials, product and energy.
5. Consumptive losses.
6. Pollution control regulations.

TABLE XII

WATER USE PER UNIT OF PRODUCTION FOR SELECTED INDUSTRIES IN JORDAN

Industry	Location	Gross water used by unit of production m^3/ton	(gal/ton)	Intake by unit of production m^3/ton	(gal/ton)	Consumption by unit of production m^3/ton	(gal/ton)
Arab Aluminum Co.	Al-Bagaa	382	(100,800)	95	(25,000)	1.5	(390)
Jordan Pipes Co.	Al-Hashimeiya	246	(65,000)	144	(38,000)	6	(1,500)
Fruit & Vegetable Canning Co.	Ruseifah	4.2	(1,120)	2	(530)	0.2	(50)
Jordan Dairy Co.	Ruseifah	8	(2,000)	5	(1,265)	0.4	(90)
Paper & Paperboard Co.	Awajan	530	(140,000)	152	(40,000)	8	(2,000)
Jordan Textiles Co.	Ruseifah and Awajan	340	(89,600)	152	(40,000)	15	(4,000)
Military Textiles Factory	Awajan	265	(70,000)	133	(35,000)	13	(3,500)
Agricultural Processing Co.	Marka	5	(1,200)	3	(600)	0.3	(60)
Jordanian Petroleum Refinery	Zarga	45	(11,889)	6	(1,580)	0.7	(1,800)
Iron and Steel Co.	Awajan	246	(65,000)	152	(40,000)	6	(1,600)
Jordan Chemical Co.	Awajan	46	(12,000)	15	(4,000)	1.5	(400)
Rainbow Poultry Co.	Amman	34	(9,000)	31	(8,200)	1.4	(370)
Phosphate Mines	Ruseifah, Hassa and El-Shiddiyya	204	(54,000)	57	(15,000)	5	(1,400)
Cement Factory	Fuheis	6	(1,500)	4	(900)	0.75	(200)
Paint Company	Zarga	114	(30,000)	57	(15,000)	3	(700)
Fertilizers Plant	Agaba	121	(32,000)	16	(4,200)	3	(750)
Copper	Finan-Wadi Araba	455	(120,000)	152	(40,000)	38	(10,000)

TABLE XIII

ANNUAL WATER CONSUMPTION FOR SELECTED INDUSTRIES IN JORDAN

Industry	Location	Water Consumption $m^3 \times 10^3$/yr
Jordan ICC and Aerated Water Co.	Amman	550
7-UP Company	Ruseifah	400
Beer		
- Heninger	Ruseifah	53
- Amestil	Ruseifah	89
Arak Star	Ruseifah	12
Jordanian Electric Power Co.	Ain Ghaga	220
Transjordan Minerals Research Co.	Ruseifah	300
Jordan Tanning Company Ltd.	Awajan	400
Ceramic Factory	Awajan	300
J. C. A. Co. Ltd.	Ruseifah	750
Timber Plant	Agaba	312
Arab Potash Company	Dead Sea	9,000
Soap	Amman, Zarga, Irbid	240
United Industry Corporation (liquid batteries)	Marka	140

7. Cost.

8. Age of the plant and age of technology.

The developed model is a valid model for a single plant. Since the objectives of this study is to develop a comprehensive (not for a single plant) industrial water demand, examine the variables affecting industrial water use, and investigate development possibilities with regard to their impact on water use, the regression analysis is more appropriate.

Historical data were collected for the dependent and independent variables to develop the industrial water requirement. The total number of independent variables are ten. Based on this information the industrial water demand is hypothesized as follows:

$$Y_I = f(X_1, X_2, \ldots, X_{10})$$

X_1 = total population in thousands

X_2 = per capita income in JD

X_3 = non-agricultural employment

X_4 = natural phosphate production, in thousand tons

X_5 = cement production in thousand tons

X_6 = paper production in thousand tons

X_7 = electric power in million K.W.H.

X_8 = petroleum refinery in thousand tons

X_9 = iron and steel in thousand tons

X_{10} = gross national income in million JD

The developed model for industrial water demand is as follows:

$$\hat{Y}_I = -20.3341 + 0.0166X_1 + 0.0017X_4 + 0.688X_6 + 0.0001X_7 \quad (6.5)$$

$R^2 = 0.9978$

$SE = 0.003$

$F_{statistic} = 5.79$ at 15%

$F_c = 1419.94$

Where:

X_1 = population in thousands

X_4 = natural phosphate production in thousand tons

X_6 = paper production in thousand tons

X_7 = production of electric power in million K.W.H.

The model is satisfactory and has a high value of the coefficient of determination (R^2) and passed the sequential F-test. The model indicates that the population and production of major industries (phosphate, paper, and electric power) are the major contributors to the industrial water use. The signs of the regression are correct.

The developed model will be used in the next chapter to forecast the industrial water demand.

CHAPTER VII

FORECASTING WATER DEMANDS

The preceding chapter serves as a foundation for projecting water demands in Jordan. The purpose of this chapter is to forecast the water demand, by applying the models developed in Chapter VI in order to obtain the water consumption projections for the Municipal, Agricultural and Industrial sectors, and evaluate the availability of the water resources in Jordan.

Forecasting Municipal Water Demand

In the municipal water demand model seven assumed explanatory variables were introduced. Only two significant variables were left in the equation at the 0.15 confidence level. The two variables are the population and per capita income. Five of the assumed variables proved to be relatively insignificant: gross domestic product, X_3, number of students, X_4, non-agricultural employment, X_5, number of tourists, X_6, and mean annual temperature, X_7.

The effect of the variation in temperature among different cities was slight. Number of students and temperature variation could be expected to influence the literal consumption of water as well as the extent of hygienic use, but this influence would not be demonstrated in the regression model. The result of the municipal water demand indicated that the population and per capita income do influence the level of water use. In order to forecast the municipal water demand, it is necessary to forecast the model's variables, population, X_1 and per capita income, X_2.

Jordan is experiencing high population growth due to the economic growth and forced emigration from the West Bank to the East Bank. There are two studies carried out on the population projection by a German Consulting Company in preparing the Jordan Master Plan in 1977, and a Japanese International Cooperation Agency in 1980. In both studies the population was projected until year 2000. Japan International Cooperation Agency stated in their study that the natural increase rate will be slow at around 3.4 percent for the period 1985 to 1990 and 3.1 percent for the period of 1990 to 2000. Upon this the assumption that the increase rate of 3.1 percent will continue into the future seems to be a valid assumption. Therefore, this rate will be used to project the population from the year 2001 to year 2020. Table XIV shows the population projection carried out by Japan International Cooperation Agency. The projection of all variables are included in Appendix B.

After obtaining the projection of all the variables, the next step is to forecast the municipal water demand by inserting the values of the independent variables into equation (6.1). The forecasting water demand is shown in Table XV and graphically illustrated in Figure 17. Details on municipal water projection on a yearly basis is presented in Table XXXV in Appendix B.

Based on the municipal water demand model and its projection the municipal water demand is expected to experience a greater amount of increase. As can be seen in Table XV, the water demand in 1990 is 194.1 MCM and 708.5 MCM in year 2000. Municipal water consumption was

TABLE XIV

POPULATION PROJECTION IN JORDAN

Year	Population
1987	2,929,487
1988	3,029,090
1989	3,132,079
1990	3,239,000
1991	3,339,409
1992	3,442,930
1993	3,549,660
1994	3,659,699
1995	3,773,149
1996	3,890,116
1997	4,010,709
1998	4,135,040
1999	4,263,226
2000	4,395,000
2001	4,531,245
2002	4,671,713
2003	4,816,536
2004	4,965,848
2005	5,119,789
2006	5,278,502
2007	5,442,135
2008	5,610,841
2009	5,784,777
2010	5,964,105
2011	6,148,992
2012	6,339,610
2013	6,536,138
2014	6,738,758
2015	6,947,659
2016	7,163,036
2017	7,385,090
2018	7,614,027
2019	7,850,061
2020	8,093,413

TABLE XV

MUNICIPAL WATER DEMAND FORECAST FOR THE MODEL:

$$Y_m = -149.0517 + 0.1059X_1 + 0.0959X_2$$

Year	X_{1i} (thousands)	X_{2i} (thousand $)	Y_{mi} (MCM)
1990	3,239	2.51	194.1
1995	3,773	2.99	250.7
2000	4,395	3.47	316.7
2005	5,119	3.95	393.4
2010	5,964	4.42	482.9
2015	6,947	4.90	587.1
2020	8,093	5.38	708.5

FORECAST MUNICIPAL WATER DEMAND ,MCM.

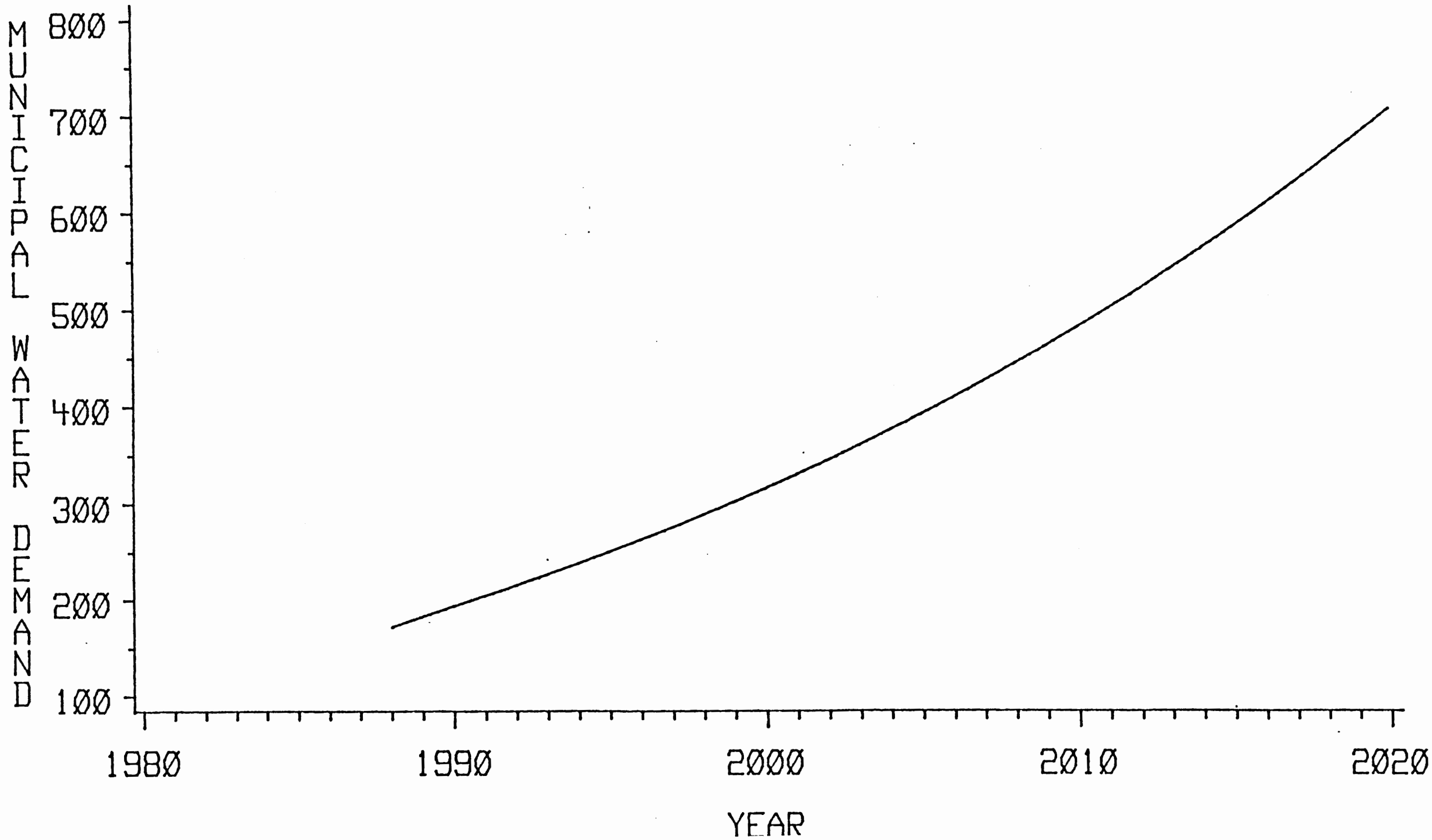


Figure 17. Forecast Municipal Water Demand in Jordan, MCM.

146.4 MCM in 1986. Comparing this consumption with year 1990 the water consumption will increase by 32 percent, and 116 percent in the year 2000.

Forecasting Agricultural Water Demand

In the Agricultural water demand model nine assumed explanatory variables were introduced. Three significant variables were left in the model; the population, X_1, land under irrigation, X_3, and the number of livestock, X_4. The other variables are rejected by the regression at 0.15 level of confidence.

Agriculture is considered the largest consumer of water. Of the water used in agriculture, over 90 percent is employed for irrigating crops and the remainder is for livestock. Irrigated agriculture is concentrated in the Jordan Valley, Azrag Basin, and Dhuleil. Other large public irrigation projects are in Qatrana, Wadi Arja and Qa Disi.

In most areas in Jordan, irrigation water supply comes primarily from natural precipitation. However, farmers in Jordan Rift Valley, Yarmouk River basin and Azrag basin supplement rainfall with water from ground water sources by direct diversion from streams and canals (East Ghor Canal) or with water from irrigation storage in reservoirs. Since irrigation is generally confined to the dry summer months, irrigation water supply is not required on a constant basis as in the case of the municipal and industrial waters. Seventy percent of the country's total water supply storage in developed reservoirs is allocated for irrigation purposes, and is contracted for in the same manner as municipal and industrial storage. At present, there is no significant use of water for purposes other than municipal, industrial and agricultural water supply.

In order to forecast the agricultural water demand the independent variables (X_1, X_3, X_4) have to be projected and used in the agricultural model. The projected variables are included in Appendix B. The projected quantities of agricultural water are shown in Table XVI, and illustrated graphically in Figure 18.

It can be seen that the agricultural water demand is 761.9 MCM in the year 1990 at 19 percent increase and 84 percent increase by the year 2000, where the demand is 1,169.1 million cubic meters.

The economy of Jordan revolved around the agriculture, and will remain the leading economic activity, with approximately 652,000 Dunum devoted to irrigation. The potential for increased irrigation development is excellent primarily due to soil suitability.

Figure 19 indicates the general extent of lands for potential long-term irrigation development. Irrigation suitability and land classifications are conducted by different government agencies for the purpose of establishing the extent and degree of suitability of lands for irrigated farming, and serve as a basis for selecting lands to be included in irrigation projects.

The rapid growth of irrigated agriculture has placed a severe strain on water supplies. Jordan's economy will face severe economic consequences if additional water supplies are not made available to assure continued agricultural growth and stability.

Forecasting Industrial Water Demand

In the industrial water demand model ten variables were introduced, but only four variables were left in the equation at 0.15 confidence

TABLE XVI

AGRICULTURAL WATER DEMAND FORECASTS FOR THE MODEL:

$$Y_A = -333.4895 + 0.2486X_1 + 0.3047X_3 + 0.0278X_4$$

Year	X_1 (in thousand)	X_3 (Dunums)	X_4 (thousands)	Y_A (MCM)
1990	3,239	716,358	2,591,397	761.9
1995	3,773	875,692	2,998,433	954.4
2000	4,395	1,035,026	3,405,469	1,169.1
2005	5,119	1,194,360	3,812,505	1,408.8
2010	5,964	1,353,693	4,219,541	1,678.7
2015	6,947	1,513,027	4,626,577	1,983.1
2020	8,093	1,672,360	5,033,613	2,237.8

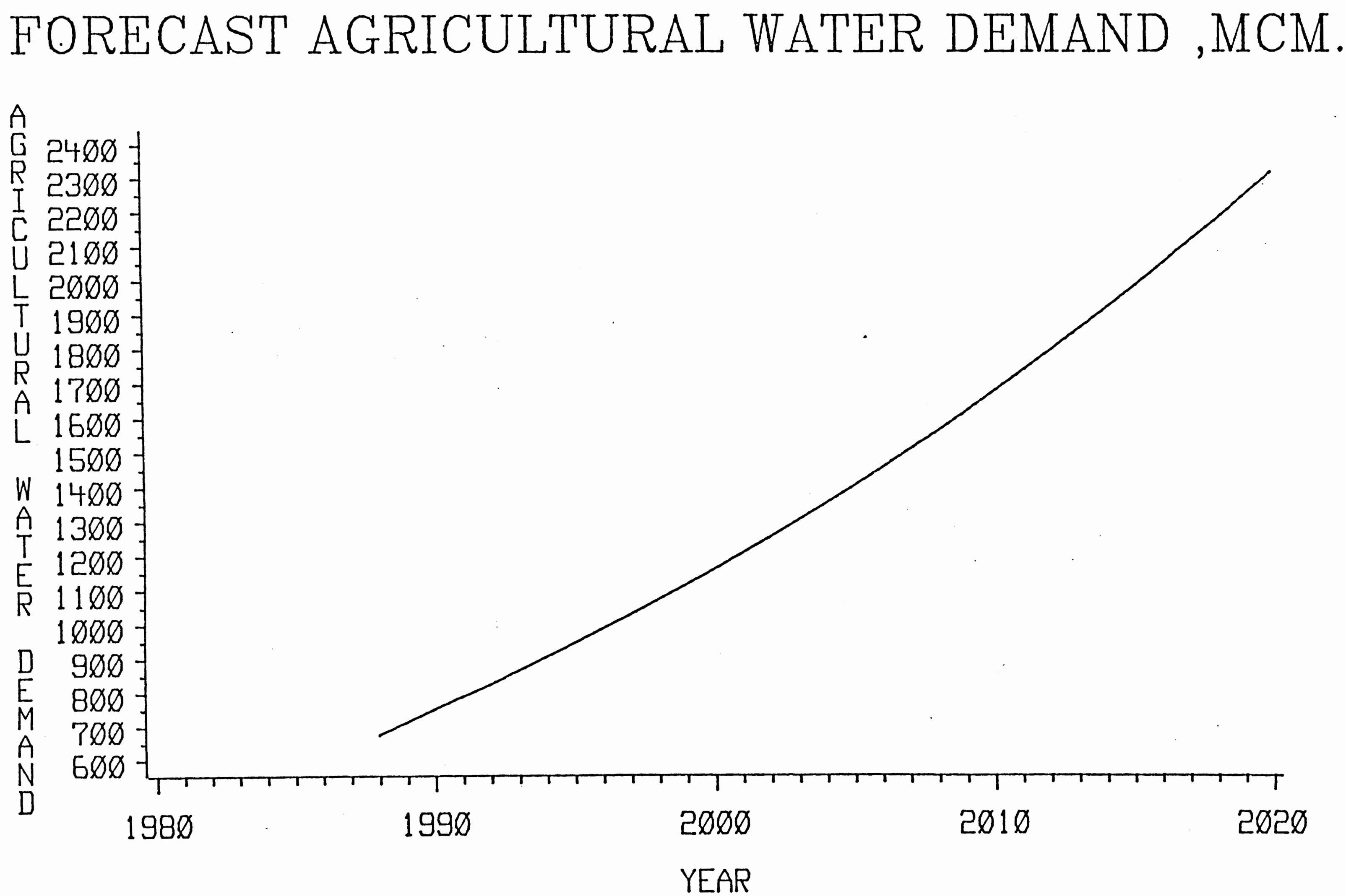


Figure 18. Forecast Agricultural Water Demand in Jordan, MCM.

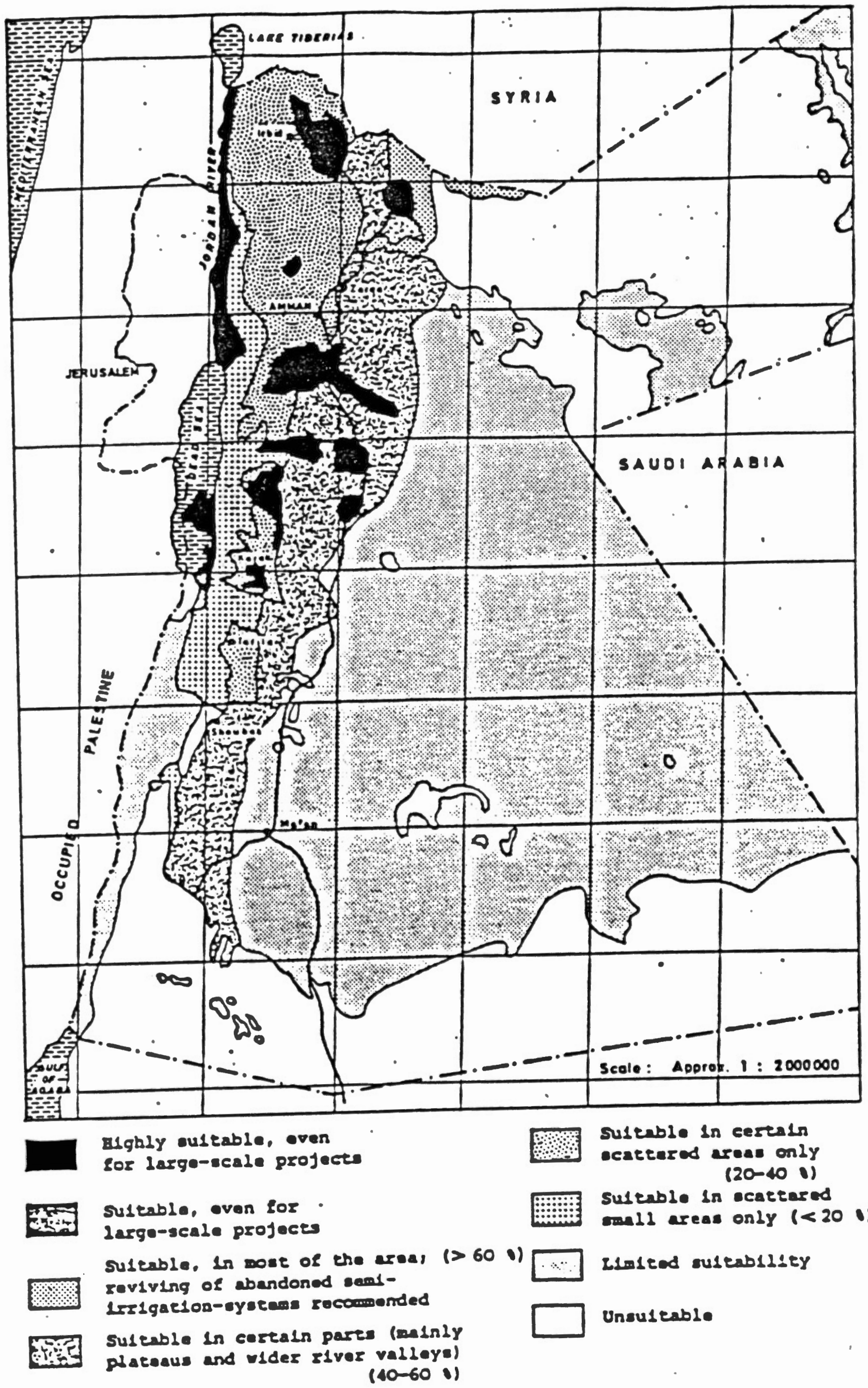


Figure 19. Land Suitability for Irrigation

level. The variables of industrial models which have significant influence on the industrial water use are population, natural phosphate, paper, and electric power generation.

The projection of the population is available in Table XIV. The other variables are projected by using time series forecasting. The data for these variables are collected from the years 1970 to 1986. For forecasting the variables, a computer program on time series forecasting is available at the Industrial Engineering Department for the course: Production Control at Oklahoma State University. The forecast of the variables are presented in Appendix B and will be used in the industrial water demand model, to project the quantities of water demand to year 2020. The projected quantities of industrial water demand are presented in Table XVII and graphically illustrated in Figure 20.

Values for water demand have been presented for a thirty year planning period, i.e., years 1988 to 2020. Comparison to present the reasonables at this forecast are presented in Table XVIII.

The total forecasted water demand were computed by summarizing the component parts: municipal, agricultural and industrial demand. The total demand is as follows:

1990	1,020.6 MCM
2000	1,586.3 MCM
2010	2,305.0 MCM
2020	3,231.7 MCM

To fulfill these demands, Jordan has approximately 1,197 MCM (970,412 ac-ft) of surface and ground water. This supply is not uniform

TABLE XVII

INDUSTRIAL WATER DEMAND FORECASTS FOR THE MODEL:

$$Y_I = -20.3341 + 0.0166X_1 + 0.0017X_4 + 0.688X_6 + 0.0001X_7$$

Year	X_1 (in thousand)	X_4 (In thousand Ton)	X_6 (thousands)	X_7 (million K.W.H.)	Y_{Ii} (MCM)
1990	3,239	7,777.6	23.0	21,899.3	64.6
1995	3,773	9,811.6	29.1	28,945.0	81.8
2000	4,395	11,845.6	35.2	35,990.7	100.5
2005	5,119	13,879.6	41.3	43,036.4	120.9
2010	5,964	15,913.6	47.5	50,082.0	143.4
2015	6,947	17,947.6	53.6	57,127.7	168.0
2020	8,093	19,981.6	59.7	64,173.4	195.4

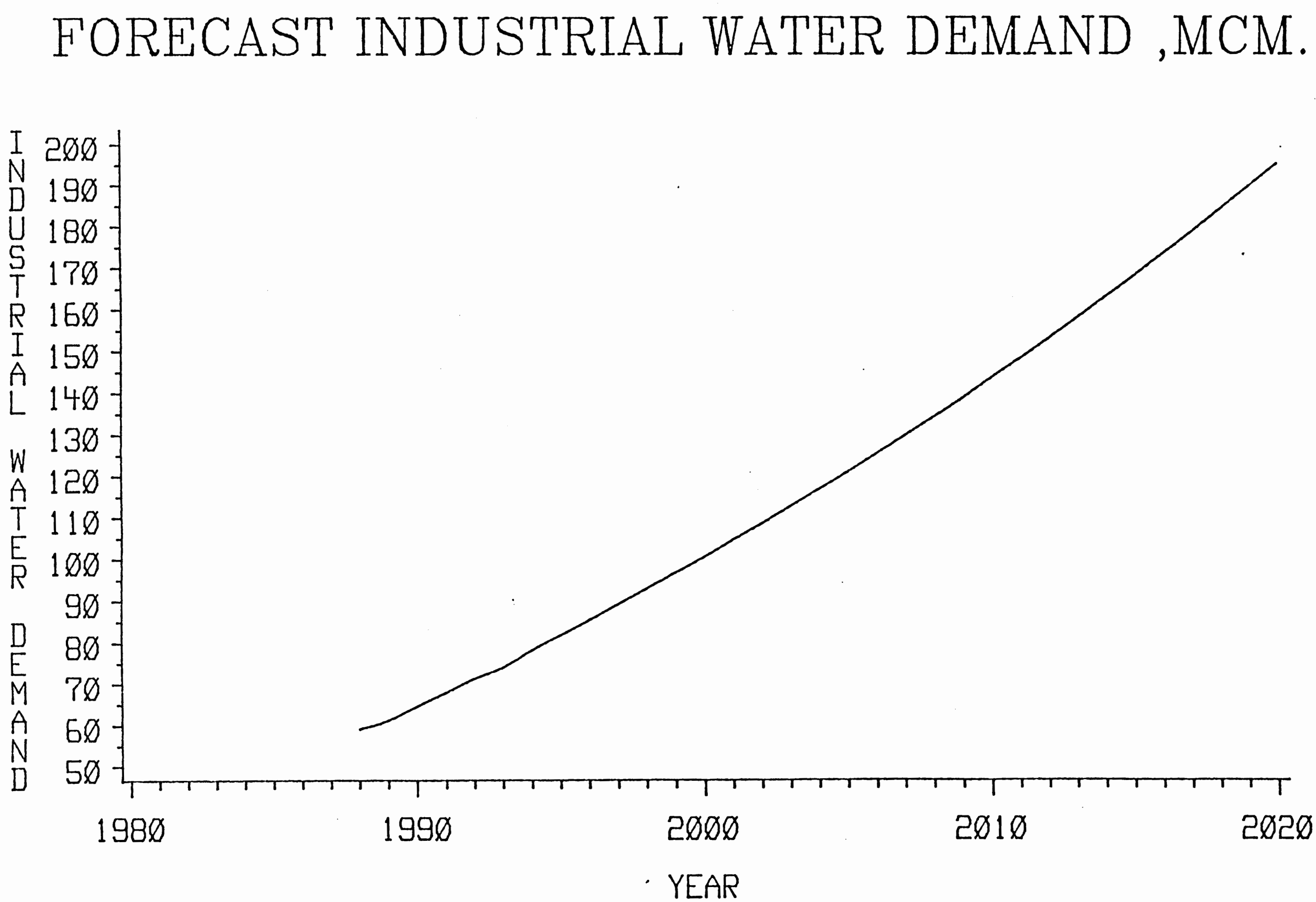


Figure 20. Forecast Industrial Water Demand in Jordan, MCM.

TABLE XVIII

COMPARISON OF WATER DEMAND STUDIES, MCM

Study	Municipal Water Demand		Agricultural Water Demand		Industrial Water Demand	
	1990	2000	1990	2000	1990	2000
AGRAR-UND-HYDROTECHNIK GMBH, Germany (1977)	205	300	730	1100	--	64
Howard Humphrey and Sons, U.K. (1978)	155	289	636	932	--	--
NRA (1985)	187	268	537	606	--	--
NRA (1975)	167	258.6	564	634	--	59.6
This Study	194.1	316.7	761.9	1169.1	64.6	100.5

and varies widely from one year to another, nor is it equally distributed on the basis of population. However, the most recent study by the Natural Resources Authority has shown that a 1197 MCM of water can be made available through the water resources development plans. This development potential includes ground water, surface water, and major reservoirs presently available or under construction. An additional 80 MCM of water was estimated to be obtainable from wastewater recycling.

At the present time, it can be seen that only a small portion of the resources is not utilized, but as time passes beyond 1990 the demand will exceed the available water supply especially in drought years.

Analysis of Jordan's population data indicates a trend toward greater concentrations in the urban areas, especially in Amman and Zarga regions. Industries, attracted by larger populations and available labor forces, are typically located in those areas, thereby placing even heavier demands on water supplies. Increased industrial activity, in turn, attracts more people, causing further increase in municipal water requirements.

Jordanian government is enhancing its domestic productive capacities, and ensuring an increased measure of economic independence by restructuring the course of economy. This target would be attained by expansion of the mining, manufacturing, and industrial sectors, along with agricultural development. This will undoubtedly result in tremendous demand for water and cause a severe shortage that could retard future economic development. Alternative water supply sources must be made available and conservation methods should be enforced if healthy development is to continue.

Analysis of Water Demand

The purpose of this section is to link the results of the developed models with the hypothesized variables of water consumption in Jordan. This can be obtained by analyzing the explanatory variables in each model. The relationship between the dependent variables and independent variables are stated mathematically as:

$$Y = f(X_1, X_2, \ldots, X_n)$$

In this form the relationship would not add much to the understanding of the patterns of water use. The hypotheses of the above relationship can be expressed as:

$$dY = \frac{\partial Y}{\partial X_1} dX_1 + \frac{\partial Y}{\partial X_2} dX_2 + \ldots \frac{\partial Y}{\partial X_n} dX_n$$

$$dY = \sum_{i=1}^{n} \frac{\partial Y}{\partial X_i} dX_i$$

Where Y denotes the dependent variables, i.e. municipal, agricultural or industrial water demands.

In forecasting future water demand, it is necessary to understand the factors affecting the dependent variables. This involves identifying the population growth and/or national policy on population control, role of the government in subsiding the irrigation projects, water pricing, quality standards of water, national income, and changes in life style.

The municipal water can be represented mathematically as follows under a condition where $Y_m > 0$:

$$\Delta Y_m = f'(X_1)\Delta X_1 + f'(X_2)\Delta X_2 + f'(X_3)\Delta X_3 +$$

$$f'(X_4)\Delta X_4 + f'(X_5)\Delta X_5 + f(X_6)\Delta X_6 +$$

$$f'(X_7)\Delta X_7$$

Where:

ΔX_1 = increment of population.

ΔX_2 = increment of per capita income.

ΔX_3 = increment of gross domestic product.

ΔX_4 = increment of number of students.

ΔX_5 = increment of non-agricultural employment.

ΔX_6 = increment of number of tourists.

ΔX_7 = increment of annual temperature.

The agricultural water has a similar representation:

$$\Delta Y_A = f'(X_1)\Delta X_1 + f'(X_2)\Delta X_2 + \ldots + f'(X_9)\Delta X_9$$

$$\Delta Y_I = f'(X_1)\Delta X_1 + f'(X_2)\Delta X_2 + \ldots + f'(X_{10})\Delta X_{10}$$

where:

ΔY_I = industrial water demand.

$f'(X_i)\Delta X_i$ = measure the changes in water demand due to the changes in the quantity of X_i.

The sum of the changes for all factors equal the total changes. This follows from a mathematical theorem concerning homogenous functions:

$$Y_t = Y_m + Y_A + Y_I$$

$$\Delta Y_t = \frac{\partial Y_t}{\partial X_i} \Delta X_i$$

where:

Y_t = total water demand.

In reaching a decision on long-term forecasting water demand, it would be necessary to investigate the factors affecting the shape of the trend curve. The upward trend reflects an increase in per capita water demand, and changes in life style in the municipal water demand. In agricultural water demand extensive farm irrigation and maintaining livestock are carried out on a larger scale. In the industrial water demand it reflects the increase in industrial production.

The major influences on the increase of per capita demand can be represented by time. But, while this might be acceptable, additional reflection suggests that it ignores at least two factors affecting the level of demand which may not be correlated with time, the weather, as an example. This has been attributed to increased bathing, lawn watering in municipal water uses. Similarly, irrigation water demand varies significantly in the summer season. Industrial water demand, also is affected by seasonal variation.

There are several water demand studies utilizing temperature and/or precipitation to account for the climatic or seasonal variations in water uses. A study conducted by Howe and Linaweaver (1967) employed the evapotranspiration in the regression analysis and found that it has a strong relationship with water sprinkling use. In other studies by Morgan (1976) and wong (1972) found that the temperature is an important factor and has a strong correlation with water consumption.

The accuracy of long term forecasting depends upon anticipating changes in some underlying causual factors such as population shifts, future industrial and technological changes and agricultural development. The inaccuracy of the forecasts results from the time span length. The longer the time span the greater the uncertainity associated with the forecasts. This does not mean that the results of the forecasts are not useful. Long term forecast is a necessary tool specially in planning and building large water resources projects. Accuracy in short term forecasting can be expected to be high. In this manner policy concerning water demand and remedy measures can be specified more reliably.

Population forecasts can be the subject of great controversy. Improved medical facilities and birth control campaigns may produce changes in patterns of mortality and live births but the migration and imigration is the biggest unknown factors. Per capita income and expenditure patterns within the social and cultural context have the potential to increase per capita water consumption. Income estimates for the future population are made with considerable uncertainty. The contributors to this uncertainty are the economic situation in the country, inflation, and the future social characteristics of the population and their habits.

The models developed in this work show that the demand for water will increase at a tremendous rate, and will exceed the available water in Jordan by the year 1994. (See Figure 21). A feasible water conservation program is urgently needed as a measure to meet the increasing water demand in Jordan. A number of conservation techniques have been suggested in the literature for saving water:

1. Regulation on water use at the national level by legislative actions to prohibit certain types of water appliances which do not meet certain levels of water conservation, enforcing water saving

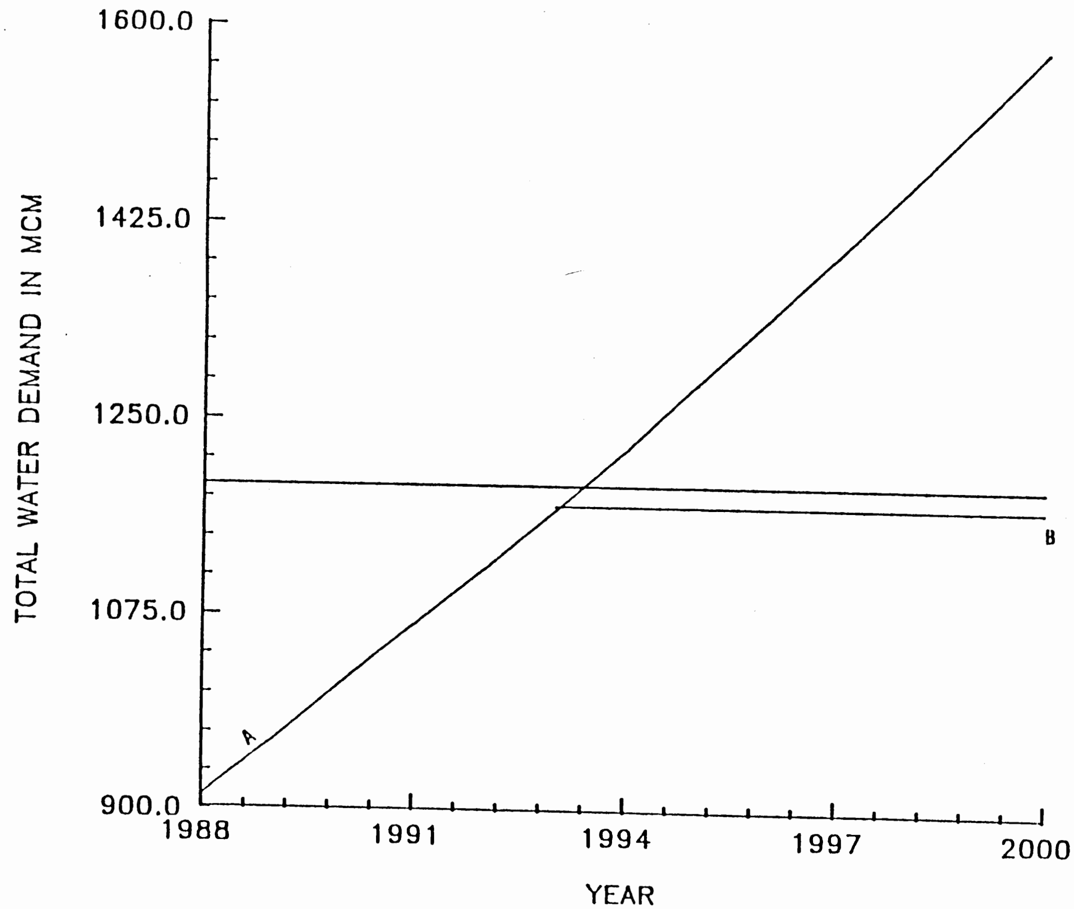


Figure 21. Total Water Demand in Jordan

devices, and specifying maximum water use.

2. Pricing policies is an effective measure of water conservation and should be enforced in Jordan to bring the water supply and demand into balance.

3. Public education of the need to conserve water is vital in carrying out an effective conservation program.

These measures will promote more efficient use of water at all levels of consumption. The implementation of these measures in Jordan is vital in reducing the rate of increase of water demand which threatens the future economical growth of the country. However, while the conservation programs may have a moderate impact on the reduction in water demand, other measures have to be taken by the government and its agencies, for example, population growth control, restructuring the course of Jordanian economy by shifting the economic activities to less water-dependent areas and expanding the search for new sources of water.

Since the demand should be limited by the available supply, then the demand curve should be forced not to exceed the supply curve and take the form of a straight line (line AB in Fig. 21). A similar statement can be made in the case of municipal water demand. As can be seen in Figure 22, the water demand is negative for a relatively small population (less than 1.407 million). This renders the model inapplicable for population of less than 1.407 million. Even for a population slightly greater than 1.407 million, the model yields a small water demand which is in contradiction with the actual water demand observed. Therefore, the confidence level is established to be at a population greater than 3.0 million which is the projected population for the year 1988. In this manner the model may be expressed as shown

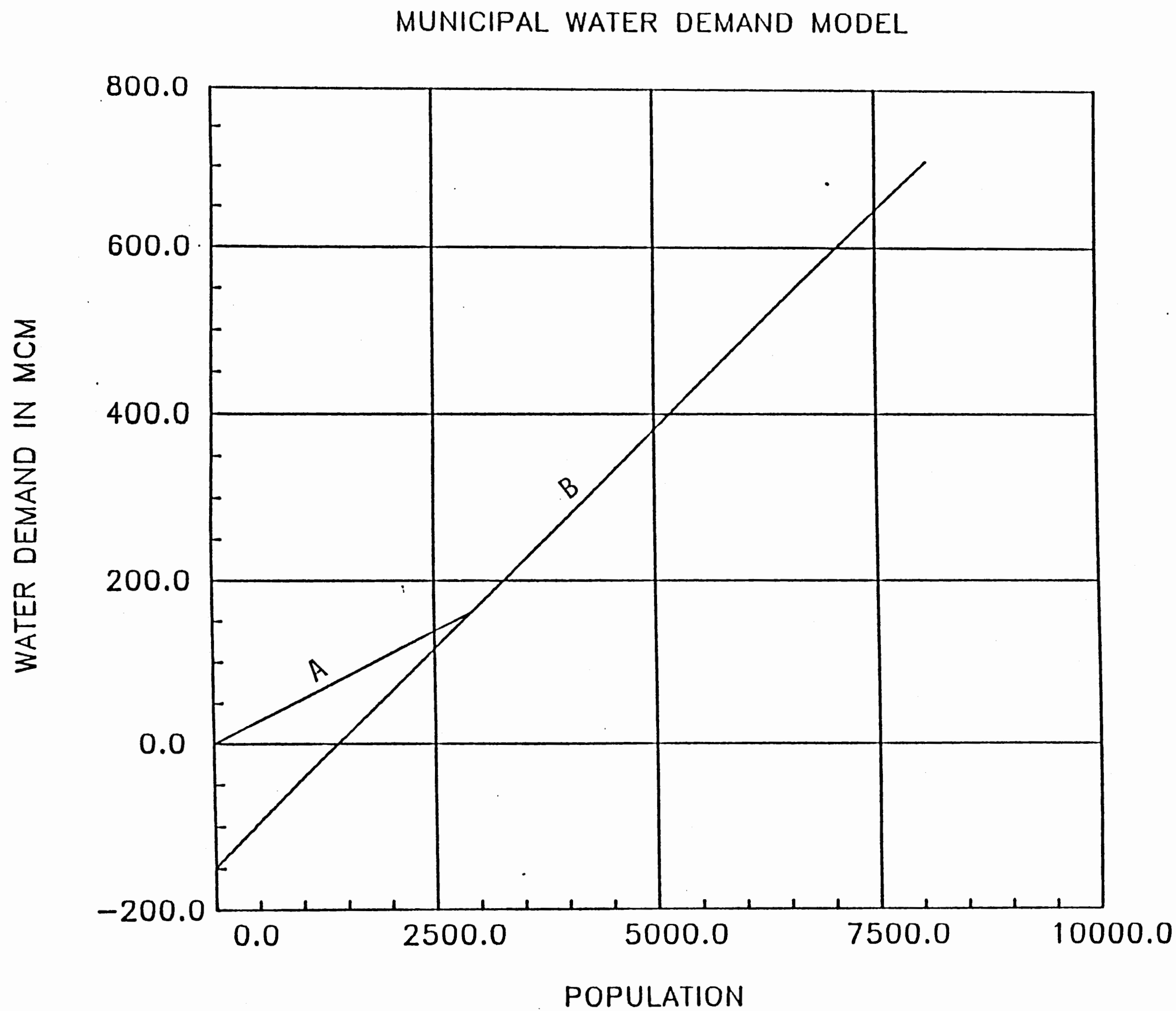


Figure 22. Demand Curve for the Municipal Water Demand Model

by two-line segments A and B in Figure 22. It should be noted that the line B is the original model without the effect of per capita income which has an insignificant effect on municipal water demand.

The fundamental conclusion is that the demand for water has reached new heights. The increase in municipal water uses is a result of seasonal variations, higher per capita income, larger homes, more water-using appliances and larger lots with gardens, population growth, their habits and behavior characteristics, which are related to the level of civilization. The increase in the industrial water demand is related to progress in science and technology and expansion in industrial production and agricultural development.

The developed models have several limitations. The demand models completely ignore several factors that could cause changes in water demand, i.e. price changes, efficient use of water and future impact of technological factors which may affect water demand. These factors are difficult to predict and are susceptible to a high degree of uncertainty. Another problem in the forecasting is the inaccuracy resulting from the time span length and the introduction of a number of errors in the forecast of independent variables. Several assumptions were made on the continuous growth in the explanatory variables, for example: population grows steadily at a certain growth rate, per capita income continues to increase and the land under irrigation continues to expand. Therefore, the results of the models are dependent on how well these assumptions are realized in the future. For example, if the population growth tends to be larger than the assumed, the water demand is going to be much more than the forecasted quantity. Therefore, the water demands presented in this study are conditional upon the forecast of the independent variables. If the independent variables are different from the data used in this study, the demand should also be at a different level. While this may seem to be restrictive of the models usefulness as they stand presently, it should be remembered that the models formulated and implemented in this study can be used with confidence as more data about the independent variables become available.

The developed models indicate the trends and relative magnitude of changes in water uses resulting from the effects of individual variables. This should provide information to the governmental agencies and policy makers to formulate new policies for resolving emerging water supply problems.

The demand models indicate that Jordan will face a grave water deficit. Therefore, the government and concerned agencies should plan to alleviate these shortages by developing new water supplies, recycling treated waste water, conserving water at all levels of use, and reaching an agreement with Syria and Iraq in diverting the water to Jordan.

CHAPTER VIII

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

During the last decade, a rapid economic growth occurred by the wise use of foreign economic assistance mainly from the United States, Great Britain, and especially Arab oil producing countries. As a result the G.N.P. rose from 757 million U.S. dollars in 1967 to 8.99 billion dollars in 1986. This period of rapid economic growth had resulted in an increase in population growth, industrial and agricultural development, urbanization, technological development, and development of environmental and cultural patterns. This, in turn, has lead to a tremendous increase in water demands.

In the current National Development Plan (1986-1990), the Jordanian government is aiming at expanding the agricultural and industrial sectors. Due to these new goals, the growth in water use is expected to be very high in the future. The increase in population in the last twenty years indicates that such supplies have now become totally inadequate. In order to cope with the increased water demand the water resources development has to be continously enlarged. Even with tremendous efforts in water resources development, almost every city in Jordan has water supply problems and these are likely to escalate before the end of this century. Thus, the water supply will be a major constraint that Jordan must deal with in the years to come to achieve its development goals.

Summary and Conclusions

Water demand forecasting is an effective water management technique that can be used to evaluate the impact of future developments in the national economy on water resources and water uses. Forecasting future demands for water is crucial in the planning and implementation of National Development Plans. Little effort has been devoted to investigate the future demand for water and its link with the futrue developments in the country's economy. The studies conducted were limited in the scope and/or used rough estimates based on limited data. Also, some of these studies were restricted to certain geographical areas of Jordan, for example, the northern region of Jordan as surveyed by the Japanese International Corporation Agency. The only specialized study on the subject was based on data covering a short period of time (1970 - 1976). Thus a comprehensive study on water resources and demands is still lacking. The present effort was undertaken to fill the gap and provide a reliable tool for forecasting the future needs and, thereby, serve in the preparation of development plans in Jordan. It is hoped that this study will be of value to the government and the agencies concerned in their effort to expand the Jordanian economy. The large amount of data gathered and the analysis techniques used in this study make it an indisputable source of reliable guidelines for planners and decision makers for years to come.

In this study, water demand forecasting utilizes an approach which allows investigation of development possibilities with regard to their impacts on demand and water use. The forecasting models are built upon the hypothesis that the future water demand is a complex function of population growth, agricultural and industrial development, technological development, life style, and new water policies and environmental quality. These factors are translated by their impacts on water demand, and water use.

The approach outlined above is the use of stepwise regression analysis to relate the water demand to a number of independent variables. The data was handled on the computer by using the Statistical Analysis Systems (SAS) package. The computer program enters the variables in single steps, at each step adds or deletes an independent variable. The independent variable that possesses the greatest amount of variance enters the equation at each step. The less significant variables are rejected.

Historical data on water use and socio-economic indicators were collected on the national level from 1970 to 1986. The data were collected from the Ministry of Municipality and Rural Affairs and Environment, Jordan Valley Authority, Natural Resources Authority, Water Supply Corporation, Amman Water and Sewerage Authority, United Nations, World Bank and data collected by the author.

After developing the models, the next step is to forecast the demand for water, by using the significant variables in the regression equation. The validity of models is checked statistically and compared to other studies to test the reasonableness of the results.

The future demand for water is shown to increase significantly despite the development potential of 1197 MCM reported by NRA. By the year 1990 the demand will exceed the water available in Jordan (see Chapter VII). Unless proper measures are taken by the government and its agencies, the shortages in water supply may result in fallback in the national development plans. The next section deals with these measures as viewed by the author based on this study.

Recommendations

The future water demand was shown to be in excess of the present supply and the added expected potential development. The following specific recommendations drawn from this study may help in reducing the gap between the supply and demand of water:

1. In order to avoid abrupt shortages in water supply, studies on water supply and demand should be conducted periodically as more data become available and the view of future developments becomes clearer. Demand forecasting on local regional basis should be considered to quantify the emerging shortages in water supply.

The present study has focused on forecasting demand and supply issues on a national level. The method of analysis adopted in this study forms the framework for further studies on a local or regional basis. Therefore, it is recommended that the present analysis be extended for such studies.

2. Conducting comprehensive hydrological and hydrogeological surveys. This should result in more accurate estimation of the potential water resources available for possible exploitation.

3. Expansion in the efforts in searching for new sources of water. Particular in this is the use of advanced techniques, i.e., seawater desalination, cloud seeding, and ground water recharge. Wastewater treatment plants should be used on a large scale to cover most of the urban and rural communities.

4. Constructing of surface water reservoirs and enlarging the capacity of the existing ones. A major source of water supply can be obtained by

renewing the interests in building the Magarin Dam with the neighboring Syria. Also, the widespread use of dug wells may enhance the usefulness of surface water, especially in the rural areas.

5. Widespread use of water conservation and management techniques in all levels of water use (industrial, municipal and irrigation) has to be encouraged by increasing the public awareness and conducting special educational programs. This includes, but not limited to, the use of advanced techniques for reducing evaporation from water surfaces and seepage losses in reservoirs, canals and farm ponds, the use of trickle irrigation systems, implementation of domestic water conservation techniques and recycling of industrial water.

It should be noted that a comprehensive program for water resources planning and development cannot be carried out without the proper administrative establishment. Therefore, modernization of the administrative system is needed to carry out the following functions effectively:

a. Collect, coordinate and evaluate the basic data necessary for water resources planning and development.

b. Establish nation-wide standards and regulatory programs to enforce water conservation and pollution control. These regulations should eliminate the discharge of wastewater into the fresh water body in the streams and ground water aquifiers and limit the unnecessary consumption of water by designing proper rate schedules.

c. Set the priority in executing the development programs and allocate the necessary funding.

d. Plan and develop nation-wide training programs to implement the concepts of water management and handling by all sectors of consumption.

The aforementioned recommendations provide the framework for establishing a sound and effective program capable of providing viable solutions to the problems of water supply and demand in Jordan. It is the responsibility of the government and its agencies to set the priorities in implementing the above stated recommendations based on the funding level available and the qualification and expertise of the personnel involved.

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APPENDIX A

DATA FOR THE INDEPENDENT VARIABLE

TABLE XIX

TOTAL POPULATION IN JORDAN

Year	Population
1970	1,668,000.000
1971	1,723,000.000
1972	1,774,000.000
1973	1,831,000.000
1974	1,890,000.000
1975	1,951,968.000
1976	2,018,407.000
1977	2,126,540.000
1978	2,129,270.000
1979	2,132,000.000
1980	2,218,300.000
1981	2,307,000.000
1982	2,399,300.000
1983	2,495,300.000
1984	2,595,100.000
1985	2,689,900.000
1986	2,798,760.000

TABLE XX

PER CAPITA INCOME IN JORDANIAN DINAR

(ONE JD = $2.9)

Year	Income
1970	216.6
1971	300.0
1972	306.6
1973	310.0
1974	316.6
1975	320.0
1976	343.3
1977	356.6
1978	380.0
1979	426.6
1980	452.8
1981	479.3
1982	511.2
1983	547.6
1984	588.4
1985	630.1
1986	639.2

TABLE XXI

NUMBER OF TOURISTS

Year	Tourists
1970	322,000.000
1971	256,775.000
1972	292,041.000
1973	307,744.000
1974	554,913.000
1975	707,623.000
1976	1,063,294.000
1977	1,106,438.000
1978	1,184,293.000
1979	1,343,594.000
1980	1,635,614.000
1981	1,580,631.000
1982	2,075,463.000
1983	1,731,289.000
1984	1,786,272.000
1985	1,889,907.000
1986	1,987,435.000

TABLE XXII

AVERAGE ANNUAL RAINFALL IN MM

Year	Rainfall (mm)
1960	320.4
1961	308.3
1962	318.9
1963	315.4
1964	320.7
1965	174.6
1966	304.0
1967	210.0
1968	268.4
1969	178.7
1970	252.0
1971	263.5
1972	124.8
1973	309.9
1974	206.6
1975	221.4
1976	283.5
1977	269.1
1978	304.5
1979	284.2
1980	240.7
1981	232.8
1982	232.5
1983	221.8
1984	191.2
1985	242.0
1986	315.6

TABLE XXIII

AVERAGE ANNUAL TEMPERATURE IN C^{o}

Year	Temperature
1960	20.35
1961	19.57
1962	19.83
1963	20.41
1964	21.32
1965	21.76
1966	19.31
1967	20.10
1968	19.65
1969	20.34
1970	21.10
1971	19.69
1972	19.76
1973	21.30
1974	19.79
1975	19.93
1976	20.52
1977	19.48
1978	19.57
1979	22.26
1980	20.21
1981	20.52
1982	19.68
1983	19.60
1984	24.42
1985	23.49
1986	24.32

TABLE XXIV

AGRICULTURAL PRODUCTION (IN 1000 TONS)

Year	Production
1970	409.000
1971	612.200
1972	725.600
1973	764.900
1974	810.100
1975	941.900
1976	1,037.500
1977	1,132.900
1978	1,228.400
1979	1,323.900
1980	1,419.000
1981	1,514.900
1982	1,610.400
1983	1,705.900
1984	1,800.100
1985	1,974.400
1986	2,044.700

TABLE XXV

AGRICULTURAL INCOME IN MILLION JD

Year	Income
1970	28.66
1971	37.81
1972	42.45
1973	31.92
1974	54.48
1975	55.90
1976	59.46
1977	57.51
1978	58.69
1979	43.57
1980	64.58
1981	76.55
1982	83.90
1983	110.41
1984	128.54
1985	156.34
1986	184.75

TABLE XXVI

NUMBER OF LIVESTOCK

Year	Livestock
1970	1,056,000.000
1971	1,103,500.000
1972	1,190,000.000
1973	1,416,100.000
1974	1,252,600.000
1975	1,375,800.000
1976	1,324,650.000
1977	1,278,200.000
1978	1,289,200.000
1979	1,537,800.000
1980	1,437,600.000
1981	2,409,499.000
1982	2,176,522.000
1983	2,005,407.000
1984	2,135,421.000
1985	2,181,624.000
1986	2,276,747.000

TABLE XXVII

AFFORESTATTION

Year	Afforestattion
1970	8,300.000
1971	19,200.000
1972	19,200.000
1973	12,200.000
1974	25,000.000
1975	36,000.000
1976	28,000.000
1977	23,500.000
1978	17,700.000
1979	20,000.000
1980	33,000.000
1981	37,000.000
1982	33,724.000
1983	35,334.000
1984	36,945.000
1985	38,566.000
1986	41,246.000

TABLE XXVIII

FERTILIZER (IN TONS)

Year	Fertilizer
1970	8,800.000
1971	10,408.000
1972	3,807.000
1973	2,210.000
1974	1,100.000
1975	1,001.000
1976	14,240.000
1977	18,299.000
1978	29,032.000
1979	38,649.000
1980	33,295.000
1981	26,335.000
1982	44,230.000
1983	68,080.000
1984	32,671.000
1985	50,670.000
1986	54,235.800

TABLE XXIX

PRODUCTION OF ELECTRIC POWER
(IN 1000 K.W.H.)

Year	Electric Power
1970	187,357.900
1971	210,105.700
1972	248,879.700
1973	280,588.400
1974	310,216.800
1975	407,294.100
1976	501,233.700
1977	601,345.600
1978	704,387.700
1979	901,000.000
1980	1,070,000.000
1981	1,237,100.000
1982	1,511,700.000
1983	1,918,216.000
1984	2,304,500.000
1985	30,811,800.000
1986	41,620,000.000

TABLE XXX

PRODUCTION OF PHOSPHATE (IN TONS)

Year	Phosphate
1970	169,000.000
1971	190,000.000
1972	714,853.000
1973	1,080,907.000
1974	1,674,808.000
1975	1,352,000.000
1976	1,421,000.000
1977	1,758,000.000
1978	2,320,000.000
1979	2,824,000.000
1980	3,911,000.000
1981	4,277,000.000
1982	4,390,000.000
1983	4,745,000.000
1984	6,119,000.000
1985	6,067,000.000
1986	6,220,000.000

TABLE XXXI

PRODUCTION OF CEMENT (IN TONS)

Year	Cement
1970	378,000.000
1971	419,000.000
1972	661,623.000
1973	616,787.000
1974	596,246.000
1975	572,182.000
1976	524,000.000
1977	532,000.000
1978	552000.000
1979	623,139.000
1980	912,707.000
1981	934,264.000
1982	793,373.000
1983	1,268,759.000
1984	1,994,082.000
1985	2,022,175.000
1986	2,120,000.000

TABLE XXXII

PRODUCTION OF IRON AND STEEL (IN TONS)

Year	Iron and Steel
1970	8,975.000
1971	9,591.000
1972	30,183.000
1973	28,078.000
1974	25,432.000
1975	31,303.000
1976	41,749.000
1977	67,391.000
1978	65,099.000
1979	78,028.000
1980	89,786.000
1981	123,418.000
1982	156,369.000
1983	148,196.000
1984	112,500.000
1985	136,000.000
1986	154,000.000

TABLE XXXIII

PETROLEUM REFINERY (IN TONS)

Year	Petroleum
1970	440,140.000
1971	519,549.000
1972	563,801.000
1973	631,250.000
1974	691,243.000
1975	756,130.000
1976	1,040,561.000
1977	1,018,271.000
1978	1,252,622.000
1979	1,422,720.000
1980	1,540,279.000
1981	1,812,224.000
1982	2,162,702.000
1983	2,231,457.000
1984	2,272,342.000
1985	2,182,000.000
1986	2,340,000.000

TABLE XXXIV

PAPER & PAPERBOARD (IN TONS)

Year	paper
1970	2,692.000
1971	2,109.000
1972	2,749.000
1973	3,072.000
1974	3,536.000
1975	4,190.000
1976	4,267.400
1977	4,612.900
1978	4,620.000
1979	5,153.600
1980	6,476.600
1981	8,799.599
1982	12,122.500
1983	16,445.500
1984	18,837.000
1985	20,530.000
1986	21,821.000

APPENDIX B

FORECASTED DATA

TABLE XXXV

FORECAST OF MUNICIPAL WATER DEMAND IN

MILLION CUBIC METERS

Year	Water Usage
1988	171.9
1989	182.8
1990	194.1
1991	204.7
1992	215.7
1993	227.0
1994	238.7
1995	250.7
1996	263.1
1997	275.9
1998	289.1
1999	302.7
2000	316.7
2001	331.1
2002	345.9
2003	361.3
2004	377.1
2005	393.4
2006	410.2
2007	427.6
2008	445.4
2009	463.8
2010	482.9
2011	502.4
2012	522.6
2013	543.5
2014	564.9
2015	587.1
2016	609.9
2017	633.5
2018	657.7
2019	682.7
2020	708.5

TABLE XXXVI

FORECAST OF AGRICULTURAL WATER DEMAND IN

MILLION CUBIC METERS

Year	Water Usage
1988	685.6
1989	723.2
1990	761.9
1991	798.7
1992	834.1
1993	874.7
1994	914.0
1995	954.4
1996	995.5
1997	1,037.3
1998	1,080.4
1999	1,124.3
2000	1,169.1
2001	1,214.6
2002	1,261.4
2003	1,309.5
2004	1,358.5
2005	1,408.8
2006	1,460.4
2007	1,513.2
2008	1,566.6
2009	1,621.9
2010	1,678.7
2011	1,736.4
2012	1,795.9
2013	1,856.9
2014	1,919.1
2015	1,983.1
2016	2,048.5
2017	2,118.0
2018	2,184.6
2019	2,255.3
2020	2,327.8

TABLE XXXVII

FORECAST OF INDUSTRIAL WATER DEMAND IN MCM

Year	Water
1988	59.5
1989	61.2
1990	64.6
1991	67.9
1992	71.3
1993	72.2
1994	75.6
1995	81.8
1996	85.4
1997	89.2
1998	92.9
1999	96.7
2000	100.5
2001	104.6
2002	108.5
2003	112.6
2004	116.7
2005	120.9
2006	125.3
2007	129.7
2008	134.1
2009	138.6
2010	143.4
2011	148.1
2012	152.9
2013	157.8
2014	162.9
2015	168.0
2016	173.3
2017	178.6
2018	184.1
2019	189.7
2020	195.4

TABLE XXXVIII

TOTAL WATER DEMAND IN JORDAN

Year	Water
1988	917.0
1989	967.2
1990	1,020.6
1991	1,071.3
1992	1,121.1
1993	1,173.9
1994	1,228.3
1995	1,286.9
1996	1,344.0
1997	1,402.4
1998	1,462.4
1999	1,523.7
2000	1,586.3
2001	1,650.3
2002	1,715.8
2003	1,783.4
2004	1,852.3
2005	1,923.1
2006	1,995.9
2007	2,070.5
2008	2,146.1
2009	2,224.3
2010	2,305.0
2011	2,386.9
2012	2,471.4
2013	2,558.2
2014	2,646.9
2015	2,738.2
2016	2,831.7
2017	2,930.1
2018	3,026.4
2019	3,127.7
2020	3,231.7

TABLE XXXIX

FORECAST OF PETROLEUM REFINING (IN TONS)

Year	Petroleum
1987	2,571,009.000
1988	2,707,152.000
1989	2,843,295.000
1990	2,979,438.000
1991	3,115,581.000
1992	3,251,724.000
1993	3,387,867.000
1994	3,524,010.000
1995	3,660,153.000
1996	3,796,296.000
1997	3,932,439.000
1998	4,068,581.000
1999	4,204,724.000
2000	4,340,867.000
2001	4,477,010.000
2002	4,613,153.000
2003	4,749,296.000
2004	4,885,439.000
2005	5,021,582.000
2006	5,157,725.000
2007	5,293,868.000
2008	5,430,011.000
2009	5,566,153.000
2010	5,702,296.000
2011	5,838,439.000
2012	5,974,582.000
2013	6,110,725.000
2014	6,246,868.000
2015	6,383,011.000
2016	6,519,154.000
2017	6,655,297.000
2018	6,791,440.000
2019	6,927,583.000
2020	7,063,725.000

Regression Equation: $Y = A + BX$
Where: Y = Petroleum Refinery
X = Time Period
A = 120,436.900
B = 136,142.900

R = 0.980; R-Square = 0.961
Standard Deviation = 143,111.100

TABLE XL

FORECAST OF PAPER AND PAPERBOARD PRODUCTION
(IN TONS)

Year	Paper Forecast
1987	19,373.580
1988	20,597.250
1989	21,820.930
1990	23,044.610
1991	24,268.290
1992	25,491.970
1993	26,715.640
1994	27,939.320
1995	29,163.000
1996	30,386.680
1997	31,610.350
1998	32,834.030
1999	34,057.710
2000	35,281.390
2001	36,505.060
2002	37,728.740
2003	38,952.420
2004	40,176.100
2005	41,399.700
2006	42,623.450
2007	43,847.130
2008	45,070.810
2009	46,294.490
2010	47,518.160
2011	48,741.840
2012	49,965.520
2013	51,189.200
2014	52,412.870
2015	53,636.550
2016	54,860.230
2017	56,083.900
2018	57,307.580
2019	58,531.260
2020	59,754.940

Regression Equation: Y = A + BX
Where: Y = Paper
X = Time Period
A = -2,652.621
B = 1,223.678

R = 0.902; R-Square = 0.813
Standard Deviation = 3,058.526

TABLE XLI

FORECASTED PER CAPITA INCOME, IN JD

Year	Income
1987	642.250
1988	667.043
1989	691.836
1990	716.629
1991	741.422
1992	766.215
1993	791.008
1994	815.801
1995	840.595
1996	865.388
1997	890.181
1998	914.974
1999	939.767
2000	964.560
2001	989.353
2002	1,014.146
2003	1,038.939
2004	1,063.733
2005	1,088.526
2006	1,113,319
2007	1,138.112
2008	1,162.905
2009	1,187.698
2010	1,212.491
2011	1,237.284
2012	1,262.077
2013	1,286.871
2014	1,311.664
2015	1,336.457
2016	1,361.250
2017	1,386.043
2018	1,410.836
2019	1,435.629
2020	1,460.422

Regression Equation: $Y = A + BX$
Where: Y = Per Capita Income
X = Time Period
$A = 195.974$
$B = 24.793$

$R = 0.977$; R-Square = 0.955
Standard Deviation = 28.166

TABLE XLII

FORECAST OF CEMENT PRODUCTION (IN TONS)

Year	Cement
1987	1,776,701.000
1988	1,872,672.000
1989	1,968,643.000
1990	2,064,614.000
1991	2,160,584.000
1992	2,256,555.000
1993	2,352,526.000
1994	2,448,497.000
1995	2,544,468.000
1996	2,640,439.000
1997	2,736,410.000
1998	2,832,381.000
1999	2,928,352.000
2000	3,024,323.000
2001	3,120,294.000
2002	3,216,265.000
2003	3,312,236.000
2004	3,408,207.000
2005	3,504,178.000
2006	3,600,149.000
2007	3,696,120.000
2008	3,792,091.000
2009	3,888,062.000
2010	3,984,033.000
2011	4,080,004.000
2012	4,175,975.000
2013	4,271,946.000
2014	4,367,917.000
2015	4,463,888.000
2016	4,559,859.000
2017	4,655,830.000
2018	4,751,801.000
2019	4,847,772.000
2020	4,943,743.000

Regression Equation: $Y = A + BX$
Where: Y = Cement
X = Time Period
A = 49,222.570
B = 95,970.990

R = 0.834; R-Square = 0.695
Standard Deviation = 331,144.100

TABLE XLIII

FORECAST OF PHOSPHATE PRODUCTION (IN TONS)

Year	Phosphate
1987	6,557,286.000
1988	6,964,085.000
1989	7,370,884.000
1990	7,777,684.000
1991	8,184,483.000
1992	8,591,281.000
1993	8,998,081.000
1994	9,404,880.000
1995	9,811,679.000
1996	10,218,480.000
1997	10,625,280.000
1998	11,032,080.000
1999	11,438,880.000
2000	11,845,680.000
2001	12,252,480.000
2002	12,659,270.000
2003	13,066,070.000
2004	13,472,870.000
2005	13,879,670.000
2006	14,286,470.000
2007	14,693,270.000
2008	15,100,070.000
2009	15,506,870.000
2010	15,913,670.000
2011	16,320,470.000
2012	16,727,270.000
2013	17,134,070.000
2014	17,540,870.000
2015	17,947,660.000
2016	18,354,460.000
2017	18,761,260.000
2018	19,168,060.000
2019	19,574,860.000
2020	19,981,660.000

Regression Equation: $Y = A + BX$
Where: Y = Phosphate
X = Time Period
A = -765,101.600
B = 406,799.300

R = 0.978; R-Square = 0.957
Standard Deviation = 451,356.200

TABLE XLIV

FORECAST OF ELECTRIC POWER GENERATION (IN 1000 K.W.H)

Year	Electric Power
1987	17,671,970.000
1988	19,081,100.000
1989	20,490,240.000
1990	21,899,370.000
1991	23,308,510.000
1992	24,717,640.000
1993	26,126,780.000
1994	27,535,920.000
1995	28,945,050.000
1996	30,354,190.000
1997	31,763,320.000
1998	33,172,460.000
1999	34,581,590.000
2000	35,990,730.000
2001	37,399,860.000
2002	38,809,000.000
2003	40,218,130.000
2004	41,627,270.000
2005	43,036,410.000
2006	44,445,540.000
2007	45,854,670.000
2008	47,263,810.000
2009	48,672,950.000
2010	50,082,080.000
2011	51,491,220.000
2012	52,900,350.000
2013	54,309,490.000
2014	55,718,620.000
2015	57,127,760.000
2016	58,536,890.000
2017	59,946,030.000
2018	61,355,170.000
2019	62,764,300.000
2020	64,173,440.000

Regression Equation: Y = A + BX
Where: Y = Electric Power
X = Time Period
A = -7,692,475.000
B = 1,409,136.000

R = 0.597; R-Square = 0.356
Standard Deviation = 9,881,079.000

TABLE XLV

FORECAST OF IRON AND STEEL PRODUCTION (IN TONS)

Year	Iron & Steel
1987	166,087.200
1988	176,004.800
1989	185,922.300
1990	195,839.900
1991	205,757.400
1992	215,675.000
1993	225,592.500
1994	235,510.000
1995	245,427.600
1996	255,345.100
1997	265,262.700
1998	275,180.200
1999	285,097.800
2000	295,015.300
2001	304,932.900
2002	314,850.400
2003	324,768.000
2004	334,685.500
2005	344,603.000
2006	354,520.600
2007	364,438.100
2008	374,355.700
2009	384,273.200
2010	394,190.800
2011	404,108.300
2012	414,025.900
2013	423,943.400
2014	433,861.000
2015	443,778.500
2016	453,696.100
2017	463,613.600
2018	473,531.200
2019	483,448.700
2020	493,366.200

Regression Equation: $Y = A + BX$
Where: Y = Iron and Steel
X = Time Period
A = -12,428.620
B = 9,917.546

R = 0.951 R-Square = 0.905
Standard Deviation = 16,749.000

V

VITA

Ayman Hassan Al-Momani

Candidate for the Degree of

Doctor of Philosophy

Thesis: MODELING OF FUTURE WATER DEMAND AND SUPPLY IN JORDAN - A TOOL FOR PLANNING

Major Field: General Engineering

Biographical:

Personal Data: Born in Sekhrah, Jordan, December 12, 1958, the son of Mr. and Mrs. Hassan Ahmad Al-Momani.

Education: Graduated from Mafrag High School, Jordan, 1977; received a Master of Science degree in Industrial and Civil Engineering and Diploma of teaching Russian language in 1983 from Leningrad Institute of Civil Engineering, USSR; received Master of Science degree in Construction Management from the University of Oklahoma in 1985; received Master of Science degree in Industrial and Applied Physics from Oklahoma Central State University, Edmond; completed requirements for the Doctor of Philosophy degree at Oklahoma State University in May, 1988.

Professional Experience: Practicing Engineer at Irbid Municipality, Jordan, 1979; Construction Engineer at Housing Corporation, Jordan, 1980-1982; Faculty member, Muta University, Jordan, 1983-present.

Professional Affiliations: Member of Jordan Engineering Association, American Society of Civil Engineers (ASCE), American General Contractors (AGC), and American Concrete Institute (ACI).