71-1479

BARTONE, Carl Richard, 1942-
A STATE PLANNING MODEL FOR WATER RESOURCES DEVELOPMENT.

The University of Oklahoma, Ph.D., 1970
Engineering, civil

University Microfilms, A XEROX Company, Ann Arbor, Michigan

THE UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

A STATE PLANNING MODEL FOR WATER RESOURCES DEVELOPMENT

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

degree of

DOCTOR OF PHILOSOPHY

BY

CARL RICHARD BARTONE

Norman, Oklahoma

1970

A STATE PLANNING MODEL FOR WATER RESOURCES DEVELOPMENT

APPROVED BY

[signatures]

DISSERTATION COMMITTEE

PREFACE

This dissertation is a planning study of the application of systems analysis to regional and state water resources problems. It is an outgrowth of an effort I have been engaged in over the past year under the Economic Development Internship Program jointly sponsored by the University of Oklahoma and the Division of Research and Planning of the Oklahoma Industrial Development and Park Department.

Under the terms of agreement reached by these two sponsoring agencies, I was to engage in a planning study addressing itself to a problem relevant to economic development in Oklahoma. Together with my major professor, Mr. George Reid, Director of the Civil Engineering and Environmental Sciences Department and Dr. Pat Choate, then the Director of the Division of Research and Planning, I formulated a proposal for developing a planning model for water resources projects in Oklahoma.

As this was an extensive proposal it was agreed that I was to undertake the development of one of the major submodels for determining future water requirements, while the remainder of the work load would be executed by the appropriate state agencies. Subsequently, Pat Choate obtained funding for a portion of the study from the Federal Ozarks Regional Commission. These monies were allocated to the Oklahoma Water Resources Board for a trial study of the 37 eastern counties of Oklahoma which are included in the Ozarks Development Region, and I was appointed project coordinator between the Division of Research and Planning, the Oklahoma Water Resources Board and the Ozarks Regional Commission. One of my functions was to provide water requirement forecasts for the Ozarks Region. I was also to assist the Oklahoma Water Resources Board with the formulation of their methodology.

The model for forecasting water requirements is presented in Chapter II, and the results of a trial application on the Ozarks Region are included in Appendix C. A description of the components of the general planning model being developed by the Oklahoma Water Resources Board is given in Chapter III.

The list of people and organizations to whom I am indebted is a long one, reflecting the size and complexity of the undertaking. I wish to thank the sponsors of the Economic Development Internship Program for their financial support and particularly Mr. Joe Ray, the Program manager, for providing guidance and coordinating the ever-necessary communication between the academic community and the state officials. A special note of appreciation is due to my major professor, Mr. George Reid, and to the rest of my dissertation committee members, Dr. Richard Bauman, Dr. James Constantin and Dr. Edward Crim, all of whom supplied me with invaluable professional advice and ideas.

I wish to thank the management of the Division of Research and Planning who provided the technical support for completing this document and afforded me an opportunity to work in and observe the American political process at first hand. I am particularly grateful, in this regard, to Dr. Pat Choate, the ex-director; Mr. Hunter Kemmet, present director; and Messrs. George Appley and Charles Musgrave, III. I appreciate all of the assistance given me by the Oklahoma Water Resources Board, especially Messrs. Paul Wilson and Glenn Sullivan. Many others deserve thanks, including Mr. Ghassan Al-Rawi who gathered much of the basic data, and the staff members and secretaries who spent long hours reviewing and typing the many drafts. Finally, warmest thanks to my wife, Margaret, who worked lovingly to assist me through the hard times.

C. R. Bartone
June 16, 1970

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

A STATE PLANNING MODEL FOR WATER RESOURCES DEVELOPMENT

CHAPTER I

INTRODUCTION

The Research and Planning Division[1] of the Oklahoma Industrial Development and Park Department is currently engaged in a number of studies aimed at facilitating regional economic development in Oklahoma. It has long been recognized that the development of the State's water resources is a vital factor influencing this economic growth - a factor whose importance is emphasized by the substantial public investments involved.

Investment in water resources development generates income, employment, and economic activity in at least three ways:

1. The construction process requires labor and support facilities. This requirement is immediate and short lived; whether it substantially affects employment within the region depends on the nature of the project, contractor preferences, and the kinds of labor needed. There may be

---

[1]The Research and Planning Division of the Oklahoma Industrial Development and Park Department has also been officially designated the State Planning Agency.

accompanying social costs such as the necessity for sudden and temporary increases in school capacity and police protection.

2. Development of water resources may result in economies to various existing economic activities. Increased availability of water may enhance agricultural productivity and increase revenues. Improved water quality may assist industrial processes and reduce their cost.

3. Water resource development affects the location of new economic activity in the region in terms of (a) availability of services and (b) quality of environment. (1) This effect may be specific as when industries locate where water is plentiful, cheap and/or of high quality, such as a brewery. In some cases, the water supply may be one of several factors influencing choice of location. The pulp and paper industry, for example, requires, besides water, supplies of raw material and a means of waste disposal.

Despite this recognized importance of water resources development, a state-wide comprehensive[2] water resources development plan has never been undertaken.

The immediate objective of this study is to design a state planning process for water resources development that will establish decision-making criteria for water allocations and for public investments consistent with the other regional economic development goals of the state. The ultimate goal

---

[2]Comprehensive planning is defined as a systematic and continuous process designed to help solve current problems and provide for future needs. It implies that the planning of water supply systems must be appropriately related to other regional systems, such as transportation and pollution control.(2)

is to insure adequate water supplies for all municipal, industrial, and rural users in the State in the most effective and economic manner as the populace and the economy expand.

This state planning process must deal with all facets of water supply systems: resources, quality, uses, transmission, storage, treatment and distribution. National, state and local interests must be fully considered. Social, cultural and economic values must be recognized.

The State Planning Model will provide a guide for the extremely complex solution to the difficult problem of matching water development and needs to the maximum extent possible. It must be adapted to changing conditions, recognizing that all economically justifiable water demands throughout the State must be met as they develop if optimum results are to be achieved.

Role of State Government

Traditionally, minor water supply projects are planned, financed and implemented at the local level, with major projects being undertaken by some Federal agency. The role of state government has been rather limited, confined primarily to a legislative role. This has, in the past, made it difficult to achieve comprehensive water resources planning.

In 1966, the President's Advisory Commission on Intergovernmental Affairs(3) made the following recommendations for specific measures for dealing with the problems of water resources development at the state level:

1. Establishment of a unit of State government for overall state water resources planning and policymaking.

2. Enforcement of water pollution and public health legislation by the States.

3. State financial and technical assistance and incentives for comprehensive development of facilities planning and construction.

Measures 1. and 2. are provided for in Oklahoma by the establishment of the Oklahoma Water Resources Board and the State Department of Pollution Control. However, presently no specific agency or strategy exists corresponding to measure three, for financial and/or technical assistance.

Among the Committee recommendations under this third measure was the establishment of ways and means at the state level to:

a. Provide grants for capital development, supplementing Federal aid;

b. Provide incentives for comprehensive development and appropriate organizations on watershed or metropolitan area bases with sufficient discretionary authority vested in the State administration to discourage uneconomical investment in water and sewer facilities;

c. Expand state technological assistance programs for water supply planning and construction;

d. Liberalize debt limits and referenda requirements for water facility financing;

e. Permit joint action by units of local government in meeting area water needs.

These recommendations, if implemented, would help to establish a wide array of partnerships between Federal, State and local governments and agencies in the area of water resources development. This would be in harmony with the trend toward these types of intergovernmental relationships between government at all levels in order to attack basic and deep-rooted problems. This policy was first described as "creative federalism" by Lyndon Johnson.

Consistent with this philosophy, the Department of Housing and Urban Development emphasizes the requirement for an area-wide approach to comprehensive water resources planning involving local and state governments. Also, President Nixon, in February of this year, in his message on the environment(4), issued an executive order establishing the requirement for comprehensive river basin plans to be developed. Compliance with such plans are to be demonstrated before the Federal Water Quality Administration which will allocate Federal funds for municipal treatment facilities. The President also encouraged local governments to cooperate in the construction of large regional facilities so that economies of scale and improved efficiency could be realized. Clearly, such regional plans and facilities transcend local political boundaries and will require coordination by the State.

Several other authors have attempted to define the state's role. Smith(5) emphasizes the legal role, but concedes a broader role should exist:

> State government must provide the enabling legislation under which local authority is exercised. . . . It may, for reasons related to its future economic well-being, have to undertake works of internal improvements which are beyond the ability or vision of local authority.

He also emphasizes that there should be state water planning to develop outputs which provide (1) programming future basic data and research activities, (2) administering existing laws, (3) evaluating the adequacy of new or amendatory legislative proposals, and (4) implementing private, local, state and Federal water development programs.

Caulfield (6) reiterates the need for the state to undertake comprehensive water resources planning. He insists that among the functions of the state in this area are (1) water research, largely through state universities, and the collection, analysis and publication of basic water data, (2) grants-in-aid to local governments, and (3) regulation of local government through the administration of water law and the devolution of authority to local levels. Thus he is in substantial agreement with Smith.

An in-depth study of water planning experiences in California (7) resulted in the recommendation that the state participation in water resource development should be:

1. Collecting and publishing all essential basic data.
2. Preparing and maintaining current a master plan on a statewide basis for the ultimate development of the state's water resources.

3. Measuring and reporting to the responsible authorities the adequacy of the planning of others at all levels of government.

4. Preparing and maintaining current a schedule and detailed plan of construction of those projects next on the list for authorization.

5. Constructing those projects needed to maintain water resource development at an adequate level which are beyond the capabilities of others.

6. Supplying leadership to all levels of government through interagency committees and otherwise, to the end that projects are built when needed and in accordance with the state's master plans.

In addition to most of the above authors many other authorities (8,9,10,11) also stress the benefits to be derived by local units accepting a regional approach to water resources development under state auspices.

State development of water resources is best illustrated in California (12), New Jersey (3), and Texas (13). Other states are likely to expand their water resources activity in this way because of scarcity of supply, population growth, competition for types of water use and the urbanization of all or large parts of the states. Experience in California and New Jersey suggests that when the state develops water resources, the local governments are willing to relinquish considerable control over their individual water supplies in return for the benefits of the state's greater capability for planning and financing a comprehensive program.

In view of the foregoing arguments, it appears desirable that the role of the State of Oklahoma be expanded to allow for assisting both financially and technically and coordinating community water facilities planning and construction.

As a first step, a State plan for water resources development is needed to guide subsequent action. The State Planning Agency recognizes the need for a State plan, and, in line with its statutory authority (14), has undertaken the responsibility for providing the coordination necessary at several levels to develop the State plan.

First of all, there is a need for coordination between local, State and Federal groups involved with water resources. All of these groups must cooperate with their resources in the development of a State plan. Since each agency has different and more specific functions, the State Planning Agency can provide the functional coordination needed for the study. Also, this office can coordinate other planning in the State with water resources planning, thus providing the required comprehensive coordination. Furthermore, since water resources planning crosses over the boundaries of many smaller political identities in the State such as city, county, or EDA districts, the State Planning Agency can provide the political coordination necessary to develop, finance and implement the comprehensive plan.

Problems with Water Resources in Oklahoma

The objectives of the State plan are linked directly to the problems facing the State of Oklahoma, but have general application to any state plan for water resources planning. Of the numerous problems hindering water resources development in the State, all can probably be placed in one, or a combination of, the following three categories: (1) problems of inadequacy of water resources; (2) planning for maximum exploitation of existing water resources; and (3) legal problems. These problem areas will be dealt with one at a time.

The first problem area deals with the inadequacies in water resources in some parts of the State and their causes. The mean annual precipitation in western Oklahoma varies from 22 to 26 inches annually. Some areas in the Panhandle receive only 15 inches per year. Furthermore, it is not unusual in the western part of the State to receive half of the entire year's rain in a single storm with most of the water running down stream and out of the area. Evaporation losses for this part of the state are practically the reverse of the precipitation gains. This evaporative loss may take over 6 feet of water from a lake during the year, while the lake will receive only one or two inches of run off from its drainage area. Thus, surface water supplies must be maintained by extremely large drainage areas. Water levels in ground water reservoirs are also dependent on precipitation, and after several years of drought and depletion, some deep ground water reservoirs, such as those in the Panhandle, may take several years to respond to the effect of increased precipitation.

However, this is not a complete picture. In the eastern areas of the State, where significantly higher precipitation levels occur and evaporation losses are much lower, a surplus of water is available. Large amounts of water flow out of Oklahoma every year, though the water leaving Oklahoma each year is needed to satisfy the demands of other parts of the State. Thus, one aspect of the shortage problem may be poor distribution.

It is conceivable that the transmission of surplus water from eastern to western parts of the state, if economically feasible, could do much to alleviate some of the water shortage problems that exist in Oklahoma. Thus planning for the second category of problems is intertwined with the problems of inadequate water resources. In addition, though sufficient quantities of water may be available, poor quality can prohibit its beneficial use. Hence, the problem of quality controls, another aspect of planning, is directly related to the problem of establishing adequate water resources.

Surface water in western Oklahoma tends to have high dissolved solids concentrations due to high evaporation losses. At our present stage of technological development, desalination costs tend to make treatment of these waters economically infeasible. However, future developments may soon alter this condition - at least for less serious dissolved solids concentrations.

Waste discharged into Oklahoma streams by municipalities and industries, and the resulting pollution, can deprive down stream users of many of the beneficial uses of those waters. Ground water deposits are extremely susceptible to infiltration by brines and other oilfield wastes. Effective controls are necessary to prevent the resulting losses of available water or the increased treatment costs resulting from poor water quality management.

Based on predictable socio-economic developments, it is certain that the shortages which exist today will only be compounded in the future. Oklahoma must face the problem of ever-increasing municipal, industrial and agricultural demands. Government projections indicate that the State population will increase rapidly in the next decade and continue to increase during the next 50 years. Not only is the number of water users increasing, but the per capita water consumption is expected to increase at a rate of about one gallon per person per year. This unit use increase reflects not only public health and safety requirements which must be met, but also the rising minimum expectations of the population demonstrated by the increase in the number of dishwashers, garbage disposals, automatic washing machines, cars to be washed, etc. Industrial and agricultural developments in the State will be accompanied by additional water requirements.

These are the problems associated with inadequate water resources. To deal with them effectively requires sound long-range water resources planning. But such planning is hindered by a number of factors. One of the foremost problems is the inadequacy of existing hydrological data and other basic data needed for water resources planning. There are not enough sites with established testing stations for gathering surface water, ground water and water quality information. Historical data on water demands has not been adequately gathered. Land use data available through other State Agencies has not been systematically collected. These problems support the need for funding and staffing of a central library for all data gathering agencies. Without a basic data collection program, specific projects may be delayed or vital decisions made on inadequate data. For each watershed, complete hydrological data is essential for making estimates of its water surpluses or deficiencies.

Another related problem is the lack of a consistent, systematic procedure for making statewide demand estimates. This is partially due to the fact that much of the data on which such projections should be based has not been acquired. Estimates of water requirements, present and future, are needed for municipal, industrial and agricultural needs in each area of the State.

Water resources planning is further hindered by the lack of consistent and rational planning objectives. Without a set of clearly defined objectives for water resources development, there is no satisfactory method of establishing measures of goal-effectiveness for projects undertaken within the State. Conversely, objectives cannot be considered "clearly defined" unless measures of goal-effectiveness can be derived and established as operational criteria, or guidelines, for each project. Ill-defined objectives lead to arbitrary and less discriminating decision-making, the selection of projects less relevant to the State's development and/or the overlooking of more essential projects.

Allied with the above problem is the absence of rational measures of cost-effectiveness and time-effectiveness upon which to base investment priorities as well as water rights allocations. Among projects relevant to the State's needs, choices must be based on financial constraints and on the immediacy of needs. The construction of a valid set of goal-, cost-, and time-effectiveness measures would allow for the evaluation of the merits of projects based on the benefits to be derived. Essentially, they must be used to answer four questions:

1. Should a project be considered?
2. Should it be undertaken relative to other projects to be considered?

3. When should it be undertaken?

4. Are there sufficient funds available to undertake it?

The third category of problems is that of legal problems. Water law was developed before the advent of modern hydrology and is sometimes at odds with today's facts and conditions. Laws which are conflicting, vague and a limiting factor in water resources development must be amended and made more compatible with today's realities.

The types of legal problems and questions that arise include the ownership of water, who is entitled to develop ground water and surface water supplies, how much water may be withdrawn for irrigation use and by whom, whether inter-basin transfer is allowed and the use of legal constraints on water pollution. Changes in water laws may be required to enhance Oklahoma's water resources development.

In summary, the problems facing the State's water resources development are:

1. Inadequacy of water resources due to:

    a. Insufficient water sources in some parts of the State.

    b. Poor distribution of water across the State.

    c. Poor quality of water because of mineralization or pollution.

    d. Increasing municipal, industrial and agricultural water requirements.

2. Water resources planning is hindered by:

    a. Inadequate hydrological data and other basic data needed for water planning.

b. Need for a systematic procedure for making statewide water requirements estimates; immediate, intermediate and long-range.

c. Need for consistent and rational planning objectives and measures of goal-effectiveness.

d. Need for specific measures of cost-effectiveness and time-effectiveness on which to base water allocation and investment decisions.

3. Legal problems resulting from out-dated, conflicting, vague and/or limiting laws.

Objectives of State Planning Model

The ultimate goal of the State has already been defined:

> To insure adequate water supplies for all municipal, industrial and rural users in the State in the most effective and economic manner as the populace and the economy expand.

Now the immediate objectives of this study can be more explicitly defined by relating a set of sub-objectives to the problems described above.

The immediate objective of this study is to establish systematic procedures for implementing the following:

1. Plan specific methods of exploiting more effectively the State's water resources.

   a. Identify new and available water sources for areas with inadequate supplies.

   b. Identify the optimal distribution system for the State's water resources particularly with regard to inter-basin transfers.

   c. Determine immediate, intermediate and long-range municipal, industrial and rural water requirements based on increasing land use intensities and water consumption rates.

2. Provide essentials for maximum effectiveness in water resources planning.

   a. Determine minimum data requirements based on specific identification of needs and available data, collect data not currently available and design a continuous data collection system.

   b. Establish a systematic procedure for determining water requirements as specified above in 1.d.

   c. Develop specific measures of goal-effectiveness which will insure the relevancy of the plan to the State's socio-economic objectives.

   d. Provide a basis for water allocation and investment decisions through the establishment of specific cost-effectiveness and time-effectiveness criteria.

3. Provide specific recommendations for legislative action which will provide a legal framework conducive to beneficial water resources planning and development.

Systems Approach to State Planning

The complexities involved in achieving the above-mentioned objectives of the State water resources planning process would appear to make it a formidable, if not impossible, task. In order to accomplish the immediate goal it becomes necessary to use a systems approach.

The systems approach involves identifying and modeling all of the systems and subsystems involved in the problem and determining the inter-actions between them. This provides a look at the problem as an entity rather than bit-by-bit and, to a large degree, forces the planner to take into account factors he might not otherwise be aware of. This approach has not been possible in the past because the proper tools for applying it did not exist even as late as the early fifties. Although it may have been recognized conceptually as a desirable methodology, it would have been impossible to handle and manipulate the large amounts of data which are required. Today, however, the advent of the modern computer with its ever-increasing storage and operating speed capabilities and the development and refinement of a body of mathematical tools for modeling and manipulating input information combine to make it possible to use the systems approach.

In recent years the tools of systems engineering have been increasingly applied in the area of water resources problems both for macroanalysis and microanalysis.[3] Specific examples of applications to planning studies on a state or regional level are: (1) the California Development Model, (2) the Hawaiian Planning Model, (3) the Lehigh Basin Model, (4) the New York Metropolitan Region Study, (5) the Ohio River Basin Study and (6) the Susquehanna Model. At the urban level several planning studies have also been made; such as the Hittman Model (15), the West Virginia Model (16),

---

[3]Microanalysis refers to the study of particular elements of a system, while macroanalysis involves the study of the internal interactions between elements of a system and interactions between the system and other systems.

and the Reid Model (17). All of the regional studies are thoroughly discussed by Hamilton in a study for the Battelle Memorial Institute (18), and by Reid and Southard (19). A summary of the various tools of regional analysis is shown in Table 1.

TABLE 1

TOOLS OF REGIONAL ANALYSIS

Microanalytic	Macroanalytic
Economic Base Studies	Simulation
Coefficient Analysis	Input-Output Analysis
Factor Analysis	Mathematical Programming
Regression Analysis	Operational Simulation
Commodity Flow Studies	
Money Flow Studies	

Source: G. W. Reid, "A Systems Approach to Urban Planning," The Oklahoma Economic Development Foundation, Inc., Norman, 1969.

The primary outputs of most of the regional models are forecasts of economic and demographic characteristics which are then tied to water sector requirements. Only three macroanalytic tools are used in the six studies above although each of the studies employs several microanalytic techniques to formulate specific requirements of the model. The Lehigh Basin Model is based on linear programming and is aimed primarily at optimizing the design of a water resources system. The Susquehanna Model is a full-scale simulation model of demographic, employment and water sectors. The remaining studies were modeled by input-output analysis, each with individual variations.

It should be pointed out that the model should not be considered an end in itself. It is merely a means of attaining an end, and as such the selection of the technique to be used in modeling the problem should be made on the basis of objectives desired. Too often the modeler attempts to fit the problem to the tool rather than to find a tool which fits the problem. Therefore, as a starting point it becomes necessary to define the problem and the objectives (which has already been done in this case). The next requirement of the systems approach is to define the systems and subsystems which enter into the study, and to describe their interactions.

Scope of State Planning Model

Essentially there are five major systems which will be considered in the State's approach. Four of them represent sectors of the State's economy:

1. The Demographic Sector
2. The Industrial Sector
3. The Agricultural Sector
4. The Water Sector

The fifth major system relates to all four of the sectors and it is the information system required to supply data for all of the sectors to be studied. The interactions between the four sectors are shown in Figure 1.

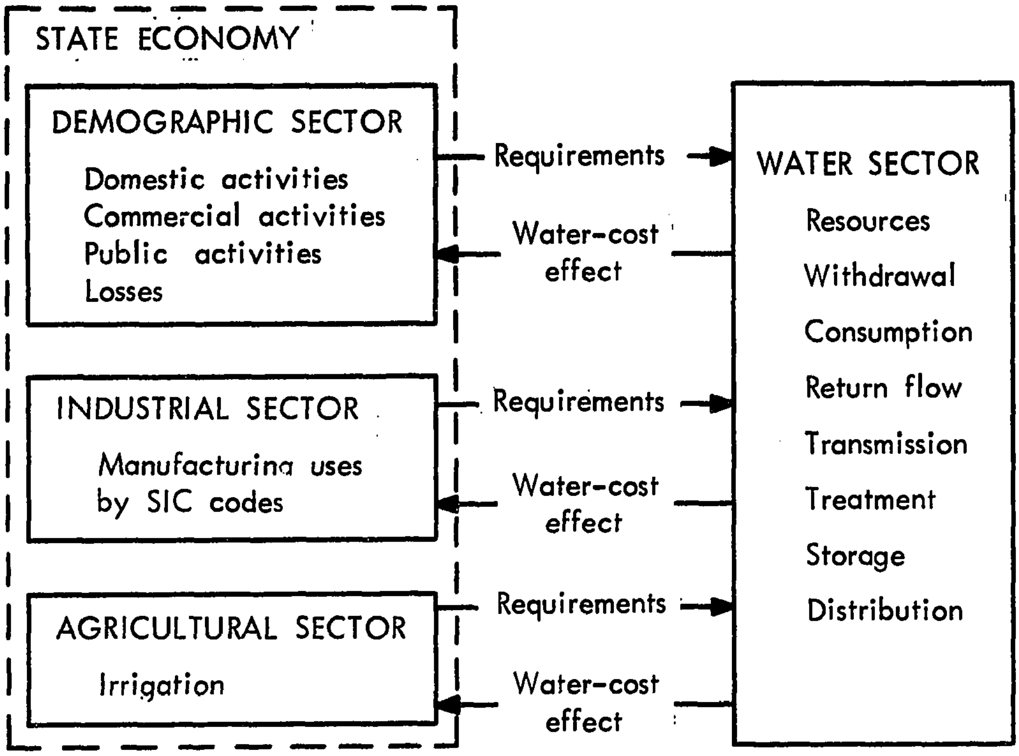

Fig. 1.--Major Sectors of the State Model

The demographic sector relates to the urban and rural populations of the State and to the normal water-consuming activities of the population; domestic, commercial and public. Also included in this category are municipal losses which can be attributed to leakage and unmetered connections. Water demands for this sector can be measured on a per capita basis. The industrial sector is concerned with the manufacturing uses of water as identified by the SIC codes. These uses include cooling, boiler feedwater, processing and cleaning. The requirements for this sector are measured on a per employee basis. The agricultural sector relates to the water used for irrigation, and is measured on a per acre basis.

The water sector of the model is very extensive and it has many elements or subsystems; resources, withdrawal, consumption, return flow, quality, transmission, treatment, storage and distribution. Because this is the sector of primary concern. an operational definition of the water sector has been developed. This operational definition has been used throughout the study and because of its importance it is included in this report as Appendix A.

The information system consists of a series of categorical inventories or data collection procedures. Preliminary to the collection of any data, an attempt was made to identify the relevant data items needed for the completion of the planning model. These identifications were, of course, subject to refinement as the construction of the planning model proceeded. Briefly, inventories are included for (1) demographic variables, (2) areal land use, (3) economic factors, (4) existing water system facilities, (5) existing resources, (6) water use patterns, (7) cost data, (8) financial resources, (9) codes, ordinances and statutes and (10) socio-political factors. A complete summary of the information system and the data items needed is given in Appendix B.

In addition to the identification of the systems above, the scope of the study is also limited by space and time considerations. The extent and divisions of the area to be served need identifying. The planning model includes all of the State of Oklahoma. Subdivisions have been set up based on the eleven major water basins in the State. The use of these basins as water planning regions is essential, even though they may cut across political boundaries already established in the State such as county, EDA or COG boundaries. These water planning regions (Figure 2) have been established by the Oklahoma Water Resources Board (20) and they serve to identify the ownership of surface waters in the State. Transfer of water across basin lines is legally questionable. Many of the water basins are wholly in Oklahoma, but several are cut by state lines. In these cases, although planning should reasonably encompass the entire basin, the water planning region consists only of

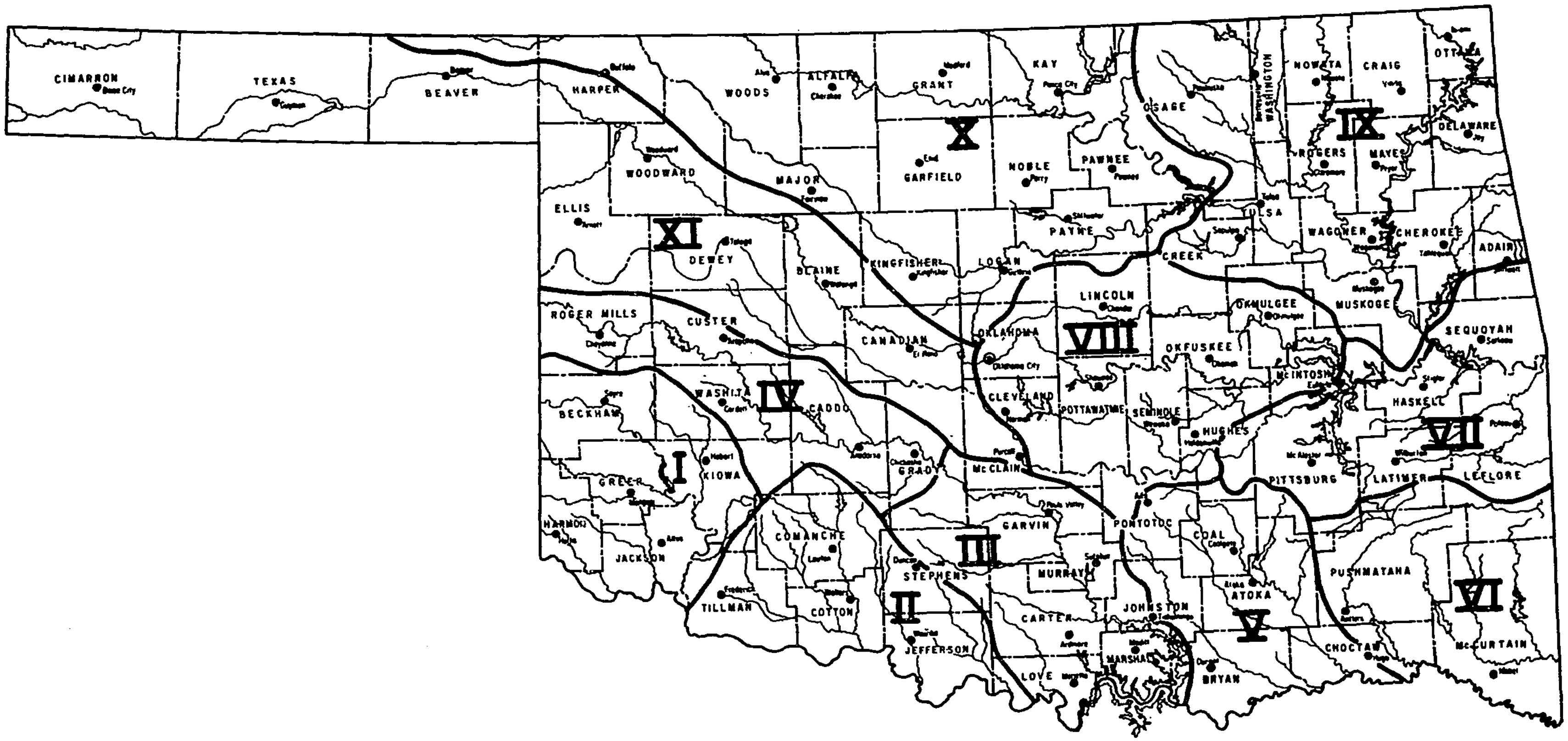

Fig. 2.--Oklahoma Water Planning Regions

Source: Oklahoma Water Resources Board, "Appraisal of the Water and Related Land Resources of Oklahoma: Regions Five and Six," Publication 27, Oklahoma City, 1969, p. 6.

that part of the basin within the State. The question of cooperative basin planning is a Federal matter, and unless an interstate compact is made the State's planning authority is politically constrained. However, the effects of water use and water flow in portions of a basin lying outside of State boundaries must be considered when determining the availability of water for State users.

Within planning regions it is necessary to identify municipal and rural water users. Strictly for the purposes of this study the term municipal will refer to cities and towns in Oklahoma in excess of 1,000 population. This cutoff point has been selected because (1) most cities above this point will have or should have a municipal water supply system,and (2) cities of lesser size, even if they have a water supply system, will not significantly impact on the regional plan in a manner discernible from rural users. Seventy-one per cent of the 1968 population of Oklahoma lived in towns in excess of 1,000 persons.

The time-frame of the planning model is divided into three periods: immediate, referring to existing conditions; intermediate, referring to the foreseeable future; and long-range, referring to projected occurrences based on historical information and trends. In terms of the methodology of making projections there is no practical difference between intermediate and long-range. However, the distinction is made because of the decreased reliability associated with projection further away in time. For the purposes of this study immediate refers to 1970, intermediate refers to 1975 and 1980, and long-range refers to 1990. The latter year is used for two reasons: (a) the Federal Government (2) requires a minimum of 20 year long-range projections for Federally funded studies, and (b) the design life of many public works facilities in the water sector can be taken as 20 years. The use of 1975 and 1980 for intermediate dates is again due to the Federal requirements for 5-10 year development programs (2).

The components of the model itself and their sequential arrangement are indicated in Figure 3. The first step is to conduct the required inventories and assemble the information system. Next the projections of the sector parameters must be made. Then, based on these projections and a set of unit-use factors to be developed, estimates of the total water sector requirements can be determined. Also, comprehensive development goals must be stipulated in terms of the sector parameters selected. Subsequently a water system plan can be designed. It should be noted that decisions arrived at in the water sector may impact on the other sectors, and this should be taken into account as a system feedback (primarily negative as will be demonstrated later). Once a plan is developed it must be evaluated in terms of the operational criteria established for measuring cost- and time-effectiveness. Finally, the compatability of

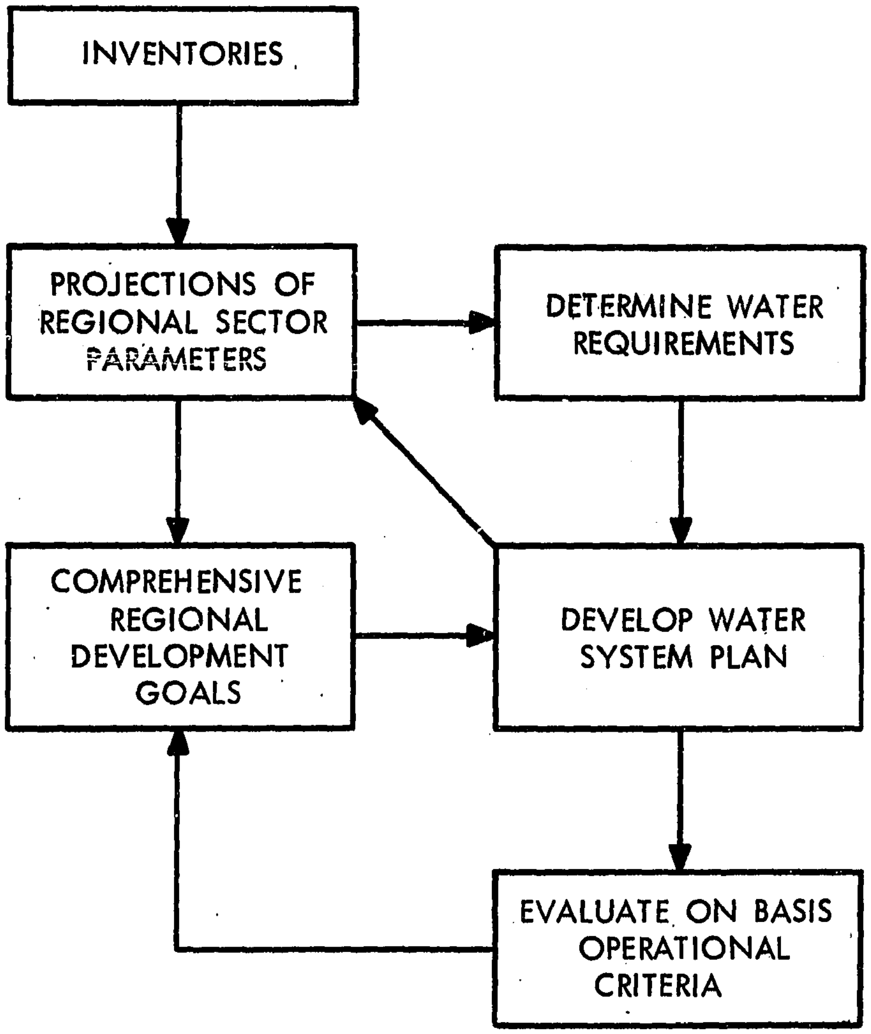

Fig. 3.--Organization of the Planning Study

the plan with the comprehensive regional development goals and, if necessary, modifications of the water plan may be required.

The remainder of this report deals in more specific terms with the components of this planning process. Chapter II is a detailed description of the water requirements model, while Chapter III describes in general terms the water system planning model and operational criteria. Furthermore, an application of the water requirements model to a test area is presented in Appendix C.

CHAPTER II

WATER REQUIREMENTS FORECASTING MODEL

Water sector facilities are generally constructed with long service lives, most being expected to provide service for at least twenty years. There is considerable uncertainty involved in estimating both the level and cost of future requirements. Yet, such estimates are essential to the rational design of a water supply system. The task is further complicated by possible changes in technology, and the difficulty in estimating demographic, social and economic changes within the geographic area served by a water resources facility. However, such estimates must be made, and the objective of this section of the study is to develop a systematic and defensible method for forecasting water requirements, taking into account, as much as possible, changes in population, industrial and agricultural activity and water use rates.

Requirements vs. Demands

Much confusion exists with reference to the use of the terminology "water requirement" and "water demand." Most forecasters speak in terms of water demands and imply that they mean by this economic demands. In reality, what they have forecasted cannot be construed as a demand in the economists' sense of the word. Therefore, some time will be spent on clearing up this point.

The economic supply-demand framework is exhibited in Figure 4. The demand function indicates the willingness of customers to pay for different quantities of a product and provides an explicit measure of the benefits associated with having the product. The supply curve, which is in reality the marginal cost curve (in the short run), indicates the additional cost incurred by producing another unit of output. The optimum quantity to be produced and taken by customers is that at which the marginal cost equals the incremental benefit as reflected in the demand function.

If the supplier can determine the marginal cost (MC) and the demand (D) functions, then it is possible to find the socially optimal output (q) and the price to be paid per unit output (p).

Attempting to apply such an analysis to water sector forecasting is difficult because of the complexities of constructing a real water demand function. There are principally two reasons for this:

1. The price elasticity of demand for water for domestic uses is quite small (i.e. demand is fairly insensitive to price and as a result, revenues generated will increase as the price is raised).

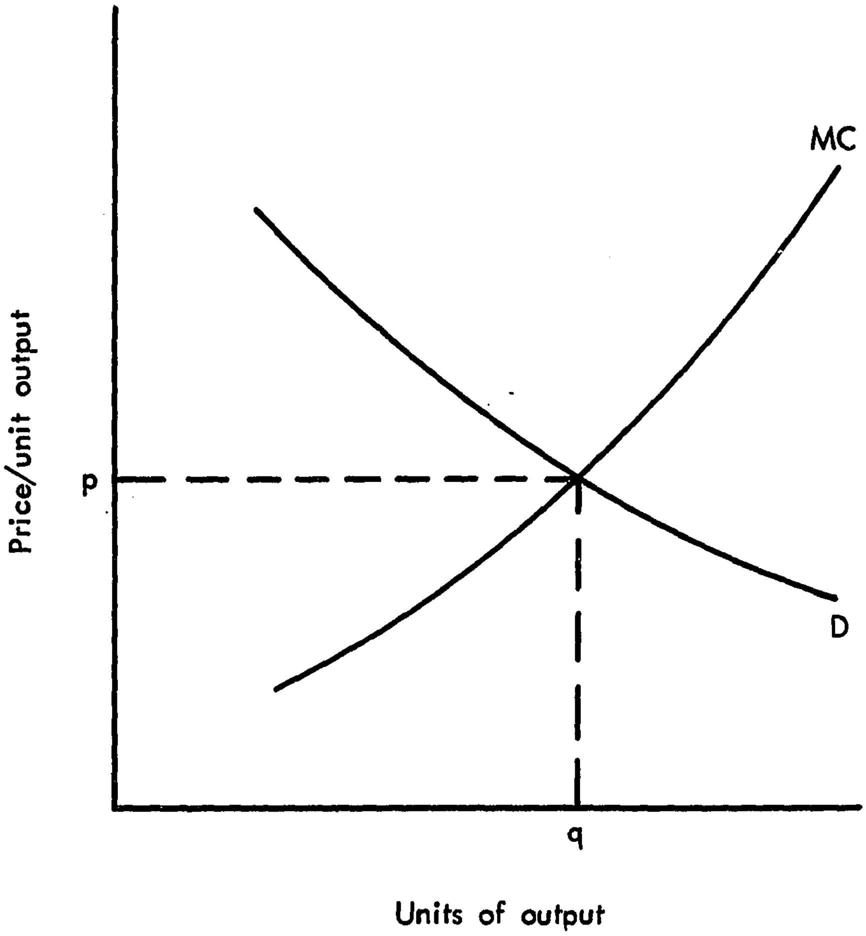

Fig. 4.--Determination of Optimum Output

2. This low sensitivity is made possible in part by the relatively low cost of water, so that only a small portion of the consumer's budget has to be allocated to it.

The first point, in addition to being substantiated by the second, is reasonable from an economic viewpoint since water is a commodity with many varied uses while having no readily available substitute. A recent study attempting to measure the price elasticity of the demand for water estimates it at -.23, reinforcing the contention that over existing price levels, the price elasticity of the demand for water is in fact quite small (21). Furthermore, it has been noted that domestic use is about the same in metered and flat-rate areas (22,23) thus substantiating the insensitivity of demand to price.

The relatively low cost of water and the historically slight increases in the price of water are both factors which may not continue long into the future. However, without further knowledge it is difficult to take this into consideration. As Saunders (16) points out, the problem, of course, is that there is no way to make estimates of price elasticities in the higher price ranges on the basis of existing relatively low price range data.

Thus, it appears unlikely that a demand function for forecasting population water usage can be formulated. Without a consideration of price, forecasts will be essentially for future water requirements. This does not appear to be a problem since this approach gives generally accurate results as long as price levels remain stable. Besides, even if prices were to rise in the long run, as long as the demand for water remains inelastic the requirements projections will be accurate (24). If that assumption should not hold, then the forecasts will be biased upwards which will not be as critical as a downward bias since it will not lead to designed water shortages. Also there are substantial economies of scale for water resources facilities such that an overdesign of ten per cent in facility capacities will increase cost by as little as six per cent and greatly reduce risk of shortages due to severe climatic conditions.

Because of these arguments the approach taken in this model will be to forecast water requirements. The implications of income levels and price will be investigated; however, there will be no attempt to define a demand function per se.

Model Formulation

The conceptual approach to the water requirements forecasting model is relatively straightforward (Figure 5). The first consideration was to determine what parameters of the various economic sectors should be forecasted in order to arrive at the water requirements for each sector. The choice of parameters was based on several constraints:

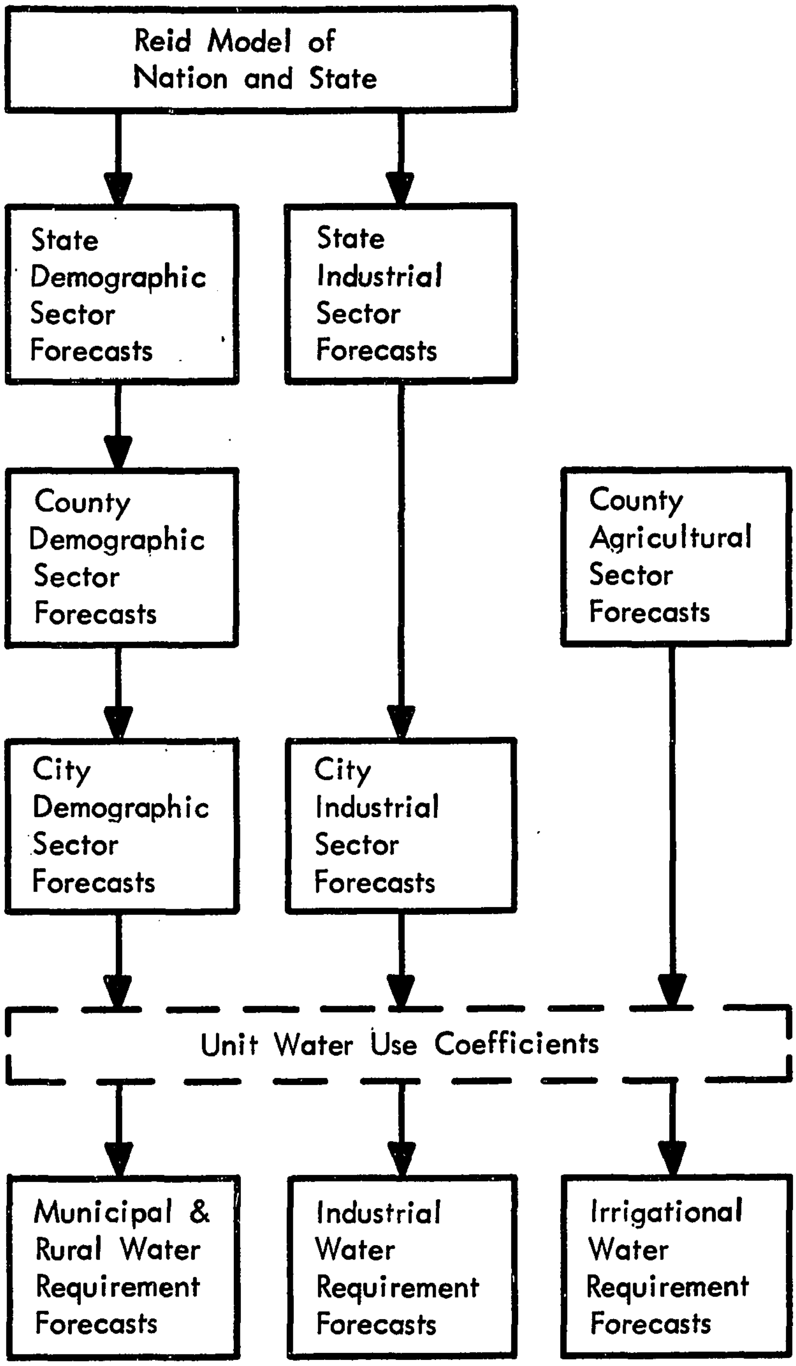

Fig. 5.--Water Requirements Forecasting Model

1. The availability of data for forecasting each parameter.

2. The availability of data for constructing unit water use coefficients for each of the parameters selected.

3. The credibility of relationship between the selected parameters, their corresponding unit use coefficients, and the actual amounts of water required for each sector.

The parameters chosen and the corresponding unit use coefficient determinations are discussed in detail in later sections of this chapter.

It was decided to use the results of the Reid Model for the State (17) as a starting point for obtaining estimates of the State's demographic and economic growth. This was considered desirable since (1) it is an established model of the State's economic structure; (2) its forecasting capabilities at the State level are excellent, as has been verified by validation procedures and by comparisons with other widely-accepted forecasts, notably the Bureau of the Census projections; and (3) it is being used as the basis for other planning studies in the State, notably the State Airport Plan and the INCOG Regional Plan.

The Reid Model is primarily an economic model made up of a population submodel based on cohort survival techniques, and an employment forecast submodel that supplies economic and employment data. The configuration of the overall model is shown in Figure 6. The industry cohort of the population model is used to provide a comparative estimate

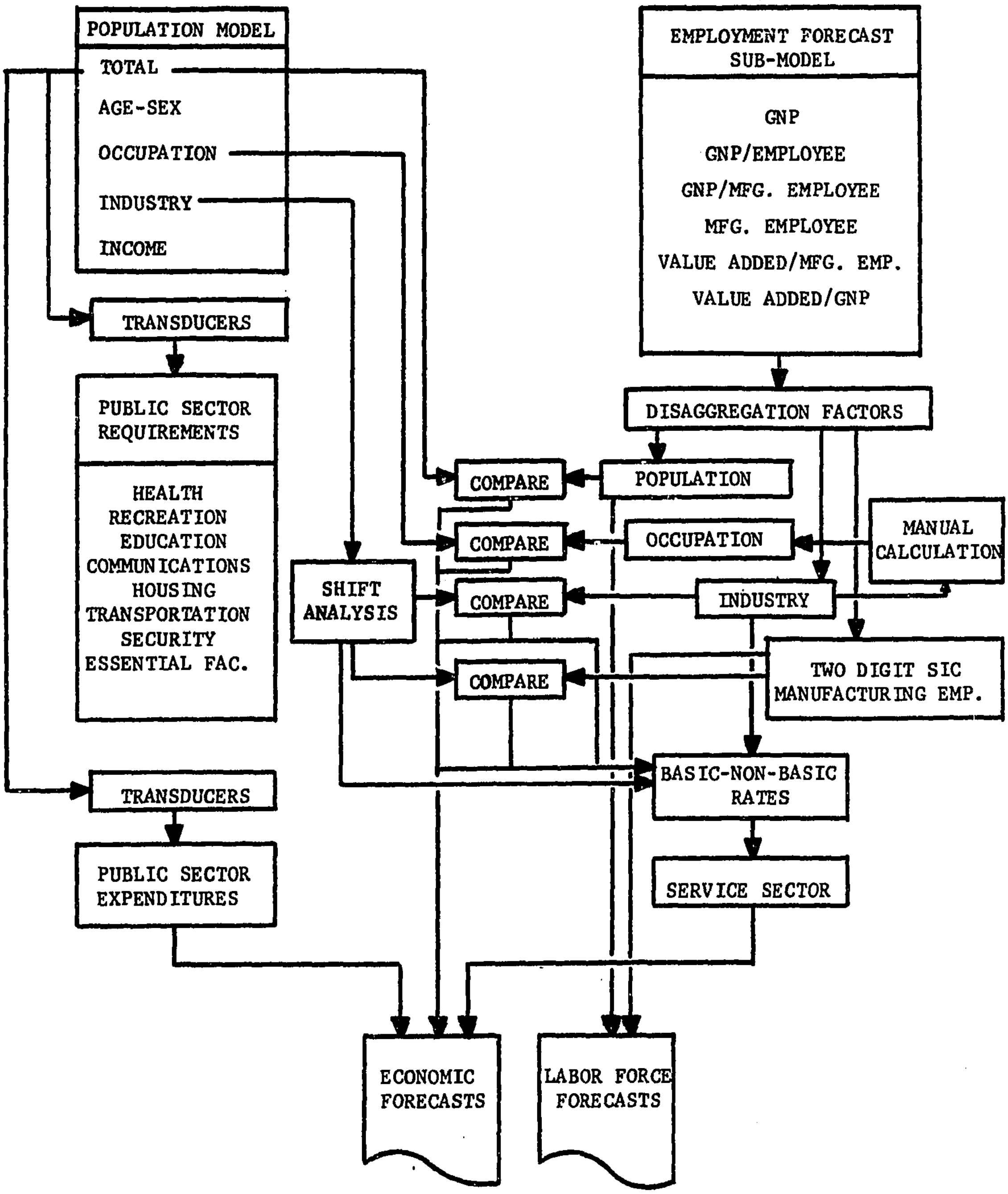

Fig. 6.--Reid Economic Model Format

Source: G. W. Reid, "A Systems Approach to Urban Planning," The Oklahoma Economic Development Foundation, Inc., Norman, 1969, p. 46.

of employment by means of a shift analysis to that developed by the employment forecast model. Both the population and employment models start with the nation, disaggregate to the region (in this case the Southwest region), and then disaggregate to the State.

In the population model the nation's population is forecast by the cohort-survival method based on cohorts of age, occupation, industry and income. These populations for the State are then developed from a disaggregation of the nation's populations. The outputs of the population model in five year increments for the State are:

1. Population by age, sex and race.
2. Population by occupational cohorts.
3. Labor force population by industry (1-digit SIC codes).
4. Labor force population and household by income cohorts.

The employment model forecasts the labor force by industry and at the 2 digit SIC code level for manufacturers. This is done by disaggregation factors from growth of the national economy GNP and value added by manufacturing employees. The outputs of the employment forecasting model in five-year increments for the State are:

1. Gross National Product.
2. GNP/employee.
3. GNP/manufacturing employee.
4. Manufacturing employees.

5. Value added/manufacturing employee.
6. Value added/GNP.
7. Labor force by 1-digit SIC.
8. Total labor force.
9. Total population.

The values of the output parameters required are disaggregated to the county and city levels by methods described in the following sections. Also described are the methods of constructing the unit water use coefficients, and the calculations necessary to arrive at final estimates of water use.

The Demographic Sector

A review of recent water forecasting studies for municipal uses reveals two predominant approaches: (1) to use population as the forecasting parameter and a unit use coefficient based on population and perhaps income measures; and (2) to use dwelling units as the forecasting parameter and a unit use coefficient based on houses and home values. The primary studies involved are: (1) the California Water Study; (2) the West Virginia Study; (3) the Johns Hopkins Study; (4) the Hittman Model, "Main I;" (5) the Reid Study; (6) the Susquehanna Model; and (7) the Metcalf and Eddy Study. The particulars of each study relating to municipal water use[4] are discussed briefly below.

---

[4]The term "municipal water use" includes several categories; (a) domestic or residential use, (b) commercial use, (c) public or institutional use and (d) systems losses. Often researchers will also include industrial users which are tied into the municipal system.

The California Water Study

The California Water study by Lofting and McGauhey (25) superimposed average water use patterns on an approximate 17 sector input-output model of the California economy. The structural water use coefficients so obtained trace out interindustry water requirements which can be reduced to single industry usage. Forecasts of industry outputs and final demands are developed, and sector water use coefficients based on correlations between gross outputs and water use data for selected years are constructed.

Estimates of commercial and undifferentiated industrial uses of water in urban trading systems were 20 gallons per capita per day for resident populations. Household and public uses as well as system losses were evaluated at 150 gallons per capita per day, bringing the total municipal use rate to 170 gallons per capita per day. No attempt was made to account for changes in the coefficients through time.

The West Virginia Study

The West Virginia study by Saunders (16) is of great importance in that it aims at identifying the major determinants of water use from among 63 data items for 81 urban areas by means of factor analysis. After subjecting the data to factor analysis to eliminate redundancies, two significant independent variables were found - urban area population and per capita income.

Next, the study used regression analysis to develop an equation relating water use to population and income. Finally, using projections of these two variables future water requirements were obtained.

The Johns Hopkins Study

The Johns Hopkins study by Linaweaver and others for the Federal Housing Administration (26, 27) investigated 41 homogeneous residential neighborhoods of urban areas in various climatic regions throughout the United States, with 40-400 dwelling units each. Using regression analysis they determine relationships for the estimation of (1) average domestic demand, in gallons per day per dwelling unit, in terms of market value of dwelling units and the price of water and (2) average summer sprinkling demand, in gallons per day per household in terms of lawn area, evapotranspiration rates, precipitation and water price.

Commercial water use by type of establishment was developed using a single parameter to describe the water consumption variable. Thus, for example, shopping center use was predicated on gross floor area, restaurants on the number of seats, churches on the number of members and so on.

The "Main I" Model

Main I was developed by Hittman Associates for the Office of Water Resources Research (15). Through the use of regression analysis, a complicated set of equations was developed to predict daily water use per household for various geographic differences and residential groupings. In most cases daily water use for households was found to be a function of the number of houses, the ratio of home valuations to a municipal tax assessment factor and average water prices.

Commercial water uses were found by a method similar to that employed in the Johns Hopkins study, relating types of commercial establishment uses to a single parameter. Public uses and losses were estimated at 20 gallons per capita per day.

The Reid Study

Reid's study has already been partially described. Using the economic model discussed earlier (pp. 34-37) and disaggregating to the urban area, forecasts of population and commercial and institutional parameters can be obtained. Then water requirements can be formed through unit use rates. For example, domestic use is given as 134 gallons per capita per day in 1970 plus 1 to 1.5 g/c/d increase per year. Commercial and institutional use rates are of a similar form, such as hospital rates of 194 gallons per bed per day for 1970 plus 0.4 g/b/d increase per year.

The Susquehanna Model

The Susquehana model (18) has also been discussed previously. The outputs of the demographic sector of the model include population which is used as the water forecasting parameter. Municipal water use requirements are then calculated using a use rate of 160 gallons per capita per day. This use rate includes all categories of urban use except industry and is increased by 1.4 per cent per year.

The Metcalf and Eddy Study

The Metcalf and Eddy study was undertaken for Management and Economics Research Incorporated as part of a report prepared for the Economic Development Administration (28). In the study they report that on the average municipal uses can be calculated on the basis of 118 gallons per capita per day. This figure includes domestic, commercial and public uses and losses. They stress, however, that this is a blanket figure which should be modified for each specific area as additional data becomes available.

Parameter Selection

The applicability of some of the above methodologies to the State planning model is questionable. Those models which deal primarily with urban areas (the West Virginia

Study, the Johns Hopkins Study, Main I and the Reid Study) require great amounts of land use data, particularly for the commercial and public categories. They are microanalytic in nature and are more suitable for an S.M.S.A. For a regional analysis format it appears more reasonable to use gallons per capita than gallons per household. This eliminates the use of dwelling unit valuations as a parameter. Certainly, though, some unit of income should be used, at least in the primary analysis. Saunders' factor analysis suggests that per capita income is the best choice, along with city population. There is the difficulty that per capita income in Oklahoma is not available for most cities, but this can be circumvented by using the county data for the required cities. This latter approach is suggested by Afifi and Bassie (29). The price of water was also suggested as an explanatory variable, although this suggestion might be questioned in Oklahoma since cities in the State use the profits made from water sales to pay other city costs.

In an attempt to determine if these, or other similar measures, could be related to municipal water use, a stepwise regression analysis was performed on data for 39 cities in the State. The dependent variable was municipal water use in gallons per capita per day. For each city the 1968 water pumpage for domestic, commercial, public, and unclassified industrial users[5] and losses, was divided by 365 times the 1968 population estimate for the city[6] to arrive at average daily per capita consumption. Independent variables were (1) 1968 city population estimates, (2) per capita income for the county, and (3) the price of 5,000 gallons of water for residential users.

Results of the regression analysis by the method of least-squares and the subsequent analysis of variance for the regression (31) showed that per capita income and price were not significant in explaining the variation in the dependent variable. The latter finding is not surprising in view of the previous observation about municipal rate structures in the State, and in view of the fact that municipal rates across the State are relatively constant. The final regression equation was of the form

$$Q_{Mi} = 89 + .002M_i \quad \text{.................... eq. 1}$$

where

Q_{Mi} = average municipal water requirement, in gallons per capita per day for i^{th} city,

---

[5]The term "unclassified industrial user" is defined to mean any manufacturing plant in the State having less than six employees. There are three reasons for this category being included under municipal usérs; (1) virtually all manufacturing plant in this size group are tied into city systems and do not use private sources, (2) their water requirements appear to be in the same range with commercial establishments, and (3) The Federal Census of Manufacturers does not report industrial water use for establishments of less than six employees.

[6]The city population estimates were taken from estimates provided by the Bureau of Business Research (30).

M_i = population of i^{th} city,

and the correlation coefficient is .7431. The standard error of estimate of unit use on population is 27.9, and the standard errors of the intercept and the regression coefficient are .0625 and .00058, respectively.

The data used above is cross-section data for a single year. Since it is known that unit use requirements change through time, an analysis of time-series data was thought desirable. Also, since other researchers have advocated a constant annual increase in the municipal unit use coefficient (17, 28), the inclusion of time as an explanatory variable was considered. The structural relationship examined was

$$Q_{Mi}^{t} = a + bM_i^t + ct \quad \text{.................... eq. 1.a}$$

where

Q_{Mi}^{t} = unit municipal water use of i^{th} town in year t,

M_i^t = population of i^{th} town in year t,

a,b,c = constants.

Time series data from 1958 to 1968 was acquired for a sample of Oklahoma cities (32,33,34). A perusal of the data indicated that for those cities not experiencing a population growth there was no significant increase in water use through the ten year period (i.e. c = 0). For cities experiencing growth, regression and correlation analyses revealed that inclusion of both population and time as independent variables lead to unexpected results. Although the analysis of variance yielded an F-value which implied the total relationship was significant, individual t-tests for the regression coefficients for population and time indicated that neither variable was significant.

The observation of exceedingly large standard errors of the estimated regression coefficients suggested that a test for multicollinearity was in order. So, population was regressed against time, and a high degree of correlation was found between the explanatory variables (r^2 = .98). This indicated that the inclusion of both variables in equation 1.a would be inappropriate since their separate influences could not be discerned.

Using population as the lone independent variable yielded significant results with small standard errors of estimate. The use of time as the lone independent variable also yielded significant results, but the correlation coefficient was considerably lower.

Based on this analysis of time-series data, population growth appears to be the controlling factor in determining unit water use through time, and equation 1 is to be preferred for estimating unit use. It is not advisable to use equation 1.a since the problem of multicollinearity makes it difficult to find the values of the regression coefficients with sufficient accuracy.

It should be noted that this equation was developed for towns in the range of 1,000 to 40,000 persons and it is not meant to be applied to the S.M.S.A.'s in the State. Each S.M.S.A. has access to Federal planning funds with which they can make a detailed study of their requirements along the lines suggested by Reid, Hittman, Saunders and Johns Hopkins, detailing commercial and institutional uses and basing domestic use on more relevant parameters. One example is the study conducted by the Indian Nations Council of Governments (INCOG) in which domestic use rates are based on the equation

$$Q_{SAUi} = 32 + .01D_i \quad \text{........................} \quad \text{eq. 2}$$

where

Q_{SAUi} = the average residential water requirement in gallons per capita per day for the i^{th} statistical analysis unit (SAU),

D_i = the population density of the i^{th} SAU.

If an S.M.S.A. in the State cannot perform a study of its own requirements in time to meet the needs of the State's planning process, the INCOG model, which is fully computerized, can be used.

Having established that population may serve as the predictor of water requirements in the demographic sector, it is necessary to define the methodology for forecasting this parameter. As already pointed out, the Reid model is used as a starting point. Two disaggregations are made, one from State to county populations, and the second from county to city populations. The methodologies will be described separately.

State to County Disaggregations

The population of each county can be projected by means of a county disaggregation ratio. These ratios are developed for each county by an exponential smoothing process (31) applied to the historical data on county population from 1946 to 1968. Based on the smoothed historical growth trend, population estimates are made for each county for 1970, 1975 and 1980.

Since all of the counties in the State are growing simultaneously in this fashion, it is possible that the sum of all the county projections will exceed the projections for the State. Therefore, a technical feature is employed to insure reasonableness of results - a prime criterion for any methodology. First, instead of using a single smoothing constant for all counties in the State, a particular smoothing constant was chosen for each county from a set of ten values ranging from .05 to .50 in increments of .05. The selection of the appropriate constant[7] is made by minimizing

---

[7]McMillan and Gonzalez (35) point out that the choice of a smoothing constant does affect the forecasts obtained by using exponential smoothing since the smaller the smoothing constant, the more heavily older observations are weighed. They suggest that we are likely to distrust a sample consisting of only three or four observations in most real processes, so our choice for α will generally lie in the range $0.05 \leqq \alpha \leqq 0.30$. In this study the range used is $0.05 \leqq \alpha \leqq 0.50$.

the difference between the average historical percentage of the State population living in the county and the average estimated percentage of the State population living in the county. In notational form this is equivalent to picking the alpha corresponding to

$$\min_{\substack{\alpha_i \\ i=1,10}} \left\{ \left| \frac{1}{T-T_o} \sum_{T'=T_o}^{T} \frac{C_j^{T'}}{P_s^{T'}} - \frac{1}{t-T-1} \sum_{t'=T+1}^{t} \frac{\alpha_i C_j^{t'}}{P_s^{t'}} \right| \right\}$$

where

α_i = i^{th} exponential smoothing constant,

T_o = first year of historical data,

T = last year of historical data,

t = last year of projection,

$C_j^{T'}$ = historical population count for the j^{th} county at time T',

$P_s^{T'}$ = State population at time T',

$\alpha_i C_j^{t'}$ = estimated population for the j^{th} county at time t' using α_i,

$P_s^{t'}$ = census estimates of State population at time t'.

So for each county, population estimates are made on the basis of the "minimum difference of percent" exponentially smoothed trend.

Second, from these individual county estimates an equation can be written, involving disaggregation ratios developed from the above estimates, to provide disaggregated forecasts:

$$P_j^t = \frac{C_j^t}{\sum_j C_j^t} \cdot P_s^t \quad \text{......................} \quad \text{eq. 3}$$

where

P_j^t = population forecast for j^{th} county,

C_j^t = population estimate for j^{th} county at time t by exponential smoothing,

P_s^t = population forecast for the State at time t (from Reid's model).

This formulation serves to insure reasonableness of results since it provides a valid upper limit for the State's population. It also has certain desirable features in that the disaggregation ratios do not remain static throughout the immediate and intermediate time periods but change in response to the growth trends established for each county. Also, due to the use of exponential smoothing, recent data is weighted more heavily than remote data, thus allowing recently-established trends to influence the forecasts rather than being obscured. Since this smoothing method is not favorable to long range estimates, however, the disaggregation ratio for 1980 was held constant to provide static long-range forecasts for 1985 and 1990.

County to City Disaggregation

It is not possible to apply the same method used in disaggregating from State to county for the county to city problem. This is due primarily to the lack of sufficient historical population data for most cities. To get around this, the technique developed disaggregates to the cities by ratios of past city-county populations adjusted by changes in the county's per cent urbanization factor.[8] The equation for this submodel is

$$M_{ij}^{t} = [1 + (t-t_o) \frac{\Delta U_j}{t_o - t_c}] \frac{M_{ij}^{t_o}}{P_j^{t_o}} P_j^{t} \quad \text{......... eq. 4}$$

where

t = year of projection,

t_o = base year,

t_c = year of last population census,

$\Delta U_j = U_j^{t_o} - U_j^{t_c}$ = difference between per cent urbanization factors for base year and last census year for j^{th} county,

M_{ij}^{t} = population of i^{th} city in the j^{th} county at time t,

P_j^{t} = population of j^{th} county at time t.

---

[8] Per cent urbanization is defined by the Bureau of the Census as the percentage of the county population residing in communities in excess of 2,500 population.

An inspection of the per cent urbanization factors for the base year and the last census period may reveal inconsistencies, since a few cities in the State will pass the 2,500 mark at some time in the interval. For example, a city of 2,400 grows to 2,600, or a city of 2,550 decreases to 2,300 in the time interval. When the inspection of the data reveals such a case, it is necessary to adjust the per cent urbanization factors. In this study an arbitrary rule is adopted to adjust the county per cent urbanization factor, for the year in which the deficient city was not included, to include the city.

Thus far, attention to the demographic sector has focused on municipal water users. It is also required to consider water use by rural inhabitants. The number of rural dwellers in a county can be found easily by subtracting the sum of the city dwellers from the total county population, i.e.

$$R_j^t = P_j^t - \sum_i M_{ij}^t \quad \ldots\ldots\ldots\ldots \quad \text{eq. 5}$$

where

R_j^t = rural population forecast for j^{th} county at time t,

P_j^t = population forecast of j^{th} county at time t,

M_{ij}^t = population forecast for the i^{th} city in j^{th} county.

The unit use coefficient for the rural population must include ordinary household uses and livestock consumption, but irrigation requirements are excluded since they appear in a separate sector of this model. Data on rural water use is scarce, since a majority of rural dwellers maintain their own domestic supply. Household use patterns have been low, but they may increase in the future as more rural water districts are formed to provide piped water from centrally located wells for domestic uses and more water-using appliances are utilized in the home.

A Department of the Interior Study for Oklahoma (36) reports an average daily rural per capita use in 1960 of 32 gallons, with an expected increase of only 2 g.c.d. by 1990. However, it gives a range of high projections which approach 47 g.c.d. by 1990, and because of the above - mentioned influences the latter appears to be more reasonable. In this study a linear interpolation between 1960 and 1990 will be used to find rural water use:

$$Q_R^t = 36 + 0.5(t-t_o) \quad \text{.................... eq. 6}$$

where

t_o = base year of study,

Q_R^t = rural water use, in gallons per capita per day, at time t.

Irrigation requirements will be dealt with in a later section on the agricultural sector.

The Industrial Sector

Water requirements for the industrial sector consist of all water uses by manufacturing establishments having six or more employees.[9] A review of other studies which deal with the industrial sector separately indicates that industrial water use is almost always expressed in terms of gallons per employee. There are some sound reasons for this.

The only substantial data available on industrial water use is from the "Census of Manufacturers: Water Use in Manufacturing," which is published every five years by the Bureau of the Census. It provides water use data by several categories, such as annual intake by source and by purpose and gross use. It also gives data on industrial employment and value added by manufacture.

Data on a less extensive basis is difficult to find, and because of the wide variability in plant designs and industrial technologies, it is difficult to find a parameter having good correlation for small samples. Surveys are generally ineffective because many establishments are reluctant to divulge financial and technological information since they consider it to be confidential.

These considerations make it practical to use employment as a forecasting parameter. Also, it exhibits good correlation with water use and can be conveniently gathered

---

[9] See footnote 5, page 43.

in most areas. In this State the 1967 "Oklahoma Directory of Manufacturers" (37) gives a detailed breakdown of the manufacturing establishments by city and by 4-digit SIC codes and the employment for each establishment. Thus the choice of employment results in the use of a parameter with an excellent data base.

Unit use coefficients have been developed in several studies. Main I (15) utilizes unit use measures at the 3-digit SIC code level, thus requiring the development of 104 coefficients and the projection of industrial populations in 104 groups. At the other end of the spectrum, the Susquehanna study (18) divides manufacturing industries, into two groups, processing and fabricating water-using industries, and assigns a use coefficient of 5700 gallons per employee per day for the processing industries, and 250 gallons per employee per day for fabricating industries. The study of unit water consumption for Interior (36) employees the breakdown of industrial activities into 2-digit SIC groups and derives use coefficients for selected groups on a per employee basis.

Since the outputs of the Reid model include industrial employment only by 1-digit SIC codes, manufacturing employment is given as a single figure. Also, it is difficult to find a rationale for disaggregating to 2-digit SIC codes at the county or city level. So, it was decided that the Susquehanna approach would be followed. The division of industries into processing and fabricating groups is shown in Table 2.

Deriving unit use coefficients for these industrial groupings is complicated by the way in which data is presented in the Census of Manufacturers (38). Actual water use data is only presented for establishments having 6 or more employees and using 20 million gallons of water or more annually. The water used by this class is approximately 97 per cent of all water used by manufacturers. Using census procedures estimates of total water use (including small users) for a specific industry by nation or water-use region can be obtained for three water-use size classes; under 1 million gallons, 1 to 9 million gallons, and 10 to 19 million gallons. These estimates are based on the number of establishments in each size class including those with less than six employees. Therefore, it is necessary before making these estimates, to subtract out the number of establishments having less than six employees.

This can be done since the Census of Manufacturers also includes a breakdown of the number of establishments by employee size groups for each 2-digit SIC code. However, these tables are divided into size groups of 1 to 4 employees and 5 to 9 employees and thus do not yield directly the number of establishments in each SIC group with less than six employees. To overcome this it was necessary to subtract from the total number of establishments the number of

TABLE 2

QUANTITY OF WATER USED BY MANUFACTURERS[1]

Industry Group	Number of Employees	Annual Water Intake Billions of Gallons	Gallons per Employee per Day Thousands
Processing Industries: SIC			
20 Food and Kindred Prod	1,589,380	812	1.400
24 Lumber and Wood Prod	489,354	161	1.146
26 Paper and Allied Prod	583,234	2,078	9.762
28 Chemicals and Allied	734,261	3,899	14.584
29 Petroleum and Coal	152,470	1,400	25.157
30 Rubber and Plastic	406,777	168	1.439
32 Stone, Clay and Glass	550,451	264	1.434
33 Primary Metal Industries	1,122,911	4,587	11.196
Weighted Average			6.507
Fabricating Industries: SIC			
21 Tobacco Products	76,989	4	.168
22 Textile Mill Products	854,543	158	.644
25 Furniture and Fixtures	360,882	8	.079
31 Leather and Leather Prod	332,747	20	.215
34 Fabricated Metal Ind	1,058,954	76	.249
35 Machinery, Except Elec	1,424,432	172	.421
36 Electrical Machinery	1,502,324	114	.264
37 Transportation Equipment	1,593,285	252	.551
38 Instruments and Related	301,650	31	.363
39 Miscellaneous Mfg.	371,858	19	.175
Weighted Average			.378

[1]This data has been gathered for manufacturing establishments with 6 or more employees.

Source: U. S. Department of Commerce, Bureau of the Census, 1963 Census of Manufacturers, Volume 1, Section 10, Water Use in Manufacturing, Washington, D. C. 1966.

establishments having 1 to 4 employees <u>and</u> one-fifth of the number of establishments having 5 to 9 employees.

Using this correction and the procedure given by the Census, the desired figures for the amount of water used by establishments of six or more employees can be calculated for each SIC group. The error introduced in estimating total water used by establishments using less than 20 million gallons per year is less than 10 per cent. Thus the total error introduced is on the order of 10 per cent of 3 per cent, or approximately 0.3 per cent of the total water used. The computed figures for annual water intake of each industry group is shown in column three of Table 2.

To arrive at the employment figures in column two a similar procedure was followed. The given number of employees in an industrial group is equal to the total number of employees less the number employed in establishments of 1 to 4 employees and less one-fifth of the number employed in the 5 to 9 employee class.

Dividing the figures in column three by the corresponding entries in column two yields the average annual water use per employee. Before reducing these to a daily use rate, a survey of industrial use patterns was taken by the INCOG planning staff. This survey revealed that processing industries have a uniform use pattern throughout the week while fabricating industries tend to exhibit reduced use on weekends. Therefore, average daily use rates for processing industries are based on a seven day week (dividing by 365 days per year), while for fabricating industries they are based on a five and one-half day week (dividing by 287 days per year). Having obtained the average daily use rates for each SIC group, a weighted average was used to obtain the average use rates for both processing and fabricating industries. The average water use for processing industries (Q_{I1}) is 6,507 gallons per employee per day, and for fabricating industries it (Q_{I2}) is 378 gallons per employee per day.

Attempts to describe time-dependent flucuations in per employee industrial withdrawal indicate that the coefficients should remain constant through time. This appears to be the result of two counteracting tendencies - improved industrial process efficiency and recycling techniques resulting in greater water reuse offset by the simultaneous decrease in employment due to automation and technological advances.

Since all of these calculations were made on the basis of national data, it was necessary to check for regional differences. The Census of Manufacturers reports water use on a regional and State basis, so the procedure was repeated for the Arkansas-White and Red water-use region. Surpisingly, the results showed 6700 and 380 gallons per employee per day being used by the processing and fabricating groups respectively, slightly higher than the corresponding national rates. This is surprising since a large portion of the region lies in relatively dry areas and one would suspect that the scarcity of water would indicate the presence of more efficient plants. However, it should be recognized that the data available for the water-use regions is much coarser than the national data, and it is not accurate to more than two significant figures. Because of this consideration and the relative closeness of the two sets of figures, it was concluded that regional uses probably did not differ greatly from national uses and that the national figures would be acceptable for the study. Unfortunately, data on the State level is so coarse that only one digit accuracy can be expected, so a comparative set of State figures could not be developed.

The use of two unit use coefficients of industrial water intakes requires the disaggregation of the State employment projections for manufacturing into two estimates for each county or city. Because the Oklahoma Industrial Development and Park Department reports industrial locations and employment by city (37), it is convenient to disaggregate from the State to the city and then aggregate back up to county or regional level as needed. Following this scheme it is necessary to include all communities in Oklahoma having classified industrial establishments not limiting the count to those cities in excess of 1,000 population. The inclusion of a smaller community serves only to locate and project employment; it does not indicate that the community is being included as a municipal water user in the study.

The philosophy used in projecting city employment assumes that the mix between processing and fabricating industries will not change significantly during the time frame of the study. This mix is expressed by the factor

$$F_i = \frac{I_{1i}^{t_o}}{I_i^{t_o}} = 1 - \frac{I_{2i}^{t_o}}{I_i^{t_o}} \quad \text{................ eq. 7}$$

where

F_i = mix factor for the i^{th} town,

$I_{1i}^{t_o}$ = classified industrial population for processing group in i^{th} town at time t_o,

$I_{2i}^{t_o}$ = classified industrial population for fabricating group in i^{th} town at time t_o,

$I_i^{t_o}$ = total classified industrial population of i^{th} town at time t_o.

The disaggregation from state to city is then expressed by two equations

$$I_{1i}^{t} = F_i \frac{I_i^{t_o}}{E_s^{t_o}} E_s^t \quad \text{...................... eq. 8}$$

$$I_{2i}^{t} = (1-F_i) \frac{I_i^{t_o}}{E_s^{t_o}} E_s^t \quad \text{.................. eq. 9}$$

where

F_i, I^t_{1i}, I^t_{2i} and I^t_i are as defined above for projection year t,

$E^{t_o}_s$ = total state industrial population at base year,

E^t_s = total projected state industrial population at time t (from Reid's model).

An obvious disadvantage of this submodel is the static nature of the mix factor. The location of a large industry in a small town will drastically change the mix factor and the disaggregation ratios. Yet it is not possible to predict such occurrences even though they are almost sure to happen. However, when aggregating to the water planning region level of the county level the effects of this type of shock on the system are dampened, and the overall result should remain valid. Also, the model should be flexible enough to handle such occurrences by continuous updating and by iterative techniques described in later sections.

The Agricultural Sector

Methods for forecasting water requirements for the rural population have already been discussed. This section describes methods applicable to irrigation water requirements only.

There are many natural factors which affect irrigation water use rates such as precipitation, runoff, temperature, evapotranspiration rate and geographic location. The Bureau of Reclamation (39) has studied the combined effects of the mean annual climatic factors and location on the unit use rates for irrigation water in Oklahoma and has compiled a set of use coefficients for Oklahoma counties (to be denoted by Q_{A_j}). These average values are shown in Figure 7. The units used are acre-feet of water per acre of crop per year (but conversion to gallons per acre per day is readily obtained by multipling the use coefficient by 893). These values correspond to data and estimates given by Reid (36), the U. S. Department of Agriculture (43,44) and the Oklahoma Water Resources Board (40).

Irrigation was not in common use in the State before the early nineteen-fifties. Since 1954, however, the number of acres under irrigation each year has increased fairly consistently at an average of 28,500 acres per year. If this trend were to continue until 1990 there would be 1,137,000 acres under irrigation compared with 510,000 in 1968 (40). The estimated land acreage physically suited to irrigation in Oklahoma is 2,012,000 acres (41), so there is no land constraint to this growth trend in the period being discussed. Furthermore, this rate appears to be consistent with growth rates expected by the Bureau of Reclamation and the Oklahoma Bureau of Business Research (42). Therefore, it will be used in this study.

The method of projecting county acreages under irrigation assumes that each county will maintain its relative proportion of irrigated acres compared to the State's.

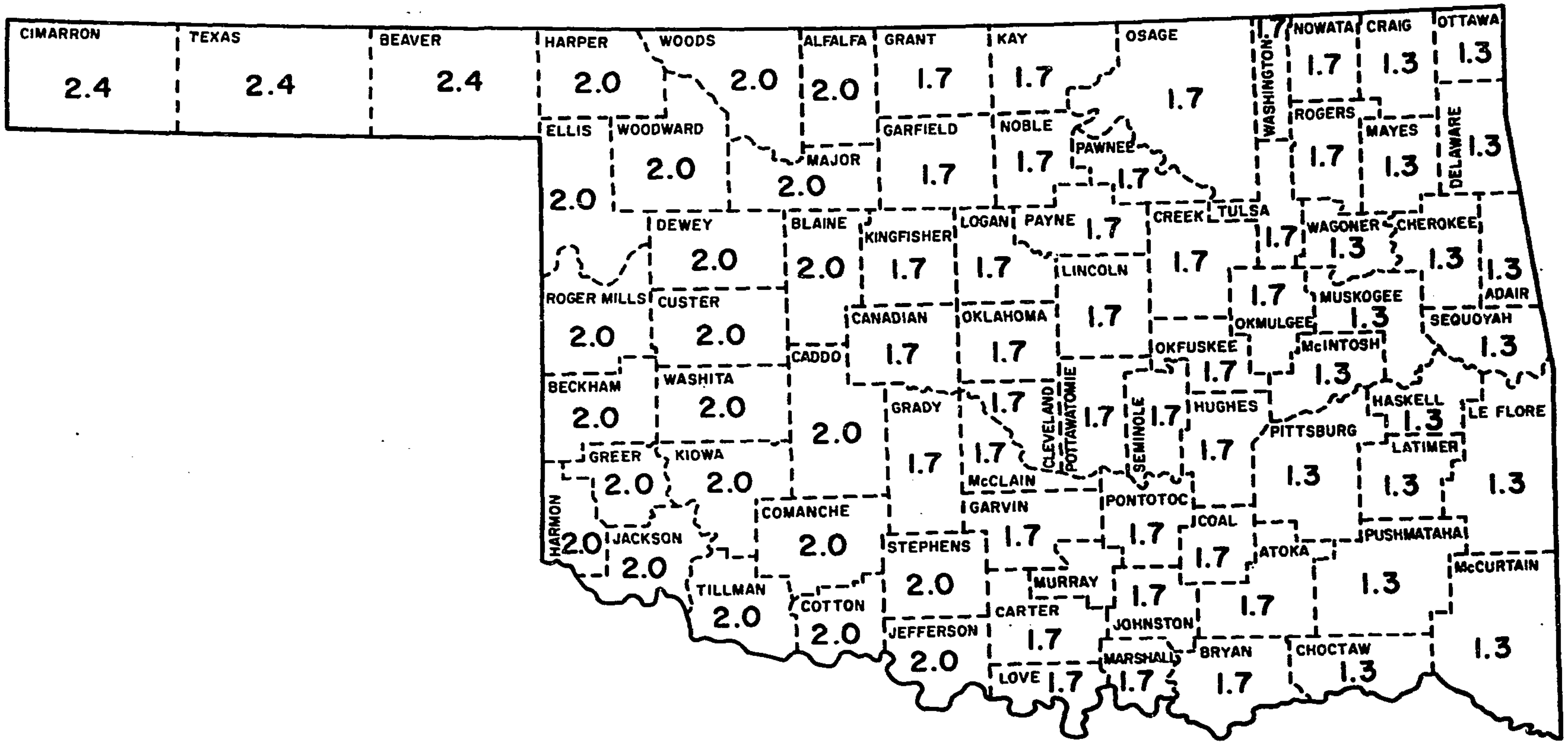

Fig. 7.--Average Unit Water Use for Irrigation (Acre-Feet/Acre/Year)

Source: U. S. Department of the Interior, "Water: The Key to Oklahoma's Future," Bureau of Reclamation, Washington, D. C., 1967, p. C-9.

The equation developed is

$$A_j^t = [\ 1 + 28.5 \ \frac{t-t_o}{A_s^{t_o}}\ ]\ A_j^{t_o} \quad \ldots\ldots\ldots\ldots \quad \text{eq. 10}$$

where

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

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

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

The use of a static distribution factor is considered valid since regional factors controlling the use of irrigation have already determined which counties will make extensive use of irrigation and which cannot.

The Water Sector

The forecasting parameters for each sector have been selected and a forecasting procedure developed for each. In addition, unit water use coefficients have been defined for each type of user. The water sector model takes the forecasted parameters and coefficients as inputs, calculates the water requirements for each sector by location, and aggregates the requirements to the regional level.

In order to do this it is necessary to use an additional code[10] for all city and county parameter inputs identifying the water planning region to which the particular city or county belongs. Also, if portions of a county lie in different water planning regions, it is necessary to allocate a part of the county's rural population and irrigated acres to each region. The criterion established for allocation is on a per cent of total land area basis. People and acres will be distributed to the appropriate regions in the same proportion as county land area is distributed between the regions. For example, if 25 per cent of the county area is in region one and 75 per cent in region two, then region one will be allocated 25 per cent of the total population and the irrigated acres while region two is allocated the remaining 75 per cent of both.

The specific input from the other sector models for a desired year are:

1. Demographic sector inputs:

$${}_kM^t_{ij},\ Q^t_{Mi},\ R^t_j,\ \text{and}\ Q^t_R,$$

---

[10]Throughout this section and the remainder of the study the following identification codes will be used:

- i = city code (subscripted right)
- j = county code (subscripted right)
- k = water planning region code (subscripted left)
- n = industrial user code (1 for processing, 2 for fabricating; subscripted right)
- t = year (superscripted right).

2. Industrial sector inputs: ${}_{k}I^{t}_{ni}$ and Q_{In},

3. Agricultural sector inputs: A^{t}_{j} and Q_{Aj}.

The notation remains as defined before with the exception of the left subscript, k, which is necessary to identify the water planning region.[11]

Water requirements for the desired year of forecast can be calculated for each water planning region as follows:

$$ {}_{k}W^{t} = \sum_{i} {}_{k}M^{t}_{ij}\, Q^{t}_{Mi} + \sum_{n}\sum_{i} {}_{k}I^{t}_{ni}\, Q_{In} + \sum_{j} {}_{k}K_{j}\,(R^{t}_{j}\, Q^{t}_{R} + A^{t}_{j}\cdot 893 Q_{Aj}) \quad \ldots\ldots \text{ eq. 11} $$

where

${}_{k}W^{t}$ = gallons per day of water required in k^{th} water region at time t,

${}_{k}K_{j}$ = percentage of land area of j^{th} county lying in k^{th} water region.

The State's total water requirements are easily found by summing over all of the water regions.

If it appears desirable to aggregate at the county level (for instance, to develop the water requirements for an EDA district) the formulation would be:

---

[11]The definitions for the symbols used in this section are given originally on pages 44, 50, 51, 58, 64.

$$W_j^t = R_j^t Q_R^t + A_j^t \cdot 893 Q_{Aj} + \sum_i M_{ij}^t Q_{Mi}^t$$

$$+ \sum_n \sum_i I_{ni}^t Q_{In} \quad \text{.................} \quad \text{eq. 12}$$

Note that the k subscripts have been dropped in equation 12 since they have no significance at the county level.

There remains one additional concept to complete the discussion of regional water requirements. As defined up to this point water requirement forecasts have been forecasts of withdrawals. However, the planner must also take into account consumptive use. Water consumption is defined as taking water from a source but not returning it, as a liquid, to the same source or a nearby source (46). Thus water that is actually consumed is lost to a region's supply once it is withdrawn, while the return flows again become part of the available supply which can be withdrawn by other users. It is common to measure consumptive use as a percentage of the total water withdrawn.

Water uses vary widely, especially in the way in which they deplete a local or regional supply. Irrigation, for example, consumes great amounts of water as the water supplied to the soil evaporates into the atmosphere. In contrast, industry consumes only slight amounts of water, because much of it is used only for cooling and is then returned to the source. The importance of this variation in consumption is shown in Figure 8, which shows that industry was responsible for 54 per cent of water withdrawn nationally in 1965 but only for 5 per cent of the water consumed. In areas suffering from chronic water shortages, such as western Oklahoma, this would indicate that irrigation will tax those supplies much more than industrial usage would.

The U. S. Geologic Survey has calculated that municipal consumption in the Arkansas-White and Red River Basins is approximately 32 per cent of withdrawals (47). This value has been verified by a recent State survey taken by the Oklahoma Water Resources Board (48). Rural consumption is 85 per cent of withdrawals. Industrial consumption has been calculated from the 1963 Census of Manufacturers data (38) and the results show that both processing industries and fabricating industries consume water at a rate of 6½ per cent of intake. This is in good agreement with values reported by the U.S.G.S. (47). Consumptive use for irrigation is 70 per cent of total withdrawals in the Arkansas-White and Red Basins. This figure is substantiated by the Oklahoma Bureau of Water Resources Research (42) and by Piper (49).

This concludes the water requirements forecasting model. Outputs from this model feed into subsequent stages of the State planning model and are used to determine the water needs of water planning regions. These processes are

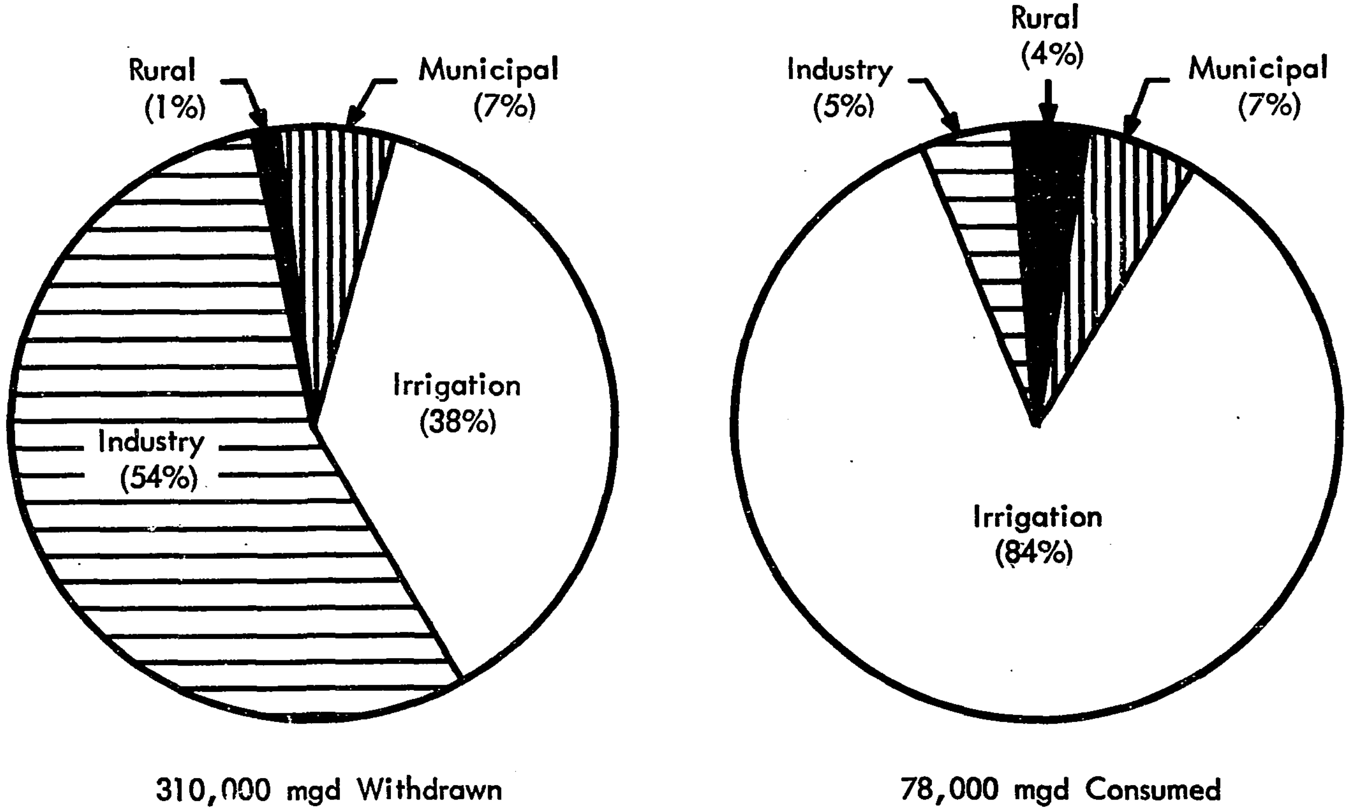

Fig. 8.--Water Withdrawal and Consumption in 1965, by Category

Source: C. R. Murray, "Water Use in the United States in 1965," Jour. AWWA, Vol. 61, No. 11, Nov., 1969, p. 567.

described in Chapter III.

The overall logic of this model is shown in Figure 9 in symbolic terms. For any year (t), by following the logic processes of the flow diagram, the water requirements for each type of user can be found for that year.

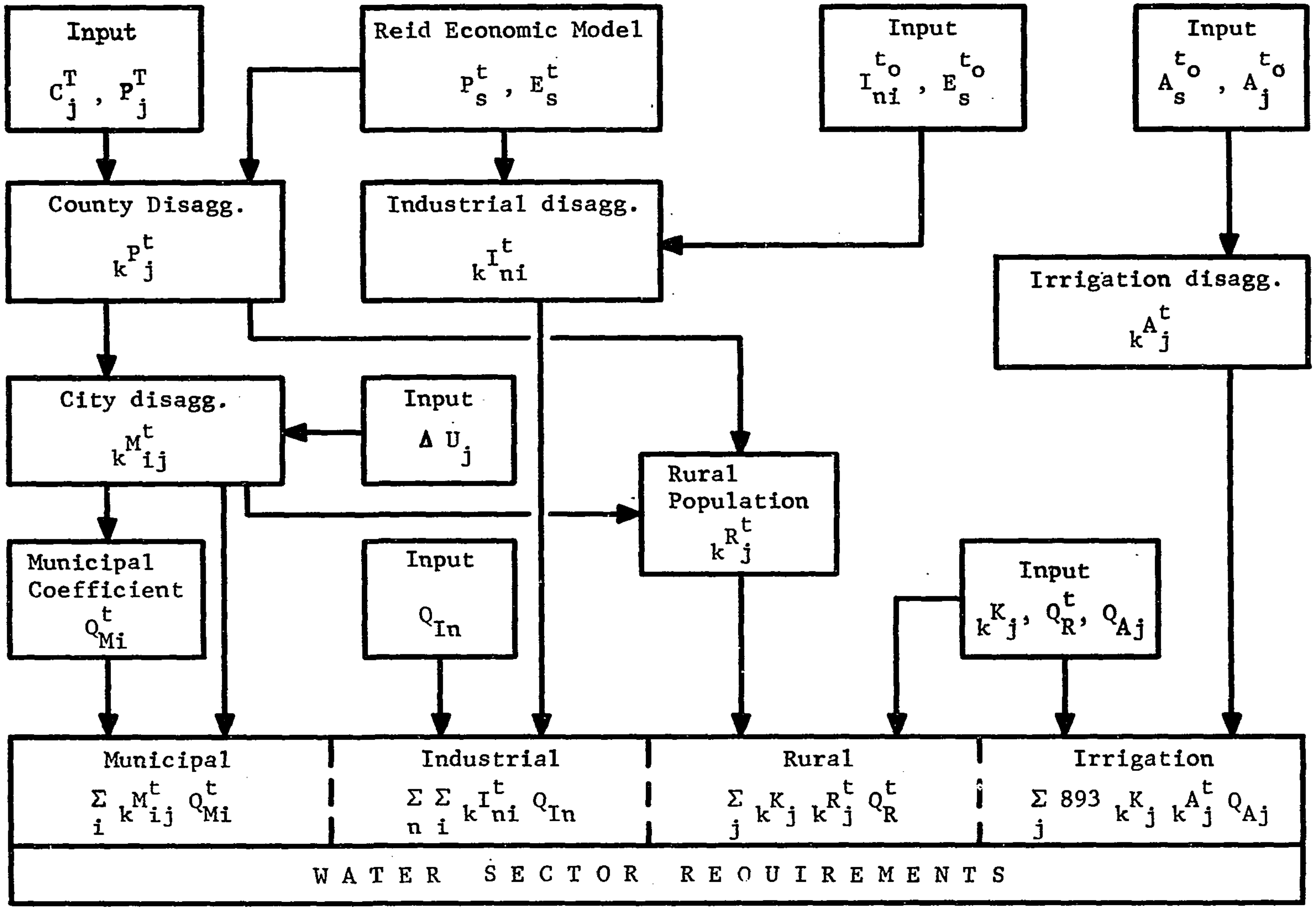

Fig. 9--Flow Diagram of Water Requirements Forecasting Model

CHAPTER III

PLANNING MODEL COMPONENTS

Up to this point identification has been made of the present and potential requirements or loads on the State's water resources. The purpose of this section is to describe methods for determining the adequacy or inadequacy of those water resources to meet the requirements and, in the case of inadequacies, to identify the most promising development measures for meeting the requirements and alleviating the water problems.

Involved in this process are considerations of supplies, costs financial capabilities, competitive uses and legal structures. Each of these will be discussed in turn.

The Supply of Water

For each water planning region, complete information about all of the sources in the region, both surface and ground water, should be collected. This will require basic studies of all of the natural factors influencing the availability of water, including the climatology, hydrology, and geology of the region. These studies are already being undertaken by the Oklahoma Water Resources Board under the auspices of the Water Resources Council.

The study of the geology of a planning region reveals the physiographic provinces of the region together with the distinctive types of bedrock and structure of the provinces that determine the topographic and drainage characteristics of the region. An identification of the drainage basins of the area and all surface waters must be made. Knowledge of soil conditions and all basic rock formations is essential to the identification of ground water sources.

Climatology studies deal with atmospheric water and provide information on precipitation, temperature, winds and evaporation. Both annual means and extremes are needed together with some measure of cyclic variation. It is important also to determine the relationships for each region between gains from precipitation and losses from evaporation and transpiration. If net losses from evapotranspiration exceed precipitation gains for extended periods of time, water deficiencies will exist.

Hydrology studies provide information about surface and ground waters and their chemical character. Knowledge of the availability of surface water requires the description of the average and extreme flows of the creeks and rivers, storage capabilities of ponds, lakes and reservoirs and the average runoff available over the drainage basins. In addition to the existing natural and developed surface supplies, proposed reservoirs, their expected capacities and dates of completion must be identified together with potential water resource development sites and estimates of future capacities. For all surface waters maximum dependable yields must be ascertained based on all of the above-mentioned factors. For those basins which are cut by state boundaries it is necessary to determine what portion of the total basin flow will be available for use in Oklahoma. This will be dependent upon legal constraints and the requirements of adjacent states.

The occurrence and movement of ground water must be evaluated. For all water-bearing rock formations specific information is needed about permeability, head, discharges and recharge rates. The safe-yield limits for all aquifers should be determined.

Information on the quality of water is necessary for the orderly and efficient development and management of water resources relative to beneficial uses. The quality of each potential water source in the region can be stated in terms of suitability or unsuitability for specific uses. For example, water unsuitable for municipal use would be that having in excess of 1,000 parts per million dissolved solids, 250 parts per million sulphates and/or 250 parts per million chlorides. Water having less than 500 parts per million dissolved solids can have industrial uses without undergoing treatment. Irrigation water can also be rated based on sodium content and salinity. Poor quality due either to natural mineralization or to pollution has the effect of decreasing the State's water resources available for beneficial use or, at best, of increasing the treatment costs required to bring the water to a standard of useable quality.

Present utilization of all supply sources should be noted, and an inventory of existing supply systems must be made. The latter includes data on present use levels and design capacities of all water supply facilities for collection and transmission, treatment, storage and distribution. It is also necessary to identify all presently-planned facilities for which financial and/or potential commitments have been made which are irreversible. The time schedules of these projects are also needed.

With this information about present and planned water supply sources and systems and a measure of potential water requirements by use and time, the development needs of each planning region can be identified. Again, these are needs, not demands, since costs and willingness to pay have not yet been considered. When they are considered, the concept of what the development "needs" are may be drastically revised.

Costs

There are several types of costs incurred in the development of water supplies. Basically they can be categorized in four components:

1. Water source costs for either surface or ground water which include costs for reservoirs, stream diversions and well fields.

2. Transmission costs which include costs for pumping stations and pipelines used to convey the water from its source to the area of use.

3. Treatment costs which include costs for raw water storage, treatment plants and pumping plants.

4. Distribution costs, which include costs for pumping stations, storage tanks and water mains.

In this study each of these costs has been analyzed and estimated. In general the costs are broken down into capital expenditures and operation and maintenance costs. Capital expenditures include costs for engineering design, land and right-of-way, water rights, construction, administration and financing. Operation and maintenance costs include labor, materials, administration and overheads, chemicals and power. In some cases chemical and/or power costs are shown separately.

Capital costs are presented as equivalent annual costs using an interest rate of 6 per cent and a period of 25 years.[12] Operation and maintenance costs are presented

---

[12] The interest rate of 6 per cent is used since it is the prevailing interest rate on public bond sales at the time of this study.

as annual costs. Both costs are presented in 1968 dollars. Adjustment to a new base year is accomplished by use of the Engineering News-Record Building Cost Index (50) for the southwest region (Dallas). The ENR index for the 1968 base period is 658.

The cost data was obtained from previous studies of generalized costs for water supply systems by the Tulsa Metropolitan Area Planning Commission (51), Black and Veatch (52) and Dawes (53).

It should be recognized that the cost estimating procedures provided here are only valid for making preliminary comparisons and serve only to measure costs to a degree which will assist in evaluating planning alternatives. Cost estimates derived by these procedures should not be used in actual facilities design since they should not take the place of detailed engineering estimates for specific projects. Cost equations are valid for facilities based on use rates from 0.1 to 100 million gallons per day. For use rates in excess of 100 mgd proportionate increases in cost estimates are suggested (52).

The cost estimating procedures applicable to this model are described below. Note that all costs given are unit annual costs and to arrive at the total annual costs it is necessary to multiply by a design capacity variable. Design capacities of future facilities are always intended to be the capacities required <u>based on water requirements</u>

at the end of the design period, i.e. the long range forecasts.

Water Source Costs

Unit capital costs for impounding reservoirs, including intake and pumping station, are given by

$$C_R = 74.2\ X_R^{-.38} \quad \ldots\ \text{eq. 13 (52)}$$

where

C_R = annual unit costs of impounding reservoirs in thousands of dollars per billion gallons,

X_R = design capacity of reservoir in billion gallons.

The minimum design capacity of future reservoirs will be that capacity capable of supplying the total average daily water requirements for all users of the reservoir.

For well development the equivalent annual cost is $2,460 per mgd capacity (52). This figure includes the development of the entire well field and should be equal to the maximum daily requirement of the user.[13]

Natural supplies, such as lakes and rivers, require only an intake and pumping station. The capital costs for these facilities are given by

$$C_s = 3.95\ X_s^{-.178} \quad \ldots\ \text{eq. 14 (52)}$$

---

[13]For municipal supplies the maximum daily use is approximately equal to 1.6 times the average daily use (54,55).

where

C_s = equivalent annual unit cost in thousands of dollars per mgd.

X_s = design capacity in mgd.

The design capacity is based on the maximum daily water requirement of the user.

Operation and maintenance costs, exclusive of pumping power, is $7 per million gallons produced (52) regardless of source. To arrive at an annual production multiply the average daily use by 365. Power costs are $5 per million gallons produced per 100 feet of head (52). Head requirements for wells are taken at 400 feet, and for surface supplies 100 feet of head is required. Again, a multiplier of 365 should be used to get annual production.

Finally, associated with each individual source there may be a water rights cost. This cost should be ascertained separately by a review of legal agreements and local practices. The cost will generally be expressed in dollars per million gallons used where the amount of total use is 365 times the average daily use.

Transmission Costs

Equivalent annual cost for capital investment in pipelines is given by

$$C_p = 41.3\ X_p^{-.49} \quad \text{eq. 15 (51)}$$

where

C_P = equivalent annual cost for pipelines in thousands of dollars per mile per mgd,

X_P = pipeline design capacity in mgd.

Pipeline design capacity is based on the maximum daily water requirement of the user. Note that the use of this cost equation for estimating pipeline costs requires an estimate of pipeline distance in miles. This is generally taken as the straight line distance between source intake point and the water treatment plant or discharge point.

Not included in the above capital costs is the cost of right-of-way for pipelines. An average cost figure for right-of-way is $2800 per mile (52). Amortizing this and reducing it to an equivalent annual cost yields $220 per mile per year. This is a fixed cost and it should not be included in equation 15 since it is independent of design capacity.

Annual operation and maintenance costs for pipelines can be expressed as

$$A_P = 1.32\ X_P'^{-.49} \quad \text{eq. 16 (51)}$$

where

A_P = annual operation and maintenance cost in thousands of dollars per mile per mgd of flow.

X_P' = pipeline utilization level in mgd.

Note that the annual operating level and not the design capacity determines costs in this instance. These will be different except at the end of the design period.

Pumping station costs are dependent upon the number of pumping stations located along the pipeline. To arrive at this number both the available head and friction losses must be taken into account. Friction losses are assumed to be 4 feet per 1,000 feet of pipe. Available head is the difference in elevation between the intake and discharge points. Positive head, by convention, will mean that the intake is higher than the discharge point. Letting

h_f = elevation difference between intake and discharge points in feet,

d = distance between intake and discharge points in thousand feet.

Then if $h_f - 4d \geqq 0$, there is enough head available to overcome friction losses and gravity flow will suffice (i.e. no pumping stations are needed). If $h_f - 4d < 0$ the number of pumping stations required is

$$n = \left| \frac{h_f - 4d}{400} \right| \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad \text{eq. 17}$$

rounded to the next higher whole number.

The unit capital cost for each pumping station is given by

$$C_n = 6.65\, X_p^{-.314} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad \text{eq. 18 (52)}$$

where

C_n = equivalent annual unit cost of pumping stations in thousands dollars per station per mgd,

X_p = design capacity of pipeline.

Annual operation and maintenance costs for pumping stations are given by

$$A_n = 2.12\ X_p'^{-.314} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad \text{eq. 19 (52)}$$

where

A_n = annual operation and maintenance cost in thousands of dollars per station per mgd of flow,

X_p' = pipeline flow level in mgd.

In addition to the operation and maintenance costs, the cost of pumping power must be included. As already stated pumping power is priced at $5 per million gallons of flow per hundred feet of head. The head requirements will be $|h_f - 4d|$ as defined above where $h_f - 4d < 0$. The annual flow is 365 X_p'.

Treatment Costs

To assure a reliable supply of water, raw water storage at the discharge end of the pipeline may be provided. The capital cost for raw water storage is

$$C_{rs} = 1.55\ X_{rs}^{-.201} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad \text{eq. 20 (52)}$$

where

C_{rs} = equivalent annual unit cost for raw water storage in thousands of dollars per million gallons,

X_{rs} = raw water storage design capacity in million gallons.

The design capacity for reliable supply should be ten times the average daily requirement. For pipelines of less than

5 miles length this capacity can be reduced proportionately.

The operation and maintenance costs for raw water storage are

$$A_{rs} = 0.10\ X_{rs}^{-.201} \quad \text{.................. eq. 21 (52)}$$

where

A_{rs} = annual operation and maintenance cost in thousands of dollars per million gallons.

Treatment plant costs include the costs of the treatment plant and treated water pumping plant. Unit capital costs are given by

$$C_T = 25.6\ X_T^{-.257} \quad \text{.................. eq. 22 (51)}$$

where

C_T = equivalent annual unit cost of treatment plant in thousands of dollars per mgd,

X_T = design capacity of treatment plant in mgd.

The design capacity is based on the maximum daily water requirement of the user.

Operation and maintenance costs of the treatment plant, exclusive of chemical and power costs, are given by

$$A_T = 7.25\ X'_T{}^{-.257} \quad \text{.................. eq. 23 (51)}$$

where

A_t = annual operation and maintenance of treatment plant in thousands of dollars per mgd.

X'_T = operating level of plant in mgd.

The operating level of the treatment plant is based on the average daily requirements for the year of operation.

Chemical costs vary widely depending on the quality of the source water. Therefore, these costs should be determined individually for each source. This can most easily be done by preparing a schedule showing costs versus water quality by type of use. These costs should be given in dollars per million gallons treated where the total amount of treated water will be 365 X'_t.

Distribution Costs

Treated water storage requires a capital investment of

$$C_{ts} = 14.3\ X_{ts}^{-.274} \quad \text{.................. eq. 24 (52)}$$

where

C_{ts} = equivalent annual unit cost for treated water storage in thousands of dollars per million gallons,

X_{ts} = design capacity of treated water storage facilities in million gallons.

The design capacity is estimated as 25 per cent of the maximum daily use. Operation and maintenance costs for treated water storage are given by

$$A_{ts} = 1.80\ X_{ts}^{-.274} \quad \text{.................. eq. 25 (52)}$$

where

A_{ts} = annual operation and maintenance costs in thousands of dollars per million gallons.

The distribution system network costs can be estimated at $700,000 per square mile of development (51). Distribution pumping power requirements assume a head of 250 feet, thus the power costs are $13 per million gallons of flow, and the total flow is 365 times the average daily flow.

Total Costs

Using the above cost data, the annual total of any water supply system for any use can be estimated in 1968 dollars. It should be recognized that each system will have its own special requirements, so that no generalized total cost equations will be attempted. For example, one town may develop a surface supply requiring treatment while an industry may develop its own well water sources requiring no treatment. For each identifiable future water use an individual total annual cost can be developed by the above-described procedures.

The cost data shown here demonstrates the effect of economies of scale on water system development. As the size of the system increases, the level of service is improved, and the unit cost of providing that service is reduced - a fact verified by the negative exponents on design capacity terms in the various unit cost equations. Water systems have long lives and require large capital investments, two factors that make consideration of scale economies imperative.

Financial Considerations

A financial study must be undertaken to determine the funds available through Federal, State and local agencies for water resource development projects. Current data on individual municipal financing capabilities should include annual operating cost, annual bond cost, bonded indebtedness, revenues from water services and all other sources, and assessed valuation. Projections of funds available from revenues, sinking funds and taxes and bonding capabilities should be made for each municipality.

An assessment of means of matching or supplementing local and State funds through Federal grants is currently underway by the Oklahoma Water Resources Board.

Plan Development and Evaluation

The needs of each water planning region relative to the various users can be determined on the basis of the ability of present resources and facilities to cope with the projected municipal, industrial and agricultural requirements. It then becomes a matter of developing alternatives for solving particular regional needs. These alternate plans should reflect the different policy approaches open to the State. For example, plans for regional treatment facilities should be investigated if the State wishes to encourage cooperative regional development.

An evaluation of the available alternate plans requires the consideration of several basic questions raised earlier. In view of the scarcity of water and financial resources and of the State's comprehensive development goals, which alternatives should be undertaken and what priorities should be assigned them? There are several different cases to be considered and a brief discussion of each is in order.

First, there are some water planning regions in which there is a surplus of water available for use. Consistent with the stated ultimate goal of the State water plan to provide adequate supplies for all users in the most effective and economic manner, the choice between alternatives should be based on a minimum-total-cost selection criterion since the benefits derived in all cases would be equal.

Second, some water planning regions, particularly in western Oklahoma, will have chronic deficiencies of water available for use. Competitive requirements for different users will force a decision on which types of use should be allowed or encouraged. Obviously other selection criteria would be required in these regions based on regional benefits and cost-effectiveness measures.

Finally, the competitive resource requirements between regions must be analyzed and State-wide priorities established. Here the difficult question of interbasin transfers must be considered. Again, goal-oriented benefit measures are required.

The use of benefit-cost analysis in water resources project planning is well established since it is a requirement for Federally-sponsored projects (56). The basis for decisions in Federal benefit-cost analysis is national economic efficiency which requires that the present value of an expected benefit stream from a project exceeds the present worth of the expected cost stream (57). Hence national income will be increased.

In addition to the desirability of an efficient investment, there are other considerations which normally are not taken into account. From the State's point of view, rather than the nation's, there are secondary benefits relative to the goals of regional economic development which should be measured. These have been defined for Oklahoma and the EDA (58) as the creation of new regional job opportunities and the increase in total regional income.

Thus, for those regions experiencing water shortages competitive use decisions should be based on criteria seeking to maximize annual net benefits for the region based on job and income considerations. The benefits for municipal, industrial and irrigation water will be different.

Because of public health and other considerations, planners often make the assumption that municipal requirements are worth meeting and therefore are considered as established constraints (59). If this approach is used then a municipal benefit function is not required and the problem reduces to optimizing net benefits for industry and agriculture.

For industry the net benefit can be defined as the difference between the annual income added due to change in employment minus the cost of providing the annual additional water required by that employment change. Thus there is a distinction between processing and fabricating industrial employees because of the different water use rates. What is not so obvious is that employee income and productivity is greater in the larger water using industries and this must also be taken into account. The average national income in 1964 for employees in major water using establishments was $7,710 while the average in all other establishments was only $5,130 (60).

Irrigation net benefits can be measured as the increased farm income from increased annual crop yield due to irrigation less the annual cost of irrigation water.

The application of this type of analysis requires adherence to the with-and-without principle which states that the effects to be attributed to a particular project must be determined as the difference between those conditions which would exist if the project were undertaken and those which would exist if it were not undertaken (61). This principle indicates that it is erroneous to consider the entire value of an irrigated crop yield as a benefit derived from the irrigation project since without the irrigation project there would still have been a yield. Thus the proper benefits measurement is based on the increase in yield due to the project.

In addition to economic evaluation, alternate plans should be subject to time-effectiveness criteria. To insure that projects required to meet future needs will be undertaken in time, a measure of the lead time required for each type of facility is needed. The lead time includes the time required for approval, design and construction, and it may range from a few years for small facilities to twenty years for major facilities such as dams. Sound program planning will depend upon accurate measures of lead time requirements.

Planning Dynamics

Planning is a dynamic, iterative process requiring feedback and modification. Once a water plan is developed and evaluated on the basis of established operational criteria, it is still necessary to determine what effect the plan will have on the State's overall comprehensive development goals and how the starting assumptions may have been altered or violated. Also, it may be desirable to test the plan against new assumptions to determine how sensitive it may be to future changes.

Decisions arrived at in the water sector will most certainly impact on growth in the other sectors, and where water sector outputs indicate that estimated future water requirements cannot be feasibly met, the implications of this knowledge should be examined. Insufficient water may inhibit industrial and population growth or expanded irrigation. When the outputs of the planning model indicate that forecasted requirements cannot be met, the starting estimates should be adjusted downward by reducing other sector parameter forecasts.

Since the forecasts of population and employment are obtained by disaggregating from control figures, a reduction in a forecast for one area implies increases in other areas. Therefore, a redistribution of the population or employment lost by that area is required. It is plausible to think of this redistribution as a shift or migration in which persons are attracted to other areas having sufficient water resources. By further assuming that other attraction factors to another area or town would be size and nearness, a shift factor can be written as

$$S_{ij} = \frac{\frac{P_j}{D_{ij}}}{\sum_j \frac{P_j}{D_{ij}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \text{eq. 26}$$

where

S_{ij} = shift factor

i = subscript denoting county or city with insufficient water resources,

j = subscript denoting county or city with sufficient water resources,

P_j = population or employment at j^{th} county or city,

D_{ij} = distance between i^{th} and j^{th} county or city (centroid to centroid).

The adjusted population figures for counties, cities and industries can then be calculated by

$$P'_j = P_j + S_{ij} \cdot \Delta P_i \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad \text{eq. 27}$$

where

P'_j = adjusted population or employment at j,

P_j = population or employment before shift,

ΔP_i = $P_i - P'_i$ = that increment of population or employment at i which cannot be supported by potential water resources.

Based on these adjusted population and employment projections, the plan development and evaluation process should be repeated. After a few such iterations an equilibrium should be reached in which no further shifts are required.

The problem of dealing with irrigation requirements is not an equivalent case since the initial assumptions in arriving at the sector parameter were different. Rather than disaggregating from a control figure, a present state growth rate was imposed on all counties. No limitation was placed on the use of available water resources. In the event of water shortages, there is no apparent rationale for shift since an acre of land is not a migratory entity.

Therefore, a restatement of the forecasting model is advised. There are several alternate models available (62) and an examination of these may be desirable in any case to test several hypothetical policies.

Specifically, iterations of the overall planning model corresponding to the following additional cases for the agricultural sector can be undertaken:

1. Rather than allowing unrestricted increases in irrigation based on historical trends, restrictions on the land acres irrigated should be imposed in recognition of projected market limitations for Oklahoma agricultural products. These restrictions should be based on projections of the State's share of future national and State requirements for agricultural products (25) thus necessitating an additional market study. No limitations should be placed on the use of available water resources.

2. Employing the same restrictions on agricultural land use as in case 1 above, limitations should be imposed on available water resources. The assumption here is that increases in municipal and industrial requirements will not allow for competing development of agricultural water resources (63,64). While not advocating this policy, an examination of its implications is certainly justified.

3. Imposing the same land restrictions, the available water supplies proposed under the Oklahoma Basins Project for interbasin transfers (39) should be assumed. In case 1 the only limitation on water availability was economic. In case 2, in addition to economic limitations, a technical limitation of scarcity was imposed. In this case sufficient water resources for all competitive uses is assumed thus removing economic and scarcity limits.

The latter case raises great legal questions, but the undertaking of such an analysis should help to provide a sound basis for arguing the question in the legislative and political arenas.

The above procedures for handling feedback and policy alternatives may yield one or more plans which appear sound on the basis of the established operational criteria. Finally, it is required that the plan, or plans, undergo re-examination in light of the overall comprehensive development goals established for the State. A water plan which is in conflict with other planning efforts in the State, or which would impede the attainment of other planning goals, may have to be altered or a restatement of the goals may be necessary. This last step completes the description of the planning process previously shown in Figure 3.

LIST OF REFERENCES

1. Arnold, R. K., Harvey, E. C., Willeke, G. E., Carrier, J. E. R., Water, Mineral, and Forest Resources in Regional Economic Development, Stanford Research Institute, Menlo Park, 1966.

2. Water and Sewer Facilities Planning Requirements Guide, Department of Housing and Urban Development, Washington, D. C., Jan., 1966.

3. Frieden, B. J., Metropolitan America: Challenge To Federalism, Advisory Commission of Intergovernmental Relations, Washington, D. C., 1966.

4. U. S., President, 1969-1973 (Nixon), Message on Environment, 91st Congress, 2d Sess., Feb. 10, 1970 House Doc. 91-225.

5. Smith, R. L., "The Role of Universities in Development of State Water Planning," Federal-State Water Resources: What Can Universities Contribute?, University of Missouri, Columbia, 1968.

6. Caulfield, H. P., Jr., "Partnership in Comprehensive River Basin Planning," Jour. AWWA, Vol. 59, No. 10, Oct., 1967, pp. 1217-1222.

7. Golzi, A. R., "Future Planning of Water Resources at the State Level," Jour. AWWA, Vol. 59, No. 4, April, 1967, pp. 425-433.

8. Graesner, H. J., "The Water Industry and Local Government," Jour. AWWA, Vol. 60, No. 1, Jan., 1968, pp. 1-4.

9. Kelnhofer, G. J., Jr., "River Basin Planning and Urban Development," Jour. ASCE, Vol. 93, No. UP4, Dec., 1967, pp. 151-162.

10. LaDue, W. R., "What Does a Good Water Resources Program Mean to a State?," Jour. AWWA, Vol. 61, No. 1, Jan., 1969, pp. 13-16.

11. Okun, D. A., "Tomorrow's Methods to Provide Tomorrow's Service," Jour. AWWA, Vol., No. 8, Aug., 1966, pp. 938-952.

12. Implementation of the California Water Plan, Department of Water Resources, Bulletin No. 160-66, The State of California, March, 1966.

13. The Texas Water Plan - Summary, Texas Water Development Board, Austin, 1968.

14. Planning Activities of the State Government of Oklahoma, University of Oklahoma Research Institute, Norman, 1966.

15. Main I: A System of Computerized Modes for Calculating and Evaluating Municipal Water Requirements, Vol. I and II, Hittman Associates, Inc., Columbia, Maryland, 1968.

16. Saunders, R. J., Forecasting Water Demand: An Inter- and Intra-Community Study, West Virginia University, Business and Economic Studies 11:2, Feb., 1969.

17. Reid, G. W., A Multistructural Demand Model for Water Requirement Forecasting (Final Report), Office of Water Resources Research, Department of Interior, Washington, D. C., Jan., 1970.

18. Hamilton, H. R., et alia, Systems Simulation for Regional Analysis: An Application to River-Basin Planning, MIT Press, Cambridge, 1969.

19. Reid, G. W., A Systems Approach to Urban Planning, The Oklahoma Economic Development Foundation, Inc., Norman, Nov., 1969.

20. Appraisal of the Water and Related Land Resources of Oklahoma: Regions Five and Six, Oklahoma Water Resources Board, Publication 27, Oklahoma City, 1969.

21. Howe, C. W., "Water Pricing in Residential Areas," Jour. AWWA, Vol. 60, No. 5, May, 1968, pp. 497-501.

22. Linaweaver, F. P., Jr., Geyer, J. C., Wolff, J. B., "Summary Report on the Residential Water Use Research Report," Jour. AWWA, Vol. 59, No. 3, March, 1967, pp. 267-282.

23. Flack, J. E., "Meeting Future Water Requirements Through Reallocation," Jour. AWWA, Vol. 59, No. 11, Nov., 1967, pp. 1340-1350.

24. Warford, J. J., "Water Requirements: The Investments Decision in the Water Supply Industry," The Manchester School of Economic and Social Studies, Vol. 34, No. 1, Jan., 1966, pp. 87,88.

25. Lofting, E. M. and McGauhey, P. H., Economic Evaluation of Water: Part III An Interindustry Analysis of the California Water Economy, University of California, Berkeley, 1966.

26. Linaweaver, F. P., Jr., Report II: Phase Two of the Residential Water Use Research Project, The Johns Hopkins University, Baltimore, 1965.

27. Wolff, J. B., Linaweaver, F. P., Jr., Geyer, J. C., Report on the Commercial Water Use Research Project, The Johns Hopkins University, Baltimore, 1966.

28. The Regional Planning of Selected Public Facilities Systems, Vol. I and Vol. II, Management and Economics Research Incorporated, Palo Alto, 1968.

29. Afifi, H. H. H., Bassie, V. L., Water Pricing Theory and Practice in Illinois, University of Illinois, Chicago, 1969.

30. Oklahoma Data Book, Oklahoma Bureau of Business Research, Norman, 1968.

31. System/360 Scientific Subroutine Package, (360A-CM-03X) Version II, Programmer's Manual, IBM, White Plains, New Jersey, 1968, n. H20-0205-03.

32. 1958 Inventory: Municipal Water Facilities, U. S. Public Health Service, PHS-2226, 1959.

33. 1963 Inventory: Municipal Water Facilities, U. S. Public Health Service, Vol. VII, PHS-775, 1964.

34. American Directory of Water Utilities: 1968-1969, Vol. VII, Public Service Research, Inc., Plainfield, New Jersey, 1969.

35. McMillan, C. M. and Gonzalez, Systems Analysis: A Computer Approach to Decision Models, Irwin, Inc., Homewood, Illinois, 1965.

36. Reid, G. W., Unit Water Consumption: Oklahoma Projections, Oklahoma University Research Institute, Norman, 1964.

37. Oklahoma Directory of Manufacturers and Products: 1967, Oklahoma Industrial Development and Park Department, Oklahoma City, 1967.

38. U. S. Department of Commerce, Bureau of the Census, 1963, Census of Manufacturers, Vol. 1, Washington, D. C., 1966.

39. U. S. Department of the Interior, Water - The Key to Oklahoma's Future: Interim Appraisal of the Oklahoma Basins Project, Bureau of Reclamation, Washington, D. C., 1967.

40. Reported Water Use in Oklahoma, Oklahoma Water Resources Board, Pub. 28, 1969.

41. Reid, G. W. and Wilson, F., Water - Facts and Futures, Bureau of Water Resources Research, University of Oklahoma, Norman, 1959.

42. Oklahoma's Long-Range Water Requirements, Bureau of Water Resources Research and Bureau of Business Research, University of Oklahoma, Norman, 1965.

43. U. S. Congress, Senate, Water Resources Activities in the United States: Land and Water Potentials and Future Requirements for Water, 86th Cong., 1st Sess., 1960.

44. A Report of Estimated Water Requirements for Agricultural Purposes and Their Effect of Water Supplies in the Years 1980 and 2000, United States Department of Agriculture, 1959.

45. Water: Oklahoma's No. 1 Problem, Bureau of Water Resources Research and Oklahoma Water Resources Board, Norman, 1960.

46. "Water: A Special Report," Power, New York, June, 1966.

47. Murray, C. R., "Water Use in the United States in 1965," Jour. AWWA, Vol. 61, No. 11, Nov., 1969, pp. 567-571.

48. A Report on the State Plan for Water and Sewer Development of 50 Cities, Oklahoma Water Resources Board, Unpublished Report, 1970.

49. Piper, A. M., Has the United States Enough Water?, U. S., Department of Interior, 1968.

50. "Third Quarterly Cost Report," Engineering News Record, Vol. 183, No. 12, Sept. 18, 1969, pp. 106-172.

51. Comparative Cost Factors for Water Supply Systems, Tulsa Metropolitan Area Planning Commission, WSS-VII, Tulsa, 1968.

52. Standardized Procedure for Estimating the Costs of Conventional Water Supplies, Black and Veatch, Kansas City, 1963.

53. Dawes, J. H., Tools for Water Resource Study, ASCE, Preprint 1074, Chicago, Oct., 1969.

54. Fair, G. M. and Geyer, J. C., Water Supply and Waste-Water Disposal, Wiley, New York, 1967.

55. Steel, E. W., Water Supply and Sewerage, McGraw-Hill, New York, New York, 1960.

56. U. S. Government Subcommittee on Evaluation Standards, Proposed Practices for Economic Analysis of River Basin Projects, Report to the Inter-Agency Committee on Water Resources, Washington, D. C., 1958.

57. Kalter, R. J., et alia, Criteria for Federal Evaluation of Resource Investments, Water Resources and Marine Sciences Center, Cornell University, Ithica, New York, 1969.

58. The Strategy for Economic Development in Oklahoma, Division of Research and Planning, Oklahoma Industrial Development and Park Department, Oklahoma City, 1967.

59. Hufschmidt, M. M. and Fiering, M. B., Simulation Techniques for Design of Water-Resources Systems, Harvard University Press, Cambridge, 1966.

60. Kollar, K. L. and Brewer, R., "Water Requirements for Manufacturing," Jour. AWWA, Vol. 60, No. 10, Oct., 1968, pp. 1129-1140.

61. Tozzi, J. J., Establishing Priorities for Public Investments, Office of the Army, 1969.

62. Schmer, F. A. and Trock, W. L., Evaluation of Resource Use and Economic Effects Due to Irrigation Water Availability in Texas, Water Resources Institute, Texas A & M University, College Station, Texas, 1969.

63. Goddard, M. K., "The East Speaks," Jour. ASCE, Vol. 93, No. SA4, Aug., 1967, pp. 31-40.

64. Kneese, A. V., Economic and Related Problems in Contemporary Water Resources Management, RFF, Reprint No. 55, Washington, D. C., 1965.

65. "Preliminary Census Results," The Daily Oklahoman, Vol. 79, No. 138, May 22, 1970.

66. Homan, A. G. and Dikeman, N. J., Jr., "Population Forecasts: Oklahoma SMSA's and Counties, 1960-1980," Oklahoma Business Bulletin Supplement, No. 2, Norman, 1969.

APPENDIX A

OPERATIONAL DEFINITION OF THE WATER SECTOR

(Outline)

I. Water Resources and Demands

   A. Water Resources

      1. Natural Resources

         a. Rainfall and runoff

         b. Surface water

         c. Ground water

      2. Development of Water Sources

         a. Dams and impoundments (reservoirs)

         b. Wells

         c. Reuse systems

      3. Variability

         a. Climatological

         b. Depletion

      4. Quality of Water Sources

         a. Acceptability

         b. Relative treatment requirements

5. Water Law

    a. Riparian rights

    b. Jurisdiction

B. Water Demands

1. Demands by Use Group

    a. Municipal

        i. Domestic

        ii. Commercial

        iii. Public

        iv. Losses

    b. Industrial

    c. Agricultural (Irrigation)

2. Unit Uses by Use Group

    a. Present demands

    b. Future demands

3. Variation in Rate of consumption

    a. Average consumption

        i. Annual

        ii. Daily

        iii. Hourly

    b. Peak consumption

        i. Annual

        ii. Daily

        iii. Hourly

II. Water Supply System

A. Water Treatment

1. Required Treatment

a. Raw water quality

b. Quality requirements

i. Domestic

a) U. S. Public Health Service

b) State Health Department

ii. Industrial

iii. Other

2. Type of Treatment

a. Coagulation

b. Sedimentation

c. Filtration

d. Disinfection

e. Demineralization

3. Treatment Plants

a. Domestic water

b. Industrial water

c. Dual system

d. Reuse

B. Water Conveyance

1. Raw Water Transmission

a. Pipeline

i. Size

ii. Distance

iii. Losses

b. Pumping

i. Pumps and pump stations

ii. Power requirements

c. Storage

2. Treated Water Distribution

a. Pipe network

i. Single or dual

ii. Primary, secondary and distribution mains

iii. Losses

b. Pressure in system

i. Gravity distribution

ii. Pumping

C. Storage

1. Elevated

2. Reservoir

3. Fireflow requirements

III. Economics of the Water Sector

A. Costs

1. Cost Factors

a. Water Rights

i. Leasing of storage space

ii. Purchase of water

b. Pipelines

i. Size

ii. Distance

c. Pumping

i. Elevations

ii. Function Loss

iii. Power Requirements

d. Storage

i. Raw water storage

ii. Distribution network storage

e. Treatment plants

i. Type of treatment

ii. Economics of scale (plant size and demands)

2. Cost Components

a. First costs

i. Design

ii. Land acquisition

iii. Construction

iv. Equipment

b. Operation and maintenance

i. Personnel

ii. Power

iii. Equipment

iv. Replacement

B. Financing

1. Methods of financing

a. Federal sources

b. Taxes

i. Ad valorem tax

ii. Income tax

iii. User's tax

c. Special assessments

d. Bonds

i. General obligation bonds

ii. Limited obligation bonds

iii. Revenue bonds

iv. Special levy bonds

2. City classified manufacturing employment, 1967-1970

   a. Total

   b. By 2-digit SIC code

B. Income

1. County per capita income, 1968, 1970

2. County personal income, 1968, 1970

IV. Water System Facilities Inventory

A. Existing Capacities

1. Pipelines

2. Treatment plants

3. Storage

B. Use Rates

1. Average daily

2. Maximum daily

C. Irreversible Decisions to Expand System

1. Increased capacity

V. Resource Inventory

A. Climatology

1. Mean annual precipitation by region

2. Mean annual temperature by region

3. Mean annual evaporation by region

4. Mean annual precipitation minus evapotransporation by region

B. Geology

1. Drainage basin identification

2. Soil characteristics by region

3. Rock formations by region

C. Hydrology

1. Surface water

a. Mean annual runoff by region

b. Stream systems

i. Mean annual streamflows

ii. Extreme flows

iii. Maximum reliable yield

c. Pond, reservoir and lake storage

i. Capacity

ii. Maximum reliable yield

d. Limitations of available supply due to interstate requirements

2. Ground water

a. Location and movement

b. Recharge rate

c. Maximum safe yield

3. Water quality

a. Dissolved solids

b. Sulphates and chlorides

c. Sodium

VI. Water Use Patterns Inventory

A. Municipal Use

1. Average daily use

2. Maximum daily use

3. Consumptive use

B. Rural use

1. Average daily use per capita

2. Consumptive use

C. Industrial Use

1. Annual use for manufacturing establishments

a. By 2-digit SIC code

b. By Census years, 1963, 1968

2. Consumptive use

D. Agricultural Use

1. County per acre irrigation requirements

2. Consumptive use

VII. Cost Inventory

A. Cost Factors

1. Capital cost

a. Engineering design

b. Land and right-of-way

c. Construction

d. Administration

e. Amortization

i. Interest rate

ii. Number of periods

2. Operation and maintenance

a. Labor

b. Material

c. Administration and overhead

3. Chemical

4. Power

5. Water rights

6. Cost trending

    a. ENR index

B. Types of Costs

1. Water source cost

    a. Reservoirs

    b. Stream diversion

    c. Wells

2. Transmission cost

    a. Pipelines

    b. Pumping stations

3. Treatment cost

    a. Treatment plant

    b. Raw water storage

    c. Pumping plant

4. Distribution cost

    a. Storage

    b. Water mains

    c. Pumping stations

VIII. Financial Inventory

A. Direct Sources of Financing

1. Income

    a. Taxes

    b. Sinking funds

    c. Bonds

    d. Revenues

2. Expenses

a. Annual operating costs

b. Annual bond costs

B. Financial Assistance

1. State

2. Federal

IX. Legal Inventory

A. Codes and Ordinances

1. Minimum service requirements

2. Quality standards

B. Legal Agreements

1. Water purchases

2. Water storage

C. Statutes

1. Water rights

a. Doctrine of riparian rights

b. Doctrine of prior appropriation

i. Interbasin transfers

2. Planning jurisdiction

3. Public health enforcement

X. Socio-Political Factors

A. Interest groups

1. Rural

2. Industrial

3. Urban

4. Ecological

APPENDIX C

VERIFICATION OF THE WATER MODEL

An Application of the Water Requirements Forecasting Model to the Ozarks Development Region

The following is a description of a verification study of the water requirements forecasting model presented in Chapter II for the Ozarks Region under the sponsorship of the Ozarks Regional Commission, the Oklahoma Water Resources Board (OWRB) and the Oklahoma Industrial Development and Park Department. The scope of this study was limited due to financial and political considerations and does not entirely agree with the scope described for a state-wide planning study.

The political requirements of the funding agency only allowed for the study of the 37 counties shown in Figure C - 1. As a result only portions of the water planning regions for Oklahoma which overlap on three counties are studied. Furthermore, the OWRB redefined some of the planning region boundaries to suit the political boundaries.

Finally, rather than include all of the cities of over 1,000 population, financial limitations caused the OWRB to include only 50 cities trying to include at most

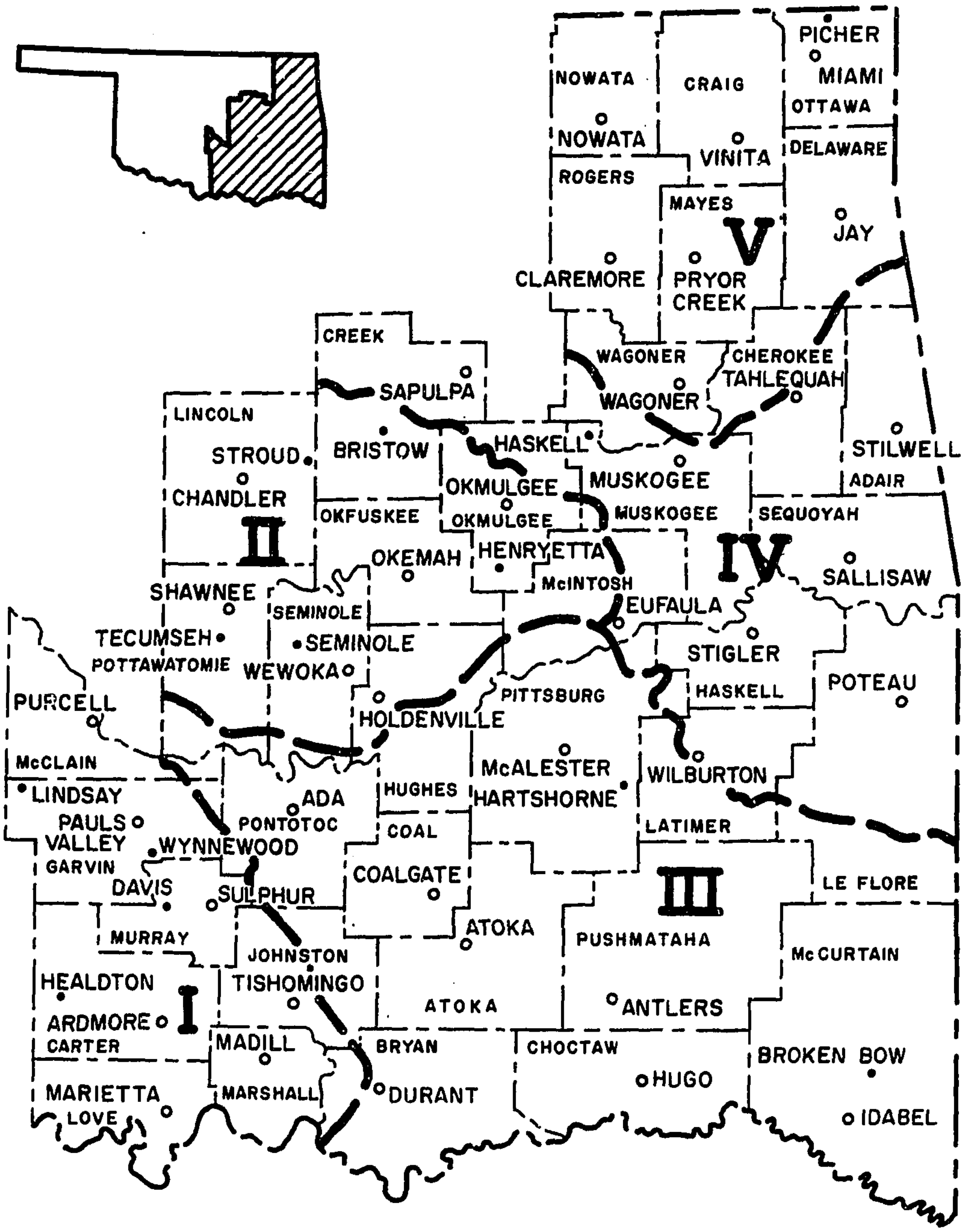

Fig. C - 1.--Ozarks Regional Commission Study Area two from each county (Figure C - 1).

The base year for the study was set at 1968, and a field survey was initiated to acquire some of the essential data items not readily available from conventional sources. From the survey, which involved a representative from the OWRB interviewing the water works superintendent of each of the 50 cities, the information in Table C - 1 was assembled. Starting with this data and the other essential inputs described in Appendix B, a series of intermediate tables was developed reflecting the steps of the process described in Figure 9 of Chapter II and leading to the results shown in Table C - 13.

All of the Tables which are presented at the end of this appendix are described below together with a discussion of how they were derived.

Explanation of Tables

Table C - 1 presents the essential municipal water systems data for the 50 cities of the Ozarks Region. This and other data was collected by the OWRB. Items shown are the maximum reliable yield from all supply sources for any day of the year, the average daily pumpage in 1968, the water treatment plant peak design capacity, the total capacity of all treated water storage facilities, and the maximum or peak day use in 1968.

Table C - 2 presents the county population forecasts from 1970 to 1990 in semidecade intervals for each county in the Ozarks Region. These forecasts were developed by means of the exponential smoothing disaggregation technique described in Chapter II. The inputs from the Reid Model were the following State population projections:

1970 population - 2,585,446
1975 population - 2,697,278
1980 population - 2,823,579
1985 population - 2,985,297
1990 population - 3,158,915

Table C - 3 presents the population forecasts for the 50 cities in the Ozarks Region from 1970 to 1990 in semidecade intervals. The cities are grouped by regions for later identification. These forecasts are based on disaggregations from county figures given in Table C - 2 taking into account both the county population trend and the county per cent urbanization trend as discussed in Chapter II.

Table C - 4 presents the rural population forecasts by county from 1970 to 1990 in semidecade intervals. The figures in this table are found by subtracting the city populations of Table C - 3 from the corresponding county populations of Table C - 2.

Table C - 5 and C - 6 present the employment forecasts for the processing and fabricating industries, respectively, for each city in the Ozarks Region. The same time periods from 1970 to 1990 are used. Note that this is for classified employment. These figures were disaggregated from the total State manufacturing employment projections of the Reid model. These total values were:

1970 manufacturing employment - 137,700
1975 manufacturing employment - 151,900
1980 manufacturing employment - 166,100
1985 manufacturing employment - 181,300
1990 manufacturing employment - 196,300

Table C - 7 presents the forecasts of the acres of irrigated land in each county of the Ozarks Region for the specified years. These forecasts were arrived at by the methods described in Chapter II for the agricultural sector.

Table C - 8 presents in million gallons per day the municipal water requirement forecasts for the 50 cities in the study area at five year intervals from 1970 to 1990. These values were derived from the population forecasts of Table C - 3 using the water use coefficient equation of Chapter II (equation 1), i.e.,

$$W_{Mi}^{t} = (89 + .002 M_i^t) M_i^t \quad \ldots\ldots\ldots\ldots \quad \text{eq. } 28$$

where the notation is similar to that used in Chapter II, and M_i^t is obtained from Table C - 3.

Tables C - 9 and C - 10 present the industrial water requirements forecasts in million gallons per day for the processing and fabricating industries, respectively. The forecasts are presented by city and region for the specified years. The figures were obtained using the employment forecasts of Table C - 4 and C - 5 and their respective water use coefficients, 6507 and 378 gallons per employee per day.

Table C - 11 presents the water requirement forecasts in million gallons per day for the rural population during the specified years both by region and county. For each region only the counties or portions of counties included in the region are included. The percentages shown for counties divided by regional boundaries correspond to the ${}_kK_j$ factors discussed in Chapter II. The county forecasts were derived from Table C - 4 using the time-dependent water use coefficient given by equation 6 of Chapter II.

Table C - 12 presents irrigation water requirement forecasts in acre-feet per year for 1970 to 1990 by region and county. Here again the ${}_kK_j$ factors were used as described above. The forecast values were derived from Table C - 7 using the water use coefficients given in Figure 9 of Chapter II.

Table C - 13 presents a summary of total regional water requirements for all uses from 1970 to 1990 in semi-decade intervals. Notice the total municipal, industrial and rural requirements are presented in million gallons per day while irrigation requirements are in acre-feet per year. However, for the grand total column, the irrigation requirements units were converted from acre-feet per year to million gallons per day. Table C - 13, naturally, summarizes the findings of Tables C - 8, C - 9, C - 10, C - 11, and C - 12.

Validation of Results

Wherever possible, the results of this study have been compared (1) to other forecasts of a similar nature to determine degree of correspondence, or (2) to historical data to determine if there is any divergence from established trends.

The county population estimates for 1970 were checked against the preliminary 1970 Census results (65) and forecasts provided by the Bureau of Business and Economic Research (66). For the State, total population estimates were: (a) Census - 2,500,300; (b) BBER - 2,551,000; and (c) this study - 2,585,500. Compared to the Census figures, the estimate of this study is 3.3 per cent high and the BBER estimate is 2.0 per cent high. For the 37 county Ozarks Region the population figures were: (a) Census - 769,600; (b) BBER - 779,200; and (c) this study - 756,600. On a comparative basis with census figures this study is 1.7 per cent low and the BBER estimate is 1.3 per cent high. Thus the population projections appear to be fairly consistent for 1970.

The municipal water requirements estimate for 1970 for the Ozarks Region is 42.6 million gallons per day (Table C - 8). The 1968 total pumpage for the same area is 47.5 million gallons per day (Table C - 1). However, this latter figure includes 3.4 million gallons per day for classified industrial establishments tied into the municipal systems and 2.0 million gallons per day in sales to adjacent rural communities. Adjusting the total figure by subtracting the two double-counted uses yields a 1968 pumpage for purely municipal use of 42.1 million gallons per day. Therefore, the total increase in water use over the last two years is ½ million gallons per day, or about the amount of water required for an additional 5,000 persons. This appears to be reasonable since it represents a growth rate of 0.7% for municipal dwellers in the Ozarks area.

In 1968 there were 38,644 acres of irrigated land in the 37 county Ozarks Region (40). At an average rate of 1.5 acre-feet per acre per year the water used for irrigation in 1968 in the Ozarks Region would be about 49 million gallons per day. Using the average 13 per cent increase in water use for irrigation across the State and applying it to the Ozarks Region would bring the 1970 estimate to about 62 million gallons per day. The results of this study show a 1970 estimate of 60.5 million gallons per day (Table C-13). It seems reasonable to conclude that this estimate is in line with recent trends in Oklahoma.

For the present there appears to be no way of validating the industrial use estimates. However, later in this year the results of the 1968 Census of Manufacturers should be released, and it will contain estimates of water use for manufacturers for 1968. This data will be presented for Oklahoma, but can, perhaps, be scaled to the Ozarks Region for a check. An appropriate scale factor would be 31 per cent of total Oklahoma use since the Ozarks Region contains 31% of the industrial population in the State.

An interesting overall comparison can be made with estimates made in 1965 in "Oklahoma's Long-Range Water Requirements" (42) although the comparison is not very meaningful. By using scale factors of 31 per cent for industry, 30 per cent for population and 7.5 per cent for irrigation (these figures represent the per cent of the State's respective "populations" in the Ozarks Region in 1970) and disaggregating from total State forecasts for 1970, the total water requirements for the Ozarks Region would be 208 million gallons per day. This study shows a total estimate for 1970 of 216 million gallons per day (Table C - 13). The difference in the two figures can be explained by the large underestimate of irrigation requirements in the 1965 study due to an underestimate of acres being irrigated.

Although this above verification procedure is not very rigorous, it appears to be the only approach available in this area due to the lack of consistent and up-to-date use data. While nothing is proven, at least no glaring discrepancies are revealed, and a measure of confidence is gained.

Based on this pilot study, it appears that the application of this model to the total State, as described in the original scope of the planning process, should be undertaken.

TABLE C - 1

MUNICIPAL WATER SYSTEMS DATA, 1968

City	Maximum Reliable Yield of Source[a]	Average Pumpage	Water Treatment Plant Capacity[b]	Treated Water Storage Capacity	Maximum 24-Hour Use
	MGD	MGD	MGD	MG	MGD
Region I					
Ardmore	7.15	4.00	6.00	2.75	6.00
Davis	482.13	.25	2.50	1.25	.31
Healdton	n/a	n/a	N.T.	.08	n/a
Lindsay	1.00	.50	N.T.	1.50	n/a
Madill	n/a	.28	.86	.36	.42
Marietta	.50	.15	N.T.	.10	.30
Pauls Valley	n/a	1.00	1.73	2.25	1.73
Purcell	n/a	.38	2.16	2.30	n/a
Sulphur	2.59	.80	n/a	.30	1.00
Tishomingo	n/a	.39	1.50	.58	.60
Wynnewood	1.00	.20	1.29	.49	1.15
Region II					
Bristow	n/a	.36	N.T.	1.15	n/a
Chandler	.67	.24	1.00	1.00	.75
Henryetta	n/a	.73	n/a	2.25	.85

[a]Maximum Reliable Yield is the maximum amount of water that can be expected from all sources for any day of the year.

[b]Treatment plant capacity is the maximum amount of water that can be treated and pumped in one day.

TABLE C - 1--Continued

City	Maximum Reliable Yield of Source	Average Pumpage	Water Treatment Plant Capacity	Treated Water Storage Capacity	Maximum 24-Hour Use
	MGD	MGD	MGD	MG	MGD
Region II (continued)					
Holdenville	n/a	.50	5.76	2.50	.70
Okemah	1.00	.23	1.00	.33	1.00
Okmulgee	5.00	2.83	6.00	2.00	n/a
Seminole	2.74	.96	n/a	2.56	1.60
Shawnee	13.10	2.06	5.00	2.00	4.50
Stroud	1.47	.23	.72	.40	n/a
Tecumseh	.60	.25	.46	.22	.31
Wewoka	n/a	.45	2.00	1.50	1.00
Region III					
Ada	7.50	4.00	7.50	6.60	7.50
Antlers	n/a	.26	.75	.30	.60
Atoka	n/a	.25	.75	.83	.50
Broken Bow	1.00	.33	1.00	.40	1.00
Coalgate	n/a	.14	.43	.58	.50
Durant	15.00	3.20	5.00	5.00	5.00
Hartshorne	n/a	.18	n/a	.23	.18
Hugo	1.5	.70	n/a	1.50	1.00
Idabel	3.30	.68	1.50	.67	1.00
McAlester	9.40	1.83	2.50	.35	3.23

TABLE C - 1--Continued

City	Maximum Reliable Yield of Source MGD	Average Pumpage MGD	Water Treatment Plant Capacity MGD	Treated Water Storage Capacity MG	Maximum 24-Hour Use MGD
Region IV					
Eufala	50.00	.33	.60	.80	.60
Haskell	n/a	.13	N.T.	2.00	n/a
Muskogee	34.39	7.80	22.00	10.00	17.00
Poteau	1.50	.62	1.00	1.85	1.00
Sallisaw	.73	.59	1.50	.30	1.25
Sapulpa	n/a	1.90	6.00	4.00	5.50
Stigler	n/a	.44	1.50	.50	1.10
Stilwell	1.00	.28	4.00	1.00	4.00
Tahlequah	3.00	1.06	3.00	2.00	3.00
Wilburton	1.50	.50	1.20	1.00	.60
Region V					
Claremore	n/a	1.00	4.00	.51	2.00
Jay	n/a	.50	1.00	.05	.65
Miami	n/a	1.25	N.T.	2.00	n/a
Nowata	2.88	.42	1.50	1.10	.95
Picher	.27	.27	N.T.	.60	n/a
Pryor	25.00	1.02	Purchase	.75	n/a
Vinita	3.24	1.29	4.00	1.35	n/a
Wagoner	2.59	.40	1.20	2.10	.55

TABLE C - 2

COUNTY POPULATION FORECASTS, 1970-1990

County	Population				
	1970	1975	1980	1985	1990
Adair	15000	14700	14600	15500	16400
Atoka	10400	10000	9800	10300	10600
Bryan	23900	23100	22400	23700	25100
Carter	37100	36800	37400	39500	41800
Cherokee	19100	19300	19700	20800	22000
Choctaw	13600	12200	11000	11700	12300
Coal	5400	5900	6400	6900	7400
Craig	15500	15600	15800	16700	17600
Creek	45300	47300	50700	53600	56720
Delaware	13600	13800	14000	14800	15700
Garvin	29500	28700	28100	29700	39400
Haskell	8500	7300	6400	6800	7200
Hughes	13300	12100	11100	11700	12400
Johnston	8200	7500	6900	7300	7700
Latimer	7800	7400	7300	7700	8200
LeFlore	31100	27900	26100	27600	29300
Lincoln	18600	18700	18900	20000	21200
Love	5500	5000	4500	4800	5000
McClain	12600	12400	12200	12900	13700

TABLE C - 2--Continued

County	Population				
	1970	1975	1980	1985	1990
McCurtain	28300	29400	31500	33400	35300
McIntosh	10900	8900	7000	7400	7900
Marshall	6500	6200	6000	6300	6700
Mayes	20400	21500	22600	23800	25200
Murray	10100	10000	9900	10500	11100
Muskogee	61300	62600	64100	67900	71800
Nowata	9900	9700	9600	10100	10700
Okfuskee	11800	9600	8800	9300	9800
Okmulgee	35200	33400	31000	32700	34700
Ottawa	28700	28700	28700	3[illegible]500	32300
Pittsburg	34100	32300	30600	32300	34200
Pontotoc	27900	28000	28300	29900	31700
Pottawatomie	46300	48200	49000	51900	54900
Pushmataha	9100	8900	8700	9200	9800
Rogers	21200	22000	22800	24100	25600
Seminole	27900	27800	27800	29400	31100
Sequoyah	17500	16800	16200	17200	18200
Wagoner	15500	14900	14400	15200	16100

TABLE C - 3

CITY POPULATION FORECASTS, 1970-1990

City	Population				
	1970	1975	1980	1985	1990
Region I					
Ardmore	22900	22700	23100	24400	25800
Davis	2200	2200	2200	2300	2500
Healdton	3100	3100	3100	3300	3500
Lindsay	4600	4500	4400	4600	4900
Madill	2900	2800	2700	2900	3100
Marietta	2000	1900	1700	1800	1900
Pauls Valley	7400	7200	7100	7500	7900
Purcell	3700	3700	3600	3800	4100
Sulphur	4800	4700	4700	5000	5300
Tishomingo	2300	2100	2000	2100	2200
Wynnewood	2700	2600	2600	2700	2900
Region II					
Bristow	5700	5900	6400	6800	7200
Chandler	2600	2600	2600	2800	2900
Henryetta	7200	6900	6400	6700	7100
Holdenville	6300	5700	5200	5500	5900
Okemah	3000	2400	2300	2400	2500

TABLE C - 3--Continued

City	Population				
	1970	1975	1980	1985	1990
Region II (continued)					
Okmulgee	17000	16100	14900	15800	16700
Seminole	12000	12000	12100	12800	13600
Shawnee	29000	30200	30700	32400	34300
Stroud	2500	2500	2500	2700	2800
Tecumseh	3000	3100	3200	3400	3600
Wewoka	6200	6200	6300	6700	7100
Region III					
Ada	16000	16100	16200	17200	18200
Antlers	2100	2100	2000	2200	2300
Atoka	2900	2800	2800	2900	3100
Broken Bow	2400	2500	2700	2900	3100
Coalgate	1600	1800	2000	2100	2300
Durant	12000	11600	11200	11900	12600
Hartshorne	2200	2100	2000	2200	2300
Hugo	5700	5200	4700	5000	5300
Idabel	7600	7900	8400	8900	9400
McAlester	19200	18200	17000	18200	19200

TABLE C - 3--Continued

City	Population				
	1970	1975	1980	1985	1990
Region IV					
Eufala	2100	1800	1400	1500	1600
Haskell	2000	2000	2100	2200	2300
Muskogee	40000	40800	41800	44200	46800
Poteau	6300	5600	5300	5600	5900
Sallisaw	3300	3200	3100	3300	3500
Sapulpa	18300	19100	20500	21700	23000
Stigler	1900	1800	1600	1600	1700
Stilwell	2500	2500	2500	2600	2800
Tahlequah	6300	6400	6500	6900	7300
Wilburton	2400	2300	2200	2400	2500
Region V					
Claremore	9100	9400	9800	10400	11000
Jay	1200	1200	1200	1300	1400
Miami	14000	14000	14100	14900	15800
Nowata	3900	3600	3800	4000	4300
Picher	2900	2900	3000	3200	3400
Pryor	8000	8600	8800	9400	9900
Vinita	7000	7000	7100	7500	7900
Wagoner	4400	4300	4100	4400	4600

TABLE C - 4

RURAL POPULATION FORECASTS, 1970-1990

County	Rural Population				
	1970	1975	1980	1985	1990
Adair	12400	12300	12100	12800	13600
Atoka	7500	7200	7000	7400	7900
Bryan	11900	11500	11100	11800	12500
Carter	11100	11000	11200	11800	12500
Cherokee	12800	12900	13200	13900	14700
Choctaw	7900	6900	6300	6600	7000
Coal	3800	4100	4500	4800	5100
Craig	8500	8600	8700	9200	9700
Creek	21300	22200	23800	25700	26600
Delaware	12400	12600	12800	13500	14300
Garvin	14900	14400	14100	14800	15700
Haskell	6600	5900	4900	5200	5500
Hughes	7000	6400	5900	6200	6600
Johnston	5900	5400	4900	5200	5500
Latimer	5400	5200	5100	5400	5700
LeFlore	24800	22200	20900	22100	23400
Lincoln	13600	13700	13800	14600	15400
Love	3500	3100	2800	2900	3100
McClain	8900	8700	8600	9100	9600

TABLE C - 4--Continued

County	Rural Population				
	1970	1975	1980	1985	1990
McCurtain	18300	19000	20400	21600	22800
McIntosh	8800	7200	5600	5900	6300
Marshall	3600	3400	3300	3400	3600
Mayes	12300	12900	13600	14400	15300
Murray	3200	3100	3000	3200	3300
Muskogee	19400	19800	20300	21400	22700
Nowata	6000	6100	5800	6100	6500
Okfuskee	8800	7100	6500	6900	7300
Okmulgee	11000	10400	9700	10200	10800
Ottawa	11700	11700	11700	12400	13100
Pittsburg	12800	12000	11600	12000	12700
Pontotoc	11900	12000	12100	12800	13500
Pottawatomie	14300	14900	15200	16000	17000
Pushmataha	7000	6800	6700	7100	7500
Rogers	12100	12500	13000	13800	14600
Seminole	9700	9500	9400	9900	10400
Sequoyah	14200	13600	13100	13900	14700
Wagoner	11100	10700	10300	10900	11500

TABLE C - 5

EMPLOYMENT FORECASTS FOR PROCESSING INDUSTRIES, 1970-1990

City	Employment				
	1970	1975	1980	1985	1990
Region I					
Ardmore	805	888	971	1060	1148
Davis	63	69	75	83	89
Healdton	0	0	0	0	0
Lindsay	0	0	0	0	0
Madill	6	7	8	8	9
Marietta	173	191	208	227	246
Pauls Valley	48	53	57	63	68
Purcell	6	7	8	8	9
Sulphur	47	51	56	62	67
Tishomingo	0	0	0	0	0
Wynnewood	273	301	330	360	389
Region II					
Bristow	57	63	69	75	82
Chandler	8	9	10	11	12
Henryetta	1518	1675	1832	2000	2163
Holdenville	0	0	0	0	0
Okemah	0	0	0	0	0

TABLE C - 5--Continued

City	Employment				
	1970	1975	1980	1985	1990
Region II (continued)					
Okmulgee	1267	1389	1529	1670	1806
Seminole	150	165	180	196	213
Shawnee	619	682	746	815	882
Stroud	128	141	154	169	182
Tecumseh	0	0	0	0	0
Wewoka	39	43	47	52	56
Region III					
Ada	861	950	1039	1134	1227
Antlers	39	43	47	52	56
Atoka	19	21	23	25	27
Broken Bow	0	0	0	0	0
Coalgate	17	19	20	22	24
Durant	382	422	461	504	545
Hartshorne	15	16	18	20	21
Hugo	165	182	199	217	236
Idabel	29	32	35	38	41
McAlester	362	400	437	477	517

TABLE C - 5--Continued

City	Employment 1970	1975	1980	1985	1990
Region IV					
Eufala	11	12	13	14	15
Haskell	111	123	134	147	159
Muskogee	2329	2570	2810	3067	3321
Poteau	13	14	15	17	19
Sallisaw	101	111	122	132	144
Sapulpa	1460	1611	1762	1924	2080
Stigler	164	181	198	216	234
Stilwell	529	584	639	697	755
Tahlequah	22	25	27	29	32
Wilburton	0	0	0	0	0
Region V					
Claremore	30	33	36	39	43
Jay	53	59	64	70	75
Miami	363	400	437	477	516
Nowata	32	35	38	42	45
Picher	0	0	0	0	0
Pryor	781	861	942	1028	1113
Vinita	48	53	57	63	68
Wagoner	17	19	20	22	24

TABLE C - 6

EMPLOYMENT FORECASTS FOR FABRICATING INDUSTRIES, 1970-1990

City	Employment				
	1970	1975	1980	1985	1990
Region I					
Ardmore	3112	3432	3754	4097	4436
Davis	383	423	463	505	546
Healdton	54	60	65	71	80
Lindsay	350	387	423	462	500
Madill	369	407	455	486	525
Marietta	413	456	498	544	598
Pauls Valley	41	46	50	54	59
Purcell	120	132	144	158	171
Sulphur	20	22	24	26	28
Tishomingo	16	18	19	21	23
Wynnewood	79	88	96	105	113
Region II					
Bristow	320	353	386	422	456
Chandler	50	55	60	66	71
Henryetta	120	132	144	157	170
Holdenville	551	608	665	726	786
Okemah	279	308	337	368	398

TABLE C - 6--Continued

City	Employment				
	1970	1975	1980	1985	1990
Region II (continued)					
Okmulgee	220	243	266	290	314
Seminole	677	747	817	892	966
Shawnee	915	1009	1103	1204	1304
Stroud	10	11	12	13	14
Tecumseh	0	0	0	0	0
Wewoka	608	617	734	801	869
Region III					
Ada	780	860	940	1026	1111
Antlers	431	475	519	566	613
Atoka	20	22	24	26	28
Broken Bow	409	451	493	538	583
Coalgate	257	284	311	339	367
Durant	502	544	606	661	716
Hartshorne	243	268	293	320	346
Hugo	165	182	199	217	235
Idabel	1375	1517	1659	1811	1961
McAlester	4453	4912	5371	5863	6348

TABLE C - 6--Continued

	Employment				
	1970	1975	1980	1985	1990
Region IV					
Eufala	17	19	21	23	25
Haskell	0	0	0	0	0
Muskogee	1337	1475	1613	1761	1907
Poteau	344	379	414	452	489
Sallisaw	142	157	172	188	204
Sapulpa	604	666	728	795	816
Stigler	445	491	537	586	634
Stilwell	104	114	125	136	147
Tahlequah	46	51	56	61	66
Wilburton	265	292	319	348	377
Region V					
Claremore	266	293	320	349	378
Jay	0	0	0	0	0
Miami	2875	3171	3467	3784	4097
Nowata	237	261	285	311	337
Picher	29	32	35	38	41
Pryor	690	761	832	908	983
Vinita	390	430	470	513	555
Wagoner	10	11	12	13	14

TABLE C - 7

IRRIGATED LAND FORECASTS, 1970-1990

County	Acres of Irrigated Land				
	1970	1975	1980	1985	1990
Adair	1085	1357	1631	1904	2714
Atoka	458	593	688	804	919
Bryan	7250	9073	10896	12719	14542
Carter	545	682	819	956	1093
Cherokee	710	889	1069	1246	1425
Choctaw	1484	1857	2231	2604	2977
Coal	79	97	117	137	156
Craig	0	0	0	0	0
Creek	59	74	89	103	118
Delaware	267	334	401	468	535
Garvin	5740	7184	8627	10070	11514
Haskell	13	17	20	23	27
Hughes	2804	3509	4214	4919	5624
Johnston	1319	1650	1982	2313	2645
Latimer	22	28	33	39	45
LeFlore	2374	2971	3567	4164	4761
Lincoln	308	385	463	540	816
Love	895	1120	1345	1570	1795
McClain	2756	3349	4142	4835	5528

TABLE C - 7--Continued

County	Acres of Irrigated Land				
	1970	1975	1980	1985	1990
McCurtain	1151	1440	1729	2019	2308
McIntosh	0	0	0	0	0
Marshall	217	271	326	380	435
Mayes	0	0	0	0	0
Murray	2533	3170	3806	4443	5080
Muskogee	2249	2815	3380	3946	4511
Nowata	79	97	117	137	156
Okfuskee	412	516	620	724	827
Okmulgee	51	67	77	90	103
Ottawa	33	42	50	59	67
Pittsburg	347	434	521	609	696
Pontotoc	1058	1325	1591	1857	2123
Pottawatomie	1978	2475	2973	3470	3967
Pushmataha	838	1049	1260	1471	1681
Rogers	951	1190	1429	1668	1907
Seminole	915	1145	1375	1605	1835
Sequoyah	1641	2054	2466	2879	3292
Wagoner	345	431	518	605	691

TABLE C - 8

MUNICIPAL WATER REQUIREMENT FORECASTS, 1970-1990

City	Millions of Gallons of Water Required per Day				
	1970	1975	1980	1985	1990
Region I					
Ardmore	2.88	2.93	3.04	3.29	3.56
Davis	.23	.24	.24	.26	.29
Healdton	.32	.33	.35	.38	.42
Lindsay	.49	.49	.50	.54	.58
Madill	.31	.31	.31	.33	.36
Marietta	.21	.20	.19	.21	.22
Pauls Valley	.81	.81	.81	.88	.96
Purcell	.40	.40	.40	.44	.47
Sulphur	.51	.52	.53	.59	.62
Tishomingo	.23	.23	.22	.23	.24
Wynnewood	.29	.29	.29	.31	.34
Region II					
Bristow	.62	.67	.73	.80	.86
Chandler	.27	.28	.28	.31	.33
Henryetta	.80	.78	.73	.79	.86
Holdenville	.68	.64	.59	.65	.70
Okemah	.32	.26	.25	.27	.30

TABLE C - 8--Continued

City	Millions of Gallons of Water Required per Day				
	1970	1975	1980	1985	1990
Region II (continued)					
Okmulgee	2.04	1.97	1.84	2.01	2.17
Seminole	1.38	1.42	1.45	1.59	1.73
Shawnee	3.85	4.10	4.26	4.64	5.05
Stroud	.26	.27	.28	.31	.33
Tecumseh	.32	.34	.35	.39	.42
Wewoka	.68	.70	.72	.79	.85
Region III					
Ada	1.90	1.96	2.01	2.20	2.38
Antlers	.22	.22	.22	.24	.26
Atoka	.31	.31	.31	.33	.36
Broken Bow	.26	.28	.30	.33	.35
Coalgate	.17	.19	.21	.24	.26
Durant	1.34	1.37	1.34	1.46	1.59
Hartshorne	.23	.23	.22	.24	.26
Hugo	.62	.57	.53	.58	.73
Idabel	.84	.90	.98	1.07	1.15
McAlester	2.34	2.25	2.12	2.35	2.56

TABLE C - 8--Continued

City	Millions of Gallons of Water Required per Day				
	1970	1975	1980	1985	1990
Region IV					
Eufala	.23	.19	.15	.17	.18
Haskell	.21	.22	.23	.25	.27
Muskogee	5.71	5.99	6.27	6.85	7.49
Poteau	.69	.63	.60	.65	.70
Sallisaw	.35	.35	.35	.38	.41
Sapulpa	2.22	2.39	2.62	2.88	3.12
Stigler	.20	.19	.17	.18	.20
Stilwell	.27	.27	.27	.30	.32
Tahlequah	.69	.71	.75	.81	.88
Wilburton	.25	.25	.25	.27	.29
Region V					
Claremore	1.02	1.08	1.16	1.25	1.36
Jay	.12	.13	.13	.14	.15
Miami	1.64	1.68	1.72	1.88	2.03
Nowata	.42	.40	.43	.46	.51
Picher	.31	.32	.33	.36	.39
Pryor	.89	.98	1.03	1.12	1.22
Vinita	.77	.79	.81	.88	.96
Wagoner	.48	.47	.46	.50	.54

TABLE C - 9

PROCESSING INDUSTRIES WATER REQUIREMENT FORECASTS, 1970-1990

City	Millions of Gallons of Water Required per Day				
	1970	1975	1980	1985	1990
Region I					
Ardmore	5.24	5.78	6.32	6.90	7.47
Davis	.41	.45	.49	.54	.58
Healdton	0	0	0	0	0
Lindsay	0	0	0	0	0
Madill	.04	.05	.05	.05	.06
Marietta	1.13	1.24	1.35	1.48	1.60
Pauls Valley	.31	.34	.37	.41	.44
Purcell	.04	.05	.05	.05	.06
Sulphur	.31	.33	.36	.40	.44
Tishomingo	0	0	0	0	0
Wynnewood	1.78	1.96	2.15	2.34	2.53
Region II					
Bristow	.37	.41	.45	.49	.53
Chandler	.05	.06	.07	.07	.08
Henryetta	9.88	10.90	11.92	13.01	14.07
Holdenville	0	0	0	0	0
Okemah	0	0	0	0	0

TABLE C - 9--Continued

City	Millions of Gallons of Water Required per Day				
	1970	1975	1980	1985	1990
Region II (continued)					
Okmulgee	8.24	9.10	9.95	10.87	11.75
Seminole	.98	1.07	1.17	1.28	1.39
Shawnee	4.03	4.44	4.85	5.30	5.74
Stroud	.83	.92	1.00	1.10	1.18
Tecumseh	0	0	0	0	0
Wewoka	.25	.28	.31	.34	.36
Region III					
Ada	5.60	6.18	6.76	7.38	7.98
Antlers	.25	.28	.31	.34	.36
Atoka	.12	.14	.15	.16	.18
Broken Bow	0	0	0	0	0
Coalgate	.11	.12	.13	.14	.16
Durant	2.49	2.75	3.00	3.28	3.55
Hartshorne	.10	.10	.12	.13	.14
Hugo	1.07	1.18	1.29	1.41	1.54
Idabel	.19	.19	.23	.25	.27
McAlester	2.36	2.60	2.84	3.10	3.36

TABLE C - 9--Continued

City	Millions of Gallons of Water Required per Day				
	1970	1975	1980	1985	1990
Region IV					
Eufala	.07	.08	.08	.09	.10
Haskell	.72	.80	.87	.96	1.03
Muskogee	15.15	16.72	18.28	19.96	21.61
Poteau	.08	.09	.10	.11	.12
Sallisaw	.66	.72	.79	.86	.94
Sapulpa	9.50	10.48	11.47	12.52	13.53
Stigler	1.07	1.18	1.29	1.41	1.52
Stilwell	3.44	3.80	4.16	4.54	4.91
Tahlequah	.14	.16	.18	.19	.21
Wilburton	0	0	0	0	0
Region V					
Claremore	.20	.21	.23	.25	.28
Jay	.34	.38	.42	.46	.49
Miami	2.36	2.60	2.84	3.10	3.36
Nowata	.21	.23	.25	.27	.29
Picher	0	0	0	0	0
Pryor	5.08	5.60	6.13	6.69	7.24
Vinita	.31	.34	.37	.41	.44
Wagoner	.11	.12	.13	.14	.16

TABLE C - 10

FABRICATING INDUSTRIES WATER REQUIREMENT FORECASTS, 1970-1990

City	Millions of Gallons of Water Required per Day				
	1970	1975	1980	1985	1990
Region I					
Ardmore	1.18	1.30	1.42	1.55	1.68
Davis	.14	.16	.18	.19	.21
Healdton	.02	.02	.02	.03	.03
Lindsay	.13	.15	.16	.17	.19
Madill	.14	.15	.17	.18	.20
Marietta	.16	.17	.19	.21	.22
Pauls Valley	.02	.02	.02	.02	.02
Purcell	.05	.05	.05	.06	.06
Sulphur	.01	.01	.01	.01	.01
Tishomingo	.01	.01	.01	.01	.01
Wynnewood	.03	.03	.04	.04	.04
Region II					
Bristow	.12	.13	.15	.16	.17
Chandler	.02	.02	.02	.02	.03
Henryetta	.05	.05	.05	.06	.06
Holdenville	.21	.23	.25	.27	.30
Okemah	.11	.12	.13	.14	.15

TABLE C - 10--Continued

City	Millions of Gallons of Water Required per Day				
	1970	1975	1980	1985	1990
Region II (continued)					
Okmulgee	.08	.09	.10	.11	.12
Seminole	.26	.28	.31	.34	.37
Shawnee	.35	.38	.42	.46	.49
Stroud	.00	.00	.00	.00	.01
Tecumseh	0	0	0	0	0
Wewoka	.23	.25	.28	.30	.33
Region III					
Ada	.29	.33	.36	.39	.42
Antlers	.16	.18	.20	.21	.23
Atoka	.01	.01	.01	.01	.01
Broken Bow	.15	.17	.19	.20	.22
Coalgate	.10	.11	.12	.13	.14
Durant	.19	.21	.23	.25	.27
Hartshorne	.09	.10	.11	.12	.13
Hugo	.06	.07	.08	.08	.09
Idabel	.52	.57	.63	.68	.74
McAlester	1.68	1.86	2.03	2.22	2.40

TABLE C - 10--Continued

City	Millions of Gallons of Water Required per Day				
	1970	1975	1980	1985	1990
Region IV					
Eufala	.01	.01	.01	.01	.01
Haskell	0	0	0	0	0
Muskogee	.51	.56	.61	.67	.72
Poteau	.13	.14	.16	.17	.18
Sallisaw	.05	.06	.07	.07	.08
Sapulpa	.23	.25	.28	.30	.33
Stigler	.17	.19	.20	.22	.24
Stilwell	.04	.04	.04	.05	.06
Tahlequah	.02	.02	.02	.02	.02
Wilburton	.10	.11	.12	.13	.14
Region V					
Claremore	.10	.11	.12	.13	.14
Jay	0	0	0	0	0
Miami	1.09	1.20	1.31	1.43	1.55
Nowata	.09	.10	.11	.12	.13
Picher	.01	.01	.01	.01	.02
Pryor	.26	.29	.31	.34	.37
Vinita	.15	.16	.18	.19	.21
Wagoner	.00	.00	.00	.00	.01

TABLE C - 11

RURAL WATER REQUIREMENT FORECASTS, 1970-1990

Region and County	Millions of Gallons of Water Required per Day				
	1970	1975	1980	1985	1990
<u>Region I</u>					
Carter	.50	.51	.53	.57	.61
Love	.16	.14	.13	.14	.15
Marshall	.16	.15	.15	.16	.18
99.0% Murray	.14	.14	.14	.15	.16
91.2% McClain	.36	.36	.37	.40	.43
90.8% Garvin	.61	.60	.60	.65	.70
57.2% Johnston	.15	.14	.13	.14	.15
10.3% Bryan	.06	.05	.05	.06	.07
5.8% Pontotoc	.03	.03	.03	.04	.04
<u>Region II</u>					
Lincoln	.61	.63	.65	.70	.76
Okfuskee	.40	.33	.31	.33	.36
90.4% Seminole	.39	.40	.40	.43	.46
80.7% Pottawatomie	.52	.55	.56	.62	.67
72.8% Okmulgee	.36	.35	.33	.36	.39
57.0% McIntosh	.23	.19	.15	.16	.18
48.5% Creek	.47	.50	.54	.60	.63
3.8% Muskogee	.33	.35	.36	.39	.42

TABLE C - 11--Continued

Region and County	Millions of Gallons of Water Required per Day				
	1970	1975	1980	1985	1990
Region III					
Atoka	.34	.33	.33	.36	.39
Choctaw	.35	.32	.30	.32	.34
Coal	.17	.19	.21	.23	.25
McCurtain	.82	.87	.96	1.04	1.12
Pushmataha	.31	.31	.30	.34	.37
94.2% Pontotoc	.50	.52	.53	.58	.62
90.7% Pittsburg	.52	.50	.49	.52	.56
89.7% Bryan	.48	.47	.47	.51	.55
55.9% Latimer	.14	.13	.13	.14	.16
51.8% Hughes	.16	.15	.14	.15	.17
42.8% Johnston	.11	.11	.10	.11	.12
26.4% LeFlore	.30	.27	.26	.28	.30
19.3% Pottawatomie	.12	.13	.14	.15	.16
18.8% McIntosh	.07	.06	.05	.05	.06
916% Seminole	.04	.04	.04	.05	.05
9.2% Garvin	.06	.06	.06	.07	.07
8.8% McLain	.04	.04	.04	.04	.04
1.0% Murray	.00	.00	.00	.00	.00

TABLE C - 11--Continued

Region and County	Millions of Gallons of Water Required per Day				
	1970	1975	1980	1985	1990
Region IV					
Adair	.56	.56	.57	.62	.67
Haskell	.30	.27	.23	.25	.27
Sequoyah	.64	.63	.62	.67	.72
93.9% Muskogee	.82	.85	.89	.97	1.04
73.6% LeFlore	.82	.75	.72	.78	.84
61.1% Cherokee	.35	.36	.38	.41	.44
51.1% Creek	.49	.53	.58	.64	.67
44.1% Latimer	.11	.10	.11	.11	.12
38.2% McIntosh	.15	.13	.10	.11	.12
35.4% Wagoner	.18	.17	.17	.18	.20
27.2% Okmulgee	.13	.13	.12	.13	.14
11.1% Delaware	.06	.06	.07	.07	.08
9.3% Pittsburg	.05	.05	.05	.05	.05

TABLE C - 11--Continued

Region and County	Millions of Gallons of Water Required per Day				
	1970	1975	1980	1985	1990
Region V					
Craig	.38	.40	.41	.44	.48
Mayes	.56	.59	.64	.69	.75
Nowata	.27	.28	.27	.29	.32
Ottawa	.53	.54	.55	.60	.64
Rogers	.54	.58	.61	.66	.72
88.9% Delaware	.50	.51	.53	.58	.62
64.4% Wagoner	.32	.32	.31	.34	.36
38.9% Cherokee	.22	.23	.24	.26	.28
2.3% Muskogee	.02	.02	.02	.02	.03

TABLE C - 12

IRRIGATION WATER REQUIREMENT FORECASTS, 1970-1990

Region and County	Acre-Feet of Water Required per Year				
	1970	1975	1980	1985	1990
<u>Region I</u>					
Carter	927	1159	1392	1625	1858
Love	1522	1904	2287	2669	3052
Marshall	369	461	544	646	740
99.0% Murray	4263	5335	6405	7478	8550
91.2% McClain	4273	5192	6422	7496	8571
90.8% Garvin	8860	11089	13317	15544	17773
57.2% Johnston	1283	1604	1927	2249	2572
10.3% Bryan	1269	1589	1908	2227	2546
5.8% Pontotoc	104	131	157	183	209
<u>Region II</u>					
Lincoln	524	655	787	918	1051
Okfuskee	700	877	1054	1231	1406
90.4% Seminole	1406	1760	2113	2467	2820
80.7% Pottawatomie	2714	3395	4079	4760	5455
72.8% Okmulgee	42	53	54	75	87
57.0% McIntosh	0	0	0	0	0
48.5% Creek	49	61	73	85	97
3.8% Muskogee	111	139	167	195	223

TABLE C - 12--Continued

Region and County		Acre-Feet of Water Required per Year				
		1970	1975	1980	1985	1990
Region III						
	Atoka	779	974	1170	1367	1562
	Choctaw	1729	2414	2900	3385	3870
	Coal	134	165	199	233	265
	McCurtain	1496	1872	2248	2625	3000
	Pushmataha	1089	1364	1638	1912	2185
94.2%	Pontotoc	1694	2123	2548	2974	3400
90.7%	Pittsburg	409	512	614	718	821
89.7%	Bryan	11056	13835	16615	19395	22175
55.9%	Latimer	16	20	24	28	32
51.8%	Hughes	2469	3088	3711	4332	4952
42.8%	Johnston	960	1201	1442	1683	1925
26.4%	LeFlore	815	1020	1223	1429	1634
19.3%	Pottawatomie	649	612	975	1139	1302
18.8%	McIntosh	0	0	0	0	0
9.6%	Seminole	149	187	224	262	299
9.2%	Garvin	898	1124	1349	1575	1801
8.8%	McClain	412	501	620	723	827
1.0%	Murray	43	54	65	76	87

TABLE C - 12--Continued

Region and County	Acre-Feet of Water Required per Year				
	1970	1975	1980	1985	1990
Region IV					
Adair	1411	1764	2120	2475	3528
Haskell	17	22	26	30	35
Sequoyah	2133	2670	3206	3743	4280
93.9% Muskogee	2745	3436	4126	4817	5507
73.6% LeFlore	2271	2843	3413	3984	4555
61.1% Cherokee	564	706	849	990	1132
51.1% Creek	52	65	78	90	103
44.1% Latimer	13	16	19	22	26
38.2% McIntosh	0	0	0	0	0
35.4% Wagoner	159	198	238	278	318
27.2% Okmulgee	24	30	36	42	48
11.1% Delaware	50	63	76	88	101
9.3% Pittsburg	42	52	63	74	84

TABLE C - 12--Continued

Region and County	Acre-Feet of Water Required per Year				
	1970	1975	1980	1985	1990
Region V					
Craig	0	0	0	0	0
Mayes	0	0	0	0	0
Nowata	103	126	152	178	203
Ottawa	43	55	65	77	87
Rogers	1236	1443	1858	2162	2479
88.9% Delaware	404	505	606	707	809
64.4% Wagoner	289	316	434	507	579
38.9% Cherokee	359	450	541	630	721
2.3% Muskogee	67	84	101	118	135

TABLE C - 13

REGIONAL WATER REQUIREMENT FORECASTS, 1970-1990

Region and Year	Municipal	Industrial MGD		Rural	Irrigation	Total
		Processing	Fabricating	MGD	MGD	MGD
Region I						
1970	6.68	9.26	1.89	2.13	20.47	40.43
1975	6.75	10.15	2.07	2.12	25.48	46.57
1980	6.88	11.14	2.27	2.13	30.76	53.18
1985	7.46	12.17	2.47	2.31	35.33	59.74
1990	8.06	13.18	2.67	2.48	41.05	67.44
Region II						
1970	11.22	24.63	1.43	3.46	7.05	47.76
1975	11.43	27.18	1.55	3.44	8.82	52.42
1980	11.48	29.72	1.71	3.43	10.60	56.94
1985	12.55	32.46	1.86	3.75	12.37	62.99
1990	13.60	35.10	2.03	4.03	14.15	68.91
Region III						
1970	8.23	12.29	3.25	4.53	22.19	50.49
1975	8.28	13.54	3.61	4.50	27.98	57.91
1980	8.52	14.83	3.96	4.56	33.62	65.49
1985	9.00	16.19	4.29	4.94	39.25	73.67
1990	9.80	17.54	4.65	5.33	44.77	82.09

TABLE C - 13--Continued

Region and Year	Municipal	Industrial		Rural	Irrigation	Total
		MGD		MGD	MGD	MGD
		Processing	Fabricating			
Region IV						
1970	10.82	30.83	1.26	4.66	8.47	56.04
1975	11.19	34.03	1.33	4.56	10.60	61.76
1980	11.66	37.22	1.52	4.51	12.73	67.64
1985	12.74	40.64	1.64	4.99	14.85	74.86
1990	13.86	43.97	1.78	5.36	17.55	82.52
Region V						
1970	5.65	8.61	1.70	3.34	2.23	21.53
1975	5.85	9.48	1.87	3.47	2.70	23.37
1980	6.07	10.37	2.04	3.58	3.36	25.42
1985	6.59	11.32	2.22	3.88	3.91	27.20
1990	7.15	12.26	2.43	4.20	4.48	30.52