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MATHEMATICAL WATER DEMAND MODELS FOR THE STATE OF OKLAHOMA

A DISSERTATION

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BY

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MATHEMATICAL WATER DEMAND MODELS

FOR THE STATE OF OKLAHOMA

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ABSTRACT

The major objective of this study is to apply the stepwise multiple regression analysis technique to develop predictive water demand models for Oklahoma utilizing socio-economic, environmental and climatological indicators. The predictive demand models developed are municipal and domestic water demand model, industrial water demand model, irrigation water demand model, per capita municipal and domestic water usage rate model and total water demand model for the State.

Data analysis and the technique used indicate that the State's municipal and domestic water demand is a function of total population, non-agricultural employment, gross-state product and precipitation. The State's industrial water demand model is formulated by total population, non-agricultural employment, coal production and precipitation. The input factors for the State's irrigation model are per capita income, irrigated acres, land in farms and precipitation. The significant explanatory variables in the State's per capita municipal and domestic water usage rate model are total population and per capita income. The State's total water demand model is a function of total population and total employment.

Analyses of the results indicate that Oklahoma municipal and domestic, industrial, irrigation and total water demands are expected to be increasing. The per capita usage rate is also expected to experience a significant gain in future years. The results show that with the projected water requirements for Oklahoma and the estimated total water resource development potential, the State has sufficient water within its boundaries to satisfy all present and future needs. But the distribution of water resources, present or potential development, is not ideal throughout the State. It is concluded in this study that the Southwest twelve region, the South Central eight region, the Central five region and the Northwest eleven region are expected to suffer from a lack of water sources, while the Southeast eight region, the North Central nine region, the Northeast fifteen region and the East Central nine region are expected to have a surplus of water by the year 2030.

The mathematical models should be valid for some time to come, that is, the technical coefficients and decision variables should not change significantly. The models validity can be confirmed by annual inventory updating. Marked changes in annual inventory from year to year would suggest exploring the need for adjusting the technical coefficients.

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Finally, I dedicate this work to my father.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES
(continued)

LIST OF FIGURES

LIST OF FIGURES
(continued)

MATHEMATICAL WATER DEMAND MODELS
FOR THE STATE OF OKLAHOMA

CHAPTER I

INTRODUCTION

General

Development of natural resources plays a very important role in general socio-economic development in the United States. It depends to a large extent on the quality and quantity of information upon which programs and plans can be based. One of the most important issues in this country is the collection of natural resource information and development of short and long-range demand and supply models.

In fact, national governments cannot build their plans and proceed in planning programs for socio-economic development by guesswork. Therefore, additional data on natural resources physical characteristics and related economic and social information must be assembled before any more natural resources can be brought into use. Premature commitments to resource development projects can be a result of the pressure for action without enough infomation in hand to evaluate them adequately. Attention must be given by those who are concerned with national socio-economic development to accure socio-economic development programs if a certain proportion of their budget is contributed to produce information and data base concerning long-range demand and supply resources.

There is no doubt that water is considered to be one of the most significant foundations for development in both developed or underdeveloped countries. Effective water demand models are highly desired specially with abundance of petro-chemicals and other natural resources. Water is a necessary and should not be separated from economic development. Projections of water requirements were less important to national planning when population was less and supply was abundance. Population, industrialization and migration of people from rural to urban areas have increased in the United States as well as many other areas in the world, specifically the last ten years, calling for better national planning which includes water projections - projections looking at total societal effect on demand (1).

The necessity of forecasting or predicting future water requirements needs no technical or for that matter public support. There are many factors which might control our future development, such as urban growth, megapolise, suburbia, etc. As a phenomena of the present time, planners, resource economists, engineers, geographers, ecologists and other specialists relate urban growth to a great variety of factors, and water always appears in either the objective function or its constraints. Doxiades (2) expressed the population growth in a function of energy, food and water as follows:

$$G = g\,(E,\ F,\ W) \quad \ldots\ldots\ldots\ldots\ldots \quad (1\text{-}1)$$

where: $F \leqq F_L$

$W \leqq W_L$

G = population growth,

F_L = upper limit of food production,

W_L = upper limit of water production.

According to his study, sea resources will need to be tapped and water and food have a present finite limits. There are several studies that indicate a present evidence of water shortages. It should be clear here that in an economics sense, a water shortage exists only in a lack of willingness to pay. This stage has not been reached yet. Therefore, these shortages might be due to shortage of planning, not water shortages. However, there are several areas that do reflect a physical lack of this commodity (3).

At present time, no one can no longer look at water but must now look at its interaction with other elements in the environment. In other words, now planners must consider the whole system. With the technology available to the world these days, a variety of techniques and approaches have become available to allow planners to look at the future and bring all the interactions over time into play. New computer capabilities, econometric and operational records techniques provide the tools and concepts which have made it possible to build models to estimate and forecast our future requirements in whatever area of study we are interested in (4).

The Role of Water in Development

Man now is currently in a transition phase from days when it was assumed water was plentiful to an immediate future in which use will be governed by increasing scarcity in various parts of the world. As a result of the changing and rapidly rising patterns of demand for water in the world, searching out new approaches, making new decisions and changing old-fashioned policies are some of the issues that are facing governments. Water should be viewed as a factor input in production process and be made to find optimum combinations of those inputs since the availability of water can no longer be taken for granted (5).

There are number of reasons for continuing increase in the demand for water. In short, these reasons can be stated as follows:

(a) the growth in population;
(b) the accelerating influence on consumption of improved standards of living stemming from increased rates of urbanization;
(c) the growth taking place in water-related commodity production and service industries in terms of both absolute and relative to the economy as a whole (5, p.1).

In many countries of the world and as a result of this galloping rise in demand for water, the supply picture is governed by rising costs and the financial limitations on resources the governments must observe.

In a report from the Department of Economic and Social Affairs at the United Nations (5), it is indicated that national, regional and local governments have a significant and fundamental role to play in adjusting the socio-economic and physical frame work of their countries to the changing patterns of water uses. In this report, the advantages of estimating the foreseeable demands for water are discussed. It is stated that an assessment of the future demands for water is the basis of the long-term planning for water resources which enables Governments:

(a) To anticipate problems in the areas of the country or in sectors of the economy;

(b) To recognize those factors that might be changed in order to forestall problems and avoid decisions that might exacerbate the situation;

(c) To recognize those factors that are embedded in present social objectives and practices which have significant effect on water use but have not generally been considered to be subject to control for the purpose of influencing water policies and practices (5, p.2).

Technological invention and innovation will have a great impact on the direction of water use and control over the future years. Some of these technologies affecting water use and/or availability will come about as a result of technological progress which is not specifically related to water while specific research undertaken to solve water problems will be the controlling factor in developing many of the technologies.

Importance of Adequate Planning

Water quality and quantity are not the only two issues associated with water and its existing problems at the present time. In addition to them, there is a matter of location of sources, surface or ground supplies, means of transportation, costs and financial capabilities to handle a solution to the problem. Each problem related to water requires special study because the ramifications of the water problem vary with locality. However, economics is the common factor in all problems. The nature of the water problem should be examined and evaluated early in its stages so that the financing of a solution can be allocated over a long period of time. Furthermore, engineers and planners should provide fully planned development of water resources, not partial planning (6).

In the State of Oklahoma, the future demands for water and the adequate water supplies will increase based on the fact of the economic growth of the State. The geographical location of this growth and the rate of growth will influence the nature of water problems. Supplies of water must be available when they are required and for the areas of the State having prior requirements. Therefore, the timing of increased needs for water will be important in order to provide adequate plans and their associated financing supports.

In fact, the general shortages of water are some of those issues that cause political subdivisions. Moreover, adequate planning will assist the State to lay claim to enough water passing through its areas to meet future needs and project its future development. There are several types of storage reservoirs that vary from small farm ponds to major reservoirs which depend on types of storage as well as purposes they might serve. The State needs to assess its agricultural, industrial and municipal water needs in order to build its future water development projects on realistic basis.

The basic challenge of water demand projections lies in trying to foresee in time and to describe quantitively the interaction between the physical and social aspects of water management.

In a report from the United Nations (7), it is stated that it is much more difficult to establish the specific framework through which water demands can be assessed and compared to available supplies in a comprehensive and systematic fashion, so as to provide a sound foundation for water management policies and planning. This concept is explained in this report and stated as follows:

This situation is due to the following reasons:

(1). Water presents itself and is used under a multitude of forms and conditions. All natural resources occur under different conditions and are used for many purposes, but the diverse and complex conditions to be considered in the demand/supply relationship are particularly striking in the case of water. Some water uses are extremely difficult to interpret and quantify in common physical terms and units of measurement. Some water uses and demand are so intriactely tied to the supply that it is virtually impossible to separate them in terms of assessment (e.g. rain-fed agriculture and forestry). Finally, there are a few water management activities that are not uses or demands in themselves, but do effect the balance between demands and supplies considerably (e.g. flood loss management, erosion control, and pollution control).

(2). Further difficulties arise with regard to the economic and social diversions of the demand/supply relationship. Although demand and supply are initially assessed and compared in physical terms, the basic questions relating to their balance are essentially of an economic nature and can only be answered on the basis of information relating the social and economic costs and benefits which pertain to the various levels of supply and demand. Such information is normally difficult to obtain and thus any attempt to quantify the values is inevitably tied to subjective value judgments........

(3). The third difficulty arises from the extremely diversified institutional structures which provide data on water demands and supplies, and which process and make available data for further application. As a result, data are scattered among the many branches and departments of local, regional and national water related administrations. These administrative regions, whether local, regional or national do not necessarily and do not normally relate to the hydrological systems (e.g. rivers and ground water basins) involved. This further aggravates the problems, since water planning which is based on available data, then does not relate to the hydrological unit concerned. Data requirements for demand/supply studies usually involve a number of public administrations and statistical services which each apply its own system and tradition in grouping, processing and publishing the required information (7, p. 2, 3).

Problems with Water Resources in Oklahoma

Water has become a very significant factor in economic development in Oklahoma. Therefore, proper planning has become a necessary prerequisite to water resource development. A continuing data collection and research program are needed to insure full utilization of available resources. Environmental planning must also be recognized as a vital part of resource development. Since resource development involves large expenditures, future plans should be developed to meet federal funding requirements.

Oklahoma has several problems associated with water resource development. These problems deal with ground, surface and atmospheric water quality and quantity. Moreover, there are some problems that are concerned with water resources planning, the geographical distribution and legability of water.

The first problem area deals with the inadequacy of water resource planning in the State. Although water resource development in Oklahoma has progressed significantly since its beginning, the State needs a well defined long-range water resources plan. A concise well defined plan of development will be necessary to meet future water requirements. The continuing increase in the State's population, land irrigated for food production, education expansion, urbanization, industrialization and many other socio-economic, environmental as well as technological development will make the State face the problem of ever increasing municipal, industrial and agricultural water demands.

Sound planning procedures must be followed and applied on a statewide basis and a well defined, yet flexible implementation schedule must be developed. Following these principles will insure adequate water for all areas of the State for many years.

The Oklahoma Employment Security Commission has projected the State's population to reach 3,772,800 by the year 2000 and 4,962,500 by the year 2040. This increase of the State's population will increase the number of dishwashers, garbage disposals, automatic washing machines, cars and equipment to be washed. Municipal water consumption is expected to increase as well as the per capita municipal water use. Records from the Oklahoma Water Resources Board show that approximately one million acres of land are being under irrigation at present, and this is expected to double within the next 20 years. Water must be available to Oklahoma to meet future water requirements.

There is a great demand for a well defined long-range planning program for water resource development in the State. In order to achieve such a plan, a number of problems must be overcome. First of all, accurate complete data is the basic element necessary in plan formulation. Planning based on incomplete or inaccurate data can result in expensive and possibly tragic errors. Information must be collected on a regular, long-term basis to insure consideration of a complete range of possible values prior to resource development. Therefore, there is a demand for more adequate data systems for different categories in water resource development. Hydrological data and its dynamic nature necessitates programs which periodically monitor these systems reactions to man's activities. Changes generally occur gradually and sometimes years of monitoring are necessary before definite trends can be shown. Therefore, information collected over a long period of time is more representative than short term data. On the other hand, climatology, well monitoring and stream flow gauging are among the data which need to be collected. There is a demand for more sites and testing stations to collect more adequate information on surface and ground water and water quality. Land use data available through other State's agencies should be systematically collected. Moreover, data on socio-economic parameters in the economy as well as historical data on water demands for different categories of water use should be more comprehensive and adequately gathered. In short, a more detailed type of data is necessary for specific plan formulation, project design and operation and regulation program development. Programs to gather this more detailed data are highly required in the State.

Another issue to be considered in order to achieve such a long-range planning program for water resource development in the State is encouragement of research programs which provide the additional information necessary in formulation of planning techniques. Additional research is needed to develop new techniques and programs for more effective utilization of existing data. Research is also necessary to increase general knowledge of existing resources and will overcome the problem of resource development. Research is desired to stabilize a systematic methodologies for making statewide water requirements estimates for both short and long-ranges. Research using computerized models to simulate the hydrologic behavior of ground and stream water systems is needed. Stream and ground water research programs are needed to be expanded. Water quality research programs are also needed to be expanded. In short, research programs will help to develop more specific methods of exploiting more effectively the State's water resources.

The second problem area facing water resource development in the State deals with the geographical distribution of water resources and the variation in their qualities. The eastern half of the State receives from 32 to 56 inches a year of rainfall. The amount of precipitation sharply declines from east to west. The lowest average rate of precipitation in the State is 15 inches in the Panhandle. The highest vaporation rate is 65 inches in the southwest. Conversely, the highest precipitation rate is in LeFlore County in the extreme southwest with an average annual rate of 56 inches. Runoff varies from 20 inches in the southeast to 0.2 inches in the Panhandle. The cumulative runoff amounts to 6 million acre-feet annually in the southeast and 820,000 acre-feet a year in the northwest. The total for the State is 22 million acre-feet a year. The annual lake evaporation ranges from 46 inches in the northeast to 64 inches in the southewest. It must be considered that western is subject to flooding and there are prolonged periods in the east when precipitation drops to a fraction of the figures quoted above. In many areas of the State, no water is available for appropriation, and other critical areas have some water available at times under certain conditions (8).

In fact, the most restricted resource is stream water. Shortages of water exist in the western half of the State due to the availability of stream water or restrictions of water use. On the other hand, there is often abundant stream water which also occasions of no and low flow in the eastern half of the State (9). This might indicate the importance of considering the planning alternative of transmission of surplus water from eastern to western parts of the State if it will be economically feasible.

Although there is a potential 309 million acre-feet of groundwater stored in 12 major underground basins in the State, the mean recovery rate of approximately 40 per-cent results in a yield of only about 123 million acre-feet. Where supply exceeds recharge, the water table lowers and makes recovery even more difficult. Over development of the groundwater basins is a problem since almost half of the State's groundwater supply is located in the western portion of Oklahoma where precipitation is not sufficient to recharge the aquifers.

The quality of both ground and stream water varies from good to poor due to natural and man-made activities and seems to be a problem facing water resource development in some areas of the State. The need for water necessitates the use of some of poor water with treatment; however, there is more water unsuitable for either domestic uses or for irrigation (8, 9). For example, due to the high evaporation losses in western Oklahoma, surface water seems to have high concentration of dissolved solids.

Again, some quality problems are due to man-made activities while the others are caused by natural conditions exist. Examples of man-made causes are waste-treatment plants, runoff from agricultural activities, discharge from industries, and runoff from urban areas. Some of the natural causes of degradation are salt intrusion, minerals from the rocks, turbidity and color from the decay of organic debris from forests, and erosion and silting.

Southeastern Oklahoma from Pontotoc County to the Arkansas border, the quality problem comes from sulfate and chloride which come in with water from the west as dissolved solids. The quality of the Red River as stream water is too poor for either municipal or domestic use.

In short, water quality programs are needed to be modified and expanded. Further research on desalination, reduction of nutrient content in runoff, industrial waste treatment and urban runoff effects is needed to prevent further degradation of the State's water resources.

Finally, water laws should be modified in order to provide a strong support for water resource development in the State. Flexibility in water laws in the State concerning many issues, such as water withdrawn for irrigation, ownership of water, responsibilities of developing ground and surface water supplies, etc., is highly needed.

Objectives

It is a fact that the rate and the amount of economic growth in the State of Oklahoma will have a strong impact on the future water requirements. Therefore, it is necessary to call attention to the problem of water forecasting specially based on socio-economic and social activities in the State. Furthermore, there is a great need for making statewide water requirements estimates and providing methodologies for forecasting future water needs in the State. Thus, the immediate objective of this study is to develop mathematical water demand models for the State of Oklahoma using socio-economic, demographic, geographic, social and environmental characteristics in the State.

More specifically, the objectives of this study are:

(1). To develop econometric predictive water demand models at the statewide level for different categories of water use; municipal, industrial, agricultural and total water use by using socio-economic and environmental input parameters.

(2). To develop a mathematical water demand model at the statewide level to establish per capita municipal water rate by using socio-economic and environmental input parameters.

(3). To apply the developed water demand models and the available forecasts of the significant socio-economic and environmental factors in order to project the State's municipal, industrial, agricultural, total and the per capita municipal water requirements up to the future year 2040.

(4). To establish a systematic methodology for forecasting county municipal, industrial and agricultural water requirements by using the forecasted water requirements of the State.

(5). To forecast municipal water requirements for some selected large cities in the State.

The State's water demand models developed in this research study will be a great help for administrators, public officals, engineers and planners in the State to recognize those factors that are affecting water uses and plan for more feasible water resources development programs based on realistic basis to meet the future water requirements.

The developed water requirements forecasting models format is illustrated in Figure 1 with the components of each model. The State's total water requirements model has two major input factors which are population and total employment. The State's municipal water demand model has four significant input variables which are population, employment, gross-state product and precipitation. The major input variables for the State's industrial water demand model are population, employment, coal production and precipitation. The State's irrigation water demand model is formulated by four input variables which are per capita income, irrigated land area, land in farms and precipitation. Finally, the per capita income and population are the major components of the State's per capita municipal water use model.

The discussion and evaluation of each of the developed models are included in Chapter IV of this study. The technique which was basically used in the process of developing these water demand models is known as the stepwise multiple regression technique which is briefly described in Chapter III.

Growth Assumptions

The following few assumptions were built in the process of developing the water demand models:

(1). Continuing increase in the State's population.

(2). Continuing increase in the State's land irrigation and food production.

(3). Continuing gain in technology and education expansion of the State.

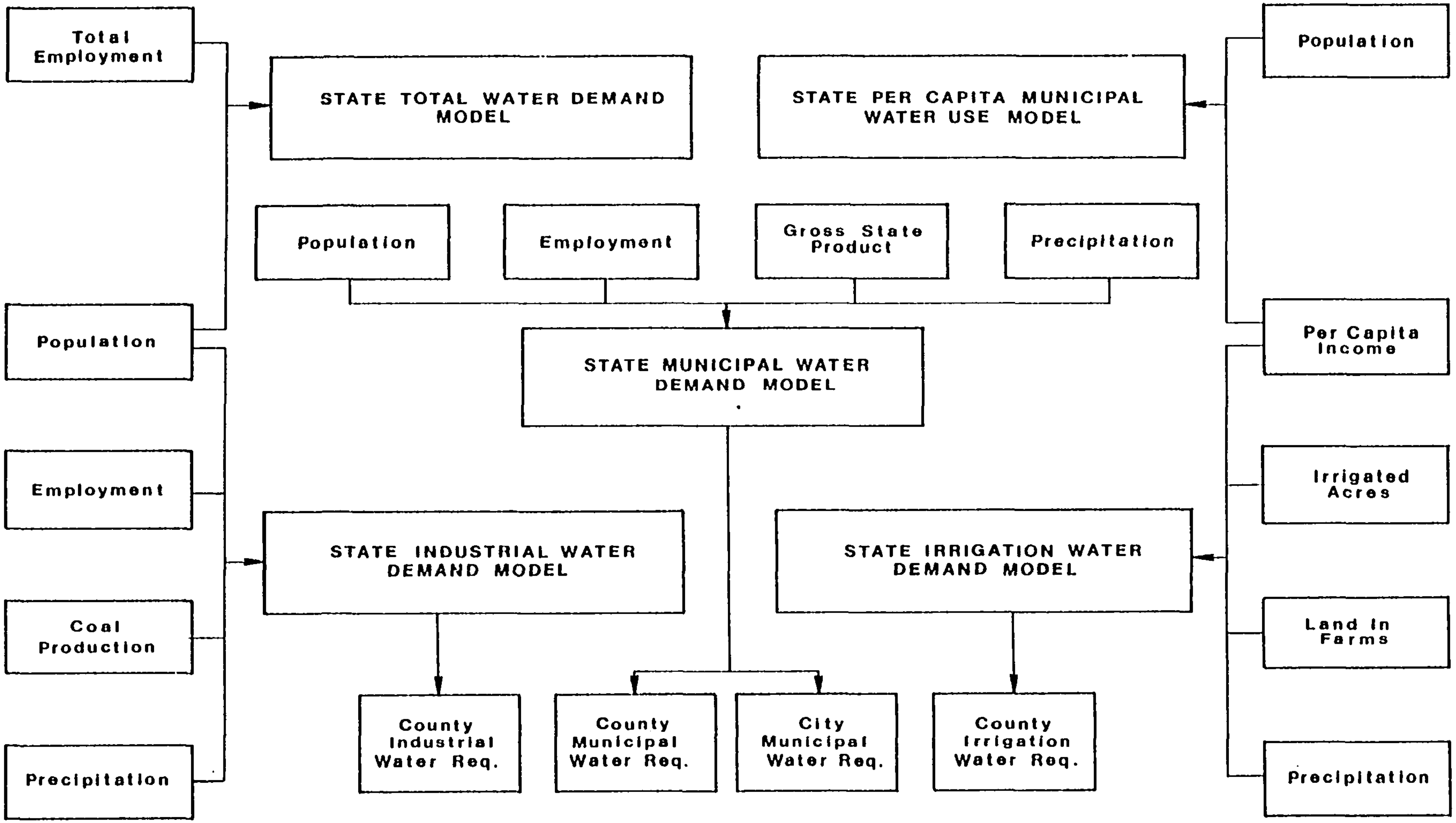


Figure 1: WATER REQUIREMENTS FORECASTING MODELS FORMAT

(4). Continuing increase in industrialization and agricultural production, thus increasing annually the gross-product and per capita income of the State.

(5). Continuing increase in urban and rural population.

(6). Continuing development of petro-chemicals and other industries in the State.

CHAPTER II

LITERATURE REVIEW

Inroduction

Since the main objective of this study is to develop mathematical water demand models for the State of Oklahoma for different categories of water use, it is necessary to review some demand models developed in other studies that are related to this study. Therefore, the purpose of this chapter is to review municipal, industrial, agricultural and total water demand models developed in other studies. The second aim of this chapter is to review, shortly, water resources in Oklahoma. The third purpose is to review the historical municipal, industrial and agricultural water uses in the State of Oklahoma.

Before going any further in this chapter, it is very essential at this stage of the study to formulate definitions of some formulated terms in order to have a common frame of reference for communication. Because of different interpretations in various countries of some of the same words in the same language as well as linguistic difficulties inherent in translations cause further obstacles to clear understanding. Such terms as "use", "needs", "requirements" and "demand" have often been used interchangeably. Also the terms "water demand", "available water", and "water resources" have been used very often.

Some of these fundamental concepts should be explained to facilitate clear and easy interpretation of the discussion in this study.

The following definitions were adapted from a recent report from the National Water Commission of the United States of America (10). These definitions will promote better understanding and minimize misinterpretation.

Water use refers to ways in which water is utilized by man. Water uses includes drinking, cooking, irrigation, industrial cooling and processing, generating electricity, transportation and recreational boating, swimming, fishing, aesthetic enjoyment, and other activities and processes.

Water consumption, or consumptive use, is the difference between withdrawal and return flow and generally consists of water that is consumed by plants, animals, industrial processes or evaporation.

Demand is used in the economic sense and is the amount of a commodity, in this case water or water-related products and services, that would be purchased or used at a given price.

The demand schedule is the functional relationship between various prices of water and the quantities that would be used at those prices.

The demand curve is the graphic presentation of the demand schedule.

Water resource (resource used in the sense of "something that lies ready for use or can be drawn for aid") represents that part of the physical amount of resource that is frequently regarded as the expected annual run-off, although additional supplies can be made available for a specific period of time by mining ground water.

Projections designates a delineation of future conditions, including water demands, supplies, modification of precipitation, reclamation of waste-water plant effluent by advanced treatment processes, forest management and inter basin transfers.

The several demands for water are usually grouped as municipal, agricultural and industrial, according to the main categories of economic statistics and planning. Moreover, these three main categories of water demands can be subdivided into subdivisions. We should keep in mind that there is no single or standardized way of undertaking these subdivisions. Overlaps among the categories as well as differences in definitions and interpretation may exist and which might necessitate arbitrary decisions in several respects. In fact, beyond the above mentioned three major categories, water demands may arise in other fields of regional and national planning, such as transportation, recreation, preservation or extension of swamp and wetland habitat and conservation or utilization of estuaries (5).

Municipal Water Demand Models Review

The term municipal water use may include several categories, such as domestic or residential use, commerical use, public or institutional use and systems losses. Often, researchers will also include industrial users which are tied into the municipal system.

Reid and Muiga (11) used socio-economic inputs to identify four activity socio-technological levels. The study was conducted in 1975 to develop an aggregate demand model for developing countries by utilizing socio-economic growth patterns.

The socio-economic development levels represented were in turn used to identify municipal, agricultural and industrial water requirements.

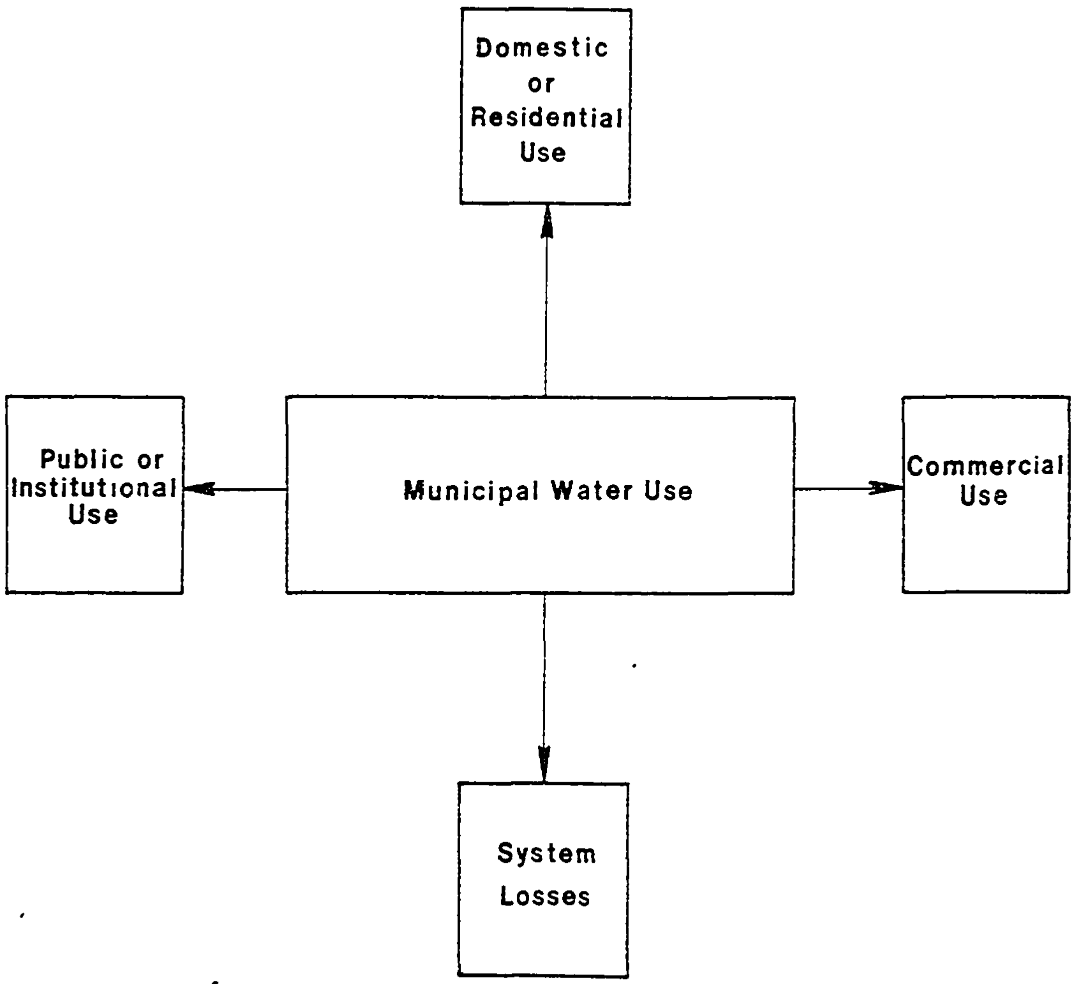


FIGURE 2: MUNICIPAL WATER USE CATEGORIES

Recently in Japan, the adequacy of estimating future needs on the basis of previous annual increments in water consumption has become a very important approach, especially in the Tokyo metropolis (5, 12). Therefore, consideration is given to such social and economic factors which might affect water consumption. Such factors are personal incomes, taxes, products manufactured, projected area of building, etc. The concept of a "modernization index" is introduced and used in estimating water demands since it is considered that water requirements increase proportionally to social modernization and economic development. The index is a symbolic factor including all the various social and economic factors which together have a comprehensive effect. Saki (13) developed a model for Tokyo, Japan using the correlation analysis to estimate the water requirements in 1985. He adopted an "urbanization index" (I) as a kind of "modernization index", with some factors having a specially great effect on urbanization being extracted. He developed the following regression estimation line, according to the available data, and the weight of each factor was appraised by applying the factor analysis:

$$I = 0.5674\ X_1 + 0.1606\ X_2 + 0.1149\ X_3 + 0.1571\ X_4 \quad . \; . \; . \; . \; . \qquad (2\text{-}1)$$

where: I = water demand in gallon per capita per day,

X_1 = population,

X_2 = personal income,

X_3 = industrial production,

X_4 = sales of goods.

He also developed the following linear equation to express the maximum water consumption in Tokyo:

$$Y = 361.521 + 32.057\ I \qquad (2\text{-}2)$$

where: Y = maximum water consumption per day.

Coefficient of correlation of the formula is 0.986 and the standard deviation 0.012. These figures express statistically that this method achieves better results than the one using each factor separately.

Another study to be reviewed is that undertaken at Johns Hopkins University during the years 1961-1966. This study was under the sponsorship of the Federal Housing Administration (14, 15, 16, 17). The objectives of this study were to determine the water use patterns and demand rates imposed on water system in residential areas and to determine the major factors influencing residential water use (17, p.4).

The Federal Housing Administration (FHA) report describes the method of data collection as follows:

> Master-meter, punched-tape recorder systems were installed to monitor continuously flow into forty one homogenous residential areas having 44 to 410 dwelling units and several apartment areas located in various climatic regions throughout the United States.....
>
> In developing the project, the number of participants desired was determined using a climatic classification, made principally according to annual and seasonal precipitation and temperature. Selected utilities were invited to participate by purchasing and installing master-meter recorder systems in several study areas of varying economic levels within their service areas. Thus, study areas were selected according to climate and economic level with all other factors that influence water use taken at random......
>
> Included are 28 metered residential areas, 8 flat rate residential areas, and 5 apartment areas. The meter areas are further classified into areas having public sewers are separated

> into Western and Eastern United States by their location relative to 100th meridian. Very little precipitation occurs in the area west of the 100th meridian during most of the growing season (17, pp. 4-8)....

The technique used was regression analysis to determine equations for estimation of average domestic demand and average summer sprinkling demand. Linaweaver (17) indicated in his report that the factor with the highest level of influence on residential water use throughout the country was the number of homes. Economic level, climate and metering of consumers were found to be the factors at the second level of influence. The third level of influence on residential water use included many factors among which the cost of water was found to be the most important factor.

The following equation was recommended for design purpose after the results of this study were compared with the (FHA) standards (18):

$$Q = Q_d + 0.6\ c\ a\ L_s\ (E_{pot} - P_{eff}) \text{ with } Q \geqq Q_d \quad . \ . \ . \ . \ . \ . \ . \quad (2\text{-}3)$$

where: Q = expected average demand for any period expressed as a rate in gallons per day,

Q_d = expected average domestic (household) use in gallons per day which applies for all periods of a day or longer and may be reliably estimated from a simple function of the average market value of dwellings as described below,

0.6 = a coefficient to adjust for the difference between actual evapotranspiration from lawns and potential evapotranspiration,

c = constant to adjust for units, 2.72×10^4 gallons per acre-inch of water,

a = number of dwelling units,

L_s = average irrigable area in acres per dwelling unit,

E_{pot} = estimated average potential evapotranspiration for the period of demand in question in inches of water per day,

P_{eff} = amount of natural precipitation effective in satisfying evapotranspiration of the period and thereby reducing the requirements for lawn sprinkling in inches of water per day (17, pp. 58-59).

The Q_d is estimated from the following equation:

$$Q_d = (157 + 3.46\ V)\ a \quad \text{. . . . .} \quad (2\text{-}4)$$

where: V = average market value in \$1000 per dwelling unit.

It should be observed here that the price of water is not included in the last recommended equation although it was found in the Johns Hopkins study to be a significant variable.

The most important point of the Johns Hopkins study is the subdivision of municipal use into its major components (residential, commercial, and so on) and then into smaller ones (domestic and sprinkling use). The number of variables included in equation (2-3) and (2-4) are fairly low but they should provide a good foundation for predicting future water use.

Another study to be reviewed is the one which was undertaken by Hittman Associates of Columbia, Maryland. They have used the Johns Hopkins study to develop the "Main I" system for estimating current water usage. Meyer and Mangan (19) have described the "Main I" system and indicated in their paper that past water use data was not used as inputs to the model. Following this study, Hittman Associates again have developed the "Main II" forecasting model using the "Main I" system. In the "Main II" model, water requirements were estimated separately for the residential, commercial/institutional, industrial and public unaccounted sectors of the community. Furthermore, these estimated water requirements for the mentioned sectors were subdivided and estimated for individual categories of water users, such as sewered residences, flat rate sewered residence, commercial establishments, institutions, manufacturing categories, etc. It should be pointed out here that estimates in the "Main II" system were made of mean annual and peak hours requirements (20, p. I-1).

In this study, data from about fifty cities was used in order to develop a regression equation for each category of water use. The independent variables were all economic and demographic factors. The variables used were in the form of rates of changes not the absolute values. The input variables were housing, population, income, employment and per capita water use. Multiple correlation coefficients (R^2) were fairly high, their range was from 0.74 to 0.90. Baton Rouge, Louisiana, Baltimore, Maryland and Columbia, Maryland were the three case studies presented. This application of the model in these three different cities was to illustrate the flexibility of the model in handling different types of cities. The first city is considered to be a complete metropolitan area with reasonable commercial and industrial activities. The second city has a low population growth but high commercial and industrial activities. The third city is a new city which is fully planned with controlled population growth.

Although the Main system is considered to be one of the best operational forecasting systems, it appears to have some shortcomings. One of these shortcomings is due to the lack of appropriate data and conclusive theoritical analysis. The result of this was that two of the most important variables in the Johns Hopkins study, irrigation area and price of water, were not included in the Main system.

Another study to be discussed in the review of water demand models is that by Saunders (21) conducted at West Virginia University. The purpose of his study was to: (1) identify factors currently closely associated with the level of water use, (2) suggest alternative methods of constructing forecasts of water use, and (3) construct several sets of projections for several urban areas, based on alternative assumptions about the future level of the price determinants (21, P.2).

He collected water related economic and demographic data from 93 Standard Metropolitan Statistical Areas (SMSA's), 32 districts in Louisville, Kentucky and 75 North-East Central cities. First, he used the factor analysis to isolate a small number of significant factors as a result of the factor analysis. It should be mentioned here that the researcher started with 65 original demographic and economic factors. Next, he applied the regression analysis technique in order to relate size of urban areas and income to water usage. He used 1960 as a base year and developed the following predictive regression equation:

$$E_{75i} = (W_{60i} \times 1.19 \times \frac{Y_{75i} - Y_{60i}}{Y_{60i}} + W_{60i}) \cdot P_{75i} \quad . \; . \; . \; . \; . \qquad (2\text{-}5)$$

where: E = total water use,

W = per capita use,

Y = per capita income,

P = estimated population,

i = SMSA number for i = 1, 2, ..., 141,

60, 75, = 1960, 1975.

Saunders estimated the water consumption for 141 Standard Metropolitan Statistical Areas (SMSA) for 1975.

Whitford (18) indicated in his report that the forecasts computed for 141 SMSA's were widely divergent and seem to be very high. For example, the city of Phoenix, which supplies about 70% of the metropolitan area, experienced only a 52 per-cent increase in the years 1960-1969, while the raise was 186 per-cent for the Phoenix SMSA estimated by Saunders from 1960-1969. However, Saunders' study is a good example for the importance of using the factor analysis and cutting through to relevant factors.

Berry and Bonem (22) studied the municipal water use in an area of norther New Mexico in 1967. Their aim was to develop a mathematical regression equation relating per capita daily municipal water use to per capita personal income to a number of cities and towns in New Mexico. Data used in their study was collected on the amount of water withdrawn (gross pumpage of municipal system) per person for a number of years. They based their regression equation on a mixture of cross-sectional and time series data. The regression equation obtained is:

$$q = 25.1 + 0.059\ Y \quad \text{(2-6)}$$
$$(R^2 = 0.766)$$

where: q = the municipal water use in gallons per capita per day,

Y = the annual per capita personal income in 1965 dollars.

The developed equation in this study is statistically a reasonable one with R^2 value equals 0.766, but there are two deficiencies. First, the equation developed was based on both cross-sectional and time series data. Second, the equation contains only one independent variable and omits variables other than personal income levels that may affect the municipal water use in New Mexico.

The authors revised and extended the 1967 work in an attempt to introduce four independent variables: per capita income, the price of water, city population and a climatological variable. They came up with an equation which was very nearly the same one developed in 1967. They concluded that the original regression equation (2-6) developed with fragmentary data is consistent with more recent improved data.

Babbitt, Dolland and Cleasby (23) quoted figures for minimum, median and maximum water use by population group, year and region. These figures were reported by Seidel and Baumann (24). Also, Capen (25) presented the following equation for well-metered, average systems:

$$G = 54\ P^{0.125} \quad \text{(2-7)}$$

where: G = gallons per capita per day, P = population in thousands.

Capen published this model in a paper in 1957 based on a survey made in 52 cities. He suggested that population is the only variable related to per capita use which seems invalid to present day conditions.

In 1971, Reid (26) has developed a mathematical equation to predict water demand by using several submodels, such as economic, population, life style and reconciliation (12). The equation can be described as follows:

$$WD_t = (Pop_t)\ uu \left[\frac{ppct_t}{ppct_s}\right]^X \left[\frac{Inc_t}{Inc_s}\right]^Y \left[\frac{Pop_t}{Pop_s}\right]^Z \quad . . . . . (2\text{-}8)$$

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 study to be reviewed is that by AVCO Economic Systems Corporation. They developed a model for the Office of Saline Water (27) called the Economic Evaluation Modeling System (EEMS). The major objective of the system was to use mathematical models for estimating water requirements and water resource costs. The United States was divided into 19 States groupings and a regression equation was derived for each one in order to determine the water demand. There were 17 regression variables included to describe population, income, housing and industrial production. Price of water was excluded and precipitation was included. The coefficients of determination of all the 19 regions were above 0.9 for twelve cases, and between 0.8 and 0.9 for five cases. The lowest coefficient of determination was about 0.6 (18). For Gardena, California, the water use was over-estimated by 180 per-cent. This was determined by comparing the results obtained from the developed regression equations with actual water use figures for each city included in the study. The errors were quite large, in most cases they were in the range between 30 and 50 per-cent.

Reid and Muiga (1) developed a municipal water demand model for the twelve Arabic countries included in the Economic Commission of Western Asia (ECWA). Data was collected from the twelve countries and by using the stepwise multiple regression analysis, the authors developed the following predictive equation for the whole region:

$$M_{n,t} = 2.2113 + 0.0003\,NP_{n,t} + 0.0361\,IN_{n,t} + 0.0017\,NC_{n,t} \quad . . \quad (2\text{-}9)$$

where: $M_{n,t}$ = municipal water demand of country n at year t,

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

$IN_{n,t}$ = 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.

The coefficient of determination (R^2) was quite high (0.98) which indicates a good level of regression analysis. The F-test indicated the non-significance for the cost of water, although it may seem to be an important factor in municipal water usage. The correlation coefficients between national population, national per capita income, national percentage of homes connected to water supply and the municipal water usage were found to be very high.

Bartone (28) attempted to develop a mathematical municipal water use model for the State of Oklahoma in 1970. He used the stepwise multiple regression analysis on data for 39 cities in the State. The original independent variables considered in his study were per capita income of the country, price of 5,000 gallons of water and 1968 city population estimates. He used the municipal water use in gallons per capita per day as a dependent variable. To arrive the average daily per capita consumption rate, he added the water pumpage of the categories domestic, commercial, public, and unclassified industrial users and losses, and divided the sum by 365 times the 1968 population estimate for each city. The municipal projection equation is given by the following formula:

$$Q_{Mi} = 89 + 0.002\, M_i \quad \ldots\ldots\ldots\ldots \quad (2\text{-}10)$$

where: Q_{Mi} = average municipal water requirement, in gallons per capita per day for ith city,

M_i = population estimate for ith city.

The coefficient of determination (R^2) was found to be 0.7431 whilé the standard error of estimate was 27.9.

Bartone indicated in his report that there were two reasons that he tried time series data in order to develop another municipal demand model. The first reason was that per capita water use changes through time. The second reason was that other researchers have stated that the average municipal water use changes constantly (4, 29). He used data from 1958 to 1968 from several cities in the State. He tried to examine the following relationship:

$$Q^{t}_{Mi} = a + bM^{t}_{i} + ct \quad \ldots\ldots\ldots\ldots \quad (2\text{-}11)$$

where: Q^{t}_{Mi} = unit municipal water use of ith city in year t,

M^{t}_{i} = population of ith city in year t,

a, b, c = constants.

This indicates that his independent variables were population and time. He concluded that the inclusion of both variables in equation (2-11) would not be appropriate since the problem of multicollinearity makes it almost impossible to find the values of the regression coefficients.

There was another study conducted by the Indian National Council of Governments (INCOG) in order to project domestic use rates in the State of Oklahoma. The equation considered was:

$$Q_{SAU_i} = 32 \div 0.01\ D_i \quad \ldots\ldots\ldots\ldots \quad (2\text{-}12)$$

where: Q_{SAU_i} = the average residential water requirement in gallons per capita per day for the ith statistical analysis unit (SAU),

D_i = the population density of ith SAU.

This equation was developed for towns with population in the range of 1,000 to 4,000 and must be applied to the SMSA's in the State of Oklahoma.

There are many other studies and models in the area of water demand to be reviewed. Fourt (30) conducted a study in 1958 applying the multiple regression analysis. His aim was to develop a regression equation to explain the water usage in terms of price, rainfall, average number of persons per meter, number of days in summer and the total population served.

The Susquehanna Model (31, 28), population was found to be the water forecasting factor in the demographic sector of the model. A municipal use rate of 160 gallons per capita per day was used to determine the total municipal water requirements. This use rate was estimated to be increased by 1.4 per-cent per year. It should be noted that the industrial use category was excluded from the use rate used in this study.

Muiga (12) developed several water demand models in his dissertation for three regions: Africa, Asia and Latin America. He used the stepwise multiple regression analysis as a basic technique to relate socio-economic, environmental and technological parameter to the water demand (in gallons per capita per day) in developing countries. The developed models are expressed in the following equations:

$$D_{w.af} = 22.0341 + 0.0973\ X_2 \quad (R^2 = 0.953) \qquad (2\text{-}13)$$

$$D_{w.af} = 12.720 + 0.0683\ X_2 + 0.142\ X_6 \quad (R^2 = 0.968) \qquad (2\text{-}14)$$

$$D_{w.as} = 7.1476 + 0.0827\ X_2 \quad (R^2 = 0.902) \qquad (2\text{-}15)$$

$$D_{w.as} = 6.6817 + 0.04397\ X_2 + 0.2204\ X_5 + 0.0263\ X_6 \qquad (2\text{-}16)$$

$$(R^2 = 0.968)$$

$$D_{w.la} = 15.3981 + 0.0663\ X_2 \qquad (2\text{-}17)$$

$$(R^2 = 0.810)$$

$$D_{w.la} = 13.7401 + 0.0645\ X_2 + 0.0682\ X_5 + 0.0330\ X_6 \qquad (2\text{-}18)$$

$$(R^2 = 0.897)$$

where: $D_{w.af}$ = water demand in Africa in gallons per capita per day,

$D_{w.as}$ = water demand in Asia in gallons per capita per day,

$D_{w.la}$ = water demand in Latin America in gallons per capita per day,

X_2 = population of the community served by water supply in thousands,

X_5 = percentage of homes connected with water supply systems,

X_6 = average national annual income in U. S. dollars.

These six developed equations have satisfactory coefficients of determination and all the independent variables included in the models (X_2, X_5, and X_6) passed the sequential F-test.

Morgan and Jonathan (32) published a paper in the Water Resources Bulletin in 1976. The objective of this paper was to determine the regression coefficients or estimators of climatic variables, price of municipal water and median family income in a relation with municipal water use. They used a data set which consists of monthly municipal water delivery data for 36 cities in Southern California within an area bordered on the north by Paso Robles, to the west by Majave and El Centro, and the south by San Diego. The data used was cross-sectional in nature. They examined the following water demand relationship in their study:

$$Q_{ij} = b_o + b_1 P_i + b_2 MFI_i + b_3 \text{ Climate}_{ij} + E \quad . \; . \; . \; . \; . \; . \quad (2\text{-}19)$$

i=1 . . . . . . 33 water agencies,

j=1 . . . . . . 12 months

where: Q_{ij} = municipal water use in gallons per capita per day of the ith district in the jth month,

P_i = average price of municipal water derived in dollars per acre-foot,

MFI_i = median family income in thousands of dollars,

Climate_{ij} = varying climatic measures where T equals temperatures in ^oF, R equals precipitation in hundredths of an inch, and (PE - R) equals to the excess of potential evapotranspiration over precipitation measured in hundredths of inches,

E = is a random disturbance term.

They tested three alternate climatic indicators: (1) temperature and precipitation; (2) potential evapotranspiration minus precipitation (PE - R); and (3) monthly binary seasonal variables. They divided the sample into four separate subgroups: total, wet domestic, dry and sprinkling groups. Total number of models developed in this study is 12 models. Some of the models are given as follows:

$$Q_1 = 235.01 - 1.282\ P + 0.0085\ MFI + 23.741\ (PE-R) \quad (R^2 = 0.61) \tag{2-20}$$

$$Q_2 = -33.778 - 0.7278\ P + 0.0089\ MFI + 3.169\ T - 1.648\ R \quad (R^2 = 0.45) \tag{2-21}$$

$$Q_3 = 2.0019 - 1.460\ P + 0.0069\ MFI + 42.205\ (PE - R) \quad (R^2 = 0.60) \tag{2-22}$$

$$Q_4 = -181.02 - 0.898\ P - 0.0024\ MFI + 6.640\ T \quad (R^2 = 0.501) \tag{2-26}$$

where: Q_1 = municipal water use in gallons per capita per day of group 1 (total) which consists of the total sample over the 12 month period,

Q_2 = municipal water use in gallons per capita per day of group 2 (wet domestic) which consists of observations collected from November through March,

Q_3 = municipal water use in gallons per capita per day of group 3 (dry) which consists of observations collected from April through October,

Q_4 = municipal water use in gallons per capita per day of group 4 (sprinkling) which includes both sprinkling and domestic demand. To isolate the summer sprinkling demand, minimum wet period monthly use of each area is subtracted from the dry period usage.

Moncur (33) conducted a study at the University of Hawaii to investigate the usefulness of two procedures for analyzing water use time series data. The first procedure was accomplished by using a standard regression estimation approach to translate price data into a form of the demand function for water. The second procedure was an application of a simple spectral density estimation model to Honolulu water consumption data in search of identifying periodicities or cyclical regulations of water demand. Using the regression technique and data from 1960 to 1971 (34, 35), Moncur developed the following predictive equation:

$$\hat{Q}_t = 326{,}710 - 773{,}090\, P_{wt}^* \quad \ldots\ldots\ldots\ldots \quad (2\text{-}27)$$
$$(4.6609) \quad (-3.5696)$$
$$(R^2 = 0.52)$$

where: Q_t = average daily water consumption in 1000 gallons for year t,

$P_{wt}^* = P_{wt}/CPI_t$,

P_{wt} = the marginal price of water for year t,

CPI_t = the Honolulu consumer price index for year t.

while t-values appear below each estimated regression coefficient. All regression coefficients were significant at the 5% level.

Because of the fact that the population increase would lead to significant changes in Q_t even if real price had remained constant, Moncur replaced the average daily water consumption variable (Q_t) with per capita water consumption to obtain the following regression equation:

$$\hat{q}_t = 0.4010 - 0.76866\ P_{wt}^* \quad . . . . (2\text{-}28)$$

(6.1459) (-3.3837)

$(R^2 = 0.55)$

where: $q_t = Q_t/Pop._t$ = per capita water consumption for year t,

$Pop._t$ = population served by the Honolulu Board of Water Supply for year t,

Again, all regression coefficients were significant at the 5% level.

Moncure indicated in his report that the developed models (2-27 & 2-28) deserve expansion to include income and perhaps rainfall as independent variables.

Industrial Water Demand Models Review

Industrialization is considered to be the principle feature of the economic and social development which has taken place the last century. The industrial water use represents one of the most important categories of water usage. The major groups of industrial water use are: (a) cooling; (b) processing; (c) boiler water; and (d) general use, such as drinking, air conditioning, cleaning, etc. The amount of water used varies from one group to another and also depends on types and sizes of industries within each group. Figure 3 shows the major groups of industrial water use categories. Table 1 shows some examples for normal daily water consumption for some selected industries in the State of Oklahoma obtained from the Bureau of Water Resources Research at the University of Oklahoma (36).

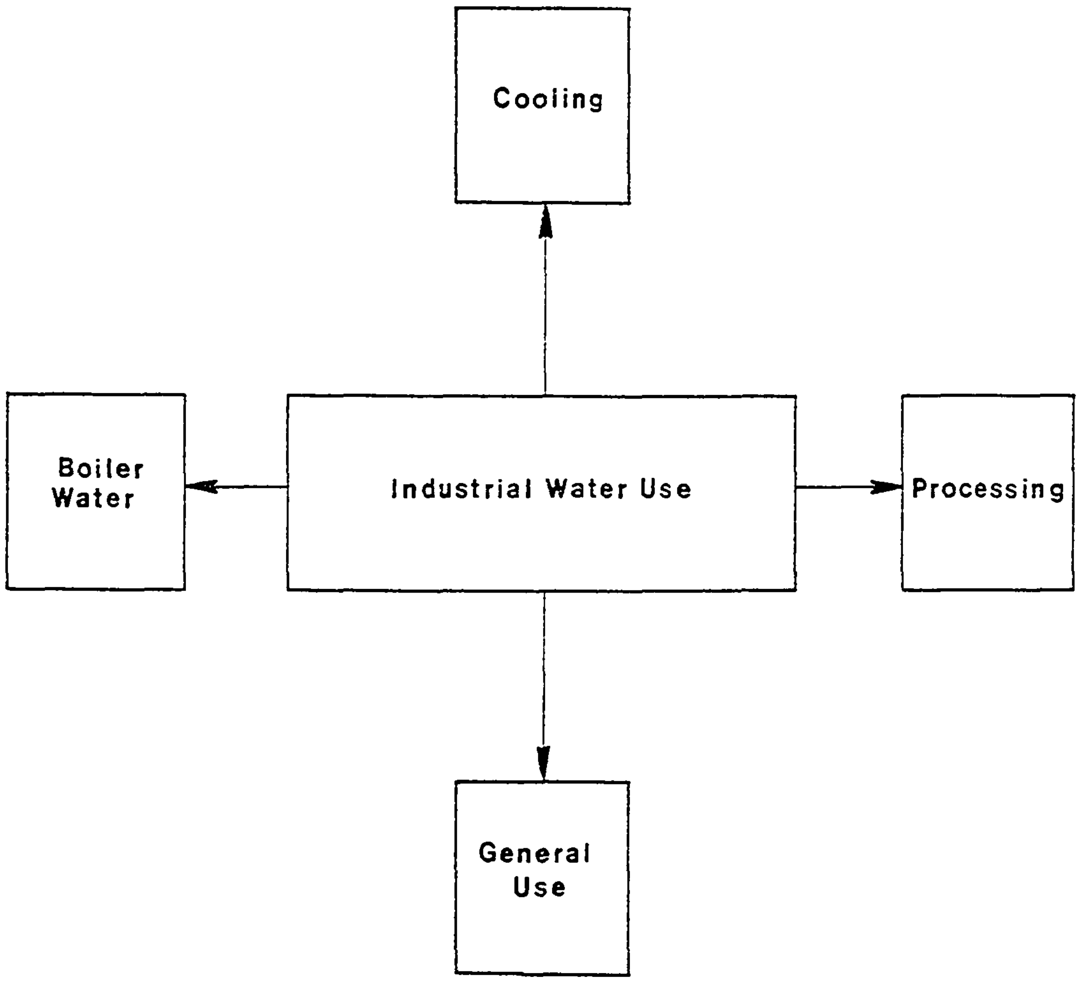


FIGURE 3: INDUSTRIAL WATER USE CATEGORIES

Again, the proportions of the major groups of water use in industry vary considerably from one case to another. For example, cooling (in the power industry and in manufacturing) is considered to be the dominant use in most countries and it may represent as much as 60 to 80 per-cent of the total industrial water use.

It is very useful to define the industrial water requirements in general and by each group. For example, water used for processing may be defined as water in manufacturing plant which comes into direct contact with the intermediate or final product. Moreover, it may be subdivided into water entering the product, as in canned food and beverages, and water serving functional purposes in technological processes, such as washing, flotation, transportation, etc. Boiler water use is sub-divided into steam generation for power production and for manufacturing process (5). Among the manufacturing industries, primary metal industries, manufacturers of chemical and paper products and petroleum refineries are usually the most significant water use. These four sectors are accounted for about 85 per-cent of the total water uses in the United States of America (37). Mining also uses significant amounts of water (including the extraction of oil and gas) for washing and drilling purposes.

Bartone (28) defined water requirements for the industrial sector as requirements which consist of all water uses by manufacturing establishments having six or more employees. He also indicated that industrial water use is always expressed in terms of gallons per employee in many other studies associated with industrial water sector.

Table 1

Normal Daily Water Consumption,

Selected Industries in Oklahoma.[36]

1956

Industry	Daily Average Water Intake[a]
Paper Manufacturing	20,600
Petro-Chemical Production	5,000
Petroleum Refining	5,000
Metal Smelting and Fabrication	2,500
Chemical Production	2,500
Glass Production	1,900
Cement Production	1,500
Food Processing	630
Transportation Equipment	400
Machinery (Except Electrical)	400
Printing and Publishing	260
Clothing Production	60

[a] Gallons Per Day Per Production Worker

Source:[36] Bureau of Water Resources Research, University of Oklahoma, Water - Oklahoma's No. 1 Problem, October, 1956, P. 10.

Reid and Muiga (1) developed an industrial water demand model for (ECWA) region. The model developed in this study identifies the factors affecting industrial water usage in the region. The technique used was the stepwise multiple regression analysis. The industrial projection equation is generated by the equation:

$$I_{n,t} = 0.7587 + 0.0018\ NP_{n,t} + 0.1373\ GNP_{n,t} + 789.8\ WF_{n,t} \quad ..(2\text{-}29)$$

where: $I_{n,t}$ = industrial unit water demand for country n at year t,

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

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

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

X_1 = percentage of national work force who are professionals,

X_2 = percentage of national work force who are skilled.

X_3 = percentage of national work force who are unskilled.

The correlation coefficients between each of the three independent variables and the unit industrial water use were high and the coefficient of determination (R^2) was found to be 0.99.

Another study to be reviewed is that one reported in the United Nations report (7). The State of Israel was chosen as a study area. One of the forecast models used was based on serial correlation analysis for the unit value product of water according to industrial branches. In this study, the total value - at market price - was divided by the total annual amount of industrial water demand. In general, it was found that the product value per cubic meters (cu.m) at a constant price has increased significantly over the past decade. Data used in this study was from 1962 to 1972 period. A typical regression equation for one of the major consuming branches - textiles - is given as follows:

$$Y = 5.299\ X - 10238 \quad \text{. . . . .} \quad (2\text{-}30)$$

where: Y = value of product per cu.m (IL/cu.m),

X = calender year, 1962, 1963, ...

Generally speaking, it seems very likely that countries and regions in which industrialization has not yet started or is currently emerging will experience extensive industrialization during the decade to come. In developed and developing countries, industrialization is the most dominant feature of the economic and social development. In fact, during the Second United Nations Development Decade, which was launched on 1, January, 1971, an average annual growth of 8 per-cent in manufacturing output and a corresponding increase in energy supplies is envisaged for the developing countries. This growth per-cent is twice as high as that envisaged for agricultural output (5).

Table 2 shows the increase of water intake for industrial uses during the past few decades in the United States of America in the overall context of major categories of water use. The rate of increase is particularly impressive in water use for steam-generated electric power production.

Table 2

Increase in Industrial Water Demand in

Comparison to Other Major Water Demands,

United States of America, 1900-1975[5]

(Billions of liters, daily average)

Year	Irrigation[a/]	Public water supplies	Domestic[b/]	Industrial and miscellaneous[c/]	Steam-generated electric power	Total
1900	76.4	11.3	7.5	37.8	18.9	151.9
1910	147.6	17.7	8.3	52.9	24.6	251.1
1920	211.5	22.7	9.0	68.1	37.8	349.1
1930	227.0	20.2	10.9	79.4	69.6	407.1
1940	268.7	38.2	11.7	109.7	84.0	512.3
1944	305.0	45.4	12.1	211.9	135.8	710.2
1945	314.5	45.4	12.1	181.6	109.0	662.6
1946	327.0	45.6	13.2	147.6	101.8	635.2
1950	378.5	53.3	17.4	174.1	145.3	768.6
1955	453.4	64.3	20.4	227.1	226.3	991.5
1960	510.9	83.2	22.7	272.1	293.7	1 182.6
1965	560.5	94.6	24.6	331.9	348.9	1 360.5
1970	601.8	105.2	26.1	389.8	408.0	1 530.9
(1975)	642.3	112.7	27.2	436.7	495.8	1 714.7

Source: [5] Water for Industrial Use (United Nations publication, Sales No. 58.II.B.1).

a/ Total take, including delivery losses but not including reservoir evaporation.

b/ Non-farm domestic use and farm domestic use as well as farm stock wells.

c/ Manufacturing, mining, commerce, air conditioning, resorts, motels, military and miscellaneous.

Agricultural Water Demand Models Review

Water is one of the most important input factors of agricultural production. The way that water is provided to different regions is usually dependent upon the nature of these regions. There are three major categories of agricultural regions: (a) humid regions; (b) arid regions; and (c) intermediate or semi-arid regions. Rainfall is the main source of water in humid regions and it has a great effect on quality and amount of runoff available for other water users within down-stream areas. On the other hand, neighboring rivers and ground waters are the basic sources of water supply for arid regions. For the intermediate or simi-arid regions, a combination of both sources, on-site and external supplies, usually satisfies the agricultural water needs.

Irrigation is considered to be the most significant key issue of water resources development on a world-wide scale and in a long-range prospective. There are several reasons to be considered in the concept of the importance of irrigation in water development. First of all, irrigation water is assumed to be one of the most consumptive water use categories. The second reason is that food production and the rising standard of living emphasize expansion and development of agriculture for which irrigation is considered to be a basic component or a controlling factor. The third reason lies in the fact that irrigation systems and supply methods have a significant impact on the local environmental conditions of any region.

There are many natural factors which affect irrigation water use rates. Some of these factors are precipitation, temperature, runoff, geographic location and evapotranspiration as well as many socio-economic, environmental and technological factors. Areas under irrigation is another important factor affecting irrigation water requirements. Moreover, the water resource planner must take into account the agricultural techniques and their effects on water use per unit of land as well as political and social forces that are likely to be operative.

In a study for the Food and Agriculture Organization of the United Nations, Holy (38) estimated an aggregate global water use for irrigation of 1,400 billion cubic meters in 1967 and the doubling of this amount by the year 2000. Another estimate was made by M. J. Lovovich (39), he estimated the global water use for irrigation of 2,300 billion cubic meters for 1965 and projected it to be around 4,250 billion cubic meters for the year 2000. Lovovich also estimated proportions returned to rivers after use of 600 billion cubic meters for 1965 and 400 billion cubic meters for the year 2000.

Reid and Muiga (1) developed an irrigation water demand projection model to estimate irrigation water requirement for (ECWA) region by applying the stepwise multiple regression technique to utilize socio-economic factors. The predictive equation is given by:

$$IR_{n,t} = 0.15 + 0.0007\ NP_{n,t} + 0.5051\ IC_{n,t} \quad \ldots\ldots\ldots\ (2\text{-}31)$$

where: $IR_{n,t}$ = irrigation unit water demand for country n at year t,

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

$IC_{n,t}$ = national percentage ratio of irrigated to cultivated land of country n at time t,

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

Bartone (28) explained the method he used in his study to project county acreage under irrigation in the State of Oklahoma. The equation developed is given by:

$$A_j^t = \left[1 + 28.5 \frac{t-t_o}{A_s^{to}} \right] A_j^{to} \quad . . . . (2\text{-}32)$$

where: A_j^t = thousands of irrigated acres in jth county at time t,

A_j^{to} = thousands of irrigated acres in jth country during base year t_o,

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

His basic assumption was that the ratio of each county irrigated acres to the State's will remain constant in the future years.

Another study to be reviewed is that one carried by the Bureau of Reclamation (40). The basic aim of the study was to develop unit use rates for irrigation water in Oklahoma counties considering the effects of mean annual climatic factors and location. Figure 4 shows the average unit water use for irrigation in acre-feet per acre of crop per year for each county in Oklahoma. The figures developed in this study were

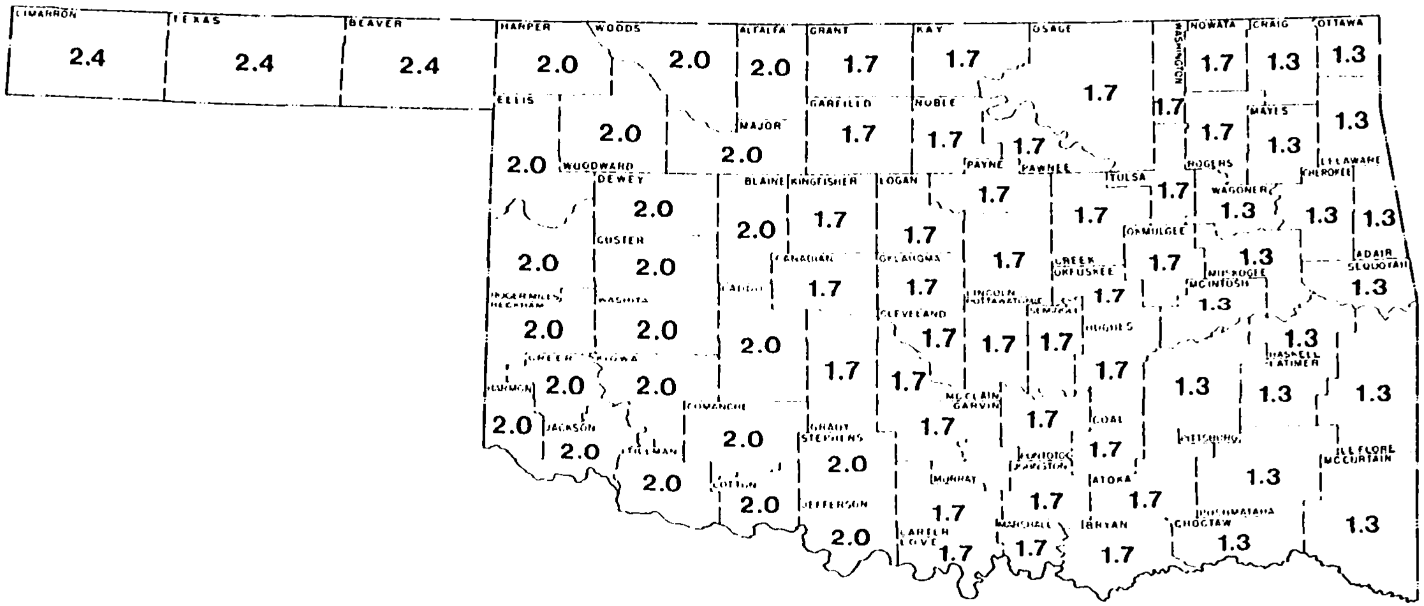


FIGURE 4: AVERAGE UNIT WATER USE FOR IRRIGATION

Acres-Feet/Acre/Year

Source: See Ref. 40

found to be consistent with data and estimates given by Reid (41), the U. S. Department of Agriculture (42, 43), and the Oklahoma Water Resources Board (44).

Review of Oklahoma Water Sources

There are several sources of water available to the State of Oklahoma, such as ground water, surface water and rainfall.

Ground water is one of Oklahoma's most valuable natural resources and is available almost everywhere in the State. Approximately 56 per-cent of the total reported water used in Oklahoma is supplied by ground water source. Over 80 per-cent of the State's irrigation needs is satisfied by ground water, and approximately 300 towns and cities obtain their water supplies from wells and springs (45).

There are large quantities of ground water available to Oklahoma which are not equally distributed throughout the State (36). The major origin for this ground water is moisture that falls on the land surface and percolates down into the soil - bearing strata. Approximately 15 per-cent of this falling water soaks down into the ground and might be classified as true ground water when it inters the zone of complete saturation. The period that this ground water remains in the soil is greatly affected by summer sun, winds and water consuming plants. Moreover, there are other quantities of ground water found in underground sand or gravel, fractured rock or rock such as limestone that has been eaten full of holes by the chemical actions of water. These underground formations are called "aquifers."

There are four principal ground water reservoirs or aquifers: (1) semiconsolidated sand and gravel underlying the High Plains; (2) alluvial deposits along streams and adjacent to valleys; (3) sandstones; and (4) limestones, including dolomite and gypsum. The locations of the principal aquifers in Oklahoma are shown in Figure 5.

It should be noted here that due to the lack of available stream water, ground water development is greatest in western part of the State. In that area, ground water is extensively used for irrigation, municipal and domestic needs. In contrast, ground water in central and eastern Oklahoma is used only by small towns and communities. Therefore, potential exists for increased development of this natural resource to help meet future water requirements.

Surface water is another source of water in the State of Oklahoma. The control and utilization of surface water is one of the most important aspects of water resource development in Oklahoma due to the fact that it often gets first attention to satisfy the demands of municipalities, industries and agriculture.

Arkansas, which drains the northern two thirds of the State, and the Red River, which drains the southern third, are the two major river basins in Oklahoma. There are several small rivers that flow into these two major ones. Some of these small rivers are very important, such as the Cimarron, Salt Fork of the Arkansas, Verdigris Grand (Neosho), Illinois, Canadian and North Canadian rivers that flow into the Arkansas. On the other hand, Salt and North Forks of the Red, the Washita river, the Boggy and Kiamichi river are some of the most important rivers that flow into the Red River.

A large amount of water flows out of Oklahoma in these rivers every year. The average annual flow of the Arkansas River at Fort Smith is approximately 24,000,000 acre-feet and the annual average flow of the Red River system into Arkansas is better than 13,000,000 acre-feet

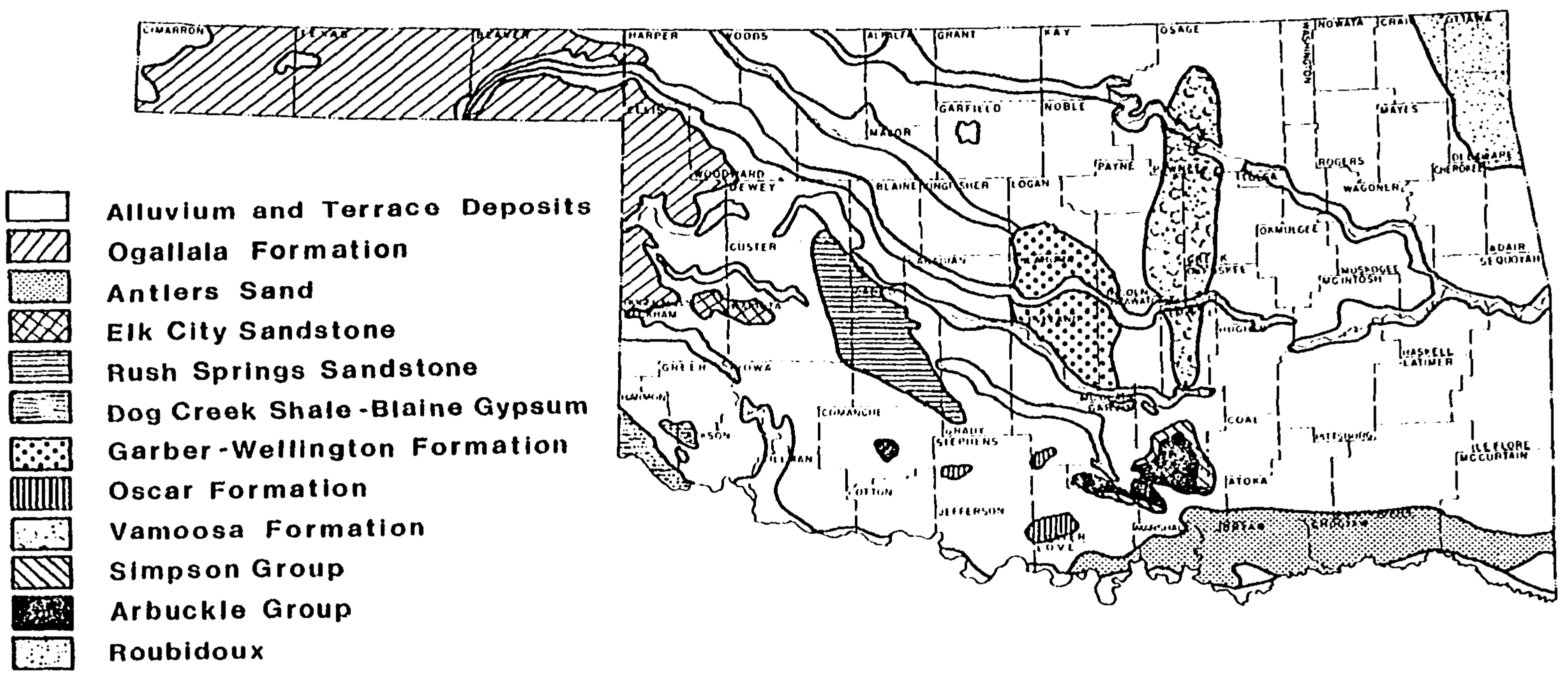


FIGURE 5: OKLAHOMA GROUND WATER RESERVOIRS

Source: See Ref.45

a year. Approximately 10,000,000 acre-feet of water flows into Oklahoma in the average year by way of the Arkansas River and its tributaries from Kansas and Missouri. This indicates that 14,000,000 acre-feet originate in the Arkansas basin within the State's boundaries. Only a very small part of this potential supply is now being used by the State. However, it should be carried in mind that it is possible that most of water now leaving Oklahoma each year will be needed to fulfill the future demands of different water use categories.

There are many reservoirs that have been already built and an even greater number are under consideration. Figure 6 is an illustration of the major reservoirs, existing or under construction. There are other lakes that have been authorized. It should be pointed here that the major municipal lakes are Atoka, Draper, Ellsworth, Eucha, Fugua, Hefner, Lawtonka, McAlester, Overholser, Shawnee and Spavinaw.

The third source of water in Oklahoma to be reviewed is rainfall. In fact, the water supply of Oklahoma is dependent upon rainfall. Part of precipitation in Oklahoma is lost back to the atmosphere through evaporation and plant transpiration. A very small portion of precipitation arrives in form of snow, hail or sleet compared to the total water resources in the State. Most of water which falls on Oklahoma as rain is from water vapor which originates through evaporation from the surface of the oceans and marginal seas, specifically from the Gulf of Mexico. Another source of water vapor is originated from the surface of freshwater lakes and streams, moist earth and the leaves of plants (6).

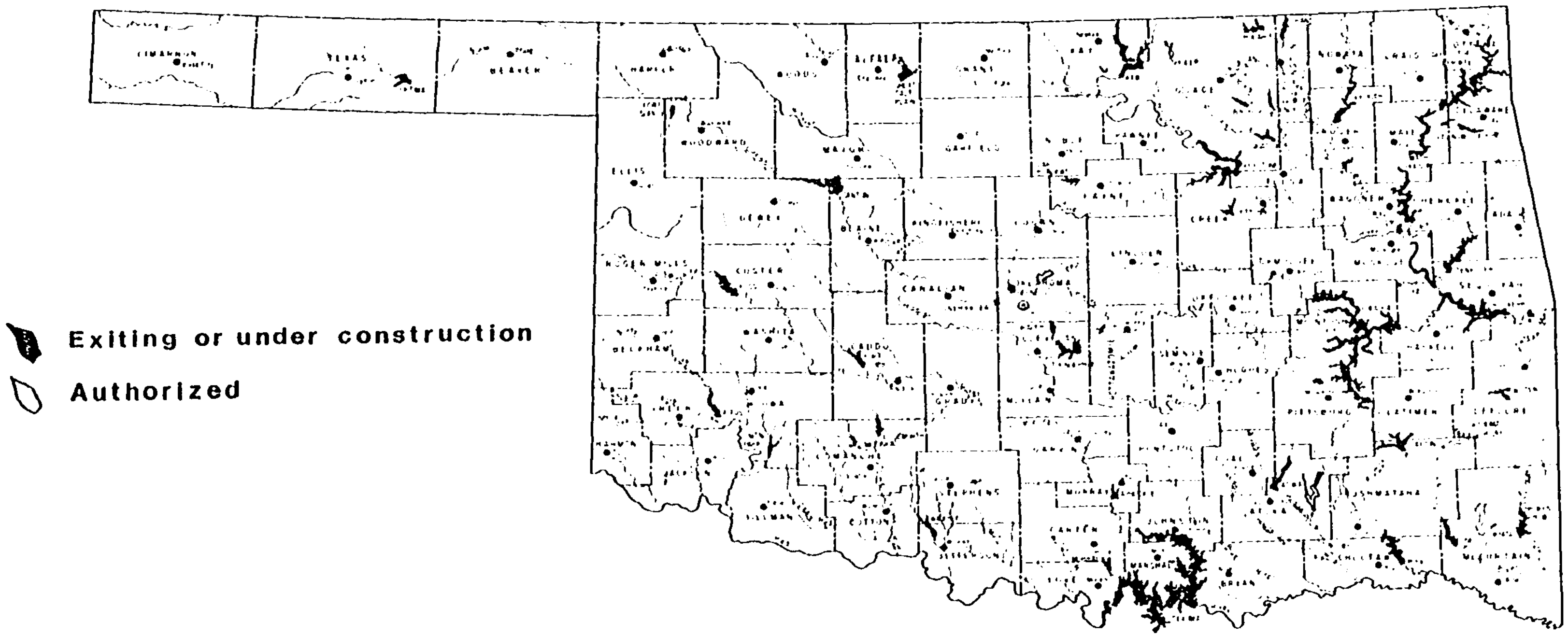


FIGURE 6: OKLAHOMA MAJOR RESERVOIRS & STREAMS
Source: See Ref. 45

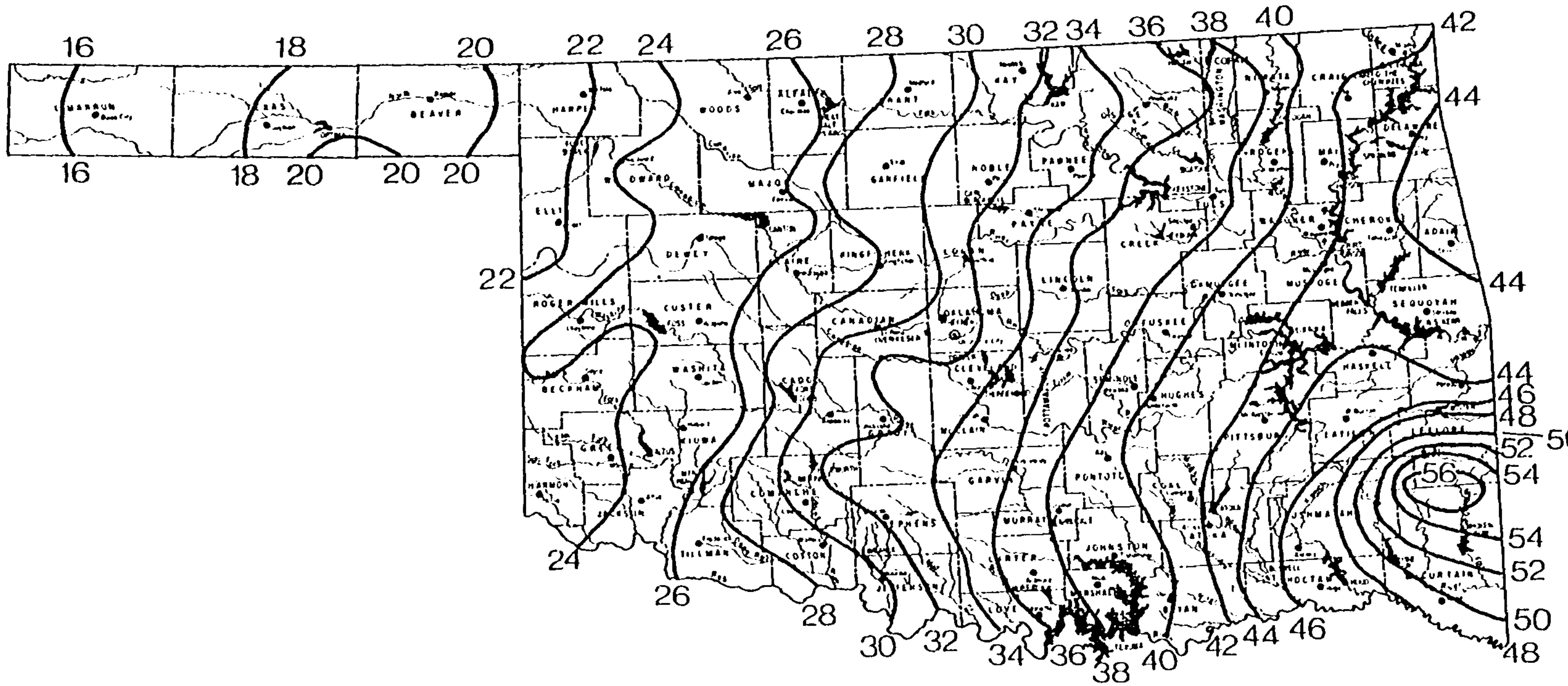


FIGURE 7: OKLAHOMA MEAN ANNUAL PRECIPITATION
(In Inches)
Source: See Ref.45

As mentioned before, the geographical distribution of rainfall decreases sharply from east to west. Average annual precipitation ranges from 56 inches in southern LeFlore County in the southeastern corner of the State to approximately 15 inches in the western section of the Panhandle. Precipitation in the form of snow rarely remains on the ground more than a few days. Figure 7 is an illustration to show the average annual precipitation in inches in Oklahoma. Once again, mean annual precipitations are not consistent in Oklahoma and there are also extreme variations from one season to another and area to area (45).

Review of Municipal, Industrial and Agricultural Water Uses in Oklahoma

Municipal Water Use

The demands for municipal supplies is usually controlled by urban population, the growth of business enterprises and some other factors, such as the increased usuage of air conditioners, automatic washing machines, garbage disposal units, etc. Urban population seems to be the most significant factor that might have a great influence on municipal water demand.

In 1930, the total number of people resided in rural areas was 1,575,000 while approximately 822,000 lived in urban areas. By 1950, the population of urban areas has increased to 1,140,000 while the rural population was only 1,094,000. These figures might indicate a consistent migration from rural to urban areas in Oklahoma. Consulting with Table 3, it is obvious that the daily municipal water use has

Table 3

Oklahoma Municipal, Industrial and

Agricultural Water Uses History[36, 46]

(In Million Gallons Per Day)

Year	Municipal Use	Industrial Use	Agricultural Use (Irrigation)
1930[a/]	170.116	25.806	1.00
1935[a/]	172.792	21.425	1.00
1940[a/]	155.152	20.260	1.00
1945[a/]	148.482	29.680	2.00
1950[a/]	192.038	39.615	3.00
1955[a/]	233.007	51.927	196.00*
1966[b/]	403.00	159.45	455.00
1975[b/]	447.00**	525.99	692.00

*An estimate

**Adjusted value

Source: [a/] Water: Oklahoma's No. 1 Problem, Bureau of Water Resources Research, University of Oklahoma, and Oklahoma Water Resources Board, 1956. See Reference (36).
[b/] Reported Water Use in Oklahoma, Oklahoma Water Resources Board. See Reference (46).

increased from approximately 170 million gallons per day to 192 million gallons per day during the year 1930-1950. The unit municipal water use rate dropped from 196 gallons per capita per day in 1930 to approximately 150 gallons per capita per day in 1940. This decline in unit municipal use rate could be due to the drought conditions that occured during that period (36).

Records from the Oklahoma Water Resources Board (46) show a reported municipal water use of 403 million gallons per day in the year 1966. That indicates an increase of 110 per-cent in the municipal water use rate between 1950 and 1966. Furthermore, the reported municipal water use in 1975 was 447 million gallons per day, indicating about 11 percent increase between the years 1966 and 1975.

Therefore, Oklahoma must increase the amount of water presently available to meet and satisfy the future expansion of its urban communities which will be resulted in increased municipal water requirements.

Chapter V in this study includes all the forecasts of municipal water requirements from 1980 to 2040 and projected for both the State and county levels as well as some selected cities in the State.

Industrial Water Use

The amount of water used in industry depends on the classification of industry (cooling, boiler, processing and other uses) as well as types and sizes of industrial plants within each group. If we take Oklahoma, for example, and refering to Table 1, it is very obvious that paper manufacturing industry represents the highest average daily water consumption per worker. Industries, such as paper mills, petroleum refineries, petro-chemicals and cement are considered to be larger users of water than other industries, such as printing and clothing industries. Therefore, each industrial process has different water requirements level which is dependent on type of industry as well as the availability of raw materials.

The geographical distribution of surface water affects the level of industrialization in the State of Oklahoma besides the availability of many other natural resources than water. In other words, surface water is more available in the northeastern part than many other portions of the State which provides a good support for better industrialization standard at present and future years.

Consulting with Table 3, the total water used by industrial plants in Oklahoma was 28.8 million gallons per day in the year 1930. In 1950, the total water used was approximately 39.6 million gallons per day, which indicates an increase of 53 per-cent from 1930 to 1950. Between 1930 and 1940, the total water used by industrial plants in Oklahoma had dropped from 25.8 to 20.3 million gallons per day due to the severe drought conditions that existed at this period.

Records from the Oklahoma Water Resources Board show that the industrial water use in Oklahoma was about 160 million gallons per day in 1966. This is considered to be a sharp increase from 1950 to 1966, which is approximately 303 per-cent. In 1975, the reported industrial water use was 526 million gallons per day. This implies an increase of 227 per-cent between 1966 and 1975.

There is no doubt that the rate of increase in the industrial water use is higher than the municipal rate. The industrial water use has increased from 1930 to 1975 at a rate of 11 million gallons per day per year, while the municipal rate was about 6 million gallons per day per year during the same period. This might be due to continuing development of petro-chemicals and other industries in the State as well as the population increase.

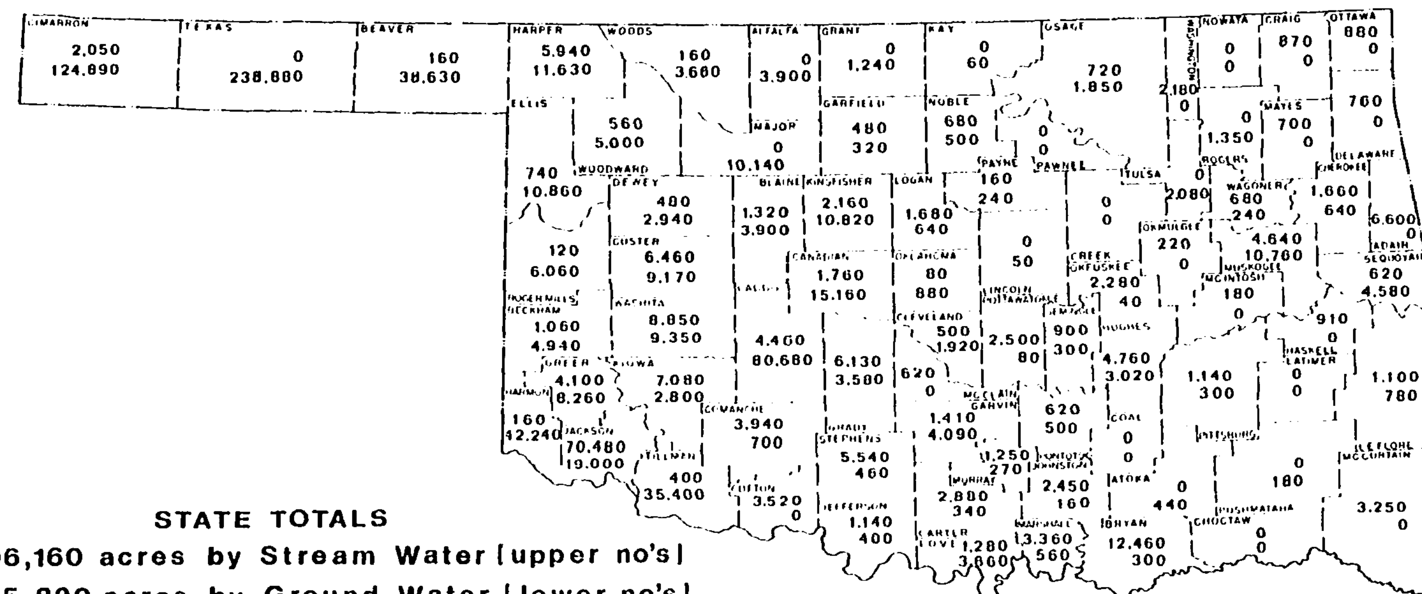
Irrigation Water Use

The concept of forecasting water demands for agricultural purposes is more difficult due to the fact that it is dependent on a variety of socio-economic, environmental and technological factors. Among all factors affecting agricultural water use, number of acres irrigated appears to be one of the most important factors which should be taken into account.

There was a rapid increase in number of acres irrigated in Oklahoma in the past 50 years. In 1940, the irrigation water use was approximately 1 million gallons per day with irrigated area equals 5,000 acres in the State. The irrigation water use had reached the amount of 3 million gallons per day with associated number of acres irrigated equals 90,000. This indicates 200 per-cent increase in irrigation water use from 1940 to 1950. In 1956, there were 284,000 acres under irrigation in Oklahoma and the water use average had reached 254 million gallons per day.

The reported water use for irrigation in Oklahoma was 455 million gallons per day in 1966, which is about 79 per-cent increase over the 1956 figure. The reported irrigated area was 428,000 acres in 1966, which is about 144,000 acres increase from 1956 to 1966. In 1975, the reported water use for irrigation was 692 million gallons per day. The increase between 1966 and 1975 in irrigation water use is around 52 percent (see Table 3).

Records of the Oklahoma Water Resources Board reflect that almost one million acres of land being irrigated, and this is expected to double within the next 20 years (45). With the improved water utilization methods and increased acres of land under irrigation, water must be available to Oklahoma farmers to feed citizens and meet the future agricultural water requirements of the State. Figure 8 shows number of acres under irrigation in Oklahoma in 1975.



STATE TOTALS

206,160 acres by Stream Water (upper no's)

745,820 acres by Ground Water (lower no's)

(Year 1975)

FIGURE 8: OKLAHOMA IRRIGATION INVENTORY

Source: See Ref. 70

CHAPTER III

FORECASTING APPROACHES AND THE STEPWISE MULTIPLE REGRESSION TECHNIQUE

Introduction

One of the main objectives of this chapter is to discuss briefly the concept of forecasting and approaches of forecasting methodologies. Then a review of the stepwise multiple regression analysis is presented since it is the basic technique used in this study in order to develop the State's water demand models required.

Forecasting Approaches

It is difficult to distinguish between estimate, predict and forecast. Certon (47) makes a fine destinction in a textbook on technological forecasting:

> A technological forecast is defined as a prediction, with a level of confidence, of a technological achievement in a given time frame with a specified level of support (47, p.4).

A forecast or prediction may be defined to be a statement about unknown events whose occurance or non-occurance typically lies in the future.

Following the history of estimating techniques, in 1930's engineers and demographers based their estimates on eye projections. In the 1940's, engineers used arithmetic progressions for small towns and farming areas and geometric progressions for vigorous cities and old dying ones in order to formulize these projections mathematically. After the 1940's, the picture of use of estimating techniques has significantly changed especially when economists entered the act. Before the 1940's, all projections were based on the past projected into the future. In the 1950's, economists applied macro-economic forecast procedures and then they related to people and water. They used population synthesis, regional analysis and market demand models as different types of estimating techniques. During the 1960's, econometricians used supply models, factor and component-analysis, cohort analysis and in[illegible] estimating techniques. In the late 1960's,[illegible]gain applying the systems approach. Reid ([illegible]ch in following steps:

(1) - The m[illegible]es)
(2) - The en[illegible] than inputs)
(3) - Valida[illegible]
(4) - Reasona[illegible]
(5) - Dissaggr[illegible]
(6) - Alternati[illegible]

Reid stated in his r[illegible] systems approach is one of the techniques which has developed from operations research and systems engineering which allows us to look at all the interactions at one time using inductive followed by deductive reasoning or feedback (4).

There are several approaches to forecasting methodology. Some of these approaches are forecasting by extrapolation, forecasting by growth analogies, forecasting by trend correlation, dynamic forecasting, delphi technique and forecasting by interpretation of forecast data.

Table 4

Use of Estimating Techniques[4]

Type	Year	Application
Eye	1930's	Engineers and
Birth over deaths		Demographers
Logistic		
Arithmetic		
Geometric	1940's	Engineers
Incremental		
Population theory		
Curvilinear		
Population systhesis		
Factor and component analysis	1950's	Economists
Cohort analysis		
Input/output analysis		
Supply Model	1960's	Econometricians
Factor and component-analysis		
Cohort analysis		
Input/output analysis		
Goal orientation	1970's	
Econometric techniques		Reid's Study

Source: [4]Reid, George W., A Multistructural Demand Model for Water Requirement Forecasting, Bureau of Water Resources Research, University of Oklahoma, January, 1970.

farming areas and geometric progressions for vigorous cities and old dying ones in order to formulize these projections mathematically. After the 1940's, the picture of use of estimating techniques has significantly changed especially when economists entered the act. Before the 1940's, all projections were based on the past projected into the future. In the 1950's, economists applied macro-economic forecast procedures and then they related to people and water. They used population synthesis, regional analysis and market demand models as different types of estimating techniques. During the 1960's, econometricians used supply models, factor and component-analysis, cohort analysis and input/output analysis as estimating techniques. In the late 1960's, engineers entered the act again applying the systems approach. Reid (4) explained the systems approach in following steps:

(1) - The model (recognition of all variables)
(2) - The emphasis on goals (output/rather than inputs)
(3) - Validation
(4) - Reasonable metrics
(5) - Dissaggregation to project level
(6) - Alternatives (4, p.8).

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Input/output analysis		
Supply Model	1960's	Econometricians
Factor and component-analysis		
Cohort analysis		
Input/output analysis		
Goal orientation	1970's	
		Reid's Study (4)
Econometric techniques		

Source: [4]Reid, George W., A Multistructural Demand Model for Water Requirement Forecasting, Bureau of Water Resources Research, University of Oklahoma, January, 1970.

Forecasting by extrapolation includes four categories which are simple, curve fitting, trend curves and systematic curve fitting. The two basic assumptions associated with trend extrapolation are: (1) that those forces which created the prior pattern of progress will more likely continue than change; and (2) that the combined effect of these forces is more likely to extend the previous pattern of progress than it is to produce a different pattern. The growth is considered in terms of cumulative time or calender year. Simple extrapolation is the most popular present method.

Forecasting by growth analogies has two major methods which are growth method using a logistic curve and historical method which is a comparison with other cases in the past where subsequent trends are known. Experience demonstrates such an extrapolation to be appropriate. Reflection upon the growth factors at play seem to indicate that until some physical limit is reached, an increase in functional capabilities is to be expected.

Forecasting by trend correlation is the trend of a technical parameter which is complex and difficult to predict by itself and may sometimes be more easily expressed as a result of a relationship between two or more other trends. The trend correlation has four major methods which are: (1) pre-cursor events which is often used in econometric models where a change in one parameter may foreshadow a change in another; (2) correlation analysis where all variables are assumed uncertain; (3) regression analysis where some variables are assumed to be deterministic; and (4) correlation coefficient which is similar to correlation analysis method.

The dynamic forecasting approach is a technique of "Industrial Dynamics." The technological progress is based upon mathematical expression of the influence of those factors over which control may be exercised. Those factors include number of people trained for a given research and development function, the number of people employed to perform that function and the facilities provided for experiment. The effect of each of these factors, and the feedback relationship, are combined in equations which provide a prediction of the technological progress to be obtained from a given input of the factors involved.

The delphi technique is simply the systematic solicitation of expert opinion instead of using the traditional approach toward achieving a consensus through open discussion. The delphi technique consists of interactive process which allows for anonymous presentation, feedback and re-evaluation of a set of judgements supplied by a group of informed individuals. This technique eliminates committee activity altogether, thus it reduces the influence of certain psychological factors. In short, the delphi technique seems worthy of study as a tool of water resource planning and it could be used in conjunction with more mathematical methods to prove that the results of these are realistic and consistent with a consensus of expert opinion (18).

With public systems, such as water systems, the model that predicts the need (demand) for water is usually generated based on past trends, casting forward; linearly or straight line; geometrically if growth is accelerating or decelerating; or by using a growth analog and find one's position in time on it, such as the logistic population theory. The demand for water can also be predicted by using operations research techniques, such as stochastic, regression analysis, autocorrelation analysis or moving and weighted averages, or other pudential smoothing techniques, or cohort analysis. These techniques are based primarily on past performance since at least by practice we are tied to the past trends.

There are two major components of any reasonable forecasting procedure which are theory and data. The levels of sophistication for the theory and the data requirements range from the naive and limited to the highly complex and extensive. In order to evaluate the theoretical aspect of forecasting, the concept of "verification" is imposed upon both the technique and the prediction. Verification of the prediction simply means that after a certain period of time has elapsed, it must be possible to ascertain if forecast is true or not. Verification of method requires that the line of thought leading to the prediction should be based upon theoretical considerations which involve mathematical concepts from the field of statistics and probability.

The other component of a forecasting procedure is data. Data used in forecasting and prediction ordinarily arise as discrete time series data that may represent large number of physical or economic measurements. If the forecast is to be effective, the data must be a good representation of the actual process and must be free of error. Errors can be a major error of inaccuracy in estimation and the use of forecasting models.

However, the principle of analytical projection is simple. First of all, it requires a systematic examination of all the factors that might affect the variable to be projected. Secondly, analysis of the relationship between these factors and the variable. The form that the relationships should take is usually very hard to be certain. In some cases, linearity seems to be the simplest assumption, but a "better" relation might turn out to be, such as linear in the logarithms of the variables, or a polynomial form. After deciding upon a certain form, statistical methods, for example, multiple regression analysis, are applied in order to estimate the "best" values of the constants given the observed values available. There are various tests to be applies to evaluate the results, in particular, to assess the significance level of the estimated constant coefficients. Once these tests are passed, projected values of the variable are obtained by inserting assumed or forecasted values of the predictor factors.

It should be mentioned here that we always deal with the problem of uncertainty of projections as we consider a systematic projection methodology. The existence of uncertainty of projections may be generated from several sources. The first group of sources of uncertainty relates to possible errors in the data base. Again, errors in measurements and interpretation in the data base can be a major source of inaccuracy in estimation and in the application of forecasting models. The second source of uncertainty might be related to structural errors of the projection model. Finally, the exogenous variables introduced into the projection model might group the third category of sources of uncertainty of projections (5).

To achieve the objectives of this study, the analysis shall consist of two major phases. The first phase deals with the identification of all orginal factors collected to be involved in computing the predictive demand equations. The second phase is the application of the "Stepwise Multiple Regression Analysis" through the use of computer programs in order to relate these factors to one another. Both of these two phases are discussed in the next chapter. However, it is necessary to give a brief discussion of the basic technique used in this study.

Stepwise Multiple Regression Analysis

Multiple regression analysis is one of the most widely used of all statistical tools. Stepwise multiple regression analysis is a technique used to help choosing independent variable which provide the best prediction possible with the appropriate number of independent variables. In general, a stepwise multiple regression program works as follows (48):

Step 1. From all the independent variables X_i considered in the study, the program will pick up the independent variable with the largest absolute value of the simple correlation coefficient (r) with the dependent variable Y, say X_1, to compute the regression equation $\hat{Y} = f\ (X_1)$. The simple correlation coefficient between any two random variables is a good indication of the linear relationship between them. In general, the mathematical equation to define the simple correlation between any two random variables can be written as:

$$r_{XY} = \frac{\Sigma(XY - \overline{XY})}{[\Sigma(X - \overline{X})^2\ \Sigma(Y - \overline{Y})^2]^{\frac{1}{2}}} \quad . . . . \quad (3.1)$$

where: r_{XY} = simple correlation coefficient of Y vs. X,

Y = dependent variable,

X = independent variable,

$\overline{Y}$ = arithmetic mean value of Y,

$\overline{X}$ = arithmetic mean value of X,

XY = product of X and Y,

$\overline{XY}$ = arithmetic mean value of XY.

Step 2. The program will pick up the subsequent independent variable which has the highest partial correlation coefficient with the dependent variable. In other words, from X_2 to X_p, the program will select X_e with the highest partial correlation coefficient with the dependent variable Y to compute the regression line $\hat{Y} = f(X_1, X_e)$. In general, the partial correlation coefficient of Y, X and Z, for example, can be defined as follows:

$$r_{YX.Z} = \frac{r_{YX} - r_{YZ}\, r_{XZ}}{(1 - r^2_{XZ})^{\frac{1}{2}}(1 - r^2_{YZ})^{\frac{1}{2}}} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (3\text{-}2)$$

where: $r_{YX.Z}$ = partial correlation coefficient of Y and X while Z is held constant,

r_{YX} = simple correlation coefficient of Y and X,

r_{YZ} = simple correlation coefficient of Y and Z,

r_{XZ} = simple correlation coefficient of X and Z.

I should be indicated here that a zero value for the simple or partial correlation coefficient does not imply "no relation." Rather, it means "no linear." Thus, correlation, simple or partial, is a measure of linear relation only; it is of no use in describing non-linear relations (49).

Step 3. By means of F-test, over-all and partial F-test, the program will decide to accept or reject new independent variables in the estimated equation. For any newly added independent variable, say X_e, if F_e - value is more than F_o - value (where F_o is an F - value pertaining to preselected level of significance), the program will allow X_e to be the new added variable in the estimated equation since it will increase the regression mean squares, otherwise, it will go back to Step 2. The program will repeat computing F_e - value for each new entering independent variable and compare it with F - value of preselected level of significance until it reaches the highest coefficient of multiple determination (R^2). This means that no increase in regression mean squares can be possibly achieved. Then, the program will go to Step 4.

R^2 is called the coefficient of multiple determination and defined by Wonnacott (49) as follows:

$$R^2 = \frac{\Sigma\ (\hat{Y}_i - \overline{Y})^2}{\Sigma\ (Y_i - \overline{Y})^2} = \frac{\text{explained variation of Y}}{\text{total variation of Y}} = \ldots\ldots\ldots (3.3)$$

where: R^2 = coefficient of multiple determination,

$\hat{Y}_i$ = estimated value for the observed ith value of the dependent variable Y,

$\overline{Y}$ = arithmetic mean value of Y,

Y_i = observed ith value of the dependent variable Y.

Thus, the program will add additional explanatory variables to the model in order to decide how helpful these variables are in improving the explanation of the variation in Y.

F-test* is used to test the statistical significance of each regressor. Simply, it is the ratio of additional variance explained by the addition of the new variable divided by the unexplained variance, which is called the residual mean square (50). Thus, it can be defined as follows (49):

$$F = \frac{\Sigma\,(\hat{Y}_i - \overline{Y})^2/K-1}{\Sigma\,(Y_i - \hat{Y}_i)^2/n-K} = \frac{\text{explained variance}}{\text{unexplained variance}} \quad \ldots\ldots \quad (3\text{-}4)$$

where: K = number of parameters considered in the model at a specific step including the intercept,

n = sample size or number of observations,

$\hat{Y}_i$, Y and $\overline{Y}$ are as defined before.

Step 4. The program will adopt the model which has the "best" R^2 value and all the possible explanatory variables that passed the sequential F-test.

The general form of all the developed water demand models for the State of Oklahoma will be expressed as follows:

$$Y_{j,i} = \beta_o + \beta_1 X_{1i} + \beta_2 X_{2i} + \quad \ldots\ldots + \beta_n X_{ni} \quad \ldots\ldots \quad (2.5)$$

where: $Y_{j,i}$ = water demand for category j of water use for year i for Oklahoma,

β_n = regression coefficients to be estimated,

X_{ni} = independent socio-economic and environmental variables for year i,

* F-test is explained in more details in Appendix A as well as R^2 and t-test.

n = number of independent variables which varies from one model to another,

j = different categories of water use of Oklahoma: municipal water use (M); industrial water use (I); total water use (T); and per capita municipal water use (PC).

The following section of this chapter is a review of the principles of the general linear regression model. Any general regression model with normal error term can be defined as follows:

$$Y_i = \beta_o + \beta_1 X_{i1} + \beta_2 X_{i2} + \dots\dots + \beta_{p-1} X_{i,\,p-1} + e_i \quad . \; . \quad (2.6)$$

where: i = 1, 2, ... ,n which denotes the number of independent variables,

$X_{i1}, X_{i2}, \dots . X_{i,\,p-1}$ = are known constants or independent variables,

$\beta_o, \beta_1, \beta_2, \dots\dots\dots , \beta_{p-1}$ = regression parameters to be estimated

e_i = are independent random variables which are normally distributed and have a constant variance, that is, $N\ (0, \sigma^2)$.

Assume $X_{io} = 1$, equation (3.6) may be defined as follows:

$$Y_i = \beta_o X_{io} + \beta_1 X_{i1} + \beta_2 X_{i2} + \dots . + \beta_{p-1} X_{i,p-1} + e_i \quad . \; . \quad (3.6a)$$

Substituting the value of $X_{io} = 1$ in equation (3.6a), we obtain:

$$Y_i = \sum_{k=o}^{p-1} \beta_k X_{ik} + e_i \quad . . . . (3.6b)$$

Since e_i are assumed to be normally distributed, thus, $E(e_i) = o$, therefore, the response function for equation (3.6b) can be given by the following mathematical equation:

$$E(Y) = \beta_o + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_{p-1} X_{p-1} \quad . . . . \quad (3.7)$$

The general linear regression model implies several basic assumptions. First, the observations of Y_i are statistically independent random variables which are normally distributed with mean value $E(Y_i)$ given by equation (3.7). Moreover, Y_i have constant variance equals σ^2. Secondly, the error terms e_i are also assumed to be independent random variables with mean value $E(e_i) = o$, and a constant variance equals σ^2. Finally, it is assumed that there are no interacting effects between the independent variables p-1 given by the general linear model, which is a first order model, given by equation (3.6).

The error terms e_i may be regarded as the sum of two major components. The first component is due to measurement error in the dependent variables Y_i. The second component is called stochastic error which occurs because of the inherent irreproducibility biological and social phenomena. Since the naturilization of extraneous influence by holding e_i constant can not be achieved, the useful technique for reducing stochastic error is to regress Y_i on X_i as well as the extraneous factors. This is called the multiple regression technique (49).

The general linear regression model defined by equation (3.6), can be expressed in matrix notation as follows:

$$\underset{n.1}{Y} = \begin{bmatrix} Y_1 \\ Y_2 \\ \cdot \\ \cdot \\ \cdot \\ Y_n \end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.8)$$

$$\underset{n.p}{X} = \begin{bmatrix} 1 & X_{11} & X_{12} & X_{1,\ p-1} \\ 1 & X_{21} & X_{22} & X_{2,\ p-1} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ 1 & X_{n1} & X_{n2} & X_{n,\ p-1} \end{bmatrix} \quad . \ . \quad (3.9)$$

$$\underset{p.1}{\beta} = \begin{bmatrix} \beta_o \\ \beta_1 \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \beta_{p-1} \end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.10)$$

$$\underset{n.1}{e} = \begin{bmatrix} e_1 \\ e_2 \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ e_n \end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.10)$$

Both of Y and e are vectors having number of rows equals to number of observations n. The β vector contains additional regression parameters. The X matrix contains a column of 1's as well as a column of n observations on each of the p-1 X variables in the regression model.

In matrix form, the general linear regression model is:

$$\underset{n.1}{Y} = \underset{n.p}{X}\ \underset{p.1}{\beta} + \underset{n.1}{e} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.11)$$

where: Y = is a vector of observations,

X = is a matrix of constants,

β = is a vector of parameters,

e = is a vector of independent normal random variables with expectation E (e_i) = o, and variance - covariance matrix as:

$$\sigma^2 (e) = \sigma^2 I \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.12a)$$

The random vector Y has expectation

$$E(Y) = X\beta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.13)$$

and the variance - covariance matrix of Y is:

$$\sigma^2(Y) = \sigma^2 I \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.14)$$

To obtain the least squares estimators, let us denote the vector of estimated regression coefficients $b_0, b_1, b_2, \ldots\ldots, b_{p-1}$ as b:

$$\underset{p.1}{b} = \begin{bmatrix} b_0 \\ b_1 \\ b_2 \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ b_{p-1} \end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.15)$$

The least squares normal equations for the general linear regression model are:

$$\underset{p.p}{(X'X)}\ \underset{p.1}{b} = \underset{p.1}{X'Y} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.16)$$

The least squares estimators in matrix form are:

$$\underset{p.1}{b} = \underset{p.p}{(X'X)^{-1}}\ \underset{p.1}{X'Y} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.17)$$

The least squares estimators are maximum likelihood estimators which have the "BLUE" properties. "BLUE" means "best linear unbiased estimators."*

$$E\ (b) = \beta \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.18)$$

* Proofs of the "BLUE" properties of the least squares estimators are explained in Chapter 2 in references (49, 50, 51).

Linear estimator is refered to the fact that the least squares estimators have a linear relation with the random variables Y_i, that is:

$$b_i = \Sigma W_i Y_i \quad \ldots \quad (3.19)$$

where each W_i is a fixed constant.

The term "best estimators" means that within the class of "linear" and "unbiased" estimators of β_i, the least squares estimators b_i have minimum variance (this is called Gauss Markov Theorem).

In summary, the basic assumptions of the least squares technique can be stated as follows:

(1) The observations of Y_i are statistically independent random variables. They are normally distributed with a constant variance and mean value given by equation (3.7).

(2) The error terms e_i are assumed to be independent random variables with mean value equals zero and constant variance. They are independent from each other (covariance of e_i and e_j is equal to zero) as well as they are independent from the independent variables X_i (covariance of e_i and X_i is equal to zero).

(3) The independent variables X_i are assumed to constant or fixed, that is, they are determined outside the model and assumed to be independent from each other.

Evaluation of Regression Models

There are several statistical indices and tests that provide helpful approaches to evaluate regression lines. However, most of these indices are based on rather strict assumptions about the explanatory variables and the error term. Violations of these assumptions might lead to meaningless results when applied to model structures.

The first problem area is called the "multicollinearity" problem. This exists when some or all the independent variables are correlated. If it is a complete multicollinearity problem, the coefficients of the regression can not be estimated (49). In the case of partial multicollinearity, some of important independent variables might be omitted from the model just because their coefficients are not significantly different from zero. That is due to misleading t and F tests.

The second problem area is due to violations of assumptions about the error terms e_i which is called the "autocorrelation" problem. It occurs when there is a correlation between the error terms e_i, that is, if they are not independent from each other. It also might occur due to measurement errors in the explanatory variables. The consequence of this problem is that we might not get the "best" coefficients estimators, that is, the estimators will have large variances. Also, we might face the problem of omitting some of the important independent variables from the relation. Moreover, if e_i are not independent from each other, we might face what is called the "heteroscedasticity" problem which means that e_i will have unequal variances. The only problem associated with the "heteroscedasticity" is that the estimators, again, will have large variances but they will stay unbiased.

There are several common sense checks that can be performed on regression lines in order to measure the "goodness of fit" of these lines. These checks are:

(1) Evaluation of signs of regression coefficients. This is one of the fundamental tests of any regression line. Suppose, for example, that population was determined to be a significant independent variable in a total municipal water demand model. The coefficient of population in this case must be positive because total municipal water use increases when population rises, otherwise, we must conclude then something must be wrong.

(2) Evaluation of standard econometric indices.* The most common methods that often used are:

(a). Statistical t-test or F-test to decide whether or not the regression coefficients are significantly different from zero, that is, $\beta_i = o$ versus $\beta_i \neq o$.

(b). Analysis of variance (ANOVA) which is basically the sequential F-test which is the ratio of the regression sum of squares (explained variance of Y_i) divided by the residual mean squares (unexplained variance of Y_i). This test is to determine how much variation of Y_i can be explained by addition of new independent variables X_i at a given significance level.

(c). The coefficient of multiple determination R^2 which measures the appropriate reduction in total variation of Y_i associated with the use of a set of X_i variables. R^2 takes on the value of 1 when all observations fall directly on the fitted response surface, that is, when $Y_i = \hat{Y}_i$ for all i.

(3) Evaluation of plots, residuals against the independent variables X_i or the fitted values of Y_i. These plots are helpful to examine whether the variance of the error terms is constant (51). Our objective is to obtain a horizontal band about the line on which the error equals zero, with a narrow band. This will indicate a small constant variance of the error terms e_i which implies a good regression model. In the case of having a conical shape of the plot, this suggests that the error

* See Appendix A for more details.

variance increases with X_i or Y_i. If we have an inclined plot shape, this indicates a systematic bias which most of the times occurs because of omitted variables (48).

Now, and after the theory and the technique have been discussed in this chapter, the practical applications are explained in Chapter IV using the "BMDO2R" & "BMDO1R" stepwise regression programs. Also, Appendix A includes discussion in more details, of F-test, t-test, analysis of variance (ANOVA), and coefficient of multiple determination R^2.

CHAPTER IV

THE DEVELOPED WATER DEMAND MODELS FOR OKLAHOMA

Introduction

This chapter is a comprehensive presentation of the major water demand models developed for the State of Oklahoma for different categories of water use. These water demand models are; total municipal and domestic water demand model, per capita municipal and domestic water demand model, total industrial water demand model, total agricultural (irrigation) water demand model and the total water demand model for the State. The original data set of all the independent and the dependent variables initially tried in the process of models development as well as sources of information are included in this chapter. Moreover, statistical indices and evaluation of the developed models are fairly discussed based on the regression theory explained in the previous chapter. Appendix B contains all tables of historical data for each variable used in developing these water demand models.

It is very essential here to define each category of water use for which the demand models have been developed. The following definitions were adapted from the Oklahoma Water Resources Board (OWRB) from annual reports (46). These definitions of terms are:

Irrigation water use includes all farm crops, such as alfalfa, grain corn, silage corn, cotton, horticulture, pasture, peanuts, wheat, small grain, soybeans, grain sorghum, forage sorghum, and other crops. Truck gardens, flower gardens, greenhouses and nursery stock are generally included as "horticulture" crops. "Other crops" term includes uses not specified, such a broom corn, mung beans, preirrigation and golf courses.

Municipal water use term is water used by all municipalities and may include industrial and irrigation whenever water is supplied by the city. It also includes domestic water use.

Industrial water use term includes all other kinds of self-supplied industries, such as paper manufacturing, petro-chemical production, petroleum refining, chemical production, glass production, cement production, food processing, printing, metals and fabrication, machinery, clothing production and many other industries. Water flood operations are not included under the industrial water use category.

Total water use term includes all the previous three categories of water use besides water used in recreation and wildlife, secondary oil recovery and other municipal and industrial uses. The term recreation and wildlife includes water used or released from storage for propagation of fish and wildlife but does not include evaporation losses related to lakes and rivers. The term secondary oil recovery covers water-flood operations using fresh water only, that is, salt water is not included. The term other municipal and industrial includes multiple-unit domestic use, laundries, cafes, hotels, institutions and housing development not reported elsewhere. Single-unit domestic use does not have to be reported.

It should be emphasized that the accuracy of the water use data obtained from the Oklahoma water use reports (46) depends, therefore, on the accuracy of these reports by the water users. The water use reports show whether the use was from ground water or from stream water. In this study and for each category of water use considered, the sum of both ground and stream water was used. In some cases and for some years, water data obtained from the (OWRB) had to be adjusted by consulting with other publications (6, 8, 36) and by taking some years data as base years.

Another point to be cleared is that the Oklahoma Statutes require that any person taking and using water for beneficial purposes, other than domestic, must first obtain a permit from the (OWRB) and must submit annual water use reports. Domestic use is defined as water for household, stock water and gardens and orchards not exceeding three acres.

The State's Municipal and Domestic Water Demand Model

In order to develop the State's municipal and domestic water demand model, and since the State's potential economic growth is rapidly increasing, a set of socio-economic and climatological explanatory variables was considered. For both municipal and domestic water use variable and the independent variables, historical data from the year 1966 to the year 1976 were used. The total number of independent variables initially tried was six variables. These dependent and independent variables with their data collection sources can be listed as follows:

Y_M = total municipal and domestic water use of Oklahoma in thousands of acre-feet per year as defined previously in this chapter. It is the sum of ground and stream water used by municipalities. Values were obtained from the (OWRB) and adjusted based on 1966 and 1976 figures.

X_1 = total population of Oklahoma in thousands. Data on population was basically collected from the Oklahoma Employment Security Commission (OESC) recoreds (54) and further checked with the records available at the Center for Economic and Management Research, College of Business Administration, Oklahoma University (55) and other published books (56). Population values used from the year 1966 through the year 1976 were mid-year estimates.

X_2 = nominal per capita personal income of Oklahoma in current dollars. Data used was collected from the same sources of information for population data mentioned above.

X_3 = non-agricultural employment of Oklahoma (annual average values) in thousands. Non-agricultural wages and salary employment relates to place of work of workers and not to their place of residence. The term non-agricultural employment - as defined by the Oklahoma Employment Security Commission - includes mining, contract construction, manufacturing, transportation and public facilities, wholesale and retail trade, finance, insurance and real estate, services and government employment. Data was collected from the (OESC) records (57, 58, 59, 60) and checked with the records of the Center for Economic and Management Research at Oklahoma University (55).

X_4 = total gross-state product of Oklahoma in millions of current dollars. Data used was developed by Liew (61) at the Center for Economic and Management Research, College of Business Administration at Oklahoma University.

X_5 = mean annual temperature of Oklahoma in F^o. It was determined by taking the average of the values of the nine divisions of the State.

X_6 = mean annual precipitation of Oklahoma in inches. The same procedure of determining the mean annual temperature of Oklahoma was followed in order to determine the mean annual precipitation. Climatological data was collected from the U. S. Department of Commerce from the National Oceanic and Atmospheric Administration records (62) and checked again with the records of the Center for Economic and Management Research at Oklahoma University (55).

There are several trials made using different combinations of the six independent variables mentioned above with the total State's municipal and domestic water use in order to develop the best multiple regression equation. For instance, total population (X_1), per capita income (X_2), gross-state product (X_4), mean annual temperature (X_5) and mean annual precipitation (X_6) were tried together with the dependent variable (Y_M). Applying the stepwise multiple regression programs (BMD02R) & (BMD01R), the following predictive equation was developed:

$$Y_M = 13.8032 + 0.1557\ X_1 - 0.0023\ X_2 + 0.8148\ X_5 + 0.0614\ X_6 \quad \ldots\ldots\ldots\ldots \quad (4.1)$$

$R^2 = 0.9937$

SEE = 1.8678

$F_c = 236.936$

$F_t = 5.53$ at 5% level

$= 9.15$ at 5% level

Employment was not included among the independent variables. The model developed in equation (4.1) has a very high coefficient of multiple determination (R^2) and all the independent variables included pass the sequential F-test at both 5% and 1% significance levels. However, the sign of the precipitation's coefficient does not look correct, that is, a positive sign for that coefficient implies a positive relationship between precipitation and municipal and domestic water use which is not logic. The rest of the coefficients have correct signs in the equation.

Another attempt was to try X_1, X_4, X_6 and excluding income, employment and temperature. The developed equation in this case is given by the following relation:

$$Y_M = 1.7788 + 0.1849\ X_1 - 0.0002\ X_4 + 0.0377\ X_6 \quad \ldots\ldots\ldots \quad (4.2)$$

$R^2 = 0.9932$

SEE = 1.80

$F_c = 340.002$

$F_t = 5.53$ at 5% level

$= 9.15$ at 5% level

The coefficient of multiple determination is high and all the included independent variables pass the sequential F-test. But the problem of a positive sign of the precipitation's coefficient still exists.

The best trial which provides the best multiple regression equation is the one using total population, per capita income, non-agricultural employment, total gross-state product and mean annual precipitation as our independent variables and excluding mean annual temperature. The steps of developing the final municipal and domestic water demand model for the State by applying the stepwise multiple regression program are illustrated in Table 5 with all the statistical indices.

The final State's municipal and domestic water demand model can be given by the following formula:

$$Y_{Mi} = 55.147 + 0.1344\ X_{1i} + 0.1145\ X_{3i} - 0.0015\ X_{4i} - 0.0668\ X_{6i} \qquad (4.3)$$

where: Y_{Mi} = total municipal and domestic water requirements for Oklahoma for year i in thousands of acre-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.

Total population of Oklahoma seems to be the factor with the highest influence on municipal and domestic water use in the State. The simple correlation coefficient (r) between total population and municipal and domestic water use is equal to 0.9964. The simple correlation coefficient between non-agricultural employment variable and municipal and domestic water use is also high with a value equals 0.9934 while it is equal to 0.9743 between gross-state product variable and the dependent variable. The simple correlation coefficient between X_6 and Y_M is low with a value equals 0.2298. The simple correlation coefficient between per capita income and municipal and domestic water use has a high value equals 0.9810, however, per capita income variable was found to be insignificant based on the analysis of variance (ANOVA) or the sequential F-test. 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% significance levels. The coefficient of determination is very satisfactory with a considerably high value equals 0.9963. All the signs of the regression coefficients are correct.

The State's municipal and domestic water demand model expressed by equation (4.3) will be used in Chapter V to forecast the future municipal and domestic water requirements for Oklahoma up to the year 2040.

Table 5

The Final Municipal & Domestic Demand Model
Statistical Indices*

<u>Step 1</u>

$Y_M = 10.834 + 0.18\ X_1$

$R^2 = 0.9929$

$SEE = 1.6234$

$F_c = 1253.635$

$F_t = 5.12$ at 5% level

$= 10.56$ at 1% level

<u>Step 2</u>

$Y_M = 107.243 + 0.12\ X_1 + 0.073\ X_3$

$R^2 = 0.9949$

$SEE = 1.4538$

$F_c = 783.167$

$F_t = 4.46$ at 5% level

$= 8.65$ at 1% level

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* R^2 = coefficient of multiple determination.
SEE = standard error of estimate of Y_M.
F_c = F-ratio or F-calculated.
F_t = F-tabulated.

Table 5 - Continued

Step 3

$$Y_M = 63.916 + 0.134\ X_1 + 0.096\ X_3 - 0.001\ X_4$$

R^2 = 0.9960

SEE = 1.3781

F_c = 581.667

F_t = 4.35 at 5% level

= 8.45 at 1% level

Step 4

$$Y_M = 55.147 + 0.1344\ X_1 + 0.1145\ X_3 - 0.0015\ X_4 - 0.0668\ X_6$$

R^2 = 0.9963

SEE = 1.4252

F_c = 408.058

F_t = 4.53 at 5% level

= 9.15 at 1% level

The State's Per Capita Municipal and Domestic Water Demand Model

There were several attempts made in order to develop the State's per capita municipal and domestic water use model. First of all, the same six independent variables tried in the process of developing the State's municipal and domestic water demand model were considered with replacing the total municipal and domestic water use variable (Y_M) by the per capita municipal and domestic water use variable (Y_{PG}). Estimates for the per capita use variable from 1950 to 1976 were used. These estimates were developed by the Bureau of Water and Environmental Resources Research at the University of Oklahoma (36) and they are presented in Appendix B (see Table B-6). Historical data on the six independent variables was collected from the same sources indicated before and from the year 1950 through 1976. The best model developed at this stage of the study is the one considering the three independent variables: total population (X_1), per capita income (X_2) and total non-agricultural employment (X_3) with the per capita municipal and domestic water use (Y_{PC}). The model developed can be given as:

$$Y_{PC} = -92.71 + 0.0322\ X_1 - 0.0181\ X_2 + 0.2740\ X_3 \quad \ldots\ldots \quad (4.4)$$

$$R^2 = 0.9413$$

$$SEE = 3.2319$$

$$F_c = 122.970$$

$F_t = 3.03$ at 5% level

$ = 4.76$ at 1% level

From the statistical point of view, the model seems to be very satisfactory with a considerably high value of R^2 and the sequential F-test evaluation. However, the model expressed by equation (4.4) will give very high values for the per capita municipal and domestic water use for the State of Oklahoma. For instance, if we apply this model and by using the forecasts of population, per capita income and non-agricultural employment (these independent variables forecasts are included in Chapter V), we obtain a per capita municipal and domestic water use equals 168 gpcd, 241 gpcd and 424 gpcd for the years 1980, 2000 and 2040, respectively. Therefore, another attempt had to be tried in order to develop a model which can provide more reasonable results.

The second attempt was to try to reduce the number of explanatory variables in the equation. Another model was developed by considering the total population as the only independent variable in the equation with the per capita municipal and domestic water use variable. Again, the same estimates for Y_{PC} were used from the year 1950-1976. The developed model can be expressed by the following equation:

$$Y_{PC} = -136.766 + 0.1061\, X_1 \quad \text{(4.5)}$$

$R^2 = 0.874$

SEE = 7.345

$F_c = 173.825$

$F_t = 4.24$ at 5% level

$= 7.77$ at 5% level

Again, the model given by equation (4.5) is a good model from the statistical point of view. But the over-estimation problem for the per capita municipal and domestic water use still exists. For example, using the forecasts of population developed by the Oklahoma Employment Security Commission (OESC), which are presented in Chapter V, we obtain a per capita rate equals 180 gpcd, 264 and 390 gpcd for the years 1980, 2000 and 2040, respectively.

There were many other trials to reach the optimum model which provides us with the best possible results concerning both statistical evaluation and forecasts for future per capita municipal and domestic water use for Oklahoma. The final model was reached by regressing per capita income and total population of the State against the per capita municipal and domestic water use. But actual values on the per capita water use were used instead of the estimates tried in the previous two attempts. Historical data on the two independent variables and the dependent one from the year 1920 to the year 1970 was collected from the Bureau of Water and Environmental Resource Research (6) and the Bureau of Business (55) at Oklahoma University. This data is included in Appendix B in Table B-7.

The final model for the State's per capita municipal and domestic water usage rate is given by the following equation:

$$Y_{PC_i} = 45.3260 + 0.0143\, X_{1i} + 0.0101\, X_{2i} \quad \ldots\ldots\ldots\ldots \quad (4.6)$$

where: Y_{PC_i} = per capita municipal and domestic water usage rate for Oklahoma for year i in gpcd,

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

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

From Table 6, it is very clear that the model has a good value for the coefficient of multiple determination and both per capita income and total population variables pass the sequential F-test. The simple correlation coefficient between total population and per capita water usage rate is 0.9699 and equals 0.6857 for per capita income and the dependent variable.

There are a variety of reasons for expecting per capita income to be closely related to per capita water use. As income rises, more water-using appliances, such as dishwashers and garbage disposal units, may be installed. Moreover, there will be more discretionary income available to be devoted to lawns, shrubs, and trees and to the purchase of lots with room for land scaping. Also, high-income areas may give rise to more commercial activities as total consumer expenditure increases. Therefore, it is not surprising that per capita income was found to be one of the major input factors in the State's per capita municipal and domestic water use model.

The model expressed by equation (4.6) will be used in Chapter V to forecast the future per capita municipal and domestic water usage rate for the State of Oklahoma.

The State's Industrial Water Demand Model

Table 6

The Final Per Capita Municipal and Domestic Demand Model Statistical Indices

Step 1

$$Y_{PC} = 76.618 + 0.011\ X_2$$

$$R^2 = 0.9407$$

$$SEE = 3.6432$$

$$F_c = 63.506$$

F_t = 7.71 at 5% level

= 21.20 at 1% level

Step 2

$$Y_{PC} = 45.3260 + 0.0143\ X_1 + 0.0101\ X_2$$

$$R^2 = 0.9643$$

$$SEE = 3.2634$$

$$F_c = 40.568$$

F_t = 9.55 at 5% level

= 30.81 at 1% level

In order to develop the State's industrial water demand model, historical data on both industrial water use (the dependent variable), socio-economic, industrial production and climatological independent variables were collected from the year 1966 through the year 1976. The total number of independent variables tried in the process of developing the State's industrial water demand model was twelve variables. The dependent and independent variables with their associated sources of information can be listed as follows:

Y_I = total industrial water use of Oklahoma in thousands of acre-feet per year. The industrial water use is the sum of ground and stream water used by all kinds of industries in Oklahoma. Data was basically collected from the (OWRB) reports (46) and then adjusted based on 1966 and 1975 values.

X_1 = total population of Oklahoma in thousands.

X_2 = nominal per capita income of Oklahoma in current dollars.

X_3 = non-agricultural employment of Oklahoma in thousands.

X_4 = total gross-state product of Oklahoma in millions of current dollars.

X_5 = mean annual temperature of Oklahoma in F^o.

X_6 = mean annual precipitation of Oklahoma in inches. Both mean annual temperature and precipitation were determined as explained previously in the municipal and domestic water demand model development.

X_7 = crude oil production of Oklahoma in millions of barrels.

X_8 = natural gas production of Oklahoma in billions of cubic feet.

X_9 = bituminous coal and lignite production of Oklahoma in thousands of short tons. Data on X_7, X_8 and X_9 was obtained from the U. S. Bureau of Mines in Oklahoma City (63) and the Center for Economic and Management Research, College of Business Administration at Oklahoma University (55).

X_{10} = total value added by mineral production of Oklahoma in millions of dollars. Data was obtained from the U. S. Bureau of mines in Oklahoma City (63) and Oklahoma University (55).

X_{11} = total value added by manufactural production of Oklahoma in millions of dollars. Data was obtained from the U. S. Bureau of Census (64) and Oklahoma University (55).

X_{12} = total industrial and commercial electrical energy sales of Oklahoma in millions of killowatt hours. Information was collected from the U. S. Department of Commerce (64), Edison Electric Institute (65) and Oklahoma University (55).

The final State's industrial water demand model developed in this study is given by the following equation:

$$Y_{Ii} = -2177.718 + 0.7626\ X_{1i} + 0.6533\ X_{3i} + 0.652\ X_{6i} + 0.028\ X_{9i} \qquad (4.7)$$

where:

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

X_{1i} = as defined before in the municipal model given by equation (4.3),

X_{3i} = as defined before in equation (4.3),

X_{6i} = as defined before in equation (4.3),

X_{9i} = total bituminous coal and liqnite production of Oklahoma for year i in thousands of short tons.

Consulting with table 6, it is obvious that the developed model has a very high coefficient of multiple determination and all the significant independent variables included in the model pass the sequential F-test. The simple correlation coefficient of X_1, X_3, X_6 and X_9 with Y_I are 0.9964, 0.9926, 0.2298 and 0.9068, respectively. Per capita income, total gross-state product, mean annual temperature, crude oil production, natural gas production, total value added by mineral production, total value added by manufactural production and total industrial and commerical electrical energy sales were found to be insignificant explanatory variables due to the analysis of variance. Table 7 is a summary of the final industrial water demand model development steps and it provides all the statistical indices for each step.

The developed model given by equation (4.7) will be used in Chapter V to forecast the industrial water requirements for the State up to the future year 2040.

Table 7

The Final Industrial Demand Model
Statistical Indices

Step 1

$$Y_I = -3458.033 + 1.486\ X_1$$

$R^2 = 0.9929$

SEE = 13.4222

$F_c = 1252.053$

$F_t = 5.12$ at 5% level

$= 10.56$ at 1% level

Step 2

$$Y_I = -3159.546 + 1.356\ X_1 + 0.019\ X_9$$

$R^2 = 0.9949$

SEE = 12.0900

$F_c = 773.137$

$F_t = 4.46$ at 5% level

$= 8.65$ at 1% level

Table 7 - Continued

Step 3

$$Y_I = -2162.925 + 0.750\ X_1 + 0.713\ X_3 + 0.024\ X_9$$

$R^2 = 0.9974$

SEE = 9.1216

$F_c = 907.834$

$F_t = 4.35$ at 5% level

$= 8.45$ at 1% level

Step 4

$$Y_I = -2177.718 + 0.7626\ X_1 + 0.6533\ X_3 + 0.652\ X_6 + 0.028\ X_9$$

$R^2 = 0.9981$

SEE = 8.3792

$F_c = 807.449$

$F_t = 4.53$ at 5% level

$= 9.15$ at 1% level

The State's Irrigation Water Demand

Model

Irrigation is considered to be the most significant key issue of water resources development on a worldwide scale and in a long-range prospective due to the fact that it is one of the most consumptive water use categories. Another reason for the importance of irrigation is that it represents the basic component of agriculture which is in turn highly related to food production and the rising standard of living.

There are a variety of natural, socio-economic, environmental and technological factors which affect irrigation water use rates. Therefore, there were many original variables considered in the development of the State's irrigation water use model. Historical data from the year 1966 through the year 1976 on both the irrigation water use as well as the explanatory variables were collected and used in order to reach the best possible model. The total number of the independent variables considered was twelve variables. The following list provides all the variables used to develop the State's irrigation water demand model:

Y_A = total irrigation water use of Oklahoma in thousands of acre-feet per year. It is the sum of ground and stream water used in irrigation from the year 1966 to the year 1976. Data was obtained from the (OWRB) reports (46).

X_1 = as defined before.

X_2 = as defined before.

X_3 = as defined before.

X_4 = as defined before.

X_5 = as defined before.

X_6 = as defined before.

X_{13} = total acres irrigated in Oklahoma in thousands. Data was collected from the (OWRB) reports (46).

X_{14} = total number of farms in Oklahoma in thousands.

X_{15} = total land in farms in Oklahoma in thousands of acres.

X_{16} = average size of farms in Oklahoma in acres.

X_{17} = total livestock on farms and ranches in Oklahoma in thousands. It is the sum of all cattle and calves, all sheep and lambs and all hogs.

X_{18} = total cash receipts from farm marketing in Oklahoma in millions of dollars.

X_{19} = total number of workers on farms in Oklahoma in thousands.

Data on the independent variables X_{14}, X_{15}, X_{16} and X_{19} was basically obtained from both the State Department of Agriculture and the U. S. Department of Agriculture (66). Data on X_{17} and X_{18} was obtained from the State and the U. S. Department of Agriculture (66) and further checked with the records available at the Center for Economic and Management Research, College of Business Administration at Oklahoma University (55).

Based on the results given by Table 8, the final State's irrigation water demand model can be given as follows:

$$Y_{Ai} = -17309.066 + 0.1095\ X_{2i} - 0.9635\ X_{6i} + 1.8021\ X_{13i} + 0.4506\ X_{15i} \quad \ldots\ldots\ldots (4.8)$$

where:

Y_{Ai} = total irrigation water requirements for Oklahoma for year i in thousands of acre-feet per year,

X_{2i} = as defined before in equation (4.3),

X_{6i} = as defined before in equation (4.3),

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 model expressed by equation (4.8) is a satisfactory model for its high value of R^2 and the sequential F-test evaluation. The highest simple correlation coefficient is between the total acres irrigated variable and the irrigation water use with a value equals 0.9004, that is, acres irrigated is the factor with the highest influence on irrigation water use in Oklahoma, which is correct. The simple correlation coefficient of per capita income and land in farms variables with the irrigation water use variable are 0.7774 and 0.7609, respectively. Precipitation has a low simple correlation coefficient with the dependent variable (0.1). All the signs of regression coefficients are correct for all the explanatory variables included in the developed model. Based on the analysis of variance, population was found to be an insignificant variable in the irrigation model although it was found to be significant in the State's municipal and industrial models.

The irrigation model given by equation (4.8) will be used in Chapter V to forecast the future irrigation water requirements for the State up to the year 2040.

Table 8

The Final Irrigation Water Demand Model
Statistical Indices

Step 1

$$Y_A = -407.844 + 2.164\ X_{13}$$

$R^2 = 0.8108$

SEE = 47.8706

$F_c = 38.565$

$F_t = 5.12$ at 5% level

$= 10.56$ at 1% level

Step 2

$$Y_A = -259.573 + 0.034\ X_2 + 1.636\ X_{13}$$

$R^2 = 0.8846$

SEE = 39.6501

$F_c = 30.666$

$F_t = 4.46$ at 5% level

$= 8.65$ at 1% level

Table 8 - Continued

Step 3

$$Y_A = -15831.461 + 0.102\ X_2 + 1.793\ X_{13} + 0.411\ X_{15}$$

$R^2 = 0.9094$

SEE = 37.5587

$F_c = 23.423$

$F_t = 4.35$ at 5% level

$= 8.45$ at 1% level

Step 4

$$Y_A = -17309.066 + 0.1095\ X_2 - 0.9635\ X_6 + 1.8021\ X_{13} + 0.4506\ X_{15}$$

$R^2 = 0.9130$

SEE = 39.7569

$F_c = 15.740$

$F_t = 4.53$ at 5% level

$= 9.15$ at 1% level

The State's Total Water Demand Model

As defined before in the beginning of this chapter, the term "total" water use or requirements includes municipal and domestic, industrial, agricultural, recreation and wildlife, secondary oil recovery and other municipal and industrial uses. The number of independent variables first tried to develop the State's total demand model was four variables. These explanatory variables are total population (X_1), nominal per capita income (X_2), total state-gross product (X_4) and a new variable which is total employment (X_{20}). Total employment is the sum of non-agricultural (which is wages and salary employment) and agricultural employment. Data on the four independent variables from the year 1966 to the year 1976 was collected as explained before in the municipal model. The total water use data was collected from the (OWRB) reports (46) and had to be adjusted.

Total population and total employment are the two significant input factors influencing the total water use in the State. The final State's total water demand model developed in this study can be given by the following equation:

$$Y_{Ti} = -6258.047 + 2.856\ X_{1i} + 0.450\ X_{20i} \qquad (4.9)$$

where:

Y_{Ti} = total water requirements for Oklahoma for year i in thousands of acre-feet per year,

Y_{1i} = as defined before in equation (4.3),

Y_{20i} = total employment of Oklahoma for year i in thousands.

The model given by equation (4.9) has R^2 value equals 0.9930 and both of the independent variables pass the sequential F-test. The simple correlation coefficient between X_1 and Y_T is 0.9962 and equals 0.9514 between X_{20} and Y_T, that is, both of the independent variables are higly correlated with the total water use variable.

Now, and after the statistical evaluation has been discussed for each of the water demand models developed for the State, the applications of these models using the appropriate forecasting methodologies for all the significant explanatory variables are explained in the next chapter.

Table 9

The Final Total Water Demand Model
Statistical Indices

Step 1

$Y_T = -6471.477 + 3.116\ X_1$

$R^2 = 0.9924$

$SEE = 28.8687$

$F_c = 1179.695$

$F_t = 5.12$ at 5% level

$= 10.56$ at 1% level

Step 2

$Y_T = -6258.047 + 2.856\ X_1 \div 0.450\ X_{20}$

$R^2 = 0.9930$

$SEE = 28.930$

$F_c = 587.853$

$F_t = 4.46$ at 5% level

$= 8.65$ at 1% level

CHAPTER V

WATER REQUIREMENTS PROJECTIONS

Introduction

The major objective of this chapter is to apply the five developed water demand models discussed in Chapter IV in order to obtain water requirements projections for the State. Projections for all the significant explanatory variables are provided in this chapter as well as the methodology involved in determining each one of them. Furthermore, comparisons of the developed water requirements projections with other studies projections are included in this chapter.

Another aim of this chapter is to present the methodology used in order to disaggregate the State's water requirements porjections from the State to county-level as well as some selected large cities in Oklahoma. The projections of municipal and domestic, industrial and irrigation water requirements for counties and selected cities are included in Appendix C and Appendix D. This chapter also contains water requirements projections for the State's planning regions.

The State's Municipal and Domestic Water Requirements Projections

It has been discussed in Chapter IV that the function of municipal and domestic water requirements of Oklahoma contains four major input factors which are total population, non-agricultural employment, gross-state product and mean annual precipitation. This is expressed previously by equation (4.3).

Oklahoma is experiencing tremendous growth in population. Population growth has varied over the last century. Between 1890 and 1970, the population grew from 258,657 to 2,559,299, an increase of more than nine times. In 1890, only 19.2 percent of the total population was classified as urban (residing in towns of 2,500 or more). This figure had increased to 37.6 percent by 1940 and in 1970, it reached 76 percent (56, 68).

The State's population projections used to forecast municipal and domestic water requirements for Oklahoma are utilized in Phase I and Phase II of the Oklahoma Comprehensive Water Plan and were developed by the Oklahoma Employment Security Commission (OESC).

The basic methodology used in the (OESC) population projections was a basic cohort-survival method. The final projections were derived to the year 1990 by combining projected births, survival of the base year population and migration of the population. Moreover, the effects of this short-range methodology were carried over into the projections beyond the year 1990. These projections by the (OESC) are slightly higher than the Census Bureau's Series "E" projections due to the differences in the firtility and migration computations in their methodologies (67).

Oklahoma's population projections are illustrated in Figure 9 and their values are presented in Talbe 10 and denoted as (X_{1i}). Figure 10

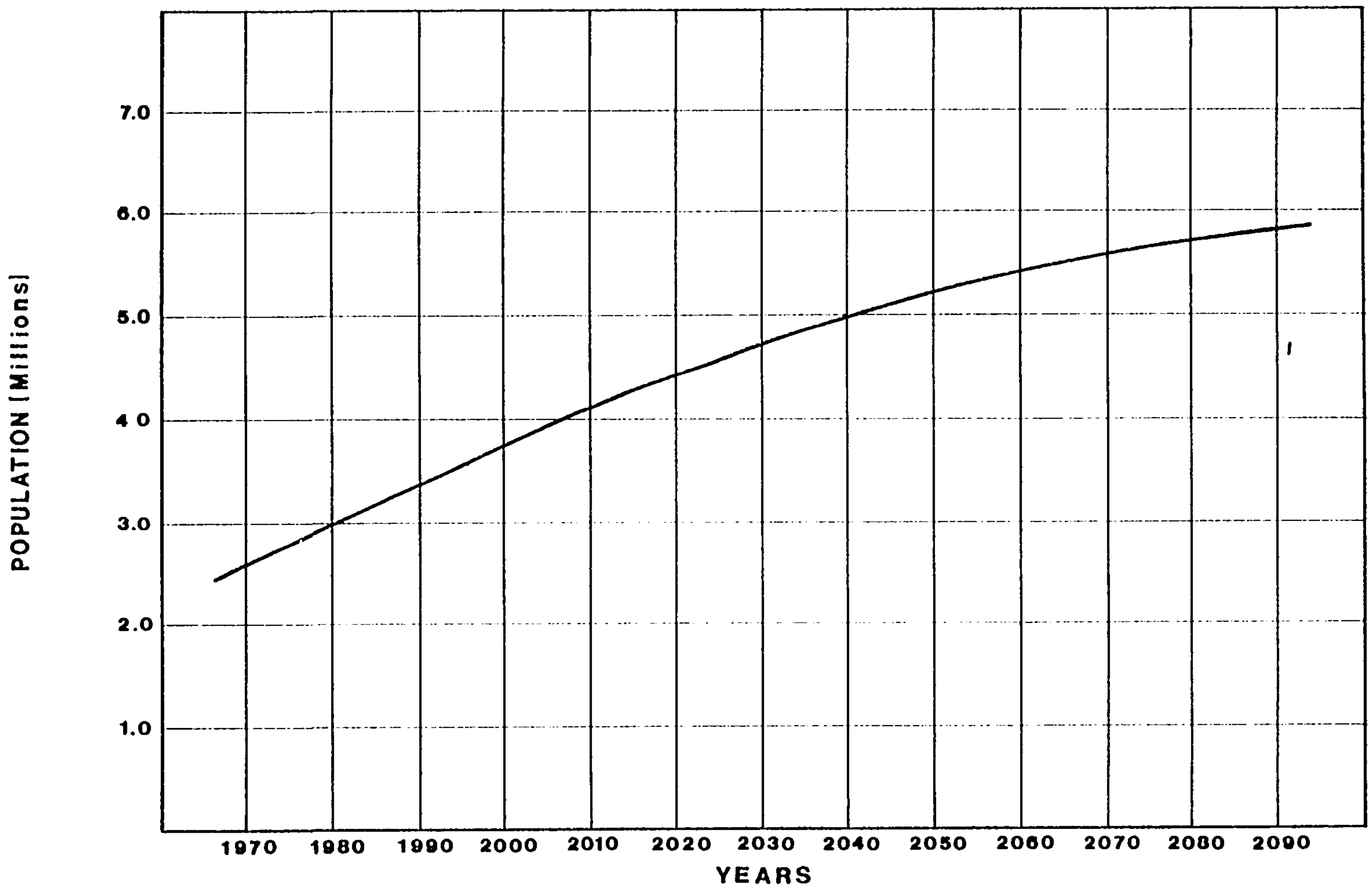

FIGURE 9: OKLAHOMA POPULATION PROJECTIONS

Source: See Ref. 67

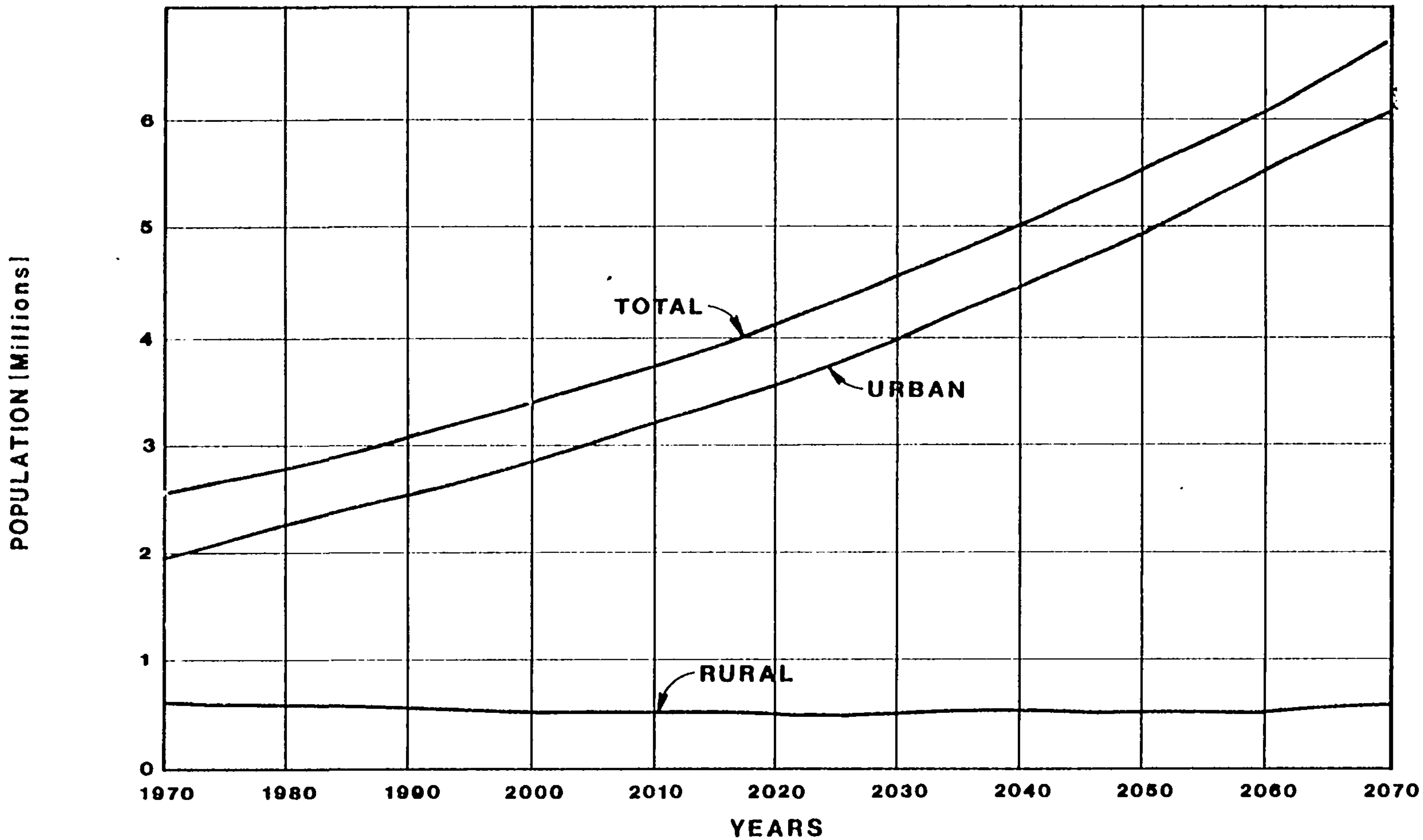

FIGURE 10: OKLAHOMA URBAN AND RURAL POPULATION PROJECTIONS
Source: See Ref. 68

show urban and rural population projections for Oklahoma from 1970 to 2070 which was developed by the (OESC).

Based on the (OESC) population projections, Oklahoma is expected to continue its population growth. The population is projected to reach over 2.9 million by 1980, more than 3.7 million by 2000 and be in excess of 4.9 million by the year 2040. Most of these people will be concentrated in urban areas. Consulting with Figure 10, urban population is expected to represent 0.79 percent of the total population by 1980 and 0.82 percent by 2000. By 2070, it is expected that 0.91 percent of the total population of Oklahoma will be classified as urban.

The second significant factor appears in the State's municipal and domestic water demand model is the non-agricultural employment (X_{3i}). Reid's economic model is used to obtain figures for projected employment by industry as well as total employment projections for Oklahoma.

Reid's economic model*, as illustrated in Figure 11, is made up of two major sub-models, the population sub-model and the employment sub-model. The population sub-model is based on the cohort-survival technique. Both the population and employment sub-models start with the nation level and disaggregate to the region, then to the next desired geographical area (4).

The employment sub-model is based on economic indices vs. demographic indices. It supplies the labor force by industry, such as agriculture, mining, construction, manufacturing, transportation, trade, finance, services, government and total employment. These labor forces are provided at the two-digit Standard Industrial Classification Code (SIC) for manufacturers which is achieved by using disaggregation factors from

* See reference (4) for complete description of Reid's economic model.

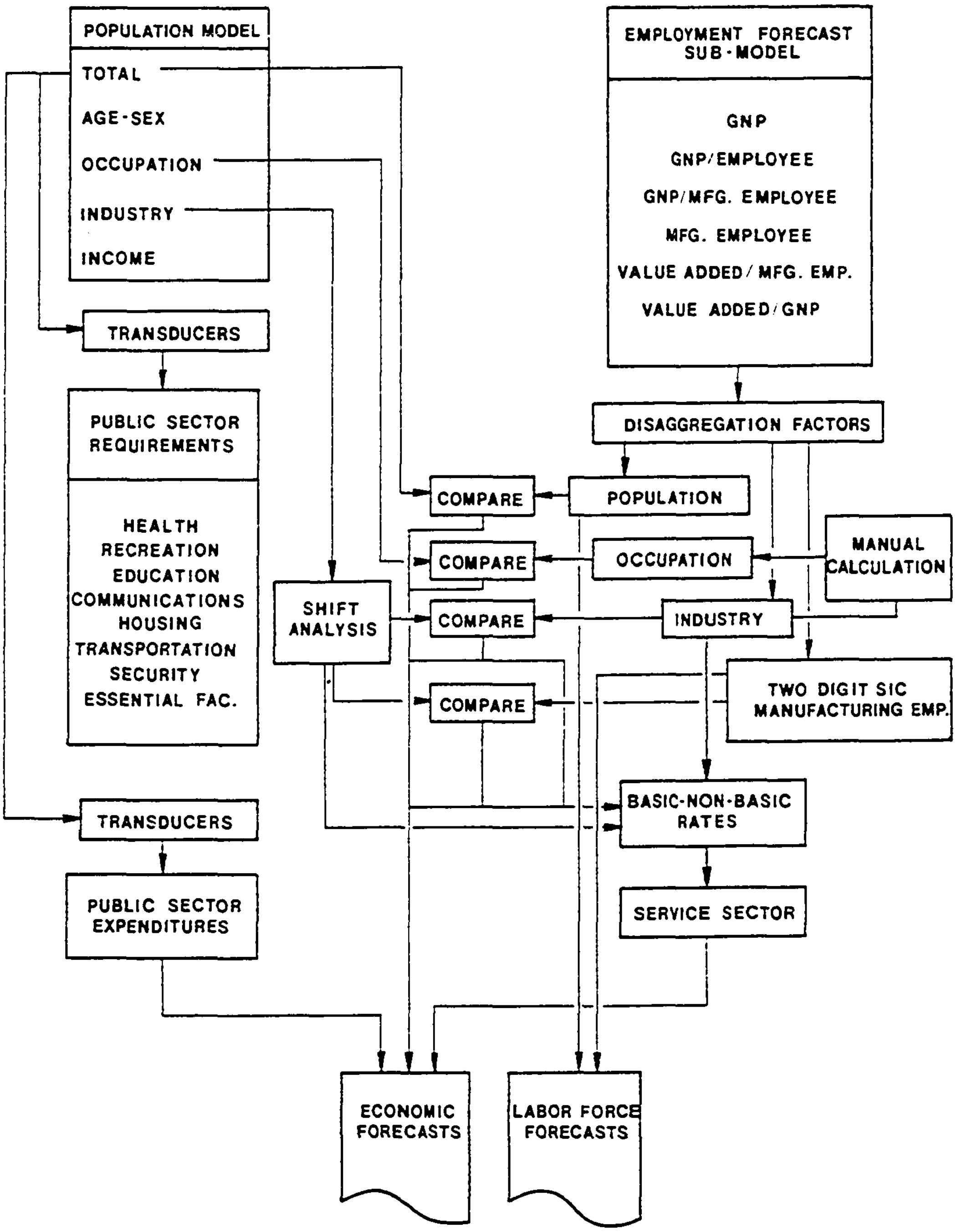

FIGURE 11: REID's ECONOMIC MODEL FORMAT

Source: See Ref. 4,69

growth of the Growth National Product (GNP) and the value added by manufacturing employees. Reid states in his reports (4, 69) that the outputs of the employment sub-model take the following format for each of the required geographical areas:

(1) Gross National Product (GNP)
(2) GNP/employee
(3) GNP/manufacturing employee
(4) Manufacturing employee
(5) Value added/manufacturing employee
(6) Value added/GNP
(7) Labor force by 1-digit SIC
(8) Total labor force
(9) Total population (4, p. 55).

Based on Reid's economic model projections, the State's non-agricultural employment is expected to reach over 1.02 million by 1980 and more than 1.43 million by 2000. In the year 2040, the non-agricultural employment is projected to be in excess of 2.42 million. These projections are tabulated in Table 10 and denoted as (X_{3i}).

The third key factor highly influencing the State's municipal and domestic water requirements is the gross-state product factor. The gross-state product has increased tremendously over the last 30 years. From 1950 to 1960, the gross-state product of Oklahoma increased from 2749.5 to 5006.61 million dollars. By 1970, the gross-state product reached 9094.81 million dollars and a value of 16729.07 million dollars by 1976. This indicates an increase of approximately 500 percent from 1950 to 1976 (53, 61).

Since there are no reasonable figures available for gross-state product projections, the straight line approach model is applied in order to obtain the required projections. The straight line approach model can be simply expressed by the following relation:

$$\Xi_t = \Xi_{t2} + n\left(\frac{\Xi_{t2} - \Xi_{t1}}{t_2 - t_1}\right) \quad \text{. . . . .} \quad (5.1)$$

where:

Ξ_t = future value of Ξ variable in year t,

t = target year to project,

t_1 = the first year for which actual data on Ξ was available,

t_2 = the last year for which actual data on Ξ was available, refered as base year,

$n = t - t_2$.

In order to illustrate the procedure of applying the straight line approach model, let us suppose that our goal is to project the state-gross product for the target year 2000. We have a value of 3699.89 million dollars for year 1954 and 16729.07 million dollars for the base year 1976 (see Table B-4 in Appendix B), as determined by Liew (61), and in this case we have $t = 2000$, $t_1 = 1954$, $t_2 = 1976$, $n = 24$, $\Xi_{t1} = 3699.89$ and $\Xi_{t2} = 16729.07$ million dollars. Applying the model given by equation (5.1), we obtain the following:

$$\Xi_{2000} = 16729.07 + 24 \left(\frac{16729.07 - 3699.89}{1976 - 1954}\right)$$

$$= 30942.72 \text{ million dollars}$$

Based on this methodology, projections of the state gross-product are computed. They are included in Table 10 and denoted as (X_{4i}). The state-gross product is expected to expand in the future to reach 30942.72 and 54632.14 million dollars by the years 2000 and 2040, respectively.

The fourth explanatory variable found to be related to the State's municipal and domestic water requirements is the State's mean annual precipitation. The projected value used in forecasting water requirements is determined by taking the average of the State's mean annual precipitation figures from the year 1950 to the year 1976 (see Table B-5 in Appendix B).

Now, and after the projections of all the four significant factors have been obtained, the procedure of forecasting the State's municipal and domestic water requirements seems to be simple. It is accomplished by inserting these forecasts of the predictor factors into equation (4.3). This is explained by Table 10 and the State's municipal and domestic water requirements projections are graphically illustrated in Figure 12.

Refering back to Table 3 in Chapter II, the State's municipal and domestic water use was 170 million gallons per day in 1930. By 1940, this figure had dropped to 133 million gallons per day due to the drought conditions existed during this time. In 1950, the State's municipal and domestic water use increased to 192 million gallons per day. In 1966, the reported municipal and domestic water use was 403 million gallons per day and 451 million gallons per day by 1976. This indicates an increase in the State's municipal and domestic water use of approximately 13 percent between 1930 and 1950 and 110 percent between 1950 and 1966. Between 1966 and 1976, the State's municipal and domestic water use increased by 12 percent.

Based on the model developed in this study and its projections, the State's municipal and domestic water requirements are expected to experience a significant gain during future years. Refering to Table 10, the State is expected to need 544 thousand acre-feet (486 MGD) by 1980 and 677 thousand acre-feet (605 MGD) by 2000 for municipal and domestic water requirements. These figures are expected to change by the year 2040 when the State will need 915 thousand acre-feet (817 MGD) for the same usage purpose. In other words, the State's municipal and domestic water requirements are projected to be increased by 68 percent from 1976 to 2040.

Table 11 provides a comparison between the projections developed in this study with other projections available at the Oklahoma Water Resources Board (67, 68), the Bureau of Water Resources Research and the Bureau of Business Research at Oklahoma University (6).

Oklahoma must be concerned with an adequate water supply system to serve the entire State and satisfy this expected increase in municipal and domestic water requirements.

The State's Per Capita Municipal and Domestic Water Usage Rate Projections

There were several models developed to describe the per capita water usage rate function of Oklahoma. These models are discussed in Chapter IV and two of them were rejected because of the over-estimation problem in forecasting the future per capita usage rate.

Table 10

Oklahoma Municipal and Domestic Water Requirements Projections*

<u>The Model:</u> $Y_{Mi} = 55.147 + 0.1344\ X_{1i} + 0.1145\ X_{3i} - 0.0015\ X_{4i} - 0.0668\ X_{6i}$

Year	X_{1i} (Thousands)	X_{3i} (Thousands)	X_{4i}^{**} (Million $)	X_{6i} (Inches)	Y_{Mi} (1000's A.F/Year)	Y_{Mi} (MGD)
1980	2989.9	1024.64	19098.00	32.74	544	486
1990	3398.7	1224.66	25020.37	32.74	612	547
2000	3772.8	1430.87	30942.72	32.74	677	605
2010	4110.1	1637.68	36865.08	32.74	738	659
2020	4428.7	1867.09	42787.43	32.74	798	713
2030	4713.7	2126.16	48709.78	32.74	857	765
2040	4962.5	2422.06	54632.14	32.74	915	817

* All the variables included in the model are as defined in equation (4.3) in Chapter IV.
** Estimated by using the straight line approach model.

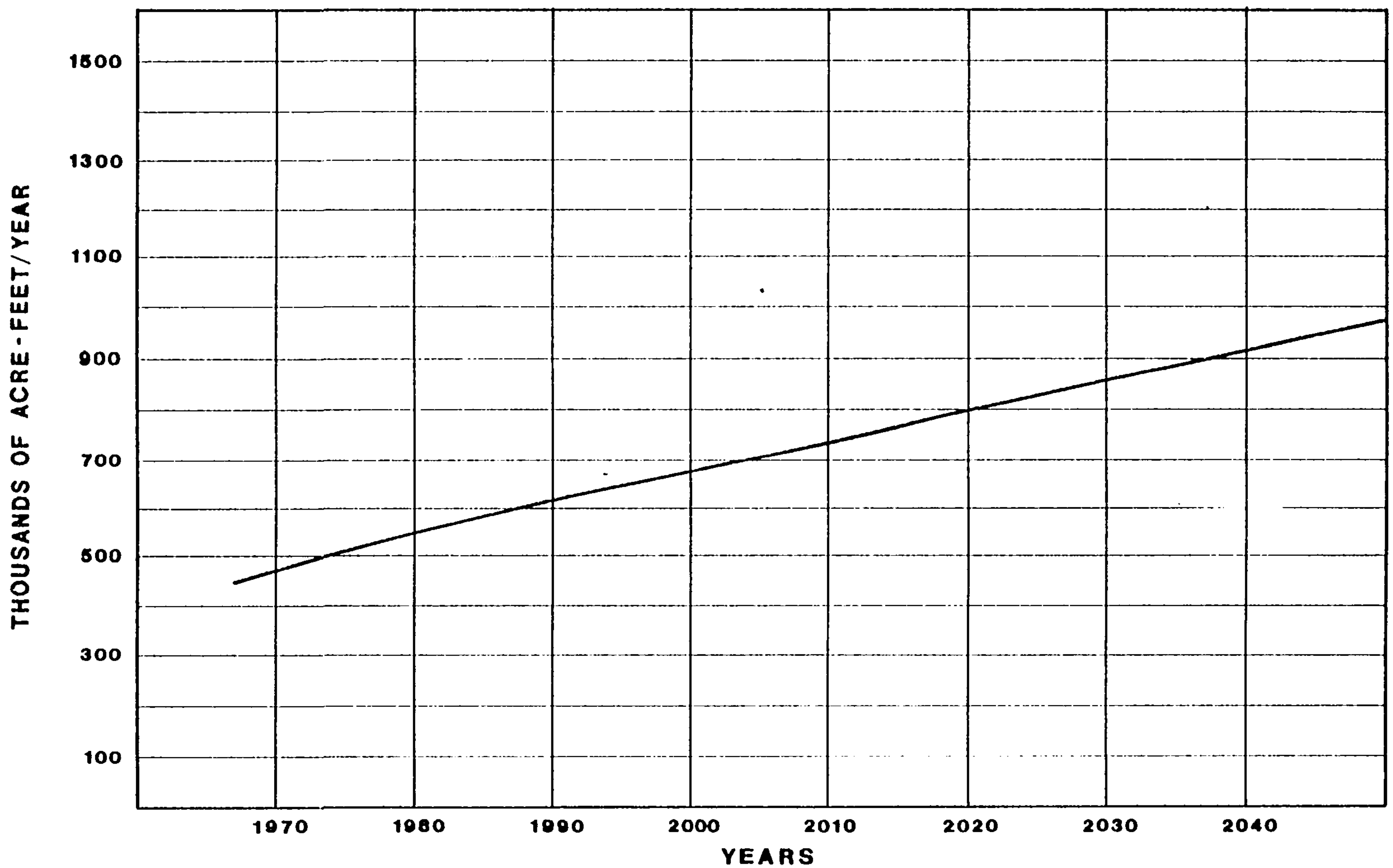

FIGURE12: OKLAHOMA MUNICIPAL AND DOMESTIC WATER REQUIREMENTS PROJECTIONS

Table 11

Comparison of Oklahoma Municipal and Domestic Water Requirements Projections

(In Thousands of Acre-Feet/Year)

Year	1980	1990	2000	2010	2020	2030	2040
Y_{Mi}^{*}	544	612	677	738	798	857	915
Y_{Mi}[6]	411	484	540	640	701	746	784
Y_{Mi}[67]	457.5	562.0	661.1	780.5	880.3	1005.0	---
Y_{Mi}[68]	381.3	472.9	563.7	682.5	788.3	------	---

* Municipal and domestic water requirements projections estimated by this study

<u>Source:</u> 6 <u>Oklahoma's Long-Range Water Requirements</u>, Bureau of Water Resources Research, and Bureau of Business Research, Oklahoma University, January, 1965.

67 <u>Statewide Water Resource and Requirement Inventory</u>, Oklahoma Water Resources Board, project report, February 22, 1977.

68 <u>Oklahoma Comprehensive Water Plan, Projected Water Requirements</u>, Oklahoma Water Resources Board, January, 1973.

The final State's per capita municipal and domestic water usage rate model is controlled by two major factors which are total population of the State and the per capita income. The population projections developed by the (OESC) are used to forecast future per capita rates for Oklahoma. The straight line approach model is applied to obtain projections for the State's per capita income by using the year 1976 as a base year. Reid's economic model provides projections for the State's per capita income but they were rejected because of the under-estimation disadvantage. For instance, per capita income of Oklahoma is projected by Reid's model to be 4143 dollars for 1980 while it was actually 5259 dollars in 1975 for Oklahoma. Therefore, the straight line approach model is prefered to obtain projections for per capita income.

Oklahoma's per capita income has impressively increased over the last 30 years. Between 1950 and 1960, the per capita income grew from 1143 to 1876 dollars, an increase of approximately 64 percent. In 1970, the per capita income was 3387 dollars and 5259 dollars by 1975 (see Table B-2 in Appendix B).

Based on the straight line approach model projections, the State's per capita income is expected to reach 6409 dollars by 1980 and 9920 dollars by 2000. By 2040, the per capita income is projected to be equal to 16941 dollars. These projections are tabulated in Table 12 and denoted as (X_{2i}).

The State's per capita municipal and domestic water usage rate was 84 gpcd by 1950 and 110 gpcd by 1960. In 1970, it was estimated in a study conducted by the Oklahoma Water Resources Board and the

Bureau of Water Resources at Oklahoma University (6) at 116 gpcd.

With the expected expansion in Oklahoma, population growth and per capita income, and based on the model developed in this study, the State's per capita usage rate is expected to reach 153 gpcd by 1980 and 199 gpcd by 2000. By 2020, this figure is projected to be 244 gpcd and 287 gpcd by 2040. This indicates that between the year 1980 and the year 2040, the State's per capita municipal and domestic water usage rate will grow at a rate of approximately 2.23 gpce per year. That seems to be consistent with that study conducted by the Bureau of Water Resources Research at Oklahoma University (36). In this study, it was estimated that the per capita rate of Oklahoma will reach a value of 150 gpcd by the year 1976 given an actual value of 84 gpcd for the year 1950, that is, a rate of growth equals 2.54 gpcd per year.

All the projections of the State's per capita municipal and domestic water usage rate are presented in Table 12 with the projections of both population (X_{1i}) and per capita income (X_{2i}). Furthermore, these projections of the per capita usage rate are graphically illustrated in Figure 13. A comparison of the projections of this study with other studies projections for the State's per capita usage rate is given in Table 13.

Municipal and Domestic Water Requirements Projections for Counties

The projections of the State's municipal and domestic water requirements are disaggregated from the State to county-level. The methodology involved in this disaggregation process is to multiply the

Table 12

Oklahoma Per Capita Municipal and Domestic

Usage Rates Projections*

(gpcd)

The Model: $Y_{PCi} = 45.5260 + 0.0145\ X_{1i} + 0.0101\ X_{2i}$

Year	X_{1i} (Thousands)	X_{2i}** (Current Dollars)	Y_{pci} (gpcd)
1980	2989.9	6409	153
1990	3398.7	8165	176
2000	3772.8	9920	199
2010	4110.1	11675	222
2020	4428.7	13431	244
2030	4715.7	15186	266
2040	4962.5	16941	287

* All the variables included in the model are as defined in equation (4.6) in Chapter IV.

** Estimated by using the straight line approach model.

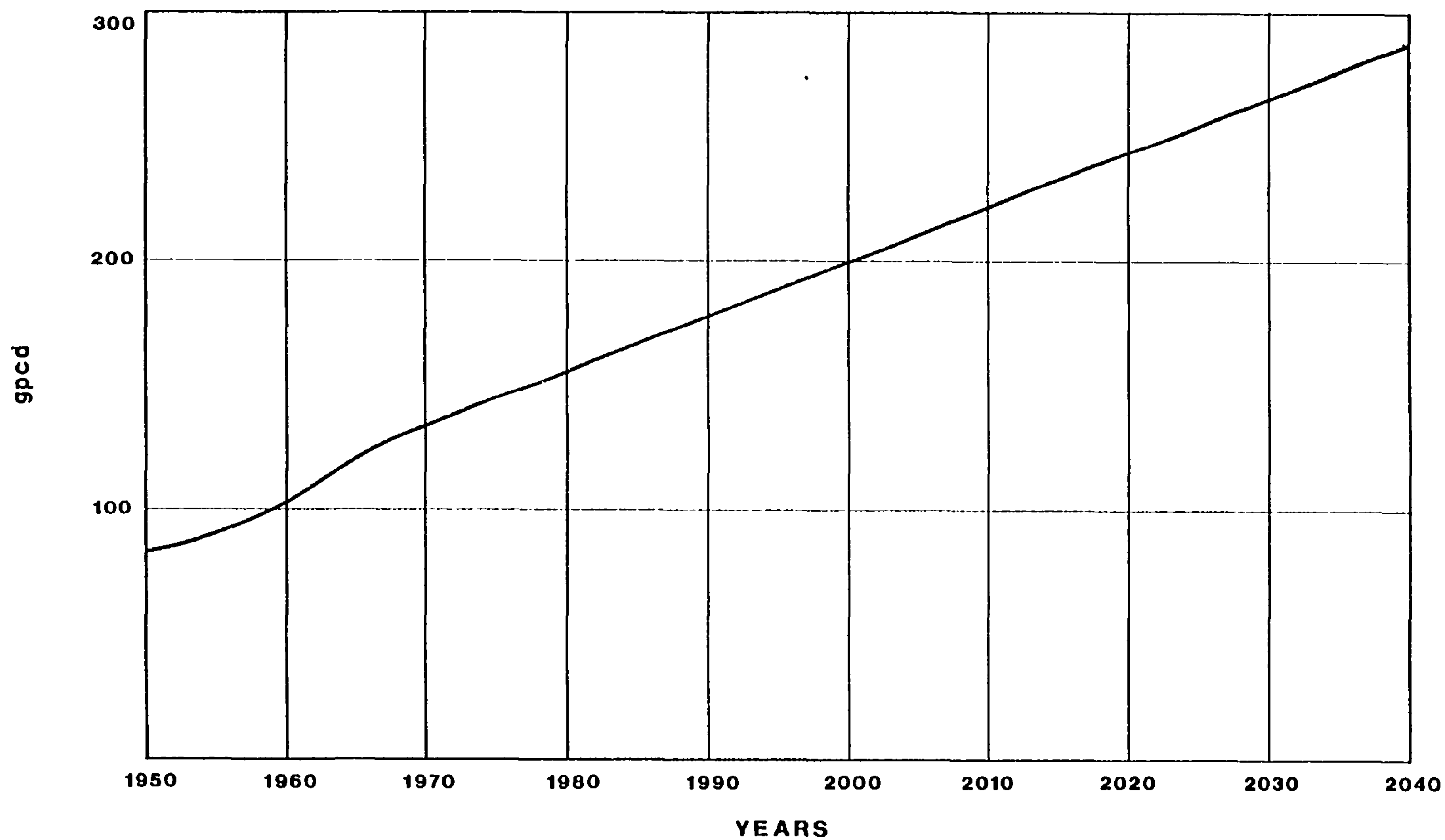

FIGURE 13: OKLAHOMA PER CAPITA MUNICIPAL WATER USAGE RATES PROJECTIONS

Table 13

Comparison of Oklahoma Per Capita Municipal and Domestic Water

Usage Rates Projections

(gpcd)

Year	1980	1990	2000	2010	2020	2030	2040
Y^{*}_{PCi}	153	176	199	222	244	266	287
Y^{6}_{PCi}	130	144	155	168	175	---	---
Y^{36}_{PCi}	156	170	190	208	223	---	---
Y^{67}_{PCi}	154	168	179	192	199	207	---

* Per capita municipal and domestic water usage rates estimated by this study.

Source: [6]Oklahoma's Long-Range Water Requirements, Bureau of Water Resources Research, and Bureau of Business Research, Oklahoma University, January, 1965.
[36]Water: Oklahoma's No. 1 Problem, Bureau of Water Resources Research, Oklahoma University, and Oklahoma Water Resources Board, 1956.
[67]Statewide Water Resource and Requirement Inventory, Oklahoma Water Resources Board, project report, February 22, 1977.

ratio of each county municipal and domestic water use to total State's municipal and domestic water use times the projected State's municipal and domestic water requirements. These counties to State ratios are determined by using 1970 figures of the State and counties which are presented in the Oklahoma Comprehensive Water Plan at the Oklahoma Water Resources Board (68). Simply, this methodology of State to county disaggregation can be expressed as follows:

$$MC_{ij} = \left(\frac{MC_{jk}}{MS_k}\right) \cdot Y_{Mi} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5.2)$$

where:

MC_{ij} = municipal and domestic water requirements for county j in future year i,

MC_{jk} = municipal and domestic water use of county j in the base year 1970,

MS_k = municipal and domestic water use of the State in the base year 1970,

Y_{Mi} = projected State's municipal and domestic water requirements in future year i,

K = the base year 1970.

Therefore, the method of projecting county municipal and domestic water requirements assumes that each county will maintain its relative proportion of municipal and domestic water use compared to the State's.

Based on this methodology, county municipal and domestic water requirements projections are derived and they are tabulated in Table C-1 in Appendix C. From this table, we can conclude that Oklahoma County will continue to dominate the municipal and domestic water requirements in the State with 22.2 percent of the State's. Tulsa County ranks 2nd with 16.6 percent of the State's total municipal and domestic water requirements. Cleveland, Comanche, Creek, Garfield, Kay, Muskogee, Oklahoma, Payne, Pottowatomie, Tulsa and Washington counties represent 60.2 percent of the State's municipal and domestic water requirements. The geographical locations of these eleven counties are given in Figure 14.

Oklahoma County is expected to need 120.7 thousand acre-feet (107.8 MGD) by 1980 and 150.2 thousand acre-feet (134.2 MGD) by 2000. In the year 2040, this county will need 202.9 thousand acre-feet (181.2 MGD) for municipal and domestic water requirements. Tulsa County is expected to need 90.2 thousand acre-feet (80.6 MGD) by 1980 and 112.2 thousand acre-feet (109 MGD) by 2000. Between the year 2000 and the year 2040, the municipal and domestic water requirements for Tulsa County are projected to reach 151.7 thousand acre-feet (135.5 MGD).

Oklahoma, Tulsa, Comanche and Cleveland counties will experince most of the State's municipal and domestic water requirements. Their projections are illustrated in Figure 15.

Municipal and Domestic Water Requirements Projections for Selected Cities

The State's municipal and domestic water requirements projections obtained in this study are disaggregated to some selected cities level. The disaggregation from the State to city-level is accomplished by using the 1976 municipal and domestic water use figures of both the State and selected cities as a base year. The methodology involved in

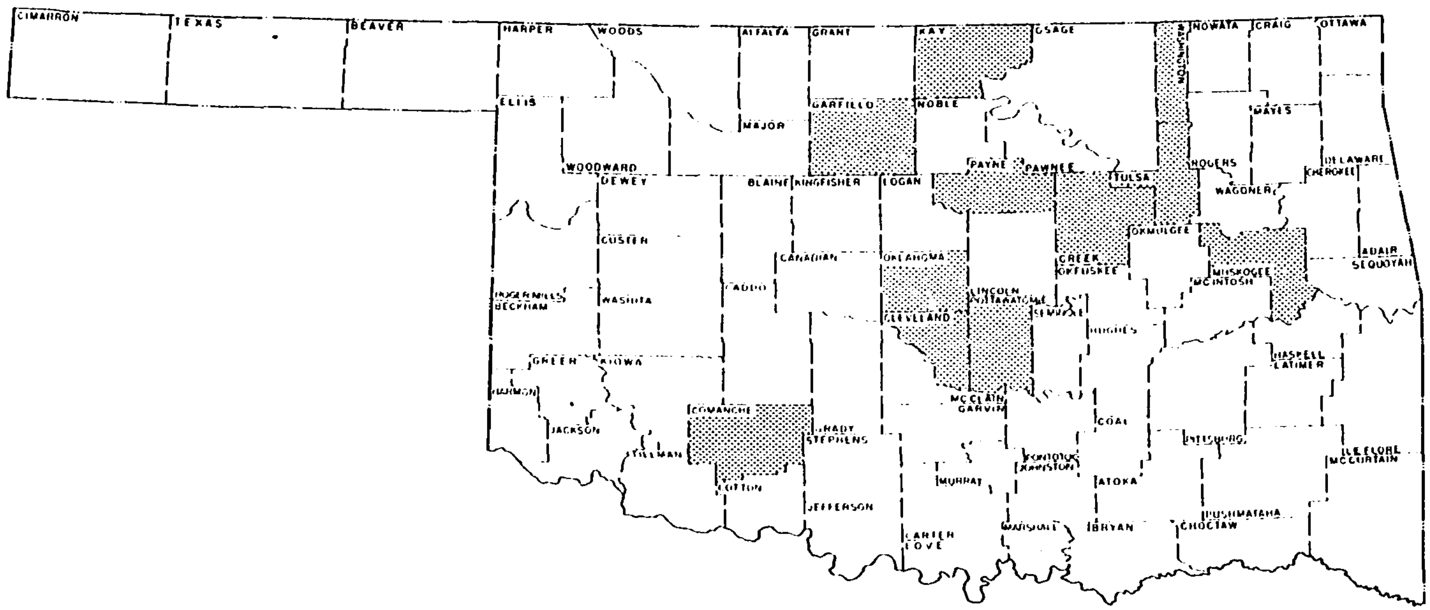

FIGURE 14: THE LARGEST ELEVEN MUNICIPAL WATER USAGE COUNTIES IN OKLAHOMA

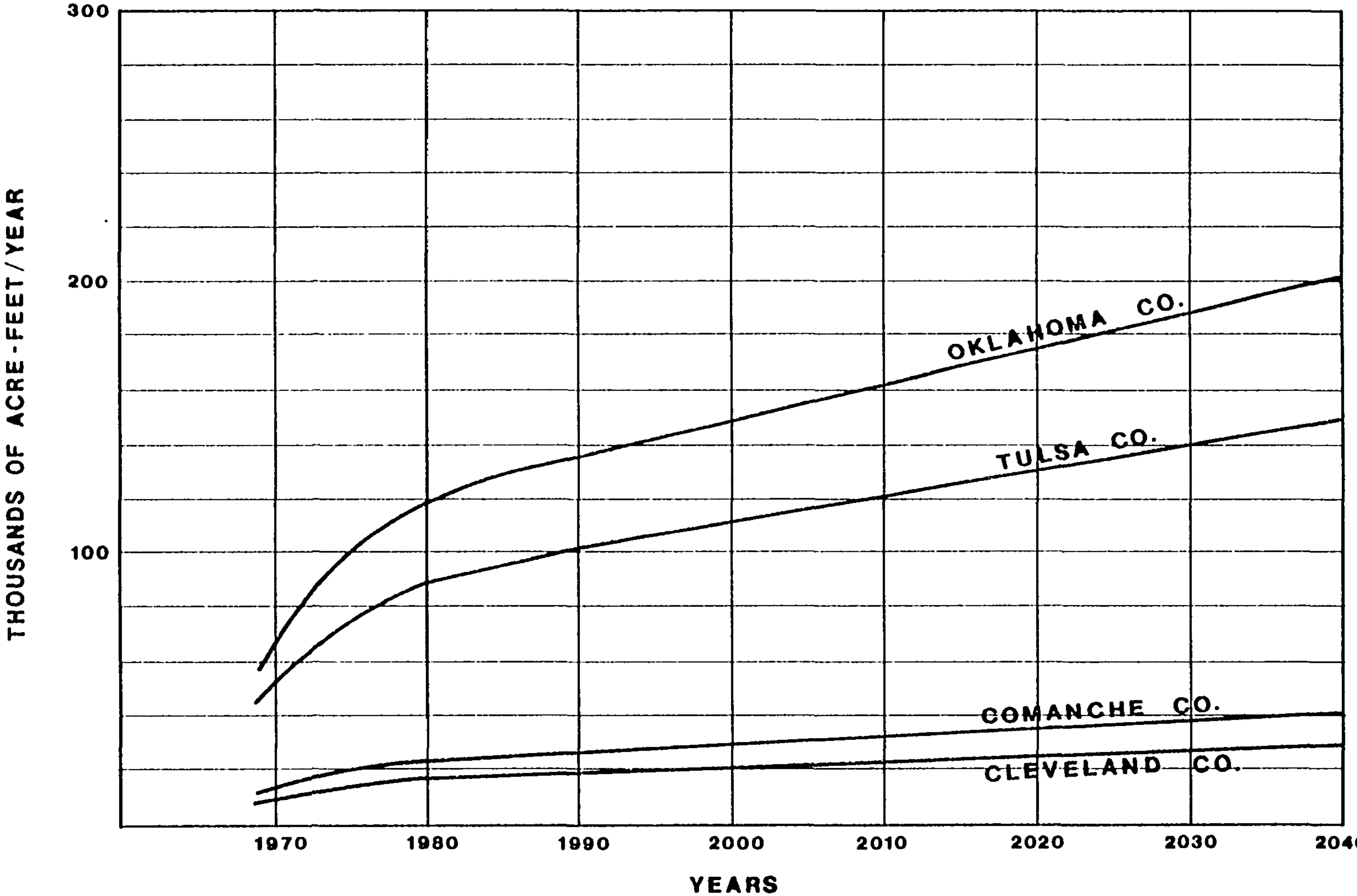

FIGURE 15: MUNICIPAL AND DOMESTIC WATER REQUIREMENTS PROJECTIONS FOR CLEVELAND, COMANCHE, OKLAHOMA, TULSA COUNTIES

the disaggregation procedure is the same as explained in the municipal and domestic water requirements disaggregation from the State to county-level. That can be explained by the following equation:

$$MSC_{ij} = \left(\frac{MSC_{jh}}{MS_h}\right) \cdot Y_{Mi} \quad \dots\dots\dots\dots\dots\dots\dots (5.3)$$

where:

MSC_{ij} = municipal and domestic water requirements for selected city j in future year i,

MSC_{jh} = existing average flow of city j in the base year h,

MS_h = municipal and domestic water use of the State in the base year h,

Y_{Mi} = projected State's municipal and domestic water requirements in future year i,

h = the base year 1976.

The basic data on water supplies for cities was obtained from a report submitted to the Office of Economic Research, Economic Development Administration, U. S. Department of Commerce by Pulliam (72). This report is an inventory of public water supplies for cities of 2000 population and over. A personal visit was made to each of the State's offices responsible for obtaining water supply information and also the federal EPA data was obtained and utilized where possible. The data in this report includes name of city served by the water supply system, name of the county where the water supply system is located, population served, design capacity, existing average flow, per capita use, percentage of plant capacity used and storage capacity.

Based on the methodology involved and the accuracy of the basic data used, Oklahoma City is expected to need the highest municipal and domestic water requirements among all cities in the State. By the year 1980, Oklahoma City will require approximately 66.7 MGD and 83.03 MGD by the year 2000. The municipal and domestic water requirements are estimated at 112.13 MGD for 2040 for this city.

The municipal and domestic water requirements for Tulsa City, which is ranked number two, are estimated at 59.17 MGD for 1980. This figure is expected to increase from 73.66 MGD by the year 2000 to 99.47 MGD by the year 2040.

Lawton is another large city in Oklahoma with population served in 1976 equals 74,000. The municipal and domestic water requirements for this city are expected to reach 12.05 MGD by 2000 and 16.28 MGD by 2040.

Projections for the largest 53 cities in Oklahoma, based on 5000 population served and over, are provided in Table D-1 in Appendix D. From this table, it is very obvious that Ardmore, Enid, Lawton, Midwest City, Muskogee, Norman, Oklahoma City, Stillwater and Tulsa are the cities that will experience and dominate most of the State's municipal and domestic water requirements in the future.

The State's Industrial Water Requirements Projections

It has been discussed previously in Chapter IV that total population, non-agricultural employment, coal production and mean annual precipitation are the major factors that explain the State's industrial water use function. Coal production of the State is the new variable here to be reviewed.

Statistics from the U. S. Bureau of Mines (63) show that the State's coal production has been fluctuating over the last 30 years. Between 1950 and 1960, coal production of Oklahoma decreased from 2679 to 1342 thousand short tons and then increased to 2427 thousand short tons by 1970. In 1976, the State's coal production was estimated at 2900 thousand short tons.

Projections of the State's coal production are determined by using the straight line approach model. Based on this approach, Oklahoma is expected to produce 2934 thousand short tons by 1980 and 3104 thousand short tons by 2000. In the year 2040, the coal production is projected to reach approximately 3444 thousand short tons. These projections are included in Table 14 and denoted as (X_{9i}).

Oklahoma is experiencing tremendous growth in industrial water use. Statistics from the Bureau of Water Resources Research at Oklahoma University and the Oklahoma Water Resources Board (36) show that between 1930 and 1955, the State's industrial water use increased from 25.8 to 52 million gallons per day. Records of the Oklahoma Water Resources Board (46) indicate that the industrial water use in Oklahoma was approximately 160 million gallons per day in the year 1966. This is considered to be a sharp increase from 1955 to 1966 which represents about 208 percent increase between the two years. The reported water use was 526 million gallons per day for the year 1975.

Oklahoma is expected to have a great expansion in industrial development. There were 2911 industries in 1972. The State ranks 33rd among all states in industry (8). With the population growth of the State, industrial development, continuing development of petro-chemicals, technology expansion and based on the industrial water demand model developed in this study, the State's industrial water requirements projections indicate a very impressive rate of increase in industrial water needs in the future. Refering to Table 14, the State is expected to need 875 thousand acre-feet (782 MGD) by 1980 and 1742 thousand acre-feet (1556 MGD) by 2000.

By the year 2040, Oklahoma is expected to require 3307 thousand acre-feet (3954 MGD) for industrial use. This indicates a rate of increase equals 40.53 thousand acre-feet per year (36.2 MGD per year) from the year 1980 to the year 2040 which is considered to be a very rapid rate. Figure 16 illustrates the future trends of the State's industrial water requirements expansion.

Industrial Water Requirements Projections for Counties

The disaggregation of the industrial water requirements projections from the State to county-level is accomplished by following the same methodology involved in the disaggregation of the municipal and domestic water requirements projections. The 1970 industrial water use figures of both the State and counties were obtained from the Oklahoma Comprehensive Water Plan at the Oklahoma Water Resources Board (68). The disaggreation method can be explained by the following relation:

$$IC_{ij} = \left(\frac{IC_{jk}}{IS_k}\right) \cdot Y_{Ii} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5.4)$$

Table 14

Oklahoma Industrial Water Requirements Projections*

The Model: $Y_{Ii} = -2177.718 + 0.7626\ X_{1i} + 0.6533\ X_{3i} + 0.652\ X_{6i} + 0.028\ X_{9i}$

Year	X_{1i} (Thousands)	X_{3i} (Thousands)	X_{6i} (Inches)	X_{9i}^{**} (1000's Short Tons)	Y_{Ii} (1000's A.F/Year)	Y_{Ii} (MGD)
1980	2989.9	1024.64	32.74	2934	875	782
1990	3398.7	1224.66	32.74	3019	1320	1179
2000	3772.8	1430.87	32.74	3104	1742	1556
2010	4110.1	1637.78	32.74	3189	2137	1909
2020	4428.7	1867.09	32.74	3274	2532	2261
2030	4713.7	2126.16	32.74	3359	2921	2609
2040	4962.5	2422.06	32.74	3444	3307	2954

* All the variables included in the model are as defined in equation (4.7) in Chapter IV.
** Estimated by using the straight line approach model.

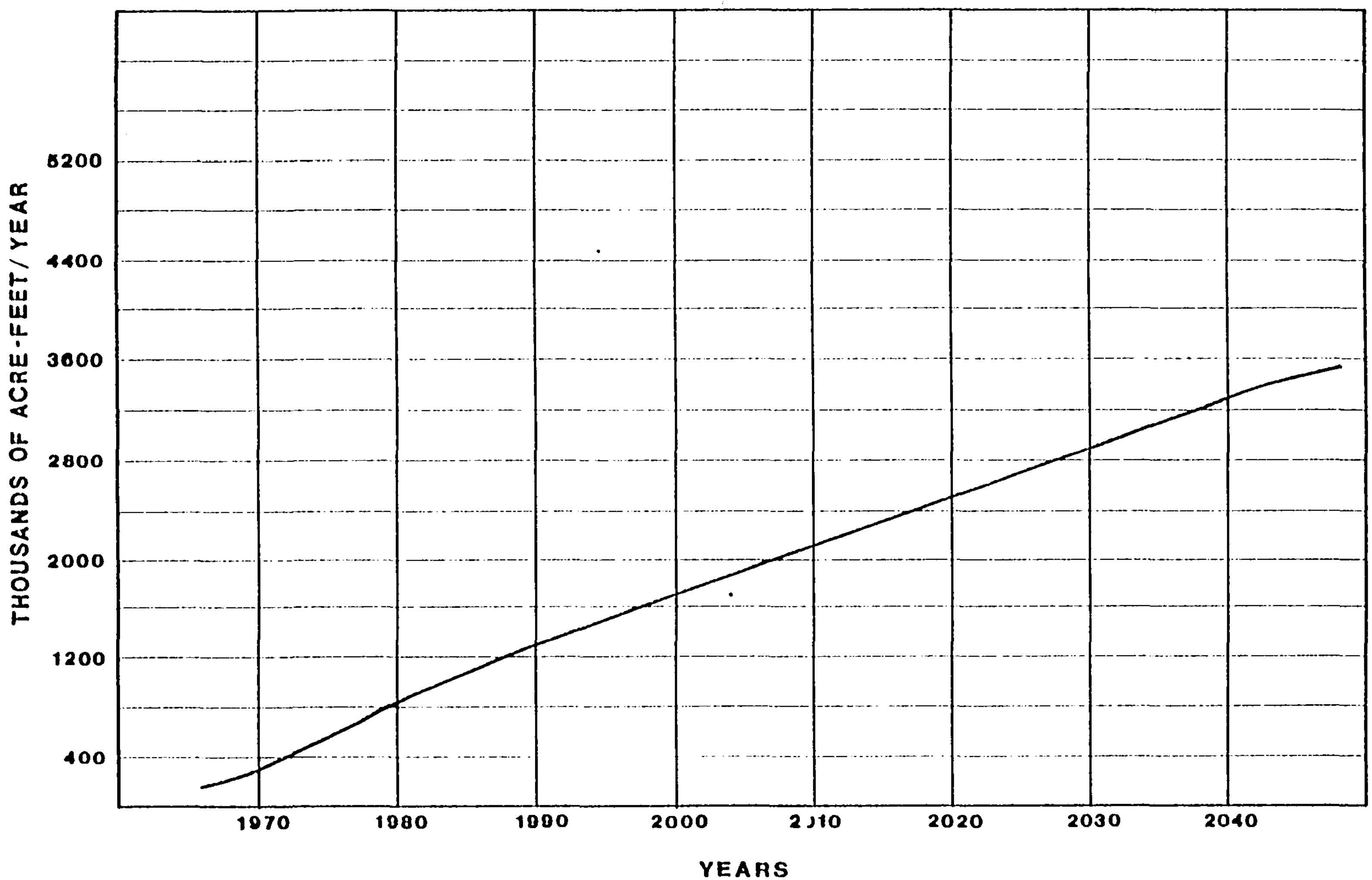

FIGURE 16: OKLAHOMA INDUSTRIAL WATER REQUIREMENTS PROJECTIONS

where:

IC_{ij} = industrial water requirements for county j in future year i,

IC_{jk} = industrial water use of county j in the base year 1970,

IS_k = industrial water use of the State in the base year 1970,

Y_{Ii} = projected State's industrial water requirements in future year i,

k = the base year 1970.

Projections for all the 77 counties in Oklahoma for industrial water requirements are tabulated in Appendix C in Table C-2.

Tulsa County is expected to continue to dominate the industrial water needs in Oklahoma. In 1980, this county will need 171.7 thousand acre-feet (153.4 MGD) to satisfy its needs for industrial water uses. This figure is expected to reach 342 thousand acre-feet (305.5 MGD) by 2000 and 649.1 thousand acre-feet (597.7 MGD) by the year 2040. Tulsa County represents approximately 19.6 percent of the State's total industrial water requirements.

Oklahoma County is ranked number two in the industrial water requirements in the State. It represents 17.6 percent of the State's total industrial water needs. Oklahoma County is projected to require 154.1 thousand acre-feet (135.2 MGD) by 1980 and 306.7 thousand acre-feet (273.9 MGD) by 2000. By the year 2040, this county will need 582.3 thousand acre-feet (520.1 MGD) for industrial water uses.

Comanche County ranks 3rd in the industrial water requirements with 4.42 percent of the State's. Comanche County industrial water needs are

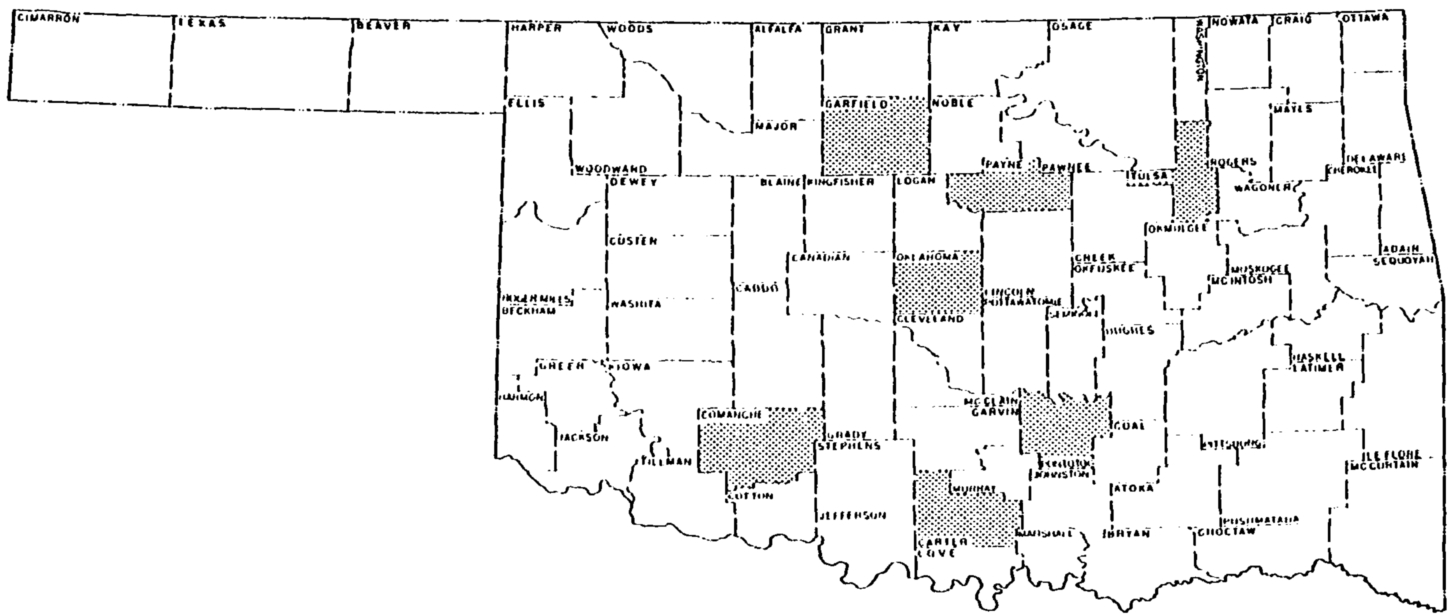

FIGURE 17: THE LARGEST SEVEN INDUSTRIAL WATER USAGE COUNTIES IN OKLAHOMA

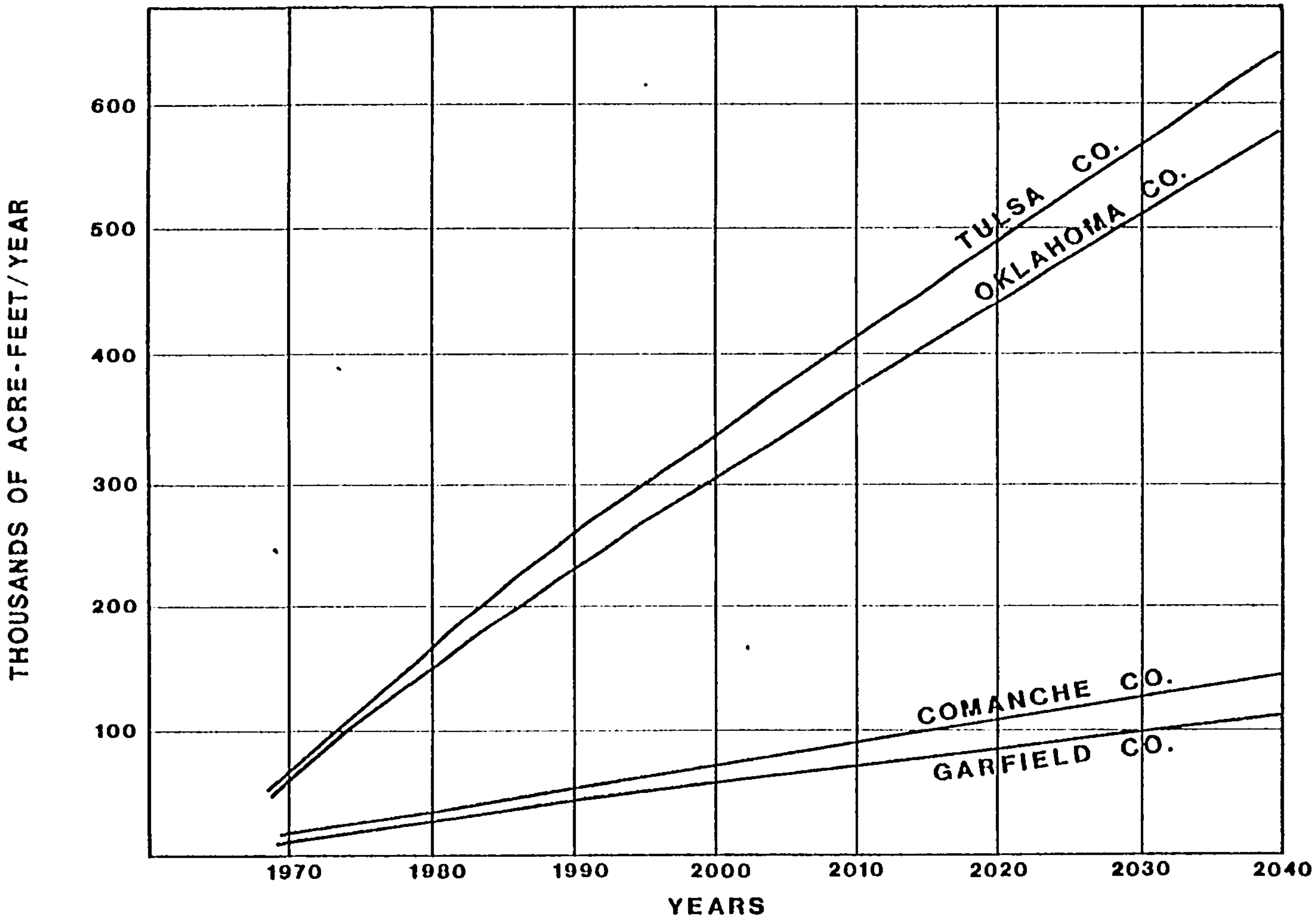

FIGURE 18: INDUSTRIAL WATER REQUIREMENTS PROJECTIONS FOR COMANCHE, GARFIELD, OKLAHOMA, TULSA COUNTIES

projected to be 77 thousand acre-feet (68.8 MGD) by 2000 and 146.2 thousand acre-feet (130.6 MGD) by 2040.

Carter, Comanche, Garfield, Oklahoma, Payne, Pontotoc and Tulsa counties represent the largest seven industrial water usage counties in Oklahoma. They altogether represent 53.7 percent of the State's industrial water uses. Figure 17 shows the geographical locations of these seven counties. Figure 18 shows the future expansion in industrial water requirements for Tulsa, Oklahoma, Comanche and Garfield counties.

The State's Irrigation Water Requirements Projections

Oklahoma's industrial economy is dependent on agriculture. There are many segments of the State's economy that constitute a multi-billion dollar contribution to the total economy of the State, such as food and allied products, agricultural supplies, materials, equipment and services, transportation and marketing. All of these segments are agriculturally oriented.

As mentioned before in Chapter II, irrigation is considered to be the most significant key issue of water resources development on a world-wide scale and in a long-range prospective.

Based on the irrigation model developed for the State and expressed by equation (4.8), Oklahoma's irrigation water use is basically dependent on four factors which are per capita income, acres irrigated, land in farms and mean annual precipitation. Acres irrigated in Oklahoma have the highest influence on irrigation water use.

Oklahoma's total land area is 43,819,111 acres. Records of the Oklahoma Water Resources Board (8) show that of this total, 12,992,641 acres are in cropland, 18,953,655 acres are in ranches and pastureland, 8,580,907 acres are in forestland and the remainder is not agricultural use. The number of irrigated acres in Oklahoma has increased rapidly in the last 50 years. Records of the Bureau of Water Resources Research at Oklahoma University (36) indicate that in 1940, the irrigated acres were 5,000 and reached 90,000 by the year 1950. In 1956, the same source of information shows that the irrigated acres in Oklahoma were 284,000. According to 1967 reported water use (46), the number of irrigated acres was 508,220 while it was 558,803 acres, reported by Oklahoma State Extension Service. In 1975, the irrigated acres were 941,214, reported by the first source of information, and 531,273 acres, according to the second source.

The State's irrigation water use has sharply increased. Between 1940 and 1950, the irrigation water use grew from 1 MGD to 3 MGD. By the year 1956, the irrigation water use had reached 254 MGD. The reported water use for irrigation was 455 MGD in 1966, 692 MGD in 1975 and 829 MGD in 1976.

Projections of irrigated acres in Oklahoma obtained from the Oklahoma Comprehensive Water Plan (68) are presented in Table 15 and denoted as (X_{13i}). Projections of both per capita income (X_{2i}) and land in farms (X_{15i}) are determined by using the straight line approach model and are included in the same table.

Table 15

Oklahoma Irrigation Water Requirements Projections*

The Model: $Y_{Ai} = -17309.066 + 0.1095\ X_{2i} - 0.9635\ X_{6i} + 1.8021\ X_{13i} + 0.4506\ X_{15i}$

Year	X^{**}_{2i} (Current Dollars)	X_{6i} (Inches)	X_{13i} (1000's Acres)	X^{**}_{15i} (1000's Acres)	Y_{Ai} (1000's A.F/Year)	Y_{Ai} (MGD)
1980	6409	32.74	795.60	36600	1287	1149
1990	8165	32.74	976.60	36100	1580	1411
2000	9920	32.74	1155.60	35600	1869	1669
2010	11675	32.74	1456.90	35100	2379	2125
2020	13431	32.74	1758.20	34600	2889	2580
2030	15186	32.74	2001.56**	34100	3295	2943
2040	16941	32.74	2244.91**	33600	3700	3305

* All the variables included in the model are as defined in equation (4.8) in Chapter IV.
** Estimated by using the straight line approach model.

Based on the developed model for the State's irrigation water requriements, Oklahoma is expected to need 1287 thousand acre-feet (1149 MGD) by the year 1980 and 1869 thousand acre-feet (1669 MGD) by 2000. In the year 2040, irrigation water requirements for Oklahoma are projected to reach 3700 thousand acre-feet (3305 MGD). This implies a rate of growth in the State's irrigation water requirements between 1980 and 2040 of approximately 40 thousand acre-feet per year (36 MGD per year).

These irrigation water requirements projections are illustrated in Figure 19. Table 16 contains a comparison between the projections derived in this study and the Oklahoma Water Resources Board projections (67) established by the planning division.

Irrigation Water Requirements Projections for Counties

The disaggregation of the State's irrigation water requirements projections to county-level is achieved by applying the same methodology explained in the municipal and domestic, and the industrial water requirements projections disaggregation. Again, the 1970 irrigation water use figures of the State and counties were obtained from the Oklahoma Comprehensive Water Plan at the Oklahoma Water Resources Board (68). The process of disaggration can be explained by the following equation:

$$AC_{ij} = \left(\frac{AC_{jk}}{AS_k}\right) \cdot Y_{Ai} \quad \ldots\ldots\ldots\ldots \quad (5.5)$$

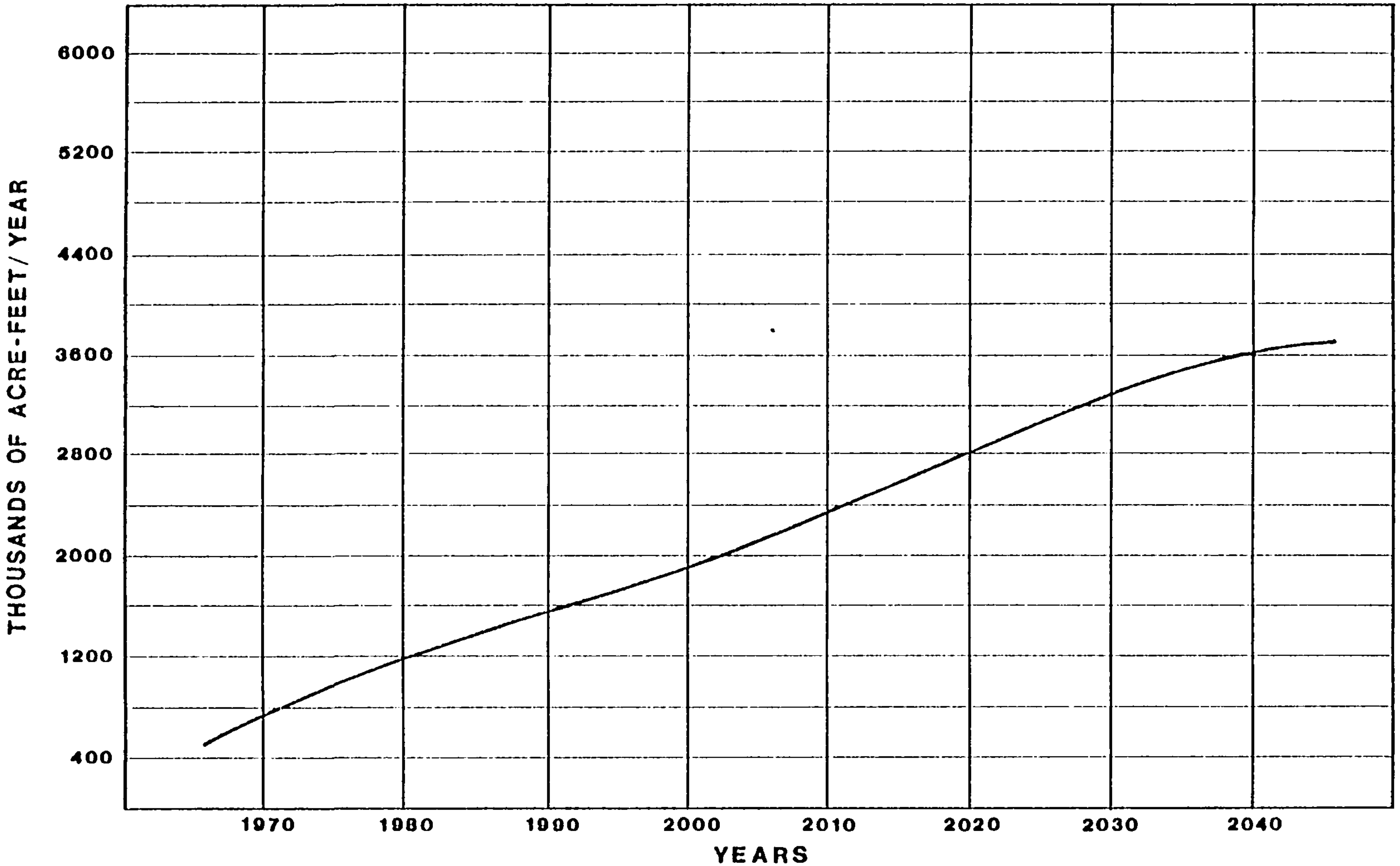

FIGURE 19: OKLAHOMA IRRIGATION WATER REQUIREMENTS PROJECTIONS

Table 16

Comparison of Oklahoma Irrigation Water Requirements Projections

(In Thousands of Acre-Feet/Year)

Years	1980	1990	2000	2010	2020	2030	2040
Y_{Ai}^{*}	1287	1580	1869	2379	2889	3295	3700
Y_{Ai}^{6}	1114	1709	1836	1894	1932	1912	1841
Y_{Ai}^{67}	1742.3	2047.7	2372.7	2901.9	3394.9	3867.0	----

* Irrigation water requirements projections estimated by this study.

Source: [6]Oklahoma's Long-Range Water Requirements, Bureau of Water Resources Research, and Bureau of Business Research, Oklahoma University, January, 1965.
[67]Statewide Water Resource and Requirement Inventory, Oklahoma Water Resources Board, project report, February 22, 1977.

where:

AC_{ij} = irrigation water requirements for county j in future year i,

AC_{jk} = irrigation water use of county j in the base year 1970,

AS_k = irrigation water use of the State in the base year 1970,

Y_{Ai} = projected State's irrigation water requirements in future year i,

k = the base year 1970.

Texas County represents the largest irrigation water use county in Oklahoma with approximately 34 percent of the State's. The number of irrigated acres in Texas County was 154,831 in 1970 with an associated irrigation water use equals 263.4 thousand acre-feet (235.26 MGD). According to the Oklahoma Water Resources Board projections (68), this number of irrigated acres is expected to reach 214,800 by 1980, 276,300 by 2000 and 502,800 acres by the year 2070. With this expected growth in irrigated acres in this county and based on the methodology involved in irrigation water requirements disaggregation, Texas County will continue to dominate the expansion in irrigation water use in the State. In 1980, irrigation water needs are projected to be 437.9 thousand acre-feet (391 MGD) and 636 thousand acre-feet (568 MGD) by 2000. In 2040, Texas County will require 1259.1 thousand acre-feet (1124.6 MGD) for irrigation use.

Cimarron County is ranked number two in Oklahoma in irrigation water use with 12.3 percent of the State's. Irrigated acres are projected to be 126,100 and 171,400 by 1980 and 2000, respectively. On the other hand, irrigation water requirements are expected to reach 158.4 thousand acre-feet (141.5 MGD) by 1980 and 230 thousand acre-feet (205.4 MGD) by

2000. Cimarron County will need 445.3 thousand acre-feet (397.7 MGD) by the year 2040.

Caddo County, which is ranked number three in irrigation water use, is expected to need 166.6 thousand acre-feet (148.8 MGD) by 2000 and 329.8 thousand acre-feet (294.6 MGD) by the year 2040. For Jackson County, which is ranked number four, it is projected that this county will need an amount of 137.9 thousand acre-feet (123.2 MGD) by the year 2000 and 273 thousand acre-feet (243.9 MGD) by 2040.

Beaver, Caddo, Cimarron, Harmon, Jackson, Major, Texas, Tillman and Washita counties are the largest nine counties in irrigation water requirements in Oklahoma, they altogether represent 77.1 percent of the State's. Figure 20 shows the geographical locations of these counties. Table C-3 in Appendix C contains projections of irrigation water requirements by county. Moreover, Figure 21 is an illustration of future irrigation water requirements for Texas, Cimarron, Caddo and Jackson counties.

The State's Total Water Requirements Projections

The two significant independent variables in the State's total water demand model are total population and total employment. The population projections developed by the Oklahoma Employment Security Commission are used to forecast total water requirements for Oklahoma. Reid's economic model is used to obtain projections for the State's total employment. These projections are presented in Table 17, total population is denoted as (X_{1i}) and total employment as (X_{20i}).

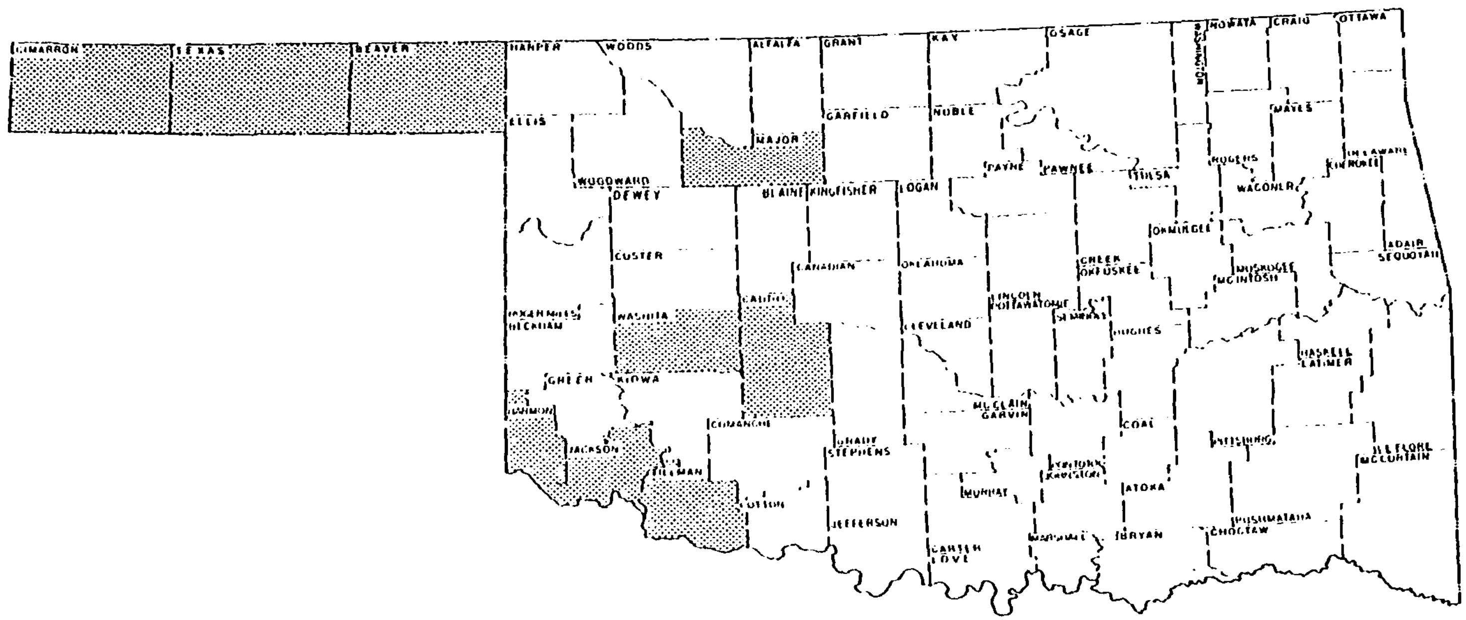

FIGURE 20: THE LARGEST NINE IRRIGATION WATER USAGE COUNTIES IN OKLAHOMA

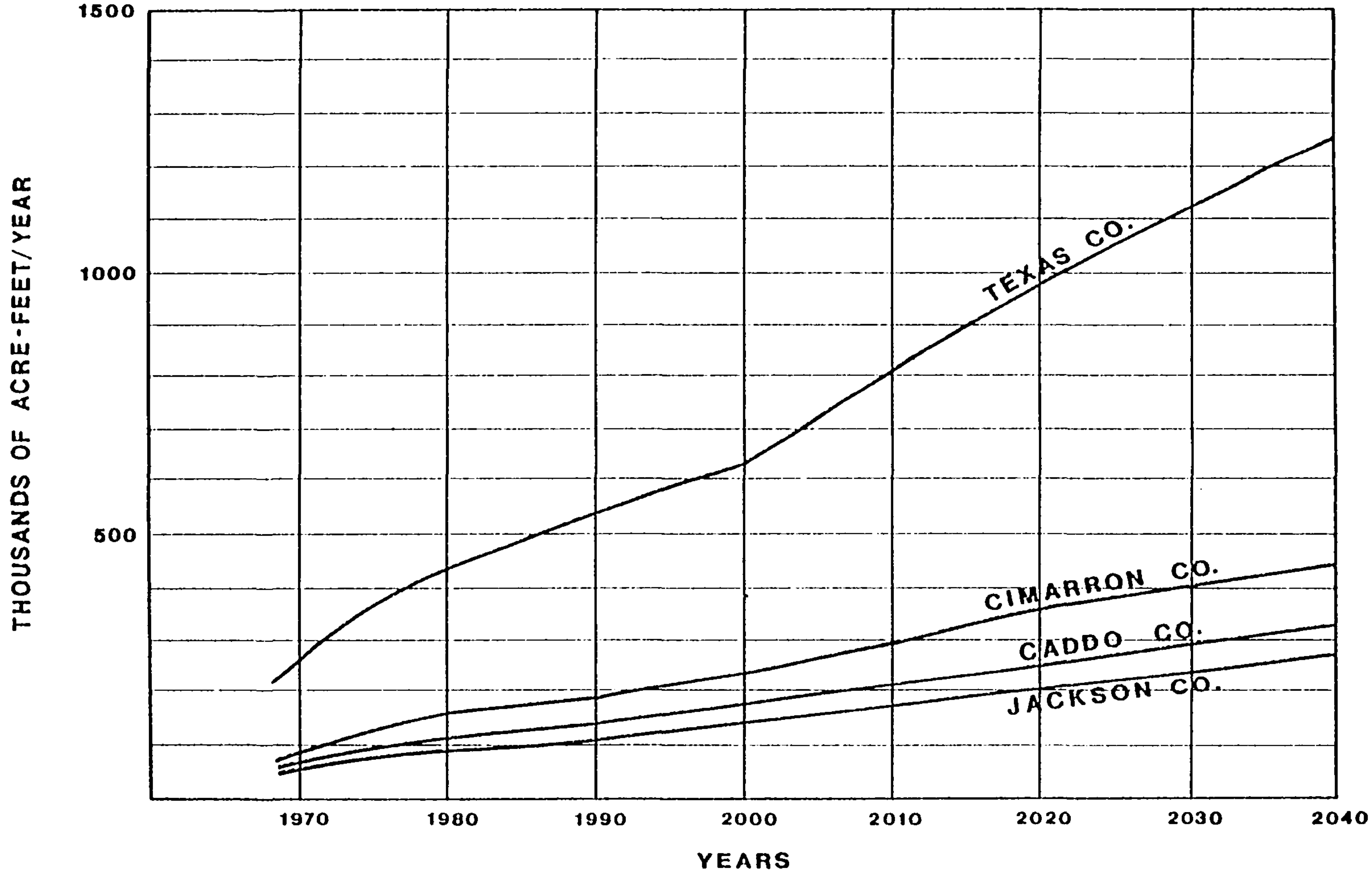

FIGURE 21: IRRIGATION WATER REQUIREMENTS PROJECTIONS FOR CADDO, CIMARRON, JACKSON, TEXAS COUNTIES

It is very essential to emphasize that the term "total" water requirements includes municipal and domestic, industrial, irrigation uses besides other uses. The term "others" includes water used in recreation and wildlife, secondary oil recovery and other municipal and industrial water uses.

Based on the developed model, the State's is expected to experience a great growth in total water requirements. In the year 1980, it is projected that Oklahoma will need 2760 thousand acre-feet (2465 MGD) and an amount of 5167 thousand acre-feet (4615 MGD) by 2000. By 2040, the total water requirements for Oklahoma is expected to reach 9007 thousand acre-feet (8045 MGD). These projections are illustrated in Figure 22.

By the year 2000, 36 percent of the total water requirements of Oklahoma is determined to be classified as irrigation, 34 percent as industrial, 13 percent as municipal and domestic and the remaining 17 percent will be for other uses. By the year 2040, the picture will be slightly different. Irrigation water requirements percentage is expected to increase from 36 percent to 41 percent of the State's total. Industrial water needs percentage will grow from 34 percent in the year 2000 to 37 percent of the State's total by the year 2040. Municipal and domestic water use percentage is projected to be decreasing from 13 percent to 10 percent while the percentage of other uses, such as recreation and wildlife, secondary oil recovery and other municipal and industrial uses is expected to decrease from 17 percent to 12 percent. These percentages of different water use categories for the years 2000 and 2040 are explained in Figure 23.

Table 17

Oklahoma Total Water Requirements Projections*

<u>The Model:</u> $Y_{Ti} = -6258.047 + 2.856\ X_{1i} + 0.450\ X_{20i}$

Year	X_{1i} (Thousands)	X_{20i} (Thousands)	Y_{Ti} (1000's A.F/Year)	Y_{Ti} (MGD)
1980	2989.9	1061.693	2760	2465
1990	3398.7	1242.148	4009	3581
2000	3772.8	1440.90	5167	4615
2010	4110.10	1637.78	6219	5554
2020	4428.7	1867.09	7233	6460
2030	4713.7	2126.166	8163	7291
2040	4962.5	2422.06	9007	8045

* All the variables included in the model are defined in equation (4.9) in Chapter IV.

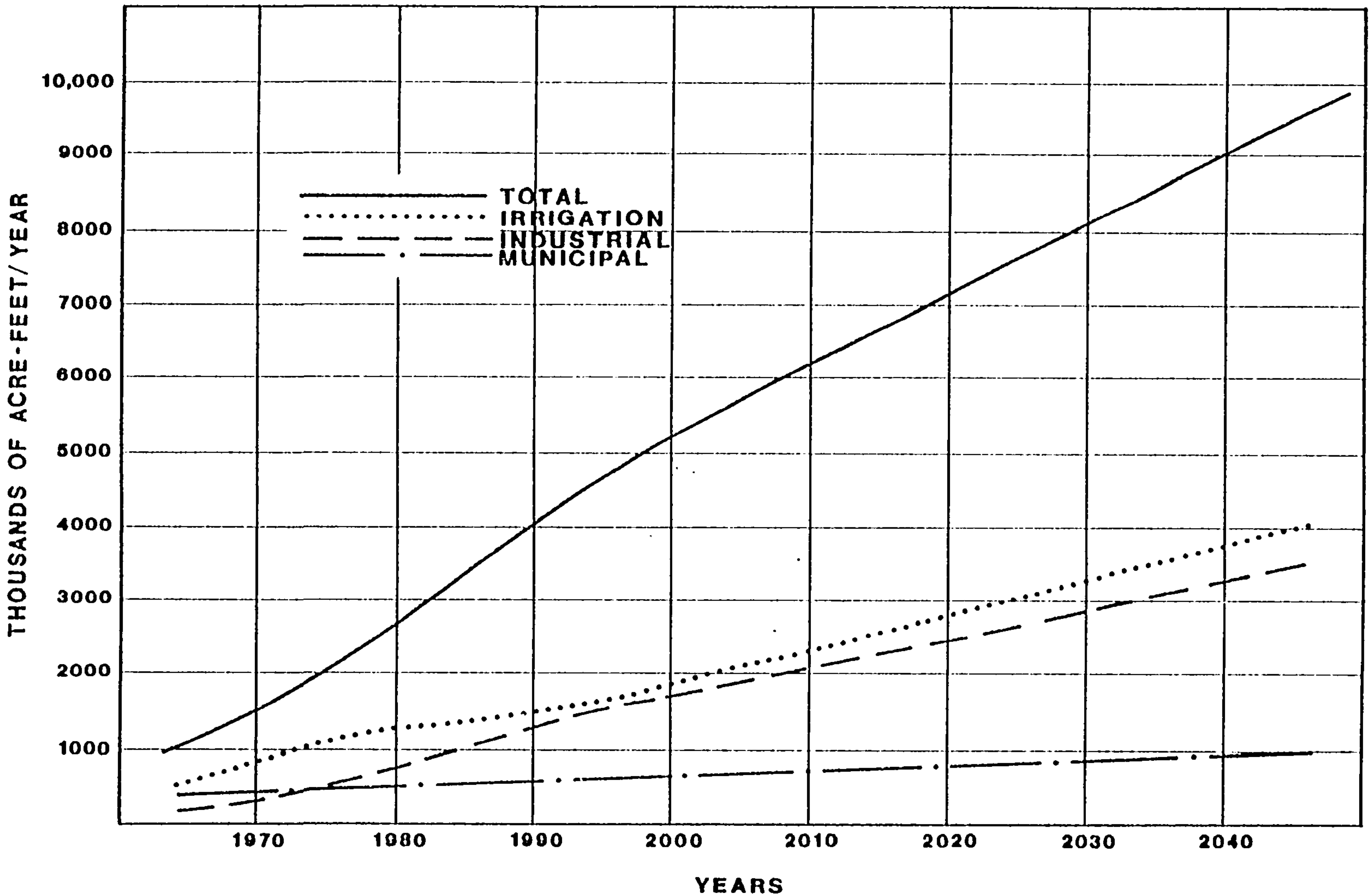

FIGURE 22: OKLAHOMA TOTAL WATER REQUIREMENTS PROJECTIONS

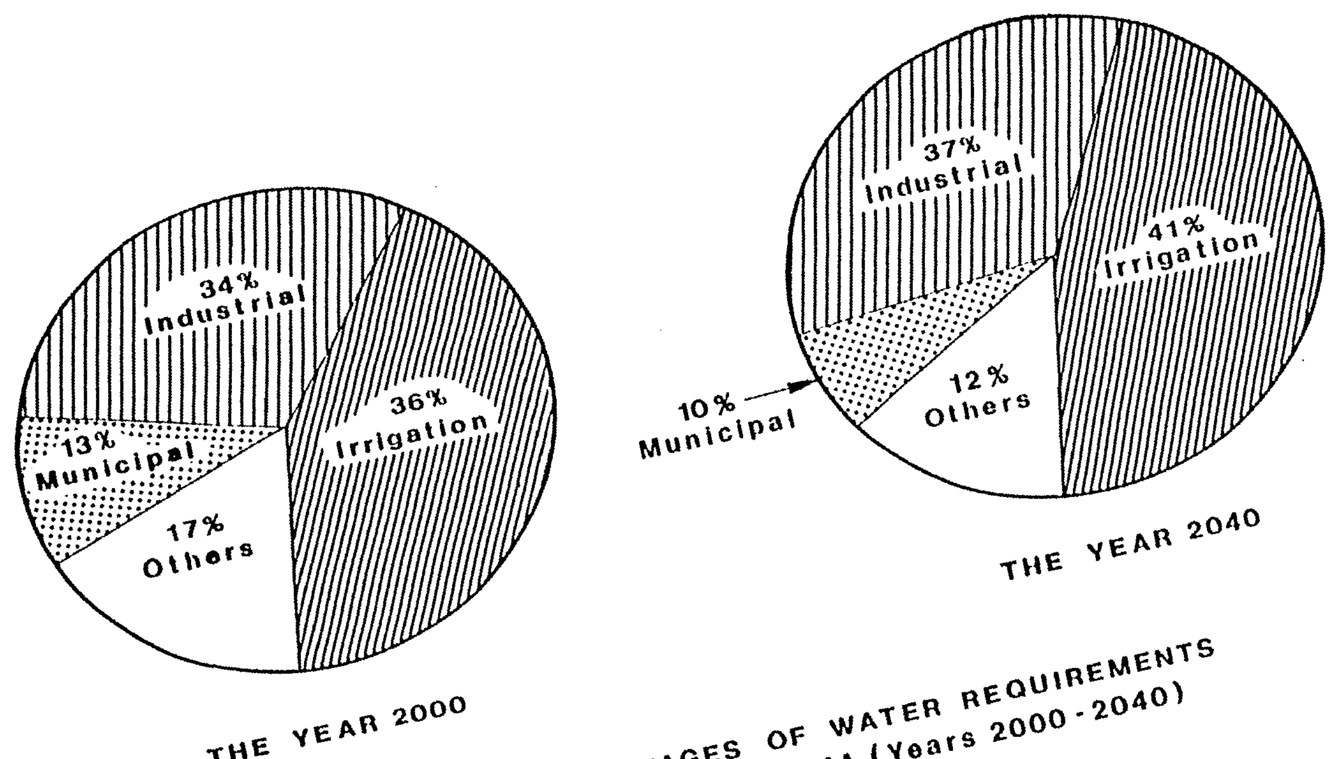

FIGURE 23 : PERCENTAGES OF WATER REQUIREMENTS PROJECTIONS IN OKLAHOMA (Years 2000 - 2040)

Table 18

Ratios of Water Requirements in Oklahoma

Ratio	1980	1990	2000	2010	2020	2030	2040
Ind./Mun.*	1.61	2.16	2.57	2.90	3.17	3.41	3.61
Irr./Mun.*	2.37	2.58	2.76	3.22	3.62	3.84	4.04

* Mun. = Municipal and domestic water requirements.
Ind. = Industrial water requirements.
Irr. = Irrigation water requirements.

Records of the Oklahoma Water Resources Board (8) show that the total water supply storage of facilities constructed and under construction is approximately 3690.3 thousand acre-feet. This storage provides a yield of 1979.8 thousand acre-feet per year (1768 MGD). The seven major lakes authorized for construction will add an additional 1710.0 thousand acre-feet of conservation storage and provide a yield of 963.8 thousand acre-feet per year (861 MGD). This indicates that the estimated present and potential water resource development from surface water is approximately 2943.6 thousand acre-feet per year (2629 MGD).

Ground water is one of the State's most valuable resources. It supplies 48 percent of the water used in Oklahoma and more than 80 percent of present irrigation water is provided from ground water reservoirs. More than 300 towns and cities obtain their water supply from wells and springs. Eighty percent of all ground water used in the State is in western Oklahoma.

Oklahoma has approximately 308,930 thousand acre-feet stored in its ground basins. Of this amount of storage, it is estimated that only 40 percent or about 123,572 thousand acre-feet, is recoverable. There is no doubt that more hydrogeologic data than is currently available is highly required to assess precisely how much ground water is available to the State.

From the previous discussion, and considering the present and potential water resource development from both surface water and ground water resources, it is obvicus that Oklahoma has sufficient water within its boundaries to supply all present and future needs. This will be explained more specifically in the next part of this chapter.

Statewide Water Supply and Demand

The major objective of this section of the study is to show that the problem of water in Oklahoma is not one of quantity rather than the distribution of the water to various sectors of the economy in all parts of the State.

Oklahoma State is divided into eight planning regions. These regions are illustrated in Figure 24. The projections of municipal and domestic, industrial and irrigation water requirements of counties are aggregated to each planning region level. These projections are tabulated in Table 19.

The Oklahoma Water Resources Board has estimated the water resource development potential for each planning region in the State for the year 2030 (67). This development potential includes ground water supply, multipurpose sites and farm ponds, major reservoirs which are existing or currently under construction and federal projects authorized for construction. These development potential estimates for the year 2030 are compared with total municipal and domestic, industrial, and irrigation water requirements projected in this study for the year 2030 in order to determine the surplus or the deficit of water for each planning region. This is summarized in Table 19.

The total water resource development for the Southwest twelve region is estimated at 639 thousand acre-feet for the year 2030. The total water requirements for this region are expected to increase from 545.1 thousand acre-feet in 1980 to 1596.2 thousand acre-feet by 2040.

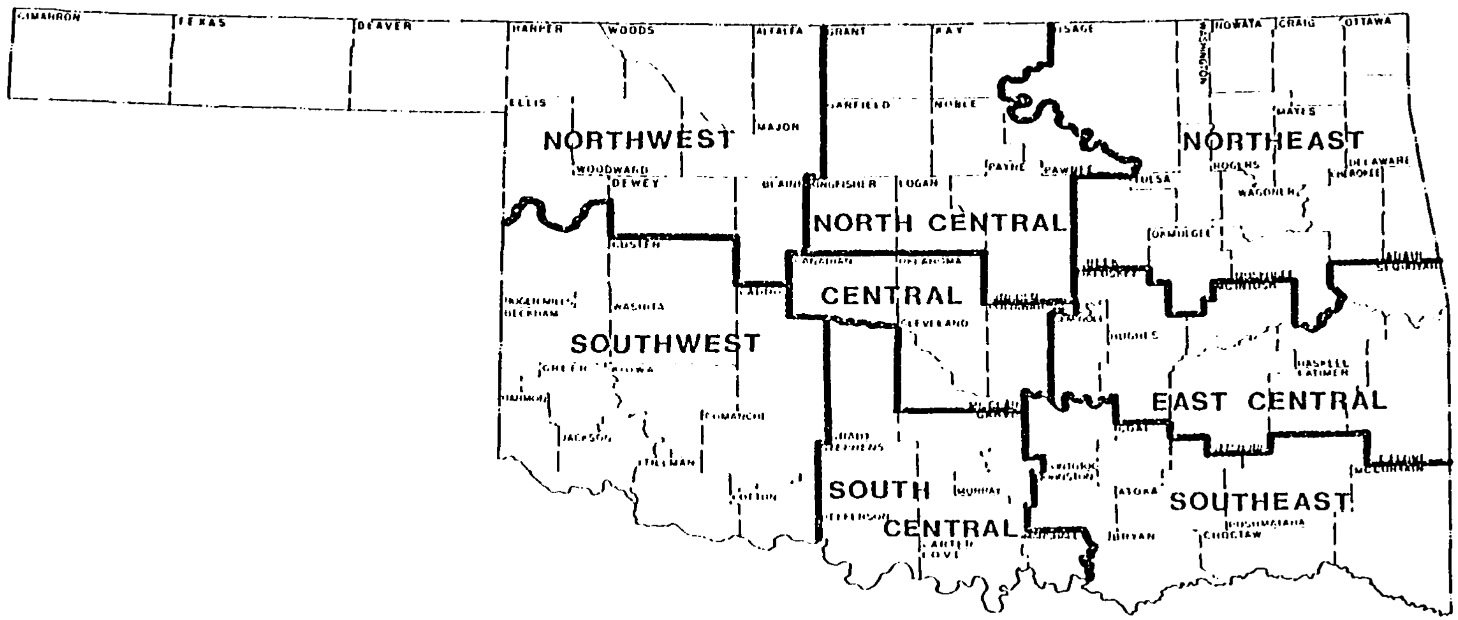

FIGURE 24: OKLAHOMA COMPREHENSIVE WATER PLAN PLANNING REGIONS

Source: See Ref. 67

Based on 2030 water requirements projections and development potential, the Southwest twelve region is expected to suffer from a deficit of 784 thousand acre-feet.

Similarly, the total 2030 water resource development potential for the South Central eight region is estimated at 232.2 thousand acre-feet with projected total water requirements equal 430.7 thousand acre-feet. This indicates a deficit of 198.5 thousand acre-feet for that region.

The picture is completely different in the Southeast eight region where a surplus of water is expected. The total water requirements are determined to increase from 114.9 thousand acre-feet in 1980 to 365.7 thousand acre-feet by 2040. The total 2030 water resource development potential for this region is estimated at 3331.4 thousand acre-feet and the water requirements at 325.6 thousand acre-feet. This implies a surplus of 3005.8 thousand acre-feet in the Southeast eight region.

The Central five region is one of the State's planning regions that will have a great lack of water sources. This region will need 901.9 thousand acre-feet in the year 2030 while the total water resource development potential is estimated at 289.5 thousand acre-feet. This region will suffer from 612.4 thousand acre-feet deficit of water if not supplied from other sources and locations within the State.

The Northwest eleven region will have the same problem of lack of water sources. The deficit of water in this region by the year 2030 is expected to be 1017.2 thousand acre-feet, which is the highest deficit among all the State's regions. The irrigation water requirements in this region represent about 62 percent of the State's. Projections of irrigation water requirements in this region show that the growth will be sharply increasing from 748.3 thousand acre-feet in 1980 to 2140.9 thousand acre-feet by the year 2040.

The total water resource development potential for the North Central nine region for the year 2030 is estimated at 573.1 thousand acre-feet with total water requirements equal 475.6 thousand acre-feet. This region will have a surplus of water equals 97.5 thousand acre-feet.

Similarly, the Northeast fifteen region is estimated to have total water resource development potential for the year 2030 equals 2251.8 thousand acre-feet. By 2030, the total water requirements projections indicate that this region will need 1283.34 thousand acre-feet. Thus, the surplus of water in the Northeast fifteen region is estimated at 968.46 thousand acre-feet.

Finally, the East Central nine region is another planning region that will have a tremendous amount of surplus water. The total water resource development potential is estimated at 2432.5 thousand acre-feet for the year 2030. Out of this amount, a total of 169.07 thousand acre-feet will be required to satisfy municipal and domestic, industrial and irrigation water needs for the same year. In other words, the East Central nine region is expected to have a surplus of water equals 2263.427 thousand acre-feet by the year 2030.

In short, the Southwest twelve region, the South Central eight region, the Central five region and the Northwest eleven region are the State's planning regions that are expected to suffer from a lack of water sources. On the other hand, the State's planning regions expected to have surplus water are the Southeast eight region, the North Central nine region, the Northeast fifteen region and the East Central nine region.

The previous discussion must imply the fact that the distribution of water resources throughout the State is not ideal. Most of the State's water resources are located in Eastern Oklahoma, while Western Oklahoma suffers from a lack of water sources.

On the statewide level, Oklahoma has and will maintain sufficient water within its boundaries to supply present needs and the future sharp increase in water demands. Consulting with Table 19, the total water resource development potential for the State is estimated at 10795.5 thousand acre-feet (9642 MGD) for the year 2030. This is more than enough to satisfy a total projected water requirements for the State of approximately 8163 thousand acre-feet for 2030 (7290.8 MGD).

Table 19

State Water Supply and Demand

(In Thousands of Acre-Feet/Year)

Region	Use	1980	1990	2000	2010	2020	2030	2040	Potential Development*	Surplus**	Deficit**
Southwest 12	Municipal	57.8	64.9	71.9	78.2	84.7	91.1	97.2			
	Industrial	108.2	163.2	215.4	264.4	313.2	361.2	409			
	Irrigation	379.1	465.3	550.6	701	851.1	970.7	1090			
	Total	545.1	693.4	837.9	1043.6	1249	1423	1596.2	639.0		784
South Central 8	Municipal	32.3	36.2	40.1	43.7	47.3	50.8	54.3			
	Industrial	78.7	118.8	156.3	192.2	227.6	262.8	297			
	Irrigation	45.8	56	66.3	84.4	102.6	117.1	131.2			
	Total	156.8	211	262.7	320.3	377.5	430.7	482.5	232.2		198.5
Southeast 8	Municiapl	24.4	27.4	30.1	33.2	35.8	38.5	41.1			
	Industrial	70.6	106.6	140.7	172.6	204.4	235.9	267.1			
	Irrigation	19.9	24.7	29	37	45	51.2	57.5			
	Total	114.9	158.7	199.8	242.8	285.2	325.6	365.7	3331.4	3005.8	
Central 5	Municipal	157.7	177.3	196.1	213.7	231.1	248.2	264.9			
	Industrial	173.2	261.4	345	423.1	501.6	578.5	655			
	Irrigation	29.4	36.2	42.5	54.3	65.9	75.2	84.5			
	Total	360.3	474.9	583.6	691.1	798.6	901.9	1004.4	289.5		612.4

Table 19 - Continued

Region	Use	1980	1990	2000	2010	2020	2030	2040	Potential Development*	Surplus**	Deficit**
Northwest 11	Municipal	19.5	21.8	24.2	26.4	28.6	30.5	32.6			
	Industrial	35.1	52.8	69.7	85.6	101.5	117.2	132.5			
	Irrigation	748.3	918.6	1086.4	1383.1	1679.4	1915.5	2140.9			
	Total	802.9	993.2	1180.3	1495.1	1809.5	2063.2	2306	1046.0		1017.2
North Central 9	Municipal	48.9	55.5	61.5	66.9	72.5	77.8	83.1			
	Industrial	105.7	159.1	210	257.8	305.5	352.4	398.8			
	Irrigation	17.6	21.8	25.6	32.7	39.7	45.4	50.8			
	Total	172.2	236.4	297.1	357.4	417.7	475.6	532.7	573.1	97.5	
Northeast 15	Municipal	169.5	190.5	210.7	230	248.6	267	285.2			
	Industrial	280.9	424.1	559.8	686.5	813.3	938.3	1063.5			
	Irrigation	30.59	37.42	44.24	56.48	68.52	78.04	87.46			
	Total	480.99	652.02	814.74	972.98	1130.42	1283.34	1436.16	2251.8	968.46	
East Cental 9	Municipal	33.7	37.8	41.7	45.4	49.5	53	56.7			
	Industrial	22.2	33.6	44.6	54.6	64.7	74.7	84.8			
	Irrigation	16.225	19.936	23.537	30.149	36.261	41.373	46.674			
	Total	72.125	91.336	109.837	130.149	150.461	169.073	188.174	2432.5	2263.427	

Table 19 - Continued

Region	Use	1980	1990	2000	2010	2020	2030	2040	Potential Development*	Surplus**	Deficit**
STATE	Municipal	544	612	677	738	798	857	915			
	Industrial	875	1320	1742	2137	2532	2921	3307			
	Irrigation	1287	1580	1869	2379	2889	3295	3700			
	Others	54	497	879	965	1014	1090	1085			
	Total	2760	4009	5167	6219	7233	8163	9007	10795.5	2632.5	

* Water resource development potential for the year 2030 by the (OWRB). See Reference 67.
** Based on 2030 projections.

CHAPTER VI

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Introduction

Oklahoma is experiencing tremendous growth and expansion. Population growth, industrial development, agricultural irrigation expansion, gross-state product growth, urbanization, technological development as well as many other economic, environmental and cultural patterns will make the State face the problem of ever increasing in water demands. The State must be concerned with the development and allocation of an adequate water supply system to satisfy the future water requirements. It is like providing a foundation for continued growth. Oklahomans are looking forward to a bright future with adequate supplies of water. But there is no doubt that the solution to Oklahoma's water problems begins with the knowledge of how much water will be needed and the time it will be required, quite independent of current, or foreseeable availability of potential needs, and then future forecasts must be considered in the light of available or potential water.

Summary

The immediate objective of this study is to develop mathamatical water needs models for the State of Oklahoma in order to predict municipal, industrial, irrigation needs; per capita municipal and domestic water usage rates; and total water requirements by utilizing socio-economic, environmental and climatological indicators. Another objective of this study is to break down the statewide forecasts of water requirements to county level, selected cities and the State's planning regions level by different categories of water use.

This process starts with identifying the role of water in development and the objectives of the assessment of future water demands. Problems associated with water resources in Oklahoma are discussed to clarify the needs for adequate planning and the importance of determining future water needs by different categories of water use in the State. Then a comprehensive literature review of water demand models are presented and used to decide on the models parameters to be used. A stepwise multiple regression analysis was selected as the basic technique to be used to develop the required water needs models for Oklahoma. A special review of regression analysis is provided presenting several statistical indices and tests to assist in the validation of regression models.

Historical data on water use as well as socio-economic and environmental indicators on a statewide level from the year 1966 to the year 1976 were used to develop the municipal and domestic water demand model, the industrial water demand model, the irrigation water demand model and the total water demand model for the State. Data on per capita usage rates and socio-economic indicators by the State's level from the year 1920 to the year 1970 were used to develop the State's per capita municipal and domestic water usage rate model.

Data analysis and the technique used indicate that the State's municipal and domestic water demand model is a function of total population, non-agricultural employment, gross-state product and precipitation. The State's industrial water demand model is formulated by total population, non-agricultural employment, coal production and precipitation. The input variables for the State's irrigation model are per capita income, irrigated acres, land in farms and precipitation. The State's total water demand model is a function of total population and total employment. Finally, the significant explanatory variables in the State's per capita municipal and domestic water usage rate model are total population and per capita income. All the coefficients of multiple determination (R^2) are over 0.90 and all the independent variables in each demand equation pass the sequential F-test at both 5% and 1% significance levels.

The five mathematical water demand models developed in this study and the forecasts of all the significant explanatory variables, available or developed, are then used to project the future water needs for Oklahoma by different categories of water use. The State's water requirements projections are disaggregated from the State's level to counties and selected cities level based on the assumption that each county or city will maintain its relative proportion of water use compared to the State's. The counties water requirements projections are then aggregated to obtain water requirements for each state planning region in Oklahoma. A comparison of the projected water requirements for each planning region with the estimates of total water resource development, provided by the Oklahoma Water Resources Board, is accomplished in order to identify regions with water surplus or shortages in future years.

The validity of the developed models is confirmed by two approaches. First, each predictive equation is evaluated from the statistical point of view. Secondly, the water requirements projections using the developed models are compared with other earlier studies projections to test the reasonableness of the results.

Conclusions

Based on the analysis of data and the water demand models developed in this study, the following conclusions can be drawn:

(1). All the models developed in this study are valid from the statistical point of view with their satisfactory values of R^2 and the results of the sequential F-test at both 5% and 1% significance levels. The water requirements projections of this study are tested against other earlier studies projections developed by the Oklahoma Water Resources Board (OWRB), the Bureau of Water and Environmental Resources Research (BWERR), and the Center for Economic and Management Research (CEMR) at Oklahoma University and they indicate very reasonable results. For example, the State's per capita municipal and domestic water usage rate is estimated by the BWERR (36) at 150 gpcd for the year 1976 given an actual value of 84 gpcd in 1950, that is, an annual rate of increase equals 2.54 gpcd from 1950 to 1976. In the same study, the per capita usage rate is estimated at 156 gpcd for the year 1980 and 190 gpcd for the year 2000. Based on the model developed in this study, the per capita usage rate is expected to reach 153 gpcd by the year 1980 and 199 gpcd by the year 2020. The annual rate of increase of the per capita usage rate is estimated at 2.23 gpcd from 1980 to the year 2040. In a study by the OWRB (68), the State's municipal and domestic water requirements are estimated at 563.7 thousand acre-feet for the year 2000 and 788.3 thousand acre-feet for the year 2020. Based on the model developed in this study, the State is expected to need an amount of 677 thousand acre-feet by 2000 and 798 thousand acre-feet for the year 2020 for municipal and domestic water use. Another example of the reasonableness of the results of this study is the State's irrigation water requirements. The OWRB (67) has estimated that Oklahoma will need an amount of 2372.7 thousand acre-feet for the year 2000 and 3867 thousand acre-feet by the year 2030 for irrigation use. The projections of this study show that the State's irrigation water requirements will reach approximately a value of 1869 thousand acre-feet in the year 2000 and 3295 thousand acre-feet by the year 2030 given a reported water use for irrigation in 1976 equals 927.8 thousand acre-feet. The reported industrial water use of Oklahoma was 588.92 thousand acre-feet for the year 1975. By the year 1980 and based on the model developed in this study, Oklahoma is expected to need an amount of 875 thousand acre-feet. Records of the OWRB show that from 1930 to 1975, the annual rate of increase was 6.15 MGD for municipal and domestic water use, 11.12 MGD for industrial water use and 15.35 MGD for irrigation water use. Based on the projections of this study, the State is expected to experience the essential same annual rates of increase mentioned above for municipal, industrial and irrigation water uses from the year 1980 to the year

2040. These previous examples should indicate the validation of the water demand models developed in this study.

(2). In general, the models developed in this study are considered to be more refined than the earlier studies models. However, it is possible that additional socio-economic and cultural variables can be introduced to the developed predictive models. The mathematical models validity can also be confirmed by annual inventory updating. Marked changes in annual inventory from year to year would suggest exploring the need for adjusting the technical coefficients.

(3). The State's municipal and domestic water requirements are expected to reach 605 MGD by the year 2000 and 817 MGD by the year 2040. The State's per capita municipal and domestic water usage rate is estimated at 153 gpcd by 1980, 199 gpcd by 2000 and 287 gpcd by the year 2040. This indicates a rate of increase in the per capita rate equals 2.23 gpcd per year form 1980 to 2040.

(4). The municipal and domestic water requirements for Oklahoma City are estimated at 83.03 MGD by 2000 and 112.13 MGD by 2040. Tulsa City will need 73.66 MGD by 2000 and 99.47 MGD by the year 2040 for the same purpose of water use. Ardmore, Enid, Lawton, Midwest City, Muskogee, Norman, Oklahoma City, Stillwater and Tulsa will represent the largest municipal and domestic water usage cities in Oklahoma.

(5). Oklahoma, Tulsa, Comanche and Cleveland counties, in order, are expected to have the largest municipal and domestic water requirements in the State.

(6). The State's industrial water requirements expansion is expected to be impressive. Based on the results of this study, the total industrial water requirements are estimated at 1556 MGD by 2000 and 2954 MGD by 2040.

(7). Tulsa, Oklahoma, Comanche and Garfield counties, in order, are expected to dominate the industrial water requirements growth in the State.

(8). The State's irrigated acres and irrigation water requirements are expected to be sharply increasing in future years. By the year 2000, the total number of irrigated acres in the State is estimated at 1155.60 thousand acres while the State will require an amount of 1669 MGD for irrigation water use. The projected water requirements for irrigation by the year 2040 are 3305 MGD with total number of irrigated acres estimated at 2249.91 thousand acres.

(9). Texas, Cimarron, Caddo and Jackson counties, in order, are expected to represent the largest irrigation water usage counties in Oklahoma.

(10). The State's total water requirements are expected to continue to increase. The projections of this study show that Oklahoma will need an amount of approximately 4615 MGD by the year 2000 and 8045 MGD by the year 2040 in order to satisfy total water requirements. That includes water used in municipal and domestic, industrial, irrigation, recreation and wildlife, secondary oil recovery and other municipal and industrial water uses. It should be mentioned here that the total water requirements or the water requirements projections for each category of water use represent the aggregate needs (withdrawals) of the State without considering multiple use of water or serious water conservation alternatives.

(11). The total water resource development potential for the State is estimated by the Oklahoma Water Resources Board at 9642 MGD while the projected total water requirements are expected to be 7291 MGD by the year 2030. We must conclude that Oklahoma has sufficient water within its boundaries to supply future water needs. Even with the projected total water requirements for the year 2040 and the estimated total water resource development for the year 2030, the State will not face the problem of water shortages. Also, we should keep in mind that there is enbeded, roughly, a factor of safety of 3.00 due to multiple and re-used levels of water.

(12). Based on the projections of this study, the ratio of industrial water use to municipal and domestic water use is expected to increase from 1.61 in the year 1980 to 3.61 in the year 2040. The ratio of irrigation water use to municipal and domestic water use is estimated at 2.37 for the year 1980 and expected to reach a value of 4.04 by the year 2040. On the nation-wide level, the ratios of industrial to municipal and irrigation to municipal water use are approximately the same of a value equals 10/1. This indicates that Oklahoma is and will remain under the national level in this prospective.

(13). The problem of water in Oklahoma is due to the fact that the distribution of present and potential water resources throughout the State is not ideal. Most of the State's water resources are concentrated in Eastern Oklahoma, while Western Oklahoma suffers from a lack of water sources. The irrigated agricultural economy that has developed in Western Oklahoma is rapidly depleting the ground water resources and additional sources will be required to avoid the economic consequences of returning to dryland farming. Based on the analysis provided in this study, the Southeast eight region, the North Central nine region, the Northeast fifteen region, and the East Central nine region are expected to have tremendous present and potential water resources that will far exceed any foreseeable demands that could develop in the next 50 years. On the other hand, the Southwest twelve region, the South Central eight region, the Central five region and the Northwest eleven region are expected to face water shortages.

(14). There are two major problems associated with data limitations in this study. The first problem is the exclusion of cost of water in the demand models developed although it seems to be a very important input variable specially in irrigation and industrial demand models, but the State's planners are more concerned with water needs than demands. The second problem area associated with data limitations in this study is the industrial water use data. Data on industrial water use in Oklahoma is not classified by each category of water use, such as cooling, boiler water, processing and other uses. Therefore, the industrial water requirements for Oklahoma are not broken down by each category of industrial water use or by each industry in each category. However, this classification of the projected industrial water use can be achieved by taking ratios of each category to the State's total industrial water use whenever data on industrial water use will be more comprehensive.

(15). From the sensitivity analysis on the precipitation input variable, excluding this variable from the State's municipal and domestic water demand model will reduce R^2 value by 0.0003 and increase the municipal and domestic water requirements projections by an amount of 2.19 thousand acre-feet per year. Excluding precipitation from the industrial water demand model will reduce R^2 by 0.0007 and the industrial water requirements projections by approximately 21.35 thousand acre-feet per year. In the case of the State's irrigation demand model, the exclusion of precipitation will lower the R^2 value by 0.0036 and increase the projected irrigation water requirements by a value of 31.54 thousand acre-feet per year.

(16). The disaggregation of the State's municipal and domestic, industrial and irrigation water requirements from the State to counties level is accomplished based on the assumption that each county will maintain its relative proportion of water use compared to the State's. If this assumption does not hold in the future, based on annual inventory by county level for example, another methodology should be considered. The similarity analysis is a good approach to be adopted. Simply, the State should be divided into groups of counties of similar socio-economic characteristics. A water demand model for each category of water use for each group of counties should be developed.

(17). Because of the extremely rapid growth of new capital investment in Oklahoma, it is probably impossible to make a reliable forecast of the status of the industrial development in the State five years from now, to say nothing of 10 to 15 years from now. For example, the nuclear power plant to be built at Inola, Oklahoma in Rogers County will affect the future water requirements of Oklahoma. This can be expressed indirectly by the models developed in this study. Building the plant will affect employment in Oklahoma, which is a significant factor in the State's municipal, industrial and total water demand models, and will have some impact on the gross-state product, which is an input variable in the State's municipal model. Moreover, this plant is located in the Northeast fifteen planning region which is expected to have surplus water equals 968.46 thousand acre-feet by the year 2030 as estimated in this study. Also, an assessment of water requirements for this industrial project can be made and added to the projected water requirements for Rogers County. Similarly, the same procedure can be followed for other significant industrial expansion at any location in the State.

Recommendations

(1). Since shortages of water exist in the Western half of the State due to the availability of stream water or restriction of water use, and since there is an over abundant stream water in the Eastern half of the State, the planning alternative of transmission of surplus water from the Eastern to the Western parts of the State is very important to be considered if it will be economically feasible.

(2). Sound planning procedures must be followed and applied on a statewide basis and a well-defined implementation schedule must be developed to insure adequate water for all areas of the State for many years.

(3). More hydrogeologic data than is currently available is required to know precisely how much ground water is available. Computer models, based on historical water level data basins, are needed to accurately predict useful life and depletion rates.

(4). In planning to hold the water passing through the State, care should be always given to the proper type of storage reservoirs. Surface reservoirs are an attractive means of capturing water. Under normal conditions, about 35 million acre-feet of water pass through Oklahoma. Records of the Oklahoma Water Resources Board indicate that in 1965, 2 percent of this amount was used while the remainder passed on to Arkansas, Louisiana, Texas and to the Gulf of Mexico. Not all of the remaining was potable, but about a third of it was fit for human consumption, another third was usable for agricultural and industrial purposes, and the remainder was totally unusable. The estimated storage capacity of upstream retention reservoirs was estimated by the Soil Conservation Service in 1965 at 808 thousand acre-feet. With the total water requirements projected in this study for Oklahoma, and considering only stream water source, approximately 15 percent of the 35 million acre-feet will be used in the year 2000, which is 5167 thousand acre-feet. The water storage of upstream retention reservoirs is estimated by the Soil Conservation Service, without including water from ground water and river flow or other agency large multiple-purpose reservoirs, at approximately 4098 thousand acre-feet. Therefore, the problem of water in Oklahoma is not one of quantity rather the retention of required amounts from the total that becomes available in a normal year.

(5). Continuous compact agreements with our neighboring states to allocate waters and control pollution become increasingly important as our need of water for beneficial use increases.

(6). The available water resource may be augmented by such methods as modification of weather to include increased precipitation. Other methods of water resource augmentation include desalination of salt water, watershed management, eradication of preatophytes (deep-rooted plants which draw water from the water table or the soil just above it and which transpire large quantities of water), increased water re-use or sequential use, suppression of evaporation and more efficient utilization of water within irrigated agriculture.

(7). The State's water resource departments should be developing research capacity concerning prospective technologies that affect demand and supply of water. Such development which will decrease the future demand for water are electrical power generation by use of wind and water, recirculation cooling pond development, industrial cooling systems using air, subirrigation and unsaturated leaching strategy and other. Technical developments that should increase usable supplies of fresh water are long canal systems to carry water from regions within the State of surplus and conservation of existing sources. Examples of conservation methods are evaporation reduction from lakes and reservoirs, run-off water control using rock tunnels and galleries, ground water storage and management and many other methods. So, a mathematical model, of supply and demand is needed to be developed and used to test new uses (reactive) and suggest structural and non-structural changes (proactive). That is, it would react to proposed activities, such as a Nuclear Reactor on the Arkansas River, or a major transfer of water from Eastern Oklahoma to Western Oklahoma, or policy decision as to the definition of available water or recall of permits, right, etc. In short, the model would be a tool that could provide, in coarse (planning level) detail but with increasing precision, as more information is added. The water quantity and quality responses, as well as, economic and conservation concerns, and external interfaces, such as interstate compacts, would be the greatest sources of questions.

(8). The lack and scarcity of basic social, economic, physical and technological data should not be allowed to jeopardize the survey for future water demands. The delineation of programs to improve the data base should beccome a high-priority objective of a survey for future demands.

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Appendix A

Linear Regression Analysis Review

Linear Regression Analysis

As mentioned before in Chapter III, linear regression analysis is a statistical tool used to explain a relationship between one or more independent variables and a dependent variable in a linear mathematical equation. If one independent variable is used, it is known as simple regression analysis. On the other hand, if more than one independent variable is used, it is known as multiple regression analysis, such as:

$$Y = A + \beta_1 X_1 + \beta_2 X_2 + \ldots\ldots + \beta_i X_i \quad \ldots\ldots\ldots\ldots \quad (1)$$

where:

A = constant (or intercept),

β_i = regression parameters to be estimated,

X_i = independent or explanatory variables which are known,

Y = dependent variable to be predicted.

i = number of independent variables.

The technique used to develop any regression model is called "The Least Squares Solution." In order to describe this technique and for the purpose of simplicity, let us consider the case of a simple linear regression model which can be expressed as follows:

$$Y_i = A + \beta X_i + e_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

A and β are the population parameters to be estimated. Y_i are random dependent variables which are normally distributed. X_i are called the independent variables which are fixed, that is, determined outside the model and are assumed to be independent from each other. The error terms e_i are assumed to be random variables, normally distributed with a mean value equals zero, and a constant variance. Y_i are also assumed to have a constant variance. The error terms e_i are assumed to independent from each other as well as from the independent variables X_i.

Estimates for A and β are determined by the least squares solution and can be denoted as a and b, respectively. The estimated line is given as:

$$\hat{Y}_i = a + b\, X_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

According to the least squares method, the sum of squares of the error terms e_i are minimized, that is:

$$S = \sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} (Y_i - A - \beta X_i)^2 \quad \ldots\ldots\ldots\ldots (4)$$

In order to find the minimum value of the sum of squares of e_i we shall take the partial derivatives of S with respect to each coefficient in equation (4) and set them equal to zero, that is:

$$\frac{\partial S}{\partial A} = -2 \sum_{i=1}^{n} (Y_i - A\ \beta X_i) = o \quad \ldots\ldots\ldots\ldots (5)$$

and

$$\frac{\partial S}{\partial \beta} = -2 \sum_{i=1}^{n} X_i\ (Y_i - A - \beta X_i) = o \quad \ldots\ldots\ldots\ldots (6)$$

The estimators a and b may be obtained by solving the above two equations (5 and 6) to get:

$$b = \frac{\Sigma\ (X_i\ Y_i\ -\ n\ \overline{Y}\ \overline{X})}{\Sigma\ (X_i^2\ -\ n\overline{X}^2)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

and

$$a = \overline{Y} - b\ \overline{X} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

where:

b = the regression estimator for the true population parameter β,

a = the regression constant estimator for the true population parameter A,

X_i = the observations of the independent variable,

Y_i = the observations of the dependent variable,

n = number of observations where i ranges from 1 to n,

$\overline{Y}$ = arithmetic mean value of the dependent variable,

$\overline{X}$ = arithmetic mean value of the independent variable.

Using equations (3) and (8) we may obtain:

$$\hat{Y}_i = \overline{Y} + b\ (X_i\ -\ \overline{X}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

The Statistical t-test

The statistical t-test can be defined as a test which checks whether the independent variables are significant ones in the model. In other words, it tests the following two alternatives:

$$A_1: \ \beta_i = o$$
$$\qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$
$$A_2: \ \beta_i \neq o$$

We compare the computed t-value (t_o) for a specific independent variable being tested with the critical or tabulated t-value (t_c) obtained from statistical t-tables given a degree of freedom and a significance level (99% or 95%). Suppose that the predicted line is given as:

$$\hat{Y} = b_o + b_1 X_1 + b_2 X_2 + \ldots\ldots + b_i X_i \ldots\ldots\ldots (11)$$

where b_i are the estimators for true population parameters β_1 using X_i independent variables to estimate the dependent variable by $\hat{Y}$. The observed t-value is given by the following equation:

$$t_o = \frac{b_i}{V(b_i)^{\frac{1}{2}}} = \frac{b_i}{S_{bi}} \ldots\ldots\ldots\ldots\ldots\ldots (12)$$

where S_{bi} is the standard error of the estimator b_i. Using the 2-tailed statistical t-test and given the degree of freedom equals n-k, where n is the number of observations and k is the number of parameters in the model, we obtain the critical t-value (t_c) from the table. If t_o exceeds the value of t_c, we have to reject the hypothesis A_1: $\beta_i \neq o$, that is, the regression coefficient whose estimator has being tested is found to be significantly different from zero. This indicates that the specific independent variable whose estimator coefficient passes the t-test is a significant factor in the regression model.

The Analysis of Variance (ANOVA)

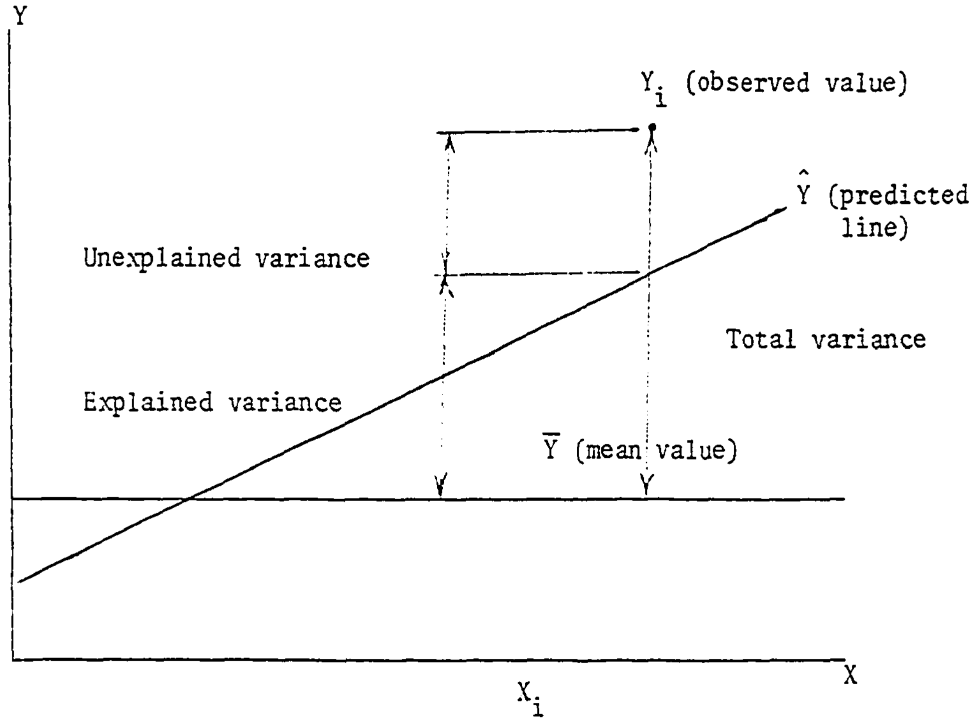

Table A-1

ANOVA Table

Source of variance	S.S	D.F	Variance
(1). Explained variance by regression model	$SSR=\Sigma\ (\hat{Y}_i-\bar{Y})^2$	K-1	$MSR=\Sigma\ (\hat{Y}_i-\bar{Y})^2/K-1$
(2). Unexplained variance	$SSE=\Sigma\ (Y_i-\hat{Y}_i)^2$	n-K	$MSE=\Sigma\ (Y_i-Y_i)^2/n-k$
Total variance	$SSTO=\Sigma\ (Y_i - \bar{Y})^2$	n-1	$\Sigma\ (Y_i-\bar{Y})^2/n-1$

where:

(1). Explained variance which occurs due to introducing X_i to the model and is explained by the regression model.

(2). Unexplained variance which happens by chance.

(3). Total variance is the sum of explained and unexplained variances.

To illustrate the procedure of analysis of variance (the sequential F-test), suppose we have three independent variables in the predicted equation which is given as:

$$Y = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (13)$$

Suppose our objective is to check the significance of introducing X_1 to our model, because it has the highest simple correlation coefficient with the dependent variable, while leaving X_2 and X_3 outside the model. We calculate F-value as follows:

$$F_o = \frac{\text{Explained variance due to } X_1}{\text{Unexplained variance due to } X_1}$$

$$= \frac{\Sigma\ (\hat{Y}_i - \bar{Y})^2/K-1}{\Sigma\ (Y_i - \hat{Y}_i)^2/n-K} = \frac{MSR}{MSE} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (14)$$

where:

K = number of parameters considered (it is equal to 2 in our example),

n = number of observations,

MSR = mean squares of regression = $\frac{SSR}{K-1}$,

SSR = sum of squares of regression,

MSE = mean squares of error term = $\frac{SSE}{n-K}$,

SSTO = total sum of squares.

and

$$SSTO = SSR + SSE \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (15)$$

By using the desired significance level and a degree of freedom equals K-1/n-K, we obtain the F-tabulated (F_c) from standard tables. Again, and as explained in the t-test, we compare F_o with F_c, and reject or accept one of the following alternatives:

$$\begin{array}{l} A_1: \ \beta_1 = \beta_2 = \ldots\ldots = \beta_i = o \\ A_2: \ \beta_1 \neq \beta_2 \neq \ldots\ldots = \beta_i \neq o \end{array} \quad \ldots\ldots\ldots\ldots \quad (16)$$

If we reject A_1 (means accept A_2), that means not all the coefficients equal zero. If we reject A_2 (means accept A_1), that means all the coefficients equal zero.

The over-all F-test or the sequential F-test is to determine how much variation of Y_i can be explained by introducing several new independent variables to the regression model.

It must be noted here that in the case of simple F-test, the same conclusion of testing hypothesis must follow from both t and F-test since we have:

$$F = t^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (17)$$

at any significance level.

The Coefficient of Multiple Determination

The coefficient of multiple determination, denoted by R^2, is defined as follows:

$$R^2 = \frac{\text{Explained variation of } Y}{\text{Total variation of } Y} = \frac{\Sigma\ (\hat{Y}_i - \overline{Y})^2}{\Sigma\ (Y_i - \overline{Y})^2} = \frac{SSR}{SSTO} \quad \ldots\ldots (18)$$

or

$$R^2 = 1 - \frac{SSE}{SSTO} \quad \ldots\ldots (19)$$

The major objective of computing R^2 is to measure the proportionate reduction of total variation in Y associated with the use of the set of X variables. We have:

$$o \leqq R^2 \leqq 1 \quad \ldots\ldots (20)$$

R^2 equals the value o when all the regression coefficients equal o, and it takes on the value 1 when all observations fall directly on the fitted response surface, that is, when $Y_i = \hat{Y}_i$ for all i.

A very important point about R^2 is that a large value of R^2 does not necessarily mean that the fitted model is a useful one. The large value of R^2 might occur because some observations may have been taken at only a few levels of the independent variables. Another important point is that adding more independent variables to the model can only increase the value of R^2 and never reduce it. Since SSE can never become larger with more independent variables, it is sometimes recommended that a modified or adjusted coefficient of multiple determination, denoted by R_a^2, to be used to evaluate the regression model, R_a^2 is defined as follows:

$$R_a^2 = 1 - \left(\frac{n - 1}{n - K}\right) \frac{SSE}{SSTO} \quad \ldots\ldots (21)$$

This adjusted coefficient of multiple determination may actually become smaller with introducing another independent variable to the model.

Appendix B

Tables of Original Data Set Used

Table B-1

Total Population of Oklahoma

(In Thousands)

Year	Population	Year	Population
1950	2229	1964	2446
1951	2210	1965	2440
1952	2219	1966	2454
1953	2182	1967	2489
1954	2209	1968	2503
1955	2250	1969	2535
1956	2273	1970	2559
1957	2283	1971	2600
1958	2267	1972	2633
1959	2289	1973	2669
1960	2336	1974	2681
1961	2380	1975	2715
1962	2427	1976	2766
1963	2439	1977	2811*

*An estimate by the research and planning division at the Oklahoma Employment Security Commission.

<u>Source</u>: See References 52, 53, 54, 55 and 56.

Table B-2

Nominal Per-Capita Personal Income
of Oklahoma

(In Current Dollars)

Year	Per Capita Income	Year	Per Capita Income
1950	1143	1964	2156
1951	1284	1965	2340
1952	1391	1966	2525
1953	1467	1967	2712
1954	1445	1968	2920
1955	1507	1969	3126
1956	1580	1970	3387
1957	1641	1971	3551
1958	1776	1972	3834
1959	1828	1973	4336
1960	1876	1974	4823
1961	1930	1975	5259
1962	1949	1976	5707*
1963	2022		

*An estimate by the research and planning division at the Oklahoma Employment Security Commission.

Source: See References 52, 53, 54, 55 and 56.

Table B--3
Annual Average Employment of Oklahoma
(In Thousands)

Year	Mining	Contract Construction	Manufacturing	Transportation & Public Facilities	Wholesale and Retail Trade	Finance, Insurance & Real Estate	Services	Government	Wages & Salaries	Total Non-Farm	Total Employment
1939	37.5	12.8	42.4	31.2	80.7	11.1	47.8	62.7	326.2	NA	NA
40	38.0	11.2	45.4	31.1	82.1	11.7	49.1	63.8	332.4	NA	NA
41	40.8	16.6	51.4	33.8	86.1	12.2	51.4	65.7	358.0	NA	NA
42	37.7	47.0	64.2	36.4	84.1	12.2	53.6	76.2	411.4	NA	NA
43	35.9	31.6	99.7	39.6	87.0	11.9	55.8	85.5	447.0	NA	NA
44	36.4	10.9	102.1	40.2	86.6	11.4	56.0	92.2	435.8	NA	NA
45	36.6	9.8	89.2	40.8	88.4	11.6	54.6	93.0	424.0	NA	NA
46	36.8	19.1	57.6	43.6	101.1	13.3	56.4	84.1	412.0	NA	NA
47	40.3	23.3	62.4	45.8	108.3	16.0	58.2	82.9	437.3	NA	NA
48	43.1	26.8	66.5	49.4	116.7	17.10	57.3	85.9	462.7	NA	NA
49	42.6	29.6	64.1	49.2	119.0	17.20	54.6	89.7	466.0	NA	NA
1950	43.1	31.2	65.6	49.4	123.1	18.6	54.1	91.7	476.9	NA	810.2
51	45.2	32.1	73.2	49.9	125.1	19.2	57.5	102.1	504.3	NA	843.6
52	46.8	32.5	80.2	50.9	127.0	19.5	60.7	109.0	526.6	NA	851.0
53	48.2	31.4	85.0	51.0	126.3	20.1	61.5	111.8	535.3	NA	873.7
54	50.0	29.1	83.0	49.2	124.2	20.9	61.7	113.2	531.3	NA	867.7
55	52.0	30.9	88.5	50.4	126.2	22.3	63.8	116.8	550.9	NA	888.6
56	52.9	29.9	92.6	50.6	128.5	23.0	66.3	119.6	563.4	NA	901.4
57	51.8	30.7	90.0	50.1	127.8	23.4	66.8	123.9	564.5	NA	899.0
58	48.5	31.7	85.1	48.0	128.0	23.9	65.8	126.1	557.1	667.2	846.2
59	47.7	34.8	87.0	47.8	132.8	25.0	70.4	127.7	573.2	695.6	861.0
1960	45.1	34.4	86.6	48.1	137.4	26.4	72.8	130.8	581.6	704.2	859.7
61	45.0	33.7	86.5	47.2	137.8	27.4	75.9	133.2	586.7	709.2	865.2
62	43.9	34.7	90.4	46.9	139.7	28.6	79.9	137.4	601.5	722.8	870.9
63	42.3	36.7	90.9	46.2	141.2	29.5	83.3	141.4	611.5	730.3	873.8
64	42.2	35.5	96.6	45.9	143.6	30.5	86.4	143.6	624.3	743.2	872.6
65	42.4	35.5	103.0	46.5	148.1	31.3	88.2	152.9	647.9	767.0	890.8
66	42.1	34.5	113.3	47.8	153.2	32.5	92.3	166.5	682.1	800.2	922.4
67	41.0	32.5	116.4	49.5	157.2	33.8	99.5	176.4	706.3	823.2	944.1
68	40.9	34.6	121.7	51.5	159.8	34.3	104.2	180.2	727.2	843.1	963.0
69	40.7	36.7	129.9	52.8	165.0	35.8	110.3	184.0	755.2	870.5	989.2
1970	38.9	37.4	133.9	52.4	168.7	37.0	115.9	185.3	769.5	884.5	1005.0
71	36.7	38.8	131.3	52.5	175.2	38.4	119.2	187.7	779.8	893.4	1058.0
72	36.1	44.1	141.1	53.3	186.6	40.1	125.7	184.9	811.9		1076.0
73	36.5	47.4	151.9	55.2	196.6	42.3	129.8	192.2	851.9		1067.0
74	39.9	49.5	156.7	57.6	204.5	44.2	135.5	199.0	886.9		1076.0
75	43.6	45.9	150.7	56.6	208.5	44.8	143.4	206.3	899.7		1073.0
1976	44.4	46.1	156.1	57.3	222.2	46.6	151.4	207.0	931.1		1093.0
1977	48.9	49.4	162.8	59.3	231.9	48.9	159.4	214.5	975.0		1098.6

Source: See References 55, 56, 57, 58, 59 and 60.

Table B-4

Gross State - Product of Oklahoma

(In Millions of Current Dollars)

Year	Gross State-Product	Year	Gross State-Product
1950	2749.5	1964	5865.04
1951	3162.6	1965	6277.70
1952	3459.0	1966	6781.44
1953	3637.3	1967	7319.35
1954	3699.89	1968	7670.23
1955	3952.39	1969	8259.82
1956	4224.67	1970	9094.81
1957	4344.28	1971	9778.79
1958	4582.60	1972	10964.70
1959	4788.74	1973	11923.04
1960	5006.61	1974	13071.40
1961	5200.88	1975	15087.39
1962	5418.97	1976	16729.07
1963	5674.09		

Source: See References 55 and 61.

Table B-5

Mean Annual Precipitation And
Mean Annual Temperature Of
Oklahoma

Year	Temperature (F°)	Precipitation (Inches)
1950	59.9	35.45
1951	60.2	32.86
1952	61.7	23.98
1953	62.4	31.68
1954	63.7	23.12
1955	61.4	29.54
1956	62.7	21.28
1957	60.2	43.26
1958	59.8	33.27
1959	60.0	40.26
1960	59.4	36.52
1961	59.3	38.03
1962	60.8	32.87
1963	61.9	21.70
1964	61.1	33.14
1965	61.4	30.18
1966	59.7	25.36
1967	60.6	32.61
1968	59.2	39.81
1969	60.2	33.89
1970	60.3	29.27
1971	60.5	34.37
1972	60.2	29.78
1973	59.9	49.17
1974	60.5	39.42
1975	59.6	36.03
1976	59.5	27.01

Source: See References 55 and 62.

Table B-6

Per Capita Municipal and Domestic Water

Usage Rate of Oklahoma

Year	gpcd	Year	gpcd
1950	84	1964	125
1951	86	1965	127
1952	90	1966	129
1953	93	1967	131
1954	97	1968	133
1955	100	1969	136
1956	102	1970	138
1957	105	1971	140
1958	108	1972	142
1959	110	1973	144
1960	112	1974	146
1961	116	1975	148
1962	119	1976	150
1963	121		

Source: See Reference 36.

Table B - 7

Per Capita Municipal and Domestic

Water Use Model Data

Year	Per Capita Rate [a] (gpcd)	Total Population [b] (1000's)	Per Capita Income [b] (Current Dollars)
1920	84	2028.3	830
1930	84	2396.0	429
1940	84	2336.4	423
1950	84	2233.4	1143
1960	110	2328.3	1876
1970	116*	2559.5	3386

*An estimate

Source: [a] See Reference 6.

[b] See Reference 55.

Table B-8

Mineral Production of Oklahoma

Year	Crude Oil (Millions of Barrels)	Natural Gas (Billions of Cu. Ft.)	Bitumonous Coal (1000's of Short Tons)
1950	164.599	482.360	2679
1951	186.869	538.756	2223
1952	190.435	554.033	2193
1953	202.570	599.955	2168
1954	185.851	616.355	1915
1955	202.817	614.976	2164
1956	215.862	678.603	2007
1957	214.661	719.794	2195
1958	200.699	696.504	1629
1959	198.090	811.508	1525
1960	192.283	824.266	1342
1961	193.081	892.697	1032
1962	202.732	1060.717	1048
1963	201.962	1233.883	1008
1964	202.524	1316.201	1028
1965	203.441	1320.995	974
1966	224.839	1351.225	843
1967	230.749	1412.952	823
1968	223.623	1390.884	1089
1969	224.429	1523.715	1838
1970	223.574	1594.943	2427
1971	213.313	1684.260	2234
1972	207.633	1806.887	2624
1973	191.204	1770.980	2183
1974	177.785	1785.682	2356
1975	163.123	1605.410	2872
1976	150.627	1710.586	2900

Source: See References 55 and 63.

Table B-9

Value Added by Mineral and
Manufactural Production of Oklahoma

(In Millions of Dollars)

Year	Mineral [a]	Manufactural [b]
1950	527.095	344.0
1951	607.486	433.7
1952	621.351	493.4
1953	679.003	553.8
1954	650.205	580.6
1955	7110.44	643.7
1956	757.080	754.5
1957	809.004	744.2
1958	761.936	725.0
1959	765.439	772.9
1960	779.116	801.0
1961	791.777	811.3
1962	855.290	825.9
1963	877.534	978.8
1964	881.270	1032.4
1965	909.256	1101.1
1966	997.391	1241.9
1967	1032.126	1346.2
1968	1016.832	1477.6
1969	1090.809	1595.4
1970	1138.272	1766.3
1971	1189.516	1834.4
1972	1210.798	2270.1
1973	1324.269	2599.3
1974	2122.690	3108.2
1975	2267.095	3451.2
1976	2670.323	3696.7

Source: [a] See References 63 and 55.

[b] See References 64 and 55.

Table B-10

Electrical Energy Sales of
Oklahoma

(In Millions of Kilowatt Hours)

Year	Residential	Commercial	Industrial
1966	4441	2587	3983
1967	4653	2737	4224
1968	5360	3031	4460
1969	6397	3362	4688
1970	7293	3646	4888
1971	7776	3924	5243
1972	9200	4500	6000
1973	9700	4700	6400
1974	10200	4900	6900
1975	11400	5400	6900
1976	12173*	5713*	7244*

*Estimated by the stratight line approach model.

Source: See References 55, 64 and 65.

Table B-11

Acres Irrigated, Number of Farms,

Land in Farms & Average Size of

Farms in Oklahoma

Year	Number of Farms [a] (1000's)	Land in Farms [a] (1000's Acres)	Average Size [a] of Farm (Acres)	Acres Irrigated [b] (1000's)
1959	107	37500	350	--
1960	103	37400	363	--
1961	101	37400	370	--
1962	99	37400	378	--
1963	97	37400	386	--
1964	96	37300	389	--
1965	95	37300	393	--
1966	94	37300	397	427.847
1967	93	37300	401	508.220
1968	91	37300	409	509.744
1969	90	37300	413	504.425
1970	90	37100	412	541.428
1971	90	37100	417	571.345
1972	89	37000	420	574.994
1973	88	37000	425	523.938
1974	87	36900	424	550.571
1975	87	36600	423	531.273
1976	86	36800	426	580.05

Source: a/ See Reference 66.

b/ See Reference 46.

Table B-12

Livestock on Farms and Ranches in Oklahoma

(In Thousands)

Year	All Cattles and Calves (Jan. 1)	All Sheep and Lambs (Jan. 7)	All Hogs (Dec. 1)	Total
1966	4396	160	278	4834
1967	4308	148	256	4812
1968	4480	139	374	4493
1969	4659	136	348	5143
1970	4985	138	442	5565
1971	5085	122	470	5677
1972	5441	123	352	5916
1973	5660	120	315	6095
1974	6020	104	310	6434
1975	6500	89	300	6889
1976	6400	79	320	6799

Source: See References 55 and 66.

Table B-13

Cash Receipts from Fram Marketing
and Number of Workers on Farms
in Oklahoma

Year	Cash Receipts (Millions of Dollars)	Number of Workers (1000's)
1950	561.1	255
1951	624.5	247
1952	679.1	236
1953	556.0	231
1954	535.9	207
1955	482.7	198
1956	501.3	183
1957	437.7	166
1958	612.5	169
1959	620.2	165
1960	706.1	156
1961	683.2	156
1962	656.6	148
1963	659.4	144
1964	618.1	129
1965	778.2	120
1966	842.8	120
1967	795.3	129
1968	796.4	125
1969	950.2	124
1970	1105.5	126
1971	1087.00	124
1972	1395.0	125
1973	2197.2	120
1974	1896.41	118
1975	1881.3	105
1976	1912.00	104

Source: See References 55 and 66.

Appendix C

Tables of Municipal and Domestic, Industrial and Irrigation Water Requirements Projections for Counties

Table C - 1

Municipal and Domestic Water Requirements

Projections for Counties

(In Thousands of Acre-Feet/Year)

County	1970	1980	1990	2000	2010	2020	2030	2040
Adair	1.4	2.5	2.8	3.1	3.4	3.7	3.9	4.2
Alfalfa	0.8	1.4	1.6	1.8	1.9	2.1	2.2	2.4
Atoka	1.1	2.0	2.2	2.4	2.7	2.9	3.1	3.3
Beaver	0.6	1.1	1.2	1.3	1.5	1.6	1.7	1.8
Beckham	1.9	3.4	3.8	4.2	4.6	5.0	5.3	5.7
Blaine	1.3	2.3	2.6	2.9	3.1	3.4	3.7	4.0
Bryan	2.8	5.0	5.6	6.2	6.8	7.3	7.9	8.4
Caddo	3.2	5.7	6.4	7.1	7.7	8.4	9.0	9.6
Canadian	3.9	7.0	7.8	8.7	9.4	10.2	11.0	11.7
Carter	4.3	7.7	8.6	9.5	10.4	11.2	12.1	12.9
Cherokee	2.3	4.1	4.6	5.1	5.6	6.0	6.5	6.9
Choctaw	1.7	3.0	3.4	3.8	4.1	4.4	4.8	5.1
Cimarron	0.4	0.7	0.8	0.9	1.0	1.0	1.1	1.2
Cleveland *	10.2	18.2	20.5	22.6	24.7	26.7	28.6	30.6
Coal	0.5	0.9	1.0	1.1	1.2	1.3	1.4	1.5
Comanche *	13.7	24.4	27.5	30.4	33.1	35.8	38.5	41.1
Cotton	0.7	1.2	1.4	1.6	1.7	1.8	2.0	2.1
Craig	1.5	2.7	3.0	3.3	3.6	3.9	4.2	4.5
Creek *	5.3	9.4	10.6	11.8	12.8	13.9	14.9	15.9
Custer	2.7	4.8	5.4	6.0	6.5	7.0	7.6	8.1
Delaware	1.7	3.0	3.4	3.8	4.1	4.4	4.8	5.1
Dewey	0.5	0.9	1.0	1.1	1.2	1.3	1.4	1.5

Table C-1- Continued

County	1970	1980	1990	2000	2010	2020	2030	2040
Ellis	0.6	1.1	1.2	1.3	1.5	1.6	1.7	1.8
Garfield *	6.8	12.1	13.6	15.1	16.4	17.8	19.1	20.4
Garvin	2.8	5.0	5.6	6.2	6.7	7.3	7.9	8.4
Grady	3.4	6.1	6.8	7.5	8.2	8.9	9.5	10.2
Grant	0.7	1.2	1.4	1.6	1.7	1.8	2.0	2.1
Greer	1.0	1.8	2.0	2.2	2.4	2.6	2.8	3.0
Harmon	0.6	1.1	1.2	1.3	1.4	1.6	1.7	1.8
Harper	0.6	1.1	1.2	1.4	1.5	1.6	1.7	1.8
Haskell	0.9	1.6	1.8	2.0	2.1	2.4	2.5	2.7
Hughes	1.5	2.7	3.0	3.3	3.6	3.9	4.2	4.5
Jackson	3.9	6.9	7.8	8.7	9.4	10.2	11.0	11.7
Jefferson	0.8	1.4	1.6	1.8	1.9	2.1	2.2	2.4
Johnston	0.7	1.2	1.4	1.5	1.7	1.8	2.0	2.1
Kay *	6.0	10.7	12.1	13.3	14.5	15.7	16.8	18.0
Kingfisher	1.4	2.5	2.8	3.1	3.4	3.7	3.9	4.2
Kiowa	1.4	2.5	2.8	3.1	3.4	3.7	3.9	4.2
Latimer	0.9	1.6	1.8	2.0	2.1	2.4	2.5	2.7
LeFlore	3.4	6.1	6.8	7.5	8.2	8.9	9.5	10.2
Lincoln	2.0	3.6	4.0	4.4	4.8	5.2	5.6	6.0
Logan	2.2	3.9	4.4	4.9	5.3	5.8	6.2	6.6
Love	0.6	1.1	1.2	1.3	1.5	1.6	1.7	1.8
McClain	1.5	2.7	3.0	3.3	3.6	3.9	4.2	4.5
McCurtain	2.9	5.2	5.8	6.2	7.0	7.6	8.1	8.7
McIntosh	1.3	2.3	2.6	2.9	3.1	3.4	3.7	3.9

Table C-1- Continued

County	1970	1980	1990	2000	2010	2020	2030	2040
Major	0.8	1.4	1.6	1.8	1.9	2.1	2.2	2.4
Marshall	0.8	1.4	1.6	1.8	1.9	2.1	2.2	2.4
Mayes	2.5	4.5	5.0	5.5	6.0	6.5	7.0	7.5
Murray	1.2	2.1	2.4	2.7	2.9	3.1	3.4	3.6
Muskogee *	6.9	12.3	13.8	15.3	16.7	18.0	19.4	20.7
Noble	1.1	2.0	2.2	2.4	2.7	2.9	3.1	3.3
Nowata	1.0	1.8	2.0	2.2	2.4	2.6	2.8	3.0
Okfuskee	1.2	2.1	2.4	2.7	2.9	3.1	3.4	3.6
Oklahoma *	67.7	120.7	135.8	150.2	163.7	177.0	190.1	202.9
Okmulgee	4.1	7.3	8.2	9.1	9.9	10.7	11.5	12.3
Osage	3.1	5.5	6.2	6.9	7.5	8.1	8.7	9.3
Ottawa	3.5	6.2	7.0	7.8	8.5	9.1	9.8	10.5
Pawnee	1.3	2.3	2.6	2.9	3.1	3.4	3.7	3.9
Payne *	6.2	11.1	12.4	13.8	15.0	16.2	17.4	18.6
Pittsburg	4.4	7.8	8.8	9.8	10.6	11.5	12.4	13.2
Pontotoc	3.1	5.5	6.2	6.9	7.5	8.1	8.7	9.3
Pottawatomie *	5.1	9.1	10.2	11.3	12.3	13.3	14.3	15.2
Pushmataha	0.9	1.6	1.8	2.0	2.2	2.4	2.5	2.7
Roger Mills	0.4	0.7	0.8	0.9	1.0	1.0	1.1	1.2
Rogers	2.9	5.2	5.8	6.2	7.0	7.6	8.1	8.7
Seminole	2.9	5.2	5.8	6.2	7.0	7.6	8.1	8.7
Sequoyah	2.4	4.3	4.8	5.3	5.8	6.3	6.7	7.2
Stephens	4.2	7.5	8.4	9.3	10.2	11.0	11.8	12.6

Table C-1 - Continued

County	1970	1980	1990	2000	2010	2020	2030	2040
Texas	1.9	3.4	3.8	4.2	4.6	5.0	5.3	5.6
Tillman	1.6	2.9	3.2	3.5	3.9	4.2	4.5	4.8
Tulsa *	50.6	90.2	101.5	112.2	122.4	132.3	142.1	151.7
Wagoner	3.1	5.5	6.2	6.9	7.5	8.1	8.7	9.3
Washington *	5.2	9.3	10.4	11.5	12.6	13.6	14.6	15.6
Washita	1.3	2.3	2.6	2.9	3.1	3.4	3.7	3.9
Woods	1.5	2.7	3.0	3.3	3.6	3.9	4.2	4.5
Woodward	1.9	3.4	3.8	4.2	4.6	5.0	5.3	5.6
STATE	305.2	544	612	677	738	798	857	915

* An indication for the largest eleven municipal and domestic water usage counties in Oklahoma.

Table C-2

Industrial Water Requirements
Projections for Counties

(In Thousands of Acre-Feet/Year)

County	1970	1980	1990	2000	2010	2020	2030	2040
Adair	2.4	5.4	8.1	10.7	13.1	15.5	17.9	20.3
Alfalfa	1.4	3.1	4.7	6.2	7.6	9.1	10.5	11.8
Atoka	0.8	1.8	2.7	3.6	4.4	5.2	6.0	6.8
Beaver	0.7	1.6	2.4	3.1	3.8	4.5	5.2	5.9
Beckham	3.3	7.4	11.1	14.7	18.0	21.4	24.6	27.9
Blaine	1.2	2.7	4.0	5.3	6.5	7.8	9.0	10.1
Bryan	6.0	13.4	20.2	26.7	32.8	38.8	44.8	50.7
Caddo	3.8	8.5	12.8	16.9	20.8	24.6	28.4	32.1
Canadian	1.2	2.7	4.0	5.3	6.5	7.8	9.0	10.1
Carter*	12.2	27.3	41.2	54.3	66.6	78.9	91.1	103.1
Cherokee	1.1	2.5	3.7	4.9	6.0	7.1	8.2	9.3
Choctaw	3.9	8.7	13.2	17.4	21.3	25.2	29.1	33.0
Cimarron	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
Cleveland	3.7	8.2	12.5	16.5	20.2	23.9	27.6	31.3
Coal	2.0	4.5	6.7	8.9	10.9	12.9	14.9	16.9
Comanche *	17.3	38.7	58.3	77.0	94.5	111.9	129.1	146.2
Cotton	1.1	2.5	3.7	4.9	6.0	7.1	8.2	9.3
Craig	0.2	0.4	0.7	0.9	1.1	1.3	1.5	1.7
Creek	5.6	12.5	18.9	24.9	30.6	36.2	41.8	47.3
Custer	6.7	15.0	22.6	29.8	36.6	43.4	50.0	56.6
Delaware	0.3	0.7	1.0	1.3	1.6	1.9	2.2	2.5
Dewey	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8

Table C-2- Continued

County	1970	1980	1990	2000	2010	2020	2030	2040
Ellis	0.4	0.9	1.3	1.8	2.2	2.6	3.0	3.4
Garfield *	13.8	30.9	46.6	61.4	75.4	89.3	103.0	116.6
Garvin	5.8	13.0	19.6	25.8	31.7	37.5	43.3	49.0
Grady	9.4	21.0	31.7	41.8	51.3	60.8	70.2	79.4
Grant	1.2	2.7	4.0	5.3	6.6	7.8	9.0	10.1
Greer	2.1	4.7	7.1	9.3	11.5	13.6	15.7	17.7
Harmon	0.7	1.6	2.4	3.1	3.8	4.5	5.2	5.9
Harper	0.7	1.6	2.4	3.1	3.8	4.5	5.2	5.9
Haskell	0.6	1.3	2.0	2.7	3.2	3.9	4.5	5.1
Hughes	0.2	0.4	0.7	0.9	1.1	1.3	1.5	1.7
Jackson	7.8	17.4	26.3	34.7	42.6	50.5	58.2	65.9
Jefferson	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
Johnston	1.5	3.3	5.1	6.7	8.2	9.7	11.2	12.7
Kay	9.5	21.2	32.0	42.3	51.9	61.5	70.9	80.3
Kingfisher	3.6	8.1	12.1	16.0	19.7	23.3	26.9	30.4
Kiowa	1.9	4.2	6.4	8.5	10.4	12.3	14.2	16.1
Latimer	1.3	2.9	4.4	5.8	7.1	8.4	9.7	11.0
LeFlore	0.9	2.0	3.0	4.0	4.9	5.8	6.7	7.6
Lincoln	2.4	5.4	8.1	10.7	13.1	15.5	17.9	20.3
Logan	2.8	6.3	9.4	12.5	15.3	18.1	20.9	23.7
Love	0.9	2.0	3.0	4.0	4.9	5.8	6.7	7.6
McClain	0.6	1.3	2.0	2.7	3.2	3.9	4.5	5.1
McCurtain	4.6	10.3	15.5	20.5	25.1	29.8	34.3	38.9
McIntosh	0.2	0.4	0.7	0.9	1.1	1.3	1.5	1.7

Table C-2-Continued

County	1970	1980	1990	2000	2010	2020	2030	2040
Major	1.0	2.2	3.4	4.5	5.5	6.5	7.5	8.5
Marshall	1.0	2.2	3.4	4.5	5.5	6.5	7.5	8.5
Mayes	9.5	21.2	32.0	42.3	51.9	61.5	70.9	80.3
Murray	1.3	2.9	4.4	5.8	7.1	8.4	9.7	11.0
Muskogee	11.1	24.8	37.4	49.4	60.6	71.8	82.9	93.8
Noble	1.6	3.6	5.4	7.1	8.7	10.4	11.9	13.5
Nowata	1.0	2.2	3.4	4.5	5.5	6.5	7.5	8.5
Okfuskee	0.4	0.9	1.3	1.8	2.2	2.6	3.0	3.4
Oklahoma *	68.9	154.1	232.4	306.7	376.3	445.8	514.3	582.3
Okmulgee	5.4	12.1	18.2	24.0	29.5	34.9	40.3	45.6
Osage	2.6	5.8	8.8	11.6	14.2	16.8	19.4	22.0
Ottawa	1.9	4.2	6.4	8.5	10.4	12.3	14.2	16.1
Pawnee	1.4	3.1	4.7	6.2	7.6	9.1	10.5	11.8
Payne *	10.9	24.4	36.8	48.5	59.5	70.5	81.4	92.1
Pittsburg	1.7	3.8	5.7	7.6	9.3	11.0	12.7	14.6
Pontotoc *	10.5	23.5	35.4	46.7	57.3	67.9	78.4	88.7
Pottawatomie	3.1	6.9	10.5	13.8	16.9	20.1	23.1	26.2
Pushmataha	2.3	5.1	7.8	10.2	12.6	14.9	17.2	19.4
Roger Mills	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
Rogers	1.0	2.2	3.4	4.5	5.5	6.5	7.5	8.5
Seminole	2.5	5.6	8.4	11.1	13.7	16.2	18.7	21.1
Sequoyah	2.2	4.9	7.4	9.8	12.0	14.2	16.4	18.6
Stephens	4.5	10.1	15.2	20.0	24.6	29.1	33.6	38.0

Table C-2- Continued

County	1970	1980	1990	2000	2010	2020	2030	2040
Texas	5.2	11.6	17.5	23.1	28.4	33.6	38.8	43.9
Tillman	2.6	5.8	8.8	11.6	14.2	16.8	19.4	22.0
Tulsa *	76.8	171.7	259.1	342.0	419.4	497.0	573.3	649.1
Wagoner	0.7	1.6	2.4	3.1	3.8	4.5	5.2	6.9
Washington	6.1	13.6	20.6	27.2	33.3	39.5	45.5	51.6
Washita	1.0	2.2	3.4	4.5	5.5	6.5	7.5	8.5
Woods	2.4	5.4	8.1	10.7	13.1	15.5	17.9	20.3
Woodward	2.5	5.6	8.4	11.1	13.7	16.2	18.7	21.1
STATE	391.3	875	1320	1742	2137	2532	2921	3307

* An indication for the largest seven industrial water usage counties in Oklahoma.

Table C- 3

Irrigation Water Requirements

Projections for Counties

(In Thousands of Acre-Feet/Year)

County	1970	1980	1990	2000	2010	2020	2030	2040
Adair	1.842	3.1	3.8	4.4	5.7	6.9	7.8	8.8
Alfalfa	3.359	5.6	6.9	8.1	10.3	12.5	14.3	16.1
Atoka	0.688	1.1	1.4	1.7	2.1	2.6	2.9	3.3
Beaver *	42.457	70.6	86.7	102.5	130.5	158.5	180.7	203
Beckham	6.206	10.4	12.7	15.0	19.1	23.2	26.4	29.7
Blaine	3.038	5.1	6.2	7.3	9.3	11.3	12.9	14.5
Bryan	6.7	11.1	13.7	16.2	20.6	25.0	28.5	32.0
Caddo *	68.992	114.7	140.8	166.6	212.1	257.5	293.7	329.8
Canadian	5.434	9.0	11.1	13.1	16.7	20.3	23.1	26.0
Carter	2.997	5.0	6.1	7.2	9.2	11.2	12.8	14.3
Cherokee	4.872	8.1	9.9	11.8	15.0	18.2	20.7	23.3
Choctaw	1.301	2.2	2.7	3.1	4.0	4.9	5.5	6.2
Cimarron *	95.244	158.4	194.4	230.0	292.7	355.5	405.5	445.3
Cleveland	1.842	3.1	3.8	4.4	5.7	6.9	7.8	8.8
Coal	0.133	0.2	0.3	0.3	0.4	0.5	0.6	0.6
Comanche	2.957	4.9	6.0	7.1	9.1	11.0	12.6	14.1
Cotton	5.735	9.5	11.7	13.8	17.6	21.4	24.4	27.4
Craig	0.100	0.2	0.2	0.2	0.3	0.4	0.4	0.5
Creek	0.097	0.2	0.2	0.2	0.3	0.4	0.4	0.5
Custer	8.491	14.1	17.3	20.5	26.1	31.7	36.1	40.6
Delaware	0.207	0.3	0.4	0.5	0.6	0.8	0.9	1.0
Dewey	2.747	4.6	5.6	6.6	8.4	10.3	11.7	13.1

Table C-3- Continued

County	1970	1980	1990	2000	2010	2020	2030	2040
Ellis	5.81	9.7	11.9	14.0	17.9	21.7	24.7	27.8
Garfield	0.675	1.1	1.4	1.6	2.1	2.5	2.9	3.2
Garvin	9.569	15.9	19.5	23.1	29.4	35.7	40.7	45.7
Grady	8.695	14.4	17.6	20.9	26.6	32.3	36.8	41.3
Grant	0.694	1.2	1.4	1.7	2.1	2.6	3.0	3.3
Greer	9.881	16.4	20.2	23.9	30.4	36.9	42.1	47.2
Harmon *	23.244	38.6	47.4	56.1	71.4	86.8	99.0	111.1
Harper	8.711	14.5	17.8	21.0	26.8	32.5	37.1	41.6
Haskell	0.003	0.005	0.006	0.007	0.009	0.011	0.013	0.014
Hughes	4.54	7.5	9.3	11.0	14.0	16.9	19.3	21.7
Jackson *	57.105	95.0	116.6	137.9	175.5	213.1	243.1	273
Jefferson	0.579	1.0	1.2	1.4	1.8	2.2	2.5	2.8
Johnston	1.097	1.8	2.2	2.6	3.4	4.1	4.7	5.2
Kay	1.087	1.8	2.2	2.6	3.3	4.1	4.6	5.2
Kingfisher	5.304	8.8	10.8	12.8	16.3	19.8	22.6	25.4
Kiowa	6.954	11.6	14.2	16.8	21.4	26.0	29.6	33.2
Latimer	0.058	0.1	0.1	0.1	0.2	0.2	0.2	0.3
LeFlore	2.068	3.4	4.2	5.0	6.4	7.7	8.8	9.9
Lincoln	0.426	0.7	0.9	1.0	1.3	1.6	1.8	2.0
Logan	1.516	2.5	3.1	3.7	4.7	5.7	6.5	7.2
Love	2.224	3.7	4.5	5.4	6.8	8.3	9.5	10.6
McClain	4.064	6.8	8.3	9.8	12.5	15.1	17.3	19.4
McCurtain	1.132	1.9	2.3	2.7	3.5	4.2	4.8	5.4
McIntosh	0.013	0.02	0.03	0.03	0.04	0.05	0.06	0.06

Table C-3- Continued

County	1970	1980	1990	2000	2010	2020	2030	2040
Major*	14.19	23.6	28.9	34.3	43.8	52.9	60.4	67.8
Marshall	0.301	0.5	0.6	0.7	0.9	1.1	1.3	1.4
Mayes	0.065	0.1	0.1	0.2	0.2	0.2	0.3	0.3
Murray	1.801	3.0	3.7	4.3	5.5	6.7	7.7	8.6
Muskogee	1.522	2.5	3.1	3.7	4.7	5.7	6.5	7.2
Noble	0.09	0.1	0.2	0.2	0.3	0.3	0.4	0.4
Nowata	0.026	0.04	0.05	0.06	0.08	0.1	0.1	0.1
Okfuskee	0.575	1.0	1.2	1.4	1.8	2.1	2.4	2.7
Oklahoma	1.916	3.2	4.0	4.6	5.9	7.2	8.2	9.2
Okmulgee	0.033	0.05	0.07	0.08	0.1	0.12	0.14	0.16
Osage	2.583	4.3	5.3	6.2	7.9	9.6	11.0	12.3
Ottawa	0.233	0.4	0.5	0.6	0.9	0.9	1.0	1.1
Pawnee	0.326	0.5	0.7	0.8	1.0	1.2	1.4	1.6
Payne	0.516	0.9	1.1	1.2	1.6	1.9	2.2	2.5
Pittsburg	0.221	0.4	0.5	0.5	0.7	0.8	0.9	1.1
Pontotoc	0.663	1.1	1.4	1.6	2.0	2.5	2.8	3.2
Pottawatomie	4.405	7.3	9.0	10.6	13.5	16.4	18.8	21.1
Pushmataha	0.328	0.5	0.7	0.8	1.0	1.2	1.4	1.6
Roger Mills	5.557	9.2	11.3	13.4	17.1	20.7	23.7	26.6
Rogers	3.12	5.2	6.4	7.5	9.6	11.6	13.3	14.9
Seminole	0.551	0.9	1.1	1.3	1.7	2.1	2.3	2.6
Sequoyah	1.727	2.9	3.5	4.2	5.3	6.4	7.4	8.3
Stephens	1.354	2.3	2.8	3.3	4.2	5.1	5.8	6.5

Table C-3- Continued

County	1970	1980	1990	2000	2010	2020	2030	2040
Texas *	263.386	437.9	537.7	636.0	809.6	983.1	1121.3	1259.1
Tillman *	19.409	32.3	39.6	46.9	59.7	72.4	82.6	92.8
Tulsa	1.929	3.2	3.9	4.7	5.9	7.2	8.2	9.2
Wagoner	0.698	1.2	1.4	1.7	2.1	2.6	3.0	3.3
Washington	1.011	1.7	2.1	2.4	3.1	3.8	4.3	4.8
Washita *	13.494	22.4	27.5	32.6	41.5	50.4	57.4	64.5
Woods	1.985	3.3	4.1	4.8	6.1	7.4	8.5	9.5
Woodward	9.017	15.0	18.4	21.8	27.7	33.7	38.4	43.1
STATE	744	1287	1580	1869	2379	2889	3295	3700

* An indication for the largest nine irrigation water usage counties in Oklahoma.

Appendix D

Table of Municipal and Domestic Water Requirements Projections for Some Selected Cities

Table D-1

Municipal and Domestic Water Requirements Projections for Selected Cities
(In Million Gallons Per Day)

City	County	Population Served*	Existing Flow Avg* MGD	Per Capita Use* gpcd	1980	1990	2000	2010	2020	2030	2040
Ada	Pontotoc	13400	1.70	127	1.83	2.06	2.28	2.48	2.68	2.88	3.07
Altus	Jackson	23302	2.56	110	2.75	3.10	3.43	3.73	4.04	4.33	4.63
Alva	Woods	7440	0.70	94	0.75	0.85	0.94	1.02	1.10	1.19	1.27
Anadarko	Caddo	6400	1.3	203	1.40	1.57	1.74	1.90	2.05	2.20	2.35
Ardmore	Carter	36500	3.50**	96	3.77	4.24	4.69	5.11	5.52	5.93	6.33
Bartlesville	Washington	29681	2.44	82	2.63	2.95	3.27	3.56	3.85	4.13	4.41
Bethany	Oklahoma	26000	2.80	108	3.01	3.39	3.75	4.08	4.42	4.74	5.06
Blackwell	Kay	8600	0.70	81	0.75	0.85	0.94	1.02	1.10	1.19	1.27
Bristow	Creek	5500	0.60	109	0.65	0.73	0.80	0.88	0.95	1.02	1.09
Broken Arrow	Tulsa	8000	0.72	90	0.77	0.87	0.96	1.05	1.14	1.22	1.30
Chickashaw	Grady	14194	1.00	70	1.08	1.21	1.34	1.46	1.58	1.69	1.81
Claremore	Rogers	7500	1.30	173	1.40	1.57	1.74	1.90	2.05	2.20	2.35
Clinton	Custer	9100	1.00	110	1.08	1.21	1.34	1.46	1.58	1.69	1.81
Cushing	Payne	8490	1.92	226	2.07	2.32	2.57	2.80	3.03	3.25	3.47

Table D-1- Continued

City	County	Population Served *	Existing Flow Avg.*MGD	Per Capita *Use gpcd	1980	1990	2000	2010	2020	2030	2040
Del City	Oklahoma	18000	1.70	94	1.83	2.06	2.28	2.48	2.68	2.88	3.07
Duncan	Stephens	18400	1.60	87	1.72	1.94	2.14	2.33	2.53	2.71	2.90
Durant	Bryan	20000	1.50	75	1.61	1.82	2.00	2.19	2.37	2.54	2.71
Edmond	Oklahoma	17700	1.70	96	1.83	2.06	2.28	2.48	2.68	2.88	3.07
El Reno	Canadian	12000	1.20	100	1.29	1.45	1.61	1.75	1.89	2.03	2.17
Elk City	Beckham	8195	0.55	67	0.59	0.67	0.74	0.80	0.87	0.93	0.99
Enid	Garfield	35300	4.50**	127	4.84	5.45	6.03	6.56	7.10	7.62	8.14
Guthrie	Logan	11000	0.60	55	0.65	0.73	0.80	0.88	0.95	1.02	1.09
Guymon	Texas	5500	0.69	125	0.74	0.84	0.92	1.00	1.09	1.17	1.25
Henryetta	Okmulgee	5200	1.00	192	1.08	1.21	1.34	1.46	1.58	1.69	1.81
Hobart	Kiowa	5000	0.50	100	0.54	0.61	0.67	0.73	0.79	0.85	0.90
Lawton	Comanche	74000	9.00**	122	9.68	10.90	12.05	13.13	14.20	15.24	16.28
McAlester	Pittsburg	18000	1.65	92	1.78	2.00	2.21	2.41	2.60	2.79	2.98
Miami	Ottowa	7254	0.35	48	0.38	0.42	0.47	0.51	0.55	0.59	0.63
Midwest City	Oklahoma	38000	3.20**	84	3.44	3.87	4.29	4.67	5.05	5.42	5.79

TABLE D -1- Continued

City	County	Population Served *	Existing Flow Avg.* MGD	Per Capita Use * gpcd	1980	1990	2000	2010	2020	2030	2040
Moore	Cleveland	16000	1.00	62	1.08	1.21	1.34	1.46	1.58	1.69	1.81
Muskogee	Muskogee	38000	6.70**	176	7.21	8.11	8.97	9.77	10.57	11.35	12.12
Norman	Cleveland	34500	3.00**	87	3.23	3.63	4.02	4.38	4.74	5.08	5.43
Oklahoma City	Oklahoma	416458	62.00**	149	66.70	75.07	83.03	90.44	97.86	104.99	112.13
Okmulgee	Okmulgee	14776	1.15	78	1.24	1.39	1.54	1.68	1.82	1.95	2.08
Pauls Valley	Garvin	5769	0.52	90	0.56	0.63	0.70	0.76	0.82	0.88	0.94
Perry	Noble	5000	0.43	86	0.46	0.52	0.58	0.63	0.68	0.73	0.78
Pittsburg	Pittsburg	5724	0.25	44	0.27	0.30	0.33	0.36	0.39	0.42	0.45
Ponca City	Kay	28000	2.24	80	2.41	2.71	3.00	3.27	3.54	3.79	4.05
Poteau	Le Flore	5500	0.44	80	0.47	0.53	0.59	0.64	0.69	0.75	0.80
Pryor Creek	Mayes	6000	0.60	100	0.65	0.73	0.80	0.88	0.95	1.02	1.09
Sand Springs	Tulsa	6300	2.50	397	2.69	3.03	3.35	3.65	3.95	4.23	4.52
Sapulpa	Creek	12000	1.00	83	1.08	1.21	1.34	1.46	1.58	1.69	1.81
Seminole	Seminole	7700	0.80	104	0.86	0.97	1.07	1.17	1.26	1.35	1.45
Shawnee	Pottawato	23700	2.30	97	2.74	2.78	3.08	3.36	3.63	3.89	4.16

Table D -1- Continued

City	County	Population Served *	Existing Flow Ag.* MGD	Per Capita Use* gpcd	1980	1990	2000	2010	2020	2030	2040
Stillwater	Payne	21351	5.50**	258	5.92	6.66	7.37	8.02	8.68	9.31	9.95
Sulphur	Murray	5000	0.41	82	0.44	0.50	0.55	0.60	0.65	0.70	0.74
Tahlequah	Cherokee	10000	1.50	150	1.61	1.82	2.00	2.19	2.37	2.54	2.71
Tecumseh	Pottawato	5500	0.16	29	0.17	0.19	0.21	0.23	0.25	0.27	0.29
Tulsa	Tulsa	416660	55.00**	132	59.17	66.60	73.66	80.23	86.81	93.14	99.47
Vinita	Craig	5200	0.93	179	1.00	1.13	1.25	1.36	1.47	1.57	1.68
Weatherford	Custer	8600	0.8	93	0.86	0.97	1.07	1.17	1.26	1.35	1.45
Wewoka	Seminole	5900	0.50	85	0.54	0.61	0.67	0.73	0.79	0.85	0.90
Woodward	Woodward	9000	0.69	77	0.74	0.84	0.92	1.00	1.09	1.17	1.25

*1976 data

**The largest municipal and domestic water usage cities in Oklahoma.