

Decision Support System for Long Term Planning of Rural and Urban Water Supply Systems Cost in Oklahoma

Final Report

Submitted to:

Oklahoma State University Environmental Institute
United States Geological Survey

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May 31, 2007

SYNOPSIS

Title: Decision Support System for Long Term Planning of Rural and Urban Water Supply Systems Cost in Oklahoma

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Descriptors: Rural Water Systems, Decision Support System, Regionalization, Investment Planning

Problem and Research Objectives:

The state of Oklahoma has embarked on a five year process to develop a state water plan. One aspect of the overall plan deals with infrastructure issues where urban areas are rapidly expanding into areas currently served by rural water systems. There are over one thousand Rural Water Districts (RWD) in Oklahoma, serving at least 10,000 rural Oklahoma residents. Oklahoma Water Resources Board (OWRB) permits RWDs based on OWRB guidelines. Oklahoma Department of Environmental Quality (ODEQ) monitors the water quality standards. Most RWDs belong to the Oklahoma Rural Water Association (ORWA) and have their guidelines for operation. The basic economic problem for Oklahoma rural communities is the lack of available funds to absorb the initial capital costs of water systems, and the potential difficulty in covering sustaining costs such as operation and maintenance. Furthermore, there is a potential fear in not being able to meet the projected increasing future demands of water supply with the existing water treatment and/or distribution capacities.

The purpose of this research project is to develop an economic Decision Support System (DSS) to be used as a management and planning tool by regional and local water planners for the sequential expansion, upgrading, and regionalization of drinking water treatment plants at a minimum total discounted future cost. The DSS will aid water resource managers to make cost minimizing investments and provide investment options on existing and future water treatment plants and to evaluate efficient supply, transmission, treatment, staging, and distribution of high quality drinking water to Oklahoma residents. The DSS will provide water managers with information on the optimal number, location, and size of drinking water treatment plants and distribution lines per county/per drinking water source in Oklahoma within existing and predicted future constraints, based on a 50 year planning horizon.

Methodology:

The first step was to meet with managers of RWDs in Northeastern Oklahoma to determine stakeholder interest in long-term planning and the current status of long term plans for each of the RWDs. The methodology has been to develop a working relationship with RWDs in the study area to explore long-term needs.

Several hydrological planning models such as EPANET, KYPIPES, and WaterCAD were evaluated. The WaterCAD program was selected because of its capacity to handle a large number of spatially separated users, graphical user interface, and flexibility in planning purposes. The shape files of the existing pipe line maps for each district were available from the Oklahoma Water Resources Board (OWRB). The data base files associated with the maps were converted to a form useable by WaterCAD so the existing water system could be simulated. Where possible the simulations were checked against known system parameters.

A critical problem faced by RWDs and by the state as a whole is how to serve the urban population that is increasing in areas served by RWDs. Each RWD could develop investment plans to meet this rapidly increasing demand on its own, it could allow the nearby urban city to serve the development, or partner with other RWDs or urban areas to meet expected future demands.

The Oklahoma Department of Commerce made population projections through the year 2060 for each county, delineated by each city in each county and the rest of the county. Water demands for the same geographic distribution were projected through 2030. It quickly became apparent that a method of projecting the location of the “rest of county population growth” more precisely within each county was required if any meaningful assessment of the adequacy of the future needs of local water infrastructure were to be made.

The proposed systems to be included in the DSS system were:

1. ArcView GIS datasets: These data sets include 30 meter land use-land cover data, existing infrastructure including highways, existing waterlines, block census data from 2000 and 1990, census tract information through 2006. The block census data included population, single and multiple family housing units, age of housing, occupation, and commuting time.
2. UrbanSim. This unit was added to test its ability to utilize information in part 1 to predict the probability that a given sub-geographical area would be developed given existing development plans, the development in surrounding areas and access to infrastructure such as highways and schools. The logit regression package within UrbanSim is being tested for ease of use relative to other packages such as SAS. The objective of UrbanSim is to develop alternative spatial distributions of the projected “rest of county population growth”.
3. IWR-MAIN. This program is used by groups such as the U.S. Army Corps of Engineers to estimate water demands by geographic area. The spatially,

sectorally, and temporally distributed population data from step 2 will be input into this program. These data include population numbers, income levels, and within-area employment.

4. WaterCAD/WaterGEMS: The first three steps above provide estimates of spatial temporal water demands. The WaterCAD/WaterGEMS hydraulic simulation program is then used to assess the adequacy of the existing water system infrastructure (supply sources, treatment facilities, pipelines, and pumping systems to meet the spatially and temporally distributed water demands.

The project is not finished at the time of this report but the work is being continued under other funding. It is anticipated the major portion of the dissertation research will be completed December 2007.

Publications:

Conference Presentations:

Childers, A.:

OWRRI Oklahoma Water Conference 2007, Oklahoma City, October 2006. Poster presentation: “Planning for Rural Water Systems to Meet Future Drinking Water Demands in Oklahoma.”

USDA-CSREES National Water Conference, Savannah, GA, February 2007. Poster presentation: “Planning for Rural Water Systems to Meet Future Drinking Water Demands in Oklahoma.”

OSU Graduate Research Symposium, Oklahoma State University, February, 2007. Paper presentation: “Planning for Rural Water Systems to Meet Future Drinking Water Demands in Oklahoma.”

Winner of Environmental Science Program’s Outstanding Research Student Award, March 2007.

Winner of the OSU Women’s Faculty Council-2007 Award for an Outstanding Research Project, March 2007.

Students Supported By Project:

Type	Number	Discipline
Undergraduate	1	Agricultural Economics
Masters	1	Environmental Science
Ph.D.	1	Environmental Science
PostDoc	0	
Total	3	

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Acknowledgements

We would like to thank Oklahoma State University's Oklahoma Water Resources Research Institute (OWRRI) for their funding of this project in 2006-2007. We are also thankful for various individuals in Federal, State, and local agencies. Without their help, ideas, and resources, the initiation and completion of this project would have not been possible. We specifically would like to thank Mr. Gene Whatley and Mr. Jerry Gammill of Oklahoma Rural Water Association (RWA) who "led" us toward the topic of this project. We would like to thank Mr. Mike Langston of OSU/OWRRI for providing his knowledge of the professionals in the field of water planning and management, and introducing us to those water planners in Oklahoma Water Resources (OWRB) and RWA. Mr. Mike Mathis of C.H. Guernsey (with OWRB until October 2006) and Ms. Terry Sparks of OWRB have been very generous of their time and sharing their vast experience in Oklahoma's water issues. Dr. Ed Rossman and Ms. Liz Beshaw of the U.S. Army Corps of Engineers (USACE), Tulsa District, have given their time and resources within USACE to benefit this project tremendously. Their generosity to provide Anna Childers access to learn and utilize IWR-MAIN software in their district office in Tulsa to forecast water demands is immeasurable. Several individuals deserve our thanks in assisting with data collection, specifically: Dr. Kit Wagner with the Atmospheric Information Systems in Norman, Mr. Gaylon Pinc, until 2007 with Indian Nations Council of Governments (INCOG), Tulsa, Mr. Arvil Morgan, Rural Water District (RWD) 5 and Mr. Bill Giles, RWD 4 in Wagoner County, and Mr. Rick Stull, RWD 3 and Mr. Steve Dunavant, RWD 5 in Rogers County.

1.0 Introduction

1.1 Scope of the Project

The general objective of this project is to demonstrate a method to develop a Decision Support System (DSS) to address how to optimally (least cost) meet the increasing demands of drinking water in selected areas, and thus the anticipated water supply infrastructural needs of small (rural) water systems. This project takes a demonstration approach to facilitate planning for future infrastructural needs of small drinking water systems in Northeastern Oklahoma. In particular, the planning process aims to provide sufficient and accurate information about the sequence of the events that triggers increased disaggregated drinking water demands which in turn trigger performance requirements on the existing water infrastructures of small water systems. In this study, the planning approach is done in four separate stages by incorporating data into four different software applications. The end-goal of the planning process is an economic performance evaluation of the four small water systems in Wagoner and Rogers Counties under the increased infrastructure needs. Based on those results, a decision-maker can further investigate the feasibility of structural regionalization of two or more small water systems to meet the increased demands together. We demonstrate how the end-goal of the planning is achieved by taking multiple intermediate steps that produce crucial data that feed into the further stages of the future drinking water infrastructure planning process.

Much of wording and ideas of this project came from the future Ph.D. dissertation of Anna Childers, who worked as a graduate student in this project. The final DSS model

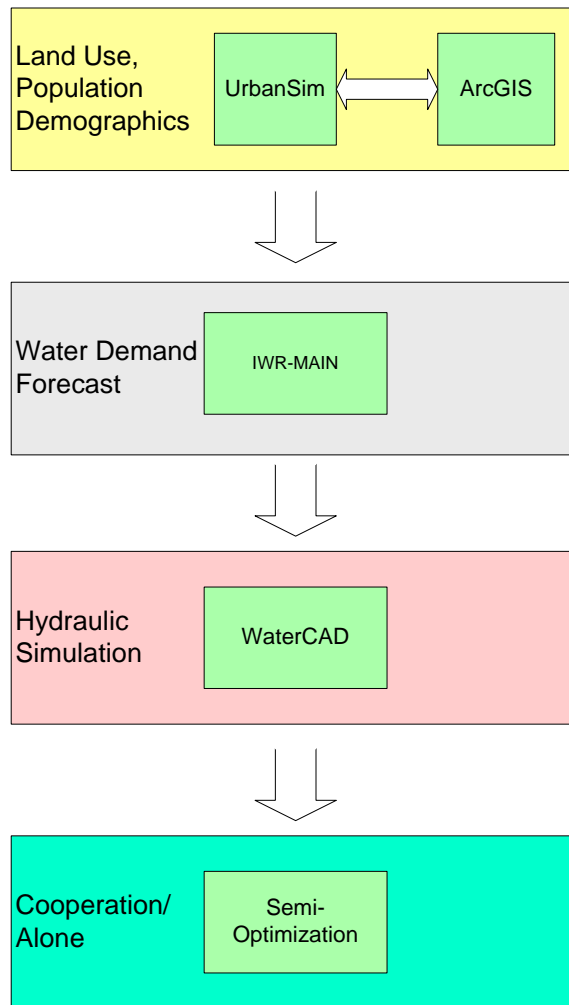
and the application of it are being utilized in Ms. Childers' Ph.D. dissertation at Oklahoma State University, Environmental Science Graduate Program, Stillwater, OK. The preliminary results of the DSS model will be available in the fall of 2007.

The capital stock of a drinking water system can be divided into four principal components: source water, treatment, storage, and transmission and distribution. In this project we use interchangeably the concepts of "water infrastructure" and "water systems". Both of these concepts include the four principal components. DSS are intended to help decision makers to use models to identify and solve problems, complete decision process tasks, and make decisions. DSS are a general term for any computer application that assists a person or group's ability to make decisions. In general, DSS are a class of computerized information system that supports decision-making activities. There is variety of DSS classes depending on the purpose of the DSS. In this project the focus is on the assembly of a model driven DSS. This type of DSS emphasizes manipulation of a model. Depending on the complexity of the problem setting and situation in question, a model driven DSS can become fairly data-intensive.

In this project we will demonstrate how DSS structure can be assembled, and what software applications and data can be incorporated. The assembly of the DSS of this project incorporates three major components: 1) water demand forecast model incorporating land-use development; 2) hydraulic model for simulation experiment, and; 3) economic model for semi-optimization. The water demand forecast model includes multiple data entries including identification of the fastest growing areas and the projections of future drinking water demands based on population growth, population

densities, land-use profiles, and probability of land-development. The hydraulic simulation model includes water system simulations under different growth scenarios and the associated cost estimates. The economic model is a semi-optimization of potential cooperative arrangements of two water systems. The end-result of this project is a demonstration model that presents how to assemble a holistic model that incorporates population demographics and land-development, hydraulic simulations and economic feasibilities of cooperative solutions of water distribution.

Figure 1-1: Flow Chart



1.2 Structure of this Report

This project is divided into nine sections. The structure of this project is as follows. In section one, we describe the reasoning to undertake the study. We look at the different components that constitute the relevance of this study and evaluate what has been done before. In section two, we will first address the components that are the triggers behind water demand analysis, including the analysis of population demographics and land-use of the planning area. This is an important intermediate step in understanding these explanatory variables and their impact on water demands, as it further aids in selecting forecast models and selection of forecast variables of land-use in the study area. In section three, we will introduce the methods of water use forecasting and make a selection to forecast water demands in spatial, sectoral, and temporal manners in IWR-MAIN software. Section four is a detailed presentation of the elements involved in disaggregated water demand forecasting, wherein we demonstrate the interconnection of the three different software applications that are needed to yield water demand forecasts, which are later input into the hydraulic simulation model. The selection of model parameters for IWR-MAIN and UrbanSim are explained in detail. Section five explains the procedural steps to the planning area's water use forecasting. In section six we input water demand forecast variables into WaterGEMS software. Section seven discusses physical consolidation of water infrastructures and the economic theories behind it. Section eight summarizes conclusions the benefits of the proposed DSS. Section nine presents the caveats and recommendations for the future research.

1.3 Justification of the Study

When water systems infrastructure fails, communities look for financing to repair, upgrade or replace it. If the communities are unable to fund the infrastructure projects themselves they will seek financial assistance in the form of grants and loans from state and federal agencies. Many times the state and federal loans and grants are not sufficient and the resultant wait can be several years. Without funding to fill the financing gap, end-users of water may face increased monthly water bills. The prevailing approach in water infrastructure planning is water supply infrastructure assessment. The infrastructure assessment approach identifies the state of the existing infrastructure in water systems, but it falls short in projecting the needs for infrastructure replacement and expansion under specified conditions. The existing water system infrastructure research highlights the “gaps” in water systems infrastructures where the results are based on questionnaires completed by water system operators. This approach works for current assessment of water infrastructure needs. However, projection of infrastructure needs is a complex undertaking that requires an understanding all the impacting variables impacting water demand and their potential influence on water distribution infrastructure. Thus, the projections require exhaustive data and simulations.

When the Safe Drinking Water Act (SDWA) was passed in 1974, many in U.S. Congress had anticipated that many small systems (serving less than 3,300 persons) would consolidate and form more cost-effective regional systems. However, the

number of small systems has continued to increase. The U.S. Congress recognized the infrastructure problems facing small water systems in the mid-1980s, and in 1987 authorized the U.S. Environmental Protection Agency (EPA) to provide greater technical assistance to small public water systems to help them meet the federal drinking water requirements. Since its enactment, the Clean Water State Revolving Fund (CWSRF) has provided states with a continuous source of funding to address water projects. Similarly, in 1996, the Congress created the Drinking Water State Revolving Fund (DWSRF) to provide States funding to support sustainability in drinking water infrastructure. Combined, the two programs represent EPA's largest single program accounting for half of the EPA's assistance award funds. States must provide matching funds equal to twenty percent of the grants. States can also loan additional funds to communities to finance water projects. EPA estimates that by 2020 there will be \$263 billion funding gap in water infrastructure (total of capital and operations and management) using the current level of investment.¹

The U.S. Conference of Mayors' Urban Water Council (UWC) conducted a survey of 414 principal cities (population 30,000 or greater) to examine water resources priorities. The study was conducted in 2005 and the respondents were asked to evaluate water resources capital investment needs during the past five years (2000-2004) and predict the next five years (2005-2009). Three priorities were identified by the respondents: first, chronic "every-day" problems; second, the potential of catastrophic events, and; third, concerns of water supplies. The chronic "every-day" problems included priority of

¹ EPA's Local Government Advisory Committee (LGAC) DVD released March 30th, 2007.

aging infrastructure, identified by over sixty percent of the respondents.² The water distribution system infrastructure category had the highest actual and planned investment needs across all three city classes (small, medium and large). According to the survey, small cities (population less than 50,000) were less likely to invest on future water infrastructure (all infrastructure categories) than the large ones (population greater than 100,000). However, a larger percentage of small cities (over 40 percent) prioritized the aging infrastructure needs compared to the large cities (26 percent). The survey also looked at how the cities have financed and intended to finance the capital improvements of water systems. In both cases, over 50 percent of respondents relied or intended to rely on a single source of financing for their major capital investments in water infrastructure, and over 20 percent of those identified the type of financing as “other”. This category of financing includes capital reserves from user charges, increased user rates, and transfers from general funds. These are generally referred to as “pay-as-you-go” approaches of financing. State revolving funds (SRF) were identified 38 percent of the time as a source for financing capital improvement projects in water infrastructure. SRF loan programs appeared to be a more important source of financing for smaller cities than larger ones.

Condition and status of community infrastructure, especially drinking water infrastructure, has gained national, regional and local attention for years. Despite the attention and need for recognition, no regional, state, or federal source collects or maintains information on the status or scale of these infrastructure needs. Although, the 1999 EPA’s report addressed the community water system needs, there is no study

² U.S. Conference of Mayors’ Urban Water Council (UWC), National City Water Survey 2005, Washington, DC.

available that directly addresses the capital make-up of drinking water systems.³ Despite the federal, state, and municipal efforts to address the infrastructure needs, the current level of information of the future infrastructural and investment needs of rural water systems in Oklahoma is unclear to the state's water planners. Many of the water supply infrastructure concerns have concentrated on the needs of the very smallest systems (serving less than 3,300 persons). The infrastructure concerns cannot be linked too tightly to the current size of water systems, but should be expanded to include systems that are experiencing growth now or are projected to experience growth in the adjacent areas. The quality and deterioration of the system infrastructure components are not the only areas of concern, but also the future infrastructure expansion needs. In order to address that concern, one needs to be able to extrapolate where this expansion is going to take place and when. By knowing the future demand increases of an area, local planners and water system managers can start identifying the water system expansion needs, budget for the capital and O&M needs, and thereby, apply for appropriate funding on time. By a proactively planning water infrastructure needs, the water planners can avoid management by crisis.

Drinking water infrastructure needs are local and are, thus best understood by local water planners. EPA conducts Drinking Water Infrastructure Needs Survey and Assessment (DWINSA or Assessment) every four years for the purposes of DWSRF as mandated by SDWA. The Assessment develops a cost model which is compiled from cost data submitted by different size systems nation-wide and from modeled costs as calculated by EPA. The sets of data items collected in the Assessment to model the

³ U.S. Environmental Protection Agency (EPA), 1999, Drinking Water Infrastructure Needs Survey. Office of Water: Washington, DC.

cost of infrastructure are the same data items that need to be collected in this DSS to model the infrastructure needs in the planning area. Thus, the Assessment is an important guide for identifying project components. However, the infrastructure components must be localized and calibrated to respond to future infrastructure needs so that cost estimating is accurate.

A planning approach assessing how to project water supply infrastructure needs of rural water systems in Northeastern Oklahoma, and the costs associated with different supply system scenarios, has not been previously addressed in a comprehensive study. Most studies in the field of water infrastructure assessment in Northeastern Oklahoma have either an engineering or a water demand emphasis. These two have not been combined in a holistic model that also addresses the concept of structural consolidation of water systems. More technologically advanced and wealthier rural water systems have hydraulic studies of their systems, but these studies have not incorporated sophisticated water demand projections of the area. Nor is there a uniform methodology or standard on how these single system based-studies were done. Nor is there a system in place in Oklahoma to advance this engineering focused information to the state's planning agents.

This project is limited to four rural water systems in Northeastern Oklahoma in Wagoner and Rogers Counties. The problem statement and the methods are limited to those specific systems in this area. The water use evaluated is residential and non-residential surface water but does not include water uses for agriculture or mining. Population projection factors and hence water demand factors vary within the region. Costs are dependent on the location and always need to be normalized using a location

factor. Similarly, cost of water treatment varies greatly depending on the source water quality, the treatment plants configuration, and local conditions. Furthermore, the cost estimates need to be adjusted to the time period in question.

2.0 Spatial, Sectoral, and Temporal Drinking Water Demands

Rural water systems adjacent to growing urban areas in Northeastern Oklahoma, in Wagoner and Rogers Counties, are expected to face challenges in the future concerning the optimal management of their water supplies, treatment as well as the optimal rate of construction of new distribution systems. As Figures 2-1 and 2-2 illustrate, these rural water systems will experience increased drinking water demands and changing water demand profiles due to urban/rural interface caused by actual population growth, annexation, and housing and commercial developments in the adjacent rural water service areas.

An important element in the accuracy of water distribution simulations is the accuracy of the associated water demand estimates and projections. Temporal, sectoral, and spatial characteristics of drinking water demands and allocations are dependent on a wide range of explanatory variables describing the demographic, cultural, economic, and legal structures of the community, as well environmental conditions such as temperature and precipitation. The steady increases in population and expansive land-use plans translate into increased drinking water demands. Increased demands translate into performance requirements on existing drinking water treatment, storage and distribution infrastructures, and demands of future water

supplies. The past studies have projected future drinking water demands based on county-wide flat data. Total county projections give a good estimate for the total volume of drinking water demands, but they are not spatially distributed (disaggregated) to small areas. Cross-sectional forecasts do not necessarily give a true representation of a small area, as small area forecasts cannot be aggregated to cross-sectional elements. Small area population forecasts and land-use plans focus on areas that are smaller than a county, generally the size of a city, census tract or group, or traffic analysis zone. Therefore, it is important to specify the model to incorporate small-scale spatially distributed disaggregated population projections and land-use plans in order to provide more defined needs for water system expansions and additions to the water infrastructure.

In order to model the relationships among water demand growths and required water infrastructure needs, the elements contributing to the water demands need to be evaluated. The water demands need to be coupled with land-use forecasting and population demographics. Also, explanatory variables need to be assessed in both residential and non-residential water demand projections.

To accomplish these objectives, we need to develop methodologies to disaggregate water demands and forecast those disaggregated demands into the future. Thus, the first task in planning process is to select and forecast the set of explanatory variables that impact water demands. The two broad categories of water demand forecasting are population demographics and land-use. Population demographics are projected by the Oklahoma Department of Commerce (ODC) up to 2030. However, land-use choices

and development potentials have not been previously projected to the planning area. The results of the simulation and forecasting of land-use feed directly into IWR-MAIN water demand forecasting software and the projection of explanatory variables of water demand within the Forecast Manager of IWR-MAIN.

The data for spatial, sectoral, and temporal water use forecasting comes from many sources. The base line conditions for water use are fairly straightforward even in a disaggregated studies, but establishing forecast values in a disaggregated manner is more demanding.

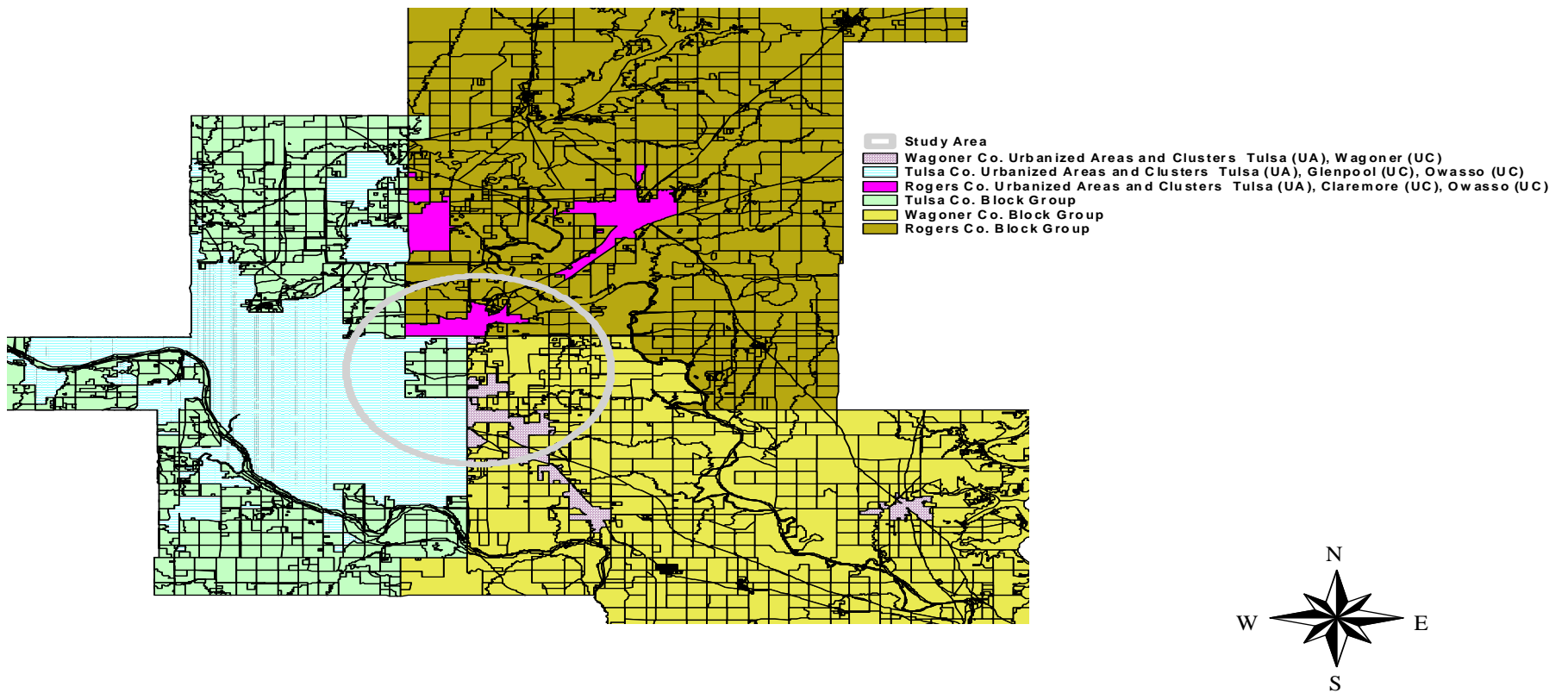


Figure 2-1: Planning Area Representing Urbanized Areas and Urban Clusters in Wagoner, Rogers, and Tulsa Counties in Northeastern Oklahoma

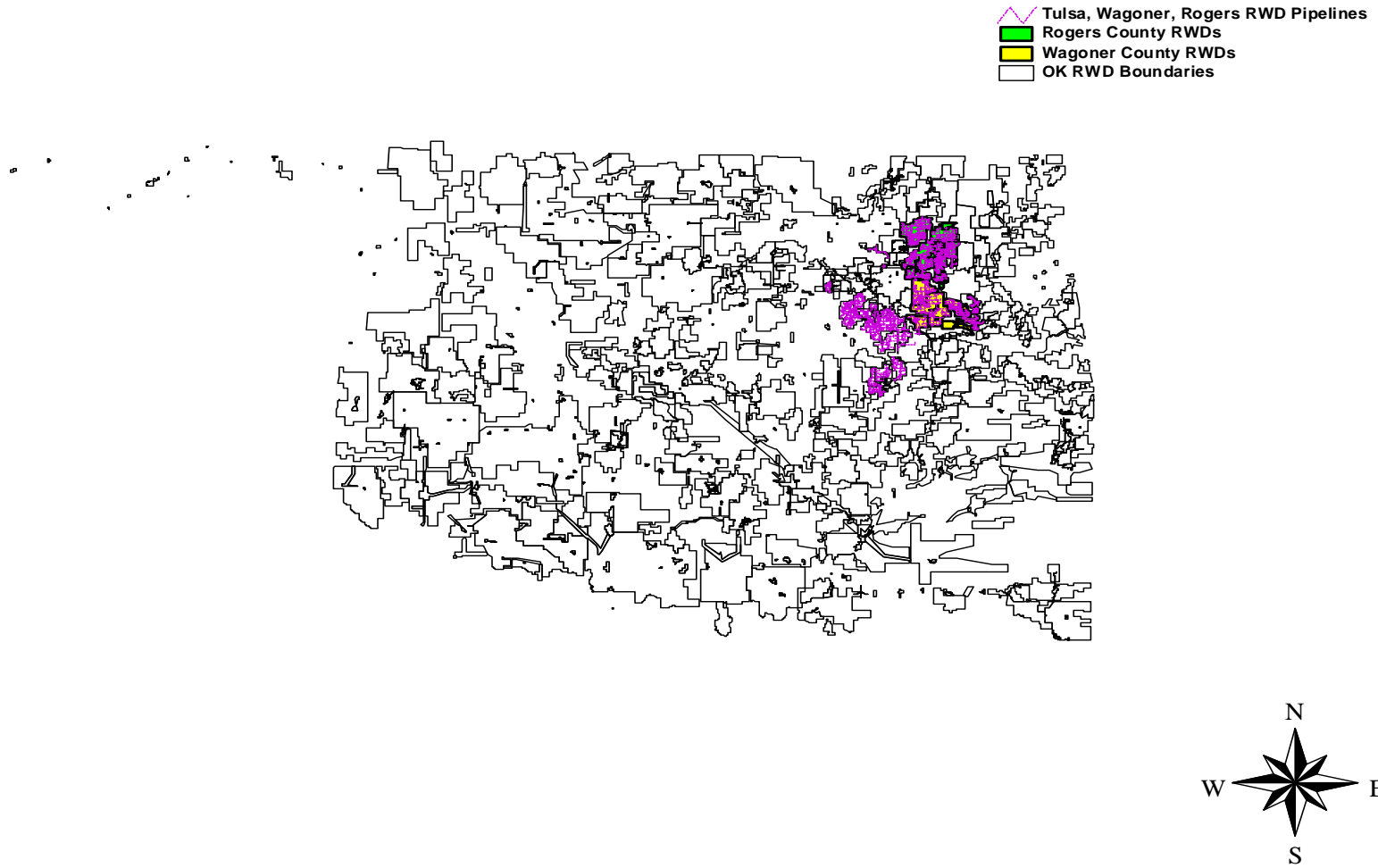


Figure 2-2: Planning Area Representing Oklahoma's' RWD Boundaries, Wagoner and Rogers County RWD Boundaries and Pipelines

2.1 Population Demographics

The population in those parts of Wagoner and Rogers Counties that are closest to urban areas (i.e. Tulsa, Broken Arrow, and Owasso) is projected to increase by more than 50 percent between 2007 and 2030. The national data generally indicate that many rural areas suffered significant economic and population declines in the 1970s and 1980s, while Wagoner and Rogers Counties experienced rapid growth in the 1990s. This national population growth pattern is somewhat different for Wagoner and Rogers Counties due to the fact that those numbers are applicable to rural farm people, and not to rural non-farm people. According to historical censuses, there was no population decline in Wagoner and Rogers Counties in the 1970s. To the contrary, there was an average annual population increase between 1970 and 1980 of 6.6 percent in Wagoner County and 5 percent in Rogers County. There was a population growth slow-down in the 1980s in the two counties, as the annual average increases in the 1980s were only 1.4 percent and 1.8 percent respectively. In the 1990s these rural county areas continued to grow with an annual average growth of 1.8 percent in Wagoner County and 2.8 percent in Rogers County. However, closer examination of the 1990 U.S. Census sub-county or census tract population (1990-1999) for these counties reveals that the population growth occurred in concentrated pockets in the cities and in the areas. The highest growth occurred in places such as Bixby and Broken Arrow (Wagoner and Tulsa Counties), Coweta (Wagoner County), Owasso (Rogers and Tulsa Counties), and Catoosa and Claremore (Rogers County). The same trend is observable in 2000-2006 estimates. The city of Bixby experienced 6.6 percent

annual average population increase, Broken Arrow 1.4 percent, Coweta 2 percent, Owasso 4.8 percent, Catoosa 3.6 percent, and Claremore 1.5 percent. Throughout the 1970s, 1980s and 1990s, all of Tulsa County was experiencing an average of one percent annual population growth indicating that the “bedroom” communities have been more attractive as well as more available for development purposes. The 2000-2005 estimates indicated negative population growth in the city of Tulsa. However, the county of Tulsa experienced an average annual growth of 3.3 percent during the same time period. The biggest contributors for the county wide population increase were non-metropolitan cities within the Tulsa County: Bixby, Broken Arrow, and Owasso. According to 2000-2005 Census data, Rogers County was the fastest growing county in Oklahoma; it grew by 16.7 percent from April 2000 to July 2006.

2.2 Land-Use

Oklahoma Department of Commerce (ODOC) made population projections for Oklahoma Water Resources Board (OWRB) through 2030. The projections are for the entire county, cities in each county, and the rest of the county. In order to utilize these projections in this study, they need to be assigned in part to the planning area in question. Population growth and land-development affect where and how people live. Also, land-development determines where businesses will locate. Therefore, probability of land-development must be estimated. The term "land-development" refers to the conversion of land for the purposes of residential, commercial, industrial, or other activities. Land-development can be described by the amount of land by type of use in

an area, as well as the characteristics of the development (e.g. residential density). Typical land-use types adopted in this study are low- and high-density residential, commercial, light and heavy industrial, parks and open areas, public areas (schools, hospitals, and government buildings), lots, and transportation areas. Land-development has an intermediate impact that results in a variety of other impacts on the physical environment such as an increased drinking water demand.

Seven primary factors drive the probability of land development:

- 1) Land use policies, such as zoning codes and taxation regulations, which may provide incentives or constraints for different types of development.
- 2) Accessibility, which is determined by the characteristics and performance of transportation system, in conjunction with the spatial patterns of existing development in the area, such as existing highways and roads, and areas connected with bridges.
- 3) Ownership of land, primarily referring to the Native American lands.
- 4) Physical characteristics of the area, such as topography, soils, and natural features, which can provide incentives or constraints for different types of development.
- 5) Economic forces.
- 6) The presence of institutional groups, such as military bases, hospitals, or prisons.
- 7) Proximity to existing development, such as urban areas.

There are many methods for forecasting land development. However, safe generalizations can be made about future trends in land development. These trend

indicators can be derived from changes in median house sizes and desired living locations over a period of time. The national trend shows that median house size has increased from 1,525 square feet to 2,227 square feet from 1973 to 2000.⁴ According to the 2004 survey by the National Association of Realtors and Smart Growth America, 13 percent of Americans want to live in a city, 51 percent in a suburb, and 35 percent in a rural community.⁵ The Survey data indicate that even historic cities such as Boston, San Francisco and Minneapolis are losing population. The primary reasons for the exodus to suburban areas are the affordability of land and the freedom to build larger homes. Ninety percent of the U.S. metropolitan growth has occurred in suburbs since the 1950s. The 2004 Survey proves that the population growth is in the fringes of the cities.

An area's geographic context has a significant effect on its development. Economic opportunities accrue to an area by virtue of population size, physical size and access to larger economies. In 2003, the U.S. Office of Budget and Management (OBM) released the Census 2000 version of metropolitan (metro) and nonmetropolitan (nonmetro) areas, new classification system often used to define urban and rural America. The metro counties are defined for all urbanized areas regardless of total area population. They are distinguished by the population size of the Metropolitan Statistical Area of which they are part. The 2003 OBM classification subdivided previously undifferentiated nonmetro territory into two distinct types of geographical entities:

⁴ U.S. Census Bureau, 2000, U.S. Department of Commerce, Economics and Statistics Administration.

⁵ National Community Preference Survey Conducted for Smart Growth America and National Association for Realtors, 2004.

Micropolitan (micro) and noncore. The micropolitan areas can also be called edge cities, galactic cities, or technoburbs. These places are largely self-contained, with many jobs for local residents, most of whom would not have to commute long distances. Micropolitans sit outside of the metropolitan areas. The OBM used the following definition of micropolitans: "At least one urban cluster of at least 10,000 but less than 50,000 in population."⁶ While micropolitans lack a large central city of over 50,000 residents, they often contain central cities akin to modest-sized towns, according to census analysis of 567 micropolitans in the continental U.S. published by Robert Lang and Dawn Dhavale.⁷

The above definitions of micropolitans do not fit directly to the planning area of this project. This is due to the facts that when looking at the weighted averages of time to commute to work and population estimates, the areas in this study currently act as bedroom communities to the larger metropolitan areas. Also, according to the 2003 OBM definition, metropolitan areas are: 1) Central counties with one or more urbanized areas, and 2) outlying counties that are economically tied to the core counties as measured by commuting to work. Therefore, these areas in the study are metropolitan areas and more specifically can be called exurbs - suburbs at the fringes of metropolitan areas. According to the National Brookings 2006 Report, exurbs are communities located on the urban fringe that have at least 20 percent of their workers commuting to jobs in an urbanized area, exhibit low housing density, and have relatively high population

⁶ OBM BULLETIN NO. 03-04, June 6, 2003.

⁷ Lang, Robert and Dawn Dhavale, 2004, Micro-Politan America: A Brand New Geography. Metropolitan Institute at Virginia Tech Census Note 05:01.

growth.⁸ People living in exurbs tend to commute to the core city. Exurbs are a subset of the suburbs, but are still part of the metropolitan community and economy. They are located on the furthest ring of a metropolitan area, are mostly residential, and the residents commute to work to metropolitan areas. According to Census data and the Urban Land Institute, these areas are growing faster than any other kind of community.⁹ Exurbs are experiencing growth to which they are not accustomed, and thus do not have the infrastructure or experience to deal with the growth. The National Brookings Report ranks Oklahoma 16th nationally with 8.9 percent of the total population being exurban. According to the same study, Tulsa Metropolitan Area (MA) ranks 13th nationally with 16.9 percent of the total population being exurban and Oklahoma City MA ranks 17th with 14.8 percent of total population being exurban. There are six counties that contribute to Tulsa MA rankings: Rogers, Wagoner, Okmulgee, Osage, Creek, and Pawnee. Rogers County's total population is 69 percent exurban; the percentage for Wagoner County is 35 percent. The increase in five year period (2000-2005) was 13.1 percent for Rogers County, and 11.2 percent for Wagoner County.

The planning approach to meet the increased drinking water demands in exurbia must be viable in that the small system costs are reduced. The trickle-down benefits of implementing a viable economic plan to small and medium systems can be experienced at many levels. First, the end-users benefit from economic feasibility of water systems in a form of a cheaper price for drinking water. Second, the system itself as well as

⁸ The Brookings Institution Report, 2006, Prepared by Alan Berube, Audrey Singer, Jill H. Wilson, and William H. Frey. Finding Exurbia: America's Fast-Growing Communities at the Metropolitan Fringe. Living Cities Census Series.

⁹ Urban Land Institute (ULI) Report/Joseph Z Canizaro Public Officials' Forum, 2004, Smart Growth in the Fringe, Prepared by Victoria R. Wilbur.

surrounding systems within the distribution area can adjust their plans based on the anticipated future infrastructural needs caused by increased demands.

3.0 Forecasting Water Use

The needs for water use forecasts are many depending on the water planning approach. In general they can be divided into short- and long-term planning approaches. Short-term planning involves usually seasonal demand forecasting, whereas long-term planning can involve many aspects of water demand forecasting. Long-term water demand forecast models can be utilized in evaluating water quality and quantity available in the future. They can also be utilized for financial planning purposes. Long-term forecasting deals with population growth, household compositions, land-development, conservation patterns, and housing mix patterns. In this study we take a long-term planning approach of forecasting water demands spatially, sectorally, and temporally in a small segment of an area so that the future financial needs of infrastructural expansion and updates of water distribution can be identified for specific systems.

3.1 Methods of Forecasting Water Use

There are many methods of forecasting water demand (Pradham, 2003, Bauman et al., 1997). Most methods have evolved from extrapolating the past water use to including more complex explanatory variables. Some simpler versions of water demand

forecast models have been used due to lack of access to more complex computerized models and inability to handle large quantities of data. Hence, for example, a multivariate coefficient demand model has been used by some modelers.

3.1.1 Time Extrapolation

Time extrapolation method's basic assumption is that the water usage in the future is explained by the past trends. The past observations of water use are fitted to a smooth curve mathematically. This method is highly subjective and more applicable to aggregate (versus disaggregate) water consumption forecasting. Also, the time extrapolation method is very limited in forecasting since time is the only explanatory variable.

3.1.2 Bivariate Models

In bivariate methods of forecasting water use, a single explanatory variable is used, which usually is population. This method is also known as per capita method. A water use forecasting in a linear form can be written as:

$$Q = a + b \cdot X \quad (1)$$

Where:

Q = water use per unit of time

X = explanatory variable

a, b = coefficients

A multivariate model can be applied to disaggregated water use forecasting, however, the use of explanatory variables is limited to one: population. The same shortcoming is in an extension of bivariate method, per capita method of water use forecasting where the only explanatory variable is the population:

$$Q = b \cdot P \quad (2)$$

Where:

Q = average daily total water use

P = population in service area

b = per capita water use

Bivariate methods of water use forecasting are simple because they require a limited number of data: water use and population. The assumption of population correlating with water use may hold true with residential water use, but that assumption cannot be extended to non-residential water-use. Non-residential water use consists of various different types of sectors that correspond to different set of explanatory variables that need to be built into the model.

3.1.3 Multivariate Models

Multivariate methods of water use forecasting are utilized in today's water use forecasting models. These models are more robust because they incorporate several explanatory variables of water use. Residential and non-residential water demand is a complex function of socio-economic characteristics, climatic factors and public water

policies and strategies. When different explanatory variables affect the water use of different sectors differently, the relationship is additive and the model can take the form of:

$$Q = a + b_1 \cdot X_1 + b_2 \cdot X_2 + \dots + b_n \cdot X_n \quad (3)$$

Where:

Q = water use

X_i = explanatory variable i

a, b_1, b_2, \dots, b_n = coefficients

When several of the explanatory variables explain the same kind of water use, the Inlog form of equation (3) in log-linear form can be written as:

$$Q = \alpha \cdot X_1^\beta \cdot X_2^\gamma \cdot X_n^\delta \dots \quad (4)$$

Where: $\alpha, \beta, \gamma, \delta$ = coefficients

The main disadvantage of this approach of multivariate form of modeling water demand is that the model tends to highlight the correlation of explanatory variables into water demand rather than the causation.

3.1.4 Disaggregated Water Demand Models

An extension of a multivariate model is an econometric approach which considers a variety of parameters to forecast and manage sectoral (residential and non-residential), spatial and temporal water demands. An example of an econometric water demand model is a propriatery IWR-MAIN (Institute for Water Resources – Municipal and Industrial Needs) Water Demand Analysis Software. The original version of the model

was developed by Hittman and Associates, Inc. (1969). Later, the U.S. Army Corps of Engineers (USACE) obtained the model and improved many of its features. Today, the software is owned by Planning and Management Consultants, Ltd. (PMCL).

4.0 Spatial, Sectoral, and Temporal Water Demand Forecasting

This section provides an overview of the methods needed to obtain water demand forecast for the desired planning area. Disaggregated water demand projections are crucial for providing valid inputs for water system infrastructure analysis. The modeler needs to make a decision how to disaggregate the data. Most water demand data is tabulated at the county level and it needs to be disaggregated to correspond the planning area geography. Water demand analysis is not an exact science but more of an interpretive one, as a complex set of explanatory variables affects water use. Depending on the model preferences, and the set of explanatory variables and their projection, the output of a forecast can vary greatly. In this project we expand the traditional approach of keeping the set of explanatory variables constant, by incorporating innovative methods of forecasting and scenario-modeling of the required explanatory variables.

The figure 4-1 on the following page (p.26) illustrates the approach that we recommend in disaggregated water demand forecasting. It requires the use of three different software applications to forecast or create scenarios for water demand. The use of the three softwares will yield outputs that provide input data for the next stage. (More of the procedural stages are discussed in Section 5).

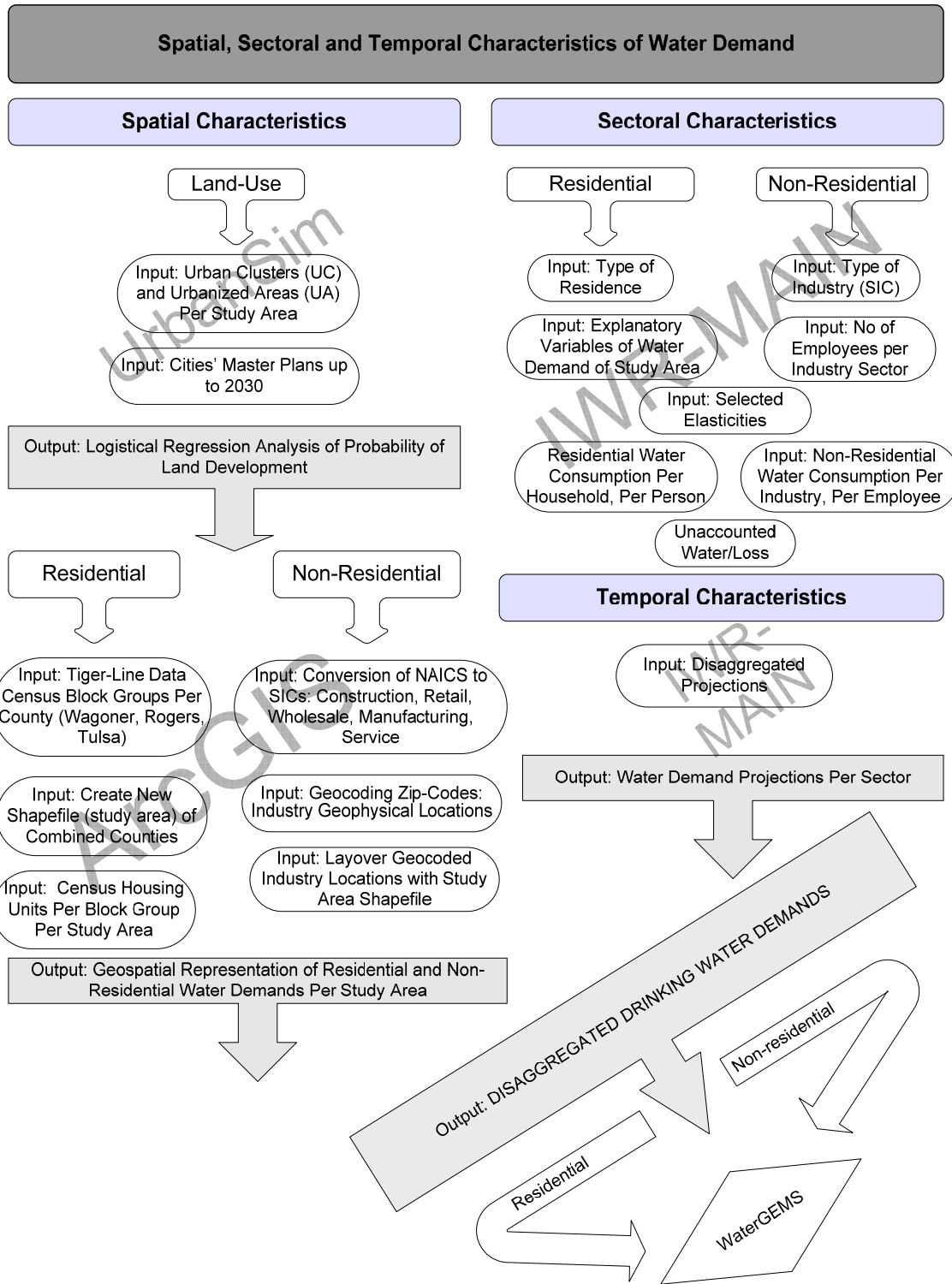


Figure 4-1: Spatial, Sectoral, and Temporal Characteristics of Water Demand

The IWR-MAIN water demand model cannot be used before ArcView GIS and UrbanSim have been used. ArcGIS maps the planning area and links census attributes to the corresponding area. This is done in Census block group level. UrbanSim is utilized to analyze land-use planning choices in ten year time-steps up to 2030. UrbanSim is constructed using logistical regression, also known as “logit” and discrete choice model. Model parameters on land-development are estimated using maximum-likelihood procedure. Also, spatial autocorrelation method is utilized. The results of UrbanSim are extrapolated to forecast scenarios of potential land-use development, which in turn aids in forecasting land-use dependent explanatory variable of water-use in IWR-MAIN.

4.1 IWR-MAIN

The theoretical basis of IWR-MAIN is to forecast water demand. Structurally, IWR-MAIN consists of three parts: The “Forecast Manager” for water demand forecasting, the “Conservation Manager” for analyzing the demand-side water use conservation options, and the “Benefit-Cost Tool” within the Conservation Manager for estimating the costs and benefits associated with implementation of water use conservation programs. The “Forecast Manager” is used to estimate future water uses sectorally, temporally, and spatially. Water use can be forecasted on a daily basis by month or total demand by month. The total demand forecast is generated adding the different time-periods together.

In this project, we recommend the use of Forecast Manager within IWR-MAIN. The Forecast Manager has an ability to consider multiple factors and project water use drivers, a flexibility to allow user to define coefficients, availability of different types of models, such as linear and multiplicative, and ability to perform sensitivity analysis. The Forecast Manager projects water use by customer type (sector): residential and non-residential. The modeler is able to define the planning area spatially. This feature allows the planner to account for regional population growths, as well as variances in socioeconomic attributes and seasonal variations in economic and climatic conditions. The disaggregated water use per space allows more accurate observation of the potential changes in water demands in specified areas. Also, the modeler is able to forecast the planning area's water demands temporally. Temporal data disaggregation enables modeler to observe variations in water demand per time change, e.g. season, time of day, and annual water demands. The sectoral water demand forecasting element of IWR-MAIN can identify major sectors of water users. These include residential, non-residential, public, and other. Residential sector can be further disaggregated into single-family and multi-family uses. Non-residential water uses can be further disaggregated into the North American Industry Classification System Codes (NAICS), or Standard Industrial Classification Codes (SICs). The IWR-MAIN model provides the modeler with the ability to study different scenarios by making changes in the explanatory variables of water demand and to analyze the impacts of these variables in a long-term water demand scenarios.

The basic structure of the IWR-MAIN model is:

$$Q_{t,d,s,i} = f(P, H, W, C, N, E) \quad (5)$$

Where: $Q_{t,d,s,i}$ = average daily water use in year t with a temporal element of d (e.g. season) in user sector i (multifamily residential); with a sample set of explanatory variables of: P =marginal price of water; W =climate (residential); C =conservation programs; N =number of users; and E =number of employees (non-residential sector). Once the water demand forecast is calculated per sector, the total municipal water use can be calculated:

$$Q_{t,d} = \sum_{s=1}^k \sum_{i=1}^n Q_{t,d,s,i} \quad (6)$$

Where: n and k represent the number of categories and water user sectors in the forecast. In this study, residential water use is estimated in IWR-MAIN by an existing set of equations. However, the IWR-MAIN equations and coefficients may be reviewed and edited based on existing literature and empirical studies of residential water use. Non-residential uses are sectorally disaggregated into hundreds of industry categories.

4.1.1 IWR-MAIN Parameters

The IWR-MAIN Forecast Manager generates a forecast for water-use as function of a base year. Thus the inputs in the software must reflect these two aspects: Base year and forecast year(s). The Forecast Manager suite has in-built algorithms to construct these models. The algorithms are easy to adjust. For each sector and sub-sector, the modeler selects one of the forecasting methods of Forecast Manager. Constant Use

Rate Method calculates the base year per unit water use rate times the number of counting units for each sub-sector. In the Multiplicative Method, the modeler must develop a multiplicative predictive model prior to using the software. In the Linear Model, the modeler must develop a linear predictive model prior to using the software. The Build Forecasting Model allows the modeler to adjust the per unit usage rate with information about the selected variables. Build Forecasting Model is the recommended primary method to use to forecast the water demand in this planning area. Each of the above mentioned methodologies follows the approach:

$$Q_{c,m,y} = q_{c,m,y} \cdot N_{y,c} \quad (7)$$

Where:

Q = water use

q = per unit use

c = customer class (sector)

m = month

y = year

Thus, the projected number of units multiplied with the estimated water use per unit use yields the estimate of water use for the given sector (customer class). The number of units (N) is the planning area. Per unit use (q) can be estimated by average rate of use, disaggregate factor forecast, or by functional per unit use models. We recommend using the disaggregate factor forecast method. It follows the general form:

$$Q = N \cdot q \quad (8)$$

Where:

$$Q_{c,m,y} = (Q_b / N_b)_{c,m} (X_{1f} / X_{1b})^{\beta_1}_{c,m} (X_{2f} / X_{2b})^{\beta_2}_{c,m} \dots (X_{nf} / X_{nb})^{\beta_n}_{c,m}$$

And:

q = adjusted per unit use

c = customer class (sector)

m = monthly use

y = year (b=base year; f=future years)

Q_b = base year unit use

N_b = counting unit (e.g. residential: housing units; non-residential: employee counts per sub-sector)

X_b = base year factor variable

X_f = projected factor variable

β = elasticity

Factor variables are not determined by regression analysis in the disaggregate factor forecast method. The factor forecast can be developed from base year values of water use (Q and N) and base year and future values for the factor variables. The factor variables recommended for this project will be discussed later. The factor variables; explanatory variables, are selected for each sector (residential and non-residential). The modeler is required to develop projected values for each explanatory variable. Also, projected values for number of counting units (N) are required. The projection of explanatory variables and number of counting units is the most challenging part of the water demand forecasting. The modeler also needs to remember that the counting unit data must be defined in the same units as the customer class (sector). For example, if per unit use is defined as water use per demographic unit (population,

housing units, and employment), the customer class (sector) unit (N) needs to be defined as the same unit (single- or multi-family classes, non-residential class). Also, customer class (N) must have projected values of the explanatory variables. Projected values are many times in county level rather than in exact planning area level. There are two methods that should be considered to disaggregate the county level estimates: 1) estimate the demand at a county level and then allocate the demand to planning area demand, or 2) allocate county level data to planning area units and then estimate the planning area demand.

The elasticities for the factor variables may be selected from the literature. There is extensive research available on water demand parameter estimation on both residential and non-residential sectors. The existing extensive literature on the subject should be utilized as it is beyond the scope of this project to develop methods of estimating water use coefficients and elasticities. Depending on the choice of explanatory variables, the corresponding elasticities need to be utilized. The modeler should be aware of the appropriate elasticity factors based on the water users' long- or short-term response time frame. Elasticity is a measure of the responsiveness of one variable (water demand) to changes in explanatory variables (water price, household size, and income). For example, if the marginal price of water is doubled and as a consequence water demand dropped 30 percent, then the price elasticity is -0.3. Alternatively, an elasticity of +0.4 on income in water demand equation indicates that a one percent increase in income will cause a 0.4 percent increase in water use. (PMCL, 1996). One of the expressions for price elasticity is:

$$E = (dq / dp) \cdot p(i) / q(i) \quad (7)$$

Where:

E = elasticity

dq = change in water quantity demanded

dp = change in price

dq / dp = regression coefficient of price (slope of quantity demanded and price)

$p(i)$ = price at some point on the curve (average price)

$q(i)$ = quantity demanded at some point on the curve (average quantity)

Elasticities of different explanatory variables for residential and non-residential water demands are built into the model but can be adjusted to better estimate these sectors' water demand coefficients. It is appropriate, in our opinion, to use the combination of built-in and observed averages of different elasticities based on past research and literature. The modeler needs to separate the water use sectors in estimating the elasticities. For example, in single-family residential sector, the average price elasticity of water is -0.20.¹⁰ This suggests that ten percent increase in water rates might reduce water demand by two percent. The range of the calculated price elasticities is: -0.09 to -0.28 in single-family sector. In multi-family sector the observed average is -0.10 and the range of the values is: -0.08 to -0.16.¹¹ In the commercial, industrial and institutional

¹⁰.Weber, Jack A., 1989, Forecasting Demand and Measuring Price Elasticity, Journal of American Water Works Association (AWWA), 81(5), 57-65.

¹¹ Gleick, Peter H., Heather Cooley, and Groves David, 2005, California Water 2030: An Efficient Future, Pacific Institute, 1-43.

sectors, the average observed price elasticity is -0.25, the range being -0.08 to -0.55.¹² Income and household elasticities for residential and non-residential of water demand have also been estimated. These values are readily available in IWR-MAIN or can be modified based on modeler's discretion. In single-family sector, the commonly used values are 0.4 in both cases. In non-residential sector these values have been estimated to be 0.45 and 0.5.¹³ It is wise to use any elasticities for the purposes of observing the order of magnitude impacts rather than for obtaining precise responses.

4.1.2 Selection and Generation of Model Variables

The selection and generation of model variables are described in Table 4-1 and the variable data availability is described in Table 4-2. The chosen explanatory variables are calculated for both base year and forecast years. The sectoral separation of water use mandates the use of different set of explanatory variables as discussed earlier. Using the disaggregate factor forecast method to estimate the per unit use value of (q), significant explanatory variables are not determined by regression analysis or kept constant. The explanatory variables are developed from base year values of water use data. Using the disaggregate factor forecast model, the residential water demand forecasting factor variables include median household income, housing density, persons per household, marginal price, temperature, and precipitation.

¹² *Ibid.*

¹³ *Ibid.*

**Table 4-1
Selection and Generation of Model Variables**

PROCEDURE	UrbanSim	ArcGIS	DATA SOURCE	IWR-MAIN	DATA SOURCE
Define Planning Area: RESIDENTIAL		Wagoner, Rogers, and Tulsa Counties	U.S. Census 2000 Tiger-Line Data		
		Urban clusters, urbanized areas			
		Block groups			
		No. of households			
Spatial Disaggregation: RESIDENTIAL	Population	New shapefile of planning area	U.S. Census 2000 Tiger-Line Data	<i>Explanatory variables: Model parameters</i>	
	Land-Use Plans			Socioeconomic: Persons per household Housing units Housing density Industrial employment Residential water price Household income	U.S. Census 2000
				Add population projections to attributes up to 2030 per block group	OK Department of Commerce
Define Planning Area: NON-RESIDENTIAL		Wagoner, Rogers, and Tulsa Counties	U.S. Census 2000 Tiger-Line Data		
			Land-use master plans: county business patterns		
			Binomial logit analysis: probability of land-development		
Spatial Disaggregation: NON-RESIDENTIAL	Regional Economic Forecasts	Basemap: Residential shapefile	Planning area residential basemap	Construction, retail, wholesale, manufacturing, service: Establishments, employees	SIC (NAICS)
	Land-Use Plans	Geocoding zip codes	U.S. Census zip codes		OK County Business Patterns
	Employment Estimates				
Water Use Coefficients				No of accounts per type Water use per customer sector: <ul style="list-style-type: none"> • Single family • Multiple family • Construction • Retail • Wholesale • Manufacturing • Service 	
Model Parameters				Elasticities: <ul style="list-style-type: none"> • Median household income • Housing density • Persons per household (pph) • Marginal water price • Av. daily maximum temperature • Total precipitation • Cooling degree days 	IWR-MAIN library Literature
Forecasting Model Type				Build forecasting model	
Define Forecast Years				10 year increments: 2010, 2020, 2030,	

**Table 4-2
Variable Data Availability**

VARIABLE	SUBJECT	GEOGRAPHY	DATA SOURCE*
Population	Total Population	Wagoner, Rogers, and Tulsa Counties Block Groups	U.S. Census 2000: Total population per block group
	Urban clusters, urbanized areas	Wagoner, Rogers, and Tulsa Counties	U.S. Census 2000: UCs and UAs per county
	No of Households	Block groups/water service area	U.S. Census 2000: No. of households per block group OK Water Resources Board: Small system service area
	Persons per Household	Block groups/water service area	U.S. Census 2000: Total persons per household per block group OK Water Resources Board: Small system service area
	Projection	Block groups/water service area	OK Department of Commerce: Sub-County Population Projections
Housing	Housing Units	Block group/ water service area	U.S. Census 2000: 108 th Congressional District summary files: Total housing units per block group
	Density (units per acre)	Block groups/water service area	U.S. Census 2000: 108 th Congressional District summary files
	Units in Structure	Block groups/water service area	U.S. Census 2000: Units in structure: Residential: Single, multiple, occupied, vacant
	Projection	Block groups/water service area	Binomial logit model
Income	Median Income	Block groups/water service area	U.S. Census 2000 FactFinder
	Projection	Block groups/water service area	REMI: Economic Forecast Series
Employment	Employment	Block groups/water service area	Geocoded Zipcodes Labor force participation (LFP) rate County Business Patterns (CBP)
	Projection	Block groups/water service area	Land-use master plans: Binomial logit model: Probability of land-development: UrbanSim. REMI: Economic Forecast Series
Climate	Average Daily Max Temperature (normal and actual)	Block groups/water service area	OK Climatological Survey: Historical Data: Monthly Average Maximum Temperature
	Precipitation (normal and actual)	Block groups/water service area	OK Climatological Survey: Historical Data: Monthly Total Precipitation
	Cooling Degree Days (normal and actual)	Block groups/water service area	OK Climatological Survey: Historical Data: Monthly Cooling Degree Days for Each Year

*data may or may not be available "as is" basis. Modeler may need to extrapolate and calculate the data to fit particular forecasting in question.

In the non-residential sector these include cooling degree days, marginal price, and employment per industry (establishment). In order to validate the elasticity coefficients available in IWR-MAIN library, the modeler has to localize the modeling effort in the elasticity selection. For example, in a water demand forecasting effort of the Twin Cities Metropolitan Area in Minnesota in 2001, it was observed that historical household water consumption was not sensitive to average household income.¹⁴ Those cities with the highest average household income did not have the highest per capita residential water demand. However, IWR-MAIN has positive (0.4) elasticity, indicating that as median household income increases, the water consumption also increases. Some modeling efforts have thus held the income constant, assuming that there is no change in water demand due to median household income. The base year forecast for income is estimated by using the U.S. Census American FactFinder web-site. The projected median household incomes for the planning area need to be extrapolated and adjust for inflation. Income can be reported in current dollars. The modeler needs to be careful not to factor aggregate and flat data of household income. State and even county median household incomes may not be the best fit with the model. Southwestern Oklahoma State University Center for Economic and Business Development (CEBD) has developed a forecast up to 2010 of the real disposable income for the planning area. See more about the CEBD forecast method in the context of employment variables. The real disposable income can be extrapolated per capita basis.

The base year estimates for housing data can be obtained from U.S. Census Bureau's 108th Congressional District File, which contains population, housing units,

¹⁴ Metropolitan Council, 2001, Regional Report Projected Water Demand for the Twin Cities Metropolitan Area, Publication No. 32-01-010, 1-56.

area, and housing densities for the year 2000. For forecasting purposes, median housing density calculations (units/acre) can be somewhat speculative. In order to forecast the change in housing densities, the modeler needs to estimate this for the forecast years. In this report, we recommend utilizing the land-use development model in combination with UrbanSim simulation method to better understand the potential changes in land-use patterns. Both of these methods are discussed later on this report. Most water demand forecasting efforts have opted to hold household density variable constant for forecast years. Although land-use forecasting may be speculative, in our opinion it is more important to try to factor the probability of land-development into the model than to hold the land-development variable constant. If it is held constant, then the modeler assumes there is no effect of land-development on water demand forecasts. IWR-MAIN has an elasticity value of -0.3 indicating that if there was an increase in population density it would yield a decrease in water demand.

When forecasting future housing data explanatory variables as well as employment variables, the examination of land-use probability is needed. The dependent variable, land-use, is categorical rather than continuous, thus the land-use model can be estimated using logistical regression, also known as “logit” instead of linear regression method. Model parameters on land-development are estimated using maximum-likelihood procedure. The land-use variable can be given two categorical values (indicating land-use change or no land-use change). When there are two categorical values, binominal logit (logit-probit) is an appropriate model. The extension of binomial logit model applies to any explanatory variable of water demand that is affected by land-use changes. There are different assumptions that should be taken into account

regarding discrete land-use choices.¹⁵ The first assumption is that the land-development process must act independently of each other (homebuyers, builders, brokers etc.). The second assumption is there are neither non-profit-maximizing buyers nor utility-maximizing sellers. In the other words, the acting agents in the market are not known (buyers and sellers). This approach is also known as reduced-form model because the outcome of the transaction is known (buy/sell) but not the agents involved in the transaction.

The use of spatial autocorrelation is a useful tool of predicting land-use change. This method theorizes that an adjacent or nearby objects tend to influence each other. Spatial autocorrelation is very useful in the planning area in question, since the planning area rural water districts are located in the fringes of the urban clusters and areas that are spreading to rural water service districts. The selection of independent variables of land-use change depends on the modeler. There are multiple resources the modeler may select to establish the right combination of dependent variables. Two variables that we suggest using are “Development Potential” and “Adjacency and Neighborhood”. In the planning area, the major cities have developed Master Plans (Broken Arrow, Owasso, and Tulsa) that outline preferred development patterns of land-use, identify land-use development potential, and land-use characteristics.

As an example, Broken Arrow’s Future Development Guide of the Comprehensive Plan is a color-coded map of the city that outlines a preferred development pattern. The Comprehensive Plan utilizes Land-Use Intensity System (LUIS), which is based on the concept that certain land-uses have similarities in intensity of use and thus, compatible,

¹⁵ McFadden, Daniel, M. Balch, and S. Wu (ed), 1974, *Essays on Economic Behavior Under Uncertainty*, North Holland: Amsterdam.

while other land-uses have different levels of intensity and may not be compatibility for land-use. The LUIS levels of intensity are tied together with the appropriate zoning classifications. The Comprehensive Plan includes a map called the Future Development Guide (FDG), which groups different zoning districts into seven different color-coded levels. The FDG contains a matrix that shows what zoning is allowed within each level. The colors represent different levels of intensity of land-use per square mile. These are rural residential (large residential lots), urban residential (standard single family lots), transition area (office uses, duplexes, townhomes, etc.), commercial and employment, downtown area, regional employment/commercial (major commercial centers oriented around highways, some light industrial), and major industrial (industrial parks, research parks, some commercial). Vacant land parcels based on the LUIS codes are calculated and incorporated into ArcGIS.

The baseline explanatory variable of persons per household (pph) can be calculated from total population and types of housing units for the planning area. U.S. Census American FactFinder and 108th Congressional District summary files have the current estimates available. Again, the dilemma arises from the projections of these values. The modeler has to decide whether to keep these values constant or project them exogenously. Oklahoma Department of Commerce has projected populations in a sub-county level up to 2030. IWR-MAIN's elasticity value for persons per household is 0.45 which indicates an increase in pph would increase water demand. Pph values can be derived from land-use forecasting results, which is discussed above.

Marginal water price should be calculated from each supplier. We recommend that modeler obtains marginal price of water in the planning area by averaging the price of

different usage categories per supplier and then averaging that price with the other average prices of area suppliers. Projection of marginal water prices can be done by factoring in the planning area's annual average price increases. IWR-MAIN library has an elasticity value of -0.04 indicating that the model is not very sensitive to changes in marginal water price.

Environmental variables, precipitation, and maximum daily air temperature, can be obtained from state climatological service or national level services such as U.S. Geological Survey, (USGS) and U.S. FedStats.¹⁶ In our project area, Oklahoma Climatological Survey has the relevant data. Climatological Survey's County Climate Summaries, Historical Monthly Average Maximum Temperatures, and Monthly Total Precipitation can be obtained directly from their web-site.¹⁷ There are sources of this data that have the data averaged on time scales varying from one hour to 30 years.¹⁸ Also, National Oceanic, and Atmospheric Administration (NOAA) and Oklahoma Mesonet provide climatological data of the area. Oklahoma Climatological Survey provides average and maximum monthly and annual temperatures and precipitation data since 1895. The projected area maximum temperatures and total precipitation data are based on historical averages. IWR-MAIN elasticity for maximum temperature is 0.5 and for total precipitation -0.02. The temperature elasticity indicates that an increase in temperature results in an increase in water demand. The rainfall elasticity indicates a decrease in water demand due to precipitation. Since forecasting weather is

¹⁶ <http://www.fedstats.gov/>

¹⁷ <http://climate.ocs.ou.edu/>

¹⁸ Personal communication with Dr. Kit Wagner, Atmospheric Information Systems, May 2007.

problematic and beyond the skills of the authors and the scope of this report, we recommend using constant temperatures and precipitation values in the projection years. It would be very interesting to test variations in temperature and precipitation (draught, flooding) on water demand in both in short-run and long-run.

In both residential and non-residential sectors, the water use data is inputted by number of accounts per customer sector. The modeler enters base year water use in gallons for each month by each sub-sector. The water use data in this study can be obtained from each water system within the current service area. The data consists of number of connections, monthly production, and monthly metered production. The data is used to provide average water consumption per account by water use sector.

The selection and calculation of parameters in the non-residential sector is slightly less complex than in the residential sector. IWR-MAIN uses SIC (Standard Industrial Classification) codes. In 1997 the Office of Budget and Management (OBM), replaced SIC system with the North American Industry Classification System (NAICS). Both SIC and NAICS are hierarchical classification code systems that are used to identify the types of businesses in the planning area. The planning area NAICS codes can easily be converted into SIC codes. Average water demands in each SIC code are determined on the basis of water use per employee per day. IWR-MAIN comes with an extensive library of water use coefficients in different SIC codes. These coefficients are best validated by comparing them to the current literature of water use per industry sector. Most likely water consumption in different industries has diminished due to improved and more efficient technologies and conservation measures.

In order to forecast job projections in the planning area, population projections data of the area and Bureau of Labor Statistics projections of trends in labor force and job growth are needed. The Center for Economic and Business Development (CEBD) in Southwestern Oklahoma State University in Weatherford, Oklahoma, has used Regional Economic Models, Inc. (REMI), based in Amherst, MA.¹⁹ REMI is a proprietary economic modeling software that enables modelers to answer “what if” questions about their respective economies. Each REMI model is tailored for specific geographic regions by using data, including employment, demographic, and industry data, unique to the modeled region. The CEBD uses the Oklahoma REMI model, which is a six region, 70 sector model, to forecast how a given economic activity or policy change occurring in one region would affect that region, a group of regions, and/or the state. The REMI simulation model uses hundreds of equations and thousands of variables to forecast the impact that an economic/policy change has upon an economy. The six regions used in Oklahoma REMI are: Northwest Oklahoma, Northeast Oklahoma, Southwest Oklahoma, Southeast Oklahoma, the Oklahoma City metro area, and the Tulsa metro area. The Oklahoma metro area and the Tulsa metro area correspond to the Metropolitan Statistical Areas (MSAs) defined by the Office of Budget and Management. The counties that comprise the Tulsa MSA are: Creek, Okmulgee, Osage, Pawnee, Rogers, Tulsa, and Wagoner. REMI generates a control forecast, which uses current data regarding the economy. The control forecast represents the projection of the economy into the future *ceteris paribus*. This approach is also commonly used, for example, in projecting population, employment, densities, and

¹⁹ Regional Economic Models, Inc: <http://www.remi.com/software/software.shtml> Obtained May 20, 2007.

urban land shares. This approach generates separate sectoral in MSA or county-level forecasts and then aggregates them into single regional total. If the modeler wants to deviate from forecasting to scenario planning instead, then the use of past similar patterns of the observed variables may not be the only means of interpreting the future job growths.

USACE has projected the employers using labor force participation (LFP) rate (number of employed/population).²⁰ The modeler has to be careful not to use population projections by residence but by employment based pm location of work. However, some studies in California, in particular, presume that there is a relationship between the size of region population and employment base. This is due to the fact that there is a long-term spatial trend in California (and elsewhere) of jobs being located outside of the city centers. The modeler needs to be familiar with the planning area in question, and whether the national trend of job decentralization applies to it. As we demonstrated in Section 2.2, it is safe to state that the decentralization of jobs has not occurred in our planning area.

The County Business Patterns (CBP) reports employment by location of work, and this can be used for base year calculations. In order to forecast those numbers into the future, the modeler needs to make a choice whether to keep the numbers constant or try to project them. USACE Tulsa district performed a water demand study for the city of Bartlesville, and they kept LFP constant. The assumption keeps the study simple and may be safe because the literature suggests that the LFP national trend is in

²⁰ Personal communication with Dr. Edwin Rossman, USACE, Tulsa District, Planning Division, May 2007.

decline.²¹ Keeping the LFP constant assumes the structure of the economy is unchanged. However, the study community may not always follow the national trend, and thus we propose that small area projections of economic forecasting may be possible by using land-use projections as discussed earlier. IWR-MAIN extracts water demands for non-residential sector by employers per establishment basis. This ratio indicates how water-intensive the industry in question is.

The other model variables chosen to forecast non-residential sector water demand are: the cooling degree days (CDD) and the marginal price of water. Cooling degree days are used to estimate how hot the climate is and how much energy may be needed to keep buildings cool. CDDs are calculated by subtracting a balance temperature from the mean daily temperature, and summing only positive values over an entire year. The balance temperature used can vary, but is usually set at 65°F (18°C), 68°F (20°C), or 70°F (21°F).²² In general, it is a measure of the severity of the summer in a given locality: the more cooling degree days, the hotter the summers. OK Climatological Survey has monthly cooling degree days for each year. The marginal price of water for each industry sector is calculated in a similar fashion to residential price of water.

4.2 UrbanSim

UrbanSim models land development for land-use. The input variables selected for different models with UrbanSim need to be generated outside the model. As we

²¹ Toossi, Mitra, 2002, A Century of Change: The U.S. Labor Force, 1950-2050, Monthly Labor Review, 15-28.

²² U.S. EPA: <http://www.epa.gov/heatisland/resources/glossary.html> Obtained 04/20/2007.

discussed above, in the context of land-use planning and housing densities and job projections to generate input variables into IWR-MAIN, the same methodologies are used to generate input variables into UrbanSim. The input data needed in UrbanSim are: population and employment estimates, regional economic forecasts, and land-use plans. All these input data are disaggregated and thus the output of the model is disaggregated.

5.0 Procedures to Planning Area Water Use Forecasting

The flow chart 4-2 (p.26) presents part of the entire model driven DSS. This flow chart contains the first set of three procedures using three software applications to obtain the output of water demand forecast. The DSS modeling at the early stages are done by using ArcGIS/ArcView 9.2, UrbanSim and IWR-MAIN 6.1 softwares. The modeling capabilities and data requirements of IWR-MAIN and UrbanSim are discussed in Section 4.

ArcView 9.2 version of desktop GIS (Geographical Information Systems) is a mapping tool to map, visualize, and analyze data with geographical components. The software is an ESRI product. The starting point in building a basic model is to define the spatial element of the forecasting, i.e. the planning area. This is done by identifying the fastest growing areas (urban clusters and urbanized areas) in the study region and mapping them in ArcGIS. This spatial element is then correlated with the rural water district pipeline data. The next stage is to further refine the planning area by breaking up the physical planning area into U.S. Census Block Groups (BG). Now the physical

base map represents geographical representation of water service boundaries. BGs do not contain any demographics data. Using a similar methodology to McPherson and Witowski (2005) and McPherson and Brown (2003), residential housing units data are spatially disaggregated to a raster representation of census blocks. This is done by adding housing units per BG and this becomes a new shapefile. The BG data and the occupied housing units per block group of each study county area and the geographical representation of these are obtained from U.S. Census. This procedure aids in calculating spatially distributed demands of residential drinking water. Block groups are clusters of census blocks and is the smallest geographic unit, containing from 600-3,000 people in each block. Many blocks correspond to individual city blocks bounded by streets, but blocks especially in rural areas may include many square miles and may have some boundaries that are not streets. The temporal/spatial element of residential water use forecast modeling is done by matching the physical planning area with the disaggregated Oklahoma Department of Commerce population projection data. This is done in 10-year time steps up to 2030.

In order to input demand forecast elements of non-residential water use, the base map is expanded to include the main classes of industry in the area. We have selected manufacturing, retail, construction, wholesale, and service sectors. Mapping of these sectors is done by incorporating Geoprocessing method in ArcView. This is done by using U.S. Census County Business Patterns data and identifying the zip codes of the industries located in the planning area. This aids in locating current non-residential water demand sectors in the planning area. ArcView is not forecasting software, but its ability to create spatial representation of the planning area as it currently exists, helps

us in extrapolating future water demands in the area. Also, linking current Census data with spatial data files gives a better understanding of the socio-economic characteristics of the planning area. We correlate the number of housing units, population, income, and population density with the physical BG. In the non-residential side of water demand, current location of businesses and industries are correlated with BGs. ArcView is also later linked with hydraulic modeling. In all the stages of DSS, ArcView functions not only as a mapping tool, but also compiles, stores, analyzes, and manages data and integrates database operations.

Once the spatial planning area is defined and the current values of the explanatory variables are added into the spatial elements, the UrbanSim land-use simulation should be started. This procedure is discussed in Section 4. The output of UrbanSim is inputted into IWR-MAIN. Also, the other exogenously extrapolated data are inputted in IWR-MAIN, as discussed above.

6.0 Hydraulic Network Simulation

WaterGEMS (proprietary) is not a single model. It is better considered as a geospatial hydrologic simulation system, consisting of software architecture for implementing different models and the interaction of the models within this environment. The models implemented in WaterGEMS employ a wide range techniques and approaches. The usability of WaterGEMS in this project stems from its ability to perform “what if?” scenarios of hydraulic systems (distribution networks). In this model a variety of alternatives (demand growth scenarios) can be employed in Extended

Period Simulations (EPS). WaterGEMS was designed, developed and programmed by Haestad Software and Civil Engineers. It consists of in-built algorithms of hydraulics. Based on the modeling desires, the appropriate in-built coefficients can be chosen to represent the hydraulic situation in question.

In essence, we are interested in finding out if and for how long the existing water distribution system can be expanded to new customers. Demand alternative of WaterGEMS allows the modeler to model the responses of the water system to different sets of demands now and, e.g. ten years later. This is done by modeling new piping that will become part of an existing system and that has a connection point that is not a tank or pump station. The new pipelines may need to be constructed for a new residential subdivision, industrial park, or mixed-use land development. The pipe sizing of the new system cannot be sized independently, since we intend to use the existing water system. Thus, the simulation process starts with constructing the base-line system of a distribution network. Each junction (node) in the network is assigned average conditions per time-frame with respective water flows, pressures, elevated storages, source reservoirs. Then the existing base model is calibrated to receive the new pipelines. Prior to simulation of the new system, the modeler must define the pressures and elevations, and all other hydraulic conditions.

The best way to model the extension of an existing system is to build the new pipes and customers into a calibrated model of the existing system. By doing this, the modeler detects the extended system's impacts on the existing one, and vice versa. Having a calibrated model of a system also allows a wide variety of situations to be simulated (e.g. modeling of different demand scenarios). The scenario management

feature of WaterGEMS allows the modeler to build scenario cycles by altering the average conditions by, for example, increasing the water flow through the system. The anatomy in scenario management begins by identifying the attributes of elements in the hydraulic networks that may experience change due to a different scenario, such as an increased water demand that needs to be piped through the existing pipelines.

The purpose of the earlier part of this project is to demonstrate how to forecast water demands and assign those into the planning area (into Block Groups, BGs). In WaterGEMS the water demands of the planning area are called “lump-sum area”. This represents total water use of the service areas based on the demand nodes (either meters or nodes of pipelines within block groups). Each service area polygon within the lump-sum area is assigned a single flow. The flow can be distributed equally among the service areas within the lump-sum area, or the flow can be distributed proportionally among the service area polygons within the lump-sum area. In order to simplify spatial and demand allocation, the proportional distribution option of lump-sum demand allocation per service area is recommended in this project. The greater the percentage of population in the service area, the greater the percentage of the total flow is assigned to that service area. The distribution networks are then simulated to meet the service area demands in the determined time-steps. The goal is to identify the point when the current system will no longer be able to meet the increased demands.

The costs of each type of element in water system stem from construction and non-construction costs. The Capital Cost Manager of WaterGEMS needs to be utilized in order to encapsulate construction costs involved in different scenarios. It tracks costs associated with water distribution capital improvements. The modeler needs to supply

this information to the software, as the costs are not built into the system. The cost calculations are thus calculated exogenously. The modeler needs to define the physical elements, demands or loads, baseline setting of the network, and then calculate the unit costs of those. In the distribution network capital cost estimating, the elements that need to be calculated are broadly categorized as pipeline and nodal element costs. Pipelines costs are: pipeline costs per unit length, number of service lines, and lengths of pipe segments. Nodal element costs are: number of valves, tanks, and pumps. The non-construction costs are assigned as a lump sum amount. Non-construction costs in general are indirect costs of construction, such as inspections, administration, and legal.

Once the physical elements have been identified and their associated costs calculated, these are entered into unit cost functions within WaterGEMS. The cost functions are in equation or tabular format. We suggest using several different equation cost formulas since pipelines have different costs associated with them depending on the soil types in question. The general form of the cost function is:

$$\$/ft = d + a(x - c)^b \quad (8)$$

Where:

X = diameter of pipe

a, b, c, d = cost coefficients

Coefficient *b* is an exponent and indicates how sensitive the costs are the size of a pipe. Hence, if costs are less sensitive to the size, *b* is small. Coefficients *d* and *a* are independent of the size of the pipe, and associated with excavation and laying the pipelines.

When the baseline system is altered, the scenario construction costs are adjusted. This is done in WaterGEMS by building costs associated with each physical scenario. Each scenario is constructed by using physical alternatives (e.g. different pipe sizes) and then associating that scenario with matching cost alternatives (e.g. cost functions).

The other important element of cost analysis is energy costs. WaterGEMS has an Energy Cost Manager feature that allows the modeler to estimate energy costs of the water system. Energy cost manager, like capital cost manager, can be run independently or in conjunction with the simulated scenarios. Also, like capital costs, energy costs are obtained outside the software. The largest energy consumptions stem from pump operations.

The results of EPS of water system networks and the associated costs provide the final components to the assembly of the decision support system. The 10-year incremental demand simulations provide information to the decision makers about the costs and infrastructural capabilities of water supply systems.

7.0 Cooperation with Consolidation or Acting Alone

Regional consolidation, collaboration, restructuring, centralization, or regionalization of water systems, especially in rural areas, has been promoted by water planning and research agencies in state and federal levels as a solution to combat the consequences of increased drinking water demands. The main idea of regionalization is that it pools individual sources of two or more water systems to better meet the growing demands of water. In this project the final product of DSS will inform water

planners and water system managers whether consolidation of physical assets in the planning area is needed at different time-periods so that costs are minimized. The structural consolidation includes any form of physical interconnectedness of two or more systems, whereas the non-structural form of consolidations emphasizes procedural changes in water system management and administration.

Table 7-1 presents the potential gains of both physical and non-physical forms of regionalization. The benefits of regionalization/consolidation are not straight-forward or unlimited. The optimal result of consolidation is decreased cost of treated water.

TABLE 7-1 Perspectives on Consolidation

Perspective	Key Reasons
Economic	Economies of scale and scope (lower unit costs)
Financing	Access to capital and lower cost of capital
Engineering	Operational efficiency and technological improvement
Natural resource	Resource management and watershed protection
Federal standards	Compliance with standards at lower cost, greater capacity development, and greater affordability of water service

SOURCE: Beecher (1996)²³

The potential gains or losses of consolidation are derived from the theories of scale economies, size economies, and scope economies. These theories stem from the nature of production processes within firms.

The nature of returns to scale (constant, increasing, and decreasing,) refers to physical relationships between inputs and outputs. Returns to scale measures how

²³ Beecher, J. A., 1996, *Regionalization of Water Utilities: Perspectives, Issues, and Annotated Bibliography*, The National Regulatory Research Institute: Columbus, Ohio.

output reacts to either increases or decreases in inputs. The constant returns to scale indicate that if all inputs were doubled, the output doubled also. If the output more than doubled as a result of doubling the inputs, increasing returns to scale is present. If the output less than doubled as a consequence of increased inputs, decreasing returns to scale are present. Scale economies refer to the costs associated with the physical relationship of input(s) and output(s). Economies of scale indicate that the average unit cost of output is falling; economies of scale indicate that the average unit cost of output stays the same, and diseconomies of scale indicate that the average unit cost of output is increasing. Size economies differ from scale economies by allowing input proportions to alter when doubling of output is achieved for less than twice the cost. However, the distinction between scale and size economies is not important for many practical purposes. Thus, size and scale economies are used interchangeably. In the context of small water systems, scale economies and diseconomies have been widely applied in justifying water system consolidation.

Capital-intensive services usually yield significant economies of scale since the cost of fixed assets can be distributed across a larger number of customers. Thus, the economies of size are easy to realize with water treatment; Lower unit costs of water are obtained with treatment plant size increase. However, transmission and distribution costs of water depend on the service area (size, population density, topography, and soil type), and thus the economies of size may be offset due to diseconomies of distribution. The past literature suggests different results of the economies of scale associated with different water system components. Some studies show high economies of scale in water treatment. Other studies show more scale economies in

water system administration than in water treatment. Also, some studies consider the possibility of economies of scale being offset due to diseconomies of distribution. In the drinking water industry the economies of scale and size can be achieved by nonstructural or structural forms of consolidation.

There is no theoretical relationship between scale/size economies and scope economies. Thus, the economies or diseconomies can be occurring independently from each other. Therefore, it is possible to achieve scale and size economies and suffer scope diseconomies simultaneously. The existing literature derives its economic reasoning of water systems consolidation from the concepts of economies of size and scope. The concept of scale economies have been applied in joint production framework but not in interactions between production processes.

The outputs of the modeling of land-use development, water demands, and simulation of distribution networks give cost estimates of different water pipeline and treatment infrastructure needs based on the simulation and modeling scenarios. These scenarios and associated costs are given in 10-year time increments up to 2030. Each one of the scenario, every ten years, is evaluated for its cost estimates. Each one of the scenario is then evaluated within the economic framework of consolidation as described above.

8.0 Conclusions

In this report we have established a basis for a comprehensive model-driven DSS of water system infrastructure planning that will enable the decision-maker to

consider future growth factors in determining the optimal utilization of current and likely future water system infrastructure. The purpose of the DSS is to guide and to inform the decision-maker rather than make the decision on his/her behalf. The options analyzed will include the determination of suitability of existing infrastructure, the need for enhancement of existing pipelines, pumps, and/or distribution systems, or semi-optimization by consolidating with other water systems. The new element of this DSS is the ability to analyze water system infrastructure at the most basic (e.g. rural water district) level such that the decision maker can perform real-world concrete analysis of the infrastructure requirements to meet future growth demand in the most cost-effective manner.

9.0 Caveats and Recommendations

There are many challenges for development of a holistic model-driven DSS. These challenges stem from data availability and requirements, model formulations, and model solutions. Data requirements relate to the type of data needed, level of forecasting, and level of disaggregation scales. Mixed types of data from various sources are used in interdisciplinary models with spatial, sectoral, and temporal dimensions. These data requirements and manipulation make the assembly of the models labor-intensive. The temporal scale of planning of infrastructure needs further complicates the assembly of the models. Continuous modeling techniques can not assume to generate solid, hard-core forecasts but take an approach of scenario modeling in both the input forecasting as well as in constructing the main models. The

modeler has a responsibility to identify the potential short-comings in the scenario planning process and incorporate to the model in a best possible manner.

Many of the input parameters in water demand forecasting need to be calculated by the states' planning agencies, who may alternatively contract professionals in land-use planning and population forecasting to generate these data. Land-use planning and population forecasting are specific disciplines and require mastery of skills that many times are beyond the skills of an engineer or a water demand forecaster.

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