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MUNICIPAL, IRRIGATIONAL AND INDUSTRIAL FUTURE WATER REQUIREMENTS IN SAUDIA ARABIA

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MUNICIPAL, IRRIGATIONAL AND INDUSTRIAL FUTURE WATER REQUIREMENTS IN SAUDI ARABIA

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MUNICIPAL, IRRIGATIONAL AND INDUSTRIAL FUTURE
WATER REQUIREMENTS IN SAUDI ARABIA

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

TABLE Page

MUNICIPAL, IRRIGATIONAL AND INDUSTRIAL FUTURE WATER REQUIREMENTS IN SAUDI ARABIA

CHAPTER I

INTRODUCTION

In the 1950's, Saudi Arabia had an agricultural economy based on raising livestock: sheep, cattle and camels. The nomades drove their animals across the country in search of forage. Further a majority of urban people lived in villages and earned a living from agriculture. There were only a few small cities scattered throughout the country and in the western part of the country (Hijaz)(see Figure A-1)* a major source of income was from the pilgrimages of Islamic followers (Knauerhase, Ramon, 1975).

During this period the water usage was several gallons per day per capita with respect to municipal provisions (UN, 1962) which came mostly from ground water. The agricultural water requirements were met

*Refers to Figure 1 in Appendix A.

by ground water and whenever surface water was available. The estimated total annual surface runoff averaged around 2025 million cubic meters with only 30 percent of the total surface runoff being diverted for agricultural purpose, 45 percent was absorbed in recharge of alluvial aquifers while the remainder was lost due to evaporation (British Arabian Advisory Company, BAAC, 1980).

In 1932, when the country was poor, the discovery of oil in the eastern province brought some hope for improvement, but during the second World War the total revenue from oil resources averaged less than 4 million dollars per year. It was not until 1947 that the total revenue from oil resources started to increase due to greater production and higher prices. Table A-1* shows crude oil production, price and revenues from 1950 to 1980.

The large revenues from oil to Saudi Arabia in the past decades, however, have changed the entire strategy of economic development in the country. This exponential economic growth has enabled the country to offer its citizens a much better standard of living. Yet, while the oil revenues are expected to remain at high levels for the foreseeable future, the Saudi Arabian government is concerned about the time when oil revenues will decline. The government's goal is

*Refers to Table 1 in Appendix A.

to build up a solid economic base independent of oil revenues before the decline occurs. New industries are being developed and an effective agricultural program to maximize resources is under way (Third Development Plan, 1980).

Economic growth has been and will be accompanied by increase in population, urbanization, industrialization, land irrigated for food production and many other social changes. Increase in urbanization, per capita income and general modernization will increase the demand for almost everything from dishwashers to garbage disposals to automatic washing machines, etc. All of these changes in the social system of the country will increase the municipal, industrial and agricultural water requirements. And this is the concern of this thesis.

Water has become a very important factor in the economic development of Saudi Arabia. Because of its scarcity in many regions, it currently is one of the major constraints on the nation's development. In fact, Saudi Arabia already faces the problem of an imbalance between water supply and water demand. Further, the problems are not limited to scarcity; there are others: non renewability, poor quality, great depth of ground water and unequal geographical distribution.

The scarcity of water in Saudi Arabia results from the lack of precipitation and a high rate of evaporation. Although, there is an indication that considerable reserves of ground water exist in the main aquifers (see Chapter Two), most of the ground water is non renewable (Al-Khalib, 1977). Further, since the water requirements have increased so dramatically, ground water usage has exceeded the limited natural recharge of most aquifers. The result has been a considerable depletion and a deterioration of the ground water.

Water problems in Saudi Arabia must be studied and evaluated soon before the quantity and quality of the currently available resources are further diminished. Moreover, an adequate comprehensive plan is needed to assist the country to meet it's future water requirements as it proceeds with rapid industrial and social development. The basis challenge of developing water strategies lies in trying to foresee in time and describe quantatively the interaction between physical and social aspect of water management.

Purpose of Study

This paper has five major objectives: first to develop three mathematical water requirements models for three different categories of water uses (municipal, irrigational and industrial) based on socio-economic, geographical and environmental characteristic in Saudi Arabia; second to forecast some of the relevant significant variables which are not available in the literature, third to use the developed models and the available and forecasted variables to project the water requirements for Saudi Arabia from 1982 to 2010, fourth to evaluate the water resources availability in the country: surface, ground, desalted and waste water, and finally to briefly provide recommendations for future water conservation.

The knowledge gained from the above endeavors will make it possible to match the water requirements against the water resources available. This comparison is expected to show severe shortages in water availability for all needs: irrigational, municipal and industrials. Although a water conservation program to reduce that shortages will be briefly discussed, this study is principally intended to provide a starting point for any further research concerning the use and conservation of water resources. It is hoped that this study will help other researchers to arrive at a correct solutions to today's and future's problem concerning water resources.

The remainder of this chapter reviews: 1) municipal, industrial, and agricultural uses of water resources in Saudi Arabia and 2) the municipal, industrial and agricultural mathematical models to be used in forecasting water needs and establishing a methodology for forecasting the water requirements of the country.

Water Uses

Municipal Water Uses. Municipal water use can be classified into several broad categories: domestic use, such as drinking, cooking, washing, bathing, toilet, fire protection, etc.; commercial use, such as restaurants, schools, shopping centers, etc., industrial use which is tied to municipalities; and losses incurred in getting water to consumers.

Agricultural Water Use. In this study agricultural water use refers to the water required to irrigate farm land and to maintain livestock in rural parts of the country.

Industrial Water Use. Industrial water use in this study refers to water, taken from sources other than municipalities, that is required for industrial operations. Water for industrial use may be classified into four major categories: cooling, boiler water, processing, and miscellaneous uses (Reid, 1962). Cooling water is the largest water use for the manufacturing sector as a whole. Water is separated from material being cooled by heat exchange surfaces. Most cooling uses involve equipment cooling, process temperature control, steam electrical power condensing and air conditioning. In refineries, for example, cooling water is applied for changing a phase from gas to liquid; and in steel and metallurgical industries large quantities of water are used to absorb and remove heat in various processes. Boiler water is used to generate steam for process purposes or steam electric power generation process uses include a variety of applications where water comes in contact with process materials or waste products or is incorporated in the final product. The most common process use is for beverages, dissolving, rinsing, scalding, spray cooling, fume scrubbing, etc. Miscellaneous industrial water uses are mainly for sanitary purposes. This includes water for plant clean up, ground keeping, fire fighting and dust control. (National Association of Manufactures, 1965).

Models Descriptions

Municipal Water Requirements Model. Previous research discloses the following facts about municipal water use. It has been found that as the population grows and the standard of living rises, the municipal water requirement increases through the establishment of new uses and through the intensification of old ones. Evidence also indicates that the use of water by municipalities tends to show a greater rate of increase with higher education, higher income, better health and better occupations. Houses which have water systems tend to use more water than those without them. Water requirements for hot countries seem to be greater than for cold countries. Municipal water requirements change as the socio-economic and climatological factors change (Reid, 1975). Water losses are less in new cities due to better and newer water systems.

The historical data of Saudi Arabia, and the dramatic socio-economic changes that started with the development of oil resources conform to the above statements. The municipal water requirements in the country have increased tremendously since 1960 as a result of these factors. Table A-2 shows the amount of water used by two cities from 1958-1980.

These socio-economic and climatological factors can be represented by different variables; for example, level of education can be represented by the total number of students. Climatic conditions can be represented by mean annual temperature and mean annual precipitation. Table 1-1 shows socio-economic and climatological factors and their corresponding variables.

Table 1-1

Socio-economic and Climatological Factors
and their Corresponding Variables

FACTORS	CORRESPONDING VARIABLES
A. Socio-economic	
1. population	Population
2. Education	Total number of students
3. Health	Number of People per physician
4. Urbanization	a. Nonagricultural employees b. Ratio of urban population to total country population
5. Income	a. Annual per capita income b. Total gross national product
6. Standard of living	a. Number of houses with water systems b. Annual per capita income c. Total number of graduate students
B. Climatological	
Climate	a. Mean annual temperature b. Mean annual precipitation c. Mean annual evaporation

The following variables were selected for this study to represent socio-economic and climatological factors:

X_1 = total population of Saudi Arabia

X_2 = total number of students in Saudia arabia

X_3 = number of people per physician

X_4 = annual per capita income

X_5 = number of nonagricultural employees

X_6 = number of houses with water system

X_7 = total urban population (cities 5,000 +) to total country population

X_8 = mean annual temperature

X_9 = mean annual precipitation

By terming the annual total municipal water requirement y, the following mathematical model may be hypothesized:

$$Y = f(X_1, X_2, X_3 \ldots X_9)$$

To build a model that relates the municipal water requirement to these different variables, relevant data were collected from various sources in Saudi Arabia for the years 1960-1980. (Ministry of Agriculture and Water (MAW), Ministry of Industries and Electricity (MIE), Ministry of Education (MOE), Ministry of Planning (MOP), Ministry of Finance and National Economy (MFNE), Saudi Arabian Monetary Agency (SAMA), Ministry of Petroleum and Minerals (MPM), Arabian American Company (ARAMCO), etc. A stepwise multiple regression analysis (discussed in Chapter 4) will be used to select the most effective variables which provided the best predictive model with an appropriate number of independent variables ($X^{'}s$).

The developed model and the available and projected forecasts of the significant socio-economic and climatological variables can be used to predict the future total municipal water requirements for Saudi Arabia.

Agricultural Water Requirements Model. The total water requirements for agricultural purposes are large. In almost every part of the country, irrigation water comprises the bulk of the total developed water needs. Despite the discovery and development of the oil industry, and the subsequent rapid development in other sectors, agriculture has maintained its position of prime importance to the country. In 1974, it was estimated that around 700,000 people or about 40 percent of the civil labor force, were engaged in agriculture. In 1979 the total number had declined sharply to 620,000 farmers, but agriculture still clearly remains the nation's main occupation. (MOP, 1980).

Several factors affect agricultural water requirements: socio-economic conditions, soil condition, technology, water quality, and the availability of arable lands. To deal with these factors mathematically and incorporate them in a workable model, they must be expressed as numbers through different indicators. Table 1-2 lists these factors and their corresponding indicator, (variables).

Unfortunately, available data from Saudi Arabia do not cover all these indicators adequately enough for them to be used in building a model. Hence, a modification was adopted as follows. Since the Saudi Arabian government's goal is to establish and maintain a prudent level of self efficiency in food production (MOP, 1970), it encourages agriculture by giving farmers a free loan to buy new machines to improve traditional agricultural methods. Furthermore, fertilizing is considerably subsidized and free guidance is available from engineers working at MAW. Using this information, the technology, soil and water quality factors are expressed by the amount of fertilizer used, the amount of loans given to farmers, and the number of engineers working at MAW. In fact, the reduction in the number of farmers coupled with the increase in agricultural production is one indication of improved technology.

Table 1-2

Factors and Corresponding Variables Affecting
Agricultural Water Requirements

FACTOR	CORRESPONDING VARIABLE
Socio-economic Conditions	Population, number of farmers, total income from agriculture sector.
Environment	Temperature, rainfall, evaporation, evapotranspiration.
Technology	Yield per hecture, total gross national product, level of education, per capita income.
Water Quality	Total solids, acidity, alkalinity, amount of Barium.
Soil Conditions	Salinity, fertility, moisture content
Availability of Arable land	Total irrigated land, rainfed land, soil conditions.

The following variables (indicators) will be used to build the agricultural water requirement model:

X_1 = total population of Saudi Arabia

X_2 = total numbers of farmers

X_3 = total output of agricultural products

X_4 = annual mean temperature

X_5 = annual mean precipitation

X_6 = total number of livestock

X_7 = total amount of fertilizer used

X_8 = total amount of loans given to farmers

X_9 = total number of engineers working at MAW

X_{10} = total amount of irrigated land

If we call the agricultural water requirement (y), then the mathematical form of the model may be expressed as:

$$Y = f\ (X_1, X_2, X_3, \ldots X_{10})$$

Relevant data for these variables from 1960 to 1980 were collected from various sources (as mentioned before) and will be used to build the agricultural water requirement model.

Industrial Water Requirements Model. Saudi Arabia has a long history as a trading nation but little experience in modern industrial development outside the oil industry. Other than oil refining and cement production, most early manufacturing activities were limited to only a few small scale local industries. However, in the mid 1970's, the government decided to reduce dependence on the production of crude oil as the primary source of national income. A standing commitment was made to widen industrial development in an effort to reduce the country's dependence on hydrocarbons, particularly oil, and to move toward a more balanced and self supporting growth in non-oil sectors.

The government has approved the establishment of three large industrial sites at Jeddah, Riyadh and Dammam. In these sites, industries are divided into hydrocarbon and nonhydrocarbon based industries. [Table A-3 lists the major industries planned for these cities: Jiddah, Riyadh and Dammam.]

By the end of 1975, the government had also adopted an even bolder plan for the rapid industrialization of Saudi Arabia. It centered on the construction of two new industrial cities, one at Al-Jubail on the Arabian Gulf Coast and the other at Yanbu on the Red Sea coast. Selected basic categories of industries are to be located in specifically planned industrial parks within Jubail and Yanbu. These industries are divided into the three following categories.

1) Primary Industries. These are the heavy petroleum based and energy intensive industries that will serve as the foundation for the development of the Jubail and Yanbu complexes. These industries include refineries, petrochemicals, fertilizer, iron and steel, aluminum and other sources based industries.

2) Secondary Industries. These industries will use the output of the primary industries as raw material. Basically they consist of manufacturing and fabricating facilities for byproducts from the refineries (rubber products, paints, insulation solvent, nylon and polyester fibers, detergents); the petrochemical plants (vinyl acetate, nitrate fertilizer, antifreeze, plastic products, adhesive, bleaches, disinfectant), iron and steel plants (reinforcing bars, wire mesh, plates, pipes); and the aluminum facilities (window frames, electrical fittings, house wares, appliances, pipes).

3) Support Industries. The function of these industries is to provide goods and services to the primary and secondary industries. Tables A-4 lists the planned primary industries in Jubail and Yanbu and Figure A-2 shows the construction planning schedule in Jubail and Yanbu.

Since water resources in Saudi Arabia are limited, increasing water requirements for industrial purposes may have to be supplied by desalinization. However water desalination is an expensive process and undoubtedly will increase the cost of domestic products. This is certainly a partial reason why government has started encouraging new industries to use saltwater for noncontact purposes, if available, or to apply the best available technology for recycling the water within its facility. The high cost of desalination and the government's promotion will certainly encourage higher levels of conservation and reuse which should tend to lower per unit product use of water.

A high percentage of water used by industries, especially oil and petrochemicals industries, is for cooling. Here, salt water can be used and, further the water can be recirculated many times. Hence, to calculate the industrial water requirements in Saudi Arabia, it would be misleading to forecast the gross water used by industries either when a large portion of the water may be used several times prior to discharge, if there is any, or where salt water is used. It is the intake water that should be considered, when recirculation is practiced, or the amount of water used for process and miscellaneous purposes, when salt water is used for cooling, for computing the industrial water requirements. [After all, there is no upper bound to the supply of seawater in Saudi Arabia.]

This study, therefore, attempts to divide industries into two main categories: 1) industries which use salt water for cooling purposes, coastal industries in general, and 2) industries which do not use salt water but practice recirculation. In the first category, the amount of water which will be used for contact purposes (process, sanitary and miscellaneous uses) will be projected, while the intake water will be projected in the second category.

One way of calculating the country's industrial water requirements for an intended use is by multiplying the production of a specific industry by the quantity of water used per unit of production for that purpose. This method assumes a constant amount of water is used for some purpose to produce a unit of production, regardless of time. This, however, does not seem correct, since history shows that there is a reduction in resource use per unit of production. Hence, a modification will be made to consider this change over time. A reduction factor will be used to overcome this problem and Chapter 5 will discuss this issue in detail.

CHAPTER II

WATER RESOURCES

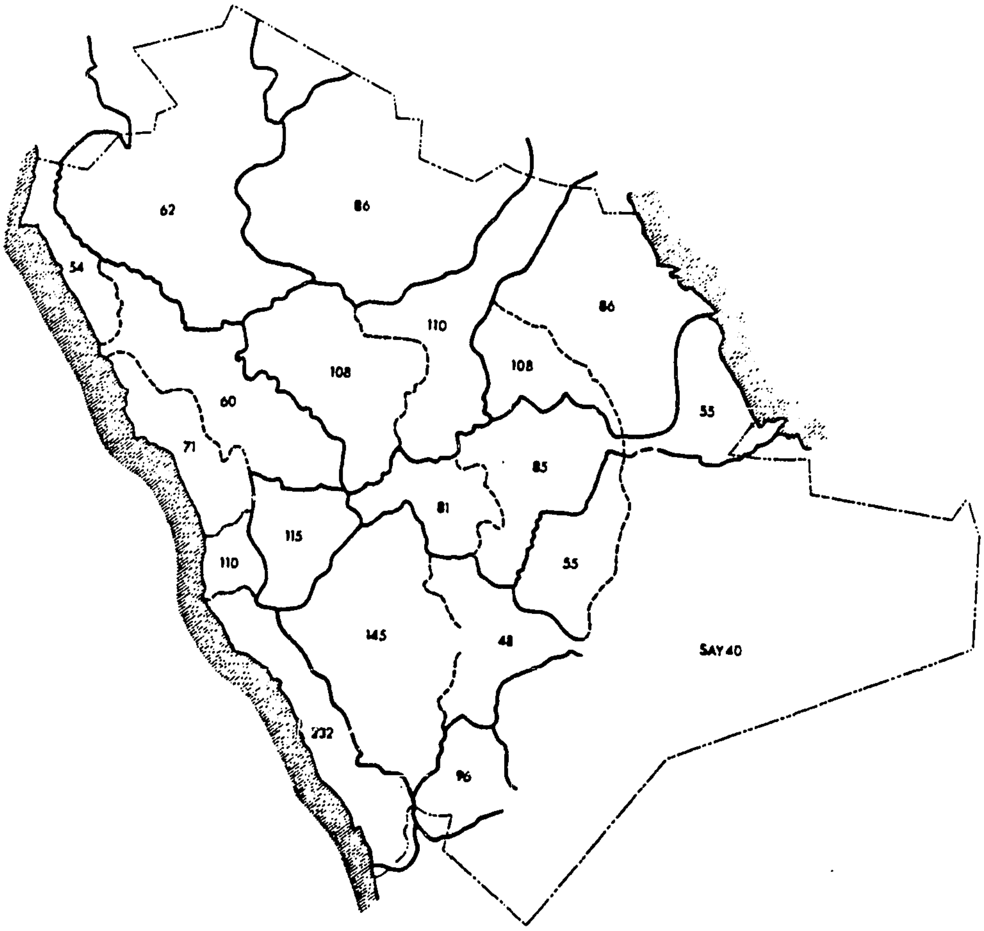
Except for the mountain range in the southwestern part of Saudi Arabia, (Part of Hijaz and Assir) (see Figure A-1) precipitation is very low and infrequent with extreme variation from one year to the next. In the Riyadh area, for example, in 1966 the amount of rainfall was 13.5mm while in 1967 it was 216.2mm (Kalthem, 1978). In general the average amount of precipitation over most of the country is less than 4 inches. In the southwestern part, the average precipitation is 10 inches. Figure 2-1 shows the drainage basin mean annual rainfall from 1966-1975 in millimeters.

Water resources in Saudi Arabia can be divided into four primary categories: surface water, ground water, sea water and waste water. Each of these is discussed in the remainder of this chapter.

Surface Water

Saudi Arabia does not have a perennial river, and temporary run-off exist only when there are effective

Figure 2-1. Drainage Basin Mean Annual Rain-
Fall 1966-1975 (mm).



Drainage basin mean annual rainfall 1966-1975 (mm)

Source: MAW and BAAC, 1980.

storms. In general run-off occurs in dry wadis (valleys) and often does not reach the sea because of the high rate of evaporation and infiltration into the wadis alluvium. To estimate the amount of run-off, the Ministry of Agriculture and Water (MAW), with the help of several private companies, has conducted numerous studies on different basins of the country. The conclusion of these studies (BAAC, 1980) is that the mean annual surface run-off is around 2025 million cubic meters (MCM).

Most of this surface run-off occurs in the western part of the country, where rain is relatively abundant and regular. In this part of the country (Hijaz and Assir), there is a chain of mountains which lie parallel to the Red Sea Coast. Between the Red Sea Coast and these mountains, there are coastal plains 80 to 100 km in width (see Figure A-1). The mountain chain is broken by 90 wadis, 36 of which contribute collectively some 95 percent of the total run-off in the mountain belt.

Rainfall varies from 20mm per year in the north to 500mm per year in the Assir mountains and the surface water resources increased markedly toward the south. The importance of the coastal belt may be seen from Table 2-1 which shows that out of a total estimated

Table 2-1

Estimated Area and Annual Runoff of the Studied Basins

Basin Name	Surface Area KM^2	Estimated Annual Runoff (MCM/Y)	Percent of Total
Red Sea Coastal Area	241,600	1265	62
Assir-Wadi Ad-Dawasir	180,000	330	16
Assir-Wadi Najran	38,400	135	7
Wadi Birk-Nisah-Sahaba	162,000	100	5
North Tuwaig	152,000	95	5
South Tuwaig	48,300	55	3
Wadi ar Rima-Al Batin	174,000	25	1
Rub al Khali	Not available		
Al Nafud	161,000	20	1
As Sirhan	192,300		
TOTAL		2025	100

Source: British Arabian Advisory Company, 1980 (BAAC)

KM^2 = Square Kilometer

MCM/Y = Million Cubic Meter Per Year

surface run-off of 2025 MCM, throughout the Kingdom, no less than 1265 MCM, of the total is found in this region. As mentioned earlier, BAAC, 1980 estimated that only 30 percent of the total surface run-off is diverted for agricultural use, 45 percent feeds the alluvial aquifers as a recharge and the rest is lost due to evaporation. They also reported that 50 to 60 percent of the surface run-off in the southwestern part of the country is controlled by temporary structures and used mainly for agricultural purposes. Figure 2-2 shows the drainage basin mean annual run-off (1967-1976).

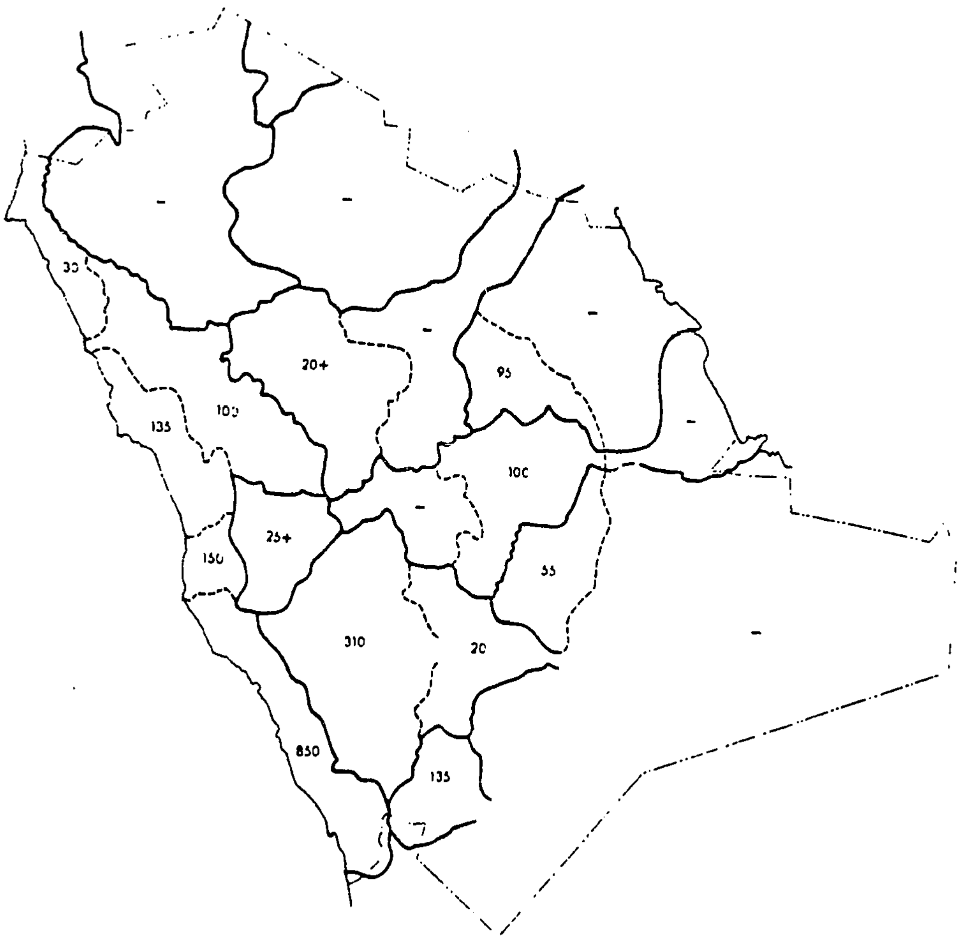
Ground Water

Ground water has been an important water resource throughout the ages in Saudi Arabia. Old water wells can be found along the wadis at different places. Some of the ancient water tunnels in Saudi Arabia are still in use even today. Currently, ground water is the main source of water for many municipalities, industries, irrigation systems, suburban homes and farms. The three different types of aquifers that provide this ground water found in Saudi Arabia are each discussed below.

Alluvial Aquifers

A large portion of the area of Saudi Arabia is covered by quarternary deposits, and the alluvium in the western region of the country is the only one which

Figure 2-2. Drainage Basin Mean Annual Run-Off 1967-1976 (MCM).



Source: MAW and BAAC, 1980.

has significant ground water. These alluvial aquifers supply water to many communities especially in the south-western region. BAAC (1980) stated

> "these alluvial deposits are found, for the most part, in the wadis filling the channel eroded in the older rock by run-off during earlier wetter periods. Large spread of such alluvial material are also found on the coastal plains of the west and where wadi systems debouch onto the flatter ground of the north and east."(1)

Figure 2-3 shows the location of these alluvial aquifers.

The alluvial aquifers are unconsolidated and of limited thickness and width, usually just several meters and only rarely more than 100m). However, the length could run up to many tens of km. They also vary in permeability due to the wide range of soils (coarse gravel to fine salt). These alluvial aquifers are charged mainly by infiltration from surface run-off flowing over permeable wadi beds (BAAC, 1980). Table 2-2 shows the estimated annual recharge and storage for alluvial aquifers in Saudi Arabia. Figures 2-4 and 2-5 also show the mean annual recharge and storage to the alluvial aquifers.

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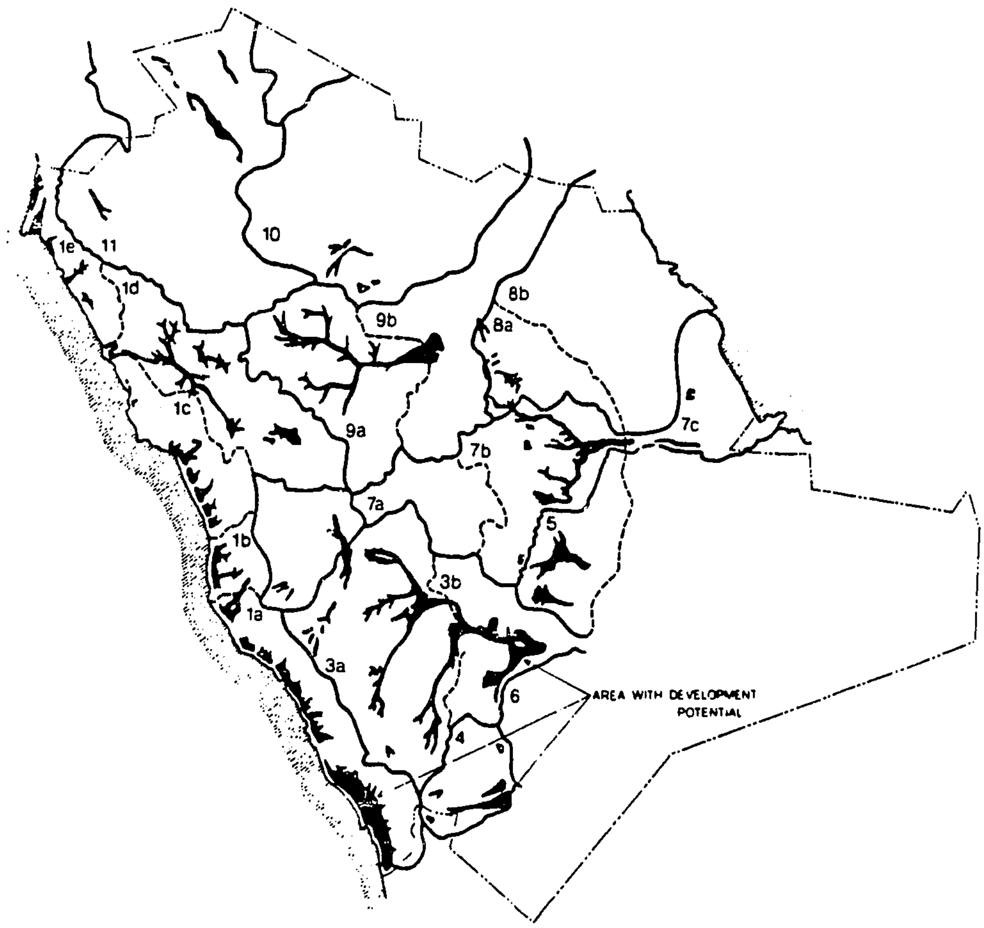
[1]BAAC, "National Water Plan," Ministry of Agriculture and Water, Riyadh, Saudi Arabia, 1980, p. 15 (unpublished reports).

Figure 2-3. Locations of Alluvial Aquifers.



Source: MAW and BAAC, 1980.

Table 2-2

SUMMARY OF RECHARGE, AND STORAGE FOR

ALL ALLUVIAL AQUIFERS

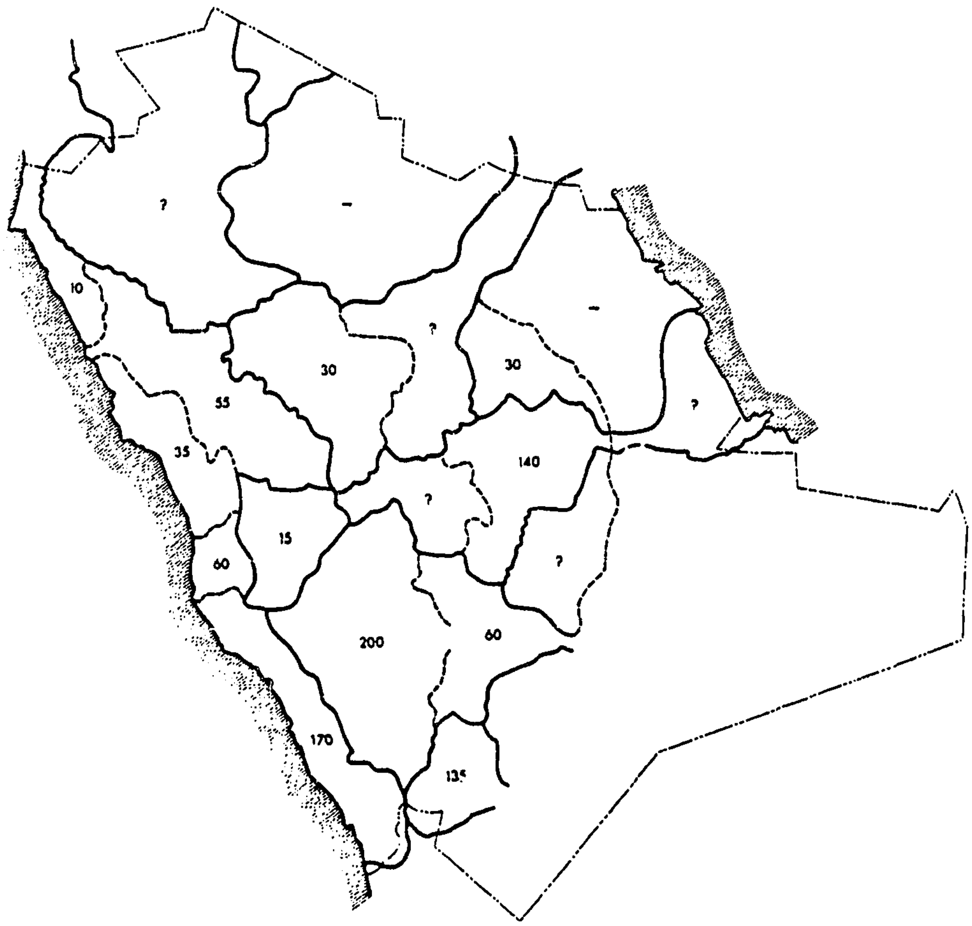
Major Drainage Basin	Mean Annual Recharge MCM/Y	Storage MCM
Red Sea Coast	330	14,250
Taif-Fadat al Mislah	15	50
Assir - Dawasir	260	17,700
Assir - Nigran	135	33,350
South Tuwayg	N.A.	N.A.
Rub-al-Khali	N.A.	N.A.
Birk-Nisah-Sahaba	135	14,100
North Tuwayg	30	500
Al Timah-Al Butin	30	4,000
Nafud	N.A.	N.A.
Assirhan	N.A.	600
TOTAL	940	84,550

Source: Al-Khatib, 1978.

MCM/Y = Million Cubic Meter Per Year

MCM = Million Cubic Meter

Figure 2-4. Mean Annual Recharge (MCM) to Alluvial Aquifers.



Mean annual recharge (MCM) to alluvial aquifers

Source: MAW and BAAC, 1980.

Figure 2-5. Alluvial Aquifers Storage (MCM) by Drainage Basins.

Source: MAW and BAAC, 1980.

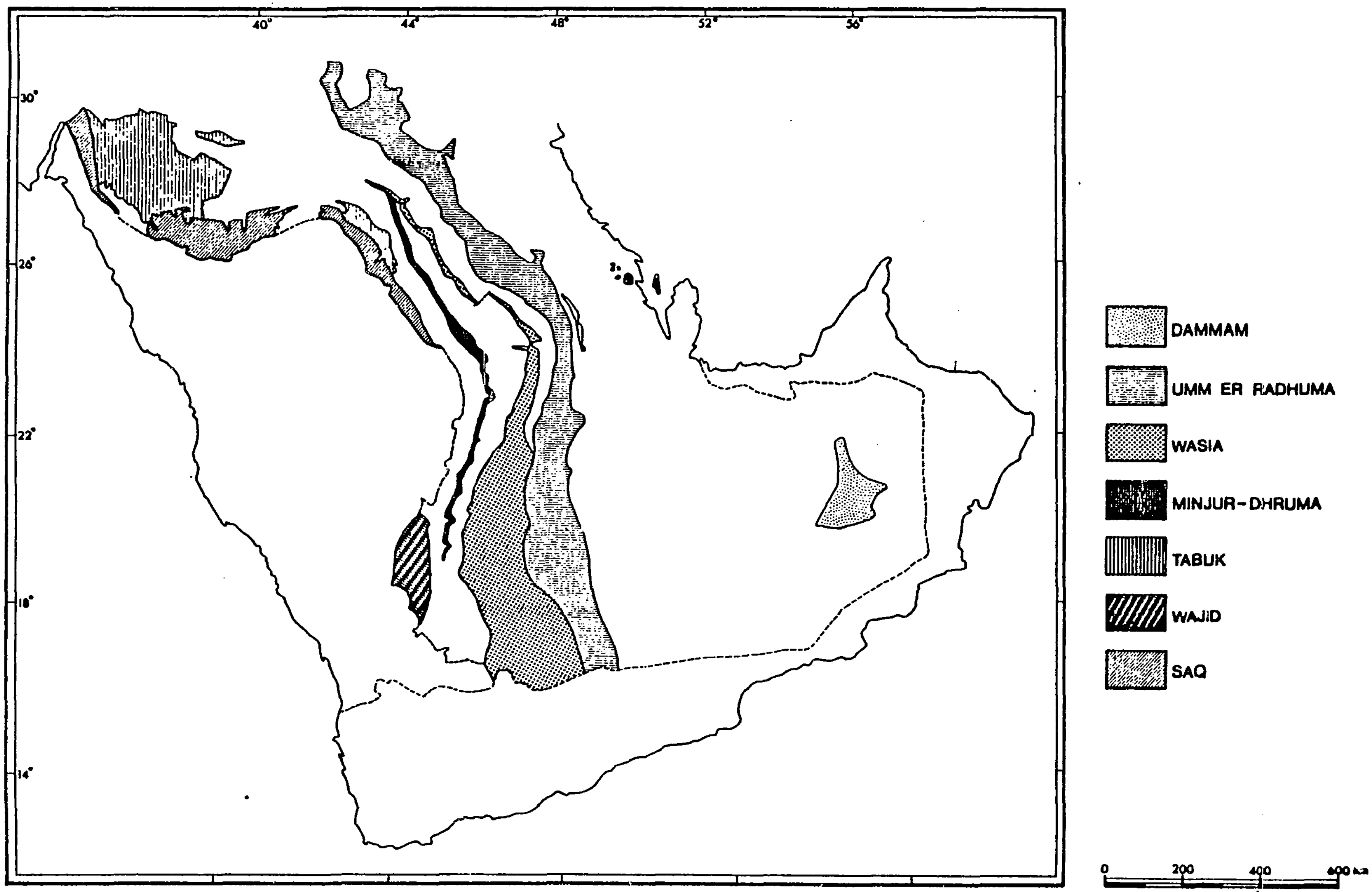
Principle Aquifers

There are seven major aquifers in Saudi Arabia: Sag, Wajid, Minjur, Dhruma, Wasia, Umm Erudhuma and Dammam. These aquifers are found within 5500 meters of sedimentary strata which underlies more than two-thirds of Saudi Arabia extending from the northern boundary southward into Rub-al Khali and eastward from the central area to the Arabian Gulf (BAAC, 1980). Figure 2-6 shows the location of these principle aquifers.

The aquifers consist mainly of either sandstone or linestone, however, the major ones are sandstones. The sandstone aquifers have a larger storage volume of ground water than the limestone aquifers because of greater specific yield and greater thickness. The sandstone predominates in the lower and in the middle part of the formation. The limestone, however, is found in the upper part of the formation where ground water moves along different sizes of fissures caused by chemical weathering.

Several consulting companies (Italo Consult, German consult, Barson Basil, Sogreah...etc.) under MAW have conducted numerous studies throughtout the country to estimate the volume of ground water in the principle aquifers. BAAC used these reports and continued further intensive study for the same purpose. They estimated

Figure 2-6. Locations of Principal Aquifers.



Source: MAW and BAAC, 1980.

the ground water which can be developed within pumping levels of 100, 200 and 300 meters below the surface. This approach was adopted due to the following statement:

> "clearly economic factors enter into ground water development. In particular the lift from the pumping water level in a well to the surface may be a factor limiting the extent to which development is possible. Thus, one method of estimating resources is to calculate the volume of water available above specified depths of pumping water level below the ground surface. This has been done for all the principle aquifers where the data are adequate. The depths below surface selected are 100, 200 and 300 M".(2)

Table 2-3 shows these figures.

Another approach was attempted to estimate the so-called, proven, possible, and probable resources for the major aquifers in the country. The terms: proven, possible and probable are defined by the report as follows:

> "The figures given in the proven category are considered to represent a quantity that can be developed with some degree of confidence given that the aquifer properties are as anticipated and therefore, adequate well yields can be obtained. The figures in the probable category are less certain but nevertheless some degree of confidence is attached to the

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[2] Ibid, p. 111.

Table 2-3

Total Storage Capacity in the Principal Aquifers
Above 100 M, 200 M, and 300 M*

Aquifer	100 M MCM	200 M MCM	300 M MCM
Sag	64,000	241,000	475,000
Wajid	37,000	233,000	430,000
Minjur-Duruma	28,500	104,000	183,000
Wasia-Biyadh	1,800	85,000	487,000
Ummer Radhuma	45,000	45,000	N.A.
Dammam	5,000	N.A.	N.A.
TOTAL	181,900	708,000	1,575,000

Note:
M = Meters
M.C.M. = Million Cubic Meters
N.A. = Not Available

Source: (BAAC, 1980)

> feasibility of the development. The possible category remains uncertain at the present stage of knowledge. The volume included in the three categories are all above a regional pumping level of not more than 300m below the surface."(3)

Table 2-4 shows these figures.

Although, the storage of the ground water is considerable, the natural recharge is very limited. BAAC reported that the total average annual natural recharge of the six principal aquifers is estimated at only about 1270 MCM/yr. This natural recharge comes from subsurface inflow from the alluvial aquifers, surface run-off and from direct infiltration of rainfall. Table 2-5 shows the mean annual recharge for the six main aquifers.

Ground water quality is determined by its chemical and biological constituents and its sediment content (Bouwder, 1978). In other words, the quality of the ground water is a result of all processes and reactions that have acted on the water from the moment it condensed in the atmosphere to the time it is discharged by a well or spring. In Saudi Arabia the time span may range from less than one day to more than 50,000 years (Al-Khatib, 1971). Due to varying geological

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[3] Ibid, p. 113.

Table 2-4

Total Reserved Storage Capacities in the Principal Aquifers

Aquifer	Proven MCM	Probable MCM	Possible MCM
Sag	65,000	100,000	200,000
Wajid	30,000	50,000	100,000
Minjur-Duruma	17,500	35,000	85,000
Wasia-Biyadh	120,000	180,000	290,000
Ummer Radhuma	16,000	40,000	75,000
Dammam	5,000	N.A.	N.A.
Total	253,500	405,000	750,500

Source: (BAAC, 1980)

MCM = Million Cubic Meter

Table 2-5

MEAN ANNUAL RECHARGE FOR THE

PRINCIPAL AQUIFERS

Aquifers	Mean Annual Recharge MCM/Y
Saq	N.A.
Wajid	104
Minjur-Dhruma	80
Wasia-Biyadh	480
Umm ER Radhuma	406
Dammam	200
Tabuk	N.A.
TOTAL	1270

MCM/Y = Million Cubic Meter Per Year

Source: BAAC, 1980.

origin, the ground water in Saudi Arabia differs among and within aquifers. Several unpublished reports from (MAW) on ground water quality have been studied, and Table 2-6 summarizes the available information on ground water quality for each major aquifer.

The above discussion shows that a huge amount of ground water is available in the country though the natural recharge is limited and some of the ground water is of poor quality. Thus, it may be concluded that excess abstraction of ground water will deplete the ground water which is not being replaced.

Secondary Aquifers

Unfortunately, at the present time, there is very limited data about secondary aquifers. Research is however, being done by the Ministry of Agriculture and Water to estimate their full potentiality.

Seawater

Saudi Arabia is bordered on the west by the Red Sea and on the east by the Arabian Gulf. Hence, saltwater availability is unlimited from the standpoint of volume. Consequently, seawater has become a very important resource for Saudi Arabia, especially on the eastern and northwestern coasts where rainfall is scarce and industrial development is progressing very rapidly.

Table 2-6

GROUND WATER QUALITY OF THE PRINCIPAL AQUIFERS

Aquifer	
1. Saq	Water quality in general is good. TDS is mostly <600 Mg/L, but at downdip water is highly mineralized. Sodium and chloride are the dominant ions. (BAAC, 1980).
2. Wajid	Water quality in general is good. TDS is mostly <800 Mg/L, however in Nijran TDS ≈ 1,000 Mg/L. (Soreah).
3. Minjur-Dhruma	The salinity of the ground water increases down-gradient and with depth. TDS ranges from 1,000-2,000 Mg/L. (Sogreah).
4. Wasia	TDS ranges from Mg/L 156-155,000 Mg/L. When TDS <600 water is calcium carbonate type. When TDS ≈ 3,500 Mg/L calcium and sulphate are the major ions. When TDS > 3,500 Mg/L water is a sodium chloride type (Shampine, 1976).
5. Umm ER Radhuma	TDS ranges from 500-65,000 Mg/L. In northwest TDS >900 Mg/L and water is a calcium sulphate type, while in the central, southern and eastern area water is a sodium chloride type. Along the Arabian Gulf Coast water is very highly mineralized and it is sodium chloride type water. (Shampine, 1976).
6. Dammam	A rapid increase in TDS toward the coast was found. In the west TDS <1,000 Mg/L along the coast and near Al Hinah, TDS ≈ 6,000 Mg/L. Sodium and chloride are the dominant ions. (BAAC, 1980).

The desalination of salt water is rapidly becoming a well proven and developed technology in the country. During the past 5 years the total production of desalinated water was 26 million gallons per day (MGD). The country hopes to increase its production capability to 500 (MGD) in the next decade. Ten stations that are either under current construction or slated for construction in the coming 10 years at different cities along the Red Sea coast will be capable of producing 180 MGD. Three other stations to be located on the Arabian Gulf will be capable of producing 320 MGD (MOP, 1980). Table A-5 shows the capacities of the existing and planned desalination station.

Sea water should be considered as a main source of water in oil production industries in the future. A huge amount of good quality water has been used for oil injection to assist oil production. In the second development plan, it was mentioned that 2,400,000 M^3/day was needed in 1980 for this purpose. However, it was understood that the future water requirements for oil injection will be met by using sea water (BAAC, 1980).

Sea water will have another industrial use, also, The coastal industrial cities in Saudi Arabia (mainly refineries, and petrochemicals) are planning to use sea water as a once-through system, for cooling purpose. This cooling water requirements comprise more than 90 percent of the total water requirements in these industries.

The above two uses of water in oil injection and for cooling purposes will unquestionably save large amount of good quality water supply. And, hence shows the importance of sea water as a new significant water supply.

Wastewater

An arid country such as Saudi Arabia is actively searching for supplementary sources of water to help meet the present and the future demand for water. Wastewater is considered an an important potential source of water because of the following reasons.

1. More than two-thirds of the water resources in Saudi Arabia are non-renewable.
2. Total water requirement is more than the renewable available water.
3. The country is progressing (developing) very rapidly and the need for more water is increasing.
4. During the last decade, there have been remarkable achievements in wastewater technology

for restoring the usefulness of fresh water supplies, in reclaiming wastewater for reuse, and in the treatment of wastewater before discharge to the seas.

5. The cost of reclaiming the wastewater is cheaper than distillation.
6. Reclamation of the wastewater (if it is done properly) helps to reduce pollution and enhances conservation of water.

The quantity of the wastewater depends on the proportion of the properties connected to the sewer system and the sewer condition, the population of these properties and the daily per capita use of water. This topic will be discussed further in Chapter 7.

CHAPTER III

LITERATURE REVIEW

Municipal Water Requirements

Municipal water requirements include residential, commercial, public and industrial uses which are tied to the municipal system (Reid, 1962). The forecasting of these requirements is normally based on the projection of established growth trends in population and daily per capita needs. Simply stated, future municipal water requirements may be expressed as follows:

$$QM_i = P_i X \ (GPCD)_{Mi} \tag{3-1}$$

where

QM_i = Municipal Water Requirement in year i

P_i = Population in year i

$(GPCD)_{Mi}$ = Daily per capita need for the municipal purpose in year i

The daily per capita use varies with several variables such as population, income, climate, price of water, degree of industrialization and the standard of living etc. (UN, 1962). Thus GPCD projection should take this criterion into account.

Sometimes an estimation of residential use is forecasted through this principle:

$$Q_{Ri} = P_i \times (GPCD)_{Ri}$$

where

Q_{Ri} = Residential water requirement for year i

P_i = As defined before

$(GPCD)_{Ri}$ = Daily per capita use for the residential purpose for year i

Public, commercial and industrial needs are added as an estimated percentage of the residential use. This percentage depends on the status of the region under study. For example if the region is a dormatory or residential town, the percentage is low. Industrial cities need a considerably greater percentage (Reid, 1962).

Another approach is based on trying to create a functional relationship between the municipal water requirements and some relevant variable or variables. The following examples show this approach. Capen (1937) developed the following model to predict the daily per capita use for a well metered area:

$$G = 54\ p^{0.125} \tag{3-2}$$

where

G = gallon per capita per day

p = population in thousands

Berry and Bonem (1974) used personnel income as a relevant variable instead of population. This was done to predict the municipal water requirements for New Mexico. They came up with the following model:

$$q = 25.1 + 0.059\ y \qquad (3\text{-}3)$$

where

q = municipal water use in gallon per capita per day

y = the annual per capita personnel income in dollars.

Capen's model suggested the only variable relevant to municipal water requirements is population, while Berry and Bonem's model proposed annual personnel income as the most significant.

The adequacy of estimating municipal future needs on these basis, however, comes into question. This is because such estimation takes no account of other effects such as climate, social consideration, economic level and modernization. Yet, clearly they would have an effect on municipal water needs.

Reid (1971) modified the above models. He considered climate, population and the economic level in his mathematical equation of predicting the water demand. The model may be stated as follows:

$$WD_t = (pop)_t \; uu_s \left[\frac{PPCt_t}{PPCt_s}\right]^x \left[\frac{INC_t}{INC_s}\right]^y \left[\frac{PoP_t}{PoP_s}\right]^z \qquad (3\text{-}4)$$

where

WD_t = water demand at time t

uu = unit use of water

pop_t = population at time t

$ppct_t$ = precipitation at time t

Inc_t = income at time t

Another model known as MAIN I was developed by Saunders (1969). 141 standard metropolitan statistical areas (SMSA) were studied to predict the total water requirement. The model is given below.

$$E_{75} = (W_{60i} \times 1.19 \left[\frac{T_{75i} - T_{60i}}{T_{60i}}\right] + W_{60i}) \times P_{75i} \qquad (3\text{-}5)$$

where

E = total water use

w = per capita use

T = per capita income

p = estimated population

i = SMSA number for $i = 1,2,\ldots, 141$

60,75 = 1960, 1975

Other forecasters tried to include more variables while searching for better estimation of the water requirements. And invariably, multiple regression analysis was used to handle such predictions.

Howe and Lina Weaver (1967) carried out intensive studies to predict residential water requirements for alternate kinds of housing and water systems. They also built a separate model predicting sprinkling use. Their models may be stated as follows:

1. Average annual increase in-house use:
   a. metered and public sewer area

   $$g_{a,d} = 206 + 3.47V - 1.3\ Pw$$
   $$\hat{\sigma}_e = 23.3$$

   b. flat rate and apartment area with public sewers

   $$g_{a,d} = 28.9 + 4.39V + 33.6\ dp$$
   $$\hat{\sigma}_e = 23.3$$

   c. metered area with septic tanks

   $$g_{a,d} = 30.2 + 39.5\ dp$$
   $$\hat{\sigma}_e = 7.0$$

2. Average summer sprinkling use:
   a. metered and public sewer, Eastern U.S.

   $$g_{s,s} = 3657 r_s^{0.309} \quad P_s^{-0.930}$$
   $$\hat{\sigma}_e = 1.95 \text{ (multiplicative)}$$

b. metered and public sewer, Western U.S.

$$g_{s,s} = 1130\, P_s^{-0.703} \quad V^{0.429}$$

$$\hat{\sigma}_e = 1.35 \text{ (multiplicative)}$$

c. flat rate with public sewer

$$g_{s,s} = 94r^{1.21} \quad V^{0.553}$$

$$\hat{\sigma}_e = 1.36 \text{ (multiplicative)}$$

3. Maximum day summer sprinkling use:

a. metered and public sewer, Eastern U.S.

$$g_{max,s} = 30160 r_{max}^{0.544} \quad P_s^{-0.671}$$

$$\hat{\sigma}_e = 1.64 \text{ (multiplicative)}$$

b. metered and public sewer, Western U.S.

$$g_{max,s} = 1634\, p_s^{-0.619} \quad V^{0.416}$$

$$\hat{\sigma}_e = 1.26 \text{ (multiplicative)}$$

c. flat rate with public sewers.

$$g_{max,s} = 12690\, r_{max}^{1.03} \quad V^{0.50}$$

$$\hat{\sigma}_e = 1.2 \text{ (multiplicative)}$$

where

$g_{a,d}$ = average annual rate of in-house use in gallon per day per dwelling unit (gpd/du)

$g_{s,s}$ = average summer sprinkling rate, gpd/du

$g_{max,s}$ = maximum day sprinkling rate gpd/du

V = value of the dwelling in thousands of dollars (1964 prices)

Pw = commodity charge (variable charge) for water applicable at in-house rates of use, cents/thousand gallon

P_s = commodity charge applicable at rate of combined in-house and sprinkling use during summer months.

r_s = estimate of physical requirements of irrigated lawn area to compensate for difference between average summer season potential evapotranspiration and effective precipitation, measured in inches per person.

r_{max} = maximum day summer rate of potential evapotranspiration, inches per day

d_p = number of persons per dwelling unit.

Saki (1972) developed a model to forecast the daily per capita needs in Tokyo, Japan. This was done by utilizing four independent variables: population, personnel income, industrial production and sales of goods. His model may be expressed as follows:

$$I = 0.5674X_1 + 0.1606X_2 + 0.149X_3 + 0.1571X_4 \qquad (3\text{-}6)$$

where

I = water demand in gallon per capita per day

X_1 = population

X_2 = personnel income

X_3 = industrial production

X_4 = sales of good

El-Messidi (1978) built a model to predict the municipal water requirement for the State of Oklahoma. His model is similar to Saki's with two exceptions. First, he utilizes non-agricultural employment instead of personal income and industrial production. Also he includes the climatological variable of mean annual precipitation. This model can be demonstrated as follows:

$$Y_{mi} = 55.147 + .1344X_{1i} + 0.1145X_{3i} - 0.0015X_{4i} - 0.0688X_{6i} \qquad (3\text{-}7)$$

where

Y_{mi} = total municipal and domestic water requirements for Oklahoma for year i in thousands of acres feet per year.

X_{1i} = total population of Oklahoma (mid-year estimates) for year i in thousands.

X_{3i} = non-agricultural employment of Oklahoma (annual average for year i in thousands).

X_{4i} = total gross-state product of Oklahoma for year i in millions of current dollars.

X_{6i} = mean annual precipitation of Oklahoma for year i in inches.

The author states the following:

> "All the independent variables included in the developed model pass the sequential F-test since F-calculated is more than F-tabulated at both 5% and 1% significant levels. The coefficient of determination is very satisfactory with a considerably high values equal 0.9963. All the signs of the regression coefficients are."(1)

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[1]El-Messidi, "Mathematical Water Demand Models for the State of Oklahoma," University of Oklahoma, Norman, Oklahoma, 1978, p. 91.

However, nothing was mentioned about the validity of the basic assumption of the regression analysis (a point discussed in Chapter 4).

Barton (1970) also tried to create a mathematical model to forecast the municipal water requirement for Oklahoma. He used cross-section data of 39 cities for a single year. The model is

$$Q_{mi}{}^{t} = 89 + 0.002\ m_{i}{}^{t} \qquad (3\text{-}8)$$

where

Q_{mi} = average municipal water requirements in gallon per capita per day for the i^{th} city.

$m_i t$ = population of the i^{th} city in year t

Realizing that per capita needs increases with time, Barton, thus used the time series data from 1958 to 1968 with the inclusion of time as an explanatory variable. The followig structural relationship was examined

$$Q_{mi}{}^{t} = a + b\ m_{i}{}^{t} + Ct \qquad (3\text{-}8a)$$

where

$Q_{mi}, m_i t$ = As defined before.

a,b,c = constants.

Afterward, he concluded the following unexpected results:

> "Based on this analysis of time-series data, population growth appears to be the controlling factor in determining unit water use through time, and equation 1* is to be preferred for estimating unit use. It is not advisable to use equation 1.a** since the problem of multicolinearity makes it difficult to find the values of the regression coefficient accuracy."(2)

[This problem will be discussed later in the course of this paper (Chapter 4).]

Irrigational Water Requirements

The irrigational water requirement (which in this study include drinking water for livestock) is the largest portion (70%) of the total water requirements in Saudi Arabia, (Ministry of Planning, 1980). These requirements are a function of several natural variables such as precipitation, temperature, run-off, soil condition and many socio-economic as well as technological factors. Namely population, income, method of irrigations and effectiveness of machineries (UN, 1975).

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*(1) is -quation 3-8.

**(1.a is equation 3-8a.

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[2]Bartone, "A State Planning Model for Water Resources Development," University of Oklahoma, Norman, Oklahoma, p. 45.

Several methods have been used to forecast irrigational water requirements. They depend on the case under study and factors such as data availability, cost and time. One of these methods is the so-called projection which is based on the assumption that irrigational water requirements are a function of time. This forecast is obtained by extrapolating past trends. This method is normally used when nothing is known about other variables which contribute to the irrigational water requirements. Although relatively simple, this method is less desirable than other methods to be discussed later. This is due to its basic assumption that prediction is a function of time only (SWELL, Bower, 1968).

Another method tries to identify the variables that are relevant to irrigational water requirements. A functional relationship between the relevant independent variables and the variables that define them are created. Next the independent variables are forecasted and used as input to forecast the dependent variable, i.e., irrigational water requirements.

One method assumed a fixed coefficient of water use per acre per year. Then future irrigational water requirements are a product of the coefficient use and the number of future irrigated acres. Reid and Wilson (1962) used an average coefficient of water use of

2.3 feet per acre per year. This was done to forecast the agricultural water requirement for the State of Oklahoma for years 2000 and 2025. The future amount of irrigated acres was determined by using accessible terrace and alluvial land to be irrigated locally.

Barton (1970) developed the following equation to project the irrigated acres in each country of the State of Oklahoma:

$$A_j^t = (1 + 28.5 \frac{t-t_o}{A_s^{to}}) A_j^{to} \qquad (3\text{-}9)$$

where

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

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

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

Bartone was, however, assuming that the ratio of each county irrigated acres to the state's will remain constant in the future years.

Al-Messidi (1978) developed the following model to forecast the irrigational water requirement for Oklahoma State utilizing several socio-economical and environmental factors:

$$Y_{ai} = -17309.066 + .1095\ X_{2i} - .9635\ X_{6i} + 1.8021\ X_{13i} + 0.4506\ X_{15i} \qquad (3\text{-}10)$$

where

Y_{ai} = total irrigational water requirement for Oklahoma for year i in thousands of acre-feet per year.

X_{2i} = nominal per capita income of Oklahoma in current dollars

X_{6i} = mean annual precipitation in inches in year i

X_{13i} = total acres irrigated in Oklahoma for year i in thousands

X_{15i} = total land in farms in Oklahoma for year i in thousands of acres

The author concluded that the model is satisfactory due to its high value of R^2 (coefficient of determination) and the sequential F-test evaluation.

Industrial Water Requirements

It has been mentioned in Chapter Two that the industrial water requirements, in this study, are the amount of water which is not supplied by municipal plants, but by its own resources. Several studies dealing with the projection of industrial water requirements were reviewed. This review shows that projection is usually expressed in terms of a unit use of water per employee or per a unit of product and the number of employees or amount of products. Other researchers tried to create a functional relationship between the industrial water requirements and several relevant variables. The relevant variables are then forecasted and used as an input to predict the industrial water requirements.

Bartone (1970) projected the industrial water requirements for Oklahoma for all manufacturers having six or more employees. He used two parameters in his model: employment and a unit water consumption per employee for different industrial groups. Further, the author relied on a constant unit use of water per employee for the following reasons:

> "attempts to describe time-dependent fluctuations in per employee industrial withdrawal indicate that the coefficient should remain constant through time. This appears to be the result of two counteracting tendencies-improved industrial process efficiency and recycling techniques resulting in greater water reuse offset by the simultaneous

decrease in employment due to automation and technological advances."[3]

Brown (1968) tried to include the rate of water reuse and rate of quality improvement, in addition to average unit use per a unit of product. This has been done to forecast the water requirements for pulping industries. The following model was suggested:

$$I_t = \left[\sum_{i=1}^{n} P_{it} W_i + (1+i)^s \sum_{j=1}^{n} Q_{jt} W_j \right] \left[\frac{r_o + 1}{r_t + 1} \right] \qquad (3\text{-}11)$$

where

I_t = total water use (intake) in period t

P_{it} = quantity of pulp produced by pulping processes i in period t

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 (the base period = o)

s = length of projection period

i = rate of product quality improvement

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[3]Ibid, p. 58.

El-Messiedi (1978) used the multiple regression technique to predict the industrial water requirements for Oklahoma. Several socio-economical and environmental variables were used to create the following model:

$$T_{Ii} = -2177.718 + 0.7626X_{1i} + 0.6533X_{3i} + 0.652X_{6i} + 0.028X_{9i} \tag{3-12}$$

where

Y_{Ii} = total industrial water requirement for Oklahoma for year i in thousands of acre-feet per year

X_{1i} = total population of Oklahoma (mid-year estimate for year i in thousands

X_{3i} = non agricultural employment of Oklahoma (average annual for year i in thousands)

X_{6i} = mean annual precipitation of Oklahoma for year i in inches

X_{9i} = total bituminous coal and lignite production of Oklahoma for year i in thousands

The author used the industrial model to forecast the industrial water requirements for Oklahoma up to the future year 2040.

Review of Studies on Water Requirements on Saudi Arabia

In 1962, a team from the United Nations visited Saudi Arabia for six weeks to investigate water problems. Studies were conducted in several selected cities: Jeddah, Riyadh, Dammam, Dahran and Rastonora. The team recommended an intensive comprehensive water survey, especially in areas which have potential for great economic growth. They also recommended building several desalination plants on the Eastern and Western coasts, especially if the study shows a limited amount of ground water. The team suggested water conservation practices to be implemented as early as possible in order to insure maximum use and economic benefits (UN, 1962).

Several studies by different engineering consultant organizations were conducted regarding water requirements. This has been done to estimate daily per capita need for different cities. Table 3-1 shows some of the relevance of their studies.

Vatten Byggnads Bryan (1967)(VBB) studied the growth of the population of Jeddah and Mecca. He found the growth rate equal to 5 and 4 percent for both cities. He further assumed that growth will continue at the same rate through the year 2000.

Table 3-1

DAILY PER CAPITA USE IN LITERS FOR RIYAD CITY (LPCD)

References/Year	1965	1975	1980	1985	1990	1995	2000
VBB (1964)	160			240		280	
BCC (1976)		200	220	244	260		300
Sogreah (1967)			250				
Saline Water Desalination Corporation (1977)		232	325	355	380		400
Abu-Butain (1977)			330		340		380

Source: Kalthem, "Evaluation of Riyadh City Water Supply and Demand," (Thesis), University of Arizona, 1978, p. 87.

Sadhan (1980) used past data (1967-1978) of the water supply for Mecca and Jeddah to project the daily per capita use for these cities. He then used VBB's estimate of population to project the water requirements for both cities. Table 3-2 shows these figures.

Kalthem (1978) estimated the daily per capita consumption for the capital city of Riyadh (located in Saudi Arabia) for the year 1980 as follows:

Total Per Capita Consumption in Litres Per Day:

Domestic	150
Irrigational, general use and losses	70
Special Uses:	
Industries	20
Institution	20
Recreation	15
Air Condition	25
TOTAL	300

He further assumes the daily per capita use will increase to 340 LPCD in 1990 due to population growth. This will be demonstrated in a higher standard of living. The author also felt Riyadh's population will be 1,200,000 and 1,800,000 in 1980 and 1990 respectively. His population projection was based on Abubutain's (1977) estimation of 1,050,000 in 1975. The above figures

Table 3-2

PROJECTIONS OF POPULATION, DAILY PER CAPITA USE AND TOTAL WATER CONSUMPTION FOR JEDDAH AND MECCA CITIES

	JEDDAH			MECCA		
Year	Population	L/CPD Consumption	M^3/Day Water Demand	Population	L/CPD Consumption	M^3/Day Water Demand
1985	858,000	187	160,000	535,000	119	64,000
1990	1,095,000	190	208,000	747,000	138	89,000
1995	1,398,000	193	270,000	783,000	160	125,000
2000	1,800,000	197	355,000	948,000	185	175,000

Source: Sadhan, "Water Plan for Wadi Fatma Basin, Saudi Arabia," (Thesis), University of Wyoming, Laramie, Wyoming, 1980, p. 102.

(population and daily per capita use) were used to predict total water requirements for Riyadh in the years 1980 and 1990. The forecasted water requirements are 130 and 300 million cubic meter in 1980 and 1990.

Reid and Muiga (1976) tried to predict the municipal and agricultural water requirements in twelve Arabian countries, (ECWA) region. The countries are: Syria, Lebanon, Jordan, Iraq, Kuwait, Saudi Arabia, North Temen, South Yemen, Oman, United Arab Emirates, Bahrain, Oman and Qatar. The stepwise technique was utilized to select the appropriate variables out of many socio-economic and environmental factors. The following predictive equations were stated in their study:

$$M_{n,t} = 2.2113 + .0003\ NP_{n,t} + .0069\ GNP_{n,t} + .0017\ NC_{n,t} \quad (3\text{-}13)$$

$$A_{n,t} = 116.0224 + 0.0046\ NP_{n,t} + .0069\ GNP_{n,t} + 0.056\ HLI_{n,t} \quad (3\text{-}14)$$

$$I_{n,t} = 0.7587 + 0.0018\ NP_{n,t} + 0.1373\ GNP_{n,t} + 789.8\ WF_{n,t} \quad (3\text{-}15)$$

where

$M_{n,t}$ = municipal water demand for country n at year t in gallon per capita per day

$A_{n,t}$ = agricultural water demand for country n at year t in gallon per capita per day

$I_{n,t}$ = industrial water demand for country n at year t, in gallon per capita per day.

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

IN_t = national annual per capita income in U.S. dollars of country n at year t

$NC_{n,t}$ = national percentage of homes connected with water supply of country n at year t

$GNP_{n,t}$ = per capita-gross national product in U.S. dollar of country n at year t

$HLI_{n,t}$ = national irrigated land of country n at year t in thousands of hectares

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

where

X_1 = percentage of national work force who are professional

X_2 = percentage of national work force who are skilled

X_3 = percentage of national work force who are unskilled

Reid and El-Messidi (1977) performed a similar study for the same countries. They created municipal, agricultural and industrial models for each country in the ECWA region. The three following models were developed for Saudi Arabia.

a. The municipal water demand model

$$Y_i = 22.85 + 4.66\ (\text{pop}) + 0.0002\ (\text{ENRO}) \quad R^2 = 0.9999 \qquad (3\text{-}16)$$

Standard error of estimate = 0.029

b. The industrial water demand model

$$Y_2 = -\ 122.53 + 25.53\ (\text{pop}) + 0.0016\ (TG_p) \quad R^2 = 0.999 \qquad (3\text{-}17)$$

Standard of estimate = 0.1944

c. The agricultural water demand model

$$Y_3 = 5.36 + 7.32\ (\text{pop}) + 0.0071\ (\text{ppc}) \quad R^2 = 0.9928 \qquad (3\text{-}18)$$

Standard error of estimate = 0.4493

where

Y_1 = municipal water use in gpcd

pop = total population in millions

ENR_o = total student enrollment by all levels of education in thousands

Y_2 = industrial water use in gpcd

TG_p = total national gas production in million cubic meters

Y_3 = agricultural water use in gpcd

pp_c = production of principal crops in thousands of metric tons.

In each of the above three models R^2 is very high and standard error of estimate is low. This indicates the three models are good, especially if the basic assumptions of the regression technique are met. (This issues, validity of basic assumption, will be discussed later in the course of this paper (Chapter 4).)

CHAPTER IV

METHODOLOGY

One of the goals of this study is to predict the water requirement in Saudi Arabia in the future through year 2010. The central theme of prediction, regarding the water requirement, is the assumption that some pattern exists in the past and this pattern will continue at a regular fashion over the next three decades.

The simplest way of deriving some pattern is by examining the historical data of the water requirement and then, through extrapolation the future water requirement may be projected. However, the matter is much more complex than that. Typically water requirement is not only influenced by time, but by many other factors as well. Future water use is more than some simple function of the past use. In fact, from the theoretical background discussed in Chapter One, it may be concluded that water requirement is a function of several variables such as population, wealth, health, level of income, level of education, degree of urbanization, etc. Thus, we should look for another pattern which contains all those variables, as much as possible and try to identify the relationship between them and the water requirement.

The multiple regression technique allows us to take into account all the variables which have a relationship with water requirements. Further, it is capable of deleting the variables which do not have significant relationships. It is also an excellent technique for discovering the shape of the trend and, it can handle all types of data. Thus, it provides a flexibility not present in some other techniques (see Chapter Three). It is also capable of testing different hypothesis regarding each variable as well as the whole model. Further, the regression technique allows us to make statistical statements about the accuracy and significance of each parameter in the model (Maddal, 1977). However, the regression technique has its own limitations. One of the most important points to remember is the validity of the regression application for prediction depends upon whether or not the existing pattern of the available information will continue in the same fashion in the periods ahead. It seems that this assumption is reasonable for Saudi Arabia due to the following facts. Saudi Arabia is a country rich in energy resources and minerals. Because of this, the Saudi economy is less constrained by external forces that are able to affect most western economies. Further, these resources give the country trade leverage to overcome any potential deficiency. And with the diverse investments made by Saudi Arabia the economy is becoming increasingly less dependent on oil and gas every day.

Regression analysis for predictive purposes will depend upon trends not being halted abruptly by constraining factors. In the case of Saudi Arabia, however, there seems to be no major constrining factors except perhaps the supply of water itself. In general Saudi Arabia's growth is unlikely to be impeded since the country is still so far away from being fully developed.

Multiple regression analysis will be used in this study and consequently will be discussed briefly in the rest of this chapter. If more detail is needed, any of the listed references in the bibliography may be consulted.

Multiple regression analysis is a statistical tool which utilizes the relationship between three or more variables so that one variable can be predicted from the others.

The true basic model can be stated as follows:

$$y_i = \beta_o + \beta_1 X_{i,1} + \dots + \beta_{k-1} X_{i,k-1} + \varepsilon_i \qquad (4\text{-}1)$$

where

y_i is the value of the dependent variable in the i^{th} trial.

$X_{i,1}, X_{i,2} \ldots X_{i,k-1}$ are known constants or the values of the independent variables in the i^{th} trial.

β_o is the intercept of the regression line.

β_1 indicates the change in the mean of the probability distribution of y_i per unit change in X_i while $X_2, X_3 \ldots X_{k-1}$ are kept constants.

$\beta_2, \ldots \beta_{k-1}$ through the same arguments, each indicates the change in the area of probability distribution of y_i per unit change in its respective X while other X's are kept constants. Mathematically speaking

$$\beta_1 = \frac{\partial E(y)}{\partial X_1}$$

$$\beta_2 = \frac{\partial E(y)}{\partial X_2}$$

$$\beta_{k-1} = \frac{\partial E(y)}{\partial X_{k-1}}$$

ε_i is a random error term for the i^{th} trial with the following assumptions:

1. The mean of these random error terms is zero, i.e. $E(\varepsilon_i) = 0$
2. The error terms have a constant variance, i.e.

$$\sigma^2 (\varepsilon_i) = \sigma^2$$

3. The error terms are uncorrelated, so that the covariance $\partial(\varepsilon_i, \varepsilon_J) = 0$ for all $i, J,$; $i \neq J$

The model

$$y_i = \beta_0 + \beta_1 X_{i,1} + \ldots + \beta_{k-1} X_{i,k-1} + \varepsilon_i$$

may be expressed in a matrix form as follows:

$$\begin{bmatrix} Y_i \\ Y_2 \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ Y_n \end{bmatrix} = \begin{bmatrix} 1 & X_{11} & X_{12} & \cdots & X_{1,k-1} \\ 1 & X_{21} & X_{22} & \cdots & X_{2,k-1} \\ \vdots & \vdots & \vdots & & \vdots \\ 1 & X_{n_i} & X_{n_2} & & X_{n,k-1} \end{bmatrix} \begin{bmatrix} \beta_0 \\ \beta_1 \\ \beta_2 \\ \vdots \\ \beta_{n-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_n \end{bmatrix}$$

or

$$\underset{(n1)}{Y} = \underset{(nk)}{X} \ \underset{(k1)}{\beta} + \underset{(n1)}{\varepsilon} \qquad (4\text{-}2)$$

where

Y is a vector of observations of the dependent variable

X is a matrix of constants of independent variable

β is a vector of explanatory parameters

ε is a vector of random errors

Each observation in Y (vector of observations) is a sum of two terms

$$Y_i = [\beta_o + \beta_1 X_{i,1} + \ldots + \beta_{k-1} X_{i,k-1}] + \varepsilon_i \qquad (4\text{-}3)$$

The first term in the above equation is constant and ε_i is a random error. In other words

$$y_i = \text{constant} + \text{random error}$$

Hence y_i is a random variable, and the mean of its probability distribution can be stated as follows:

$$E(y_i) = E(\beta_0 + \beta_1 X_{1,i} + \ldots + \beta_{k-1} X_{k-1,1}) + E(\varepsilon_i)$$

but from our assumption

$$E(\varepsilon_i) = 0$$

In a matrix form, the random vector Y has expectation

$$E(Y) = X\beta$$

Hence

$$E(y_i) = E(\beta_0 + \beta_1 X_{1,i} + \ldots + \beta_{k-1} X_{k-1,i})$$

and we know that β_0, β_1, ..., β_{k-1} are all constant. So

$$E(y_i) = \beta_0 + \beta_1 X_{1,i} + \ldots + \beta_{k-1} X_{k-1,i} \qquad (4\text{-}4)$$

Thus, equation (4-1) implies that the response variable observations Y_i come from a probability distribution whose means are

$$E(y_i) = \beta_0 + \beta_1 X_{1,i} + \ldots + \beta_{k-1} X_{k-1,i}$$

The variance of the response variable y_i may be written as follows:

$$\sigma^2(y_i) = \sigma^2(\beta_0 + \beta_1 X_{1,i} + \ldots + \beta_{k-1} X_{k-1,i}) + \sigma^2(\varepsilon_i)$$

As it has been stated before in equation (4-3) that

$$(\beta_0 + \beta_1 X_{1,i} + \ldots + \beta_{k-1} X_{k-1,i})$$

is a constant term, and since the variance of a constant term is zero. Thus the variance of the response variable y_i is

$$\sigma^2(y_i) = \sigma^2(\varepsilon_i)$$

It is also assumed that ε_i has a constant variance, thus

$$\sigma^2(y_i) = \sigma^2(\varepsilon_i) = \sigma^2$$

Also, along with the constancy of the variance of the residuals we also assume them to be independent. Thus in the matrix form

$$\sigma^2(Y) = \sigma^2 I$$

where

I = identity matrix

Estimation of Regression Parameters

$\beta_0, \beta_1, \ldots, \beta_{k-1}$ in equation (1) are called regression parameters and they are unknown but remain constant. The procedure used to estimate these parameters, is the least square methods. This procedure has certain properties. It provides for the best linear unbiased estimates (BLUE). The idea behind BLUE is to find the mimimum sum of squares of the deviation of the estimated line from the true values given that the model is linear and unbiased (Figure 4-1). In mathematical terms

$$D = \sum_{i=1}^{n} \varepsilon_i^2 = \sum_{i=1}^{n} (y_i - E(y_i))^2$$

apply equation (2)

$$D = \Sigma(y_i - \beta_0 - \beta_1 X_{1i} - \ldots - \beta_{k-1} X_{k-1,i})^2 \qquad (4-5)$$

We shall choose our estimate $b_0, b_1, \ldots, b_{k-1}$ such that D is minimized.

We can determine b_0, b_1, ..., b_{k-1} by differentiating equation 4-5 with respect to β_0, β_1, β_2, ..., β_{k-1} respectively and setting the results equal to zero. Since we have several variables, differentiating, arranging and solving for b_0, b_1, b_2, b_{k-1} can be difficult and tedious. However, the matrix mechanism may help in solving this problem as follows:

Equation 4-2 states

$$\underset{(n1)}{Y} = \underset{(nk)}{X}\ \underset{(k1)}{\beta} + \underset{(n1)}{\varepsilon}$$

or

$$\underset{(n1)}{\varepsilon} = \underset{(n1)}{Y} - \underset{(nk)}{X}\ \underset{(k1)}{\beta}$$

but

$$\underset{n1}{\varepsilon} = \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \varepsilon_n \end{bmatrix}$$

Hence, $D = \Sigma \varepsilon_1{}^2 = \varepsilon' \varepsilon$

$$= [\varepsilon_i\ \varepsilon_2\ \dots\ \varepsilon_n] \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \cdot \\ \cdot \\ \cdot \\ \varepsilon_n \end{bmatrix}$$

$$= [Y - X\beta]'[Y - X\beta]$$

$$= Y'Y - \beta'X'Y - Y'X\,\beta + \beta'X'X\quad\beta$$

but $(X\beta)' = \beta'X'$

and Y X β is a (1 x 1 matrix) which is also equal to its transpose β X Y

Thus

$$D = Y'Y - 2\beta'X'Y + \beta'X'X\,\beta$$

to find the values of β which minimize D, we differentiate with respect to $\beta_o, \beta_1, \ldots, \beta_{k-1}$

$$\frac{\partial D}{\partial \beta} = \begin{bmatrix} \frac{\partial D}{\partial \beta_0} \\ \frac{\partial D}{\partial \beta_1} \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \frac{\partial D}{\partial \beta_{k-1}} \end{bmatrix}$$

then it follows that:

$$\frac{\partial D}{\partial \beta} = -2X'Y + 2X'X\,\beta$$

we equate this equation to zero and substituting b for β gives

$$X'X\,b = X'Y$$

if X´X is non singular, the solution of this equation is

$$b = (X'X)^{-1}\,X'Y \qquad (4\text{-}6)$$

since $(X'X)^{-1} X'$ is a matrix of constants, the elements of the b vector are linear functions of y. Thus b is called a linear estimator. To show that the b vector is an unbiased estimate of the β vector, we substitute equation 4-2 into equation 4-6. We get the following:

$$b = (X\ X)^{-1} X\ (X\ \beta + \varepsilon)$$

$$= \beta + (X\ X)^{-1} X\ \varepsilon$$

or

$$E(b) = \beta + (X\ X)^{-1} X\ E(\varepsilon)$$

but

$$E(\varepsilon) = 0$$

$$E(b) = \beta$$

Thus, b is unbiased estimate of β. We may conclude that vector b has the following properties:

1. b is an estimate of β which minimize the error sum of squared D
2. The elements of matrix b are a linear function of the observations y_i
3. b is an unbiased estimate of the unknown parameters.

After we have estimated the explanatory parameters we would like to calculate their variances.

The variance of b vector may be expressed as follows:

$$V(b) = E(b - \beta)\ (b - \beta)'$$

$$= (X'X)^{-1}\ X'E(\varepsilon\varepsilon')\ X\ (X'X)^{-1}$$

but

$$E(\varepsilon\varepsilon') = I\ \sigma^2$$

Thus

$$V(b) = \sigma^2 (X'X)^{-1} \tag{4-7}$$

Equations 4-6 and 4-7 will be used to calculate the regression coefficients and their standard errors, where standard error equal the square root of the variance, i.e.

$$\sigma = \sqrt{\alpha^2}$$

Significance of Regression Equation

After we have constructed our model by estimating the parameters of the regression line, we should test these parameters and make sure that they are significantly different from zero. The t-test may be used to determine the significance of the regression coefficient as follows: Since we computed the values of the coefficients and their standards errors in equations 4-6 and 4-7, the number of standard deviations (t) from the mean (b_i) may be computed by the following

$$t = \frac{\text{Value of } b_i}{\text{Standard error of } b_i}$$

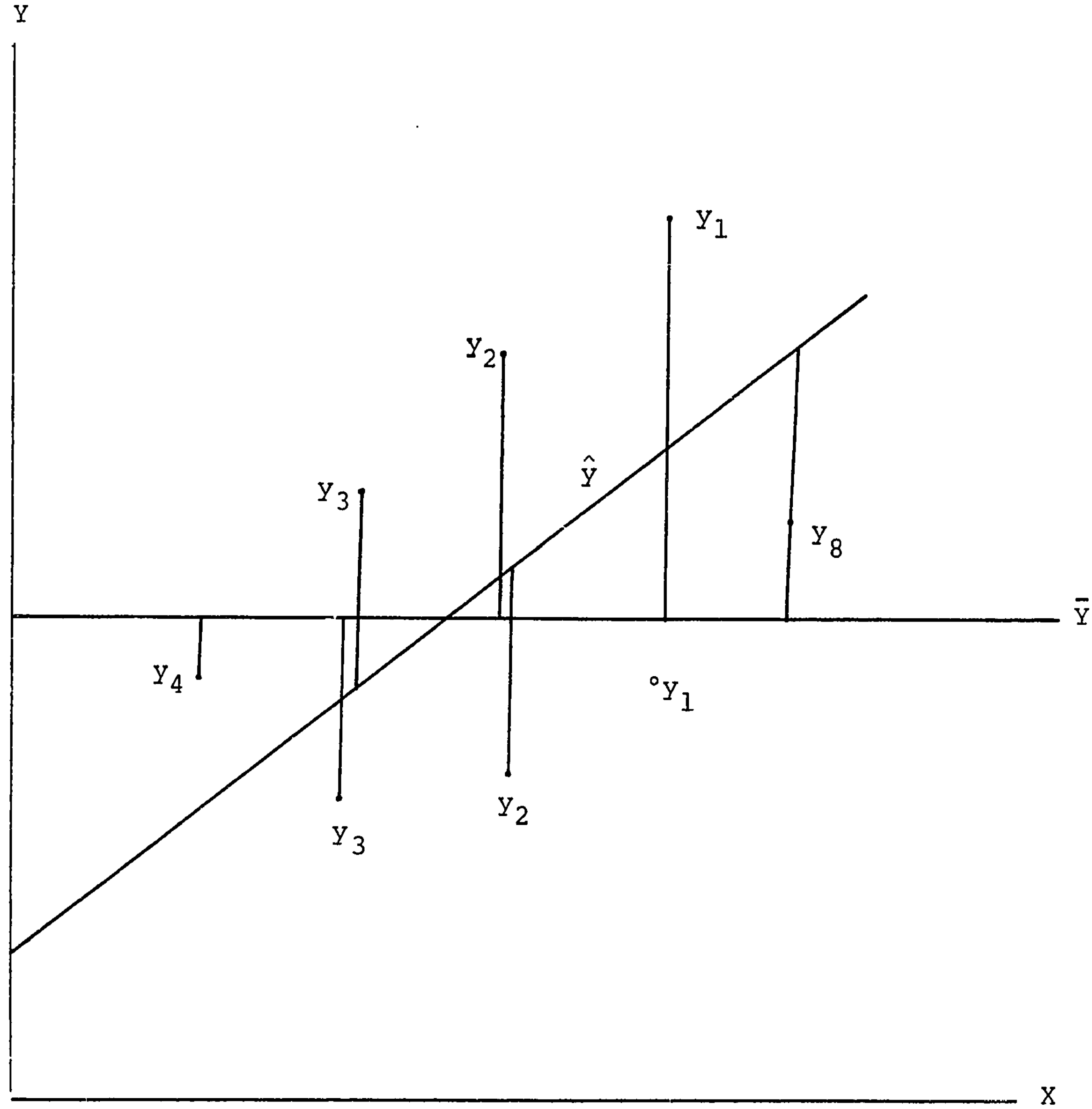
This t (computed value) is then compared with some critical t value to test whether or not the value of that coefficient is significant. The critical t is derived from a normally distributed function (area = 1) given a particular sample size and level of confidence. It tells us the number of standard deviation units we should expect to vary from some mean given a predetermined probability of acceptance. To clearify, let us assume that the value of $b_1 = 3$ and the standard error $\sigma(b_1) = .30$. Then t (computed) = 3/0.3 = 10. Thus the b value we computed is 10 standard error units from zero. Now when we compare it with a tabulated t value we may conclude with almost 100% certainty that the regression coefficient is significantly different from zero, (since over 99% of all expected values are within 3 standard error units of any given mean). We could test the significance of any of other coefficients in similar manner.

Although the t-test indicates the significance of each of the coefficients, another test called the F-test is used to determine the significance of the entire regression equation through the analysis of variance.

Total variation is defined as the sum of the square of the differences between each of the dependent observations and their mean, see Figure 4-1. In mathematical term

$$\text{Total variation} = \Sigma(Y_i - \bar{Y})^2$$

Figure 4-1.



For simplicity, the graph represents simple regression case where one independent variable is used.

Total variation $= \sum_{i=1}^{8} (Y_i - \bar{Y})^2$

Explained variation $= \sum_{i-1}^{8} (\hat{Y}_i - \bar{Y})^2$

Unexplained variation $= \sum_{i=1}^{8} (Y_i - \hat{Y}_i)^2$

This variation may be divided in two categories: Explained and Unexplained variation, where Total variation is the sum of Explained variation and Unexplained variation

Where

$$\text{Explained variation} = \Sigma(\hat{Y}_i - \bar{Y})^2$$

and

$$\text{Unexplained variation} = \Sigma(Y_i - \hat{Y}_i)^2$$

When these variations are divided by their degree of freedom, we have the so-called variance

Total variance = total variation/n

Explained variance = Explained variation /k-1

Unexplained variance = Unexplained variation/n-k

where

n = number of observation

k = number of variables

The ratio of explained variance to the unexplained variance is the so-called F-Statistics

$$F = \frac{\text{Explained Variance}}{\text{Unexplained Variance}}$$

In a mathematical term

$$F = \frac{\Sigma(\hat{Y}_i - \bar{Y})^2/(k-1)}{\Sigma(Y_i - \hat{Y}_i)^2/n-k}$$

To write that in a matrix form, we have the vector of the unexplained residuals

$$e = Y - \hat{Y}$$

or

$$e = \begin{bmatrix} e_1 \\ e_2 \\ \cdot \\ \cdot \\ \cdot \\ e_n \end{bmatrix} = \begin{bmatrix} Y_1 - \hat{Y}_1 \\ Y_2 - \hat{Y}_2 \\ \cdot \quad\quad \cdot \\ \cdot \quad\quad \cdot \\ \cdot \quad\quad \cdot \\ Y_n \quad \hat{Y}_n \end{bmatrix} = [Y - Xb]$$

$$e' = [e_1 \; e_2 \; \ldots \; e_n]$$

$$e' e = [e_1 \; e_2 \; \ldots \; e_n] \begin{bmatrix} e_1 \\ e_2 \\ \cdot \\ \cdot \\ e_n \end{bmatrix}$$

$$= \Sigma e_i^2$$

Thus

$$\Sigma e_i^2 = (Y - Xb)' (Y - Xb)$$

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

From equation (5)

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

Hence

$$e'e = Y'Y - 2b'X'Y + b'I'XY$$

$$= Y'Y - b'X'y$$

$$= \text{Unexplained Variation}$$

Similarly,

$$\text{Explained variation} = b'X'Y - N\ \bar{Y}^2$$

and

$$\text{Total variation} = Y'Y - n\ \bar{Y}^2$$

Hence

$$F = \frac{[b'X'Y - n\ \bar{Y}_2/k-1}{Y'Y - b'X'Y/n-k}$$

Now the value of F calculated must be compared with the appropriate entry in a table of F values (predetermined in a similar fashion as were the critical t values) to determine whether or not the model is significant at a desired level. Generally speaking, the higher the F value the greater the ratio of explained to unexplained error and hence the more acceptable the estimate.

Multiple and Partial Correlation

The coefficient of multiple correlation (R^2) is defined as

$$\text{Multiple Correlation} = \frac{\text{Explained Variation}}{\text{Total Variation}}$$

or

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

$$= \frac{b'X'Y - n\ \bar{Y}^2}{Y'Y - n\ \bar{Y}^2}$$

It measures the proportion of total variation explained by the independent variables to the total variation in y. When we have only one independent variable, say X_1, the correlation coefficient measures the reduction in the total variation due to X_1 only. Let us denote this R^2 as r^2y_1,X_1. Similarly, if we have several variables X_1, X_2, X_3, then r^2y,X_2 and r^2y,X_3 denote the reduction in variation explained by X_1, X_2 and X_3 respectively. Now, we would also want to know something else. For example, how much does X_2 explain after X_1 is included? How much does X_3 explain after X_1 and X_2 are included? These are measured by the partial correlation coefficients. For example r^2yX_2,X_1 measures the correlation between Y and X_2 after the effect of X_1 has been considered to effect.

To compute the partial correlation coefficient, let us assume for simplicity we have two independent variables X_1 and X_2 and $r^2_{Y_{X_2,X_1}}$ and $r^2_{Y_{X_1,X_2}}$ are computed as follows:

$$r^2_{Y_{X_1,X_2}} = \frac{t_1^2}{t_1^2 + N}$$

$$r^2_{Y_{X_2,X_1}} = \frac{t_2^2}{t_2^2 + N}$$

Partial correlation is very important in deciding whether or not to include more independent variables. Suppose we have two independent variables X_1, X_2 and r^2_{Y,X_1} and r^2_{Y,X_2} are both high, but $r^2Y_{X_2,X_1}$ is very low. What this says is, if X_2 is added to the equation which already has X_1, X_2 does not help much in explaining y (the dependent variable). Hence in this case there is little use including X_2.

The Examination of the Residual

The residuals e_i are the difference between what is actually observed, and what is predicted by the equation. In other words, they measure the amount of the dependent variable which independent variables are not able to explain. The mathematical term of those observed residuals are

$$e_i = y_i - \hat{y}$$

If we recall from equation 4-1, we have made several assumptions about the unknown true error ε_i

$$\varepsilon_i = y_i - E(y_i)$$

and what we would like to know is that our assumptions do not appear to be violated. To check that, usually we perform a procedure known as graphic analysis of residuals. The residuals may be plotted against the fitted values $\hat{y}_i$ or against the independent variables $X_1, X_2 \ldots X_{k-1}$ or sometimes, in a time sequence if the order is known. In any of the above the existence of a horizontal band usually (see Figure 4-2a) indicates that our assumption has not been violated. However, any departure from that horizontal band is considered as a warning of assumption violation. Figures 4-2b, 4-2c and 4-2d show different pattern. For example Figure 4-2b shows that the variance is not constant but increasing with time and a transformation on y_i may be needed to keep our estimate from being biases. Figure 4-2c indicates that a linear term expressed as a function of time should be included in the model. And finally in Figure 4-2d linear and quadratic terms should be included to keep the model unbiased.

There is also another way of checking the validity of the afore mentioned assumption. Certain statistics have been suggested which provide a numerical measure such as F-test for linearity, goodness y-fit test for examining the normality and Durbin-Watson test to check the constancy of variance (Neter and Wasserman, 1974). Although the graphical analysis is a visual technique, it is often as informative if not more informative than certain statistic tests, and will almost certainly reveal potential violations of assumptions.

Figure 4-2a

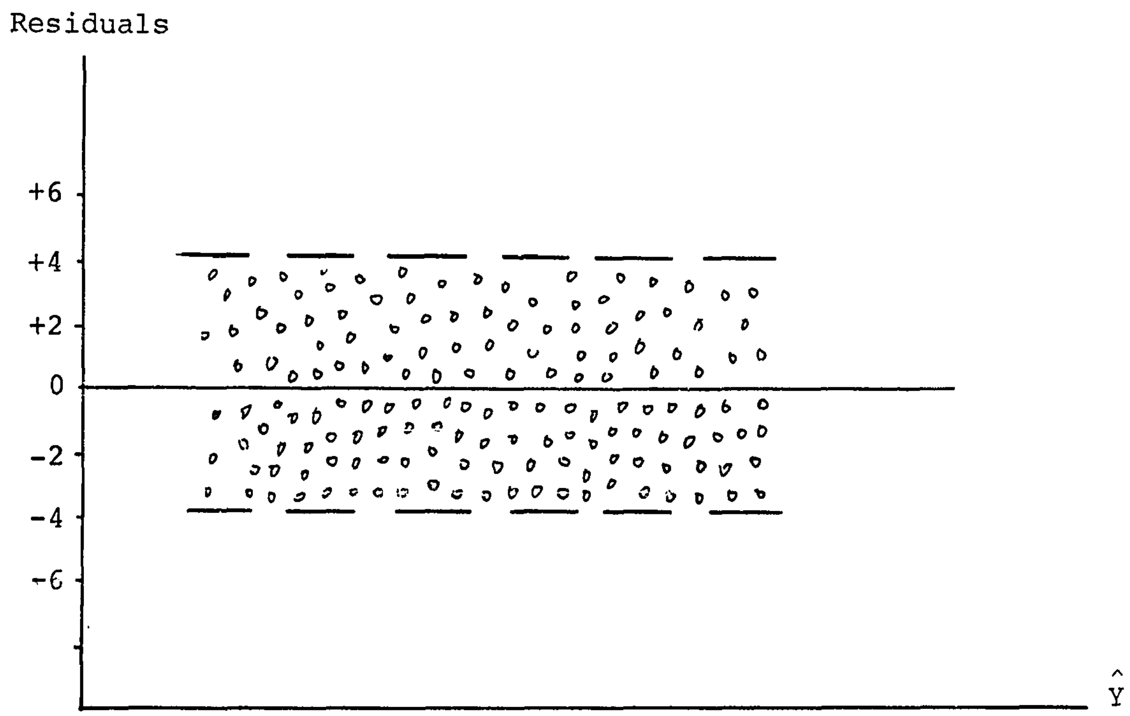


Figure 4-2b

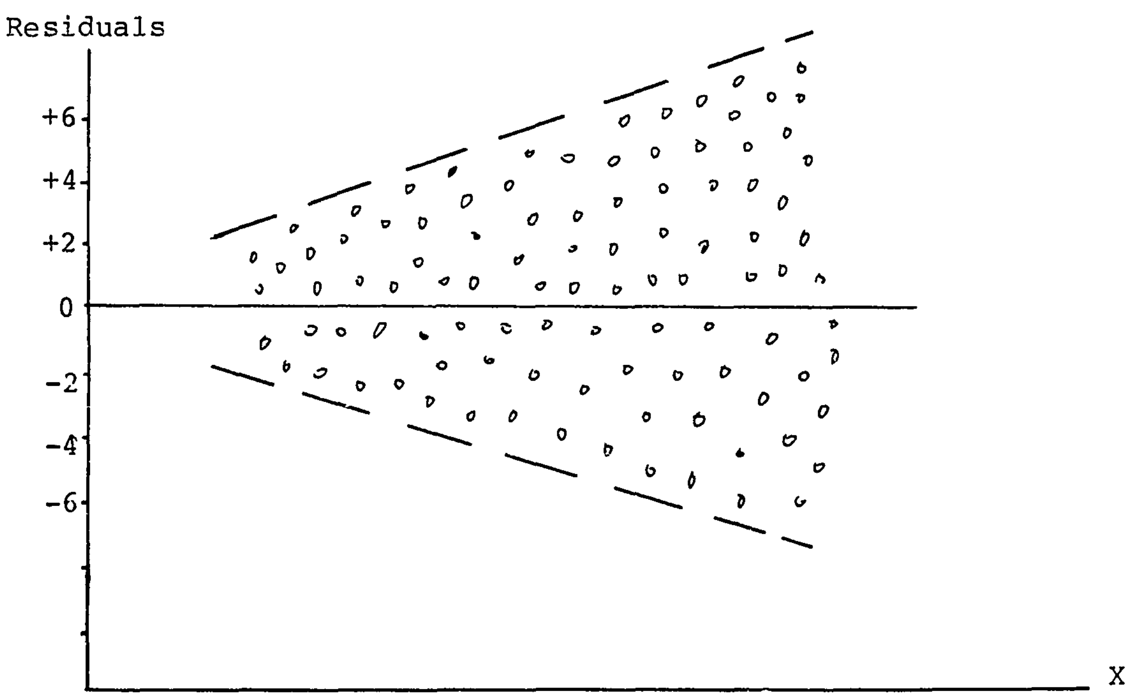


Figure 4-2c

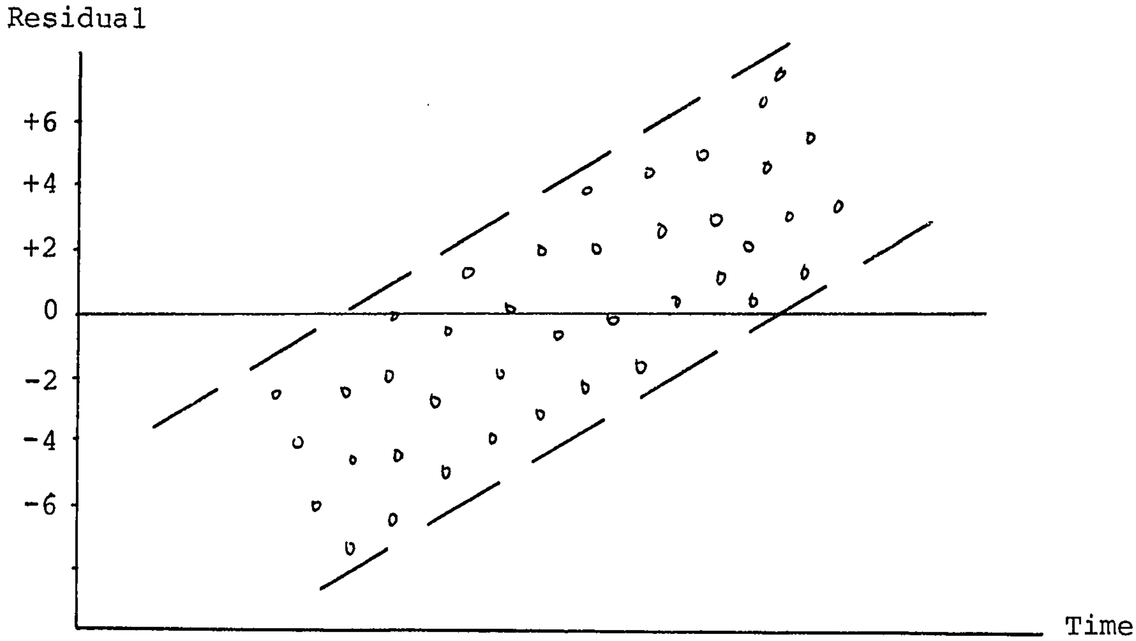
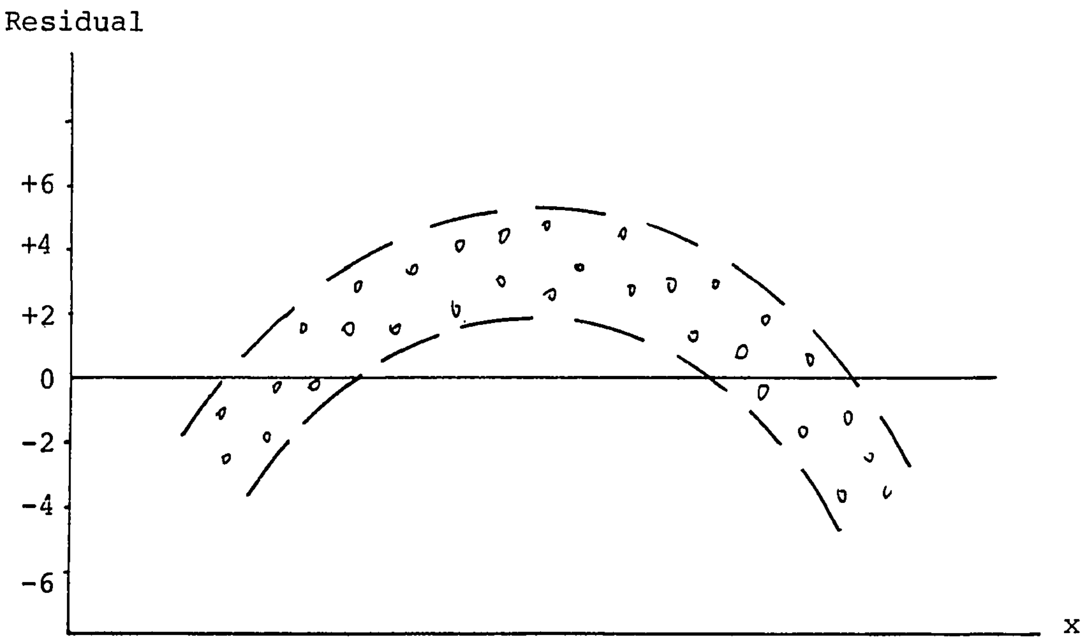


Figure 4-2d



Multicolinearity

Multicolinearity refers to the situation in which some or all of the independent variables are highly correlated. If there is perfect multicolinearity the matrix (XX') will be singular and there is a computational problem. Usually there is no perfect multicolinearity among the explanatory variables but high multicolinearity may exist. The main problem of multicolinearity is that it may affect the accuracy of the results of regression analysis. The coefficient of determination can be very large but one or more of the t-values can be very small indicating that some individual regression coefficients are not significant. The other problem of multicolinearity is "non-constancy" which implies that the estimates of the regression coefficient from sample to sample fluctuate significantly. One of the uses of multiple regression analysis is to evaluate the relative importance of different independent variables. However, when a high multicolinearity exists, the relative importance of each variable is less reliable.

The existance of multicolinearity is usually detected by examining the simple correlation matrix which shows the correlation between each set of independent variables. There are several suggested solutions to multicolinearity such as: obtaining more data, dropping some of the variables, adding new variables and creating new variables from the existing data. Each of the above solutions has its own advantages and disadvantages depending upon the situation (for more detail reference (35,23) are recommended).

Selecting the Best Set of Independent Variables

When the number of independent variables is large, there are two opposed criteria of selecting the best set of independent variables. The first one is to include as many independent variables as possible so that the reliables fitted values can be determined. The second one is to include as few independent variables as possible so that multicolinearity and cost (in terms of compilation and computation, etc.) will be minimized. Compromise usually leads us to some middle solution. Unfortunately, there is no unique statistical procedure for determining which variables to include. However, the following methods have been used in attempting to find the best set of explanatory independent variables

1. All possible regression
2. Backward-elimination
3. Forward selection
4. Stepwise method

Personnel judgment will be a necessary part in selecting one of the above methods.

Neter (1974) suggests a combination of the first and the last method. He recommends that the stepwise method be run first and then all possible regressions run to check whether or not there is a match between the two techniques.

Maddal's solution is to initially choose all variables which have strong theoretical significance and continue from this point only after examining the initial results. He states:

> "All these regression - selection procedures can be easily misused. It is too easy to let the computer pick up variables. What one should do is exercise some judgment in the initial selection of variables, and also examine at each stage whether the equation estimated makes sense. This involves an examination of the signs and magnitudes of coefficients and an analysis of the residuals."(1)

It has been decided in this study that all possible regression and stepwise method will be used together in an attempt to come up with the "best" set of independent variables. Then Maddal's recommendation will be applied to test the significance of the suggested models.

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[1]Maddal, G.A., "Econometric," McGraw-Hill, New York, 1977, p. 126.

Since the all possible regression and stepwise methods will be used in this study, a brief description of their mechanism will be discussed as follows:

All Possible Regression

In this technique $(2^k - 1)$ equation will be examined where k is the number of independent variables. For example if there is four independent variables, 15 equations will be tested. The best equation will be selected according to some criteria. The criteria may be the increase in R^2 (coefficient of determination) or the reduction in the unexplained variation.

Stepwise Method

This is the most widely used method for selecting a set of independent variables in the model. Essentially, this method computes a sequence of regression equations adding or deleting an independent variable. The independent variable with the greatest value of coefficient of determination will be the first candidate to be in the model. The second independent variable will be the one which has the greatest partial coefficient. After the addition of the second variable, the first variable will be examined to check whether or not its presence is significant. The addition or deletion of an independent variable is based on the result of an overall and partial F-test. This mechanism will continue until no further independent variable can either be added or deleted.

CHAPTER V

THE DEVELOPED WATER REQUIREMENTS MODELS

Municipal water requirement for the whole country, Saudi Arabia, will be estimated (using a linear regression model) with particular socio-economic and climatological variables such as population, national income, level of education..., precipitation and temperature. In order to develop the municipal water requirements model, the historical data of the relevant variables had to be researched and collected from different sources (see data sources in the Appendix D). Unfortunately, data for the relevant variables was not adequate to build a municipal model for the whole country. This is because data from rural areas was incomplete. Nevertheless, fair data can be obtained for major cities and small towns.

Because of the scarcity of information about the rural section of the country, another approach was attempted. The approach is to divide the total municipal water requirements into two main categories: rural and urban. The urban model will be developed statistically while the rural requirement will be based upon general observations from previous studies and visits to such areas.

In 1962 United Nations (UN, 1962) estimated the daily per capita use in the rural section to be 3-4 gallons. Later on, several studies were conducted by (Muiga, 1975, MAW, 1980) for the same purpose. From a review of those studies, it may be concluded that the daily per capita use ranges from 5-10 gallons. In 1981, the author visited several rural locations in the country for almost a month, in order to estimate the daily per capita use. He found the average usage to be 8.5 gallons per capita per day with a standard deviation of 2.0 gallons. Further, the above literature reveals that there is an increasing trend in the daily per capita water use in rural areas. Much of this is due to government intervention providing an increase in public services such as schools, hospitals, etc., to improve the living standard of these rural citizens (Ministry of Planning, 1980).

Based on the above discussion, the author assumes the average use to be 8.5 gallon per capita per day with one gallon increase per year for the foreseeable future. The model may be expressed as follows:

$$Y_{r,t} = (POP)_{rt} \times (8.5 + t) \qquad (5\text{-}1)$$

where

$$Y_{r,t} = \text{water requirement for the rural section of the country in year } t$$

$$(POP)_{r,t} = \text{rural population in year } t$$

$$t = 1,2,3,\ldots,30, \text{ from 1980 to 2010}$$

This model will be used in this study to forecast the domestic water requirements for rural sections

Urban Water Requirements

Although the historical data of urban water requirements from major and small cities are available, these water usage amounts do not represent the total urban water requirements for these cities. The reason behind this is as follows: some parts of each city are not connected to the government water system. These non-connected houses meet their water needs (usually) from some local source which is not included in the given data.

The percentage of connected houses differ from one city to another. However, the percentage of connected houses has been increasing with time since 1960. In 1970 the average percentage was less than 30 percent while it is 38 at present (MAW, 1980). Further, (L'vivoch, 1976) estimates the average use of a house which is not connected to the water system to be around 75 percent of those houses which have the system. From the above discussion, the historical data of the urban water requirements may be modified as follows:

$$y_{ij} = A_{ij} + 0.75 \text{ X } B_{ij} \text{ X } A_{ij} \qquad (5\text{-}2)$$

where

y_{ij} = the total urban water requirement, for city j in year i

A_{ij} = the given urban water requirements for city j in year i

B_{ij} = the percentage of non-connected houses in city J in year i

i = 1960-1980.

The following variables will be utilized to develop the urban model.

y_{ui} = total urban water requirements in million gallon's per year for year i

X_{1i} = total population of major cities and small towns in thousands in year i

X_{2i} = gross domestic products of the kingdom in million Riyals in year i

X_{3i} = total number of houses connected to the water system in thousands in year i

X_{4i} = total number of students in the country in thousands in year i

X_{5i} = number of population by physicians in thousands in year i

X_{6i} = average price of 1000 gallons of water in Riyals in year i

X_{7i} = mean annual precipitation in the country in millimeter in year i

X_{8i} = mean annual temperature of the Kingdom in celcuis degree in year i

The stepwise regression analysis and the all possible regression were used to develop the urban model by utilizing the above variables: Y_{ui} as a dependent variable and X_{1i}, X_{2i}, $X_{3i} \ldots X_{8i}$ as independent variables.

All possible regression analysis was used, as a first trial, searching for the best set of those variables. Several combinations of the variables were suggested by the program. However, as expected, temperature, price and precipitation were not given in any of those sets. The reason for the exclusion of temperature, price and precipitation is that their correlation with urban water requirements (dependent variable) was low. This is because, temperature and price values were relatively constant through the 21 year period, 1960-1980.

Other trials using stepwise technique were attempted to screen out variables which are not significantly related to the urban water requirements. Several predictive equations from different combinations of independent variables are shown in Table 5-1. It is

Table 5-1

Model I

$$y = -7003.5 + \underset{3.6}{11.42}\ pop + \underset{32.4}{100.33}\ Hom$$

$R^2 = .980$ $\qquad$ $F = 441.7$

Standard Error of Estimate = 2515

Model II

$$y = 1835 + \underset{14.7}{64.9}\ GN + \underset{24.6}{94.2}\ Hom$$

$R^2 = .98$ $\qquad$ $F = 615.9$

Standard Error of Estimate = 2165

Correlation Matrix

	y	pop	Hom	GN
y	1			
pop	.98	1		
Hom	.987	.978	1	
GN	.986	.993	.97	1

clear from Table 5-1 that each predictive model has a high coefficient of determination (R^2), all the independent variables have the appropriate sign and they successfully passed the F ratio tests. However, when residuāls analysis and correlation matrices were studied, two problems were detected in each model.

In the residual analysis, a certain pattern was found to exist in each model. This is consistant with the low value of the Durbin-Watson statistics achieved. When gross domestic product was examined, it was found that a very sharp increase in oil revenues took place in 1974 (see Table A-1). This was due to the high increase in the price of oil in 1973. Nonetheless, examination of the growth rate in oil revenued showed an average growth rate of 18 percent between 1960 and 1973, and 16 percent afterward - not much of difference. Consequently, to account for this jump in oil revenue as well as other variables directly and indirectly related to the increase in oil revenues in 1974, an indicator variable will be used as an independent variable in the prediction of urban water requirements. The indicator variable (INV) may be expressed as follows:

$$INV = 0 \text{ IF time} < 1973$$

$$INV = 1 \text{ IF time} \geq 1973$$

The second problem was discovered when the correlation matrices were studied. It was noticed that the inter-dependencies between independent variables were extremely high, which suggested that tests of multicolinearity were needed. When the independent variables were regressed against each other a high degree of multicolinearity between them was in fact discovered. This may have indicated that the inclusion of all independent variables is inappropriate. The reason is that high levels of multicolinearity can cause significant bias in the regression coefficients of the independent variables. The result is that the coefficient may not reflect any inherent effect of that independent variable on dependent variable but, only some partial effect.

Several methods were considered to reduce the degree of multicolinearity. Neter and Wasserman, 1974 suggested adding more observations which will hopefully break the pattern of multicolinearity. This approach was adopted in this study and monthly data were used for the last decade with dummy variables to overcome the problem of seasonality.

With the new modification, two other trials were attempted. The first one, utilized the independent variables given in page (97) plus the indicator variable (INV) for 21 years. The new output from several of the adjusted models was better than the previous models with lower standard of errors for the estimators. However the interdependency between the independent variables was still high. For this second model, only X_{1i}, X_{2i} and X_{3i} were available from the monthly data. After utlizing these variables with appropriate dummy variables, the final predictive equation was good, but still a high interdependency between the independent variables existed.

Since the previous trials did not help in reducing the multicolinearity effect, another approach suggested by Maddal, 1977 was tried. This method recommended using ratios or first differences (rate of changes) of variables to reduce the effect of multicolinearity. The first differences of the variables given in page (97) were calculated and several trials were attempted. The following model was found to be the best of several.

$$Dy = 1042.79 + 20.99 \text{ Dpop} + 4.65 \text{ DG} \qquad (5\text{-}3)$$

Model 5-3 has a high value of F ratio and the t-test shows the coefficients of the two independent variables to be significantly different from zero with a coefficient of determination $R^2 = 0.46$. The correlation matrix also shows the interdependency between X_{1i} and X_{2i} to have been reduced significantly.

Model 5-2 forecasts the annual increase in the urban water requirements. For example the Δy_{u83} represents the increase in the amount of urban water requirements in 1983. Thus the total amount of urban water requirements in 1983 may be expressed as follows:

$$y_{71983} = y_{u1982} + \Delta y_{71983} \qquad (5\text{-}4)$$

The author considered using a combination of rates of change of variables (dynamic) which have a high interdependency and static variables. Further a lagged variable of the dependent variable was used as an independent variable in an attempt to increase the value of the coefficient of determination (R^2). The following variables were used in addition to independent variables given in page (97).

1. $y_{u(i-1)}$ = the urban water requirements in year (i-1)
2. $\Delta(\text{Stud})_i$ = the annual increase in the number of the students in thousands in year i
3. $\Delta(\text{pop})_i$ = the annual increase in the number of population in thousands in year i

4. $\Delta(GNP)_i$ = the annual increase in gross national product in Millions Riyal in year i

5. $Ly_{u(i-1)} = Log_e\ y_{u(i-1)}$

6. $Ly_{ui} = Log_e\ y_{ui}$

7. $\Delta(Hom)_i$ = the annual increase in the number of houses connected to the water system in thousands in year i

INV = as defined before

Several trials were made trying to determine the best combination of the above mentioned variables fulfilling the basic assumption of the regression analysis technique. The following two models were found to be the best

a) $$Y_{ui} = 1401 + .87\ y_{u(i-1)} + 59.5\ \Delta(Stud)_i + 42.5\ \Delta(Hom)_i + 4501\ INV \qquad (5\text{-}5)$$

b) $$Y_{ui} = 388.5 + .393\ y_{u(i-1)} + 134.6\ \Delta(Stud)_i + 47.8\ (Hom)_i + 8435.6\ INV \qquad (5\text{-}6)$$

The use of the lagged water consumption in the above models increased R^2 from 0.46 to 0.998. The correlation matrices show significant reduction in the interdependency between independ variables. Further, the four independent variables have passed the F test and all of them have the appropriate sign. The standard error of estimators in both model was very low.

Residual Analysis

Generally, graphs of residuals are analyzed to provide information as to whether or not the suggested model meets the basic assumption of the regression technique. In other words, we should check the linearity of the regression function, the constancy of the error variance, and the independency and normality of the error terms.

Plots of the residuals against each of the independent variables as well as against the fitted values $\hat{Y}$ were given in the output. In all of these plots, the residuals do not show any systematic pattern of deviation. This may lead to the conclusion that there is no clear violation of our basic assumption about the linearity of the model, nor the constancy of error variance, nor the independency of the error terms. To enhance this conclusion, the Durbin-Watson test was run to test the null hypothesis of the presence of dependency among residuals. The test concluded that the null hypothesis were rejected at 0.01 and 0.05 levels. Normal probability paper were used to check for normality distribution of the error terms. The graphs shows that there is no reason to reject the assumption of normality (the two models are shown in detail in Appendix C).

Aptness of the Model

The final check on these two models is to check for constancy in predicting within the given data. The two models 5-5 and 5-6 with the first 16 years of observations were tried. The results were closely similar to those for the entire sample. However, as expected, the relevant importance of the indicator variable was reduced since it is applicable to the last 9 years of observations only. The models with 16 observations were used to forecast the urban water requirement for the last 5 years from 1975-1980. Model 5-5 was good but model 5-6 was more accurate. The predicted values were very close to the actual observations. Based on the above discussion, model 5-6 will be used to forecast the urban water requirements through the year 2010.

Irrigational Water Requirements Model

As mentioned before, irrigation water use in this study represents the total amount of water which has been abstracted from underground or diverted from some springs for irrigation and livestock purposes.

This amount of usage is related to several natural, socio-economic and technological factors (see Chapter One). Consequently, historical data on the irrigational use as well as relevant explanatory variables were collected and compiled. The variables to be used are listed below:

1. W_i = irrigational water requirement for the whole country in million cubic meter in year i
2. L_i = total irrigated lands in thousands of hectares in year i
3. G_i = total income from agriculture in millions of Riyals (base year 1965) in year i
4. S_i = total amount of subsidies for agricultural purposes in millions of Riyals (base year 1965) in year i
5. P_i = total population of the Kingdom in millions in year i
6. R_i = mean annual precipitation in millimeters in year i
7. M_i = mean annual production of meat in metric tonnes in year i
8. Tem_i = mean annual temperature in celcuis degrees in year i
9. Far_i = total number of farmers in thousands in year i

Several combinations of the independent variables were tried in an attempt to come up with the best possible set. The following models were found to be the most appropriate:

$$W = -287 + \underset{(71.8)}{589.3\bar{p}} - \underset{(2.4)}{4.75L} - \underset{(.33)}{.76R} \qquad (5\text{-}7)$$

$R^2 = .99 \qquad F = 458$

Standard Error of Estimate = 201

$$W = 618.5 + \underset{(.49)}{3.63G} - \underset{(7.45)}{40.6L} - \underset{(.36)}{.71R} \qquad (5\text{-}8)$$

$R^2 = .99 \qquad F = 388$

Standard Error of Estimate = 21.8

In the first model, total population and precipitation are found to be statistically significant while agricultural output and irrigated land are the dominant variables in the second model. Irrigated land and precipitation in each model respectively explain just a small amount.

The sign of the irrigated land coefficient in either model seemed to be inappropriate, however, since an increase in irrigated land should increase water requirements. Further, the correlation matrices showed that high multicollinearity exist between G, L and p.

Several transformation, e.g., taking the natural logarithm of several variables were attempted without too much success. Although these models had statistically significant coefficients with a low standard error of estimate, the problem of a negative sign of irrigated land coefficient still existed.

Another attempt was made by combining several independent variables such as the agricultural output per hectare, amount of subsidies per hectare...etc. Further, a dummy variable representing the potential economic growth after 1973 is also adopted as a new variable. Nevertheless while several sets of regression trials were made the results were unacceptable. Standard errors of regression coefficients were exceedingly high and individual T-tests for those regression coefficients indicated that none were significant.

As a last result, as in the urban model, the first differences of some of the variables were taken. Further a lagged variable representing the total irrigational water requirement in a previous year was added as a new variable. After several trials utilizing the new approach, the following two models were found:

$$W_i = 212.4 + \underset{(0.56)}{0.62\ WD} + \underset{(12.15)}{187.51\ Dp} + \underset{(.767)}{2.94\ L} + \underset{(10.3)}{33.98\ INV} \qquad (5\text{-}9)$$

$R^2 = 0.999$ $\qquad$ $F = 1975$

Standard Error of Estimate = 8.8

$$AW_i = 2.097 + .707\ AWD + .095\ Dp + .019\ INV + .05\ LD - 0.002\ R$$
$$\quad (.05) \qquad (.009) \qquad (.006) \qquad (.0024) \qquad (.001)$$

(5-10)

$R^2 = .999$ $F = 1136$

Standard Error of Estimate = .0052

where

W_i = the total irrigational water requirement for the whole country in million cubic meters in year i

AW_i = $\mathrm{Log}_e\ (w_i)$

W_D = the total irrigational water requirement for the whole country in million cubic meters in year (i-1)

AW_D = $\mathrm{Log}\ (W_D)$

Dp_L = the annual increase in the number of total population in thousands in year i

LD = the annual increase in total irrigated land in thousands of hectare in year i

L, R, INV = as defined before

In model 5-9, the irrigational water requirements are expressed as a function of the irrigated lands, the dynamic increase in population, the dummy variable which reflects the economic growth in the country after 1973 and the lagged variable representing the amount of water used for irrigational purpose one year back. In model 5-10 one more independent variable was added (precipitation) while the annual increase in irrigated land was selected instead of the total irrigated lands.

Both models 5-9 and 5-10 are found to be significant from a statistical standpoint. Coefficients of determination and F ratios are high and the standard error of estimate in either model was low. Further the signs of all regression coefficients in both models are correct. However, individual t-tests for the regression coefficients showed a higher degree of significance for the variables in model 5-9 than for those in model 5-10, thus model 5-9 was chosen for predictive purposes.[1]

As a first step to check the validity of the basic assumption of the regression model, the correlation matrix was examined. It was found that the multicollinearity had been reduced substantially between the four independent variables with the exception of the inter-dependency between WD and L. Nevertheless, while

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[1]I chose model 5-9 over 5-10 because given a small sample, I felt t-ratios should be higher than 2. Further model 8 loses predictive ability since future rainfall cannot ever be determined beforehand.

multicollinearity is a problem for the estimation of the regression coefficients, it is not a problem for prediction when the inter-dependency among independent variables is stable (Maddal, 1977). This is especially true in our case since the multicollinearity is high between only two of the independent variables. Further, it seems reasonable to assume that irrigated lands and the amount of water used one year back will both continue to significantly affect the irrigational water requirements independently regardless of their own interdependency. Consequently, both variables were left in the final model.

The second step for checking the validity of the basic assumption of the regression line is residual analysis. This analysis did not show any reason to assume that there is violation of the basic assumption (i.e., autocorrelation). Further, the numerical Durbin-Watson test enhanced the same conclusion that there is no interdependency between residuals.

A final check was made to examine the normality of the residuals. Normality paper graphs was used to check this and nothing was found to reject the normality distribution of the residuals.

[1]Based on the above discussion, it is decided that model 5-9 will be used to forecast the irrigational water requirements for Saudi Arabia up to year 2010. The irrigational water requirements model is given in detail in Appendix B.

Industrial Water Requirements Models

The purpose of this section is to develop several models to project the water requirements for the industries which are supplied with water from other sources, such as private wells, rather than the public water system. This is because industrial water taken from the public system has already been included in the urban water requirements.

Although the industrial sector in Saudi Arabia is of a small scale, the government plans to enlarge this sector mainly by refining oil and natural gas into final products. However, since water availability is very important to such industries, it must be met through some means if such a goal is to be achieved. Surface water is very limited and ground water, in general, is non-renewable. Although desalination can do the job, it is expensive and will undoubtedly increase production costs. Nevertheless, several steps have been made by the government to assist in reducing the problem of scarce water.

1. Fresh water intensive industries are to be discouraged now and excluded in the future.
2. Wastewater must be considered as a valuable resource.

3. Seawater should be used when ever it is feasible.
4. Industrial management should consider water conservation.

Evidence of these steps can be seen by the following. Two industrial cities, Yanbu and Jubail, are being constructed on the Red Sea and Arabian Gulf, respectively, so seawater will be available in unlimited amounts. Large facilities in these cities include major water intake and outfall channels with pumping stations and distribution systems being build to furnish seawater primarily for once through use as a cooling medium for heavy industries.

In oil industries, cooling water comprises more than 90 percent of the total water requirements. And since cooling water will be sea water which has no value for agriculture or similar uses, it does not need to be included in this study. Only water needs for proceeding, sanitary and miscellaneous uses (see Chapter One for definition), must be considered in coastal industrial area. However, where seawater is not available, water intake will be projected instead. Thus, the industries will be divided into two categories; coastal industries which use sea water as a cooling medium and others where seawater is not available. The following will discuss each separately:

1. <u>Industries where seawater is not available</u>.

Before we discuss the method for estimating industrial water requirements, several terms should be defined:

a. Grosswater, the total volume of water required to run a plant.

b. Withdrawal or intake of water. It is the amount of water taken from the resource only as required to replenish the water irricoverably consumed in the production processes, where consumption is the loss of water due to evaporation in corporation and leaks in the water system in the manufacture.

From the above definition, it is clear that the withdrawal is equal to grosswater if no recycling is practiced. However, if recycling is taking place, then

Intake = grosswater - recycled amount

The above equation shows that the estimation of industrial water requirements to produce, for example, a unit of some product depends on the amount of water available for recycling. If there is no recirculation at all, the industrial water requirements may be estimated using the following model:

$$\text{Grosswater requirements for product } i = \text{Amount of product } i \times \text{Grosswater use by unit of production}$$

or

$$GW_i = P_i \times GU_i \tag{5-11}$$

Thus, the total gross industrial water requirements is equal to = $\sum_{i=1}^{i=i} GW_i$ (5-12)

However, major industries in Saudi Arabia which have their own sources of water do recycle the water as a result of scarcity and high costs. Thus industrial water intake should be projected rather than the industrial grosswater. The following model is more appropriate:

$$\text{Industrial Water Intake for product } i = \text{Amount of product } i \times \text{Water Intake by a unit of product } i$$

or

$$IW_i = p_i \times I\,U_i \tag{5-13}$$

thus

$$\text{total industrial water Intake} = \sum_{i=1}^{i=i} I\,W_i \tag{5-14}$$

In model 5-13, a constant amount of water is used to produce a unit of production, regardless of time. This, however, does not seem correct, since the history shows that there is a reduction in the amount of intake mainly due to increased recycling. In fact, the Second National Water Assessment by the United States Water Resources Council expected that water withdrawal to decline from 69,000 in 1975 to 23,000 in 2000, while the grosswater will increase from 153,000 to 371,000 MGD during the same period. The study claims that the decline will be due to increases in water use, efficiency, recycling and conservation.

It seems reasonable to assume that decline in water intake will take place in Saudi Arabia also due to the government's policies, scarcity of freshwater and high cost of desalination. Hence, to project the industrial water intake in Saudi Arabia, model 5-13 should be modified to consider this change overtime. The modified model may be demonstrated as follows:

$$IW_{ij} = P_{ij} \times IU_i \times (PRF)_j \qquad (5\text{-}15)$$

where

P_{ij} = amount of product i in year j

$IW_{i}j$ = industrial water intake for product i in year j

IU_i = water intake used by a unit of production i in year 1980

$(PRP)_j$ = the projected reduction factor of water intake in year j (where $PRP_j \leq I$)

J = 1,2,3,...,30 from 1980 to 2010

Thus, the total industrial water intake in year j is equal to

$$\sum_{i=1}^{i=i} IW_{ij} \tag{5-16}$$

Model 5-15 and 5-16 will be used to project the total industrial water intake for industries which do not use seawater as a cooling medium.

2. Coastal Industries.

As mentioned before, in these industries, contact water for processing, sanitary and miscellaneous uses, will be projected. The following model will be used.

Industrial Water Requirements for Contact Purposes (Processing...etc.) for product i = Amount of product i x Amount of Contact Water Used by a unit of product i

or

$$PW_i = p_i \times p_{ui} \tag{5-17}$$

Thus

$$\text{Total amount of contact water in year j} = \sum_{i=1}^{i=i} PW_{ij} \tag{5-18}$$

In model 5-17, J = 1,2,3,...,30 from 1980 to 2010. I assumed a constant amount of water per unit of production based on the facts that: (1) the total amount of water used in oil industries comprises only 5.0 percent of the total grosswater needs and, (2) the historical data does not show any significant reduction regarding contact water use per unit of production.

The projection of the elements in models 5-15 and 5-17 will be discussed in the following chapter.

CHAPTER VI

EXPLANATORY VARIABLES PROJECTIONS

Several of the models which were developed in Chapter Five will be applied in this chapter in order to forecast the urban, rural, irrigational and industrial water requirements for Saudi Arabia. To do so, the explanatory variables need to be projected to be used as input in the developed models. The explanatory variables are: urban population, rural population, total number of students, number of houses connected to the water system, irrigated land, and industrial outputs. Fortunately most of these explanatory variables have been forecasted. Still, a few need to be calculated. The projection of the explanatory variables will be discussed as follows:

1. Population. Saudi Arabia is undergoing a substantial growth in population. This population growth is mainly due to the extensive economic growth over the last two decades. The Ministry of Agriculture and Water (MAW) and the British Arabian Advisory

Company (BAAC) did an in depth study to project total rural and urban Saudi population including non-citizens for the years 1990 and 2000. In their study, birth rates, death rates and immigration total were used with several socio-economic indicator variables to forecast the different categories of the population. This study concludes that there will be a decline in both the death and birth rates. The reason for believing this was stated as follows:

> "improved medical care should slowly reduce infant mortality and extend lives that would otherwise be shortened by sickness. Medical care cannot do much about victims of traffic accidents, but clearly, on balance, the death rate must fall. On the other hand it seems likely the birth rate will also fall especially among those parents seeing the virtue of full education but realizing the financial consequence of providing this education to many children. Extending girl's education and thus raising the age of marriage will inevitably restrict child bearing years, and the cultural pressures which favored large families in the past, seem likely to gently lessen as society develops. It's this thought that the trend to smaller families in Saudi Society will occur at a very modest pace, while the death rate could fall much more quickly". (1)

Further since Saudi Arabia is experiencing different regional of growth rate depending on the leading

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[1]British Arabian Advisory Company and the Water Resources Development Department "Water Demand and Reuse" Ministry of Agriculture and Water, Rijadh, Saudi Arabia (unpublished report), 1980 Section (2.4.3).

sectors of each region (agricultural, industrial, etc.), different growth rates were given to each province. Table (B-1) shows the growth rate of rural population in different sectors of the country as well as the growth rate of the nomadic population up to year 2010. Also Table B-2 shows the rural population projection up to year 2010. Further, Table B-3 shows the growth rate of and the total population up to year 2010*. Also, Table B-4 and Figure B-1 shows the projection of the total population.

2. <u>Houses Connected to Water System Projection</u>. The annual data of the number of houses connected to some water system between 1960 and 1970 were examined. It has been found that the average rate of growth was four percent during this period. The increase in the number of the connected houses was mainly due to new construction (MP, 1970). After 1970, the government (through the first and second development plans) decided to connect old houses to the water systems as well. This decision increased the rate of growth of the houses connected to some water system. In fact, the available data shows that this average growth has jumped to eight percent per annum during the last decade. The result

*Table B-1 refers to Table 1 in Appendix B, etc.

of this growth made it possible for 38% of the urban population to have internal plumbing by the end of 1980 (MP, 1980). Further, the government is planning to connect around 90 percent of the urban population to water systems by the year 2000. It seems reasonable to assume that almost all urban population (cities + 5000) will enjoy having water delivered to their houses by the year 2010.

Based on this assumption the projection of the amount of the connected houses will be carried out as follows: Since 38% of population presently is connected to some water system and 100% will be connected by 2010*, this implies that 2,192,000 are connected to the system now while 15,803,000 will be connected to the system by 2010. Further, if urban population is divided by the number of inhibitants in each house, we will be able to find the number of houses connected to the water system.

The number of inhibitants per house has been declining, but very modestly. The available data shows that the average number of inhibitants per house in 1980 is approximately 6.2. In this study it will be assumed that the decline in the number of inhibitants per house will continue smoothly from 6.2 to 5 by the year 2010. This assumption seems reasonable since the cultural pressures which favored large families should

*This growth rate is found to be 3.25 percent when assumed constant.

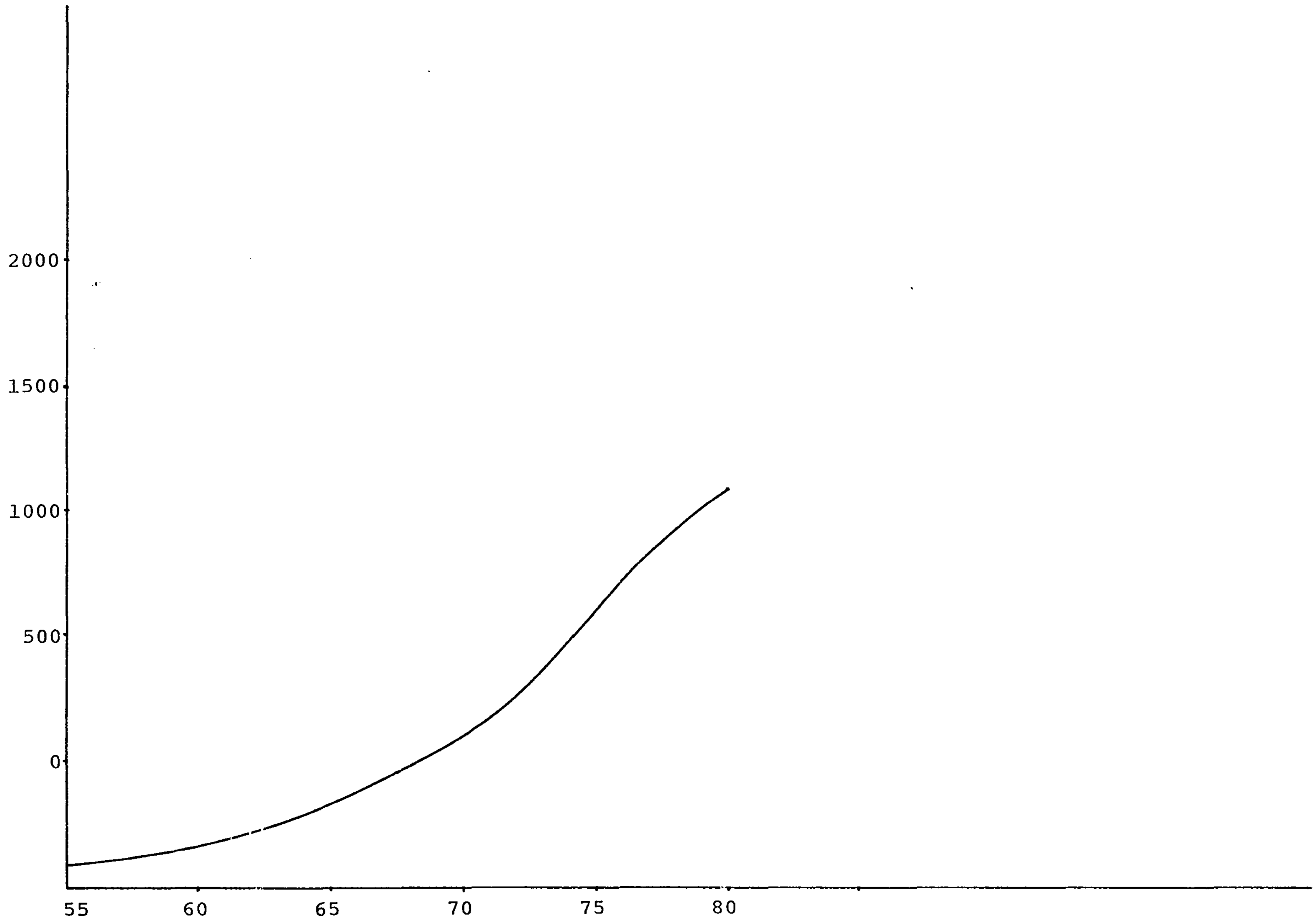
tend to modestly lessen as society develops (again, BAAC & MAW, 1980).

Table 6-5 shows the projection of the number of houses connected to the water system.

3. School Enrollments Projections. Total school enrollment between 1955-1980 was plotted to detect the general pattern of growth. Figure 6-1 shows varying rate of growth in enrollment over time. By reviewing the history of enrollment, it seems that the last 25 years may be divided into three different periods: stagnation (pre 1960), establishment (1960-1970) and rapid growth period (1970-1980). The following discussion will illustrate this concept.

Back in the 1950's, public schools were, in general, available only in large cities and exclusively for males. Figure 6-1 shows that during this time the increase in enrollment was mild. After 1960, the government decided to expand education over all the Kingdom, in fact, hundreds of schools were constructed in large and small cities as well. This was done to provide equal opportunities in urban and rural areas. During this establishment period the increase in enrollment was high due to the availability of schools. Further the government started encouraging students, regardless of age and sex, to enroll in schools. This was enhanced

Figure 6-1. Enrollments Versus Time.



by offering free education, books, transportation and allowances to needy students resulting in a very substantial growth in enrollment. However, after 1976, it can be noticed that ths increase in enrollment started declining modestly. This decline is due to the fact that during the rapid growth period, the student population contained a high percentage of older, non-literate individuals taking advantages of their earliest opportunity for education. After 1976, however, the schools started losing this older segment of the population since over the years fewer people advanced through childhood without attending schools. Ultimately the older segment of students will disappear entirely as schooling is subsidized in the Kingdom (leading almost all children through the education system before they become adults). Further, since females accounted for much of the growth in the 60's and 70's, the rapid growth in enrollment that was partially due to their numbers cannot help but decline. However, while the decline in growth is expected to continue in the future, i.e., it will be at a very modest pace. The reason for believing this is due to the following: first, the government, as a long range goal, is planning to settle nomadic people in small villages where schools are available for their children; second, in some remote villages where schools do not exist, new schools will be opened and/or people in these villages will migrate to larger towns which can provide the schooling that they lack.

The growth rate over time were plotted and the projection of future enrollment were made while the above points were taken into account. Table B-6 shows the projection of the total enrollment up to year 2010.

4. Irrigated Lang Projections. One of the goals of the Saudi Arabia government in its first and second plans (1970-1980) was to make the country, as much as possible, agriculturally self-sufficient. To achieve that goal, the government has been offering substantial subsidies such as interest free loans, guidance, subsidized fertilizing, machinery, seeds and free land for cultivation. Further, several information centers were built in different parts of the country to offer assistance and to run tests on local lands to improve crop production. These assistance programs have resulted in an increase of around 50 percent in the number of irrigated hectares and the doubling of agricultural output at constant prices in the last decade (MAW).

In the third plan, 1980-1985, the strategy is to continue toward the goal of self sufficiency by continuing subsidies. MAW and BAAC conducted very intensive studies to forecast the amount of irrigated land in the future. Several studies (Basil, Pastral, Italconsult and Sogreah) were consolidated by MAW and BAAC in predicting that 175,000 and 269,000 hectares will be irrigated by the years 1990 and 2000 respectively. This substantial increase in the amount of irrigated land was based on the assumption that subsidies will continue at the same rate as in the recent past - a reasonable assumption considering the goal stated in this third plan. Moreover, several plants for producing fertilizers have been constructed and more will be built in Yanbu and Jubail (see the Appendix A). Further, more information centers are planned in several small cities located around agricultural areas.

In considering the amount of irrigated land per year from 1980 to 2010 I found that if an annual compound growth of 4% is adopted, the projection (for 1990 and 2000) will be very close to MAW's prediction. Although this growth is exponential, it seems reasonable due to the government's goal and the absence of constraint on the amount of usable land which is estimated at around 4.5 million hectares. This 4% rate will also be used to project the amount of irrigated lands 2000 to 2010. Table B-7 shows the projection of irrigated land.

5. Industrial Output Projections. Saudi Arabia has been a major supplier of energy, in particular crude oil, to the world. Further, crude oil export has been the largest contributor to the Kingdom's revenue. The government, through the first and second development plans, decided to lessen the dependency on crude oil exports. One of the policies adopted to attain this goal was to support the development of hydrocarbon-based industries. Further, attempts are being made to more toward more balanced growth in the non-oil sectors.

From the above policies, industries in Saudi Arabia may be divided into two main categories; hydrocarbon and non-hydrocarbon industries. Hydrocarbon industries include oil refineries, natural gas processing industries and associated industries which are based on feedstock from petroleum refineries and natural gas processing. Non-hydrocarbon industries include food and beverage, textile and leather, paper products, chemical products, non-metallic mineral products, fabricated metal products and basic metal industries. The projection of hydrocarbon and non-hydrocarbon industries will be discussed separately as follows:

a. Non-Hydrocarbon Industries. The Ministry of Industry and Electricity, in its master plan, conducted studies to forecast non-hydrocarbon industrial output for the coming decade. In their work, it was assumed that the Kingdom will be able to eliminate most of its constraints to the development of industries (such as water and power supplies). Further, water and labor intensive industries were not considered in those studies, because these industries are being discouraged. Projections are based on the analysis of demand and supply utilizing an input-output model.

Since, there are no figures beyond 1990 in that projection, a linear extension will be used in this study to increase the projection up to the year 2010.

b. Hydrocarbon Industries. Although, there are several refineries in use in different parts of the country, the major refineries will be located in the two industrial cities (Jubail and Yanbu) which are under construction and will be in full operation by 1985. The capacity of the hydrocarbon and basic metal industries in the two cities are shown in Table A-4 in the Appendix A. To project the output of these industries, the following approach is adopted.

The amount of contact water used for refining purposes can be considered directly related to the total refinery production. However, production estimates for the refining industries in Saudi Arabia do not exist (beyond 1986) what can be created, however, are the estimates for the number of refinery workers from the year 1985 to 2000 (given projections of the number of workers at refining plants in the years 1985 and 2000 which are supplied by). If output per worker is assumed constant over these years the growth rate of refinery workers (about 2.8% can be considered equal to the growth rate of output per year and hence also equal to the increase in the amount of contact water used in the refining process per year.

While the assumption of constant productivity per worker is somewhat naive, from the available data there would seem to be no practical way to determine appropriate increases in output per labor. This will tend to bais our estimates for the hydrocarbon industry water requirements. However, these industries account for a very small percentage of total fresh water usage in the Kingdom. Consequently, this assumption will not significantly alter the predictions for the total water requirements in the country.

Industrial Water Intake for a Unit of Production

Most of the existing industries in Saudi Arabia are fairly new and the available data are not adequate to derive the amount of industrial water intake.

However, these industries have been constructed under consultation of western experts. These modern plants should use about the same amount of water used in similar new plants in western countries. But, modern design cannot do much about the lack of experience regarding water conservation. Therefore, on balance, using the average per unit of output intake of all similar industries in the U.S., old and new, would seem to provide reasonable measure of Saudi industrial water use. Consequently, the average intake of water for a unit of production in the U.S., which represents averages for all industries, will be used in this study (see Table B-8).

Reduction Factor Projection

The Commerce Department's Bureau of Domestic Business Development forecasted that the actual water intake, for 98% of industrial water uses in the United States, will decline from 69,000 in 1975 to 27,000 and 23,000 million gallon per day (MGD) in year 1985 and 2000 respectively, while the gross water use will increase from 153,000 to 227,000 and 371,000 MGC for the same years. This shows that the ratio of the industrial water intake to gross amount will decrease substantially up to the year 2000.

The above information will be used to estimate the reduction factor which will be used to predict the industrial water intake for those industries which do not use seawater as a cooling medium. The year 1975 will be taken as a base year and it will be assumed that the gross water use per x unit of production will remain constant (Kollar and Brewer, 1975). The ratio of the water intake to gross water in 1975 is 0.42. However, the ratio will be 0.12 in 1990. This means that, if a specific amount of water intake is used, in 1975, to produce a unit of production, then .12/.42 = .27 or 25% of that amount will be used to produce the same unit of production in 1990. This is based on research which has been done for the United States which is a developed country. However, Saudi Arabia is a developing country and this projection may not be applicable (to Saudi Arabia) due to the lack of experience in this field. Nevertheless, half of that reduction seems appropriate and will be used in this study. Table 6-2 shows the reduction factor projection.

Industrial Water Needs for Contact Purpose

The oil industries in the two industrial cities, Jubail and Yanbu are, in general, refineries with the following processes: topping, cracking, lubes and

Table 6-2

PROJECTION OF REDUCTION FACTOR

Year	1975	1985	2000	2010
Gross water use (MGD)	153000	227000	371000	
Industrial Water Intake (MGD)	69000	27000	23000	
Ratio of Intake to Gross	0.45	0.12	.067	
Amount of Intake as a Percentage of the Base Year 1975	100%	27%	15%	
Adjusted Reduction Factor	100%	54%	30%	20%*

*Assumed in this study.

petrochemicals. In this industry, on the average 90 gallons of water for each barrel of oil refined are used for contact purposes: processing, steam, sanitary and miscellanesous (Elvers, 1978). In the steel and aluminum industries, 11350 and 14210 gal/ton as used respectively for the same purpose.

Water Requirements Projections

After the relevant variables were projected, they were plugged in models (5-1), (5-6), (5-9) and (5-15) through (5-18) to calculate the rural, urban, irrigational, industrial and total water requirements from 1982 to 2010. Figures B-2 through B-5 show the projections of different categories of water requirements.

CHAPTER VII

WATER NEEDS AND AVAILABILITY

Water requirements in Saudi Arabia have increased significantly in the last decade. Indeed, the available data show that total water requirements have doubled. This sharp increase in water uses has resulted in serious problems. First, ground water has dropped noticeably in several areas. Secondly, in some regions the quality of ground water has deteriorated, and in fact, the deterioration in several places has been so bad that this water cannot be used, especially for domestic purposes, without expensive treatment.

Kalthem (1978) concluded that the ground water level has dropped 30 feet during the last three decades around Riyadh. Sadhan (1980) stated the following:

> "Withdrawing huge quantities of water from lower wadi (valley) fatma area reduced the water table rapidly causing almost all ains (springs) to dry up. Of 360 ains producing at one time, only four remain."(1)

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[1]Sadhan, "Water Plan for Wadi Fatma Basin, Saudi Arabia" (Thesis) University of Wyoming, Laramie, Wyoming 1980, p. 16.

He also added,

> "the extensive withdrawal of water has caused the water level to sink below the main channel, causing more saline water surrounding the areas to move laterally and down to the lower level."(2)

Further, Kaltham (1978) found that in several parts of Najd, ground water has been contaminated by Riyadh sewage waste disposal.

If not solved, the above problems will have severe negative effects in the future and undoubtedly will slow down the planned economic growth. Thus, it is necessary for these problems to be seriously considered with every effort made to abate them. The first step to evaluating these problems is by determining when, where and how much water will be needed. In fact, one of the main objectives of this study is to predict municipal, irrigational and industrial water requirements up to year 2010.

The result of this study shows that the municipal water requirements will increase almost 5-fold by the year 2010, while the irrigational water requirements will be more than doubled during the same period (see Appendix B). This increase in water requirements is very substantial, nevertheless, history shows that this kind of growth in water requirements is quite likely if the present practices are not changed.

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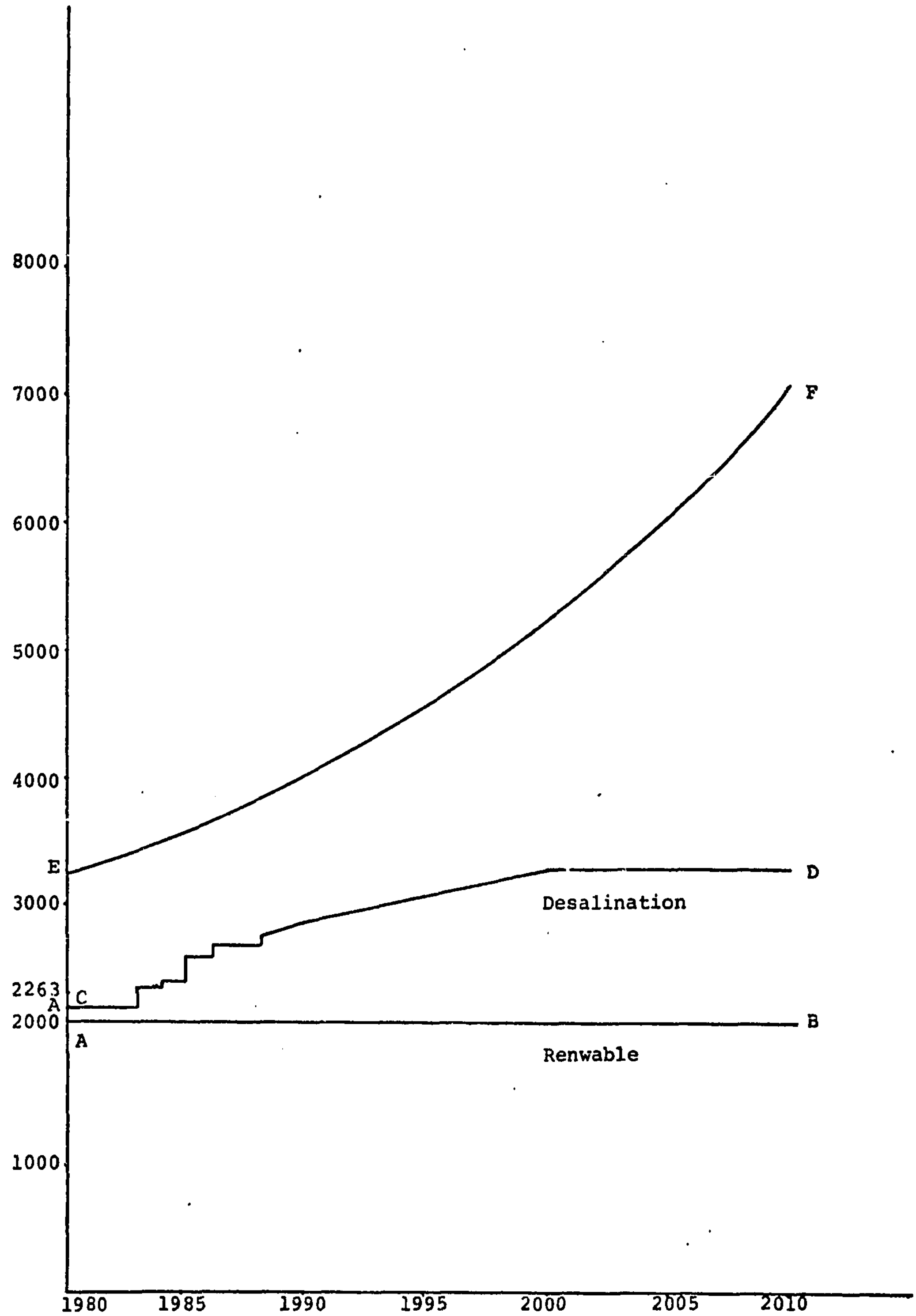
[2]Ibid, p. 87.

Now, what remains after predicting future water requirements is evaluating the availability of the water resources. In Chapter 2 it was shown that the total recharge of water averages 2025 Mm^3/yr. The rest of the water requirements are met partly by desalination plants and mainly by reserved ground water. The ground water reserves are shown in Table 2-4. This may be considered a large amount of ground water, however, in general, it is non-renewable and occasionally of poor quality (see Chapter 2).

A comparison between the water requirements and availability will show where the country stands with respect to its water resources. In Figure 7-1 the graphs are plotted utilizing water resources data given in Chapter 2 and water requirements projections from Chapter 6. The area under AB represents the average amount of renewable water while the area between AB and CD represents the projected amount of water from desalination plants. The area under EF shows the total water requirements into the future (excluding salt water used for oil injection and cooling purposes in coastal cities). The area between EF and CD must be met from other sources. In fact, at the present time, the rest of the water requirements are met mainly by using ground water reserves. If we accept our forecast

Figure 7-1. Total Water Requirements Versus Supply Without Conservation (MCMY).



and consider 75 percent of the amount of proven water reserves to be economically exploitable, around 35 percent of the ground water will be exhausted within 30 years, the range of this forecast (see Figure 7-1).

It is possible that our forecast will not materialize on schedule and the exhaustion of ground water may occur earlier or later than any given year. This, however, has no great bearing on our estimate of future water resources. What is important for us is that sooner or later, if the present practices remain unchanged, water reserves, will ultimately be depleted.

The general approach in Saudi Arabia to meet the growth rate in water use is by searching for other supplies such as towing an iceberg from North Pole and building more desalination plants. However, this should be considered as only one side of the problem. The other side of the problem which is as important is avoiding wasteful uses and conserving water as much as possible. In addition to the huge cost of bringing new sources of water to the country, it should always be remembered that using more water will result in more waste water and discharging waste water is the principle reason for deterioration of ground and surface water.

Further, any reduction in the quantity of water and wastewater, in addition to prolonging the ground water reserves would result in lower costs due to smaller operations and reserved costs.

A policy requisite is the establishment of a long-range program which must consider both sides of the problem, and should be environmentally acceptable and economically feasible. Water conservation should not be interpreted as prohibition of water uses, but rather as a guideline to its uses. To move toward this goal, the principles governing the use and conservation of water resources must be radically revised. Further, certain regulations and purposive laws for violation should be established.

The program should be built with emphasis on educating people in the basic principles of our natural resources and how important they are not only to us, but to the many generations to come. Public education, regarding this matter, will, in the long-run, have a major role in achieving our goal of conservation, since people are the ones using the water and will be the ones to conserve it. L'vivoch concluded that to achieve a reduction in water uses, a compulsory program concerning the attitude to all natural resources is necessary. He stated the following:

> "In every family, in the nursery school and still more in schools, the child must be brought up in a spirit of love for nature and a stewardly attitude toward natural resources including water resources."(2)

The establishment of the above policies will gradually help the conservation program to progress in an appropriate and effective climate with great response and cooperation to any plan to conserve water. Now with these principles in mind, we will discuss how one may be able, physically, to conserve the urban, irrigational and industrial water requirements and to create some new sources of water.

Urban Water Conservation

In the last decade a considerable portion of rural people have moved to urban areas seeking better living conditions. This migration from rural areas to urban centers is expected to continue into the foreseeable future (see Chapter Six). Due to this migration, expansion of existing cities has taken place and new cities have been and are being built - a goal of the Third Development Plan.

This degree of urbanization will result in a higher standard of living. Hence, there are two major

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[2]L'vovoch, "World Water Resources and Their Future," 1979. Litho Crafters, Inc. Chelsea, Michigan, p. 280.

factors which will cause the urban water use to increase - both the increase in the urban population and the increase in the urban standard of living. To minimize the volume of water needed to serve the urban areas, the following are recommended: Whenever water is treated, transported or used, losses take place, some of which may be considerable. SCET (1975) estimated that 50 percent of the water supplied to Madina is lost, most of which is due leakage. BAAC (1980) reported that the waste in Jeddah and Riyadh exceeded 50 percent of the originally delivered amount. They claimed that the waste rises from inadequate design, poor maintenance, poor water filtering, poor installation and many other problems.

It is very clear that the first step in conserving water is to minimize losses in existing systems and to plan to avoid such problems in the future. In new construction, 38 percent of the population are presently being connected to the water systems and the government is planning to connect all the houses in the future (see Chapter 6). Thus, it is necessary that future designs be efficient and have effective maintenance programs to detect and reduce leakage. This will play a predominant role in water usage reduction.

Another element which should be considered in the saving program is water-saving devices. Automatic clothes and dishwashers, water-saving toilets and showers, pressure reducing and spray taps, time-controlled taps, etc. are available in the market, and have been used successfully in several places in the world. Building codes requiring these water devices in new construction and encouraging the replacement of old existing devices will go a long way in helping to minimize water uses.

Metering is also a potential conservation tool. It allows for different prices depending on usage. All reasonable needs can be cheaply charged. Water taken in excess of this need could be charged at or well above cost.

All the above recommendations should be approached with careful consideration. Economic and environmental consequences cannot be neglected. For example, metering could be costly option which might not be economically justifiable. Good management is essential for a well-run water conservation program.

Irrigational Water Conservation

The amount of water which is used for irrigation comprises more than 70 percent of the total water requirement at present. Further, the government plans to double the amount of irrigated land by the end of this century. This will almost double the amount of water required for irrigation if the present practices are not changed.

Although, some farms are applying new technology to irrigate land, most of the farms have been traditionally irrigated leading to much waste. This, at least, is the conclusion of a study conducted by (BAAC and MAW, 1980) which estimated that the average coefficient of efficiency in agriculture is around 0.55. This implies that 55 percent of the water reaches the field while the rest is lost in canals due to infiltration and evaporation.

It is obvious from the above discussion, that a considerable amount of water can be saved if efforts are made to raise the level of the irrigational efficiecny. There are, in fact, numerous ways to increase efficiency and consequently reduce the amount of water required. In several places in the world (USA, Europe, Central Asia), the efficiency coefficient of irrigation systems has been raised to more than 0.8 by successfully combating the problems of infiltration and evaporation (L'vivoch, 1976).

Another way to reduce the amount of irrigational water is to avoid using excessive amounts of water when it is unnecessary. Research (L'vivoch, 1976) shows that in many cases the amount of water used for irrigation substantially exceeds the actual needs of irrigated crops. Further, it has been reported that over irrigation will cause the salinity in the soil to rise and

and hence reduce the yields. This is in addition to the loss of water which could have been saved. New technology in the agricultural sector is progressing fast to save water and increase the yield at the same time. The selection of the appropriate type of technology which considers specific conditions (soil, kind of crops, water quantity and quality, temperature evaporation, etc.) should be done through good management and effective regulations.

One of the most popular techniques, to save fresh water, which has been successfully and internationally, applied is to use sewage effluent for irrigation. This concept will be discussed under water reuse in another part of this chapter.

Industrial Water Conservation

The development and growth of the industrial sector in Saudi Arabia will depend in large measure on the water availability. Due to the scarcity of freshwater, it was indispensable that Saudi Arabia look for another source of water to allow the continuation of industrial growth. Seawater was adopted as this new source in coastal industries being used primarily for cooling purposes. Still, a considerable amount of freshwater is needed for other uses and where seawater is not available or unacceptable.

The objective of this section is to recommend some means to minimize the use of freshwater and to enhance the idea of using seawater whenever it is possible. Unfortunately, there is no applicable program to all industries to minimize water uses due to the wide variation in the industries. Nevertheless, a general approach considering the basic principles of conservation will be discussed.

Since we are in the first stage of planning for the industrial sector, we should consider conservation in every step before we build this new economic area. The first element in our plan is to direct our production toward industries which use low amount of water or no water at all (dry technology). In the cases where water must be used, coastal locations may be preferable due to the availability of seawater. Locations where sewage can be used must also be considered. Further, in designing an industrial plants, volume and strength of waste reduction should also be considered and updated whenever it is possible. And, where water is used by workers for sanitary purposes, as in the urban model, water-saving devices may be considered. Pricing and regulatory policies will aide in conservation in the industrial sector by providing incentives for efficient utilization of water.

In large cities such as Jeddah, Riyadh and Damman with sizable water consuming industries, a dual system may be considered. One can deliver water of high quality for drinking and sanitary purposes, while the other meets the industries needs and some non-potable purposes. This may be economically feasible in new cities and the new planned suburban areas around the existing cities. This division should save high-quality water.

The second element in this area is the enhancement of seawater use in the future. It should be recognized that using seawater for cooling and other services has some difficulties due to the residual of the salt left behind when the water evaporates. Although, special metals have been used to overcome this problem, relevant scientific research should be set up to solve further problems as they develop. It is very important to recognize that failure to use seawater will drastically change the amount of industrial water requirements.

Applying these conservation issues will save a considerable amount of water. However, it is very difficult to put a number on how much water will be saved through conservation practices. The reason is that saving will depend largely on the following: usage patterns, degree of conservation or restriction, and most importantly, acceptance of the program by the water users. This could be the reason for L'vivoch's emphasis on the ethical and social orientation of any water conservation program.

Potentials for Water Conservation

The following are studies which show potential water saving due to conservation. Fitcher and Sharpe (1980) claimed that the current water-saving devices together with water conservation practices could save more than 40 percent in sewage flow. Kim and McCuon (1980) concluded that more than 30 percent reduction of the total water demand can be achieved through changes in regulations and pricing policy accompanied by emphasis on more current technology. L'vivoch (1976) conducted research and found that a 30 percent reduction has been achieved in water used by irrigation when forest belts are constructed around farms to reduce evaporations. He further, concluded that the minimum possible reduction in irrigation water requirements in Central Asia is 20-25 percent if conservation is practiced. And finally, Miller (1980) found that water users in Denver, Colorado have reduced their need of water by 30 percent when a maximum of three hours per week was used for irrigating lawns. (This estimate was based on the average usage of the previous five years.)

Although these studies reflect local reactions, they still indicate that a considerable amount of water can be saved if wasteful practices are avoided. Based on this philogophy and these studies, it does not seem unreasonable to assume that 25 percent of the total water requirements can be saved if conservation is considered and practiced.

New Water Resources

Now that the possibility of reducing water requirements has been discussed, I will discuss the other side of the problem - increasing our water supplies.

One of the most popular ways to increase water supplies is recycling treated waste water. Recycling waste water will create a substantial long-term local source of water. It also minimizes waste water discharge and could ultimately put an end to the formation of effluent and its waste product in general. This will reduce the adverse effect of sewage in our environment. In fact, secondary waste water treatment is often required for effluent discharge and, in some instances, tertiary treatment is necessary to meet the required criteria for discharge. In both cases the waste water reclamation and reuse system may be easily adopted. The necessity of treating waste water reduces the total cost of reusing the water. Ogles (1981) predicted that the cost of reclamation will compete with the cost of obtaining additional water supply. Further, several studies (Diamant, Vitolins, Robert, 1981) have claimed that using renovated water yields a considerable economic return.

Due to the above discussion and the needs for additional water supply to meet new demands for maintaining and improving the standard of living, waste water must be considered as an important long-term alternative supply. If fact, renovated water has been used successfully in several countries of the world for industries and agricultures. However, while renovated water is in use in several municipal areas, the quality criteria has limited its popularity.

Waste water reuse in Saudi Arabia is in its infancy period. A small amount of treated waste water is used in Jeddah for recreation purposes while a considerable amount is discharged in the Red Sea. In Riyadh and Dammam a small portion of treated waste water is used by refineries.

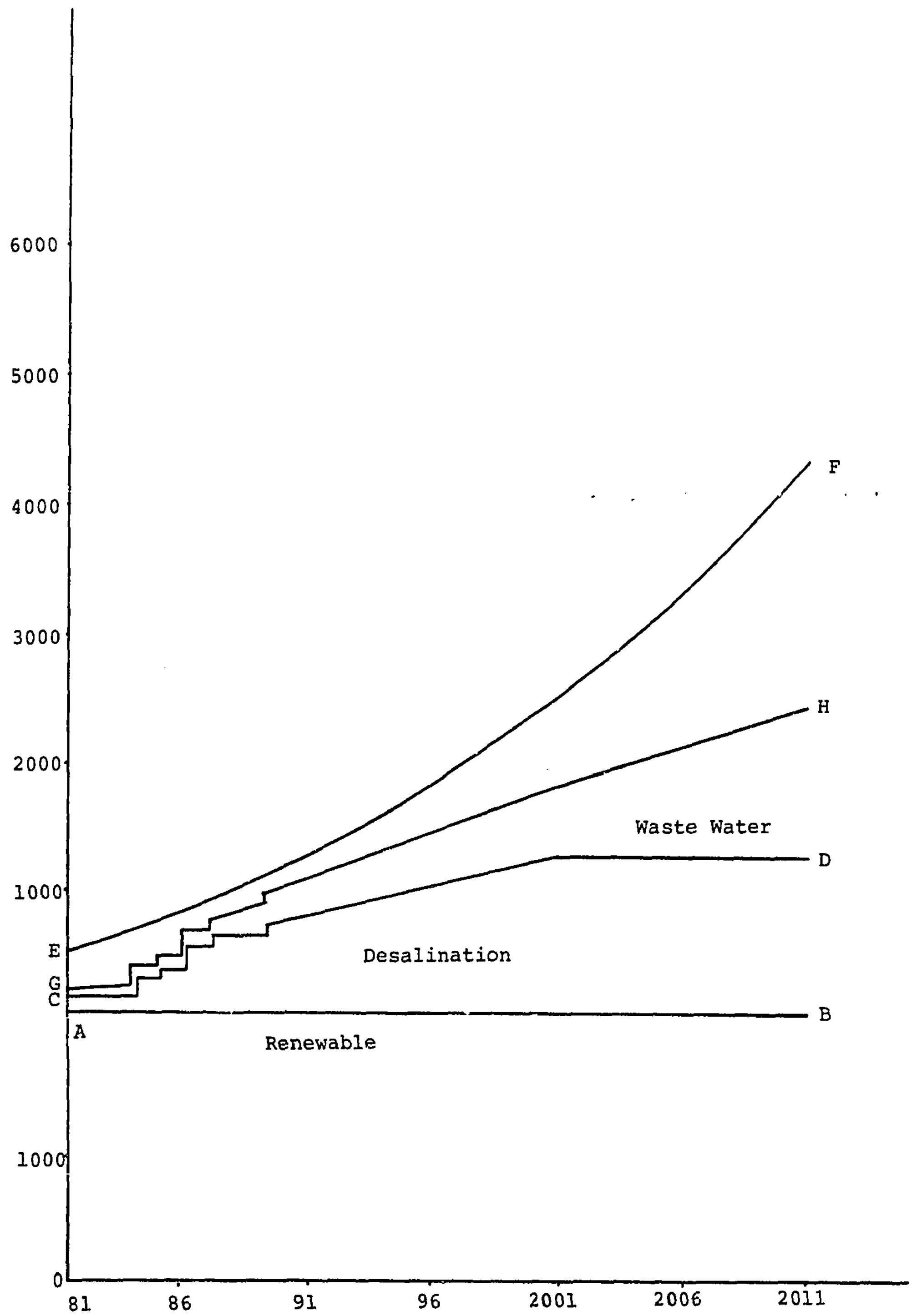
Saudi Arabia is a large country with different region experiencing different economic situations. This implies that while a specific use of treated waste water may be appropriate for one region, it could be unacceptable for another. In other words the type of reuse is a very site-specific question.

Selection of the most appropriate type of reuse in each region cannot be extensively covered in this study since it is beyond the scope of this research. However, the general approach in doing so is to study the present situation and the anticipated growth of each region. This will help in characterizing the region's activity by quantity and quality regarding water supply and waste water as well. Availability of lands, the agricultural soil properties, degree and kind of industrialization, the acceptance of water reuse, and the environmental and economic impact of that reuse are all necessary factors to be considered in the selection of the type of reuse. The above information will also be used to prepare for a specialized treatment whose technology will correspond to the type of reuse and the local conditions in economical and efficient way.

The quantity of the waste water depends on the portion of the properties connected to the sewer system and its condition, the population of these properties and the average per capita use of water. It is very difficult to quantify the amount of the waste water which will be used in the future. Instead, however, an attempt will be made to give an approximation on how much waste water will be available for reuse. We have assumed that 25 percent of the municipal water requirement will be saved due to conservation practices. Also, it has been reported that 38 percent of the urban population have the water system now and, all of the population will have that system by the year 2010. If we assume that the water system will go side by side with the sewer system and 60 percent of the water returns as wastewater, then we will have around 150 Mm^3 of wastewater at present while 1060 Mm^3 will be available for reuse in 2010.

The water conservation program, if it is applied, will change the picture of the natural water resources in the country. Figure 7-1 is replotted in Figure 7-2 including the new local supply from wastewater and the anticipated reduction in the total water requirements from other conservation practices. The new figure shows that the dependency on ground water reserves will be reduced substantially. Still there will be a deficit which must be met by other methods. Option here include: building more reservoirs for storing surface water, primarily flood water, which will help in creating a stable source of water supply and would also enhance water quality. Enlarged desalination programs might be adopted.

Figure 7-2. Water Requirements Versus Supply With The Conservation (MCMY).



CHAPTER VIII

CONCLUSIONS AND RECOMMENDATIONS

Saudi Arabia has experienced substantial economic growth in the past decade. The major source of this economic growth is revenue from exported oil. This revenue has enabled the country to offer its citizens a greatly increased standard of living. Further, urbanization and the agricultural sector have expanded significantly. These have resulted in doubling the amount of the total water requirements which have created shortages in several areas of the country.

The government has built several desalination plants to supplement the municipal water requirements. Further, ground water has been used extensively to meet the agricultural, municipal and industrial needs. However, over-withdrawal from the ground water caused the water table to fall considerably. Further, due to the increase in the use of water resources and poor waste water treatment, ground water quality has been deteriorating.

In the second and third development plans, it was mentioned that the government is planning to change the course of economy of the country. It is their goal to build a solid economic base, not only dependent on exported oil revenues, but on other sectors as well. The country is planning to continue to enlarge the agriculture sector and to extend the industrial sector mainly by refining oil and natural gas into final products.

Due to these new goals, the growth in water use is expected to remain high in the foreseeable future. This will consequently result in a substantial increase in the future water requirements. Unfortunately, even at the present time water requirements are far more than the renewable water supply. Thus, the limitation of water supply could be a major constraint that Saudi Arabia must deal with to achieve its goals.

Water Requirement

The first step that is needed in any water plan is to determine the future water needs. The primary sources of these needs are the following: (1) municipal, (2) agricultural and (3) industrial. One of the main goals of this study is to develop several models to forecast these three different water requirements. Historical socio-economic and climatological data were researched, collected and assimilated to develop these models. Assumptions were made in several instances due to the lack of adequate information. In fact, for this reason, the municipal water requirement is divided into two main categories: rural and urban requirements. The rural water requirement projection was based upon general observations from previous studies and visits to such areas. (8.5 gallon per capita per day was adopted as an average value for rural use [for nomadic people and villages with less than 2000 population] with an annual increase of one gallon per capita per year.)

The industrial water requirements was also divided into two main categories: (1) industries which use salt water as a cooling medium (coastal industries, in general) and (2) industries which do not use salt water. In the first category, the industrial water requirements for contact purposes only was forecasted. However, in the second category the industrial water intake was predicted. In the first category, the product of the average amount of water needed for contact purposes, to produce a unit of specific industrial product, and the total production were used in forecast. In the second categories, the same concept was used but the amount of intake to produce a unit of production was considered instead.

Regression analysis was used to build urban and agricultural models to forecast these needs. The relevant (explanatory) variables of these models were then forecasted and used as an input in the developed models to project the different water requirements. The developed models show that the municipal (rural and urban) water requirements will increase 5-fold in 30 years, while irrigational water requirements will be more than doubled during the same period.

It must be emphasized that the accuracy of this forecast depends on the quality of the data and the validity of the assumptions. Further, the forecast is compatible with a view of the future made at the present time. Each new piece of information and each new policy decision will alter the picture of this forecast. This idea will be clear when we discuss water conservation programs later.

Water Availability

The second objective of this study was to evaluate the total water resources availability in the country. The available data show that a vast amount of ground water is available. However, this ground water, in general, is non-renewable and occasionally of poor quality. Also adding to the water supply are desalination plants which are producing around 66 Mm^3/year at present and will be increased by 10-fold in the coming decade.

The future water requirements were matched against the available water resources. It was found that the future will see a growing dependence on ground water supplies to satisfy the need of agriculture, industry and municipalities if no other supply is found and the present practices are not changed.

Ground water is presently Saudi Arabia's most valuable water resource. The country's irrigation needs are mainly satisfied by ground water and, if we exclude the desalination plants, all cities, towns, and villages obtain their water supply from wells and springs. This shows how important ground water resources are to the country.

To reduce the dependency on ground water reserves while achieving the goal of economic development a water conservation program is recommended. The program consists of three basic elements: (1) using less water, (2) using available water more efficiently, and (3) looking for extra supplies. Several studies regarding water conservation were revised to evaluate the effect of water conservation. The results shows that a 25 percent reduction in total water requirement, was a reasonable assumption, could be achieved from the first and second elements in the program.

With regard to the third element in the program, while there are many ways to increase water supplies resources, desalination, importing water, etc., it was thought to be more economical to start with a source at hand rather than importing or extending the search for more water. In fact, a substantial source which has until now been ignored by many municipalities is reclaimed wastewater. This water may be used for different purposes: irrigation, manufacturing, recreation, etc. The projected significant increase in the amount of irrigated land in the future should be considered as marvelous opportunities opened up for irrigation with wastewater.

To select the appropriate kind of reuse, it was suggested that properly planned regional water reuse programs, should be established with the consideration of local conditions. These sub-programs should be considered as important parts of overall program to maximize use of the Kingdom's limited water resources.

Due to the difficulties of putting a number on how much water will be reused, the available amount for reuse was estimated instead. It was found that the available waste water will increase from 150 Mm^3/year at present to more than 1000 Mm^3/yr in 2010. This shows that waste water will be a reliable local resource, which must be used and further recirculated so as to help prevent the depletion of natural fresh water resources.

Application of improved water conservation measures, storage of surplus run-off in underground aquifers or surface reservoirs, and recirculation practices would extend available fresh water supplies, reduce deficits and confirm that Saudi Arabia is making efficient and proper use of its water resources. Again, to achieve this goal, a long range adequate comprehensive plan is needed to assist the country to meet its future water requirements as it proceeds with rapid social developments.

Inadequate Data

The lack of information to Saudi Arabia was a major constraint in this study and presently is a major constraint for all necessary future works. There is a need for accurate water records. These records should cover the amount of water at the source, in water treatment plants and at all domiciles. The same logs should be kept with respect to wastewater. Among other purposes, is the detection and quantification of the amount of leakage. The quality of the water should also be recorded, since it deteriorates as the use of water steps up. Further research in the field of water resources in Saudi Arabia is a must. Intensive hydrological studies are needed to supplement currently available data on the quantity and quality of the ground water.

A conservation program which considers conservation in each stage of planning, designing and updating in municipalities, manufacturing and agriculture will provide this data. The goal of this program is to reduce the water consumption per unit of output in industries and irrigation which consume very large amounts of water. Specifically, the reduction in municipal per capita needs may be reduced by adopting water-saving devices, different rates, lowering the pressure, etc. In agriculture more modernized systems with increased efficiency in irrigation will save a very considerable amount of water. In industries, moving toward dry technology and/or using salt water and wastewater should be seriously considered. The above recommendations must be built on a strong social and educational foundation to make it possible for users to cooperate in an effective manner at least alleviating - if not completely solving - the problem of water scarcity in Saudi Arabia.

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APPENDIX A

DATA AND ILLUSTRATIONS

TABLE A-1

Crude Oil; Production; Price and Revenue

Year	Million Barrels/Y	Crude Oil Price ($/barrel)	Oil Revenue (Millions of dollars)
1950	200	1.75	56.7
1951	278		111.0
1952	302		212.2
1953	308	1.43	169.8
1954	351		236.2
1955	356		340.8
1956	367		290.2
1957	376	2.08	296.3
1958	386		297.6
1959	421	1.9	313.1
1960	481	1.8	333.7
1961	540		377.6
1962	600		409.7
1963	652		607.7
1964	694		523.2
1965	805		662.6
1966	950		789.7
1967	1,024		909.1
1968	1,114		926.8
1969	1,174		949.6
1970	1,387		1,213.9
1971	1,741	2.285	1,944.9
1972	2,202	2.479	2,794.5
1973	2,773	2.591- 5.036	4,340.0
1974	3,095	11.651-11.251	22,573.5
1975	2,583	12.376	25,676.2
1976	3,054	12.376	30,767.0
1977	3,358		36,540.1
1978	3,285		32,233.8
1979	3,384	24	48,443.1
1980	3,384	26	52,480.2

Source: From 1950 - 1976: (Clean, 1978)
From 1977 - 1980: (Saudi Arabian Monetary Agency, 1980) (SAMA)

TABLE A-2

Amount of Ground Water Used by Two Cities
From 1958-1979

Year	Riyadh MGY	Jeddah MGY
1958	749.7	1,237
1959	1,291.2	1,277
1960	1,582.7	1,313
1961	1,874.3	1,353
1962	2,665.6	1,393
1963	2,457.4	1,438
1964	2,332.4	1,699
1965	2,582.3	1,960
1966	3,207.1	2,221
1967	4,081.7	2,482.7
1968	4,998.0	3,775
1969	5,581.1	3,974
1970	6,080.4	6,222
1971	6,580.7	6,140
1972	6,913.9	6,645
1973	9,371.3	7,215
1974	9,662.8	7,170
1975	10,236.4	7,721
1976	11,880.3	6,339
1977	13,450.9	7,259
1978	14,529.9	9,298
1979	18,270.6	11,727

Sources: For Riyadh 1958-1968 (Sogreah, 1970)
1969-1975 (VBB, 1978)
1975-1979 (Al-Sudhan, 1980)
For Jeddah 1958-1960 (Al Sudhan, 1980)
1961-1966 Figure obtained from Jeddah's water operation and maintenance
1967-1970 (MAW, 1975)
1971-1972 (Matthew, 1972)
1973-1974 (MAW, 1976)
1975-1980 (Al-Sudhan, 1980)

MGY = Million Gallon Per Year

Table A-3

Major Industries and their Products in Jeddah, Riyadh and Demmam in 1975

Type of Industry	Output	
Canned Vegetables and Fruits	525	MT*
Meat Packing	1,580	MT
Dairy Products	21,050	MT
Blended Animal Feed	89,400	MT
Paper Products		
a. paper board	60,000	MT
b. paper bags	26,900	MT
c. book binding	350	MSR**
d. miscellaneous	2,500	MT
Rubber footwear	5,620	1,000 pairs
Other Rubber Products	100	MT
Ammonium Suphate	41,000	MT
Phosphatic Fertilizer	25,000	MT
Other Fertilizer	4,000	MT
Plastic Powder	3,197	1,000 MT
Plastic Leather and Clothes	8,960	1,000 M^2***
Plastic Bags	1,860	MT
Plastic Footwear	300	1,000 pairs
Sulfric Acid	16,500	MT
Alkalies and Chlorine	22,600	MT
Soap	15,000	MT
Cement Products	189,130	1,000 Brick
Cement	1,007	1,000 MT
Ceramic Products for Construction	10,206	1,000 Tiles
Steel Rod Bars	39,200	MT
Steel Pipes, Tubes	5,600	KM****
Tin Cans	515	1,000 Box
Steel Furniture	20	MSR
Aluminum Windows and Doors	61	MSR

*MT - Metric Ton
**MSR - Million Saudi Riyals
***M^2 - Square Meter
****KM - Kilometer

Source: Ministry of Industry and Electricity, 1980.

Table A-4

Planned Primary Industries at Jubail and Yanbu

Plant/Capacity	Major Products
Jubail	
Refinery I, 250,000 BPD	Fuel Oil, Naphtha, Chemical Gas Oil, Benzene
Refinery II, 250,000 BPD	Fuel Oil, Diesel, Petrochemical Feedstocks
Refinery III, 53,000 BPP	Lube Oil Stocks, Naphtha, Bunker Fuel, Diesel
Petrochemical I, 1,800,000 TYP	Styrene, Crude Ethanol, Caustic Soda, Ethylene
Petrochemical II, 700,000 TPY	Glycols, Ethers, Polyethybners, Dowanol Voranol
Petrochemical III, 240,000 TYP	Low-Density Polyethylene
Petrochemical IV, 650,000 TPY	High-Density Polyethylane, Glycol, Acetric Acid
Methanol I, 600,000 TYP	Methanol
Methanol II, 600,000 TPY	Methanol
Fertilizer I, 580,000 TPY	Urea
Fertilizer II, 500,000 TPY	Urea, Ammonia, NPR Fertilizers
Iron/Steel, 850,000 TPY	Steel Billets
Rolling Mill, 360,000 TPY	Bar and Wire Rods
Aluminum, 210,000 TPY	Aluminum Ingots
Bulk Storage, 1,050,000 TPY	Sale of Bunkering Fuel, Diesel Gasoline, Jet Fuel
Polyisoprene, 40,000 TPY	Polyisoprene, Polybutajiene
Petroprotein, 50,000 TPY	Petroprotein Powder
Yanbu	
Crude Terminal, 1,850,000 BPD	Crude Oil for Export, Local Reginery
Domestic Refinery 170,000 BPD	LPG, Gasoline, Kerosene, Jet Fuel, Diesel Fuel Oil
NGL Plant, 300,000 BPD	Ethane Gas, Propane, Butane Naphtha
Petrochemical I, 500,000 TPY	Polyethylene, Glycol
Export Refinery, 250,000 BPD	Propane, Gasoline, Jet Fuel, Diesel, Boiler Fuel, Sulphur

The Royal Commission for Jubail and Yanbu
The Annual Reports, 1977-1980

TABLE A-5

PROJECTION OF WATER SUPPLY FROM DESTINATION PLANTS

IN DIFFERENT CITIES IN SAUDI ARABIA

	1399/1400	1400/01	1401/02	1402/03	1403/04	1404/05	1405/06	1406/07	1407/08
WATER SUPPLY CAPACITY IN '000 Cm/DAY									
o Existing Plants	179.2	179.2	179.2	179.2	179.2	179.2	179.2	179.2	179.2
o Ongoing Plants									
- Yanbu I	-	-	-	95.0	95.0	95.0	95.0	95.0	95.0
- Rabigh I	-	-	-	1.0	1.0	1.0	1.0	1.0	1.0
- Jeddah IV	-	-	-	190.0	190.0	190.0	190.0	190.0	190.0
- Jubail I	-	-	-	114.0	114.0	114.0	114.0	114.0	114.0
- Khobar II	-	-	-	190.0	190.0	190.0	190.0	190.0	190.0
- Jubail II	-	-	-	-	-	665.0	665.0	665.0	665.0
o New Plants									
- Al Birk I	-	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
- Mobile Units	-	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
- Al-Lith I	-	-	-	0.4	0.4	0.4	0.4	0.4	0.4
- Masturah I	-	-	-	1.9	1.9	1.9	1.9	1.9	1.9
- Tuwal I	-	-	-	1.9	1.9	1.9	1.9	1.9	1.9
- Duba III	-	-	-	-	3.8	3.8	3.8	3.8	3.8
- Haql II	-	-	-	-	5.7	5.7	5.7	5.7	5.7
- Al-Khafji II	-	-	-	-	23.0	23.0	23.0	23.0	23.0
- Umm Lajj II	-	-	-	-	3.8	3.8	3.8	3.8	3.8
- Al-Qunfundah I	-	-	-	-	-	3.8	3.8	3.8	3.8
- Yanbua II	-	-	-	-	-	-	76.0	76.0	76.0
- Mecca/Taif I	-	-	-	-	-		152.0	152.0	152.0
- Al Wajh III	-	-	-	-	-	-	-	3.8	3.8
- Assir I	-	-	-	-	-	-	-	-	94.0
- Jeddah V	-	-	-	-	-	-	-	-	94.0
TOTAL WATER CAPACITY	179.2	181.8	181.8	776.0	812.3	1,481.1	1,709.1	1,712.9	1,900.9

Source: Third Development Plan 1980-1985,
Ministry of Planning, Riyadh,
Saudi Arabia.

Table A-6

LOANS GRANTED BY THE AGRICULTURAL BANK TO THE FARMERS IN (000) SR[1]

Year	
1965	4389
1966	8927
1967	13182
1968	12019
1969	13877
1970	16136
1971	16627
1972	16558
1973	19394
1974	36304
1975	145505
1976	269433
1977	489838
1978	585666
1979	709672
1980	859931

[1] S.R. = Saudi Riyal ≃ 0.29$

Source: Saudi Arabian Monetary Agency, "Statistical Summary," First and Second Issues, 1980 and 1980.

Table A-7

TOTAL NUMBER OF STUDENTS (000)

Year	
1960-1961	143.01
1961-1962	178.88
1962-1963	213.85
1963-1964	260.52
1964-1965	299.46
1965-1966	337.22
1966-1967	385.59
1967-1968	438.82
1968-1969	485.37
1969-1970	537.70
1970-1971	593.63
1971-1972	665.48
1972-1973	744.99
1973-1974	850.24
1974-1975	977.97
1975-1976	1143.21
1976-1977	1214.46
1977-1978	1329.42
1978-1979	1452.87
1979-1980	1550.94

Source: Ministry of Education, "Educational Statistics in the Kingdom of Saudi Arabia", (Issues, 13,14) Ministry of Education, Riyadh, Saudi Arabia.

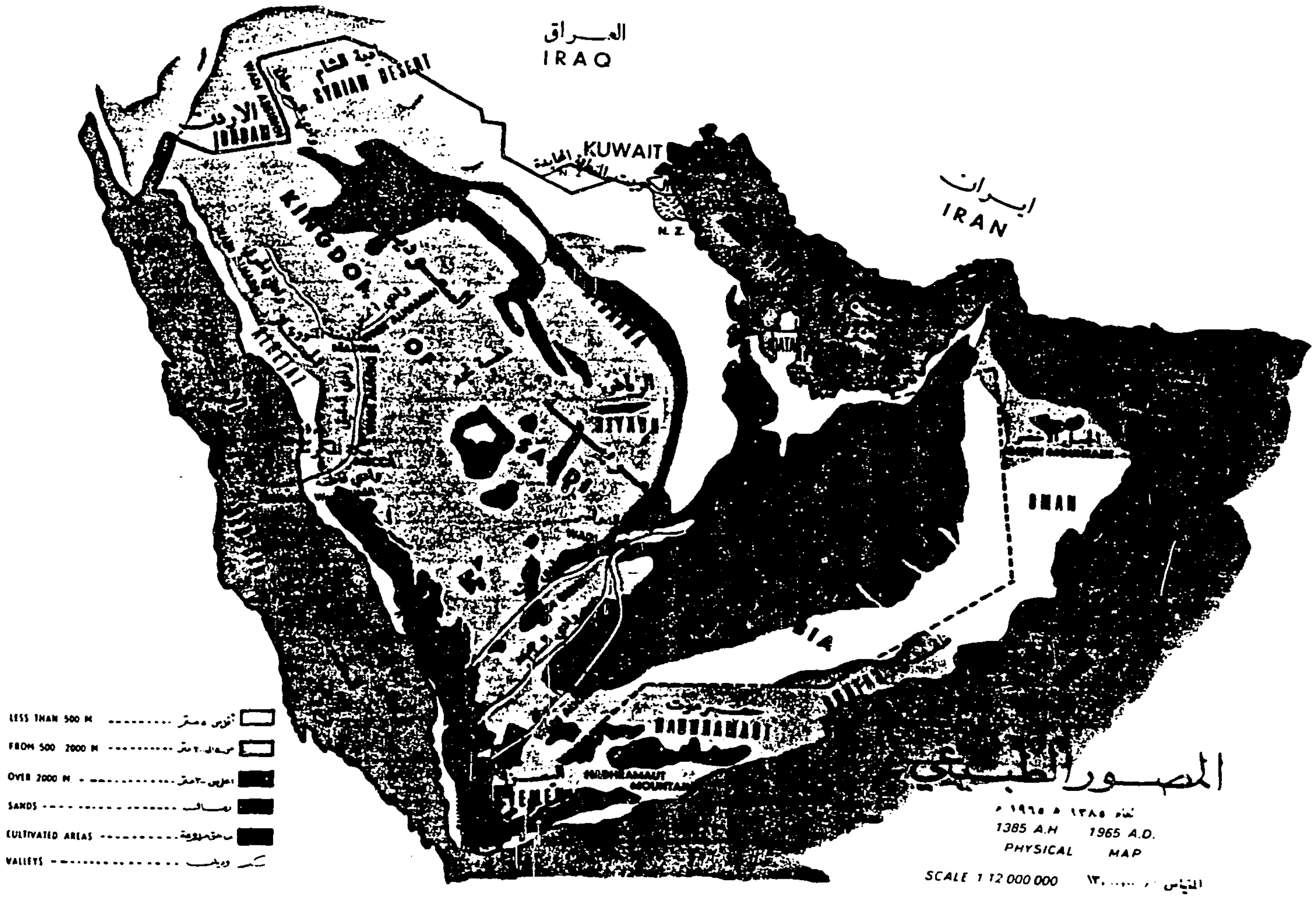
TABLE A-8

WATER USE VERSUS INDUSTRIAL UNIT OF PRODUCTION

Industry	Parameter of Water Use	Intake by Unit of Production
Canned Meat	gal/T	9400[1]
Canned Fruit and Vegetables	gal/T	9400[1]
Dairy Product	gal/T	1035[1]
Soybean cakes and bran	gal/T	7500[2]
Yarn and thread of synthetic fiber and artificial fabric	M^3/000SR[3]	0.374[2]
Cotton and blended yarn	M^3/000SR	0.5887[2]
Woolen yarn	M^3/000SR	1.528[2]
Garments & Other Textile Product	M^3/000SR	1.025[2]
Leather and Leather Product	M^3/000SR	.95[2]
Synthetic Rubber and Types	gal/T	14500[4]
Nitrogeneous Fertilizer	gal/T	4000[1]
Phosphatic Fertilizer	gal/T	8460[1]
Plastic Material and Resin	gal/T	13380[1]
Petroleum Refining	gal/bb	289[1]
Iron and Steel Foundries	gal/T	3024[4]
Alkalis and Chlorine	gal/T	22302[4]

Sources:
1. From Kollar and MacAuley, January 1980.
2. From MIE, May 1977.
3. SR = Saudi Riyal = .29$
4. From Census of Manufactures, 1980.

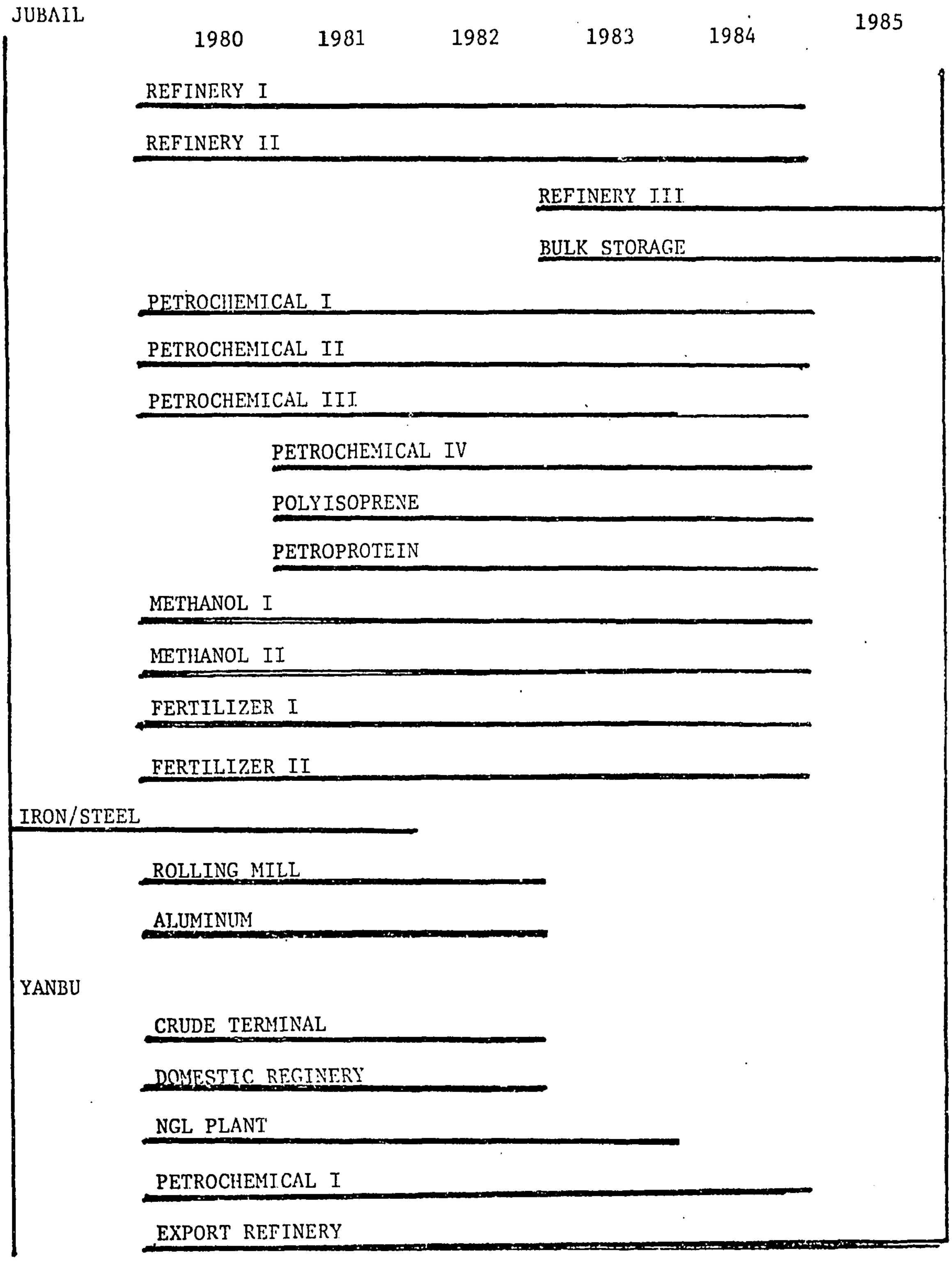
Figure A-1



Source: Statistical Year Book
Volume 15, Ministry of Finance
and National Economic

Figure A-2

CONSTRUCTION PLANNING SCHEDULE



Source: The Royal Commission for Jubail and Yanbu
The Annual Reports, 1977-1980

APPENDIX B

EXPLANATORY VARIABLES AND WATER

REQUIREMENTS PROJECTIONS

Table B-1

GROWTH RATE PROJECTION IN RURAL AREAS IN THE FIVE

PROVINCES IN SAUDI ARABIA

Province/Years	Central, Eastern & Western Regions	Northern Region	Southwestern Region	Nomad in the Whole Country
1980-1990	-1.0%	+1.0%	-1.0%	-2.0%
1990-2000	-1.0%	+1.5%	-1.0%	-2.0%
2000-2010	-1.0%	+1.5%	-1.0%	-3.0%

Resources: 1980-2000 from MAW and BAAC, 1980.
2000-2010 Estimation of this study.

Table B-3

GROWTH RATE PROJECTION OF TOTAL POPULATION

Year	
1974-1980	4.1%
1980-1990	3.2%
1990-2000	2.6%
2000-2010	2.5%

Resources:

1974-2000	MAW and BAAC
2000-2010	Assumption of this study

Table B-4

PROJECTION OF URBAN AND TOTAL POPULATION (000)

Year	Urban	Total
1981	6036	7748
1982	6305	7990
1983	6575	8234
1984	6845	8479
1985	7116	8725
1986	7410	8974
1987	7685	9225
1988	7961	9479
1989	8240	9734
1990	8519	9992
1991	8760	10254
1992	9090	10521
1993	9380	10792
1994	9679	11067
1995	9977	11346
1996	10283	11632
1997	10592	11922
1998	10907	12219
1999	11229	12521
2000	11553	12829
2001	11896	13145
2002	12242	13467
2003	12593	13796
2004	12954	14132
2005	13320	14476
2006	13692	14827
2007	14072	15186
2008	144458	15552
2009	14854	15926
2010	15255	16309

Table B-5

PROJECTION OF THE NUMBER OF THE HOUSES CONNECTED TO THE WATER SYSTEM (000)

Year	
1980	385
1981	423
1982	463
1983	506
1984	551
1985	598
1986	651
1987	704
1988	760
1989	819
1990	961
1991	1026
1992	1094
1993	1164
1994	1238
1995	1314
1996	1395
1997	1477
1998	1564
1999	1655
2000	1923
2001	2020
2002	2181
2003	2247
2004	2366
2005	2487
2006	2612
2007	2742
2008	2876
2009	3016
2010	3161

Table B-6

PROJECTION OF THE TOTAL ENROLLMENT (000)

Year	
1981	1605
1982	1700
1983	1797
1984	1896
1985	1998
1986	2101
1987	2206
1988	2313
1989	2422
1990	2532
1991	2644
1992	2758
1993	2874
1994	2992
1995	3112
1996	3233
1997	3356
1998	3481
1999	3608
2000	3736
2001	3866
2002	3998
2003	4131
2004	4266
2005	4402
2006	4540
2007	4680
2008	4821
2009	4964
2010	5109

Table B-7

PROJECTION OF IRRIGATED LANDS (000) HECTARE

Year	
1981	124.8
1982	129.8
1983	135.0
1984	140.4
1985	146.6
1986	151.8
1987	157.9
1988	164.2
1989	170.8
1990	177.6
1991	184.7
1992	192.1
1993	199.8
1994	207.8
1995	216.1
1996	224.8
1997	233.7
1998	243.1
1999	252.8
2000	262.9
2001	273.5
2002	284.4
2003	295.8
2004	307.6
2005	319.9
2006	332.7
2007	346.0
2008	359.8
2009	374.2
2010	389.2

Table B-8

PROJECTION OF RURAL WATER REQUIREMENTS (MCMY)

Year	MCMY
1981	26.2
1982	28.5
1983	30.8
1984	32.9
1985	35.0
1986	36.6
1987	38.5
1988	40.4
1989	42.2
1990	44.0
1991	45.6
1992	47.3
1993	48.9
1994	50.4
1995	51.4
1996	53.3
1997	54.7
1998	56.1
1999	57.3
2000	58.7
2001	59.4
2002	60.3
2003	61.1
2004	61.7
2005	62.5
2006	63.2
2007	63.8
2008	64.4
2009	64.8
2010	65.5

Table B-9

PROJECTION OF URBAN WATER REQUIREMENTS (MCMY)

Year	
1981	290
1982	307
1983	324
1984	242
1985	362
1986	379
1987	399
1988	420
1989	442
1990	481
1991	511
1992	539
1993	566
1994	593
1995	621
1996	650
1997	674
1998	711
1999	743
2000	813
2001	863
2002	917
2003	953
2004	1036
2005	1080
2006	1126
2007	1222
2008	1173
2009	1222
2010	1273

Table B-10

PROJECTION OF IRRIGATIONAL WATER REQUIREMENTS (MCMY)

Year	
1981	2491
1982	2629
1983	2733
1984	2816
1985	2887
1986	2953
1987	3015
1988	3079
1989	3139
1990	3201
1991	3269
1992	3342
1993	3417
1994	3495
1995	3575
1996	3664
1997	3753
1998	3848
1999	3946
2000	4047
2001	4156
2002	4267
2003	4383
2004	4503
2005	4628
2006	4757
2007	4891
2008	5027
2009	5170
2010	5314

Table B-11

PROJECTION OF FRESH WATER REQUIREMENTS IN JUBAIL AND YANBU IN MCMY (SEAWATER USAGE INDUSTRIES)

Year	Processes	Sanitary	Total
1983	7.03	1	8.03
1984	7.38	1.05	8.43
1985	22.78	4.4	27.18
1986	23.59	4.56	28.15
1987	24.53	4.71	29.24
1988	25.39	4.88	30.27
1989	26.37	5.04	31.41
1990	27.27	5.21	32.48
1991	28.29	5.38	33.67
1992	29.35	5.55	34.9
1993	30.52	5.83	36.35
1994	31.64	6.01	37.65
1995	32.77	6.19	38.96
1996	34.04	6.38	40.42
1997	35.34	6.68	42.02
1998	36.68	6.88	43.56
1999	38.05	7.18	45.23
2000	39.55	7.39	46.94
2001	41.01	7.7	48.71
2002	42.59	7.93	50.52
2003	44.23	8.25	52.48
2004	45.91	8.58	54.49
2005	47.73	8.82	56.55
2006	49.43	9.17	58.6
2007	51.45	9.52	60.97
2008	53.43	9.88	63.31
2009	55.68	10.25	65.93
2010	57.67	10.63	68.30

Table B-12

PROJECTION OF WATER REQUIREMENTS FOR INDUSTRIES WHICH DO NOT USE SEAWATER (MCMY)

Item/Year	1980	1985	1990	1995	2000	2005	2010
Non Hydrocarbon Industries	17.1	42.2	66.6	91	115.5	138.9	163.5
Hydrocarbon Industries	326.9	454.6	582	710	837.8	965	11187
Total	344	496.8	648.9	810	953	1104	1282
Reduction Factor	.77	.54	.43	.35	.3	.275	.25
Net Water Intake	265	268	279	280	286	304	320

Table B-13

PROJECTION OF TOTAL INDUSTRIAL WATER REQUIREMENTS (EXCLUDING SEAWATER) IN (MCMY)

Item/Year	1980	1985	1990	1995	2000	2005	2010
Industries which do not use seawater	265	268	274	280	286	304	320
Industries which use seawater	8	27	33	40	47	57	68
TOTAL	273	295	312	320	333	361	388

Table B-14

PROJECTION OF TOTAL WATER REQUIREMENTS (MCMY)

Year	
1981	3159
1982	3310
1983	3432
1984	3516
1985	3580
1986	3669
1987	3758
1988	3849
1989	3938
1990	4051
1991	4150
1992	4251
1993	4354
1994	4454
1995	4568
1996	4690
1997	4813
1998	4944
1999	5077
2000	5252
2001	5417
2002	5586
2003	5744
2004	5911
2005	6088
2006	6265
2007	6450
2008	6638
2009	6836
2010	7046

Figure B-1. Projection of Total Population (000).

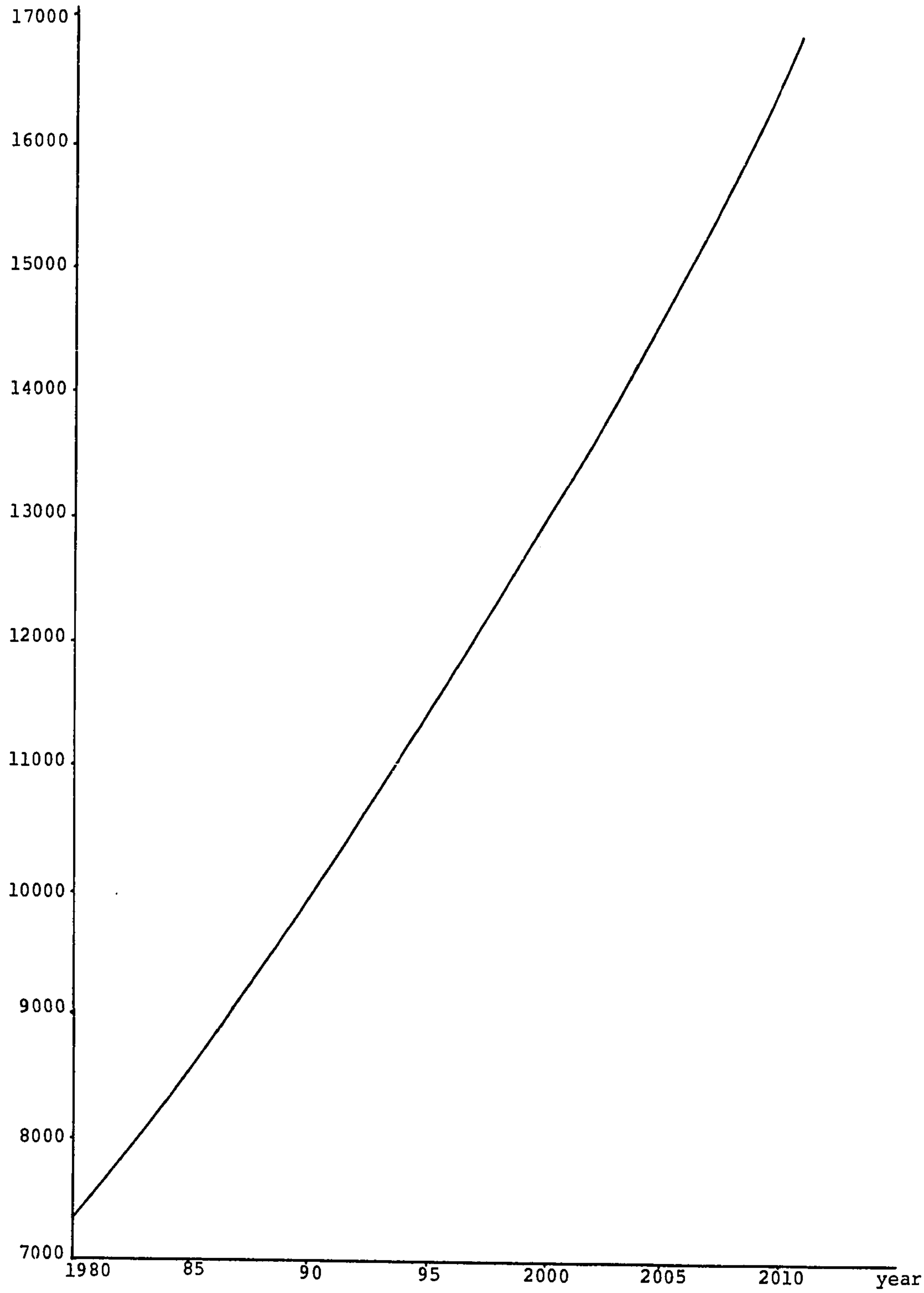


Figure B-2. Projection of Rural Water Requirements (MCMY)

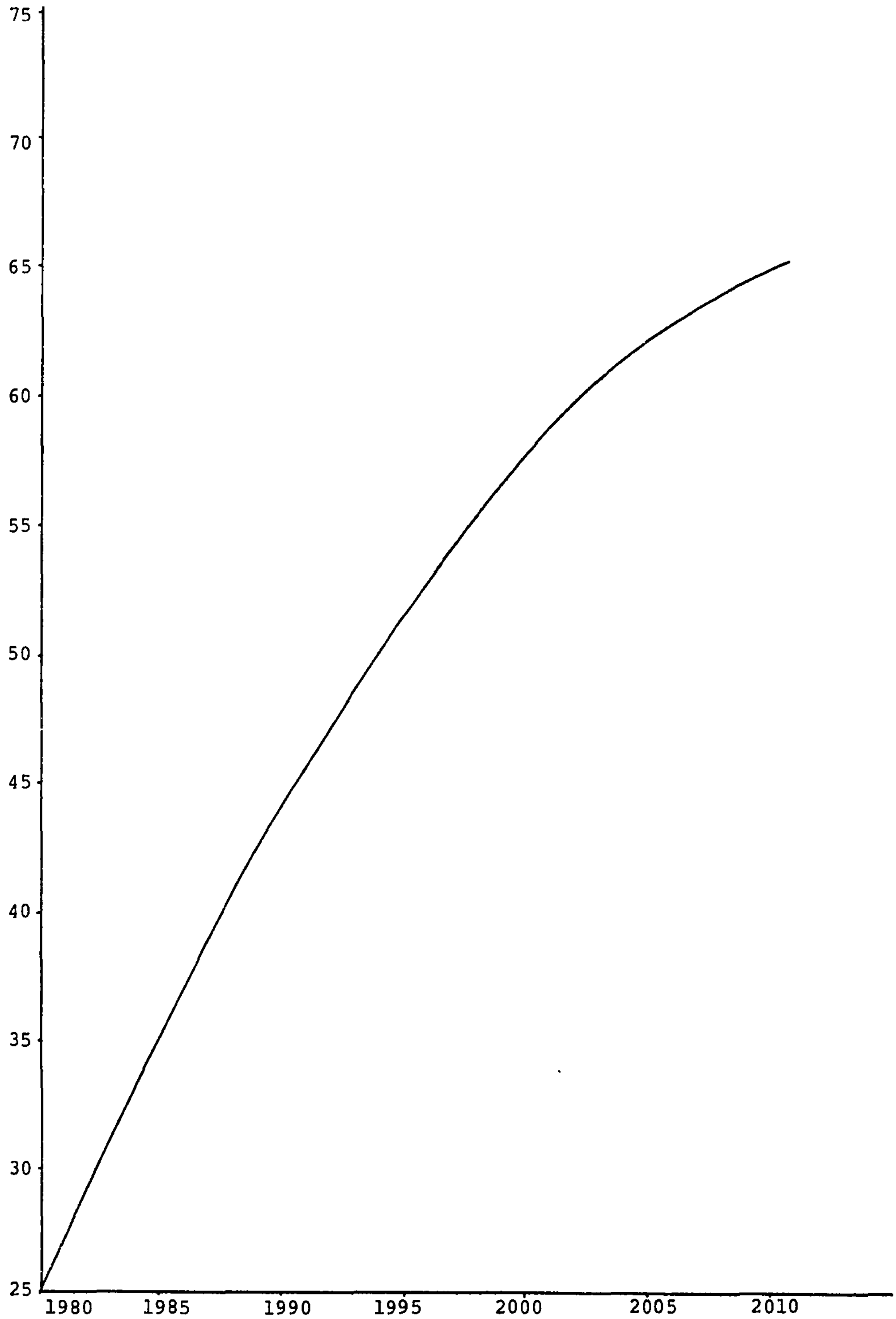


Figure B-3. Urban Water Requirements (MCMY)

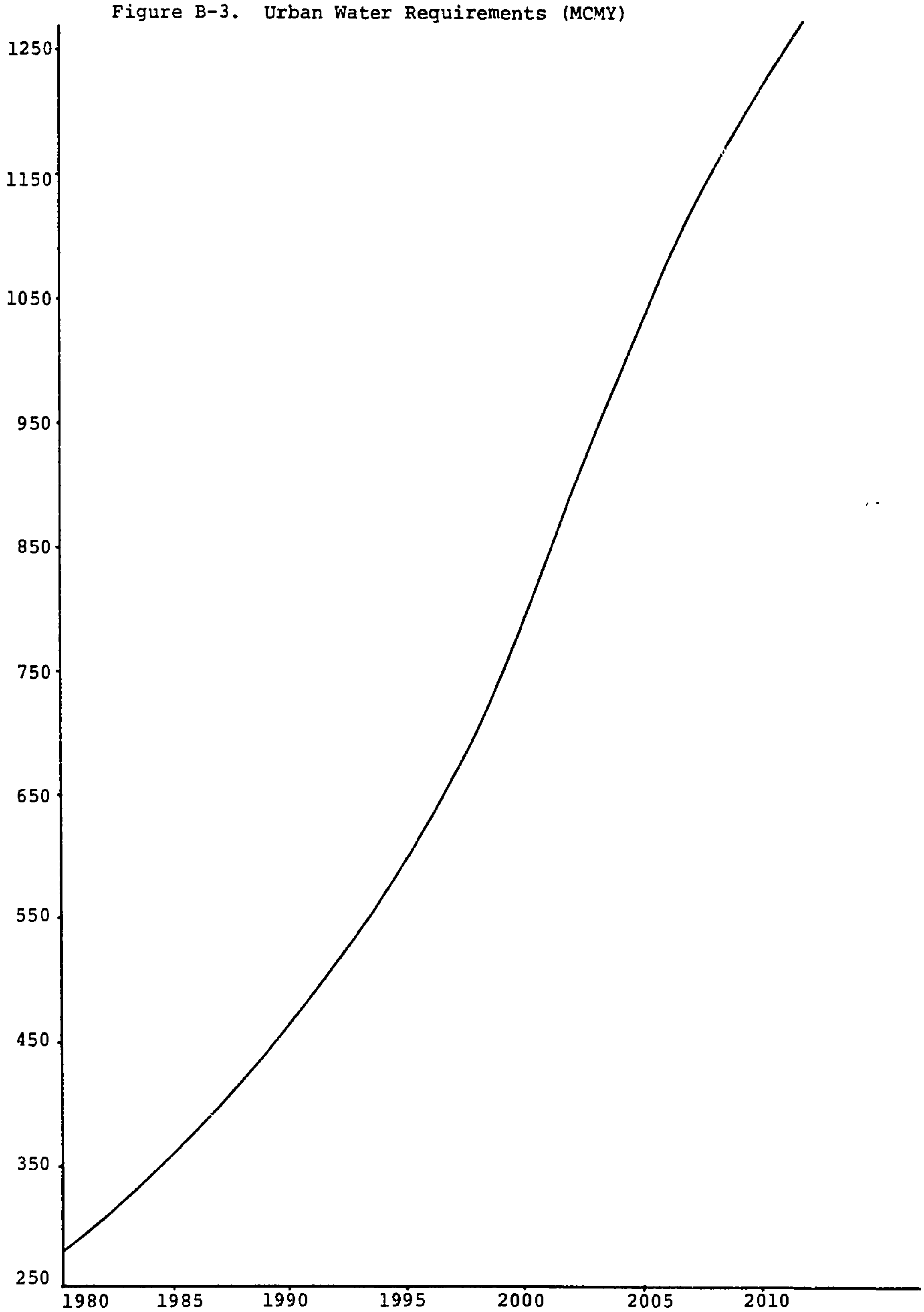


Figure B-4. Projection of Irrigational Water Requirements(MCMY).

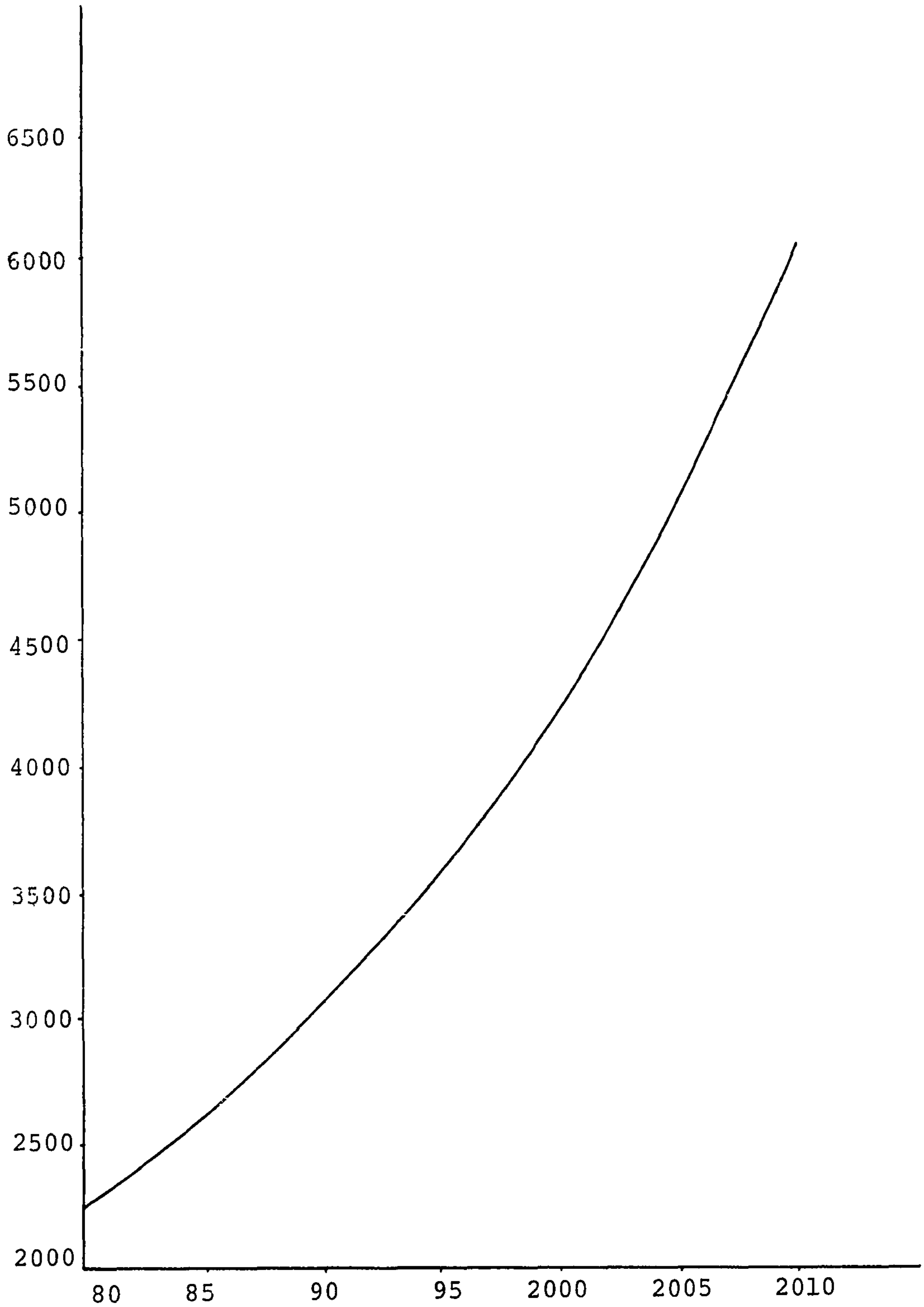
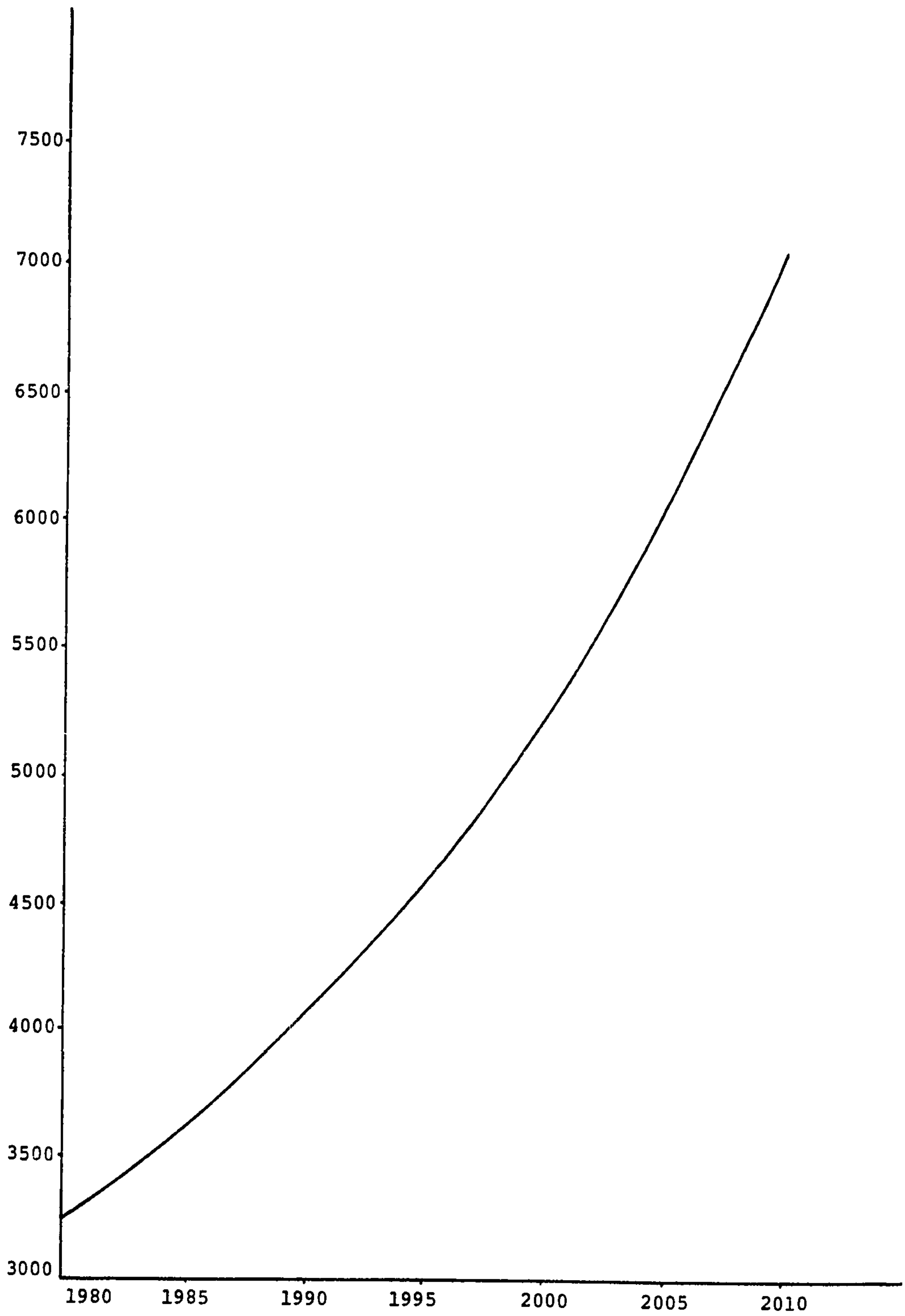


Figure B-5. Total Water Requirements Projection (MCMY).



APPENDIX C

URBAN AND IRRIGATIONAL WATER REQUIREMENTS MODELS

The Irrigational Water Requirements Model (5-9)

Dependent Variable W

Variable entered on step number (1) WD

R Square	.956
Standard Error	49.513
F Ratio	218.165

Variables in the equation

Variable	B	Std Error B
WD	1.019	.068
(constant)	29.707	

Variable entered on step number (2) DP

R Square	.995
Standard Error	16.67
F Ratio	1001.75

Variables in the equation

Variable	B	Std Error B
WD	.883	.028
DP	1917.63	21.55
(constant)	10.03	

Variable entered on step number (3) L

R Square	.998
Standard Error	13.016
F Ratio	1097.709

Variables in the equation

Variable	B	Std Error B
WD	.698	.074
DP	179.106	17.514
L	2.943	1.131

Variable entered on step number (4) INV

R Square	.999
Standard Error	8.82
F Ratio	1795.136

Variables in the equation

Variable	B	Std Error B
WD	.621	.056
DP	187.505	12.151
L	2.935	.767
INV	33.98	10.52

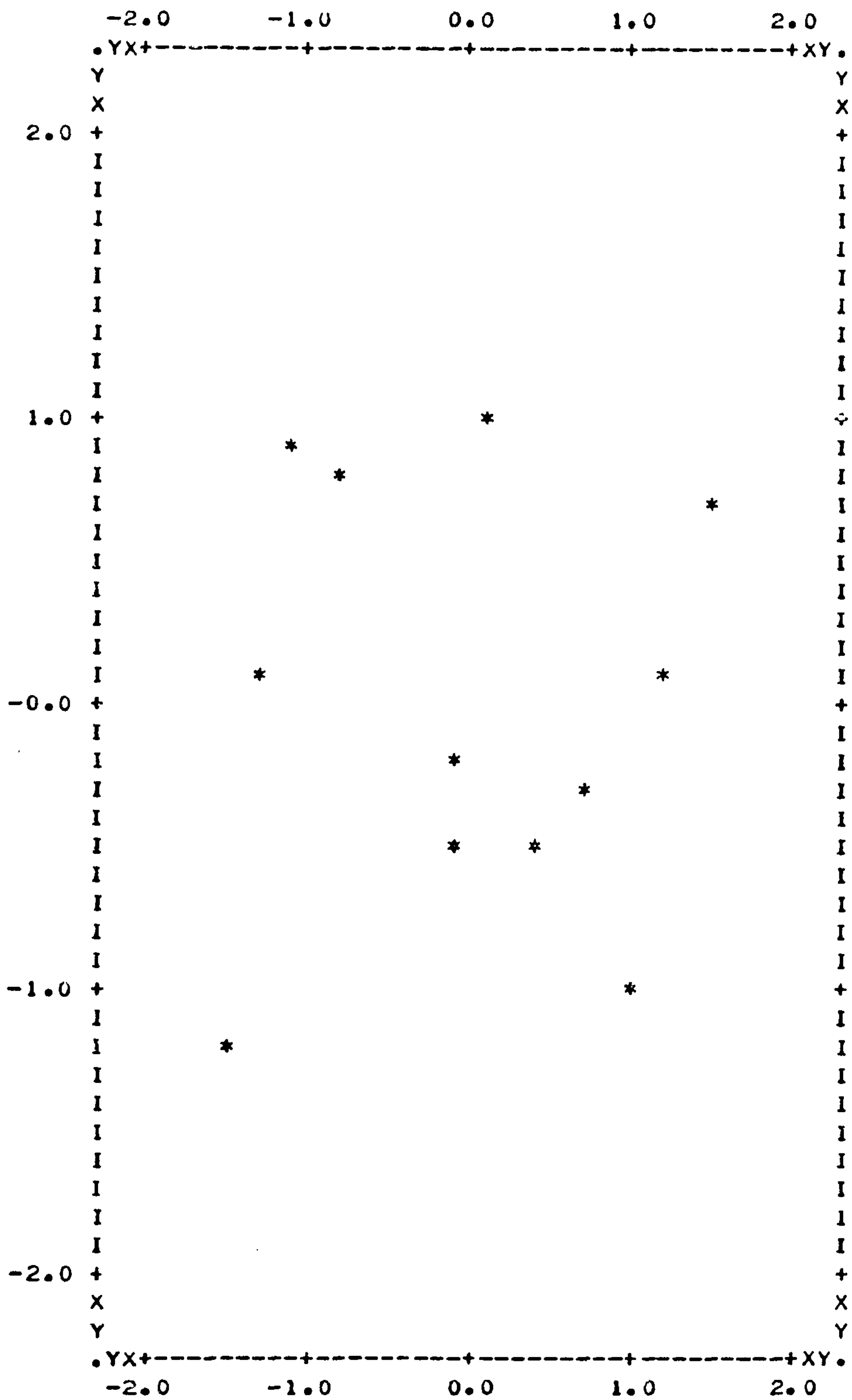
Correlation Matrix

	W	WD	DP	L	INV
W	1				
WD	.978	1			
DP	.703	.549	1		
L	.972	.969	.589	1	
TAM	.846	.868	.385	.834	1

Durbin-Watson Test 2.07205

Standarized Residual Versus Predicted Standarized

Dependent Variable W



The Irrigational Water Requirements Model (5-10)

Dependent Variable AW

Variable entered on step number (1) LWD

R Square	.952
Standard Error	.027
F Ratio	198.5

Variables in the equation

Variable	B	Std Error B
LWD	.986	.069
(constant)	.142	

Variable entered on step number (2) DP

R Square	.995
Standard Error	.00831
F Ratio	1096.1

Variables in the equation

Variable	B	Std Error B
LWD	.846	.026
DP	.106	.010
(constant)	1.046	

Variable entered on step number (3) INV

R Square	.997
Standard Error	.006
F Ratio	1156.9

Variable in the equation

Variable	B	Std Error B
LWD	.761	.0396
DP	.111	.0088
INV	.199	.0079
(constant)	1.664	

Variable entered o. step number (4) LD

R Square	.998
Standard Error	.006
F Ratio	1036

Variables in the equation

Variable	B	Std Error B
LWD	.687	.0587
DP	.1055	.0088
INV	.01936	.0073
LD	.00478	.0029
(constant)	2.209	

Variable entered on step number (R)

R Square	.999
Standard Error	.005
F Ratio	1136

Variables in the equation

Variable	B	Std Error B
LWD	.706	.0512
DP	.0947	.0094
INV	.0192	.0062
LD	.005	.0025
R	.00022	.0001
(constant)	(2.090)	

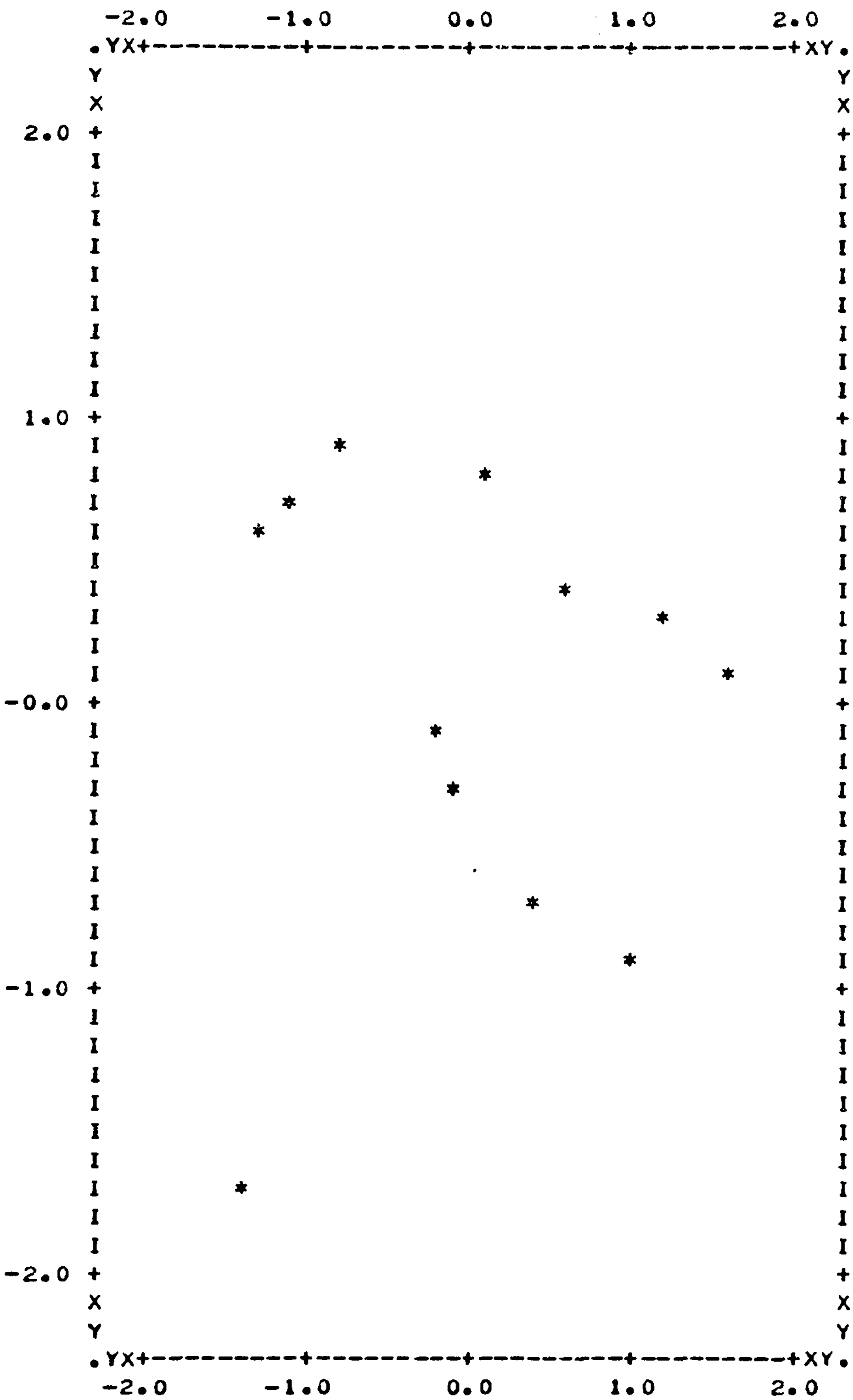
Correlation Matrix

	AW	LWD	DP	INV	LD	R
AW	1					
LWD	.976	1				
DP	.713	.552	1			
INV	.845	.870	.385	1		
LD	.960	.950	.626	.819	1	
R	.081	.235	- .388	.272	.157	1

Durbin-Watson Test 1.64262

Standarized Residual Versus Predicted Standarized

Dependent Variable AW



The Urban Water Requirements Model (5-6)

Dependent Variable Y2

Variable entered on step number (1) Y1

R Square	.990
Standard Error	1712.604
F Ratio	1924.9

Variables in the equation

Variable	B	Std Error B
Y1	1.0737	.0245
(constant)	548.933	

Variable entered on step number (2) S

R Square	.992
Standard Error	1593.061
F Ratio	1114.32

Variables in the equation

Variable	B	Std Error B
Y1	1.006	.041
S	44.558	22.395
(constant)	730.083	

Variables entered on step (3)   INV

R Square	.994
Standard Error	1369.186
F Ratio	1008.3

Variables in the equations

Variable	B	Std Error B
Y1	.717	.112
S	113.29	31.807
INV	698.998	2549.063
(constant)	140.761	

Variable entered on step (4)   HOM

R Square	.996
Standard Error	1242.877
F Ratio	917.262

Variables in the equation

Variable	B	Std Error B
Y1	.393	.182
S	134.598	30.557
INV	8435.605	2421.378
HOM	388.49	22.28
(constant)		

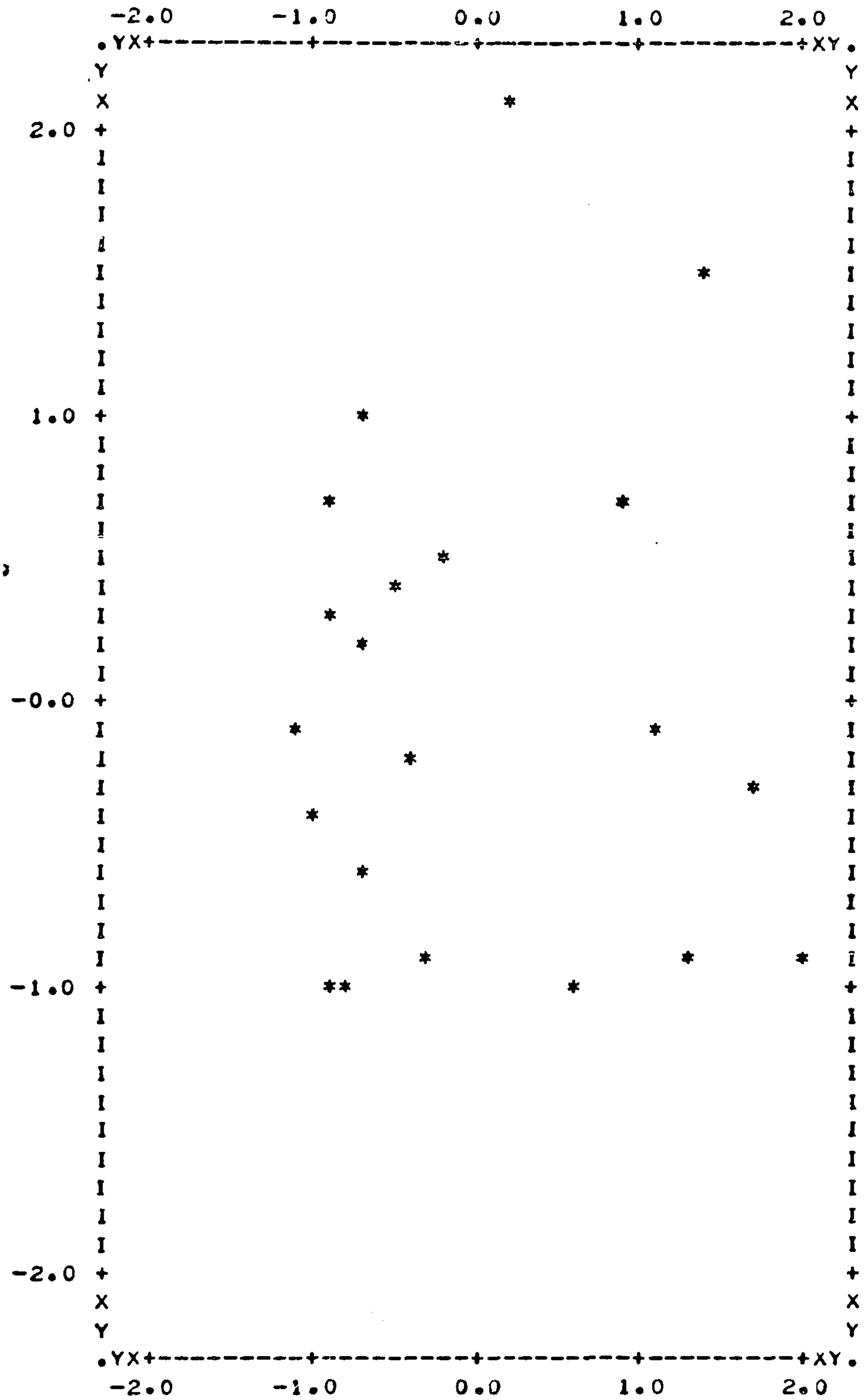
Correlation Matrix

	Y2	Y1	S	HOM	INV
Y2	1				
Y1	.995	1			
S	.851	.831	1		
HOM	.984	.987	.806	1	
INV	.897	.903	.561	.888	1

Durbin-Watson Test 2.23157

Standarized Residual Versus Predicted Dependent

Variable Y2



APPENDIX D

SOURCES OF MATERIALS

Source Material

1. Ministry of Agriculture and Water (MAW)
2. Ministry of Industry and Electricity (MIE)
3. Ministry of Finance and National Economy (MFNE)
4. Ministry of Petroleum and Minerals (MPM)
5. Ministry of Planning (MOP)
6. Ministry of Education (MOE)
7. Ministry of Health (MOH)
8. The Royal Commission for Jubail and Yanbu (RCJY)
9. Saudi Arabian Monetary Agency (SAMA)
10. Department of Water and Sewer in the Western Province
11. Saudi Arabian Agricultural Bank (SAAB)
12. Economic and Social Affair Department, United Nation (UN)