A WATER RESOURCES PLANNING SUPPORT SYSTEM FOR A GROWING COMMUNITY WITH MULTIPLE WATER SUPPLIERS – APPLICATION IN OWASSO, OKLAHOMA

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Abstract

This dissertation answers the general question of when and where consolidation of rural and medium size community water systems is appropriate and should be considered as a solution to address the growing water demands of a single critical community. To this end, a planning support system was developed, applied and consolidation recommendation were identified. This Planning Support System is applicable to urban fringe communities.

A two-module Planning Support System was developed: 1) Problem Analysis and 2) Solution Analysis. Problem Analysis consisted of using a Current Reality Tree to identify the core problem of a critical community: lack of a long-term water plan. The first sub-module accomplishes two tasks: selection and combining of individual community water systems to be included in the analysis. The combined systems were evaluated for their existing service characteristics and their ability to meet the critical community system's water needs. The second sub-module consisted of technical analysis of forecasted demands and needs analysis. The third module consisted of economic analysis of costs associated with consolidation.

The Planning Support System was applied to the City of Owasso (critical community). The Problem Analysis module identified the core problem of lack of long term planning for the critical community. The Solutions Analysis module combined four community water systems to address the core problem in the City of Owasso: the town of Collinsville, Rogers Rural Water System 3 and Washington Rural Water District 3. Each consolidation scenario was evaluated for their water treatment and storage capacities, as well as water permits for a 50-year planning horizon. The IWR-MAIN forecasting model forecasted the entire service area of the City of Owasso's water demands to increase by approximately 37 percent per decade for the 50-year planning period.

The Planning Support System for the City of Owasso recommended the schedule for consolidation, the required water rights, additional treatment capacity, and storage required. The net present costs were estimated for water treatment plant construction, storage and the O&M. The most cost-effective consolidation scenario is the one that meets the City of Owasso's required future water demands at least cost. The least-cost consolidation scenario for the 50-year planning period was Rogers Rural Water District No. 3 with Washington Rural Water District No. 3 with a plant expansion in Rogers 3.

I. INTRODUCTION

Decision makers will need to tackle short- and long-term availability, reliability and cost-effectiveness of drinking water. The long-term decisions are those associated with availability of water resources to meet the long-run future water demands in growing exurban pockets. The decisions are especially critical to those community leaders and planners, whose communities have experienced higher than average growth as compared to the surrounding county and are currently served by a combination of water systems.

The many characteristics of water supply make planning a challenging task. Water is usually a location-specific resource and mostly a non-tradable output. Also, markets for water may be subject to imperfection. Features related to the imperfect nature of water markets include physical constraints, the high costs of investment for construction, legal constraints, complex institutional structures, the vital interests of different user groups, limitations in the development of transferable rights to water, cultural values and concerns of resource sustainability. Typical water resources investments are made in short or medium term (10 years) (Shih et. al, 2006).

Rural water systems adjacent to growing urban areas in Northeastern Oklahoma, in particularly Washington and Rogers Counties, are expected to face challenges in the future concerning the management of their water supplies, treatment as well as the optimal rate of construction of new water plants. These water systems will experience increased drinking water demands and changing water demand profiles due to urban/rural interface issues caused by actual population growth, annexation, and housing and commercial developments in the adjacent rural water service areas. The characteristics of these growth areas include fragmented water supply profiles. Other critical factors leading to long-term water resources management issues may also be combined with other technical, financial and managerial problems. The water systems can choose to meet the expansion needs and the associated costs as well as other managerial, financial and technical issues by themselves or alternatively, consolidate their system with other nearby community water systems (CWSs).

Water resources planning and management can be approached at systems level, or alternatively a wider approach can be taken to include a specific community, region, or water-shed. An attempt to accomplish all possible levels of water resources planning in one dissertation is an impossible task, thus the approach taken in this dissertation is in a system level but including the surrounding communities as being part of the solution.

Regional consolidation, collaboration, cooperation, restructuring, centralization, or regionalization of water supply systems, especially in rural areas, have 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 and water quality requirements (AWWA, 2001b). The main idea of consolidation is that it pools individual sources of two or more water systems together to better meet the growing drinking water demands. The justification for consolidating water systems stems from potential economic, financial, engineering, and natural resources benefits. The benefits can be gained from consolidation include more efficient water distribution networks, more reliable water quality, ability to anticipate future water demand requirements and access to capital and materials to expand the system requirements to meet future growth scenarios and water quality requirements (Levin et al., 2002; Coy, 2007; Shih et al., 2006.) In the context of small and medium size drinking water systems, scale economies and diseconomies have been widely cited in justifying water system consolidation. Capital-intensive drinking water services usually yield significant economies of scale when the cost of fixed assets can be distributed across a large number of customers, and as a consequence the unit cost of treated water is falling. Therefore, as a consequence, the economies of scale are easy to realize with water treatment: low unit costs of water are obtained with treatment plant size increase (Shih et. al, 2006).

In the drinking water industry the economies of scale can be achieved by nonstructural or structural forms of consolidation. Water systems can be divided into three separate components with distinct cost functions. The first includes treatment of water, the second transmission and distribution, and the third administration and management services.

1.1 Study Objectives

The principal research objective is when and where a consolidation of rural and medium size community water systems is appropriate and should be considered as a solution to address the growing water demands of a single community. The objective is accomplished by developing and applying a Planning Support System (PSS).

The PSS is developed consisting of modules that produce outputs that are needed as inputs in the next planning stages. The approach taken in this dissertation is in the planning analysis context. The first module in the PSS is the Problem Analysis. The Problem Analysis answers the general question: What are the roots causes for the problem? The second module in the PSS is the Solution Analysis. The Solution Analysis does the following:

- selects and combines individual water systems;
- evaluates the existing characteristics of water systems;
- analyzes forecasted demands and needs; and
- analyzes the associated costs of consolidation.

This dissertation constructs water resources planning support system for a single critical community. A critical community is defined as a community that is located in an urban fringe area and is dependent on multiple water sources. The goal is to decide where and when water system consolidation could be proposed as a solution to critical community water resources problem.

This dissertation is guided by a planning framework using the literature from water resources planning that are guided by the theories of consolidation and water resources planning (USACE, 2000; National Academy of Sciences, 2004; National Research Council, 2004; Page and Susskind; 2007; USACE, 2009). The dissertation generates the planning methodology to propose a solution in a form of a water system consolidation to address the growing water demands, short-term water resources planning, uncertainty about future water supplies, and inadequacy of community water system infrastructure, and water allocation needs.

1.2 The Planning Support System

The PSS consists of two main modules, Planning Analysis and Solution Analysis. The Planning Analysis module main determines root causes while the Solution Analysis module provides planning recommendations. Both modules are discussed in detail in the following paragraphs.

In the Planning Analysis module, demographics, housing densities, work location, and work commute time data from the U.S. Census Bureau (2000 and 2006) are used to justify and identify the larger study setting. The study area characteristics are analyzed further for potential water resources problems in the study area. From this analysis, a critical community is identified. Using a tool from the Theory of Constraints and the Root Cause Analysis, a Current Reality Tree is constructed as a problem identification method to address water resources core problems in the identified in a critical community. The use of

Current Reality Tree helps to identify symptoms and core problems (Klein and Debruine,1995; Matchar et al., 2006; Dettmer, 1997).

In the Solution Analysis module, a physical consolidation is proposed as a solution to the core problem as identified in the Root Cause Analysis. The water system consolidation scenarios are assembled by using evaluative screens to identify the existing water system structures and dependencies on one another. The use of these screens and the criteria select the community systems considered for further analysis. In the Technical Analysis sub-module of the Solution Analysis, the developed cooperative scenario water demands are forecasted over a planning period. The different water supply scenarios are evaluated for their feasibilities based on their existing water treatment capacities, water storage, and water rights. All scenarios are forecasted to be independent from the other water systems. In the Economic Evaluation sub-module of the Solution Analysis, the decadal costs of meeting the forecasted demands are evaluated. The costs include are the construction costs for water treatment plant and the distribution storage.

The PSS is constructed using primary and secondary screens. The screens set up using different criteria in the PSS that guide the decision-making process. The primary screens help in identifying the target study setting and critical communities, justifying the water resources' problem, evaluating the proposed solution to perceived water resources problems, and delineating a combination of water system consolidation scenarios. These tasks are carried out by using flow diagrams, computerized models (ArcView) and a conceptual model (CRT). The secondary screens are used in identifying the treatment, storage, and water rights gaps based on the study areas forecasted water demands. IWR-MAIN water demand forecasting tool is used secondary screening.

The PSS guides the planning process and helps with a plan formulation by comparing and combining user-defined criteria and solutions to a critical community meeting its future water demands. The PSS supplies recommended schedule for consolidation, the required water rights, additional treatment capacity, and storage required. The outcome will not be a single plan but a series of options evaluated in terms of their net present cost with a list of non-monetized characteristics. Based on the outcome of the PSS, recommendations can be made as which consolidation scenarios would be reliable and cost-effective based on their supply and treatment feasibilities and net-present value of the costs through-out the planning horizon. In conclusion, this dissertation contributes to the improvement to the planning process to support decision-making in the context of small and medium size rural water system consolidation.

1.3 Application of the Planning Support System

The Planning Support System will be applied to the City of Owasso (critical community) in Northeastern Oklahoma with three individual water systems and their service areas. These are: Oklahoma’s Rogers County Rural Water District (RWD) 3, Washington County Rural Water District 3, the Town of Collinsville (Rogers County), and the City of Owasso (Rogers and Tulsa County). The selected CWSs all are currently supplemented by the City of Tulsa's water ranging from ten to forty percent of their total daily requirements. Presently, Tulsa provides all the water needs within Owasso's city limits. However; the greater Owasso (outside corporate city limits) area households are served by Rogers RWD 3 and Washington RWD 3. The total forecasted Owasso water demands are included in all the water supply evaluations. Four physical consolidation scenarios are evaluated for water treatment capacities, sufficiency of water permits, and treated water storage requirements based on the demand forecasts and independence from the large regional water supplier. The costs are estimated for each consolidation scenario. The most cost-effective consolidation scenario is the one that meets the required future water demands at least cost.

1.3 Study Justification

"Small" and "rural" water systems are typically characterized by the number of people they serve and the service area location, consecutively. Small water systems according to the U.S. Environmental Agency (EPA) include systems that serve fewer than 10,000 people (water system characteristics discussed later). This definition includes service area regardless how the served area needs are met. Since the 1960s, rural water systems have had a strong presence in rural communities in providing water for sparsely habited areas. The definition of rural systems according to the Oklahoma Water Resources Board (OWRB, 1980) Rural Water Systems in Oklahoma include: "All public rural water districts, rural water corporations and communities with a population of 10,000 or less" (OWRB, 1980). Since the 1980, the number of rural water systems has doubled and some systems grown out of the 10,000 people served benchmark (OWRB, 2006).

Many small and rural water systems have grown in recent years due to their population increases but their infrastructure from distribution pipelines to water treatment and water supplies have not kept up with the rapid growth. In order to meet their grown demands, these previously small and/or rural systems have had to find innovative ways to meet the growing demands. The typical ways have included supplementing (buying) some portion of the required demands from another districts or municipalities water, dividing the service areas with other nearby systems, and buying all of the required water from another district or a municipality (OWRB, 2006).

When a water supply portfolio becomes fragmented, it creates uncertainty to all parties involved, including the end-users. Regardless of the past definitions of the water systems, the baseline conditions and the anticipated community characteristics and demands will dictate the future characteristics of all water systems.

Most studies in the field of water resources planning have either an engineering or a water demand emphasis and a short-run planning horizon. The short-run water supply studies have an emphasis on individual systems and their predicted infrastructure needs (EPA, 2002a and 2003a). These system-specific and individualized studies may lead to over-estimated infrastructure and funding needs and have gaps or overlaps their service areas. When water supply systems are unable to fund their 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 an adequate external funding, smaller size systems resort to “pay-as-you-go” approach of financing their infrastructure needs (EPA, 1999). Even with the most sincere effort to accomplish long-term water resources planning secure funding such as the State Revolving Funds (SRF), the planning is based on individual system’s existing water demands. The SRFs are the most common source of funding to small and medium size water systems (EPA, 2002a).

The most predominant solution to the dilemma of ensuring affordable future drinking water to different types of growing communities has been to propose physical consolidation of small and medium sized (rural water) systems (AWWA, 2001). Consolidation of these utilities has been promoted as a mechanism that increases economic efficiency of water supply. Most empirical studies (Shih et al., 2004; Jaffe et al., 2007; and F.S. Bagi, 2002) have concluded that production unit costs of water systems are generally higher with smaller size water systems. Shih et al. (2007) found that doubling a system’s production would lower unit costs between ten and thirty percent (depending on studies and cost components). Consolidating small water systems into a large system could double the small system’s scale several times over, providing gains of 50 percent or more (Cadmus Group Inc., 2002). Furthermore, purchase systems, according to studies using national data, are more expensive than groundwater or surface water systems (EPA, 1999).

The Walkerton Inquiry (2002) used the capital cost scale factors from the Cadmus Group Inc. (2002) report and the operating cost factors from Kingdom, Knapp and LaChance (1996) and made cost comparisons between water treatment plants that served 5,000 people, 50,000 and 500,000. According to the Walkerton Inquiry (2002), the magnitude of potential cost savings that exist as water system size increases demonstrate that there are economies of scale in water supply operations and capital facilities. For example, the 2002 study found the per unit capital costs associated with chlorination for a water treatment plant serving a population of 50,000 were 48 percent per unit of capital cost for chlorination for a plant serving 500,000 populations is only 23 percent of the cost of a plant to serve 500. Kingdom, Knapp and LaChance (1996) looked at the economies of scale in unit capital costs of different population sizes served. The authors looked at various capital and Operations and Maintenance (O&M). This is the cost associated with operating and maintaining water treatment plant. The principal cost components of O&M activities are labor, materials, chemicals, repairs, and energy for both processes and enclosures (Montgomery, 1985). Kingdom, Knapp and LaChance (1996) studied the O&M unit costs between plants that serve populations of 5,000, 50,000 and 500,000. The authors found that the capital costs associated with a plant serving a population of 50,000 with a conventional filter plant (new) were 76 percent of the capital costs of a plant serving 5,000 and 58 percent for a plant serving 500,000. Similarly, the capital unit costs associated with a plant serving a population of 50,000 with conventional filter plant (rehabilitation) were 40 percent compared to the capital unit costs serving 5,000 and 16 percent for plants serving 5000,000. For the same service size comparisons (50,000-5,000 and 500,000-5,000), the authors found that for reverse osmosis plant (new) the unit costs were 65 percent *versus* 42 percent, and for reverse osmosis-rehabilitation: 19 *versus* 4 percent. The operation costs demonstrated similar trends than capital unit costs for the same population size served comparisons (50,000-5,000 and 500,000-5,000). The transmission and distribution: 88 *versus* 77 percent, and total O&M: 65 *versus* 43 percent (Walkerton Inquiry, 2002). These findings are consistent with the EPA Community Water System Surveys of 1995 and 2000 surveys (EPA, 1995 and 2000c).

Physical consolidation, however; it is not necessarily a *panacea*. Each water system possesses unique features that should be taken into a consideration when evaluating different types of consolidation scenarios. The system characteristics constitute the selection criteria of consolidation partners and the final cost of implementation of consolidation. Physical consolidation should not be used as a global solution to all water systems. Not all systems may benefit from consolidating their water systems with another system. The economies of size may be offset with the economies of transmission (Clark and Stevie, 1981c). However, this is not to state that consolidation of water systems would not yield cost efficient outcomes. Previous studies seem to indicate that the very smallest of community water systems would benefit but not by necessarily merging with the largest systems. It has been suggested that the larger efficiency gains would be possible when the small systems are merged with medium size systems (≥10,000 people served) compared to large systems (≥100,000 served) (Shih et al., 2006). The majority of costs savings have been shown to occur from capital, material, and labor.

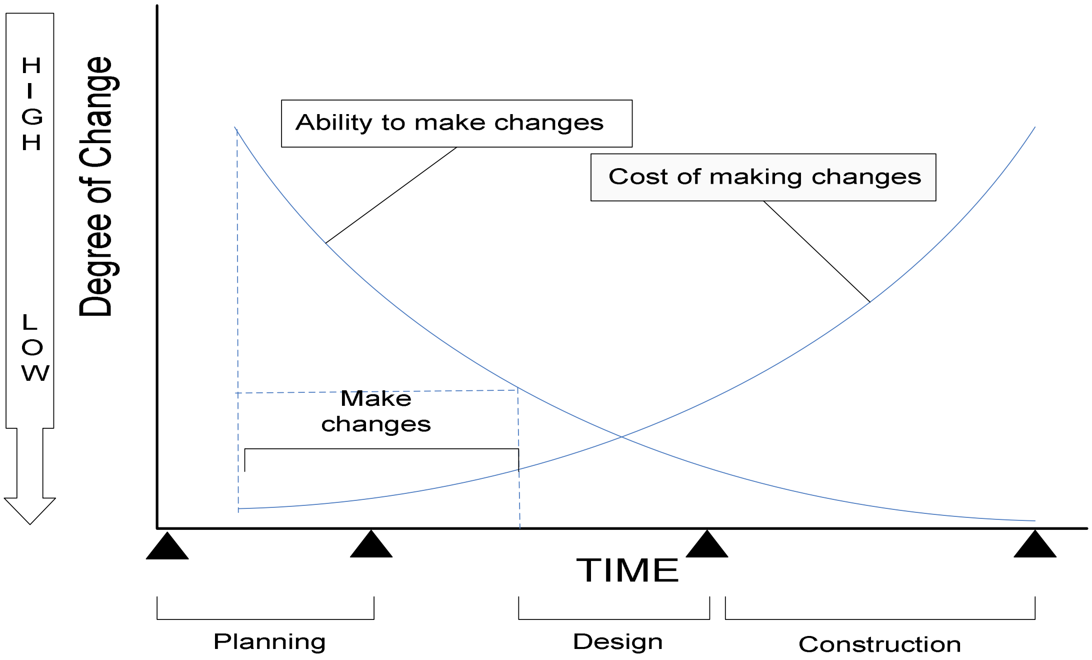
Since the political popularity and economic reasoning behind water systems regionalization and consolidation by policy planners have not waned but grown in intensity, a decision-making mechanism needs to be improved and developed further. The lack of existing mechanisms and criteria to test out the feasibility potential of consolidation of water systems and how this could be best accomplished to achieve the most cost-effective outcome create the need for this study (Duffy, 2009).

The undertaking of long-term water resources planning process that incorporates problem and solution analysis to identify screened cost-effective water supply alternatives that meet the water systems’ sectoral, temporal and locational water needs has not been previously done. The past approaches taken to assemble a cost-effective water supply partnership have not had an integrated planning support framework. The robustness of the planning support framework depends on the accurate identification and justification of the water resources planning problem, the location of the problem, and the choice of the consolidation partners. The water resources strategy selection approach taken in this dissertation should be a pre-cursor to preliminary engineering studies.

Traditional engineering studies are expensive, relatively small in scale, and design driven (Coy, 2007; Dell'Isola, 2002).

An evaluation of unviable system consolidation scenarios for their economic efficiencies is a pointless task. A method of establishing criteria for consolidation scenario viability has to be performed before an actual performance outcome of the scenario can be assessed. Final selection must always be based on sound engineering judgment; but it should never guide the planning of water systems alone. Costs of water projects can be formulated in several stages. It may be approached in several different ways and with differing levels of detail and accuracy. Figure 1 is a modification of typical cost estimating approach from engineering/architectural literature (Dell'Isola, 2002). In water resources planning, the planning and solutions (alternatives) evaluation need to be performed first and separately from project design and construction. The outcome of this procedure helps to weed out infeasible alternatives and thus, save costs of advancing to project design level. As Figure 1 demonstrates, the further into design and construction the project advances, the ability to make changes to the project diminishes.

Figure 1
Cost Estimating and Ability to Make Changes in Planning, Design and Construction (M. Dell'Isola, 2002)



Source: Modified from M. Dell'Isola: Architect's Essentials of Cost Management, 2002

1.3.1 Water System Characteristics

According to the U.S. Environmental Protection Agency (EPA), there are approximately 155,000 public water systems in the United States (EPA, 2000d). The U.S. Environmental Protections Agency's (EPA) Safe Drinking Water Information System defines the public ownership category of water systems as those that are owned by a state, federal, or local governments (EPA, 2008). According to the National Rural Water Association (NRWA), public ownerships of water systems are categorized into different types depending on ownership and operation (OWRB, 2000). Municipal systems are owned and operated by town or city governments. Rural systems are owned and operated by county governments. Water districts and authorities are separate organizational entities formed by local, county, or state governments. According to the NRWA, the type of ownership is established to solely own and operate a water system within a designated service area. Non-profit homeowners associations are cooperatives established by residential developers and may operate water systems serving housing developments. Non-profit rural cooperatives are formed to own and operate water systems in rural communities.

The EPA classifies water systems by their size: the population they serve. There are different classification classes per water system size. The EPA classifies these water systems according to the number of people they serve, the source water, and whether they serve communities year-round or on an occasional basis. The EPA defines three types of public water systems (EPA, 2008):

1) Community Water System (CWS): supplies water to the same population year-round (minimum of 25 people served).

2) Non-Transient Non-Community Water System (NTNCWS): supplies water to a minimum of 25 of the same people at least six months per year, but not year-round (schools, factories, office buildings, and hospitals which have their own water systems.)

3) Transient Non-Community Water System (TNCWS): supplies water in gas stations or campgrounds (people do not remain for long periods of time).

All three types of public water supply systems provide water for human consumption through pipes or other constructed conveyances to at least 15 service connections or serve an average of at least 25 people for at least 60 days a year. The EPA (2008) also classifies water systems according to the number of people they serve:

- Very Small water systems serve 25-500 people
- Small water systems serve 501-3,300 people
- Medium water systems serve 3,301-10,000 people
- Large water systems serve 10,001-100,000 people
- Very Large water systems serve 100,001+ people

According to the EPA (2008), the U.S. drinking water system is fragmented between few large systems serving majority of population and many small system serving minority of population. The total number of CWSs in the U.S. is approximately 52,000 with 4,132 being very large and large (8 percent of total) serving approximately 240 million people (82 percent of total); 4,838 being medium size (9 percent of total) serving approximately 28 million people (10 percent of total); and small or very small systems represent 43,000 CWSs (83 percent of total) serving approximately 25 million people (9 percent of total).

1.4 Organization of the Dissertation

The dissertation is divided into four main components:

1) Theory
2) Model Description
3) Test Model

4) Result and Analysis

Section II is an overview of literature encompassing relevant research from water resources planning and management, water resources project evaluation, consolidation, and decision analysis. This section consists of literature review that establishes the theoretical and conceptual framework. The expansion of the literature review includes theory development. Analytical framework encloses the theory component and the Chapter II. The model description component is accomplished in Chapter III of this dissertation. Chapter III (“Research Methods”) outlines the research methodology that comprises the Planning Support System (PSS) and the two analysis stages. It develops and describes the modules used in evaluating and assessing the different consolidation scenarios. This chapter establishes the model for the planning support system. Each analysis stage is explained and the different modules within those.

Chapter IV tests the planning support system outlined in the previous section. The model is tested on Northeastern Oklahoma. The final component of this dissertation, the analysis, concludes the dissertation. It will outline the research results, analysis, and recommendation for future research.

II. LITERATURE REVIEW

2.0 Research and Concepts

The literature on water resources planning and community water systems (CWSs) takes many forms. The planning can be approached from water resources management, water resources planning, economic, and engineering perspectives. Each one of these broad categories contains further sub-categories. In general, the body of literature supporting the approach taken in this dissertation to address the cost-effects of consolidation of small/medium sized CWSs is interdisciplinary.

The selection of literature for this dissertation is based on the ability of the literature to provide guidance on how water resources planning can be accomplished. The literature reviewed for this dissertation guides the theoretical framework of this dissertation, establishes the concepts, and justifies the analytical approach.

2.1 Water Resources Management

The literature on infrastructure asset management is important in identifying and understanding the underlying problems in water systems where some form of system cooperation may be beneficial. Infrastructure asset management literature incorporates assessments of current systems as well as projections what the future infrastructure needs may be. This is also known as gap analysis (REF). The main purpose of infrastructure asset management is to identify the future financial needs of water systems based on the evaluation of current status of water systems and determining the gap between the current status and the desired state.

Water resource management and planning are sub-fields of natural resource management (Romero and Rehman, 1987). Water resources management literature is a common denominator to a body of literature that incorporates different management measures to control different aspects of water resources. A sub-set of water resources management is water resources planning. Water resource planning can be further divided into policy planning and project planning. In water resources management, the actual management of the water resources should be preceded by some type of a planning process incorporating social, economic, environmental, and technical elements. In water resources project planning, the goal is to evaluate the effects of implementing a set of solutions (or a solution) to a water resources problem (USACE, 1983). It is more than formal project planning. Decisions in water management are characterized by multiple objectives and multiple stakeholder groups. Outcome measures are in monetary and non-monetary units (USACE, 1983).

According to the U.S. Army Corps of Engineers (USACE), the term “planning” includes process-driven steps that govern investment and management strategies for the “portfolio” of natural and infrastructure assets (USACE, 1983). The portfolio “includes the water and related land resources of rivers and coastal areas, as well as Corps-built projects in these rivers and coastal areas,” (NRC, 2004:24). This body of literature focuses on comparison of alternative water resources plans to address a problem. The emphasis in water resources project planning is placed on a group of experts in identifying the problem and proposing solutions to the problem.

2.1.1 Infrastructure Asset Management

Both federal and local water planning authorities are aware of the future drinking water infrastructure funding shortfalls that will be faced by many drinking water systems. In order to address these shortfalls, different entities have provided assessment management guides and manuals. The AMPs look at capital and operating expenditures together to get the most value over the life of the asset, while delivering reliable and high quality serve to customers. The *pro-forma* style analysis includes inventory methods for capital planning purposes, worksheets to organize data and determine the best approach to maintenance and replacement of physical assets, lists of resources to apply for financial assistance, and strategic planning tools.

The Environmental Protection Agency's (EPA) Office of Water has published several STEP-guides (EPA, 2003a) to address the performance of small water systems. The guides include inventory methods for capital planning purposes, worksheets to organize data, determine the best approach to maintenance and replacement of physical assets, lists of resources for which the unit apply for financial assistance, and strategic planning tools. The Maryland Center for Environmental Training (MCET) has developed training videos and tutorials to provide training to small water system administrators to address their asset management (MCET, 2007). The Institute of Public Works Engineering Australia (IPWEA) has published an International Infrastructure Management Manual (2006). The manual enlists topics of benchmarking, condition grading, valuations, asset hierarchy structures, information systems, and planning for growth. The manual sets forth an infrastructure assessment management goal, which is to "meet a required level of service in the most cost-effective way through creation, acquisition, maintenance, operation, rehabilitation, and disposal of assets to provide for present customers" (IPWEA, 2006:1-3). The key elements are: taking a life-cycle approach, developing cost-effective management strategies for the long-term, providing a defined level of service and monitoring performance, managing risks associated with asset failures, sustainable use of resources, and continuous improvement as asset management practices. All these guides provide self-help manuals to perform infrastructure assessment.

The Safe Drinking Water Act (SDWA, 1974) requires the EPA to conduct assessment of nations' water infrastructure every four years and use the results to allocate Drinking Water State Revolving Funds (DWSRF) to systems that need the assistance. The 2003 EPA Drinking Water Infrastructure Needs Survey estimates the total needs nationwide based on voluntary participation of 4,000 water system owners and operators across the country (EPA, 2003b). The EPA's Clean Water and Drinking Water Gap Analysis (2002a) quantified the relationship between the estimated infrastructure needs of drinking water systems over the next 20 years and current levels of spending. The needs were divided into classes of transmission and distribution, and source, treatment and storage (non-pipe needs), and cost of future regulations. All these financial needs were distributed to different system size categories: large (>100,000), medium (10,000-99,000), and small (<10,000). Non-community and American Indian and Alaskan Native were separate categories. The report estimated that capital needs for drinking water infrastructure over the twenty-year period would range from $154 to $446 billion with a point estimate of $274 billion. Similarly, the operating and maintenance (O&M) needs are estimated approximately at $161 billion (EPA, 2002a). The report acknowledged that some communities would have a difficult time in meeting infrastructure funding challenges due to their lack of the economies of scale associated with a large customer base. The importance of innovative management practices and technologies by drinking water systems to be able to meet the funding gap in the future were empathized in the report.

The 1999 EPA Survey, Drinking Water Infrastructure Needs estimates the transmission and distribution needs to account for 55 percent of the total financial needs (EPA, 1999). Treatment facilities, according to the same survey, account for 25 percent of the total financial needs, storage tanks 12 percent, and source water six percent. Many local reports and studies on water system infrastructure planning and asset management have been conducted by local water systems. The common themes of these studies are to estimate the current inventory of infrastructure and projections of future financial requirements needed to update and expand water system infrastructure. This approach is also known as asset management of water systems. Most of the asset management literature focuses primarily on inventorying and managing the current infrastructure, and giving a lesser emphasis on planning on potential growth. In 2003, West Central Minnesota Communities commissioned a study by the West Central Initiative (WCI) to estimate current and projected future needs for water, wastewater, and storm sewer repairs and their replacement in nine counties in Western Minnesota (WCI, 2003). The study utilized questionnaires to look at both immediate and forecasted infrastructure needs for a nine county-area. The breakdown by type of immediate infrastructure needs for water was $3.2 billion, which represents 46.4 percent of the total immediate infrastructure needs. The report projects that by the year 2012 the numbers will nearly double. The results were derived by using a community infrastructure profile questionnaires for wastewater, drinking water, and storm water. The questionnaires were filled out by the system operators.

2.1.2 Small, Medium and Rural Water Systems

Rural water systems vary in numerous ways: current and future potential physical, economic and service type characteristics (Lee and Braden, 2006; 2007; 2008; OWRB, 2006). Rural public water systems possess unique characteristics in providing water to their customers. The long tradition of rural water systems of providing water to primarily rural customers is changing due to increasing and shifting population growth. There are three major types of rural water systems based on their supply of drinking water: purchase, consecutive, and supply systems (OWRB, 2006). Purchase systems strictly purchase treated water from a larger system and distribute the purchased water to their customers. Consecutive systems both treat and supplement their water supplies with purchased water. Supply systems both treat and supply all their water.

According to the EPA 1995 and 2000 Community Water System Surveys, there has been a steady decline from 1976 in the percentage of systems that do not treat their water. In the EPA 2000 Community Water System Survey, 28 percent of the smallest systems did not provide water treatment (EPA, 1995 and 2000d). The systems serving 501-10,000 people, average of approximately 15 percent did not provide water treatment. The surveys did not look at systems that supplement portion of their water from another system in detail. Purchase water systems represent fifteen percent of publicly owned water systems. These systems' primary water source is purchased water. More systems relied primarily on purchased water in 2000 than in 1995, increasing from 10.6 percent to 15.3 percent. Many small and growing communities buy wholesale or treated water from a larger system. Wholesale deliveries account for more than one-quarter of all water delivered. Wholesales of water account for ¼ of the revenues made by systems serving more than 100,000 people. The fragmented water supplies and different supply configurations may become problematic for many reasons to water resource planners. The main concerns are associated with the future needs of water systems: infrastructure requirements, water quality and monitoring needs, and adequate availability of water supplies. The dependence of supplemental water from other systems restricts all water systems in the scenario from comprehensive planning to identify all future needs.

In addition to changing water demand profiles and infrastructure needs, increased regulations, especially the Stage 2 Disinfectants and Disinfection Byproducts Rule (DBP) under the SDWA Primary Drinking Water Standards, will impact small and medium systems (Levin et al., 2002; AWWA, 20010). The Stage 2 DBP rule builds upon earlier rules that addressed disinfection byproducts in drinking water distribution by tightening compliance monitoring requirements for two groups of DBPs, trihalomethanes (TTHM) and haloacetic acids (HAA5) (EPA, 2008). These new regulations require more monitoring and more frequent sampling. The monitoring and sampling requirements are addressed based on the size of population served by the utility. However, if CWS gets any part of its water from a larger utility, the smaller utility must comply with the same sampling and monitoring requirements under this rule as the “donor” utility. These requirements are more vigorous and frequent than smaller utilities’ requirements would be if no additional water was supplied by a large utility. The requirements in the Stage 2 DBPR will apply to all community water systems and non-transient non-community water systems that add a disinfectant other than UV or deliver water that has been disinfected (AWWA, 2010).

The cost of the compliance of SDWA Primary Drinking Water Standards and the additional compliance of disinfectant byproduct rules differs greatly due to the size of the system and the types of contaminants in the raw water supply (AWWA, 2010). New regulations and monitoring requirements increase the operations and monitoring costs (O&M). The O&M costs per water unit are greater for small systems than for larger systems because it is more difficult to spread the additional costs over fewer people (Bagi, 2002; Kingdom, 1996; AWWA, 2010). The smaller systems must combat high per unit costs. Larger systems devote more of their expenditures to debt service and other expenses (which include capital expenditures). To meet the EPA's new regulations, water systems may have to upgrade the existing facilities or construct new ones. Smaller systems will face the greatest challenge in meeting compliance requirements. The drinking water industry is large and capital intensive.

The 2000 EPA Survey indicates that 53 percent of capital investments of all infrastructure investments (1995-2000) were spent on replacing aging and failing infrastructure, 27 percent were spent on system expansion and 20 percent were spent on water quality (EPA, 2000d).

The smallest systems (serving fewer than 501 persons) have experienced less growth than the systems serving 3,301-10,000 persons (EPA, 2000d). Production per connection increases steadily as system size increases. In many rural areas this may be due to the fact that small rural customer base consists primarily of residential users, where as large systems serve customer base consisting of agricultural, industrial and residential users (Lee and Braden, 2006; 2008). This difference could also be caused by the difference in the residential water usage profile in entirely in rural areas versus in suburbia and exurbia and because of declining populations in some rural areas. The water usage in traditionally rural areas could be more conservative due to combination of higher unit cost of treated water and lower median household incomes compared to suburban water users.

A system's raw water source is a key factor in determining operation characteristics and source corresponds closely to system size (Daughterty, 1973). Large systems are more likely to use surface water or purchase treated water as their primary source, whereas most small systems use groundwater requiring less treatment (Lee and Braden, 2006; EPA, 200d). The ownership, operating, and financial characteristics of RWDs determine the cost functions of RWDs (Lee and Braden, 2006; 2008. Water systems' total water revenues are generated from treated water sales (rates), water-related services (fines, connection fees), and general fund revenues (EPA, 2000d).

2.1.3 Water Resources Planning

> "Planning is a process of determining future actions through a sequence of choices. It is a structured rational approach to achieving desired ends. Other definitions: Planning is the determination of the goals and objectives of an enterprise and the selection, through a systematic consideration of alternatives, of the policies, programs and procedures for achieving them. Planning is an activity devoted to clearly identifying, defining, and determining courses of action, before their initiation, necessary to achieve predetermined goals and objectives," (USACE, 2009: 12).

The water resources planning project planning literature reviewed for this dissertation originates from local, federal and global water resources projects and studies. In a municipal level throughout the U.S., communities have set forth water resources planning goals. According to the City of Tucson Water Plan:

> “Water resource planning is a way to ensure that social, economic, environmental, and technical issues are considered in the management and development of our water resources.” (the City of Tucson, 2000:4)

To achieve this, they propose to develop water demand projections using demographic trends and historic water use. This demand projection is compared to a review of our existing water supplies. If existing supplies do not meet the forecasted needs, additional water supplies need to be identified.

The USACE implement planning procedures in their water resources planning studies as embodied within the federal *Principles and Guidelines for Water and Related Land Resources Implementation Studies* (USACE, 1983) and within the Corps’ own *Planning Guidance Notebook* (USACE, 2000). These two documents contain the key planning concepts and methods employed in the agency’s planning studies. The USACE (along with the U.S. Bureau of Reclamation, the Natural Resource Conservation Service (NRCS), and the Tennessee Valley Authority) are mandated to follow the water resources planning guidelines embodied within the federal P&G according to the Water Resources Development Act (WRDA) of 2007 (U.S. WRDA, 2007).

In 1974, the Congress passed the Water Resources Planning Act (WRDA), which represented a commitment by both the executive and congressional branches to rational water resources planning (U.S. WRDA, 1974). The Act created a three-part planning approach to national water resources management. Water projects were to serve and be evaluated according to multiple criteria set forth by the Water Recourses Council (WRC). Federal objectives for water management were to be equally balanced between national economic development (NED) and environmental quality (EQ). The federal objective and criteria for water projects have been redefined to be to maximize NED benefits (net benefits) subject to compliance with all relevant environmental laws.

The World Bank has issued *An Approach to the Economic Analysis of Water Supply Projects* (World Bank, 1992) and the Asian Development Bank has issued similar guidelines for economic evaluation of water resources projects in *Guidelines for the Economic Analysis of Water Supply Projects* (Asian Development Bank, 1998). These studies guide on the application of principles and methods of economic analysis to water resources projects. The primary focus of the guidelines is on economic analysis of water supply projects. The purpose of the economic analysis of projects is to bring about “a better allocation of scarce resources and the projects must relate to the Bank’s sectoral strategy and also to the overall development strategy of the country” (Asian Development Bank, 1998: 24). According to the Asian Development Bank’s procedures for economic analysis of water resources projects:

> “The goal may be improved health and living conditions, reduction of poverty, increased productivity and economic growth, etc. Based on careful problem analysis, the Project (Logical) Framework establishes such a format showing the linkages between “Inputs and Outputs”, “Outputs and Purpose”, “Purpose and Sectoral Goal” and “Sectoral Goal and Macro Objective”. The key assumptions regarding project-related activities, management capacity, and

> sector policies beyond the control and management of the Project Authority are made explicit" (Asian Development Bank, 1998: 12)

The U.S. Bureau of Reclamation defines and executes the water resources planning as investigations of the capability and dependability of the water supply to meet growing and changing demands (U.S. Bureau of Reclamation, 2003). The Bureau of Reclamation's water resource planning concentrates on investigations for improved river and reservoir administration and operation, conjunctive use of surface water and ground water supplies, new and expanded storage and conveyance facilities, water banking, and water exchanges and transfers. The Bureau of Reclamation evaluates the project alternatives through the National Environmental Protection Act (NEPA) -process. The projects and their alternatives are evaluated based on their relative impact to the baseline conditions and their cumulative impacts.

The Corps' planning studies are conducted in two phases: a preliminary reconnaissance study ("study") and a more detailed feasibility study ("project") (USACE, 2000). In the World Bank's water resources studies, the economic analysis comes into play at three different stages of the project cycle: project identification, project preparation and project appraisal.

The theoretical base of the water resources planning in the USACE's and the World Bank's projects (and studies) is the rational theory. The foundation of the decision making in project planning literature and the institutional framework is in "rational" planning. The use of "rational" planning philosophy has been justified because it would provide an objective process for identifying the best projects. Experts would find solutions from the full range of physical and social sciences in this rational process. Rational planning has been seen as “a scientific alternative to an unfiltered and politicized project planning and funding process” (NRC, 2004: 38).

The genesis of the rational model dates to the beginnings of the U.S. Constitution, but the application of “rational model” of public administration was articulated in 1945 when Herbert Simon wrote that:

> “Public administration is about decision making, and that decision making involves some variant of three steps: scanning the environment, developing alternatives, and choosing alternatives,” (Simon, 1945).

Through the improvements in computer technology, Simon believed that decisions could be made scientifically using computer modeling and mathematical models. In the mid-1950s, a water resources system design seminar located in the Harvard Graduate School of Public Administration (the Harvard Water Program) led by Arthur Maass and Maynard Hufschmidt published *Design of Water Resources Systems*, which created the foundation for the 1972 Federal *Principles and Standards* (Maass et al., 1962). The Harvard Water Program combined engineering, systems analysis, and economics into a planning framework:

> “The planning framework was expected to rationally guide identification and construction of only those projects that would

> serve the national interest as described by the language of the 1936 Flood Control Act,"(NRC, 2004:40).

The rational approach of the planning process draws criticism in a theoretical level. The core critique of rationalism concentrates on the weakness of the rational approach to recognize the intellectual/analytical boundaries of decision making (Clemmons and McBeth, 2001). The intellectual boundary of decision making includes the human dimension of limited capacity to comprehend the problem and to exclude human subjectivity in interpreting the problems. Even Herbert Simon (1945), the scholar of realism, agreed that humans practice bounded rationality (Simon, 1957). The other area of critique of rational approach stems from the analytical boundaries in decision making. These include the complexity of defining the problem, conceptualizing and assessing the impact of time, and utilization of data in decision making (Clemmons and McBeth, 2001).

However; the defense for the federal planning process comes from its "practical", "streamlined", "sound", and "swift" approach of addressing water resources problems with proposed solutions and decision making (NRC, 2004). In this dissertation, it is suggested that some of the weaknesses in water resources decision making could be overcome by creating a procedural planning process; a planning support system that first identifies the different water resources problems and then proposes a solution to the problem. This approach enables the planner and the stakeholders to inspect what components were considered during the planning process and where the decisions and recommendations are based upon. Since the proposed planning process in this dissertation is based upon a problem and solution analysis of water resources planning, the problems and/or solutions could be changed in that process. By doing this, some of the “rigidity” and “stiffness” of the planning is alleviated and different outcomes could be evaluated.

A component of a federal water sources planning formulation is the alternative plans formulation by deriving every possible combination of the management measures (IWR, 1995). Once the alternatives and their management measures have been clearly defined, these can be evaluated and the comprehensive plan selected (IWR, 1995; 2006). The application of the USACE plan formulation in water resources project planning can be found from ecosystem restoration studies (USACE, 2000; IWR, 2006). An integral part of the alternative plans formulation is the identification and screening of the plan components (USACE, 2000). An economic evaluation of the alternative plans could be both the final.

The interrelationships of different measures within the alternative plans are evaluated in the USACE water resources plan formulation using concepts of “combinability” and “dependency” (IWR, 2006). In a typical USACE study, management measures are evaluated for combinability. Combinability is the ability to mix and match the different components in within plan (IWR, 2006). The combinability concept was adopted from biological sciences (IWR, 2006). This concept has been typically applied to ecosystem restoration projects, such combining rip-rap with grass or sand with grass. The dependencies occur in two different ways according to the USACE plan formulation. These are mutual dependency and path dependency (IWR, 2006). Path dependency concept has been used in other fields of planning. In agricultural sciences, Clark et al. (2010) studied path dependence and the role of nature and society relations in exurban farm survival. The authors looked at how farming practices have changed in exurban communities and what practices should be kept for future farm survival.

The path dependence has been also used in archeology. Different authors have looked at which initial conditions establish a trajectory. This helps the research to interpret the past initial conditions and theorize what may have followed chronologically - path dependency (Hegmon, 2009).

The plan formulation tools of combinability and dependency are used in this dissertation in evaluating the CWSs that are included in the consolidation scenarios.

2.1.4 Community Characteristics

Many of the small CWSs are anticipated to have challenges in the future to meet increasing demands and/or changing water demand profiles of their communities (Mann et al., 1986; Young, 2002; Troesken and Geddes; 2003; Ottem and Raucher, 2003; Lee and Braden, 2006; 2007; 2008). The transformation of previously rural and/or agricultural communities has transformed the water demand requirements. Many small communities have changed from being rural to more residential and suburban communities (Clark et al., 2006; Clark et. al, 2005; Sharp and Clark, 2008; Clark et al., 2009.) In some of the previously small communities, agricultural water demands have been replaced with residential, commercial and/or light-industrial water demands. The water supply characteristics of these previously rural and/or agricultural communities include interconnectedness of small water systems to large systems for additional supply of water to meet their seasonal water demands, fragmented water supplies, aging infrastructure, and lack of long-term planning to secure the future water demands (Castillo et. al, 1997b).

The national trend shows that median single-family house size has increased from 1,525 square feet to 2,227 square feet from 1973 to 2000 (Smart Growth America, 2007). In 2006 the median house single-family house size was 2,237 square feet (U.S. Census Bureau, 2000, U.S. Department of Commerce, Economics and Statistics Administration). 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 (the National Association of Realtors and Smart Growth America, 2004). 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, according to the 2004 Survey (the National Association of Realtors and Smart Growth America, 2004). The 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.

Exurbs are experiencing growth to which they are not accustomed, and thus do not have the infrastructure or experience to deal with the growth (Urban Land Institute, 2004). The implications from unplanned growth to water resources planning can cause uncertainty in communities about their water resources availability and adequacy of water supply infrastructure (Jain and Singh, 2003; Landis and Reilly, 2006). 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. The suburbs at the surrounding fringes of the metropolitan areas are called exurbs. These areas attract primarily residential growth and thus are transferring from primarily rural low density areas to high density urban areas (Landis and Reilly, 2006).

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 growth (Brookings Institution Report, 2006). 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 (Urban Land Institute, 2004). Exurban communities exist thought the U.S. but yet many of these communities' growing needs including future water demands have not been captured in the areas' long-term water resources planning (Urban Land Institute, 2004).

2.2 Evaluation of Water Resources Projects

Water resources projects can be evaluated using many feasibility criteria, such as economic, legal, administrative, political, technical (engineering), and social. Many alternatives may have more than one potential solution. According to *Water Resources Systems Planning and Management* (Jain and Singh, 2003) some criteria include: capital costs; O&M costs; design life; land-use and visual impacts; construction noise and traffic impacts; reliability and risk; ability to meet long-term goals; environmental impacts; flexibility to meet changing conditions; and potential for regional benefits.

The introduction of economic criteria for public water resources projects was intended to alleviate inefficient projects and gain public support to evaluate the different merits of project alternatives.

The premise of water resources project evaluation is to choose economically feasible alternatives that meet legal, administrative, political, technical, and social criteria. The criterion for judging alternatives is based on economic analysis that fall into one of three categories of inputs and outputs:

1. Fixed input. The amount of money or other input resources are fixed. The objective is to effectively utilize those resources to maximize benefits.
2. Fixed output. There is a fixed task or other output to be accomplished. The economically efficient criterion for a situation of fixed output is to minimize the costs or other inputs.
3. Variable inputs and outputs. This category is the general situation where neither the amount of money or the other inputs, nor the amount of benefits or other outputs are fixed. The economic criterion is to maximize the difference between benefits and costs.

2.2.1 Least-Cost Analysis/Cost Effectiveness

Cost effectiveness and incremental cost effectiveness analyses are tools for comparing alternative solutions to planning problems (IWR, 2006). A solution is considered cost-effective if it is determined to have the lowest costs expressed in present value terms for a given amount of benefits (Jain and Singh, 2003). Cost effectiveness analysis is appropriate whenever it is unnecessary or impractical to consider the dollar value of the benefits provided by the alternatives under consideration. This is the case whenever (i) each alternative has the same annual benefits expressed in monetary terms; or (ii) each alternative has the same annual affects, but dollar values cannot be assigned to their benefits. Analysis of alternative defense systems often falls in this category. Cost-effectiveness is a systematic quantitative method for comparing the costs of alternative means of achieving the same stream of benefits or a given objective (Newnan, 1980).

Least-cost analysis or cost-effectiveness approach generally deals with the ranking of mutually exclusive options or alternative ways of producing the same output of the same quality. In some cases, there may be differences in the outputs (quantity wise or quality wise) of the alternatives. When project benefits cannot be measured accurately in monetary terms, cost effectiveness and incremental cost analysis offer a viable method for evaluating project alternatives. “Cost-effective” means that, for a given level of non-monetary output, no other plan costs less and no other plans yields more output for less money. While cost-effectiveness of alternatives may not identify a unique or optimal solution, they can lead to better informed choices from among alternatives by elevating the decision making process above cost oblivious decision making (Yoe, 1992).

The task of identifying the options or alternative ways of producing the required project output could be accomplished by selecting the least-cost alternative from the technically feasible options. According to the Asian Development Bank’s *Guidelines for the Economic Analysis of Water Supply Projects* (1998), three least cost methods exist to choose between alternatives:

1. Lowest Average Incremental Economic Cost or AIEC;
2. Lowest Present Value of Economic Costs or PVEC;
3. Equalizing Discount Rate or EDR.

The three approaches all are used in water resources evaluation. They all arrive to the least cost alternative. The three approaches vary in the use of discount rate throughout the planning period. The PVEC approach used a fixed discount rate throughout the planning period (Asian Development Bank, 1998).

In the least cost analysis, the initial capital costs for the life-time of the alternative and future O&M costs are be evaluated. The discounted value of the economic costs for each option is accomplished by using an appropriate economic discount rate. On this basis, the alternative with the least economic cost can be selected. It must be noted that least-cost analysis, while ensuring production efficiency, does not provide any indication of the economic feasibility of the project since even a least-cost alternative may have costs that exceed the benefits (in both financial and economic terms) (Asian Development Bank, 1998).

2.2.2 Consolidation of Water Systems

The terms “centralization”, “regionalization”, and “consolidation” are employed in the sense of geographical concentration; the term “decentralization” is used in the sense of geographical dispersion. The National Resources Council (NRC) defines regionalization to include “the combination of utility organizations, wholesale service arrangements, cooperative agreements, and satellite management of multiple systems, as well as public or private partnerships, water supply agreements, system interconnection, water wheeling, and system consolidation” (NRC, 1997:4).

The AWWA (2007) lists six general types of regionalization strategies for water utilities:

1) mutual aid agreements
2) sharing arrangements
3) water purchase arrangements
4) collaborative water resource development
5) contract services arrangements
6) consolidation

Consolidation of water systems literature can be divided into five sub-groups. Depending on the perspective, water systems are assumed to have pre-defined key reasons for mergers and the analysis is performed based on those. Beecher (1996) (Table 1) presents the potential gains of both physical and non-physical forms of regionalization.

Table 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)

Consolidation literature provides a practical as well as theoretical basis to investigate cooperative solutions between water supply systems. Despite the different theoretical foundations of consolidation, most water systems consolidation literature evaluates and justifies the end-result of mergers in the context of economics. The initial trigger to consolidation, as literature supports, may be compliance, supply and/or distribution driven, but economics is used to measure the outcome (Beecher, 1996).

There are at least two distinct kinds of scale economies in water supply systems: physical and non-physical. The former includes capital equipment and operating costs whereas the latter includes administrative and business operations. Options noted by the National Research Council (NRC) (1997) for consolidation include:

- direct transfer of system ownership
- receivership or regulatory take-over
- purchase of contract services
- technical support

The nonstructural regionalization includes administrative and managerial cooperation between water systems. The structural regionalization includes any form of physical interconnectedness of two or more systems (NRC, 1997). Nonstructural regionalization emphasizes procedural changes in water system management and administration. In contrast, structural options require an establishment of new managerial or political entity to operate and manage the water system. The American Water Works Association (AWWA) defines consolidation being a physical interconnection of two or more water systems (AWWA, 2007). The non-physical collaboration it defines as cooperative planning and management.

2.2.3 Justification for Water System Consolidation

With respect to water system consolidation, the concepts of economies and diseconomies of scale in production economics have driven much of the future planning of water systems. It is conventional wisdom that by consolidating (centralizing) the efforts of two of more water systems would reduce duplication of services and take advantage of economies of scale, therefore reducing the unit cost of water. If the goal of consolidation is to achieve economies of scale, the two distinct kinds of scale economies in water supply systems must be distinguished. The first kind of economies of scale in the drinking water systems is in the capital equipment and operating costs and the second kind is in the business operations, such as billing, accounting, testing, sampling, monitoring, and other day-to-day business operations. The former type of economies of scale is more sensitive to physical connections of two or more water systems, whereas the latter can be achieved without physical connection. Since this dissertation is merely interested in physical interconnection possibilities of water systems in the study area, little attention will be devoted to the non-physical form of consolidation.

In the context of small drinking water systems, scale economies and diseconomies have been widely applied in justifying water systems consolidation. Capital-intensive drinking water services usually yield significant economies of size when the cost of fixed assets can be distributed across a large number of customers, and as a consequence the unit cost of treated water falls. Therefore, a consequence the economies of scale are easy to realize with water treatment.

That is unit costs of water decrease as the treatment plant size increases (Ottem, Jones, and Raucher, 2003).

System size is one component of affecting water supply costs. Others, such as water supply costs, climate, topography, and geology also impact the costs. Also, the spatial distribution of water demand will also cause variation in water supply cost. Higher population density enables the fixed costs to be distributed over a greater number of customers. Finally, there are different levels of technical efficiencies amongst water systems: some systems are able to produce more output with same inputs due to higher level of technical efficiency (Shih et al., 2004).

Due to the different cost elements of water supply, the benefits of regionalization/consolidation are not straightforward and unlimited. In order to understand how the potential gains or losses of consolidation are derived, the theory of size economies is reviewed. The theory stems from the nature of production processes within firms. The production process requires inputs, such as capital, labor, and materials, to be applied in varying proportions to technological process that can generate one or more outputs. Production functions calculate and measure the relationship of input variables to output. In the economics literature, there are two basic theories to estimating production relations (Coelli et. al., 1998). The first theory treats all decision making units (DMUs: firms) as technically efficient. This theory assumes that firms (e.g., water supply systems) are operating on the production possibility frontier and that no additional output is technically possible with the given level of inputs. The second theory of production assumes that the DMUs are not necessarily technically efficient. This theory investigates the “technology frontier”: the maximum output achievable from a given set of inputs. Furthermore, the theory investigates the degree to which other DMUs lie inside the production frontier and/or use the cost-minimizing combination of inputs.

Water systems can be divided into three separate components, each having distinct cost functions. The first is treatment of water, the second is transmission and distribution, and the third is administration and management services. In all cost functions, the selection of variables in the cost analysis greatly impacts the total costs. The fixed costs are not marginal and thus have no influence on the optimum level of production, but they do influence whether or not benefits exceed total costs or whether project should be constructed at all. Fixed costs remain constant regardless of the level of output. Marginal costs are used to determine the optimal level of production. Variables costs vary with the level of output. These costs include cost of labor, outside services, energy, and materials (EPA, 2000d).

Average cost (-benefit) curves are developed from total cost (-benefit) curves. Average cost curves are usually U-shaped. They decrease at first because of the economies of scale due to the savings in production cost per unit stemming from increases in size of plant and output. Therefore, the nature of returns to scale (constant, increasing, or decreasing) refers to physical relationships between inputs and outputs. Returns to scale (size) measures how output reacts to either increases or decreases in inputs. The constant returns to scale indicate that if all inputs are doubled, the output doubles also. Increasing returns to scale is present if the output more than doubles as a result as a consequence of increased inputs. Size economies refer to the costs associated with the physical relationship of input(s) and output(s). Therefore, increasing economies of size indicate that the average unit cost of output is falling; economies of size indicate that the average unit cost of output stays the same, and diseconomies of size indicate that the average unit cost of output is increasing.

The EPA report of 2003 highlighted several case studies on efforts to promote water system consolidation in several states (EPA, 2003). Again in 2007 and 2009, EPA's Office of Water conducted case studies on operational and managerial efficiencies through water system partnerships (EPA, 2007 and 2009). All three studies are qualitative and highlight the projected benefits of consolidation. They describe the types of partnerships, factors leading to the partnerships and key players and drivers, the qualitative benefits of the partnership and lessons learned. These studies separated the consolidation by the degree of interconnectedness into informal cooperation, contractual assistance, joint powers agency, and ownership transfer. Table 2 shows the types of partnerships as defined by the EPA's Office of Water (EPA, 2009).

Table 2
Water System Partnership Spectrum

Non-Structural			Structural
Informal Cooperation	Contractual Assistance	Joint Powers Agency	Ownership Transfer
Voluntary cooperation with other systems	Work with other system	Creation of new entity by several systems that continue to operate independently. Administrative decisions made jointly.	Takeover by existing system or newly created system
No contractual obligation. Two neighboring systems each with an asset that benefits the other system. Exchange of services.	Contractual agreement: legal contract. The most common. Used in wholesale or retail contracts.	New entity between neighboring communities with insufficient water supply.	New entity. Service extended to new areas.
Shared: • equipment • bulk supply • mutual aid arrangements	Shared: • O&M • Engineering • purchasing water	Shared: • system mgmt • operators • source water	• Acquisition and physical interconnection • Acquisition and satellite mgmt • Transfer of privately-owned system to new of existing public entity

Source: EPA, 2009.

The degree of interconnectedness in Table 2 grows from left to right. The ten case studies profiled in the 2009 Report, all claimed the benefits from the different types of partnerships. The benefits were not quantified in monetary terms but they were described as having benefitted in terms of technical, managerial, and financial capacities. All systems profiled in the Report were small systems serving 3,300 or fewer customers.

The *post hoc* analyses of the benefits of consolidation in the 2003, 2007, and 2009 reports, identify the benefits from consolidation in three main classes: technical, managerial, and financial. In a case of joint powers agency and ownership transfer (see Table 2) type of consolidation, the technical benefits include water source security, better quality source water, better treatment technology, and shared infrastructure. The managerial benefits include shared expertise, avoidance of duplication of services, local/regionalized control, and larger staff.

Young (2002) investigated twelve small public groundwater systems (service population under 3,300) in Virginia. She investigated the feasibility and gained efficiencies in management and operation of small public water systems by forming a cooperative entity. The analyses are based on survey that was given to system operators. Using statistical methods in SAS (GENMOD), Young tested correlation of surveyed variables and collected summary data about the characteristics of the systems. The results indicate that the drinking water violations increased with the age of the water systems amongst the data collected. Most operators were confident about the systems' capabilities to meet the future water quality requirements and demands. Most of the systems in the study had committed drinking water violations within last ten years and lacked certified operators.

Young (2002) summarized factors impacting the forming of a cooperative water agreement. These include both barriers to cooperative scenarios and advantages forming a cooperative scenario. Barriers to forming a cooperative scenario include conflicting personalities, monetary issues, internal politics, size of operation, distance between the systems, resistance from homeowners, competition between businesses, right of way issues, and liability issues. Raucher et al. (2004) looked at previous literature to assess the disadvantages of and barriers to consolidation. They include the physical terrain and distance between the systems. They also include loss of power and community independence, different management goals, conflicting regulations, cost and benefit inequities, workforce reduction, equipment reduction, public confusion, and debt (pre-existing debts). The NCR (1997) study identified the barriers to consolidation of small water systems which include:

> “Disputes over who should pay for the system improvements, lack of data for assessing what will be involved in assisting a system, requirements that restructuring agents be held liable for violations of drinking water standards by the small system, political resistance to ownership changes, lack of funds to promote feasibility studies, and water resource allocation policies” (NRC, 1997:181-182).

Young (2002) listed the advantages of cooperation of water systems include exchange of information, pooled expertise and resources, availability of additional resources in a case of emergency, and specialization. Raucher at al. (2004) listed the incentives for consolidation based on previous studies to include economies of scale, increased financial opportunities, elimination of duplicated services, increased reliability (water quality and quantity), increased flexibility (tailored systems to meet community needs), enhanced protection of public health, skill improvements, and service efficiency.

The 2007 EPA Report on Restructuring and Consolidation of Small Drinking Water Systems provides an individual summary for each state by listing available statutes, regulations, or policies that encourage or require consolidation or restructuring of drinking water systems (EPA, 2007). The purpose of the Report is to provide option guidelines to systems that are having problems or those that are worried about the future. These options may include restructuring of system/management operations, utilization of appropriate technology, financial assistance (grants or loans), training, and technical assistance. Restructuring options can range from relatively minor changes in a system's procurement processes to transferring ownership of a system through consolidation or regionalization. A total of 27 states were included in the Report. Oklahoma was not included in the Report. According to the Report summary, only five states of the 27 have requirements for detailed studies or assessment on regionalization or consolidation. According to EPA (2009), only Indiana requires a new system to submit a Water System Management Plan that includes an assessment of consolidation or interconnection with other systems including a cost and benefit comparison. Most systems listed in the report use technical efficiency and health risks as the merger criteria.

A prevailing characteristic of water supply technology is the effect of economies of size. There are limited data and limited number of studies on whether consolidation of water systems is an economically viable solution to small and medium size water systems under different conditions.

Fox (1980) reported declining average unit cost curves with reported significant unit cost reductions available in municipalities serving drinking water for more than 50,000 customers. Small water systems in rural areas may not be able to take advantages of economies of size. Thus, the impacts of more stringent treatment, testing and sampling regulations, and increasing construction costs are generally passed onto the customers in a form of a higher water bill. The idea of consolidation suggests that consolidating efforts would reduce unit costs by reducing duplication of efforts and taking an advantage of economies of size.

Traditionally, rural water system service areas have had smaller population densities. Thus, there is a relationship between the volume of water produced and the size of the area where water is delivered (Ford and Warford, 1969). The size of the water system is closely related to the service area (population density and size) and distance of distribution. Therefore, Marshall's (1920) concept of economies to size (advantage to size) may be offset in many rural areas due to sparse population in the service area. Furthermore, Coase (1947) argued that the shape of the cost curve of water depends on quantity of water consumed, and marginal cost of supply rise with an increased water distribution distance. Moberg (1976) observed the rural water system per-connection "support costs" to rise as the number of connections decreased. Daugherty and Jansma (1973) found the number of water users positively affected municipal water systems' average unit operating costs. Other variables that affect the unit cost of drinking water are raw water quality and source (groundwater or surface water), topography, soil type, system efficiency, water quality desired for treated water, climate, type of water users (agricultural, industry, household, or commercial), method of distribution, quantity of water demanded, water labor costs, and cost of future regulations.

Beecher et al. (1992) calculated the use of capital in relation to the size of the water system. They concluded that in the small water system class (served less than 10,000 people) the use of capital in relation to the scale of the operation becomes large. Water systems serving 500-3,300 persons require four times as much capital per gallon of water sold as systems serving more than 50,000 persons. Very small systems serving fewer than 500 persons require about eight to ten times as much capital per gallon of water sold as systems serving more than 50,000 persons.

Shih et al. (2004) conducted a study on economies of size of community water systems and examined the potential for achieving reductions in unit costs of water supply by increasing system size, and in particular in consolidating existing small systems with large ones. They first estimated the economies of scale in water supply by estimating the total unit cost and then individual cost elasticities. The cost data were acquired from EPA’s 1995 and 2000 Community Water Surveys (CWSs). Their output variable is total water produced. The input variables are: capital, labor, material, energy, outside service, and other costs.

Shih et al. calculated average unit costs (2000 dollars per 1,000 gallons) for total costs, capital, labor, material, energy, outside, and other costs. The cost categories were calculated for each water system category. The water system categories include very small (25-500 served), small (501-3,300 served), medium (3,301-10,000 served), large (10,001-100,000), and very large (greater than 100,000) systems. Using the 1995 data, the 1995 median cost per one thousand gallons of water produced by a very small plant is 135 percent greater than that of a very large plant. Despite generally falling costs with a larger water system, the study concluded that 20.7 percent of very small plants (less than < 500 served) and 22 percent of small-medium plants (3,301 – 10,000 served) have a unit cots lower than the median unit cost of very large plants. The authors used linear regression analysis for a sub-sample of 132 water supply systems surveyed in both 1995 and 2000 CWSs. Based on Shih et al., the estimated elasticity of 0.47 indicates that doubling a water volume would lower unit costs by almost 30 percent.

Another way of estimating scale economies in water supply systems, Shih et al. (2006) considered individual cost components of water production (per 1,000 gallons of water produced). The 1995 data set included six factors of production: capital, labor, materials, energy, outside service, and other costs. The average unit costs of production fall as system size increases for all six factors of water production, but not at the same rate. Thus, they found that smaller systems face higher unit production costs across the full range of production inputs. However, they also concluded that size of water system explains only a part of the cost distribution because the variations were large in unit costs across and within system sizes.

The greatest economies of scale existed in capital and other material costs, while labor and energy costs exhibited the fewest economies of scale. The energy costs associated with water production stem partly from water distribution and transmission. The lower elasticity value for energy costs suggests that larger systems may have to pump water farther away per unit delivered and thus off-setting some of the economies of scale gained elsewhere in production. This finding would suggest that some economies of scale of consolidation of water supply systems could be achieved without physical interconnection or reducing the distance of distribution of water to the end-users (Shih et al., 2006).

Shih et al. (2006) also estimated a model to quantify the effect of size, and tested water source variables (surface water, groundwater, or purchased water) as well as ownership variables (a dummy variable indicating whether the system is privately or publicly owned). Controlling for size of water system, the groundwater systems had the lowest costs, surface water systems were 17 percent more costly, and use of purchased water was 52 percent more expensive than groundwater. The lower cost of groundwater is mostly due to the lower treatment needs and thus acquired cost savings. However, the study did not investigate the impact of raw water quality and compliance status on individual systems nor between the outputs (groundwater, surface water, and purchased water).

Shih et al. (2006) also simulated annual cost savings from consolidation for three different scenarios: 1) combine small water systems (< 500 people served) with large system (> 50,000 people served); 2) combine small water systems (< 500 people served) with medium size water systems (3,301-10,000 people served); and 3) double the size of small systems (< 500 people served). The sample size was 565 water systems using 1995 and 2000 CWSS data. The median of total water produced was used (50,000 population served: 6,506 MG; and 3,301-10,000 served: 242 MG). The first scenario total cost savings results were $1,500,000 of cost savings, the second were $700,000 and the third were $280,000 in 1995 dollars. The major cost savings accrued from labor, capital, material, and other costs. Cost savings from energy were relatively small compared to other factors. This result suggests that as the plant size increases so do the pumps, and thus energy costs go up. But this does not necessarily apply per unit of production.

Ottem et al. (2003) investigated the physical proximities of small and very small water systems to the nearest larger systems both in rural and metropolitan areas in 34 states. The authors tested the feasibility of physically consolidating small systems with nearby larger systems. They calculated the distance from each small system to the nearest facility in a large system. Distance was calculated to a central facility within the nearest system. Since there is no pre-defined central point, they prioritized the types of facilities in large systems and calculated distance by priority. They first checked for the presence of a nearby medium, large, or very large treatment plant (category 1). If multiple treatment plants were present within 25 miles, the distance was set equal to the minimum distance within the category. If no treatment plants were present within 25 miles, then we checked for facilities in category 2, and so on. The categories were prioritized as follows:

1. nearest treatment plant within 25 miles
2. nearest reservoir within 25 miles
3. nearest storage facility within 25 miles
4. nearest intake within 25 miles
5. nearest well within 25 miles
6. nearest pump facility within 25 miles
7. nearest treatment plant, reservoir, storage facility, intake, well, or pump facility between 25 to 50 miles.

In cases where no facility in a medium, large, or very large system was found within 50 miles of a small system, that small system was eliminated from the analysis.

Ottem et al. (2003) analyzed the location and system data to answer the following questions for small water systems:

- What is the average physical distance from a small system to the nearest large system, in rural as opposed to in metropolitan areas?
- Are the number of persons and service connections served by small systems similar in rural and urban areas?

- Is there a significant difference in the incomes of customers of small rural water systems as compared to customers of small systems in more urban areas?

Ottem et al. (2003) concluded that over half of small rural water systems (serving 501-3,300 persons) in the study were located more than 7.5 miles from the nearest medium, large, or very large system. The average distance of a small system to a larger system was 9.3 miles (rural and urban). For very small systems (serving < 500 people), the median distance is over six miles. For both size categories, however, a large number of systems are much farther from larger systems. Small systems and very small systems are on average located approximately 8.5 miles or more from the nearest medium, large, or very large system. More than twenty-five percent of systems in both size categories would have to connect to a larger system that is 12 or more miles away.

Ottem et al. (2003) found that the distance comparison between rural and urban very small and small water systems concluded that approximately half of the very small systems in urban areas are less than 4.5 miles from a larger system. In rural areas, less than twenty-five percent of very small rural systems are within 5 miles to a partner system. More than 50 percent of urban small systems are within 3.9 miles or less from a larger system. In rural areas, less than 25 percent of small systems are within 5.8 miles of a potential partner system.

According to Ottem at al. (2003) the average distances to a larger system in rural and urban settings of both size categories of water systems are similar: in urban setting the distance was approximately 12 miles, where in the urban areas it was 5.4 miles.

Ottem et al. (2003) conclude that due to the physical distance, small community water systems in particular are likely to face relatively high costs to connect to larger systems. These costs may pose a more significant barrier to consolidation. Since rural systems tend to be located farther from a larger system than are small systems in urban areas, their costs will be even higher. The authors also suggest that rural systems are likely to have a harder time paying for these types of connections because the income of the population served by rural small community water systems is generally not as high as it is for urban systems. Raucher et al. (2004) note that while potential benefits from consolation include costs savings and increased regulatory compliance; the costs include the physical inter-connection as well as a loss of local control of water supplies.

Clark and Stevie (1981b) indicated that economies of distribution could exist only at distances of only a few miles of water distribution: an evidence of decreasing returns to scale. More recent studies suggest that treated water can be transported as much as 100 miles under favorable physical conditions (topography and soil type). Kim and Clark (1988) investigated the efficient water system size with respect to service distance. They found that a plant size capacity of 22 million gallon per day (MGD) was the most efficient with a maximum service area less than 448 miles. If the service distance exceeded beyond this distance, the water system exhibited overall diseconomies of scale is due to economies in water treatment being offset by diseconomies in water distribution. According to these authors and Beckenstein (1975), this implies that decentralization of water production to more than one location would be then more cost efficient.

Based on the findings above by Stevie and Clark (1981abc, 1988), Ottem et al. (2003) and Shih et al. (2004) and the economic principle of optimal economic water system size requiring a balance between the returns to scale in production and distribution, a simple conclusion can be drawn that large systems should be located near major population centers and smaller systems should serve rural populations with smaller service regions. However, Rubin (2001) found that many small water systems are actually located in urban and metropolitan areas and may be located close enough to a larger system for consolidation to be feasible. But as the Shih et al. (2004) study found using the EPA's national community water system data, 21 percent of very small plants (less than < 500 served) and 22 percent of small-medium plants (3,301 – 10,000 served) have a unit cots lower than the medium unit cost of very large plants. Therefore, the consolidation of small systems to a very large system may not automatically result in economies of size. This could be due to rural water system using groundwater as a primary water source compared to surface water source for the large systems or that the rural system infrastructure is dated and needs replacement.

Castillo et al. (1997b) study tested the hypothesis set forth by the EPA that 50 percent of all small systems (501-3,300 served) in the USA could benefit from physical interconnection of small systems to a larger one (Castillo, 1997b). The authors examined the cost-effectiveness of restructuring of small system ownership through physical interconnection and satellite management, using geographical location of systems, distances between the systems and other data of water systems in 17 states (Castillo, 1997b). The authors ranked locations in order of preference with respect to evaluating the potential for physical interconnection (treatment plant, storage, pumping facility, wellhead, and the “other”). They used the most preferred data point available (“treatment plant” was the first choice and “other” was the last choice). The cost-effectiveness criterion used in the study include the level of investment per new customer that is similar to (or less than) the level of investment per existing customer. The maximum level of investment per new customer was chosen to be $2,500 per customer (based on previous national studies that were below $2,000 for 75 percent of all systems). The cost of interconnection was assumed $60/foot including planning and construction. Dividing the $2,500 per customer by $60/ft, would yield 42 ft of water main per customer. Therefore, the authors conclude that if a large water system was connected to a small system with 100 customers, the maximum economical distance between the two systems should be 4,200 ft (0.8 miles). The authors separated the costs between urban and rural location. The costs in urban areas were assumed to be $40/ft for interconnections and $20/ft in rural areas. For small systems in urban areas, the authors considered interconnection with the closest medium-sized or large system would be economically feasible if the straight-line distance between the two was less than or equal to the number of service connections in the small system multiplied by 62.5 (2,500/$40).

Castillo et al. (1997b) study does not specify how the costs were generated in the national level and the distances were measured as straight-line connections between systems without incorporating physical barriers, such as roads, water bodies or other man-made or natural and physical elements. The authors acknowledge that the study should not be used to implement any particular restructuring option. Instead, the study reveals the potential and different elements of restructuring options of water systems that should be analyzed further. Of the 17 states evaluated, 8 to 48 percent of small systems have the potential to physically interconnect with a medium-sized system based on economic feasibility of the interconnection. Interconnection between small and larger water systems potential ranges from 6 to 35 percent. The study concluded that physical consolidation would be economically viable for ten to twenty percent of small systems in most states. The main reason for the lack of economic viability of consolidated infrastructure is the cost of implementation. As of satellite management, the authors suggest that of the 17 states studied, all the states except the most sparsely populated states (Utah and New Mexico) have potential for satellite management because more than 95 percent of small water systems are located within 60 miles of a large system.

Chicoine et al. (1984) studied the costs of operating rural systems: the relationship of cost-output variables. In their study, the authors found that economies of size do affect per unit operating cost of drinking water; however, acknowledging that other variables may offset the gains from large-scale water productions. These variables are population low density of the service area and capital costs.

The 1993 EPA study of small water systems in three states (Alabama, South Dakota, and West Virginia) concluded that as many as fifty percent of those small systems included in their study could engage in some type of collaboration with another system to reduce the cost of meeting more stringent water quality and monitoring standards. The study mainly addressed non-physical forms of consolidation. The study did not address the costs of physically consolidating small systems. Lee and Braden (2007) investigated consolidation strategies from a water quality compliance perspective. They used random a utility model (RUM) to test six hypotheses as which ones have significant impact on the acquisition of CWSs. They used data from EPA's Safe Drinking Water Information System (SDWIS) for Region 5 and 7 from six states. Two types of violations were included: monitoring and quality violations. The other SDWIS data were used: service connections, ownership, and water source. Also, demographic variables such as median income and growth rates were used. The findings include: 1) small water systems are more likely to be acquired than large ones; 2) monitoring and quality violations increase both increase the probability of merger; and 3) systems that are already interconnected physically (infrastructure) are able to complete a merger at a lower cost than systems that must pay for expensive infrastructure to finalize the merger. Water systems that are purchase-systems are approximately 15 percent more likely to be acquired than systems that had no preexisting connection to another system. The water system's form of ownership and the extent to which the system is already interconnected with an adjacent system have the greatest influence to the transaction costs (the costs associated with transferring the ownership from one system to another). 4) Publicly-owned systems are six percent less likely to be acquired as compared to privately-owned water systems. Rural systems are less likely to be acquired. This supports the previous research that suggests that privately- and publicly-owned firms may have different motives regarding consolidation.

Mann, Dreese, and Tucker (1986) found that well-performing water systems were more often acquired by private systems, while poorly performing systems were more often acquired by municipalities (Mann, Dreese, and Tucker, 1986). 5) The effect of service connection density on merger is small. An increase in the service connection by ten connections per square mile increased the probability of mergers by 0.2 percent. This implies that density and distance of water service are not significant in explaining mergers in rural systems. 6) Water systems located in counties with higher incomes are more likely to be acquired.

Much of the water supply economics has been published in the engineering literature. This field of literature focuses on the development of cost models of water supply. The most important works come from Robert Clark. Clark has developed useable water supply cost equations in his many works. He has also tested the validity of these equations in case studies. The main objective behind the development of water supply cost equations has been to establish the cost of water. Cost of drinking water is established by estimating the unit costs of water produced as well as analyzing the variables affecting those costs. These variables usually include the total number of population served, population density, average daily demands, system characteristics (private, public, consecutive, purchase, rural, urban, primary, secondary), and source water. Most the water supply economics literature however, has focused on the costs of meeting drinking water standards.

Clark and Stevie (1981c) studied the costs of water treatment and distribution together. They examined the relationship between system expansion, increasing per capita demand for water, and unit cost for water supply. They purpose of their work was to examine the tradeoffs that may exist between economies of scale for producing water and the diseconomies of delivering water to the end users. High transportation costs and low treatment costs indicate decentralization; the opposite indicates centralized treatment facilities. Clark and Stevie's combined treatment and distribution into a total cost model:

$$C_{TOT} = C_T + C_D \tag{1}$$

Where:
C_{TOT} = annual cost of water supply ($/million/yr)
C_T = annual cost of water treatment ($/million/yr)
C_D = annual cost of distribution ($/million/yr)

They estimated the equation parameters for acquisition and treatment, and distribution and transmission. Clark and Stevie also investigated water usage independent variables, such as price, income, population, land size, and precipitation. They presented a marginal cost equation of water production with respect to distance with the estimated values of cost of treatment and distribution, and the independent variables. The authors modeled hypothetical growth scenario of water system over a 10-year period with declining values of λ (a measure of a rate at which population density declines with distance), with increasing values of service area, per capita consumption, and total water production. They also incorporated associated water system costs. As a result of modeling, the total unit costs declined over time. The flexibility of this model accommodates most service area configurations (circular, noncircular, pie slice, and semicircular). The model can also be used to illustrate the effect of declining population densities on the cost of supplying water. The authors found that the most determinant variable of least cost system size is population distribution in the service area (instead of population density or per capita consumption).

2.3 Decision Analysis

Decision-making cannot begin until the existence of a problem is recognized. There is no fixed path to choosing the best alternative. Decision analysis looks at the paradigm in which an individual decision maker (or decision group) contemplates a choice of action in an uncertain environment. The decision theory helps identify the alternative with the highest expected value (probability of obtaining a possible value). The theory of decision analysis is designed to help the individual make a choice among a set of pre-specified alternatives. The decision making process relies on information about the alternatives.

The literature that has focused on water resources planning and management literature includes multi-criteria decision analysis (MCDA) and multi-criteria analysis (MCA). The MCA can be defined as a grouping of techniques for evaluating decision options against multiple criteria measured in different units (Voogd, 1983). A decision option is an action, or project, which contributes to the decision maker's objectives. Decision systems in water resources have been conducted in the fields of multi-criteria decision analysis (MCDA) and multi criteria decision making (MCDM). In discrete choice MCA there are a finite set of decision options being appraised. Weights can be assigned to criteria to represent their relative importance. Multi-criteria analysis or multi-objective decision making is a type of decision analysis tool that is particularly applicable to cases where a single-criterion approach (such as benefit-cost analysis) falls short, especially where significant environmental and social impacts cannot be assigned monetary values. MCA allows decision makers to include a full range of social, environmental, technical, economic, and financial criteria. The methodologies can be categorized in a variety of ways, such as in the form of model (e.g. linear, non-linear, stochastic), characteristics of the decision space (e.g. finite or infinite), or solution process (e.g. prior specification of preferences or interactive).

2.3.1 Theory of Constraints

The Theory of Constraints (TOC) applies the cause-and-effect thinking process problem solving to understand and improve different systems and thinking processes. It answers the questions: “What to Change?” and “What to Change To?” and “How to Cause the Change?” (McMullen, 1998). The TOC proposes to focus attention on the core problem. The core problem is called the “constraint” in TOC terminology. This constraint prevents an organization from reaching its goal (McMullen, 1998).

The Theory of Constraints (TOC) which is an overall management and business philosophy introduced by Dr. Eliyahu M. Goldratt (1984) was developed to help organizations continually achieve their goals and provide insights of the underlying cause and effect dependency and variation of the system in question. The Thinking Process TOC is a set of tools; graphical trees that can be used to map and verbalize the cause and effect relationships (Dettmer, 1997). The methodology of Thinking Process consists of tools that allow the user to derive simple solutions to complex problems and to implement these solutions (Dettmer, 1997). The TOC Thinking Process, taken as a whole, provides an integrated problem-solving methodologies or trees (Lepore and Cohen, 1999).

TOC proposes that this detailed investigation can be best performed through systematic exercises. Each of these exercises requires construction of corresponding logic “trees.” Most of these logic trees can be used as stand-alone tools, depending upon the nature of the questions under consideration

(Matchar et al., 2006). This dissertation analysis for the current community water problem is based on the Current Reality Tree (CRT). The CRT informs about the existing situation. The CRT is recommended when asking the question of “what to change?” (Berry and Smith, 2002). The CRT can be used as a systematic approach of addressing the core problems by looking past the symptoms (Berry and Smith, 2002). A CRT is a statement of an underlying core problem and the symptoms that arise from it. It maps out a sequence of cause and effect from the core problem to the symptoms. Most of symptoms will arise from one core problem or a core conflict. Remove the core problem and the symptoms should disappear (Dettmer, 1997).

The emphasis in the CRT is in problem analysis which in turn helps in solution formulation (Dettmer, 1997). By revealing the true problems, countermeasures can be taken and problems will be truly solved (Ohno, 1978). A CRT is a way of organizing, analyzing, and identifying the root causes common to most or all problems (Lepore and Cohen, 1999). Constructing a CRT is a first and critical step toward finding solutions to perceived problems. The CRT process verbalizes the symptoms and underlying causes. This process treats multiple problems as symptoms arising of a problem scenario and leads ultimately to the apparent root causes. The CRT maps out a chain of cause and effect reasoning in a graphical form. The identification of the problems is done by assessing a set of symptoms that stem from root causes.

The current empirical TOC literature and research are from business applications and studies of organizational structures. Therefore, the analytical tools are typically used for conflict resolutions and addressing constraints blocking business success (Dettmer, 1997). The CRT specifically has been applied in various business and health-care industry applications, but not in water resources planning. TOC is similar to traditional process improvement techniques, with the exception that it is designed to accommodate complex processes, which, unlike some industrial processes, are non-linear (Matchar et al., 2006).

In the health-care industry application, Matchar et al. (2006) for U.S. Department of Health and Human Services used the TOC theory and the tool of CRT to improve the process of generating reports that synthesize and evaluate the scientific literature on topics of particular interest to health care policymakers, clinicians, and other decision makers. The authors set to identify potential solutions to the core constraints as identified by the study. The TOC methods were applied in the study to identify the common undesired effects (symptoms) related to the problems studied by the authors. Matchar et al., constructed a CRT by working from the symptoms identification through proximate causes, and finally core problems were identified during the process.

In the business applications, Klein and Debruine (1995) used the CRT to identify the common thread underlying the U.S. companies' failure to operate successfully in the global environment and presented a systematic thinking approach designed to recognize the root causes facing the U.S. companies. By identifying the root causes, Klein and Debruine argue that corrective actions can be made for the benefit of the U.S. companies.

In a community water resources planning context, the TOC and CRT can be applied in addressing what needs to be changed and what are the common threads underlying the community's water demand problems . The theory of TOC can be applied in mapping out and verbalizing the causes and the effects (Goldratt, 1984).

2.3.2 Decision Support System

The different disciplines of decision support (DS) fall into operations research, decision analysis (DA), and decision support systems (DSS).

L. Adelman has defined DSSs as:

> "interactive computer programs that utilize analytical methods, such as decision analysis, optimization algorithms, program scheduling routines, and so on, for developing models to help decision makers formulate alternatives, analyze their impacts, and interpret and select appropriate options for implementation," (Adelman: 1992: 2).

Another definition has been offered by S.J. Andriole, who defined decision support as consisting of "any and all data, information, expertise or activities that contribute to option selection" (Andriole, 1989: 3). A common idea explicit in each of these definitions is that DSSs integrate various technologies and aid in option selection. Implicit in each definition is that these are options for solving relatively large, unstructured problems. An effective and useful DSS is generally characterized by the integration of computer technologies for the benefit of a decision maker.

The DSS is a process where a sequence of interdependent and linked procedures which convert inputs (data) into outputs. These outputs then serve as inputs for the next stage until a known goal or end result is reached. As a tool, a DSS can consist of mathematical models, data, and point-and-click interfaces that connect decision-makers directly to the models and data they need to make informed decisions. A DSS collects, organizes, and processes information, and then translates the results into management plans that are comprehensive and justifiable. DSS are further classified into four main categories: data, model, process and communication oriented (Bohanec, 2001).

The traditional applications of decision making in water resources include management of different types of water resources, such as river basins and estuaries, storm water and flood, lakes and reservoirs, non-point source pollution, irrigation, water treatment and groundwater and conjunctive uses. DSS has also been applied to water distribution design and operations analysis.

Preliminary interactive computer technologies and decision support systems for studying water resources problems first appeared in the mid-1970s. The first applications were discussed in the water resource's literature in the mid-1980s [Loucks et al. (1985); Loucks and Fedra (1985); Johnson (1986); Labadie and

Sullivan (1986)]. The most rapid growth of DSSs in water resources, however, has occurred in the late 1990s.

A DSS is much more comprehensive than traditional methods of decision-making in water resources management. System analysis (design and optimization), uncertainty and reliability analysis (risk), distribution analysis (simulations), location analysis, and rule curves are examples of common traditional methods. However, they are discrete and confined to specific conditions, while a DSS can be adapted to any conditions. DSS recommendations are based on scientific data and models and can account for all stakeholder objectives, cause/effect relationships, risks, costs, and reliability, whereas traditional decision processes have had difficulty aggregating all of these considerations.

There are several commercially available software tools that can be applied to different stages of the planning process (UASCE, 2009). In problem formulation and identification, graphic organizers, mind maps, conceptual maps, or causal loop diagrams can help to identify the problem and the symptoms (software: MindMapper, Stella, Vensim). In alternatives formulation, comparison and evaluation steps, analytical tools like simulations models, optimization, and influence diagrams can aid the steps (software in water resources projects: WEAP, OASIS, RiverWave, HEC-models). The selection of the alternatives can be accomplished using ranking tools, decision trees, shared vision model, or trade-off analysis (software: EVAMIX, IWR-PLAN, DPL).

Rapidly advancing computational ability, the development of user-friendly software and operating systems, and increased access to and familiarity with computers among decision makers are a few of the reasons for this rapid growth in both research and practice. However, the field of computerized DSSs in water resources has not become a custom yet. One reason for this is a fear of complexity of designing DSSs. They are multidisciplinary in nature and their theoretical underpinnings stem from mathematical models. This can bring a design and development of a DSS into a stalemate. Also, there is a lack of case studies in which the performance of water resources DSSs has been evaluated in the appropriate institutional settings. In spite of the advances in the DSS developments and the proliferation of computer technologies for decision support, classical simulation and optimization models have remained at the heart of most water resources DSSs.

The traditional DSS, however, is not a *panacea* in resolving all types of water resources management issues. This is especially the case when there is one agreed objective (instead of many competing objectives) and the objective is derived by interlinking different modeling efforts to generate output that works as input in proceeding model elements. It is easy to overlook the applicability of the selected input parameters and hence, assume that they “fit” the model since they produce quantifiable results and eventually the objective. Therefore, the DSS should be designed to consider user-specified incoming parameters.

2.3.3 Planning Support System

A sub-class of DSS is planning support systems (PSS), or planning DSS. These are also computerized systems and assist analysts in completing planning analysis and tasks. Specialized PSS and software have been developed for project management, budget planning and management, operations and supply chain optimization, resource allocation and scheduling. The targeted user of PSS is a planner. Abdin and Khaireldin (2001) outlined a schematic of the planning support system for Egyptian water resources. They developed a schematic to accommodate the integration of water resources planning and the links to social, economic, and environmental impacts. The authors' goal was to identify the environmental interlinks in order to achieve more balanced water resources development.

As a design, the PSS can be utilized to incorporate models and arranging different steps in a schematic. As a process, PSS is a systematic method of aiding planners through the task of identifying the problem and defining it and formulating and analyzing the solution. The PSS aids planners and decision-makers along the way by organizing, arranging and disclosing all the information and data considered. As a tool, the PSS produces outputs as defined in the objective.

2.4 Analytical Framework for Water Resources Planning Support System

The analytical framework concerns a planning analysis objective of water recourses in a growing community. The solution in a form of consolidation is proposed to achieve, in whole or in part the planning objective. The above sections have outlined the theoretical framework and discussed an overview of existing literature which theories exist to explain the applicable concepts.

The water resources planning and decision support literature provide the framework for this dissertation as how water resources planning under the expected growth scenarios in growing communities can be addressed. The literature provides the procedural elements for solution analysis and evaluation (measure performance). The planning literature provides the procedural methods to link the analysis stages together by a generic model consisting of steps. Using the existing water resources planning and decision support literature, the planning support system in this dissertation is expanded to include the water resources problem identification. An accurate solution to the water resources problem can be proposed once the problem has been correctly identified. The Theory of Constraints (TOC) literature provides the theory and the Systems Thinking Process provides the methodology to systematically organize the thoughts and verbalize the underlying problems within the water resources decision making and planning. In water resources planning applications, a Current Reality Tree (CRT) can be applied in the context of a question of “what to change?” If the planning goal is to identify what needs to be changed in the water resources planning and then to decide where and when water system consolidation could be proposed as a solution, the CRT provides the tool to lead to the correct countermeasure.

The body of literature that serves a dual purpose in this dissertation is derived from consolidation research. First, the consolidation theory provides the theoretical and institutional solution to the identified water resources problem. Second, the empirical consolidation research provides the justification for water system consolidation. The reviewed research on the economics of consolidation suggests that although there is no single criterion when and how to achieve economically efficient consolidation of water systems, the economies of size exists in water treatment and thus; larger regional water treatment plants could be economically viable to serve growing urban communities instead of multiple small systems.

The review of theories, concepts, and methodologies help to better explain how water resources planning can be approached. These theories and methodologies lead to the objective of this dissertation of creating a planning support system for urban fringe areas that presently are dependent of multiple community water systems. The reviewed theories and methodologies alone lack the interconnectivity, a systematic and a holistic approach to address the problem and evaluate the solution of this dissertation. The broad suite of literature and application of diverse methodologies to address numerous types of water resources planning problems clouds the targeted problem and objective-specific planning process. One can use a discreet discipline to define and identify the problem, another discipline can be used to propose a solution, yet another to assemble a range of solution alternatives, and finally to assess and evaluate the potential outcomes.

Using the existing research and literature, a water resources planning support system is proposed where the problem is identified and solutions analyzed and evaluated. The proposed planning support system is then tested in a case study.

An analytical framework is composed of four major components: tools, solution pattern, model forms, and methods for grouping information. Table 3 shows the necessary elements in the analysis framework for long-term water supply planning of small/medium sized CWSs.

Table 3
Analysis Framework

Element	**Description**
Tools	ArcView GIS, IWR-MAIN, IWR-PLAN
Solution pattern	Consolidation
Technique	Data collection, computer modeling
Model forms	Planning model, demand analysis, infrastructure inventory, supply gaps, cost-effectiveness
Categorization	Planning support-decision support.

III. RESEARCH METHODS

3.0 Generic Model Development

The concept of a generic planning support model in this dissertation refers to a schematic description of a framework designed to describe the operation of analysis modules and decision support tools (models).

The model application in this dissertation consists of multiple model types. The types of models employed in this dissertation include:

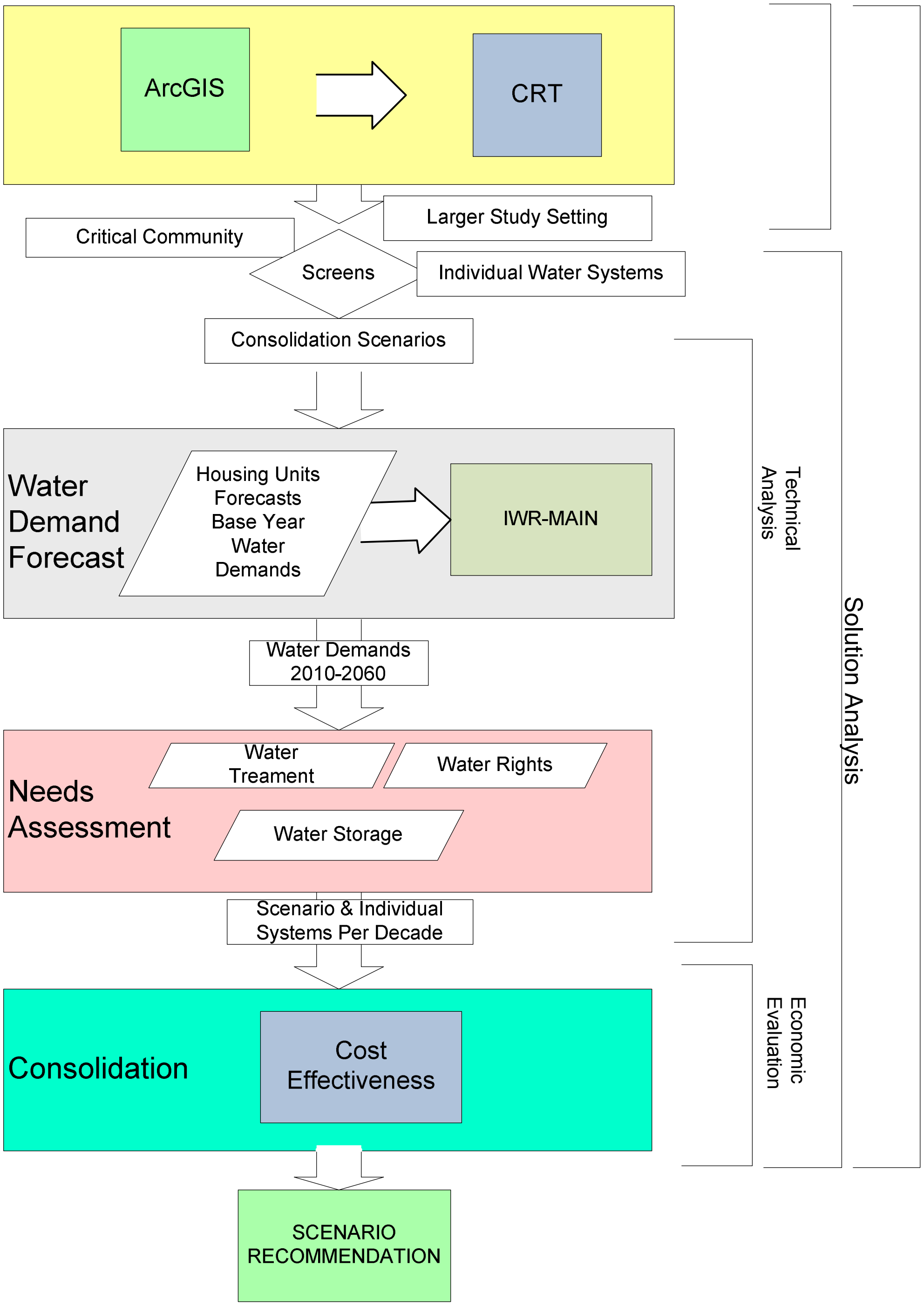
1. Conceptual models: Define the reality and help to explain the problem. Conceptual models used to identify root causes that generate the core problem and the undesired effects. The model structure depends on the interpretations of the situation by the planner.
2. Analytical model: Computer-based water demand forecasting model.
3. Planning models: Planning frameworks view the foregoing models as "diagnosis" preceding the selection of appropriate strategies for "intervention". The planning model guides the decision making process to match solutions and strategies with identified issues. Not a single solution.

Figure 2 depicts schematically how the two analyses modules: Problem Analysis and Solution Analysis are interconnected and implemented. The different modeling efforts connect the two main modules together: Problem and Solution Analysis. The analytical stages are separate yet interactive. The output produced by one model becomes input of another model.

Each phase and step provides further information that can be taken to the next phase or provides information that the analysis of that particular scenario can be stopped because it is deemed unfeasible.

Each module shown in Figure 2 has a set of tasks that are performed in the PSS. In the Planning Analysis module, ArcView GIS is used as a tool to map the community characteristics that are used as symptoms in the Current Reality Tree (CRT). The CRT is used in community water resources problem identification. The outputs from the Problem Analysis stage include the characterization of a study and critical communities and the initial set of community water systems in the study area that are considered for solution formulation. In the Solutions Analysis sub-module of Technical Analysis, the decadal water demands are forecasted for the solution scenarios. The output from this sub-module includes different water demands for the planning period. In the Needs Assessment sub-module, the gaps of water treatment and storage capacities are evaluated along with water rights. The output from this sub-module is the feasible consolidation scenarios. In the final sub-module, the associated costs are estimated. The final output from the PSS is the scenario recommendation based the cost and feasibility.

Figure 2
Planning Support System Model



The analysis timeframe is the period of time for which project related costs are compared and evaluated. The general principles for selecting an analysis period include: 1) analysis timeframe should be consistent with that used for other analyses being under-taken for similar projects, and 2) timeframe should be consistent for all alternatives. An analysis period of 50 years is typical for CWS improvement projects, because demographic information is generally available for this timeframe.

3.1 Problem Analysis

The purpose of the first module of the PSS, the Problem Analysis module, is to define and identify the water supply problem. This is accomplished by using the community characteristics. The tasks in the Problem Analysis include: 1) identification of a larger study setting and 2) critical community. These tasks are accomplished using a Current Reality Tree (CRT).

This dissertation applies techniques described in the Theory of Constraints (TOC) reproducible means of identifying and addressing problems in a systematic and comprehensive manner (Goldratt, 1985). TOC understands that processes do not function in isolation, but are part of a larger, intertwined system. Therefore addressing root causes at process levels does not result in sustainable solutions.

In this dissertation community characteristics and the literature are used to organize the problems to develop the CRT for a community to meet their future water demands. For this purpose, the following is done:

- Identified the most relevant symptoms (undesired effects: UDEs).

- Explore other symptoms (undesired effects: UDEs).
- List a set of root causes that led to the symptoms (undesired effects: UDEs).
- Explore the relationship between the symptoms (undesired effects: UDEs) and the root causes, so that one (or two) core constraint (s) could be identified.

In this dissertation, the community characteristics are chosen as a source for problems to be used in CRT. Water resources problems are unique in certain geographical areas. Rural community water resources problems differ from water resource problems in urban communities (Moberg, 1976; Bagi 2002; Ottem 2003). The rural CWSs face a great difficulty in supplying water of adequate quality and quantity because their service areas typically smaller than in urban areas. The long distribution distances, low-density population and small plant size lead to diseconomies of scale and diseconomies of distribution (NRC, 1997; Moberg, 1976; Bagi 2002; Ottem 2003). Using the urban and exurban community characteristics and the community water system characteristics in the exurban and urban areas, the CRT can be constructed (refer to Chapter 2 for definitions).

3.1.1 Study Setting

The larger study setting for water resource planning is chosen based on the population growth characteristics and the likely growth direction. The community characteristics are important in a close examination of the problem of water resources planning in a specific area. The characterization of the larger study setting provides information about the future growth potential of the area and this in turn will have an impact on long-term water resources planning. In water resources planning, the knowledge of the type of water users and the direction of growth determine what the area’s future water demands may look like. The historical growth pattern and the likely future growth pattern are from a large city to suburb to exurb to rural areas. Population growth and land development affect where and how people live. Also, land development determines where businesses will locate. Therefore, direction and type of land development are identified.

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). Land-development has an intermediate impact that results in a variety of other impacts on the physical environment such as an increased drinking water demands. 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 a 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, and prisons.
7) Proximity to existing development, such as urban areas.

3.1.1.1 Larger Study Setting

The larger study setting criteria include areas that are part of an urbanized area (UA) and exurban area. The U.S Census Bureau defines the urbanized areas (UA) as an area with population density greater than 1,000 people per square mile, urban nucleus that consists of an urban center and the surrounding areas whose population is greater than 50,000 (U.S. Census Bureau, 2000). Exurban communities exist at the outer fringe of a metropolitan area. They are less developed than the suburbs, but no longer truly rural, with increasing ties to the urban center.

Exurbs are towns and counties with an agricultural heritage, now containing large-lot subdivisions, a growing population of “super-commuters,” and a slate of difficult questions about schools, roads, land preservation, and community character. At least 20 percent of exurbanites travel to jobs in the urban or suburban core, and roughly half work outside of their home county. The commuting distance is determined by analyzing commuting data from the 2000 U.S. Census. Exurbanites tend to be non-Hispanic white and middle-income homeowners. While some exurbs have evolved into upscale enclaves, others draw newcomers because the homes are more affordable than in the suburbs (The Brookings Report, 2006).

The urbanized area (UA) characteristics as defined by the U.S. Census Bureau and exurban characteristics as defined by the Office of Management and Business (OMB) of metropolitan and micropolitan areas as discussed in the study setting. In this dissertation, the UA and exurban community characteristics, as listed in Table 4, are used in identifying the larger study setting.

Table 4
Study Area Screens - Urbanized Area and Exurban Characteristics

1.	Distance to large metropolitan center <50,000 people -- fringe
2.	Population >50,000
3.	Population Density >1,000 people per square mile
4.	Travel Time to Work <20 minutes
5.	Work Commute Outside County >50%
6.	Surrounding Agricultural Land for Development
7.	Annual Growth Rate Surrounding the Urbanized Areas Higher than the Rest of the County

3.1.1.2 Critical Community

A critical community is defined as a community that is located in an urban fringe area and is dependent on multiple water sources. The identification criteria for the critical community from the larger study setting includes: 1) the fastest growing non-metropolitan cities close to the major metropolitan center in the larger study setting; 2) does not have its own water rights or water treatment; 3) a large CWS system (≥100,000 served) provides water; and 4) small CWSs (≤10,000 served) provides water. Table 5 lists the five characteristics that are considered critical for growing communities that are located in urban fringe areas.

Table 5
Critical Community Characteristics

1.	Population Growth 5%/year
2.	Supplier No. 1 ≥ 100,000 served
3.	Supplier No. 2 ≤ 100,000 served
4.	No own water treatment
5.	Anticipated future growth

These types of unique communities have been considered rural and low density communities in the past water resources planning efforts. When communities are relatively small and have low housing density, the water supplies are typically fragmented and divided between small and rural community water systems. However; when these previously low housing density and rural communities have begun to grow, the water supplies have not changed at the same rate. The communities are still dependent on all their water supplies from multiple water systems and consequently, have lessened ability to influence their water recourses planning in the future.

Typical characteristic for a critical community is the availability of land (previously rural) to accommodate increased population growth. The pattern of land development ultimately depends on the availability and suitability of land for desired development purposes. Land-use maps are developed for the critical community that will help further in defining the land-use types in the study area

3.1.2 Current Reality Tree – CRT

The literature for the Current Reality Tree and the Theory of Constraints were review in Chapter 2. The characteristics of the larger study setting and the critical community are used further in addressing the water resources problem. The use of the Current Reality Tree (CRT) in the Problem Analysis module helps to investigate the community characteristics and their linkage to the water resources problems.

By combining the larger study setting and critical community characteristics, the core problem to water resources problem can be accomplished by using the CRT. As the literature reviewed in this dissertation suggested, community characteristics (urban, rural, exurban, and suburban) are important determinants for types of water resources problem may exist (Moberg, 1976; Beecher and Stevie, 1992; Beecher, 1996; Ottem et al., 2003; Koo, 2005; Sharp and Clark, 2008). Water resources planning problem identification is accomplished by mapping out root causes and the symptoms [undesired effects (UDEs)] of water recourses problem. This process reveals the “real” causes behind the water resources planning problem (Lepore and Cohen, 1999). The output of the problem analysis provides input for further Solution Analysis.

A CRT is a way of organizing, analyzing, and identifying the root causes common to most or all problems. A CRT is a systematic approach of addressing the core problems, root causes and looking past the symptoms (Lepore and Cohen, 1999). A CRT is a statement of an underlying core problem and the symptoms that arise from it (Dettmer, 1999). It maps out a sequence of cause and effect from the core problem to the symptoms. Most of the symptoms will arise from the one core problem or a core conflict (Dettmer, 1999; Merry and Smith, 2006). Remove the core problem and we may well be able to remove each of the symptoms as well (Dettmer, 1999; Merry and Smith, 2006).

Constructing a CRT is a first and critical step toward finding solutions to perceived problems. This process verbalizes the symptoms and underlying causes. This process treats multiple problems as symptoms arising of a problem scenario and leads ultimately to the apparent root causes. The CRT maps out a chain of cause and effect reasoning in a graphical form.

3.1.2.1 Building CRT

The Current Reality Tree (CRT) is diagrammatic representation of a current state of affairs and is useful in identifying water resources planning problems in the study area and in identifying solutions to the core problems. Operationally, the CRT is constructed by identifying the apparent undesirable effects to uncover or discover the underlying root causes and core problems. The symptoms arise from the one core problem or a core conflict. Removal of the core problem would remove the symptoms and the undesired effects as well. The tree is constructed upwards from the “bottom” of the tree: “if cause, then symptoms and undesired effects.” Using the basic principles of constructing the CRT is applied. Operationally, the tree is constructed in three major steps and these are described below.

Step 1: The undesired effects (UDEs); symptoms and root causes are identified. UDEs are at the top of the tree, root causes lead to the symptoms and the core problem is at the bottom of the tree. The UDEs are identified by organizing different possible symptoms of water resource problems. Using the theories and principles of CRT construction, the UDEs identification include a listing at least five UDEs and verifying that these are not in a cause-and-effect relationship (Dettmer, 1999; Merry and Smith, 2006). The potential UDEs are identified using the community characteristics and how these lend to water resources problems. To identify the root causes, an analysis is performed whether any of the UDEs are in a cause and effect with one another. If so, then the cause (root cause) is placed at the bottom and the effect at the top in the CRT. This step reduces the amount of UDEs.

The root causes are divided into larger driving forces; triggering events (more distal causes) and proximal causes; the key factors. The driving forces can be thought of as "clusters of events". The components selection of the driving forces is done by identifying more distal causes behind the undesired effects. The triggering events are typically clusters of events and more distant causes of the symptoms. The key factors; the proximal causes are the immediate causes behind the symptoms.

The identification of key factors and driving forces must be technically valid and demonstrate the interconnectedness between the causes and the symptoms. They cannot be arbitrary, and they must accurately describe the problem and be rational. Both the larger driving forces (triggering events) and the key factors of the current reality of the UDEs are substantiated based on their relevance and ability to explain the UDEs and their relationship to the core problem(s). (Lepore and Cohen, 1999)

Step 2: Once the final set of UDEs is identified, their hierarchy organized based on the cause and effect relationships. The core problem is identified based on the fact that if they were removed (or solved), the UDEs would not exist or at least be minimized.

Step 3: The final step in CRT construction includes the organization of CRT using the larger driving forces, key factors, neutral factors, and feed-back loops. Neutral factors include causes that alone do not alone impact the UDEs but combined with another cause, will affect the UDE. Feedback-loops, the vicious cycles undesired effects arisen from the core problem and in turn make the core problem worse than if it occurred in isolation.

3.1.2.2 Tools

The identification of the causes and symptoms requires identification of key factors (proximal causes) and larger driving forces (triggering forces). ArcGIS/ArcMap mapping software is used in identification of these and formulating the study setting. ArcGIS is a mapping tool to map, visualize, and analyze geospatial data. The U.S. Census Block Group data is mapped to identify the community characteristics. The mapping effort includes all the larger driving forces (the distal causes) to the core problem.

The purpose of the mapping is two-fold: 1) it helps to spatially identify and characterize the problem as defined in the CRT and; 2) the output of the CRT helps in study setting identification

3.2 Solution Analysis

The Solution Analysis module consists of three sub-modules. These include: 1) delineation and pre-screening of consolidation scenarios as a solution formulation, 2) technical analysis (needs assessment based on water demands: water treatment, storage, and permits), and 3) economic analysis of different partnership scenarios. The Problem Analysis module, the methods for identifying the core problems and root causes were discussed. The solution formulation begins by identifying possible solutions to the root causes.

3.2.1 Delineation and Pre-Screening of Consolidation Scenarios

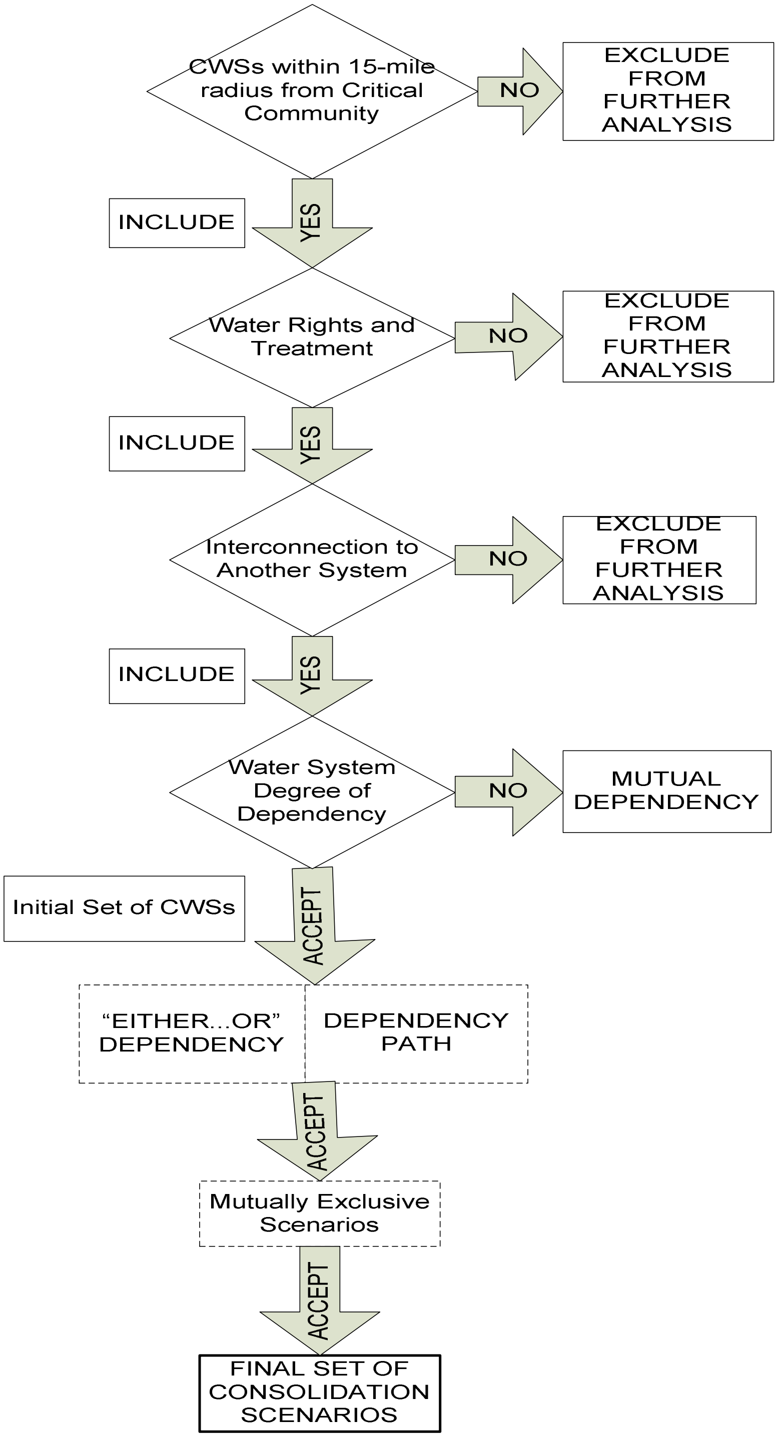
The goal in solution formulation is to address one or many root causes of the water resources planning of a critical community. The overall goal in this dissertation is to be able to decide where and when water system consolidation could be proposed as a solution to water resources planning of a critical community. A CWS consolidation is a proposed solution or response to the root causes. The solution formulation begins with the delineation of consolidation partnerships. The user-defined criteria are selected for the partnership screening.

There are many different types of CWSs and each may have unique characteristics based on their service area size, water treatment capacity, water source and availability, treatment, and operations. The general characteristics of CWSs were discussed in Chapter 1. Many small and medium size and rural CWS have existing physical interconnections with other CWSs. Examples of these include small rural water systems whose is entirely supplied by another system (purchase systems).

Combining some of the CWSs into new consolidation scenarios may be a pointless task unless the existing types of physical interlinkages are assessed. In this dissertation, it is determined to what extent the existing CWS relationships should be maintained and combined together. This is accomplished by creating entry criteria of consolidation. The purpose of this process is to weed out any CWSs from further analysis that do not meet the combinability requirements. The analyst (user) needs to screen the inputs; an algorithm cannot do this.

The initial selection of CWSs that could be part of the solution in a form of consolidation to provide a long-term water supply solution to a critical community is accomplished by locating all the CWSs in a larger study setting in a close proximity to the critical community. All these systems should already have an existing relationship with the critical community. Using a screening method diagram, the selection of suitable CWSs to be included in the consolidation partnership scenario is performed. The initial screening process of CWS selection includes the following criteria: 1) all current CWSs within a 15-mile radius from the critical community; 2) CWS has exiting water rights and water treatment, and 3) CWS supplies other CWSs: has an existing interconnection to other CWSs. The flow chart in Figure 3 depicts these criteria.

Figure 3
CWS Consolidation Partnership Criteria



The output from the screening includes the initial set of consolidation candidates based on the screening criteria. The screened individual CWSs are then combined together into all possible combinations. In some instances, there may be a very large number of CWS consolidation candidates for the consolidation scenario.

The combinability of CWSs into consolidation scenarios depends on the “ability to mix and match” the CWSs into different future scenarios. There is no existing mechanism to evaluate the combinability of CWSs. In this dissertation, the Institute of Water Resources (IWR) methodology of addressing the interrelationships of solutions in plan formulation is extended to apply to the components within the solutions (IWR, 1995; 2006). The components within the solutions in this dissertation include the different CWSs.

The criteria for the CWS combinability include 1) one of the consolidation partners has existing water rights to a surface water source; 2) the scenarios are mutually exclusive; 3) maintaining the level of interconnectedness of those CWSs that are classified as purchase systems; and 4) the CWS has an existing water treatment plant.

The mutual exclusiveness is defined by: 1) Location: two (or more) different CWSs cannot occupy the same space at the same time; 2) Function: different CWSs may not work against one other; 3) “Nested” systems: part of the service area cannot be served by a combination of different size systems. These assure that the scenarios are mutually exclusive to achieve the water resource planning objective to have one regional water system to serve the critical community.

The knowledge of the CWS interconnectedness requires expert knowledge of the individual water systems. The analyst makes the decision as what CWSs are crucial to be screened at this point that can help to assure that time and resources are not wasted evaluating partnerships that could not be implemented because they fail to meet desired requirements.

Using the IWR-MAIN plan formulation guidelines, the types of CWS are assessed for level of interconnectedness (IWR, 1995; 2006). These three types of decencies include:

1. Mutually dependent: one CWS cannot exist without the other: these would be any size CWSs that receive raw water from one CWS and the “receiver” CWS treats the water and pumps it to the raw water provider’s service area.
2. Dependency order: these are order dependencies, where one system must “occur” first in order for the other to exist. These are CWSs where the another CWS supplies water to another system. There are two sub-types included: one where both systems have water rights. Another is where the other CWS is dependent on another system based on “necessary to function” because one of the systems does not have water rights.

3. Either-or- dependency: these are CWS where one system or the other system needs to exist in the scenario.

Once the dependencies and combinability criteria have been satisfied, all the possible combinations of CWSs can now delineated. The consolidation solution to achieve the planning objective of water resource planning requires the proposed consolidation scenarios to be able to meet the future water needs of the service area. The existing water rights and available supplies are important in entering consolidation scenarios and thus are identified for in each scenario. The sources are later assessed for the ability to support the forecasted demands.

3.2.2 Water Demand Forecasting

After the initial screening of CWSs, the water systems that are kept for further analysis, their consolidation scenario water demands are forecasted based on population forecasts. The criteria for water demand forecasts include:

1. Water demands for each consolidation service area.
2. The growth projections must include the existing water demands of a service area as well as the future water service area demands.

The water demands forecasts must accommodate the planning objective: Each consolidation scenario must be able to meet the forecasted demands without supplemental water from another system. It is not the only the past and the existing water demand scenarios that drive the exurban areas' water demands, but mainly the future anticipated growth projections as well as the future service areas that dictate the study areas' water demands. Water demands of all CWSs chosen as part of the solution formulation are forecasted throughout the 50-year planning period.

The first step in water demand forecasting is to determine the planning horizons for the current service area and the number of people living there. The second step is to forecast future population growth in the project area. This estimate will be based on available data about local population growth. It should also take into account the effects of urban and/or regional development plans and the effects of migration from rural to urban areas.

The water demands are generated by using population projections for high, medium, and low growth scenarios. All water system combination water demands will be forecasted in ten-year increments until 2060. The water demands are forecasted for systems that have been pre-screened in the previous section. Peaking demands are forecasted for water treatment design purposes. The water demand forecasting tool used in this dissertation (IWR-MAIN) forecasts future water demands using base year water use data of the current and existing water service areas.

3.2.2.1 IWR-MAIN

The Institute for Water Resources' software is utilized for projecting the study area's water demands (CDM-Planning and Management Consultants, Ltd., 1999, proprietary). The current IWR-MAIN development has been accomplished by

Planning and Management Consultants, Ltd. (PMLC), of Carbondale, Illinois, under the sponsorship of the Institute for Water Resources, U.S. Army Corps of Engineers; Metropolitan Water District of Southern California; Phoenix Water Services Department; and the Illinois Department of Transportation. The users include fifty water authorities, utilities, state water resource offices, USGS offices, and Army Corps of Engineers District offices (U.S. Department of Energy, 2010).

The Forecast Manager module of the IWR-MAIN software provides water use accounting and analysis tools for forecasting residential and non-residential water demands. The water use forecasting algorithm of Forecast Manager is built to operate on data corresponding to the study area, water use sectors and sub-sectors, months, and forecast years. Water Demand Management Suite is Windows-based PC software that uses econometric water demand models for interpreting existing water demands for different water use sectors and forecasts demands into the specified future.

The IWR-MAIN 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 water demand 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.

Forecasting relationships used in IWR-MAIN (Version 6.1) were developed throughout the 1980s for the non-residential and residential sectors. The non-residential relationships are based on over 10 years of research on the relationship between employment and water use in over 7,000 establishments representing the eight major industry/commercial groups throughout the U.S. In the same model version, the forecasting relationships used for the residential sector are based on the integration of approximately 60 studies of residential water demands, which contained about 200 empirically estimated water use equations.

The forecast methodologies do not incorporate potential conservation measures and assume continued growth throughout the forecasting period. As with any forecasting model, the degree of uncertainty increases with length of time of projections.

3.2.2.2 Model Description

The linear and multiplicative model suites allow complex water demand forecasting situations in urban and/or multi-water use settings. These are models require explanatory variables such as medium household incomes, different types of elasticities, environmental variables, and conservation rates. Constant use rate model calculates the base year per unit water use rate (q) from the base year water use and the numbers of counting units for each subsector. The calculated rate of use is held constant for all the forecast years for each sub-sector and is multiplied by the forecast year counting units to generate the forecasted water use for each sub-sector. Thus, the quantity of water use in a given subsector, month, and forecast year is calculated as:

$$Q_{s,m,y} = N_{s,m,y} * q_{s,m,b} * d_m \quad (2)$$

Where:
Q = Gallons of water used in subsector (s) in month (m) in year (y)
N = number of units in subsector (s) in month (m) in year (y)
q = average daily use rate per unit in subsector (s) in month (m) in base year (b)
d = number of days in month (m)

3.2.2.3 Residential Sector Water Demand Forecasting

Population growth is the major driver for water demand increases. Thus, these forecasts are fundamental for accurate water resources master planning. Population and housing characteristics (i.e. household income, lot size, persons per household, home value) are determinants of residential water use. Population demographics data translates into population densities and persons per household that help further to extrapolate water demands in residential sector. Knowledge of the number and type of housing units in the service area is are needed in the water-demand analysis. On both per housing unit and per capita basis, water-use in multi-family housing tends to be less than in single-family residences. In this dissertation, the residential model is used. The study area's water demands are primarily residential. The non-residential model is useful when water demands consist of large commercial and industrial water users.

3.2.2.4 Baseline Data Needs

Data need to be developed for the baseline service area throughout the planning period. These data need to be developed for all selected systems on monthly and decadal basis. The individual CWSs provide the base year water use rates per day and peaking factors. Also, the number of water connections is included in the baseline data input. These counting units are extrapolated to population counts using locational number of persons per household by location. This number is assumed to decline in the long run for exurban type communities due the changing characteristics of these communities from rural (traditionally more people per household) to more urban households (traditionally less people per household). The population counts are forecasted using local and state generated forecasted growth rates. These rates should be adjusted to generate population forecasts for high, medium, and low growths.

Table 6
Baseline Model Input Data – Residential Water Demand

<table>
<tr><td colspan="6">Number of Meters</td></tr>
<tr><td colspan="6">Housing-Population
Residential Single Family Forecasts</td></tr>
<tr><td colspan="2">High</td><td colspan="2">Medium</td><td colspan="2">Low</td></tr>
<tr><td colspan="6">Base Year Water Demands</td></tr>
<tr><td colspan="3">Monthly (MG)</td><td colspan="3">Peaking Factors (MGD)</td></tr>
</table>

3.2.2.5 Output

The output of the IWR-MAIN modeling will include water demands for each selected CWS and consolidation scenarios throughout the planning horizon from 2010-2060 for low, medium and growth scenarios. The output includes average and maximum daily demands per time period for all growth scenarios. The maximum daily demands are generated for required water treatment plant capacities. Average daily demands are used for allocated water supply evaluations and sizing of water distribution storage. The output of the IWR-MAIN modeling will include water demands for each selected CWS and combined systems.

3.2.3 Needs Assessment

The needs assessment consists of three tasks based on the forecasted demand output of the previous stage: 1) quantification of water treatment plant capacity gaps under the selected growth scenarios throughout the planning horizon for individual and consolidated scenarios; 2) distribution storage and 3) identification of required water permit gaps during the same period. All stages generate information for each individual system in the consolidation scenario as well as for the selected consolidation scenarios.

3.2.3.1 Water Treatment Plant Capacity

The baseline information needed for the treatment plant capacity assessment include: 1) existing water treatment plant capacities and 2) scheduled future expansions. The existing plant capacities and scheduled expansions are compared to the decadal forecasted maximum daily demand requirements. Water treatment facilities should have a nominal capacity sufficient to treat water to meet the demands on the highest use day of the year (i.e., max day demand). The maximum daily capacity is the flow rate that a water treatment plant can reliably operate with any unit out of service and still meet all mandated design criteria (e.g., detention times, loading rates). Hydraulic capacity is the maximum flow rate at which water can flow through a water treatment plant without overflowing the processes (Kawamura, 2000). You can expect performance of the system to decline over time. The nominal plant capacities are used as given by the individual water plant engineers and operators. The data of the water treatment plant capacities for this dissertation were collected in 2006 and 2010.

3.2.3.2 Water Storage

The baseline information for water storage includes treated water storage of individual CWSs.

The distribution system storage should be equal to, or in excess of, one day's consumption with consideration of fire flow needs and emergency storage. In this dissertation, it is assumed that the distribution storage consists of three components: operating storage, fire flow storage, and emergency storage. As a general rule, a steady state supply of water at the rate of maximum daily usage will require an equalizing storage of approximately 15 percent of the average day's consumption. Storage allowances for fire flows are generally a function of population served pursuant to the National Board of Fire Underwriters (NBFU) guidelines. The magnitude of the emergency reserve is dependent on the danger of interruption of the inflow and the time required making repairs. It is assumed that the emergency reserve is equal to 30 percent of the total storage capacity. The industry standard is 25% (Chin, 2006).

3.2.3.2.1 Fire Flow

The fire flow for a region can be calculated in a variety of ways. Most methods require knowledge of the size and type of buildings within the distribution system (ISO, 2004). Since the future types of structures, effective area sizes, or the intended purpose of the structures are not known at the time of fore flow needs, a fire flow method based on study area's population is used in this dissertation instead. Using the California State University, Sacramento Office of Water Programs: Water Treatment Plant Operation Manual (2004): the fire flow is calculated based on a population as follows:

$$Fire\ Flow\ (gpm) = 1020\sqrt{P}\,(1 - 0.01\sqrt{P}) \tag{3}$$

Where:

P = population (x 1,000)

The total amount of water the plant has available, in the plant and any storage structures, should be equal to the total flow. The total flow of the plant is calculated as follows:

$$\text{Total flow (MGD)} = \text{Maximum daily water demand} + \text{Fire flow} \tag{4}$$

Unlike the residential water demand, water demand for firefighting typically last only short periods of time. The formula to calculate the duration of fire flow is as follows:

$$Duration\ of\ Fire\ Flow\ (hrs) = \frac{fire\ flow}{1{,}000} \tag{5}$$

The required storage capacity for fire flow is calculated as follows:

$$\text{Capacity (GAL)} = \text{Fire flow} \times \text{Duration} \tag{6}$$

In addition to storage capacities, emergency capacities and operating capacities are calculated. The emergency capacities of 30 percent are added to the needed distribution storage capacity (the California State University, 2004). The existing capacities are reported (percent) for each consolidation scenario.

3.2.3.3 Water Rights

The decadal demand forecasts for the planning horizon are compared to the existing water rights and the potential reallocation rights. The exiting allocated water rights and reallocation potential are obtained from state water resources agencies. Acquiring additional water rights can take several years, depending on the ownership of the water source. All the U.S. Army Corps lakes require re-allocation studies if reallocation from other intended uses are desired (e.g., from navigation to water supply) which require a lengthy and expensive feasibility study. Also, the application of additional water permits from the state regulatory agencies (Oklahoma Water Resources Board) can be a lengthy process and always needs a solid justification for additional water permits. The different types of permits depend on the state laws and the existing regulations. In Oklahoma, water rights are allocated in seven year increments based on the needs assessment. If a system uses its total allocated water volume during the 7-year period, it must use the maximum allocated volume again within the next 7-year period (OWRB, 1989). If during the 7-year period the system does not use its entire allocated water right, the system could face a potential reduction of the allocated water volume. A CWS should maintain water rights equal to, or in excess of, it's projected average daily usage.

3.2.4 Economic Evaluation

After having arrived at the demand forecasts and needs analysis, the final task in the Solutions Analysis module is to calculate the costs associated with each consolidation scenario. The selection of the least-cost alternative in economic terms from the technically feasible options promotes production efficiency and ensures the most economically optimum choice.

In order to assess alternative scenarios on a comparable basis, the cost implications of each scenario on a decadal basis over time are calculated. The different consolidation scenarios will yield different service capacities; therefore the decadal costs per scenario are divided into costs per service (cost per MGD) for each given decade during the planning period. The preliminary construction cost estimates are typically based on historic data from other treatment plant constructions in various locations and times. The historic cost data need to be adjusted using appropriate cost indices.

3.2.4.1 Present Value

Present value is the current worth of a future sum of money or stream of cash flows given a specified rate of return. Future cash flows are discounted at the discount rate, and the higher the discount rate, the lower the present value of the future cash flows. The equation to discount the present value is calculated as follows:

$$PV = \frac{FV}{(1+r)^n} \tag{7}$$

Where:
PV = present value
FV= future value of money spent in the future
r = discount rate
n = number of years until money is spent

3.2.4.2 Inflation

Inflation is measured by the Bureau of Labor Statistics in the United States using the Consumer Price Index. The specific rate of inflation is calculated as follows (Bureau of Labor Statistics, 2010):

$$((B - A)/A) * 100 \tag{8}$$

Where:

A = year X Consumer Price Index (CPI)
B = year Y CPI

The use of the current average inflation rate as a fixed single inflation rate for future cost calculations is assumed in this dissertation. The other alternative would be to use constant cost dollars which is a common practice in benefit-cost calculations in e.g., transportation projects (Zerbe, Jr., R. O., and D. D. Dively, 1994).

3.2.4.1 Construction Cost

The different construction costs are generated by the needs to expand the existing water treatment plants to meet the forecasted demands in each consolidation scenario as well as to construct additional storage capacity.

The water treatment plant cost components are developed for water treatment of different sizes by construction using cost curves in Integrated Design and Operation of Water Treatment Facilities (Kawamura, 2000) and the Handbook of Public Water Systems (1986). The curves are particularly useful in the preliminary evaluation of general costs levels of proposed projects. The basis for the cost curves were developed by the EPA in Estimating Water Treatment Costs (EPA, 2003b). Preliminary cost estimates are budget estimates and their expected accuracy is approximately +30 percent to -15 percent. The cost estimates include the capital costs necessary to install the systems

The EPA developed water treatment project construction curves generating costs per water treatment process (EPA, 1978; 1986). These construction cost curves were developed using equipment cost data supplied by manufacturers, cost data from actual water treatment plant construction, unit takeoffs from actual and conceptual water treatment plant designs, and published data. The EPA construction cost curves were derived from eight construction components: 1) excavation and site work; 2) manufactured equipment (pumps, process equipment); 3) concrete; 4) steel; 5) labor; 6) pipes and valves; 7) electrical equipment and instrumentation; and 8) housing (slab, foundation, heat and air).

The 1978 EPA costs were used as the basis in Handbook of Public Water Systems (1986). In this dissertation, these costs are used and updated using an appropriate construction cost index. This cost is further adjusted for construction cost (considering an additional 35% of treatment plant cost) to get the total construction cost of the plant. This value is further adjusted for administration, legal and engineering fees (considering an additional 35% of total construction cost) to get the total project cost. This makes total project adjustment 70% over the subtotal of the eight construction categories.

3.2.4.2 Use of Indices

Indices are used for adjusting costs between geographic locations and time periods. An index is calculated value that is a function of an established quantity of material and labor. The index number varies with geographical location and time. The index number encapsulates the trend with time and place to place. The costs have been indexed by using a Means Historical Cost Index as printed in the Engineering News-Record (ENR).

The Construction Cost Index (CCI) was created in 1921. The ENR built the index using 200 hours of common labor at the 20-city average of common labor rates, plus 25 cwt of standard structural steel shapes at the mill price prior to 1996 and the fabricated 20-city price from 1996, plus 1.128 tons of Portland cement at the 20-city price, plus 1,088 board ft of 2 x 4 lumber at the 20-city price.

The costs are indexed using the following equation:

$$Upated\ Cost = historical\ cost \times (\frac{present\ CCI}{historical\ CCI}) \tag{9}$$

The EPA construction costs curves for water treatment were developed in 1978. The CCI value for 1978 (October) in the EPA's Estimating Water Treatment Costs Manual is reported 265.38. That value differs from the CCI listed in the

ENR which is listed in the ENR construction cost index history for 1978 is 2776. The value given in the EPA manual of 265.38 is a 1967 base-year value. The current method of reporting CCI uses a 1913 base year (CCI 1913 = 100) which is where the 2776 comes from. To convert from 1967 base year to 1913 base year, the following formula is used:

$$\frac{CCI\ (1967)_{1978}}{CCI\ (1967)_{present\ year}} = \frac{CCI\ (1913)_{1978}}{CCI\ (1913)_{present\ year}} \tag{10}$$

Accurately developed equations can enhance the cost estimating process. Preliminary estimates have approximately 20 percent reliability; study estimates have lesser reliability, approximately 30 percent reliability (AACE, 1997).

3.2.4.3. Operations and Maintenance Costs

The principle cost components of operation and maintenance (O&M) activities are labor, materials, chemical, repairs, and energy for both processes and enclosures. The task of developing O&M cost data are accomplished by using the O&M cost curves for water treatment. Kawamura's O&M cost estimates are shown in Table 7. The basis for Kawamura's O&M costs is the EPA 1978 O&M costs for municipal water treatment (EPA, 1979).

Table 7
Typical O&M Costs 22 MGD Treatment Plant (Kawamura, 2000)

Component	Cost per MG Treated	$ Cost per 1,000 Gallons year basis 1979 EPA
Power Costs	80.00	0.08
UV/Power/Patent Costs	30.00	0.03
Solids Handling and Disposal	25.00	0.03
Labor Costs	160.00	0.16
Chemicals	50.00	0.05
Supplies	15.00	0.02
WTP Capital Improvements	25.00	0.03
Repairs	15.00	0.02
Total O&M	400	0.40

In accordance with cost estimation curves and validation with the operators of water treatment plants in the region, the economies of size is reflected in the cost of MG treated indicating the larger facilities can produce water at lower costs per MG treated. Based on a personal conversation with a Professional Engineer, Mr. Thomas Mansur, Table 8 shows average O&M cost estimates per plant size from CWSs in Northeastern Oklahoma in 2005 (Mansur, 2006).

Table 8
Typical O&M Costs in Northeastern Oklahoma

Treatment Plant Capacity (MGD)	O&M per 1,000 Gallons Water Treated 2005
2.1	1.50
3.0	1.35
6.2	1.00
9.3	0.80
10	0.78
20	0.48
22	0.44
24	0.40
25	0.39
30	0.35
39	0.34

Maintenance and material requirements do not include chemicals, nor testing or sampling. The O&M costs are assumed to be affected by inflation over time, increasing the nominal values of future operating expenses above the value of the base year.

IV. PLANNING SUPPORT SYSTEM APPLICATION

4.1 Problem Analysis

The tasks in Problem Analysis Stage include identifying the geographical characteristics of a larger study setting and a critical community. As discussed in the Chapter 3 (methodology), the community characteristics contribute to the problems of water resources.

This section will aim to accomplish the following tasks:

1- Selection of larger study setting based on the urbanized area and exurban characteristics: Northeast Oklahoma.
2- Identification of study community based on critical community screens: city of Owasso.
3- Identification of water supply root causes based on symptoms. The identification, justification and analysis of the symptoms stemming from the root causes.

Using the characteristics and criteria for the larger study setting and critical community, the Current Reality Tree (CRT) is constructed based on the principles and theories as outlined in Chapter 3.

4.1.1 Larger Study Setting

The characterizing the larger study setting has a dual purpose: 1) identification of the exurban community and 2) identification of critical communities. The large study area characteristics are listed in Table 4 in Chapter 3. These attributes were mapped to identify the lager study.

The larger geographical focus area of the Tulsa Metropolitan Area in Northeastern Oklahoma is identified based the urbanized and exurban area community characteristics. It is ranked as a metropolitan area based on its population size being the second largest metropolitan area and the highest ranking exurban community in Oklahoma. The closer examination of the area reveals that three adjacent counties to city of Tulsa are the fastest growing communities in Oklahoma (U.S. Census, 2010). These counties include Rogers, Washington, and Wagoner Counties. According to the National Brookings Report (2006) ranking of exurban communities, the Tulsa Metropolitan Area (MA) ranks 13th nationally with 16.9 percent of the total population being exurban and the Oklahoma City MA ranks 17th with 14.8 percent of total population being exurban. According to the 2006 report, Oklahoma ranks 16th nationally with 8.9 percent of the total population being exurban. There are six counties that contribute to the Tulsa MA ranking: Rogers, Wagoner, Okmulgee, Osage, Creek, and Pawnee.

The attributes that contribute to the community characteristics of “urbanized “areas (UA) and “exurban areas” are identified in the larger study setting. This is accomplished by mapping using ArcGIS (ArcMap 9.2 version of desktop GIS - Geographical Information Systems, ESRI proprietary). Mapping helps in characterizing the spatial elements of the growth areas. ArcMap is a mapping tool to map, visualize, and analyze data with geographical components. The Table 9 lists all the themes needed for the study area analysis.

Table 9
Census Variables

Census Variable	
Housing	**Population**
Total Housing Units (H1)	Total Population (P1)
Occupancy Status (H3)*	Urban and Rural (P5)
	Place of Work for workers 16 years and out of state and county level (P26)
	Travel Time to Work for workers 16 years and over (P31)*

*P1 contains travel time sub-categories in 5-minute increments, ranging from >5 minutes to 90 or more minutes, also worked at home is included. The 20-24 mins, 25-29 mins, 30-34 mins, and 35-39 mins sub-categories are used to demonstrate the exurban characteristics of commute time to work patterns.
*H3 is used in IWR-MAIN modeling to include only occupied housing.

In both urbanized and exurban areas characterization, the census block groups (BG) are used as the geography. The census BG data is the second highest resolution dataset for the census. BGs are clusters of census blocks containing from 600-3,000 people. Each BG is a separate polygon. The BGs are derived from the U.S. Census Bureau’s TIGER/Line vector data files (Topologically Integrated Geographic Encoding and Referencing). The TIGER/Line files are a digital database of geographic features and census statistical boundaries covering the entire United States.

ArcMap cannot open TIGER/Line files, thus they were converted into GIS-readable format by using open access TGR2SHP Version 7.01 (Ralston, 2009). The computer program makes Tiger files handling effortless and free. Instead of including hundreds of datasets/themes per geographical location, the user can narrow down the themes needed in the study area. The user selects the needed input data files from Census Tiger/Line web site (Ralston, 2009). Each data file is numerically coded per Census coding system. TIGER maps come in zipped format; each file represents a unique single county in a single state, with the numbers rising in alphabetical order. State of Oklahoma, Rogers, Washington, Wagoner, and Tulsa counties are selected. The TGR2SHP software allows the user to choose which version of the TIGER data the software needs to process. TIGER data is updated on a yearly basis. The 2006 Census information was used. In this dissertation, the most recent data available is used from the Census website. Thus TIGER 2006 data in 1st and 2nd Editions processing is used. The software also gives an option which themes to choose for conversion per geographical area. This process eliminates the inclusion of thousands of unneeded themes.

The BG shapefiles do not contain any census enumeration data. Again, the use of the online cost-free open source software to link demographics and housing data with BG data is useful. The SF1toTable converter is used for extracting attribute tables from Census 2000 files. This program converts SFs into .dbf format files that can be joined with ESRI BG shapefiles and thus the feature attribute data can be mapped in ArcGIS.

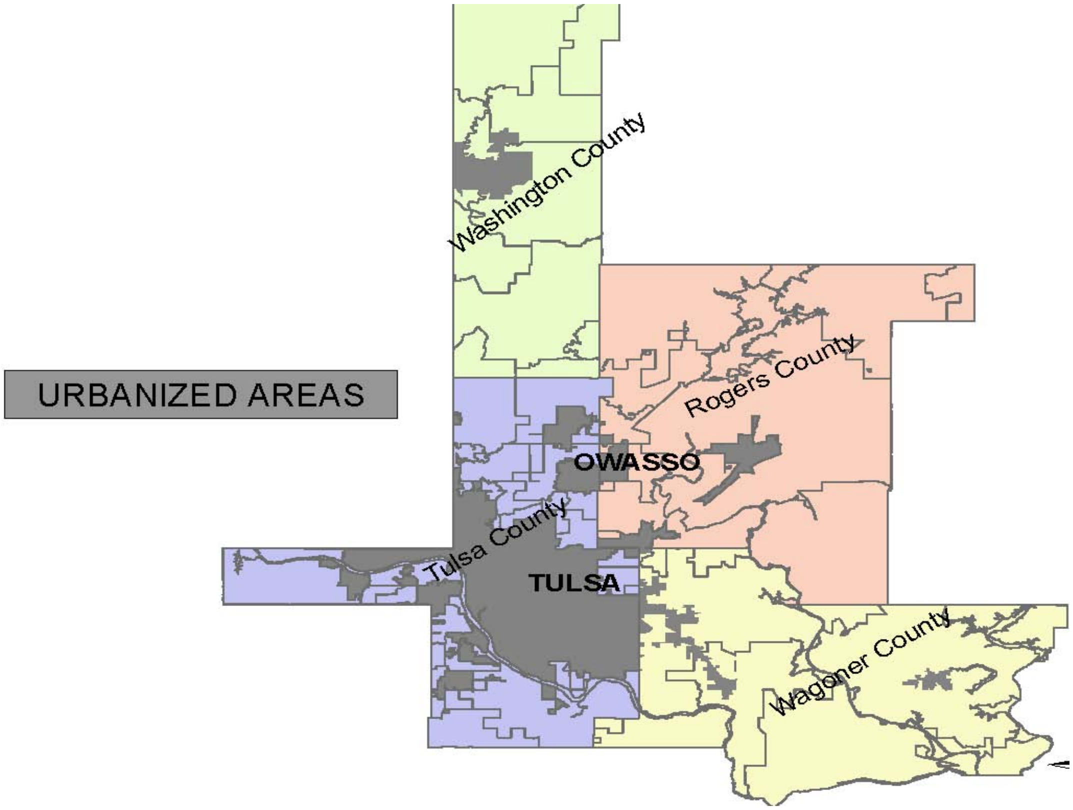
The SF1 contains BGs in its geographical coverage (U.S. Census Bureau, 2000). The SF1 files contain a wealth of information (813 tables containing over 16,500 variables). Extracting a particular table or tables for specific summary levels and population groups can be a laborious task. The use of SF1to Table aids in limiting the amount of themes needed. The converted SF1toTable files are .dbf file formats and these are joined with the matching shapefiles of BGs in ArcMap.

By doing this, each BG of the study area receives unique themes that are used in analyzing the characteristics of the study area.

Urbanized Areas

Mapping of urbanized areas give a partial picture of the population and land-use characteristics of the area. Traditionally, the degree of urbanized land can be obtained by mapping the U.S. Census urban clusters and urbanized areas attributes per county. These simply indicate the largest population concentrations. Urban land, as defined by the U.S. Census Bureau, includes all block groups or blocks that have a population density of at least 1,000 people per square mile that are surrounded by census block groups with at least 500 people per square mile (U.S. Census Bureau, 2000). Figure 4 depicts the urban clusters and urbanized areas in the four county areas (Washington, Tulsa, Wagoner, and Rogers).

Figure 4
Urbanized Areas in Study Area

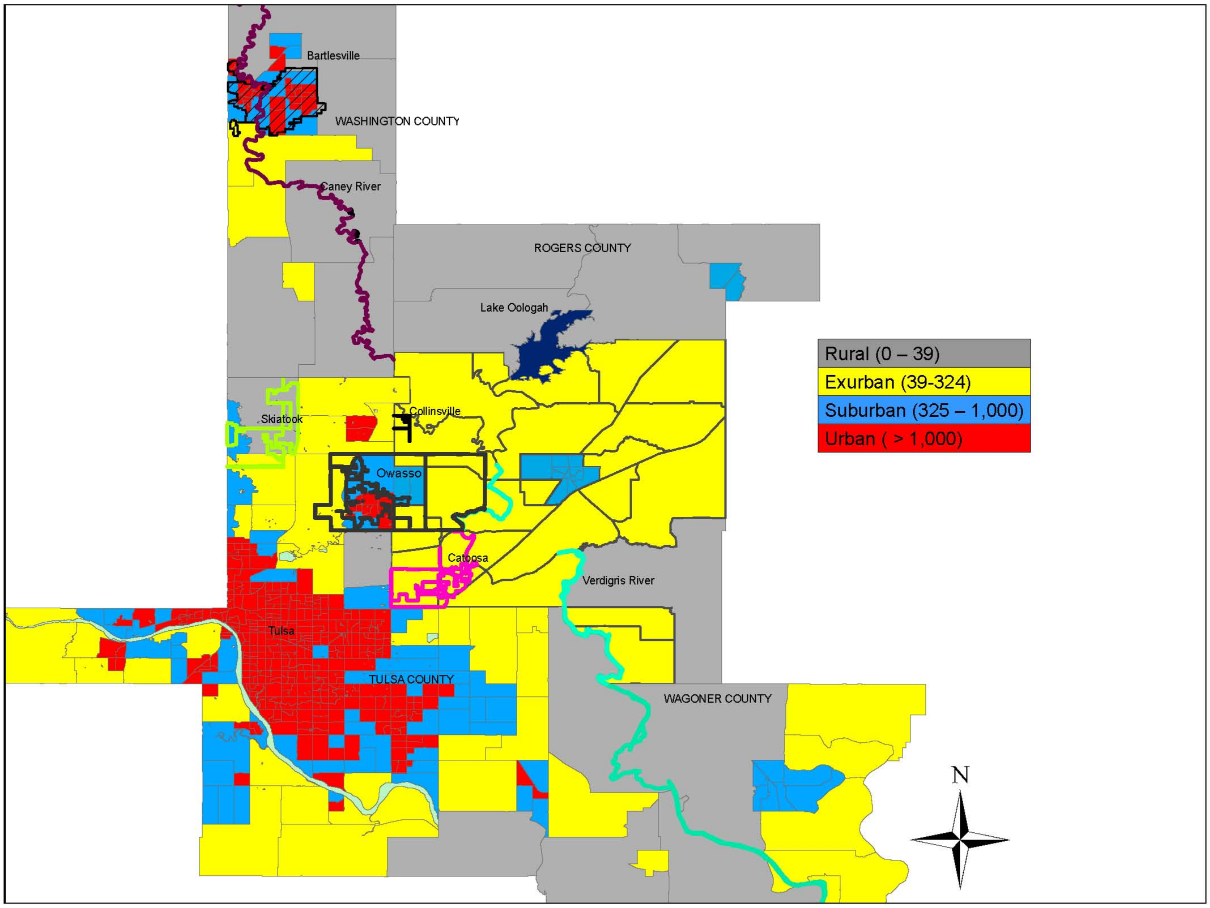


The urban area provides information about the population densities surrounding city of Tulsa. The UAs around the city do not capture the changing nature of larger study area; the urban fringe. Researchers have used other data than high residential density urban population clusters to define as what counts as urban land development (Irwin, et al., 2005). This is an important aspect in water resources planning of urban fringe areas. Depending of the characteristics of the urban fringe whether suburban or exurban, the growth and development occur differently. Exurbia, although growing rapidly per land conversion from rural to urban, may not be characterized as high-density urban areas, at least not yet, and thus may be overlooked in land development analysis and future water resources planning.

Using a similar methodology used in the Urban Exchange Program of the Department of Agricultural, Environmental, and Development Economics of Ohio State University, the U.S. Census block groups in the larger study area are classified into suburban, exurban, and rural areas based on their population densities per square mile. This demonstrates and verifies quantitatively the existing exurban and suburban areas in the study area based on the chosen classification.

Jill K.B. Clark et al. (2005) classified exurbia by settlement types per total population: high (>1,000), medium (100-1,000), low-emerging (10-100), and very low (0-10). Using the 2006 U.S. Census data, the block group densities are in the larger study area. The classes are divided into classes by population per area (square miles). These include: 1) rural areas (<40), 2) exurban areas (40-324), 3) suburban areas (325-1,000), and 4) urban areas (>1,000). The block group population densities and classifications are depicted in Figure 5.

Figure 5
Urban, Exurban, Suburban, and Rural Areas



The importance of the focus on the communities surrounding a large metropolitan area is quantified by its relatively rapid growth and a change in their community profiles transformation from rural to exurban. The mapping based on the population densities per block group, demonstrates that rural areas are the furthest away from the urban areas, where as the exurban areas (yellow) of NE OK are not only extensions of suburbia, but border urban (red) and suburban (blue) areas. Although these areas have relatively low population densities now, they are expected to grow in the future and therefore should be factored in the water resources planning.

Population densities are one way of characterizing the larger study setting. Contrary to micropolitans that are self-contained cities or towns with industrial or commercial base that offers employment to the residents, exurban communities are characterized by travel times to work and commute outside of their home county for work (“super-commuters”) (Clark, 2006). At least 20 percent of exurbanites travel to jobs in the urban or suburban core, roughly half work outside of their home county and exhibit a relatively high population growth.

Parts of the NE OK counties closest to the Tulsa County, currently act as bed-room communities to a larger metropolitan area. Therefore, the communities act as suburbs at the surrounding fringes of the metropolitan areas and therefore; are called as exurbs. 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/population density, and have relatively high population growth.

Growth

According to the 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. Also, the highest exurban population is in Rogers County. The population in those parts Rogers County that are closest to urbanized areas is projected to increase by more than 50 percent between 2007 and 2030 (2.2% per year). Rogers County in Northeastern Oklahoma is mostly considered rural per land-use characteristics; however the county has urbanized clusters and urban areas.

These urbanized areas in Rogers County are located in the Southwestern part of the county close to the Tulsa County border. These areas can be considered as considered as urban fringe areas.

The second fastest growing county in Oklahoma was Wagoner county where population increased by almost ten percent between 2000 and 2005. Throughout the 1970s, 1980s and 1990s, all of Tulsa County was experiencing an average of one percent annual population growth. 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 diminished population growth rates in parts of the Tulsa County and city of Tulsa when compared to the adjacent counties and non-metropolitan cities within the Tulsa County, indicate that “bedroom” communities have been more attractive as well as more available for development purposes.

Commute: Time and Place

To further demonstrate the community characteristics and exurban characteristics of the Northeast Oklahoma, two types of population characteristics are looked at: 1) travel time to work (minutes) in BGs adjacent to the city of Tulsa and 2) place of work and place of residence (inside county/outside county) to demonstrate whether the travel times from the adjacent BGs in different counties are outside of the county of the employee’s place of residence. These were mapped with ArcGIS using the U.S. Census BG data (Figures 6-13).

The travel times to work are classified to four different sub-classes: 20-24 minutes, 25-29 minutes, 30-34 minutes, and 35-39 minutes. The typical commute times to work to one direction in exurban areas are 20-29 minutes (Clark, 2009). The assumption is that the BGs adjacent to the Tulsa MSA have travel times to work between 20-29 minutes. Travel times to work less than the smallest class of 20-24 minutes were looked at but deemed useable for this analysis because the travel times less 20 minutes were not a major class in the BGs in this analysis.

In northern Tulsa County BGs in Figure 6, the most prevalent travel time to work is 20-24 minutes (green slices in the pie-chart). The major area of employment from these BGs is within 20-24 minute travel time (city of Tulsa area). In the BGs adjacent to the city of Tulsa in Rogers County, the travel time to work is 20-24 minutes. The central Rogers County BGs (Figure 7) travel times to work are split between 20-24 minutes and 30-34 minutes, indicating different travel directions based on two major places of employment in the region: Claremore in Rogers County (20-24 min.) and the city of Tulsa (30-34 min.). There are no other major employment areas within those travel times from these BGs. The BGs of Washington County (Figure 8) adjacent to the Tulsa MSA, the travel times to work increase when compared to BGs of Rogers and North Tulsa Counties. In the BGs adjacent to the city of Tulsa in Washington County, the most prevalent travel time to work class is 30-34 minutes (blue in the pie-chart). The BGs in Washington County that are further away from the city of Tulsa, the travel times actually diminish, indicating the major place of employment in the city of

Bartlesville in Washington County instead of city of Tulsa. The BGs closest to Tulsa County line in Wagoner County have split travel times to work: 20-24 minutes and 30-34 minutes (Figure 9). These are green and blue areas in the pie-chart.

The commute times to work characteristics of the BGs adjacent to city of Tulsa support the exurban nature of the urban fringe area. The BGs that had travel times to work greater than 29 minutes but less than 35 minutes are commuter communities with mixed rural and exurban characteristics.

In order to further validate the above analysis of the travel times to work, the places of residence and places of work were mapped. This information validates the theory of exurban community characteristics that at least 20 percent of the total population travels to a major urban center for work. Since the area in question is conveniently located in a four-county intersection, the county level BG data were used. The patterns were classified per place of residence-county and place of work-county. This analysis is useful in this particular study area because its location in the four county corners. The assumption is that the place of work is outside of the residence county in the BGs located outside of the Tulsa County but the closest to city of Tulsa. The purple slices of the pie-chart represent workers who do not work in a same county than they reside.

The majority of the workers in the northern Tulsa County appears to reside and works in the same county (Figure 10). This reinforces the theory that suburban/exurban workers commute to Tulsa County and the urban city area to work. The majority of residents in the Rogers County BGs bordering the Tulsa County commute to work in another county (Figure 11). This phenomenon is also apparent in Washington and Wagoner counties (Figures 12-13). The workers in Washington County BGs that are further away from the Tulsa County line work within the county of residence indicating a place of employment/urban center within the Washington County (city of Bartlesville) (Figure 12). The same phenomenon exists in Wagoner County also (Figure 13). However, in Washington County the total number of people working outside of the place of county residence is greater than in Wagoner County.

Figure 6
Travel Time to Work – North Tulsa County

Figure 4-5
TRAVEL TIME TO WORK –
NORTH TULSA COUNTY

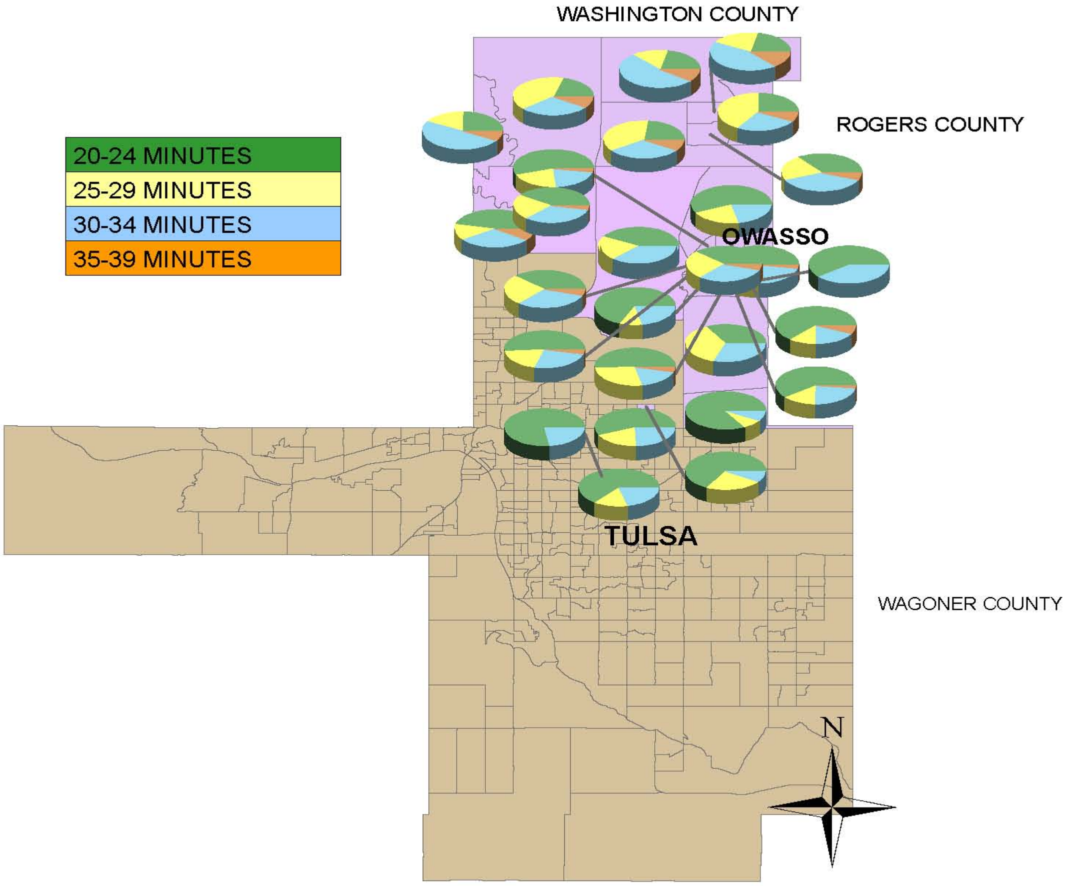


Figure 7
Travel Time to Work – Rogers County

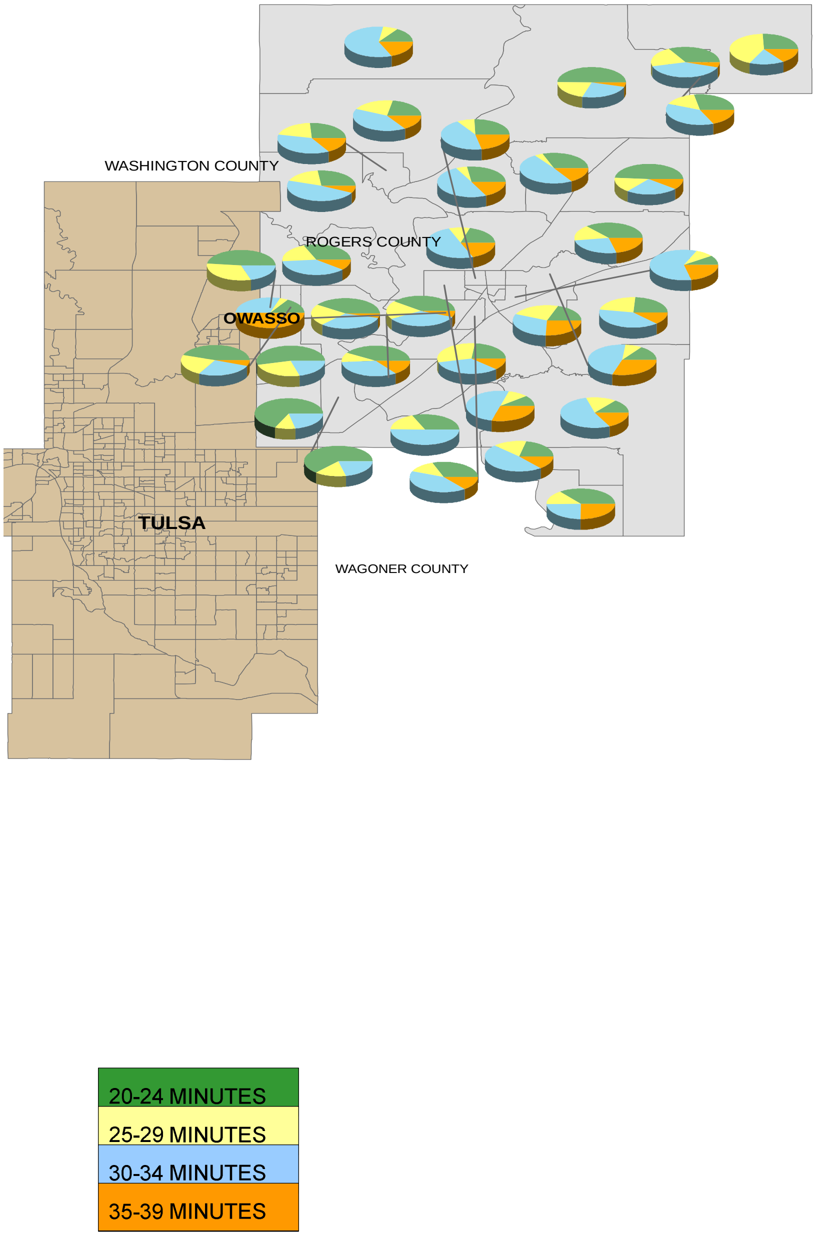


Figure 8
Travel Time to Work – Washington County

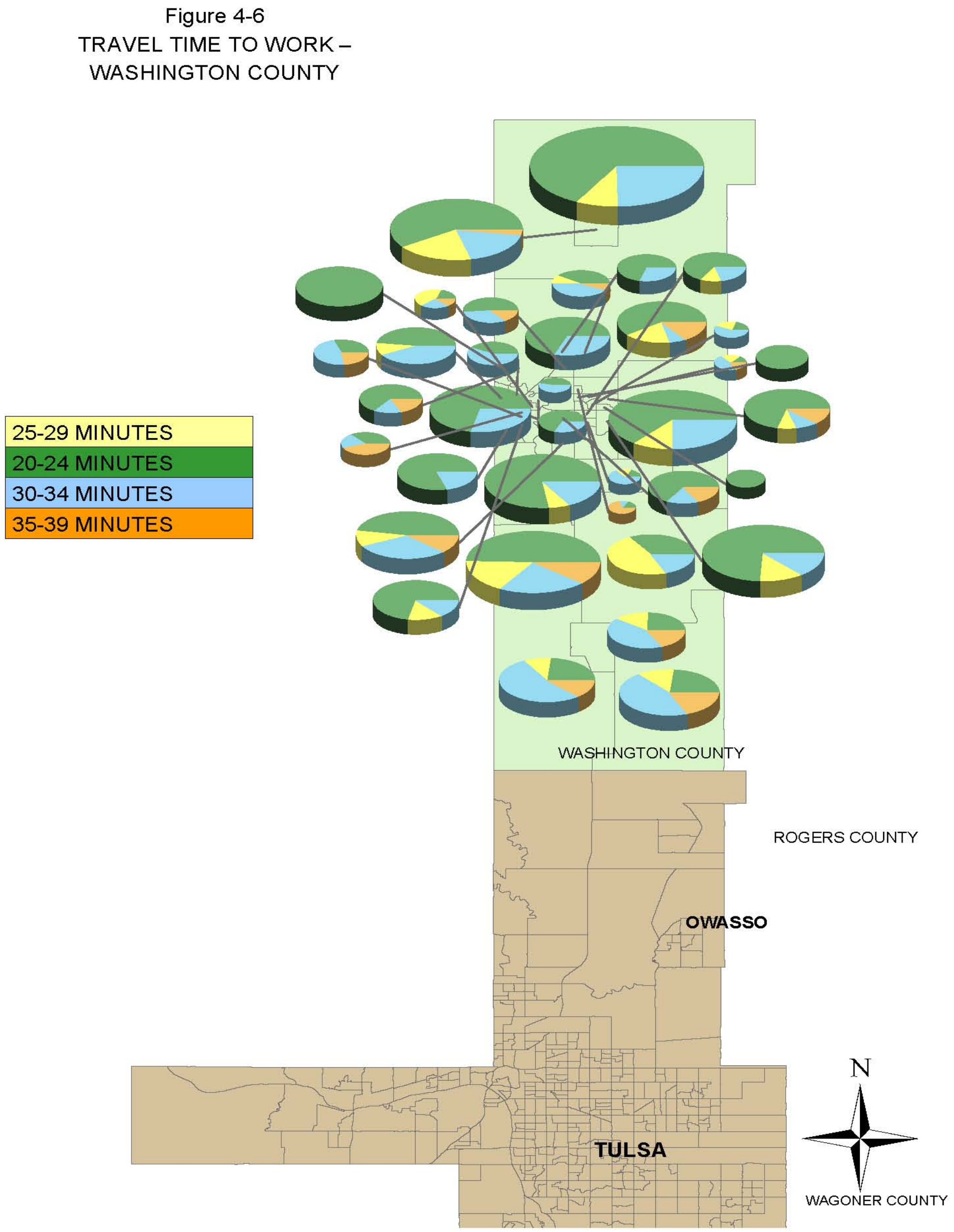


Figure 9
Travel Time to Work – Wagoner County

Figure 4-7
TRAVEL TIME TO WORK –
WAGONER COUNTY

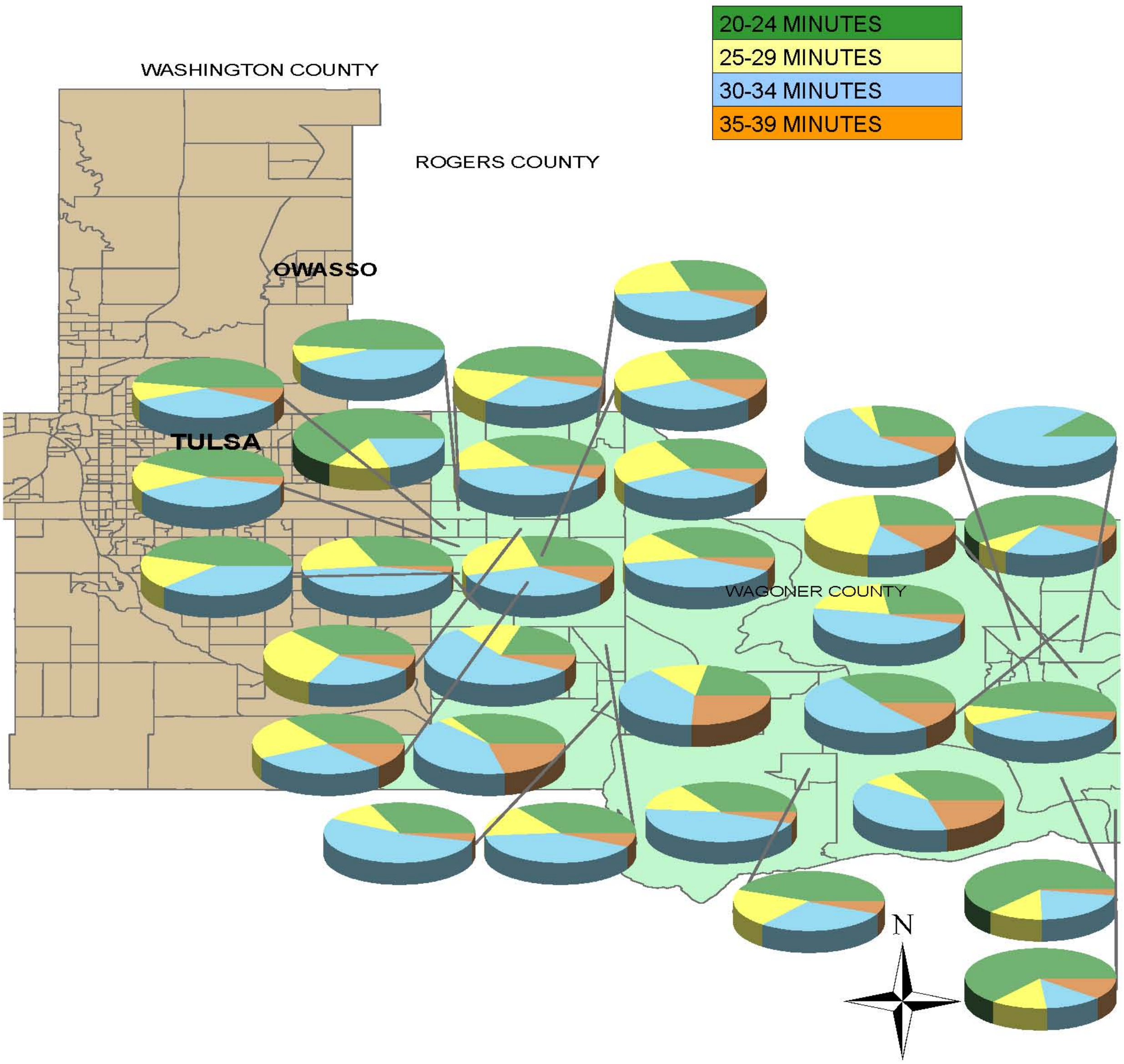
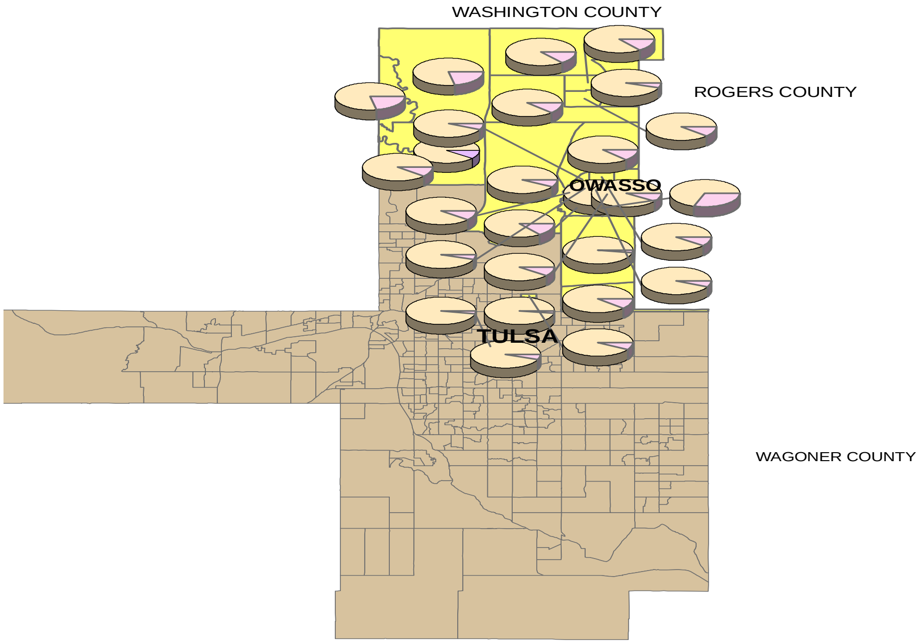
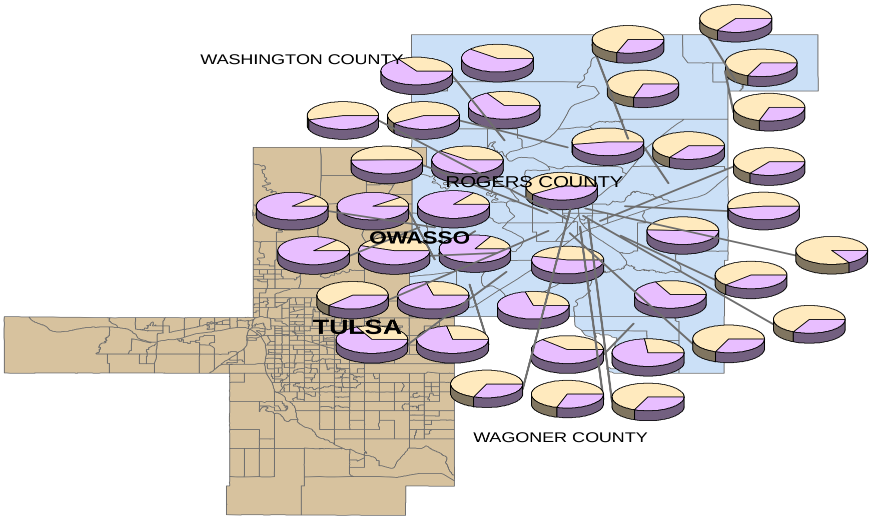


Figure 10
Place of Work - Place of Residence North Tulsa County



🟪	OUTSIDE
🟧	INSIDE

Figure 11
Place of Work – Place of Residence Rogers County



OUTSIDE

INSIDE

Figure 12
Place of Work – Place of Residence Washington County

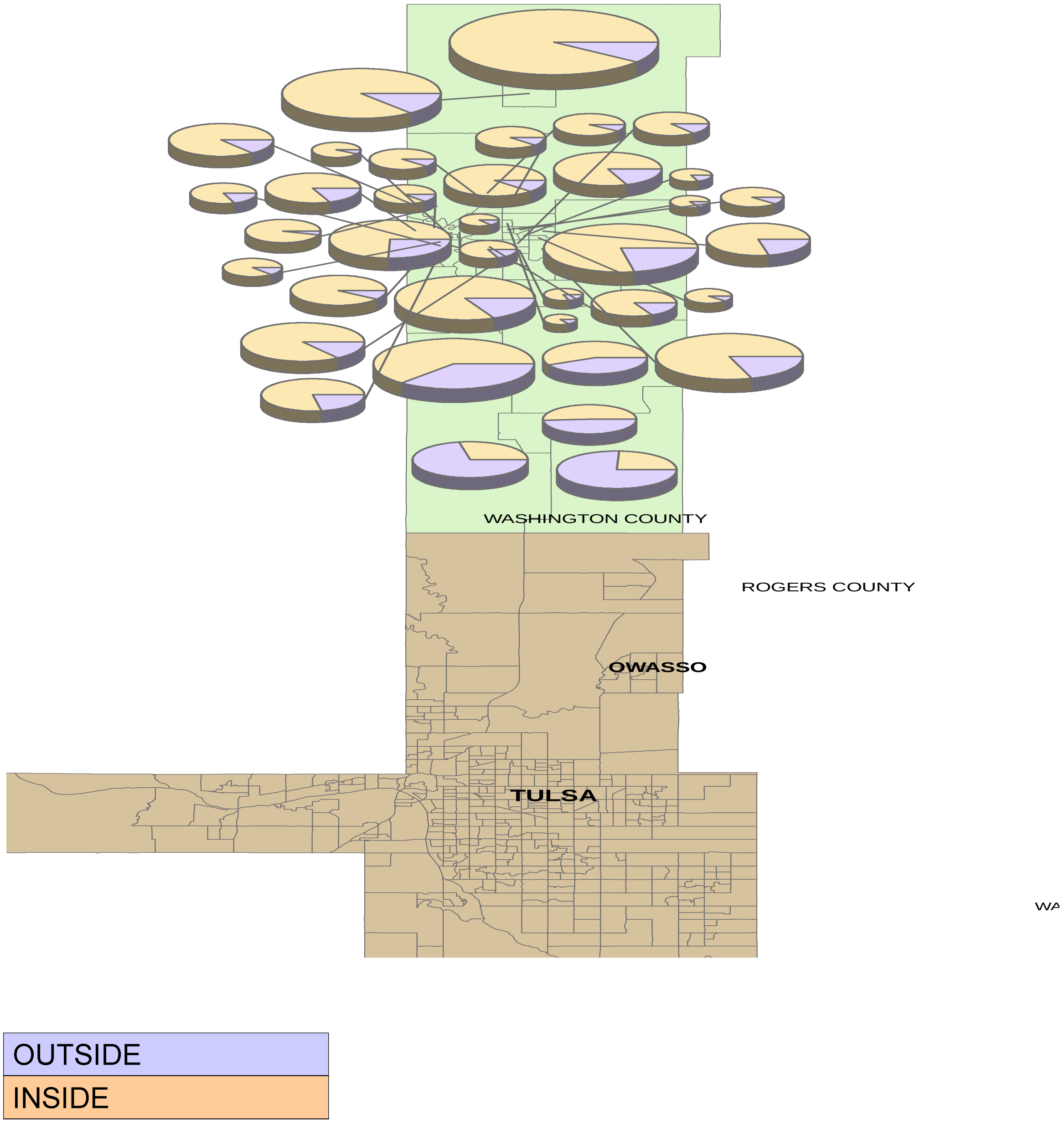
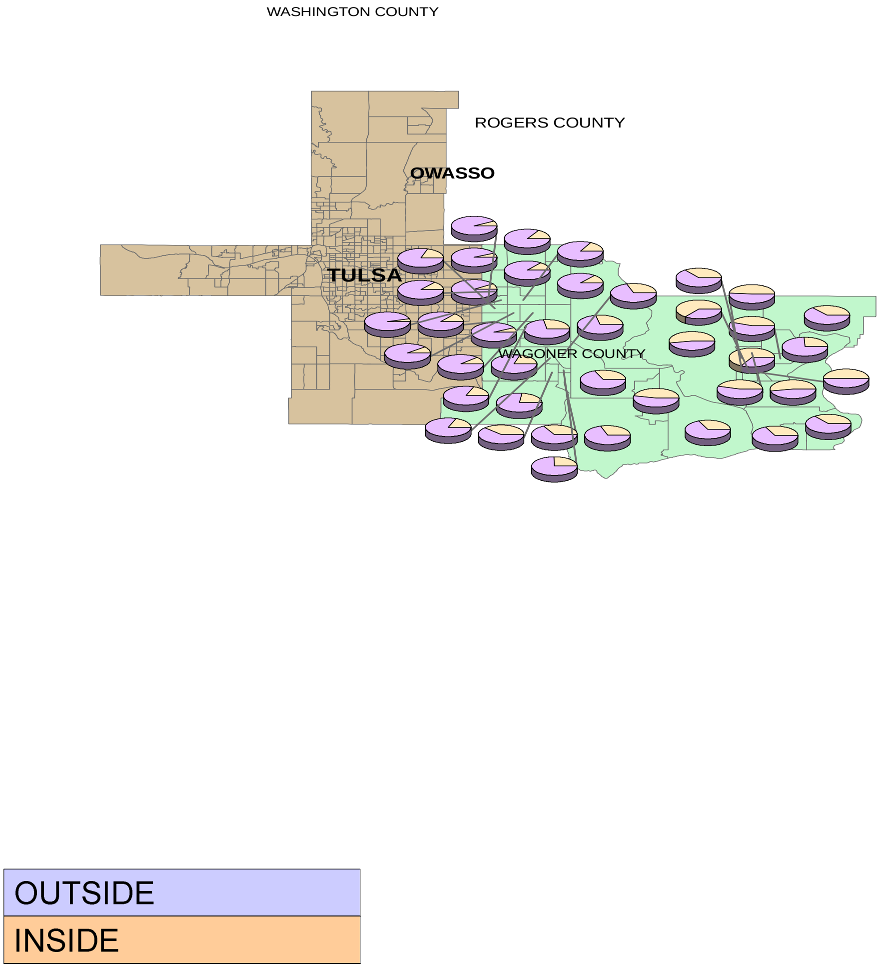


Figure 13
Place of Work – Place of Residence Wagoner County



Based on the interpretation of the characteristics as depicted in Figures 6-13, the study area manifests the typical characteristics of exurbia located in the fringe areas of a major urban area. The travel times to work data demonstrate that most workers commute at minimum of 20 minutes but not beyond 34 minutes in the area BGs. The further analysis of place of work county versus place of residence county help to confirm the exurban characteristic of the larger study area: the place of residence does not provide employment (no near-by center business district) and the need to travel to a close-by larger metropolitan center. The close proximity of the BGs of Washington, Wagoner, and Rogers Counties to Tulsa County makes it feasible for workers from these counties to commute from their place of residence (other than Tulsa County) to city of Tulsa to work and yet to enjoy the surrounding bedroom communities for their residence. For water resources planning, this implies the communities are mainly residential with limited commercial and industrial demands for water.

The study area has a significant cross commuting by residents of the region's counties (Wadley Donovan Group, 2002). Tulsa County is the principal work site for the residents of five of the region's counties: Creek (56 percent), Osage (56.8 percent), Pawnee (59.6 percent), Rogers (95 percent), and Wagoner (71.7 percent). The study area can be categorized as exurbia based on its geographical location to a larger city (Tulsa), relatively high growth rate and the high percentage of population commuting to work with at least 20-minute commute times to work each direction and thus, its reliance on employment opportunities within the surrounding communities. Rogers County has the largest exurban population of 69 percent of the total population with a 13 percent increase within the five-year period from 2000-2005.

The characterization of the larger study setting provides information about the future growth potential of the area and this in turn will have an important impact on long-term water resources planning. The historical growth pattern and the likely future growth patterns are from a large city to suburb to exurb to rural areas. This trend has already happened in the area and can be confirmed by looking at historical growth patterns of residential growth from Tulsa city to outlying and surrounding suburbs of Bixby, Jenks, Broken Arrow and Owasso (primarily in Tulsa County) to Catoosa (Rogers County), Bartlesville (Washington County), and Collinsville and Claremore (Rogers County).

4.1.2 Critical Community

The characterizing the community has a dual purpose: 1) identification is to find a single critical community within the larger study setting and 2) the characteristics of the critical community are used in identifying the problem in CRT. The critical community characteristics are listed in Table 5 in Chapter 3. These attributes are used to identify the critical communities.

The critical community identification starts by identifying the fastest growing non-metropolitan cities within exurban and urbanized portions of the study area are identified. The largest contributors to the Tulsa MSA's population increases include non-metropolitan cities within the Tulsa County: Bixby, Broken Arrow, Jenks, and (parts) Owasso. Bixby has grown 55 percent since 2000, Broken

Arrow has grown 24 percent, and Jenks 63 percent. The highest non-metropolitan growth in Rogers County (adjacent to Tulsa County) has occurred in Owasso, Catoosa and Claremore. Owasso has experienced an average 6.9 percent annual population increase, Catoosa 3.6 percent, and Claremore 1.5 percent since 2000 (until mid-2008).

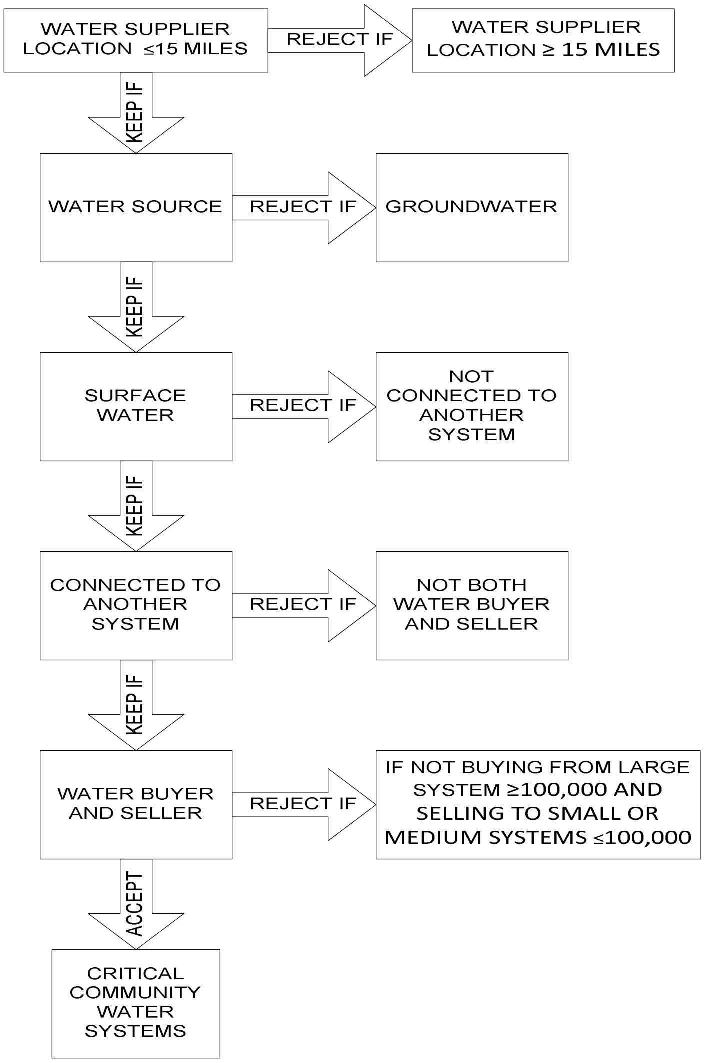
Each of the growing non-metropolitan areas water supply is further evaluated by using a schematic for screening as shown in Figure 14. The two major criteria include:

Criterion 1: surface water source. Majority of the NE OK public water supplies come from surface water. The national drinking water standards are the same regardless of the source but the infrastructure for groundwater production differs substantially from surface water production. Raw water make-up is different between groundwater and surface water. Water rights are allocated differently for groundwater. Adequate supplies of groundwater are generally unavailable in the area.

Criterion 2: water dependency. The critical community must be dependent on drinking water from a large CWS and a combination of small and medium size water systems.

Based on the above criteria of this dissertation and the study objective of finding a critical community to be served in the future by an independent single entity through consolidation, each of the fastest growing communities and their water service characteristics were evaluated for the following criteria: 1) surface water source; 2) must be interconnected to another system (i.e. purchase system or supplemental water); 3) water source must be supplied (wholesale, distribution) from a combination of water systems, one of which is a large metropolitan CWS system (≥100,000 served) and the other(s) is/are small or medium size CWS (≤100,000 served). Each of the growing non-metropolitan cities water supplies is further evaluated by using a schematic for screening as shown in Figure 14.

Figure 14
Water Supply Characteristics of Non-Metropolitan Community



Using the evaluative criteria in Figure 14, the initial set of six non-metropolitan communities in the urban fringe area of the City of Tulsa were screened for their existing water supply structures to identify single critical community for further evaluation. The six communities are all located in the urban fringe area and are the fastest non-metropolitan growing communities in Northeastern Oklahoma. The six communities were all screened for the existing water supply characteristics as shown in Figure 14.

The fastest growing non-metropolitan cities in the exurban and urbanized areas of Northeastern Oklahoma in Rogers, Wagoner and Tulsa Counties are identified and evaluated as shown in Table 10 using the selection criteria. The distance between each community was also recorded.

Table 10
Critical Community Selection

Water Supply Characteristics	Non-Metropolitan Cities NE OK					
	Owasso	**Catoosa**	**Claremore**	**Broken Arrow**	**Bixby**	**Jenks**
Surface Water	Y	Y	Y	Y	Y	Y
Purchased Water	Y	Y	N	Y	Y	Y
Water Rights & Treatment	N	N	Y	Y	N	N
Supplier #1 ≥100,000 served	Y (City of Tulsa)	Y (City of Tulsa)	n/a	Y (City of Tulsa)	Y (City of Tulsa)	Y (City of Tulsa)
Supplier #2 ≤ 10,000 served	Y (Washington RWD 3 and Rogers RWD 3)	N	n/a	Y (Wagoner RWD 4)	N	N
Community has own plant	N	N	Y	Y	Y	N
Population Growth %/yr*	6.9	3.6	1.5	3	6.9	7.9
Distance (miles)	Owasso-Catoosa 12	Catoosa-Claremore 12	Claremore-Broken Arrow 25	Broken Arrow – Bixby 15	Bixby Jenks 12	--
	Owasso-Claremore 20	Catoosa-Broken Arrow 18	Claremore-Bixby 40	Broken Arrow-Jenks 15	--	--
	Owasso-Broken Arrow 20	Catoosa-Bixby 25	Claremore-Jenks 36	--	--	--
	Owasso-Bixby 25	Catoosa-Jenks 25	--	--	--	--
	Owasso-Jenks 25	--	--	--	--	--
Keep for Analysis (Y/N)	Y	N	N	N	N	N

*2000 - mid-2008 growth.

Of the six communities screened, the City of Owasso Tulsa (part Rogers) County is screened to be the critical community based on the evaluative criteria.

Owasso does not have water rights and its drinking water is supplied by a combination of water systems (large and medium-small) and the CWSs serving Owasso both buy and sell water in the study area.

4.1.2.1 Owasso

Owasso is currently the second largest growing non-metropolitan city in Oklahoma in the fastest growing county (Rogers) in Oklahoma. Owasso is a primary municipality of concern in NE OK based on the lack water supplies and the rapid population growth. The central business district (CBD) of Owasso is located within 15 miles north of Tulsa. Owasso has grown more than 50 percent since 2000, adding 8,965 new residents. The 2009 total city limit population of Owasso was 35,708 (within the city's zip code area). The 2009 greater Owasso population is 42,000 (also school district). Figure 2 in Appendix A shows the 2004 Owasso and corporate city boundaries.

The City of Owasso was created more than thirty years ago with the understanding that properties within greater Owasso (areas not within city limits) would eventually be annexed into the incorporated city. This land-use planning feature of Owasso is the reason why Owasso’s historical growth pattern has occurred in concentric rings from the CBD outwards. From the water resources planning perspective, the greater Owasso is not included in Owasso’s current water service area. The corporate City limits are served solely by city of Tulsa. Outside of the corporate limits of the City are served by Rogers RWD and

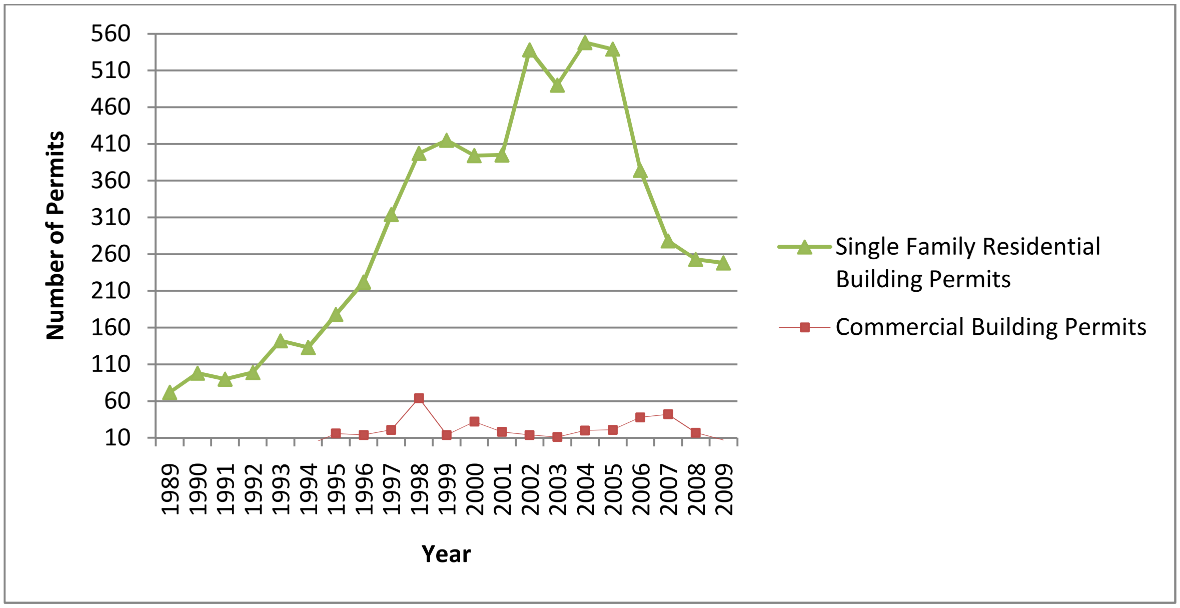
Washington RWD 3. The greater Owasso expands both west of the city (Tulsa County) and east (Rogers County).

The 2009 population density within the city limits is 13,202 people per square-mile and within the city limits there are little over 7,000 housing units at an average density of 700 per square mile. The city limit area of Owasso is 10 square miles. Owasso purchases water approximately for 21,000 people (9,150 connections) from Tulsa. Part of northern Owasso in Tulsa County is served by Washington County RWD 3. Parts of eastern Owasso (Tacora Hill) are served by Rogers County RWD 3. The dependency on three water supply systems to provide Owasso's future water has raised concerns among the city officials (Wiles, 2006, 2008).

A bulk of Owasso's unincorporated population lies within Roger County and the water for these areas is served by Rogers County RWD 3 and Washington County RWD 3. According to the 2000 Census population distribution, 9,398 of Owasso's population lived in Rogers County. The population during the same period in Tulsa County side of Owasso was 2,809. Using this population distribution, approximately 31 percent of the total Owasso population lives in Rogers County, 9 percent lives in rural Tulsa County, and remaining 60 percent live within incorporated areas in Tulsa County. Using the population trends and building permits of Owasso from 1970 to 1998 both the greater Owasso and city limit population have grown approximately the same rate. The county boundary is North 145th East Avenue. Only about one square mile of the city boundary is on Rogers County. Approximately 27 square miles of greater Owasso is in Rogers County.

Most of Owasso's residential, industrial, and commercial development is along the U.S. Highway 169. The northern part of the city includes pockets of residential areas surrounded by agricultural areas. Transportation improvement projects have accelerated the housing developments in Owasso since 1986 (historical building permit data 1986-2009). The building permit data shows that the residential growth begun to steadily increase within three years after the completion of Owasso Expressway. The highway improvement of the 1986 enabled faster access to employment centers in Tulsa. Similarly, widening of SH-20 has had similar effects, particularly in northern portions of Owasso. Since 2005 there has been a steady decrease in building permits for both residential and commercial buildings. The economists predict that the downward slump in the Owasso's economy will result in reduction in construction (Evans, 2010). It is also predicted that in 2011 this area is likely to gain economic strength again (Evans, 2010). Both the commercial and single family residential building permits (1989-2009) are shown in Figure18.

Figure 15
Single Family Residential and Commercial Building Permits



Source: City of Owasso: 2010.

The residential profile of Owasso is primarily single-family residential dwellings. In 2009, approximately 2,370 multi-family residential units within five apartment complexes are located in Owasso. If these are all occupied that would include approximately 3,350 residents. Owasso uses 65 percent of its' developed land for single family residential purposes within the city limits. Within the greater Owasso area, nearly 83 percent of the developed land is used for single family residential purposes.

The future growth of Owasso boundaries will consists of rural and urban densities. The urban densities exist in Tulsa County area within city limits of Owasso. Table 9 shows the 2004 city's ratios of land-use by type to population.

Table 11
Land-Use Type (2004)

Land-Use Type	Area (ac)	Land-use ratio (ac/1,000 people)
Residential	2,666	158
Commercial/Office	370	13
Industrial	75	4.4
Parks	535	31.73
Public Access Areas	485	28.75

Source: City of Owasso Master Plan 2025

The current population distribution of Owasso includes sixty percent within city borders, nine percent outside the city borders in Tulsa County, and 31 percent in Rogers County outside the city borders. The residential growth according to the building permits has grown within the city and within the greater Owasso at the same rate.

During the first part of the 50-year planning horizon, it may be reasonable to assume that Owasso's growth will be largely shaped by three determinants. These include: 1) the development that occurs at four large commercial sites (96th and Garnett Road, southwest of intersection of 96th Street and 129th East Avenue, southwest of the interchange of 116th Street North and the Owasso Expressway, and southeast of the interchange of Highway 20 and the Owasso Expressway). 2) The ability to expand northwardly direction due to the inability to expand eastwardly direction. The eastern parts of Owasso (between 145th East Ave. and 161st East Ave) are assumed to remain in rural densities due to lack of sewer services (east of 161st East Avenue) and limits the area's ability to develop at urban densities. The area has exposed bedrock and hence it would be expensive to lay pipelines (water or sewer). 3) Southwardly development (from 76th Street North) is limited because of the South Creek 100-year floodplain (wetlands). Development on wetlands and floodplain requires regulatory decisions and determinations by the USACE.

The 2004 city limits, the 2025 Master Plan city limits and land-use categories are shown in Appendix A. The desired city limits in the first part of the planning horizon would add 2,842.86 acres of additional undeveloped land to Owasso. Sixty percent of Owasso's population currently lives within the city limits.

Part of Owasso in Tulsa County is outside the city borders. These areas include west of 97th East Avenue to Memorial Drive. This area lies is predominately in the 100-year FEMA flood area, hence considered not desirable for residential development. Approximately nine percent of greater Owasso's population lives in this area. Using city zoning codes, this will comprises of an approximately one square mile or 620 acres is suitable for residential development. This area includes a park and some industrial areas.

Thirty-one percent of Owasso's population resides in Rogers County. According to the zoning map, approximately 6 square miles (3,840 ac) are available. Based on the aerial imagery, approximately 1.94 square miles of that is available for residential (or other) development. That is 1,241.6 acres. It is assumed that the existing current agricultural lands will be converted to either residential or industrial/commercial developments in the future. The close proximity to major highways and the general location to other services make this type of development very likely.

In order to accommodate the maximum forecasted population growth during the second half of the 50-year planning horizon, eastwardly growth direction is considered during the second part of the planning horizon. The area expands east from 161st East Avenue to 241st East Avenue. Appendix A includes figure for the 2025 land-use map and zoning the development will likely expand toward east because the area is bordered in the south (66th St. North) and North (126th Street North). The estimated total available land for development in Owasso is approximately 11,830 acres by assessing the undeveloped land using the aerial imagery NAEP resolution (Google maps imagery of 2010).

All the growth would be concentrated in Rogers County that currently is served by Rogers County Rural Water District 3. If all this undeveloped land area were zoned as residential, this additional acreage will be able to accommodate Owasso's population forecasts.

4.1.3 Larger Study Area and Critical Community Output

In the above sections the larger study area was defined and the critical community within it is selected. The larger study area includes Northeastern Oklahoma adjacent to the City of Tulsa. This area is characterized as an exurban community. The City of Owasso was selected as the critical community based the screening criteria. The critical community characteristics are used for Owasso to define their water resources problem.

4.1.4 Current Reality Tree

The above sections have outlined the community characteristics of the larger study setting and the critical community within the study setting. The larger study area is identified as Northeastern Oklahoma adjacent to the City of Tulsa and the critical community is the City of Owasso. Using the community characteristics, the core problems, root causes, and the undesired effects; the symptoms are investigated. Using these community characteristics, as discussed in Chapter 3, the CRT is constructed in three steps. The CRT is a systematic approach of identifying the core problems, root causes, and the symptoms (undesired effects) of water resources planning. The identification of the core problems and root causes begins by working the CRT "backwards": identification of undesired effects, organizing the symptoms that stem from the root causes.

4.1.4.1 Construction of Current Reality Tree

Step 1: The various symptoms in the critical community include: 1) lack of long-term water resources planning; 2) a large CWS dominates water resources planning; 3) dependency on multiple water sources; 4) changing community characteristics (exurbanization); 5) population growth; 6) dependency on large CWS's water quality testing and sampling schedule (Stage 2 DBPR); 7) short-term water resources planning; 8) individual community water systems' infrastructure needs unpredictable; 9) increased water demands; and 10) uncertain future water supply availability. These are shown in Problem Identification Table 12.

Step 2: By rearranging the symptoms in Step 1; causes and effects are identified: “If ‘cause’ then ‘effect’”. The root causes are divided into larger driving forces; triggering events (more distal causes) and proximal causes; the key factors. These are shown in Table 12. The “effects”; the UDEs, are caused by the root causes. The core problem is the lack of long-term water resources planning. By removing the core problem the UDEs would not exist.

Table 12
Current Reality Tree

SYMPTOMS	UNDESIRED EFFECTS	Uncertain future supply availability
		Unsatisfied water demands
		Individual community water systems’ infrastructure needs unpredictable
		Short-term water resources planning**
		Increased cost of water
ROOT CAUSES	Larger Driving Forces (Triggering Events)	Population growth
		Unplanned growth: Exurbanization
		Consecutive systems’ water quality testing and sampling schedule (Stage 2 DBPR)
	Key Factors (Proximal Causes)	Dependency on multiple CWS + historical rural CWS presence*
		Tulsa water supply dominates community’s water resources planning
CORE PROBLEM		Lack of long-term planning

*neutral factor **feed-back loop.

Step 3: The final step in the Current Reality Tree (CRT) construction includes the organization of the CRT. The Larger Driving Forces, Key Factors, Neutral Factors, and Feed-Back Loops are organized. The definitions of these were explained in Chapter 3. The Neutral Factor, while of its self is not a root cause it is needed to sufficiently describe the current reality. In the City of Owasso, the Neutral Factor is the historical presence of rural water systems. The Neutral Factor is combined with the City of Owasso’s dependence on multiple types of

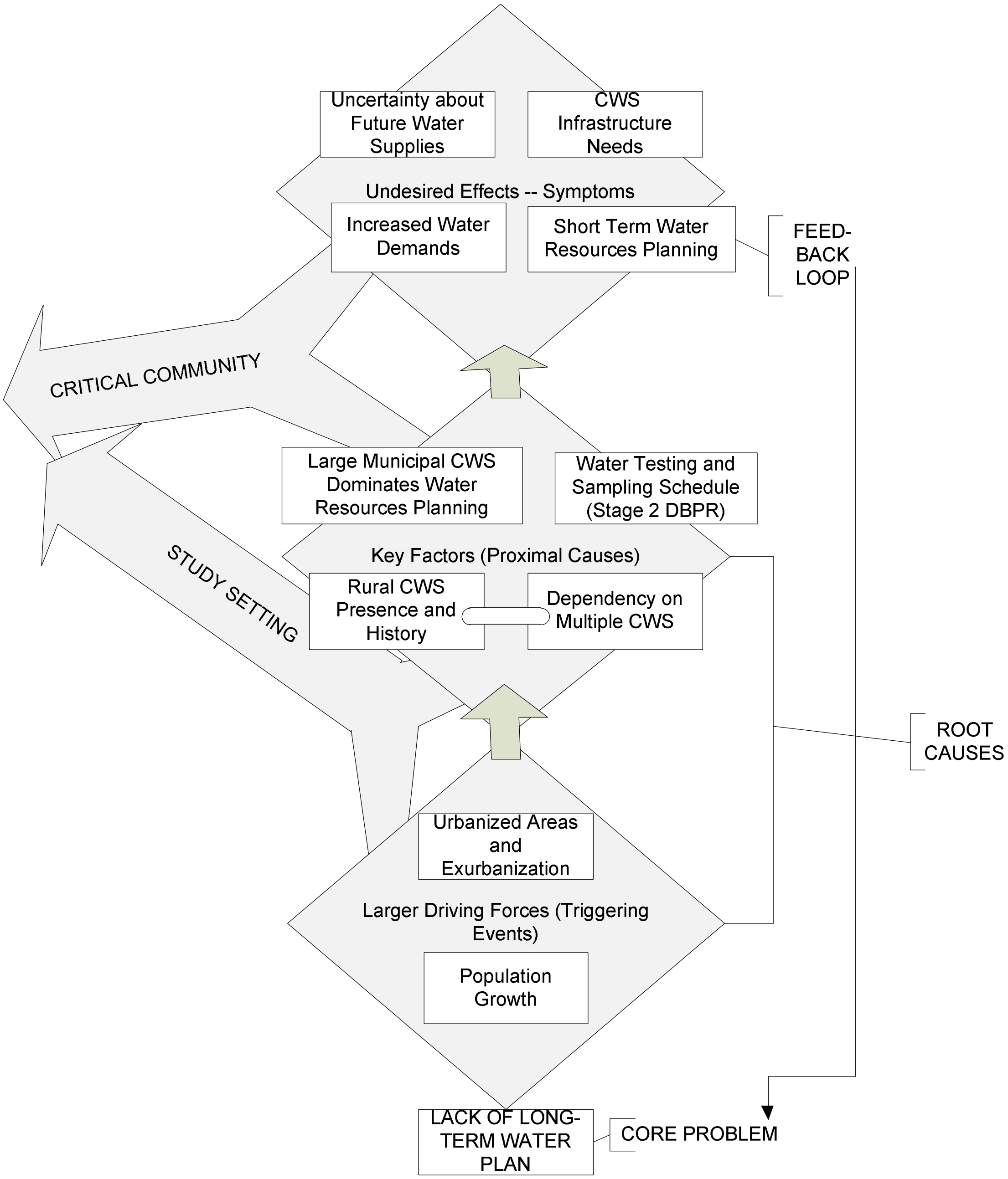
CWS for water supplies. This combination of the Neutral Effect with a root cause better explains the current reality of Owasso's water resource problem. The CRT includes a Feedback-Loop. This is the short-term water resources planning. The Feedback-Loop causes a vicious cycle in Owasso. This vicious cycle is fragmented short-term water planning in Owasso.

4.1.3 Current Reality Tree Output

The three steps of constructing the CRT revealed that the core problem of Owasso is "lack of long-term planning". This problem should be the target of any proposed solutions. The CRT with all the components considered of the cause and effects are shown in Figure 16. The City of Owasso's water resource problem is dominated by the community characteristics. From the Figure 16 the following conclusions can be drawn: because Owasso does not have a long-term water plan, then:

- unplanned residential subdivisions are built;
- population increases;
- reliance on purchased water: small/medium size CWS water and municipal water;
- small consecutive water systems must meet the sampling and testing with their largest water seller;
- increase residential water costs;
- uncertainty about water supplies.

Figure 16
Root Cause Analysis (CRT) for City of Owasso



4.2 Solution Analysis

Solution Analysis is the second module of the PSS. This module consists of the following tasks:

1- Identification of CWSs within the larger study setting.
2- Solution formulation based on the selection of CWSs using screens, existing and future combinability targets.
3- Technical analysis
4- Economic analysis

Assumptions

The following assumptions were made during the Solution Analysis of this dissertation:

1. Plant life is 20 years for conventional water treatment.
2. Water treatment plants will be expanded and refurbished not decommissioned.
3. All solution scenarios will not be supplied with purchased water in the future.
4. Existing pipeline infrastructure to the existing raw water sources is sufficient.
5. The portion of Tulsa’s water rights for Lake Oologah that is presently supplied to the study CWSs will be reallocated during consolidation scenarios as additional water rights to the consolidation scenarios.

6. Population per household multiplier was reduced in each scenario after first 20 years of forecasting based on the assumption that the persons per household will decline over time reflecting the national trend in persons per household (U.S. Census, 2000).
7. Water demand forecasts used ODOC 2006 population growth rates (a place per county) was used in low population growth rates; the City of Owasso's annual growth rates were used for high growth rates; the average of the lowest and highest population growth rate was used for medium growth rate.
8. Liner growth rate for 50 year forecasting period.
9. Discount rate 7%.
10. Annual inflation rate 2.1%.
11. Emergency distribution storage of 30%.
12. Final construction costs were adjusted for 70% (considering additional 35% of treatment plant cost) to get total construction cost of the plant and then adjusted for an additional 35% for administration, legal and engineering fees.

4.2.1 Delineation and Pre-Screening of Consolidation Scenarios

The above sections characterized the larger study setting in Northeastern Oklahoma and the critical community of Owasso. The goal of this section is to construct the problem solution of consolidation of CWSs. The existing inter-linkages between different CWSs of the study-area are taken into account when selecting CWS partnership scenarios. Using the screening criteria in Figure 3 in Chapter 3, the CWSs were selected.

4.2.1.1 Community Water Systems in the Larger Study Setting

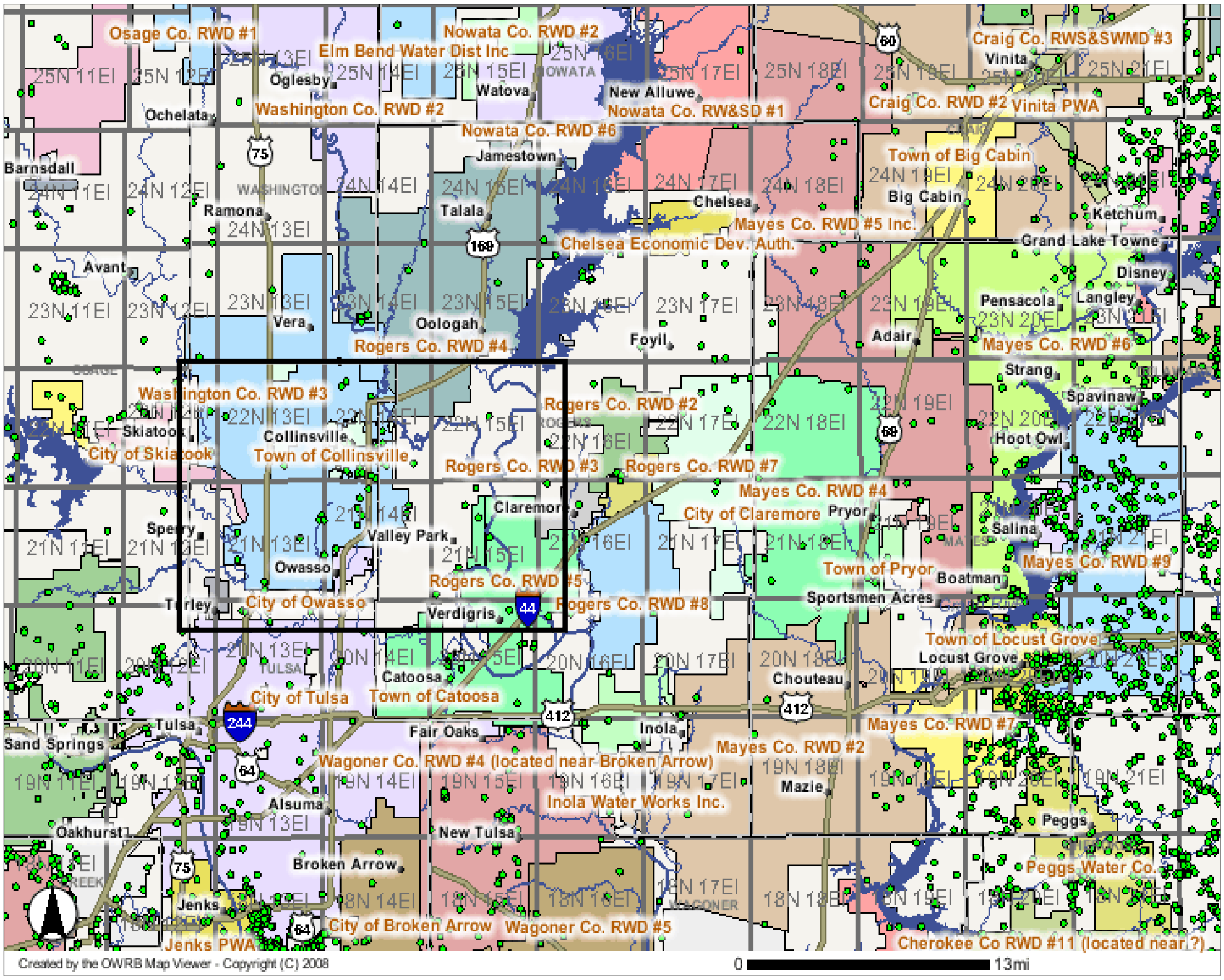
The area generally includes municipalities and rural customers "along" the US Highway 169 corridor from north of the State Highway 233, the Port Road, to Oologah Lake, and from US Highway 75 on the west to the westerly boundary of Claremore on the east. The area is north and northeast of Tulsa, east of Sperry, west of Claremore, and generally south of State Highway 88. The general study service area includes three municipalities and parts of three counties as seen in Figure 17. The study area is generally composed of rolling hills and flat plains, cut by degrading streams including the Verdigris River and the Caney River and Bird Creek. Across its width and breadth the elevation within the study area varies about 300 feet from its lowest point south of Owasso at Highway 169 and Bird Creek to its highest point near Oologah.

Figure 17
Study Area

The initial selection of community water systems (CWSs) that could be part of the solution in a form of consolidation to provide a long-term water supply solution to the critical “receiver community” of Owasso is accomplished by selecting CWSs along the U.S. Highway 169 and I-44 corridors in close proximity to Owasso.

Figure 18 displays the Oklahoma Water Resources Board (OWRB) map of the water systems in Northeast corner of Oklahoma in the vicinity of Tulsa.

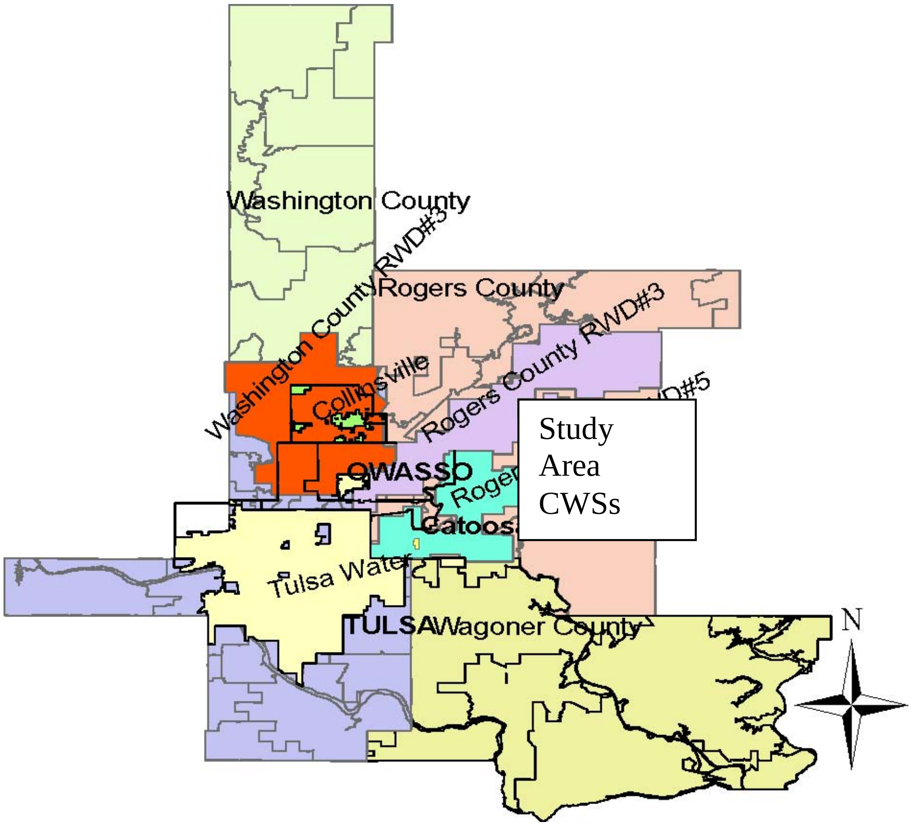
Figure 18
Water Service Areas Surrounding the Critical Community



Courtesy: Oklahoma Water Resources Board (OWRB) 2009

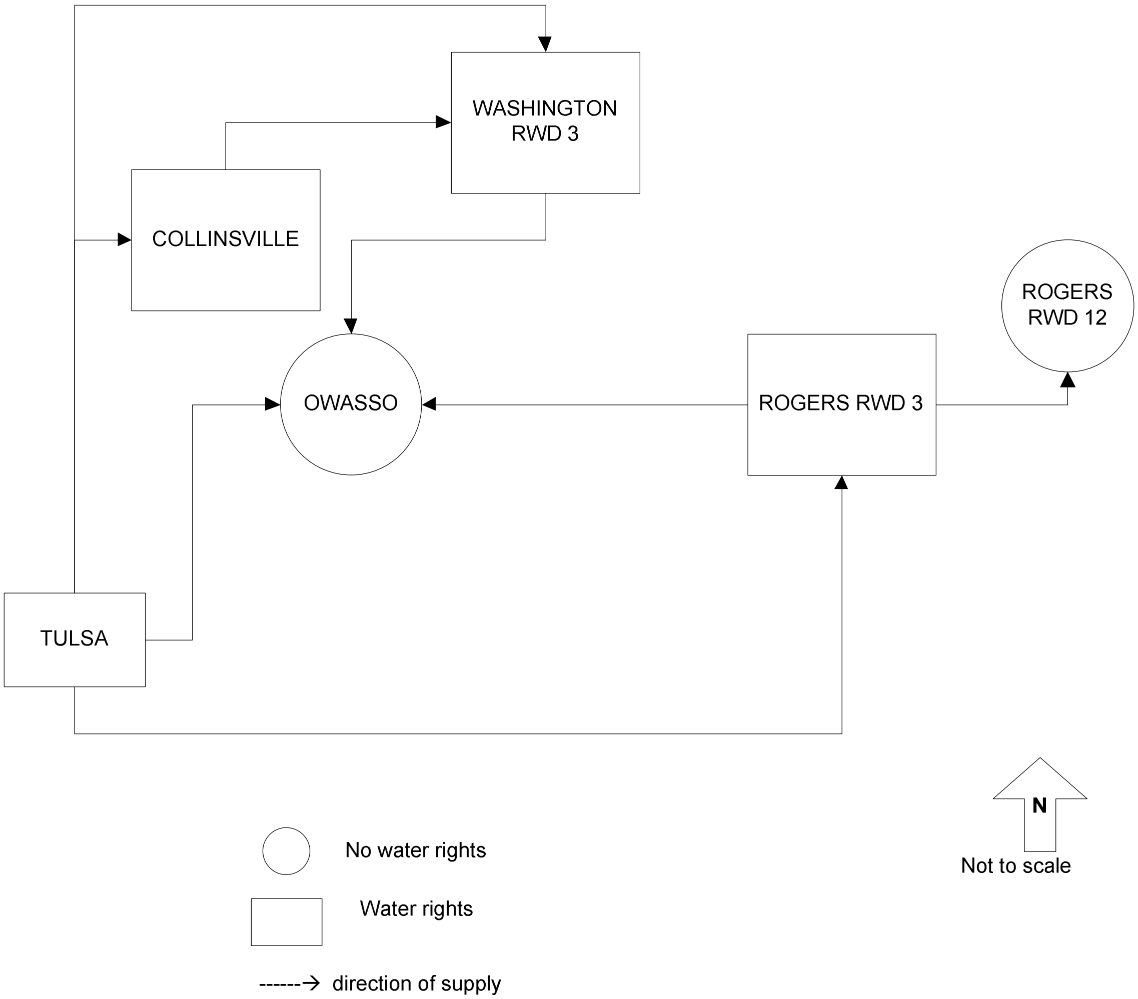
After the examination of the larger study area, the different drinking water service areas of surrounding Owasso within fifteen miles were selected as potential partners for consolidations scenario. Three CWSs serving the area include: Rogers County Rural Water District (RWD) 3 and Washington County RWD 3, and Collinsville CWS. Figure 19 shows the CWSs. All these CWS have existing relationships to the critical community.

Figure 19
Water Systems in NE OK



The study area's 2009 population is distributed across 500 square miles, most whom reside in Owasso and Collinsville. The remainder population reside in small communities, subdivisions and rural aggregates. Like its population distribution, the study area population growth is primarily centered in Owasso and its municipal boundaries. The existing relationships and water supply sources are shown in Figure 20. The existing interconnectedness of the three CWSs to the critical community is further examined. Figure 20 depicts the existing inter-linkages between each system in the study area.

Figure 20
Existing Inter-Linkages of the CWSs



The current total Rogers RWD 3 service area includes approximately 17,300 people. Rogers RWD 3 gets its raw water from Lakes Skiatook and Oologah. Rogers RWD 3 gets 40 percent of its treated water from Tulsa. Sixty percent of all water from Rogers RWD 3 is provided to the greater Owasso (Owasso East) area that is expected to be in the desired (and only) growth direction in the future. Owasso's population is determining the water treatment and meter additional needs in this district. The small portion of the treated water is sold to Rogers RWD 12 (two percent). This RWD serves only rural customers in low density and low growth areas.

The current total Washington RWD 3 service area includes 16,800 people. The CWS gets its raw water supplies from Lake Oologah. It buys a small portion of its water from Collinsville and Tulsa. Washington RWD 3 provides approximately fifteen percent of its water to northern parts of Owasso. Washington RWD 3 has water rights to Lakes Oologah and Hulah.

None of the CWSs serve large industrial users and commercial use is fairly minimal. The primary water use is residential, single family use. The circled system indicates a purchase system that does not have water rights. The solid arrows show the direction of supply and the dependency paths. Tulsa is the major large CWS (>100,000 people served) in the study area.

Appendix A includes zoning maps for the larger study area. The figures indicate that the majority of the surrounding land around the study area is agricultural. The areas historical growth trends and the transfer of land support the theory that these areas will very likely be transferred for residential purposes as the demands for more residential development occurs due to increased population growth. The area will be able to support increased population growth from a land availability perspective.

The town of Collinsville is located approximately 25 miles northeast of Tulsa, less than ten miles north from Owasso, and 20 miles north-west from Catoosa. The current total population served by Collinsville includes approximately 4,400 people with 1,900 housing units. The area consists of 6 square miles. Collinsville CWS has water rights to Oologah Lake. Collinsville supplies 10 percent water for Washington County RWD 3 and purchases 10 percent from Tulsa. Collinsville has water rights to Oologah.

The Collinsville's zoning index map reveals that most of the surrounding area of the central business district (CBD) is agricultural. The current residential development trend is to (south) easterly direction. However, the available agricultural lands in the northern part of town, makes it feasible to develop the city to that direction, toward Washington County.

4.2.1.2 Formulation of Consolidation Partners with Owasso

All selected possible scenarios (plans) include providing water to Owasso. The CWSs selected to be part of consolidation scenarios have a current total population served of over 39,000 people distributed across 500 square miles in Northeastern Oklahoma. In addition, Owasso proper (presently served by Tulsa) adds another 21,000 people approximately. Each one of the identified CWSs either individually or in a combination could potentially provide an efficient and feasible solution to provide water to the critical community. Using a table format, all possible combinations of consolidation partnerships are formulated. Table 13 presents each potential partner (three CWSs) to the consolidation scenario and all the potential scenarios (eight alternatives). These combinations have not been screened for their feasibilities. Three of the scenarios are “single system” scenarios and one is a do-nothing-scenario.

Table 13
All Combinations of CWS Scenarios with Owasso

R3	**CO**	**W3**	3
R3+CO+W3			1
R3+CO	CO+W3		2
R3+W3			1
Do nothing			1
TOTAL			**8**

R3=Rogers RWD 3, CO=Collinsville, W3=Washington RWD 3

All the identified CWSs and their existing interconnections to the communities and other CWSs could make the future consolidation scenarios feasible or unfeasible depending on the type and the degree of the existing dependencies. The existing interconnections and their relationships are depicted in Figure 20.

The combinability of the CWSs is examined from two perspectives: 1) the mutual exclusiveness and 2) the existing degree of inter-connectedness of CWSs. The types of interrelationships between CWS between CWSs: 1) mutual dependency, 2) dependency path, and 3) either-or-dependency.

Mutual dependency is present when two CWS need to exist simultaneously. Dependency path requires that one system must "occur" first in order for the other one to exist. The either-or relationship exists where one or the other system needs to be present. The examples of these are discussed in Section 3.

A dependency path relationship exists when one system needs to exist first in order for the other(s) to exist. This type of relationship exists from Tulsa to Rogers RWD 3. Tulsa provides water to Rogers RWD 3. Rogers RWD 3 has a path dependency relationship between Rogers County RWD 12. Rogers 3 provides water to these areas. Also, Tulsa and Collinsville have a path dependency relationship as well as Tulsa and Washington RWD 3. Tulsa provides water to these CWSs. Collinsville has a path dependency relationship with Washington RWD 3.

Using the criteria of mutual exclusives and desired future targets for interconnectedness between CWSs, the future combinability of the CWSs into different scenarios are shown on Table 14. The combinability targets show each future scenario (1-4) for the type of target dependencies are desired between CWS partners in the scenario. Path dependencies are only kept in the future scenarios if the characteristics of the path dependency meet the criterion "necessary to function". These are systems that purchase water from another system and do not have water rights. This helps to identify which other communities' water needs must be incorporated in the new scenario due to the type of existing "necessary to function" path dependency. The solution is a way to achieve the planning objective of water resources planning for Owasso. The solution is a consolidation scenario independent of a large CWS. Therefore, the do-nothing alternative does not meet the criterion of independence from larger CWS. Also, the do-nothing alternative violates the mutual exclusiveness. Individual systems as a solution are included to identify the point of consolidation need.

Table 14
Combinability of CWSs with Owasso

Scenario		CWS	Target Dependency			Mutually Exclusive	Source Water Options	Include
			Mutual	Path	Either-Or			
1		R3+ CO+ W3	No	R3-R12	N/A	Yes	Oologah/Skiatook/Caney	Yes
2		R3+ W3	No	R3-R12	N/A	Yes	Oologah/Skiatook/Caney	Yes
3		R3+ CO	No	R3-R12	N/A	Yes	Oologah/Skiatook/Caney	Yes
4		CO+ W3	No		N/A	Yes	Oologah/Skiatook/Caney	Yes
Individual Systems	5	R3	No	R3-R12	N/A	Yes	Oologah/Skiatook/Caney	Yes
	6	CO	No		N/A	Yes	Oologah/Skiatook/Caney	Yes
	7	W3	No		N/A	Yes	Oologah/Skiatook/Caney	Yes
8		Do nothing	Yes	yes	N/A	No	Oologah/Skiatook/Caney	No

All CWSs can be combined into consolidation scenarios with Owasso. As the Table 14 shows, scenarios 1-3 contain an existing path dependency relationship that is included into the scenarios. The initial possible consolidation scenarios included 4 different combinations of CWSs. All the scenarios were analyzed for path, mutual and “either-or” dependencies as well as for their combinability so the dependency criteria were not compromised as well as the goal of consolidation is reached. This task can help weeding out any unfeasible partners per scenario. The four consolidation scenarios are evaluated further.

4.2.2 Consolidation Scenario Output

After the examination of the larger study area, the different drinking water service areas of surrounding Owasso were selected. Screening and combinability criteria were used to pick the following CWSs: Rogers County Rural Water District (RWD) 3 and Washington County RWD 3, and Collinsville CWS.

4.3. Water Demand Forecasts

The water demands are forecasted for each CWS and for each consolidation scenario. In order to achieve the goal of single entity as a solution to the long-term water supply planning, all demand forecasts exclude currently purchased water from other water systems and includes all the demands of Owasso's. The largest supplier of water to all systems is the City of Tulsa. It will be assumed that in the future Tulsa will not provide water to any of the consolidation or individual systems in this study. The City of Tulsa is a largest regional supplier to the study area communities with the two plant capacities ranging from 90 to 190 MGD (City of Tulsa). The plants presently serve 500,000 people in the surrounding communities (City of Tulsa, 2010). When the goal is to establish a single new regional CWS to serve communities adjacent to Tulsa, this can benefit both Tulsa and the exurban communities. The exurban communities can plan for economic growth e.g., industrial and commercial users and the large supplier can implement better conservation measures.

4.3.1 IWR-MAIN Modeling

The goal of this stage is to provide forecasted water use data to IWR-MAIN model in the Technical Section of the PSS. The inputs required for the study area forecast include study area, housing unit forecasts, and forecasts years, base line water demands for the study area, and peaking demands of the base line demands. The water demands of each sector are expressed as a product of the number of users (housing units) and the average rate of water use per household.

Population growth is a major driver for water demand increases. Thus, these forecasts are fundamental for accurate water resources planning. The Oklahoma Department of Commerce (ODOC) and the U.S. Census Bureau are the primary sources of population forecasts used for this section of the dissertation. In 2006, ODOC, under the contract with the Oklahoma Water Resources Board (OWRB), tabulated population forecasts in Oklahoma per county per place through 2060. These projections were made using cohort component projection model. With this method, each component of the population numbers (birth, death, and migration) is projected separately, based on algorithms developed by the U.S. Census Bureau (ODOC, 2006).

Residential sector includes two sub-sectors: single family housing and multi-family housing. Due to the nature of the communities analyzed in this dissertation, none of the communities have true multi-family residential units. Also, the future water demands are assumed to remain mainly residential based on the exurban characteristics of the area. The study area characteristics were discussed in Problem Analysis section.

In this dissertation, all water forecasts were initially modeled for each CWS and community using both linear and multiplicative models. These models are substantially more complex and data hungry than constant usage rate model (U.S. Department of Energy, 2010). The linear and multiplicative models are suitable for more complex water demand profile communities that consist of various types of water users that are sensitive to explanatory variables such as weather, persons per household, cost of water, and income (U.S. Department of Energy, 2010). In this dissertation, the use of linear and the explanatory models did not provide additional insights to the water uses in the study area. These models could be beneficial per CWSs in larger communities to model impacts of anticipated changes in different communities or in brainstorming situations of "what if". Therefore, it was decided that the use of explanatory variables would not provide valuable information and as a matter fact, would skew the water forecasts due the uncertainty in forecasts for climate and socio-economic explanatory variables for 50-year planning period.

The base year water uses were obtained from each CWS and Owasso. The utility usage data is required for base year water consumption. The base year water consumption is used for model calibration and model adjustment. The use of intercept values were used to calibrate the model so that the model would estimate (forecast) the actual water use of 2000. As a rule of thumb, according to IWR-MAIN procedural guidance, differences in the 3-5 percent range indicate good performance of the model; differences exceeding 10 percent usually mean further calibration is needed.

The counting units (housing units) were forecasted for each of the CWSs service area by using the 2006 Oklahoma Department of Commerce (ODOC) population growth rates through 2060. The ODOC and the U.S. Census Bureau are the primary sources of population forecasts used for this section of the dissertation. In 2006, ODOC, under contract with the Oklahoma Water Resources Board

(OWRB), tabulated population forecasts in Oklahoma per county per place through 2060. Projections were made using cohort component projection model. With this method, each component of the population numbers (birth, death, and migration) is projected separately, based on algorithms developed by the U.S. Census Bureau.

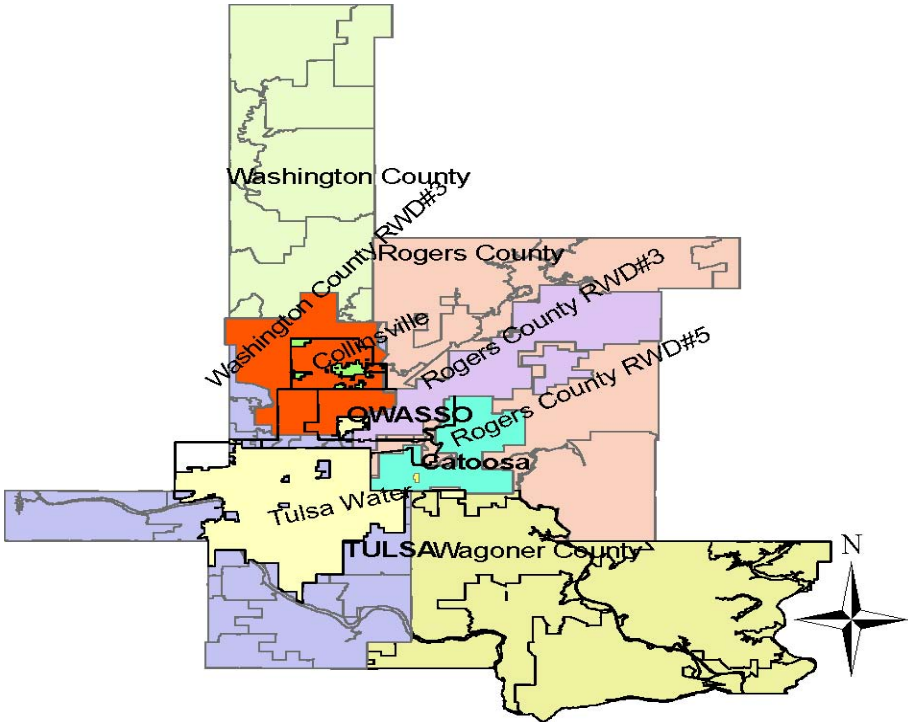
In order to satisfy the variation in population forecasting, for the modeling purposes, three scenarios of housing unit growth rates were used: low, medium and high. The sensitivity analysis feature in the IWR-Main Forecast Suite allows the forecasting with these growth ranges.

The ODOC population forecasts include counties and selected places. The growth rates were modified to apply each CWS service area. The low growth scenario was calculated using the total number of occupied housing units for each forecast existing service area. These numbers were validated with the each evaluated service area current meter counts. The occupied housing unit numbers were forecasted to increase with the same growth rates as the ODOC 2006 forecast rate of the planning area population. Also, the population per household multiplier was reduced in each scenario after first 20 years of forecasting based on the assumption that the persons per household will decline over time reflecting the national trend in persons per household (U.S. Census, 2000). The population per household number was reduced gradually throughout the forecasting period based on the assumption that in the future less people will occupy a household. Second, the medium growth rate was adopted by using the mean of the lowest ODOC annual growth rate for the area and the highest city growth rate value of Owasso. The population per household multiplier was reduced after the first 20 years of forecasting. The growth rate was kept constant throughout the forecasting period. Third, the high growth scenarios were forecasted according to the highest growth projection for the area by the City of Owasso projection. This growth rate was kept constant throughout the forecasting period. The population per household multiplier was reduced after the first 20 years of forecasting.

4.3.2 Model Input: Base Year Data

The below tables include the input data used for the IWR-MAIN forecasting for residential. All water demands were forecasted as residential water demands due to the baseline water-use profiles. The base year water demands are actual numbers of water produced and purchased per system. The service areas are shown in Figure 21.

Figure 21
Existing Inter-Linkages of the CWSs



4.3.2.1 Owasso

The ODOC 2006 forecasts are conservative compared to individual city forecasts. For example, using the ODC 4.75 percent growth rate for Owasso between years 2005 and 2007 (2.4 percent per year), the population obtained is 20,018 in 2007. The City of Owasso cites, however, the population being 35,708 in 2007, which is 78.4 percent higher than ODOC's estimate. Based on the city's forecasts, the 2010 population is forecasted to increase 17 percent from 2007-2010, which averages 5.7 percent a year. This rate would yield 37,731 people compared to the ODOC forecast of 19,670. Comparing the ODOC 2010 forecast rate of change to 2005 forecast, the increase would be less than 3 percent. If the

ODOC 2007 forecasts were used, this would indicate a substantial decline in the population by 2010.

The below tables include two different service areas for Owasso: Owasso proper (the city limits) and Owasso greater (outside city limits). Owasso proper includes the service area presently being supplied by Tulsa. Owasso greater includes the service area presently supplied by Washington RWD 3 and Rogers RWD 3. Owasso's service areas were split for the demand forecasts so the entire demand of Owasso is captured. The assumptions in this dissertation are that all of the consolidation scenarios will include Owasso's total demands and Owasso will be able to accommodate the medium housing growth projections.

4.3.2.1.1 Housing Unit Growth Rate Projections

Table 15 shows low growth housing projections (per decade) for the Owasso proper service area (presently supplied by Tulsa water). The low growth projections were forecasted using ODOC 2006.

Table 15
Owasso – Housing Units and Persons per Household
Low Growth Owasso Proper

Year	Housing Growth Rate %*	Persons per Household	Housing Units
			LOW
2010		2.3	9,150
2020	12	2.3	10,253
2030	9	2.15	11,199
2040	8	2.15	12,085
2050	7.5	2.15	12,992
2060	6	2.15	13,898

*Average annual growth per Owasso ODOC, 2006 forecast.

Table 16 shows medium growth housing projections (per decade) for the Owasso proper service area (presently supplied by Tulsa water). The medium growth projections were forecasted using the average of ODOC 2006 forecasts and the highest City of Owasso annual forecast.

Table 16
Owasso – Housing Units and Persons per Household
Medium Growth Owasso Proper

Year	Housing Growth Rate %*	Persons per Household	Housing Units
			MEDIUM
2010		2.3	9,150
2020	52.5	2.3	12,627
2030	52.5	2.15	17,425
2040	52.5	2.15	24,047
2050	52.5	2.15	33,185
2060	52.5	2.15	45,795

*The average of annual growth rate for Owasso 6.9% and Catoosa 3.6% (10 years).

Table 17 shows high growth housing projections (per decade) for the Owasso proper service area (presently supplied by Tulsa water). The high growth projections were forecasted using the highest City of Owasso annual forecast.

Table 17
Owasso – Housing Units and Persons per Household
High Growth Owasso Proper

Year	Housing Growth Rate*	Persons per Household	Housing Units
			HIGH
2010		2.3	9,150
2020	69	2.3	15,464
2030	69	2.15	26,133
2040	69	2.15	44,165
2050	69	2.15	74,639
2060	69	2.15	126,141

*The highest projected annual growth rate for Owasso 6.9% (10 years).

Table 19 shows low growth housing projections (per decade) for the greater Owasso service area (presently supplied by Rogers RWD 3 and Washington RWD 3). The low growth projections were forecasted using ODOC 2006.

Table 18
Owasso – Housing Units and Persons per Household
Low Growth Greater Owasso

Year	Housing Growth Rate %*	Persons per Household	Housing Units		
			LOW		
			Rogers RWD 3 Side	Rogers RWD 3 Side	Total
2010		2.3	4,400	1,096	5,536
2020	12	2.3	4,975	1,118	6,093
2030	9	2.15	5,434	1,129	6,563
2040	8	2.15	5,864	1,144	7,008
2050	7.5	2.15	6,304	1,160	7,464
2060	6	2.15	6,744	1,177	7,921

*Average annual growth per Owasso ODOC, 2006 forecast.

Table 20 shows medium growth housing projections (per decade) for the greater Owasso service area (presently supplied by Rogers RWD 3 and Washington RWD 3). The medium growth projections were forecasted using the average of ODOC 2006 forecasts and the highest City of Owasso annual forecast.

Table 19
Owasso – Housing Units and Persons per Household
Medium Growth Greater Owasso

Year	Housing Growth Rate %*	Persons per Household	Housing Units		
			MEDIUM		
			Rogers RWD 3 Side	Washington RWD 3 Side	Total
2010		2.3	4,440	1,096	5,536
2020	52.5	2.3	6,127	1,480	7,607
2030	52.5	2.15	8,456	1,997	10,453
2040	52.5	2.15	11,669	2,697	14,366
2050	52.5	2.15	16,103	3,640	19,743
2060	52.5	2.15	22,222	4,915	27,137

*The average of annual growth rate for Owasso 6.9% and Catoosa 3.6% (10 years).

Table 19 shows high growth housing projections (per decade) for the greater Owasso service area (presently supplied by Rogers RWD 3 and Washington RWD 3). The high growth projections were forecasted using the highest City of Owasso annual forecast.

Table 20
Owasso – Housing Units and Persons per Household
High Growth Greater Owasso

Year	Housing Growth Rate*	Persons per Household	Housing Units		
			HIGH		
			Rogers RWD 3 Side	Washington RWD 3 Side	Total
2010		2.3	4,440	1,096	5,536
2020	69	2.3	7,504	1,852	9,356
2030	69	2.15	12,681	3,130	15,811
2040	69	2.15	21,431	5,290	26,721
2050	69	2.15	36,218	8,940	45,158
2060	69	2.15	61,209	15,109	76,318

*The highest projected annual growth rate for Owasso 6.9% (10 years).

4.3.2.1.2 Baseline Water Demands

Table 21 shows the total greater Owasso service area water demands for 2009 (monthly MG). The baseline water demands are used in IWR-MAIN. The monthly baseline demands were provided by the City of Owasso, Rogers RWD3 and Washington RWD3.

Table 21
Owasso – 2009 Base Year Water Demands (MG)
Greater Owasso

Month	Owasso Proper (MG)	Distributed by Roger RWD 3 Tacora Site (MG)	Washington RWD 3 (MG)	Total Greater Owasso Area Demands (MG)
January	70.4	33	5.84	102.24
February	73.65	28.8	5.37	107.82
March	63.41	31.2	4.73	99.34
April	66.04	31.8	5.16	103
May	67.7	34.8	5.43	107.93
June	83.97	40.8	6.35	131.12
July	104.6	45	8.24	157.84
August	124.73	45	10.73	180.46
September	96.1	30	10.06	136.16
October	75.06	36	6.44	117.5
November	75.12	31.2	6.12	112.44
December	67.33	33	5.46	105.79
TOTAL	968.11	420	79.92	1,468.03

The daily peaking demand for Owasso proper was 4.3 MGD was in July. All the commercial water demand in Owasso was included in the residential demand side (typically even less that average residential consumption). Owasso's water demands include one large industrial water user (poultry and meat plant). These use an average of 2.5 MG per month (30 MGY).

4.3.2.2 Rogers RWD 3

The Rogers RWD 3 water demands were forecasted for two scenarios: the total Rogers RWD 3 (includes Owasso) and Rogers without Owasso demand. All demands forecasts include Rogers RWD 12 that is purchase system.

4.3.2.1.1 Housing Unit Growth Rate Projections

Table 22 shows low growth housing projections (per decade) for the entire Rogers RWD3. The low growth projections were forecasted using ODOC 2006.

Table 22
Rogers RWD 3 – Housing Units and Persons per Household
Low Growth Entire Area

Year	Housing Growth Rate %*	Persons per Household	Housing Units**
			LOW
2010		2.3	7,400
2020	12	2.3	8,929
2030	9	2.15	9,057
2040	8	2.15	9,774
2050	7.5	2.15	10,507
2060	7	2.15	11,240

*These represent 5-year averages as reported by ODC:~0.7-1.2% annual growths (table 10 years).
**All accounts in the service area.

Table 23 shows medium growth housing projections (per decade) for the entire Rogers RWD3. The medium growth projections were forecasted using the average of ODOC 2006 forecasts and the highest City of Owasso annual forecast.

Table 23
Rogers RWD 3 – Housing Units and Persons per Household
Medium Growth Entire Area

Year	Housing Growth Rate %*	Persons per Household	Housing Units**
			MEDIUM
2010	38	2.3	7,400
2020		2.3	10,212
2030		2.15	14,093
2040		2.15	19,448
2050		2.15	26,838
2060		2.15	37,036

*The average of annual growth rate for Owasso 6.9% and the lowest ODC projected for the area 0.70% (table 10 years).
**All accounts in the service area.

Table 24 shows high growth housing projections (per decade) for the entire Rogers RWD3. The high growth projections were forecasted using the highest City of Owasso annual forecast.

Table 24
Rogers RWD 3 – Housing Units and Persons per Household
High Growth Entire Area

Year	Housing Growth Rate %*	Persons per Household	Housing Units**
			HIGH
2010		2.3	7,400
2020	69	2.3	12,506
2030	69	2.15	21,135
2040	69	2.15	35,718
2050	69	2.15	60,364
2060	69	2.15	102,015

*The highest projected annual growth rate for Owasso 6.9% (10 years).
**All accounts in the service area.

Table 25 shows low growth housing projections (per decade) for Rogers RWD3 (without Owasso). The low growth projections were forecasted using ODOC 2006.

Table 25
Rogers RWD 3 – Housing Units and Persons per Household
Low Growth East Owasso

Year	Housing Growth Rate %*	Persons per Household	Housing Units
			LOW
2010		2.3	2,960
2020	12	2.3	3,317
2030	9	2.15	3,623
2040	8	2.15	3,910
2050	7.5	2.15	4,203
2060	7	2.15	4,496

**These represent 5-year averages as reported by ODC:~0.7-1.2% annual growths (table 10 years).
**All accounts in the service area.

Table 26 shows medium growth housing projections (per decade) for Rogers RWD3 (without Owasso). The medium growth projections were forecasted using the average of ODOC 2006 forecasts and the highest City of Owasso annual forecast.

Table 26
Rogers RWD 3 – Housing Units and Persons per Household
Medium Growth East Owasso

Year	Housing Growth Rate %*	Persons per Household	Housing Units**
			MEDIUM
2010		2.3	2,960
2020	38	2.3	4,085
2030	38	2.15	5,637
2040	38	2.15	7,779
2050	38	2.15	10,735
2060	38	2.15	14,815

*The average of annual growth rate for Owasso 6.9% and the lowest ODC projected for the area 0.70% (table 10 years).

Table 27 shows high growth housing projections (per decade) for Rogers RWD3 (without Owasso). The high growth projections were forecasted using the highest City of Owasso annual forecast.

Table 27
Rogers RWD 3 – Housing Units and Persons per Household
High Growth East Owasso

Year	Housing Growth Rate %*	Persons per Household	Housing Units
			HIGH
2010	69	2.3	2,960
2020		2.3	5,002
2030		2.15	8,454
2040		2.15	14,287
2050		2.15	24,146
2060		2.15	40,806
2060		2.15	102,015

*The highest projected annual growth rate for Owasso 6.9% (10 years).

4.3.2.1.2 Baseline Water Demands

Table 28 shows Rogers RWD 3 service area water demands for 2009 (monthly MGD). The baseline water demands are used in IWR-MAIN. The monthly baseline demands were provided by the Rogers RWD3.

Table 28
Rogers RWD 3 – 2009 Base Year Water Demands (MG)

Month	Produced (MG)*	Owasso and Rogers RWD 12 (MG)	Owasso (MG)
January	55	34.1	33
February	48	29.76	28.8
March	52	32.24	31.2
April	53	32.86	31.8
May	58	32.96	34.8
June	68	42.16	40.8
July	75	46.5	45
August	75	46.5	45
September	50	31	30
October	60	37.2	36
November	52	32.24	31.2
December	55	34.1	33
TOTAL	701	434.62	420

*used in IWR-MAIN forecasting.

In 2009, Rogers RWD 3 purchased 60 percent (654 MG) of the finished water used from Tulsa and treated the remaining 40 percent (434.6 MG). The total finished water used was 1,090 MG. Less than 2 percent is provided to Roger RWD 12. This is included in the demand forecasts. Peak demand was both in July and August in at 46.5 MGD. The peaking factor for Rogers RWD was 3.15 MGD in July.

4.3.2.3 Washington RWD 3

The Washington RWD 3 water demands were forecasted for two scenarios: the total Washington RWD 3 (includes Owasso) and Washington RWD 3 without Owasso demand. Washington RWD 3 supplies water to parts of Owasso (north). That is estimated at 15 percent of the total water produced

4.3.2.3.1 Housing Unit Growth Rate Projections

Table 29 shows low growth housing projections (per decade) for the entire Washington RWD 3. The low growth projections were forecasted using ODOC 2006.

Table 29
Washington RWD 3 – Housing Units and Persons per Household
Low Growth

Year	Housing Growth Rate %	Persons per Household	Housing Units
			LOW
2010		2.3	7,309
2020	2	2.3	7,457
2030	1	2.15	7,530
2040	1.36	2.15	7,632
2050	1.34	2.15	7,735
2060	1.51	2.15	7,852

*ODC growth rates <1% per year.

Table 30 shows medium growth housing projections (per decade) for the entire Washington RWD 3. The medium growth projections were forecasted using the average of ODOC 2006 forecasts and the highest City of Owasso annual forecast.

Table 30
Washington RWD 3 – Housing Units and Persons per Household
Medium Growth

Year	Housing Growth Rate %*	Persons per Household	Housing Units
			MEDIUM
2010		2.3	7,309
2020	35	2.3	9,867
2030	35	2.15	13,321
2040	35	2.15	17,983
2050	35	2.15	24,277
2060	35	2.15	32,774

*The average of annual growth rate for Owasso 6.9% and the lowest ODC projected for the area 0.098% (table 10 years).

Table 31 shows high growth housing projections (per decade) for the entire Washington RWD 3. The high growth projections were forecasted using the highest City of Owasso annual forecast.

Table 31
Washington RWD 3 – Housing Units and Persons per Household
High Growth

Year	Housing Growth Rate %*	Persons per Household	Housing Units
			HIGH
2010		2.3	7,309
2020	69	2.3	12,352
2030	69	2.15	20,875
2040	69	2.15	35,279
2050	69	2.15	59,622
2060	69	2.15	100,761

*The highest projected annual growth rate for Owasso 6.9% (10 years).

Table 32 shows low growth housing projections (per decade) for Washington RWD 3 (without Owasso). The low growth projections were forecasted using ODOC 2006.

Table 32
Washington RWD 3 – Housing Units and Persons per Household
No Owasso Area Included Low Growth

Year	Housing Growth Rate %	Persons per Household	Housing Units
			LOW
2010		2.3	6,213
2020	2	2.3	6,338
2030	1	2.15	6,401
2040	1.36	2.15	6,488
2050	1.34	2.15	6,575
2060	1.51	2.15	6,674

*ODC growth rates <1% per year.

Table 33 shows medium growth housing projections (per decade) for Washington RWD 3 (without Owasso). The medium growth projections were forecasted using the average of ODOC 2006 forecasts and the highest City of Owasso annual forecast.

Table 33
Washington RWD 3 – Housing Units and Persons per Household
No Owasso Area Included Medium Growth

Year	Housing Growth Rate %*	Persons per Household	Housing Units
			MEDIUM
2010		2.3	6,213
2020	35	2.3	8,388
2030	35	2.15	11,323
2040	35	2.15	15,286
2050	35	2.15	20,637
2060	35	2.15	27,859

*The average of annual growth rate for Owasso 6.9% and the lowest ODC projected for the area 0.098% (table 10 years).

Table 34 shows high growth housing projections (per decade) for Washington RWD 3 (without Owasso). The high growth projections were forecasted using the highest City of Owasso annual forecast.

Table 34
Washington RWD 3 – Housing Units and Persons per Household
No Owasso Area Included High Growth

Year	Housing Growth Rate %*	Persons per Household	Housing Units
			HIGH
2010		2.3	6,213
2020	69	2.3	10,500
2030	69	2.15	17,745
2040	69	2.15	29,989
2050	69	2.15	50,681
2060	69	2.15	85,651

*The highest projected annual growth rate for Owasso 6.9% (10 years).

4.3.2.3.2 Baseline Water Demands

Table 35 shows Washington RWD 3 service area water demands for 2009 (monthly MG). The baseline water demands are used in IWR-MAIN. The monthly baseline demands were provided by the Washington RWD 3.

Table 35
Washington RWD 3 – 2009 Base Year Water Demands (MG)

Month	Produced (MG)	Owasso Area (MG)	Washington Only (MG)*
January	38.94	5.84	33.10
February	35.77	5.37	30.40
March	31.54	4.73	26.81
April	34.40	5.16	29.24
May	36.22	5.43	30.79
June	42.34	6.35	35.99
July	54.92	8.24	46.68
August	71.51	10.73	60.78
September	67.07	10.06	57.01
October	42.90	6.44	36.47
November	40.82	6.12	34.70
December	36.40	5.46	30.94
TOTAL	532.83	79.92	452.31

*used for IWR-MAIN forecasting.

Fifteen percent of produced water is delivered to Owasso area. Collinsville supplies approximately additional 10 percent of water to Washington RWD 3. Tulsa supplies less than five percent. The 2009 peak demand was 3.5 MGD. The below tables include housing forecast for Washington RWD service area without Owasso's housing.

4.3.2.4 Collinsville

Collinsville purchases water from Tulsa and supplies water to the town of Collinsville and Washington RWD 3. The housing forecasts show the total expected future connections by Collinsville.

4.3.2.4.1 Housing Unit Growth Rate Projections

Table 36 shows low growth housing projections (per decade) for the town of Collinsville. The low growth projections were forecasted using ODOC 2006.

Table 36
Collinsville – Housing Units and Persons per Household
Low Growth

Year	Housing Growth Rate %	Persons per Household	Housing Units
			LOW
2010		2.3	1,900
2020	5.6	2.3	2,007
2030	4.9	2.15	2,105
2040	3.6	2.15	2,181
2050	2.3	2.15	2,230
2060	2.0	2.15	2,275

*ODC growth rates <1% per year.

Table 37 shows medium growth housing projections (per decade) for Collinsville. The medium growth projections were forecasted using the average of ODOC 2006 forecasts and the highest City of Owasso annual forecast.

Table 37
Collinsville – Housing Units and Persons per Household
Medium Growth

Year	Housing Growth Rate %*	Persons per Household	Housing Units
			MEDIUM
2010		2.3	1,900
2020	35	2.3	2,575
2030	35	2.15	3,489
2040	35	2.15	4,727
2050	35	2.15	6,406
2060	35	2.15	8,680

*The average of annual growth rate for Owasso 6.9% and the lowest ODC projected for the area 0.098% (table 10 years).

Table 38 shows high growth housing projections (per decade) for Collinsville. The high growth projections were forecasted using the highest City of Owasso annual forecast.

Table 38
Collinsville – Housing Units and Persons per Household
High Growth

Year	Housing Growth Rate %*	Persons per Household	Housing Units
			HIGH
2010		2.3	1,900
2020	69	2.3	3,211
2030	69	2.15	5,427
2040	69	2.15	9,171
2050	69	2.15	15,499
2060	69	2.15	26,193

*The highest projected annual growth rate for Owasso 6.9% (10 years).

4.3.2.4.2 Baseline Water Demands

Table 39 shows Collinsville service area water demands for 2009 (monthly MG). The baseline water demands are used in IWR-MAIN. The monthly baseline demands were provided by the town of Collinsville.

Table 39
Collinsville – 2009 Base Year Water Demands (MG)

Month	Produced (MG)	Sold To Washington RWD 3 (MG)/Purchased from Tulsa (%)	Production without Washington (MG)	Purchased from Tulsa (MG)
January	15.5	10	13.95	17.05
February	15.22	10	13.698	16.742
March	15.42	10	13.878	16.962
April	15	10	13.5	16.5
May	16.3	10	14.67	17.93
June	18.88	10	16.992	20.768
July	22	10	19.8	24.2
August	22	10	19.8	24.2
September	19.56	10	17.604	21.516
October	17.1	10	15.39	18.81
November	15.3	10	13.77	16.83
December	16.4	10	14.76	18.04
TOTAL	208.68	10	187.812	229.548

Ten percent of the produced water was sold to Washington RWD 3 in year 2009. The 2009 peak demand was MGD in July at 1.07 MGD. Additional 10 percent of water is purchased from Tulsa.

4.3.3 Model Output

All those water systems that currently provide water to greater Owasso area are forecasted without Owasso's water usage. Instead, Owasso's water is forecasted as the total demand for the area. All demands were calculated for low, medium and high growth scenarios throughout the planning horizon. The total demands for each consolidation scenario represent the individual forecasted demands without future water sales and purchases to other community water systems.

The IWR-MAIN model used to forecast the water demands for the study area:

$$Q_{s,m,y} = N_{s,m,y} * q_{s,m,b} * d_m \tag{10}$$

Where:
Q = Gallons of water used in subsector (s) in month (m) in year (y)
N = number of units in subsector (s) in month (m) in year (y)
q = average daily use rate per unit in subsector (s) in month (m) in base year (b)
d = number of days in month (m)

Annual average water demands are used for water permit analysis, daily average demands are used for distribution storage analysis, and system peak forecasts are used for water treatment plant expansion.

4.3.3.1 Water Demand Forecast: Annual

Table 40 is the annual water demand forecasts for low growth projections for each service area. The forecasts were generated using ODOC 2006 population forecast rates. Each service area was forecasted to meet the entire demand alone.

Table 40
Annual Water Demand Forecasts 2010-2060 *Low Growth*

IWR-MAIN Forecasted Water Demands (MG) – YEAR-LOW					
YEAR	Roger RWD 3 no Owasso	Washington RWD 3 no Owasso	Collinsville	Owasso Proper	Owasso Greater
2010	701.00	452.90	208.70	968.10	500.00
2020	785.50	462.00	220.40	1,085.0	550.90
2030	856.00	466.62	231.20	1,185.0	593.40
2040	924.60	473.00	239.50	1,279.0	633.62
2050	993.90	480.30	245.00	1,375.0	674.90
2060	1,063.00	486.51	249.90	1,471.0	716.20

Table 41 is the annual water demand forecasts for medium growth projections for each service area. The forecasts were generated using the average annual ODOC 2006 and the City of Owasso's population forecast rates. Each service area was forecasted to meet the entire demand alone.

Table 41
Annual Water Demand Forecasts 2010-2060 *Medium Growth*

IWR-MAIN Forecasted Water Demands (MG) – YEAR - MEDIUM					
YEAR	Rogers RWD 3 no Owasso	Washington RWD 3 no Owasso	Collinsville	Owasso Proper	Owasso Greater
2010	701.00	452.90	208.70	968.10	500.00
2020	966.00	611.46	283.00	1,336.00	687.80
2030	1,333.00	825.40	383.20	1,843.60	945.10
2040	1,839.60	1,114.30	519.20	2,544.30	1,230.00
2050	2,542.36	1,504.40	703.60	3,511.00	1,785.00
2060	3,503.00	2,030.80	953.30	4,845.30	2,454.00

Table 42 is the annual water demand forecasts for high growth projections for each service area. The forecasts were generated using the City of Owasso's annual population forecast rates. Each service area was forecasted to meet the entire demand alone.

Table 42
Annual Water Demand Forecasts 2010-2060 *High Growth*

IWR-MAIN Forecasted Water Demands (MG) – YEAR - HIGH					
YEAR	Rogers RWD 3 no Owasso	Washington RWD 3 no Owasso	Collinsville	Owasso Proper	Owasso Greater
2010	701.00	452.90	208.70	968.10	500.00
2020	1,182.90	765.40	352.70	1,636.00	846.00
2030	1,999.00	1,293.60	607.04	2,765.00	1,430.00
2040	3,378.70	2,186.00	1,007.40	4,673.00	2,416.00
2050	5,710.00	3,694.50	1,702.28	7,897.00	4,083.00
2060	9,650.00	6,243.70	2,876.82	13,346.30	6,900.00

4.3.3.2 Water Demand Forecast: Daily

Table 43 is the daily water demand forecasts for low growth projections for each service area. The forecasts were generated using ODOC 2006 population forecast rates. Each service area was forecasted to meet the entire demand alone.

Table 43
Daily Average Water Demand Forecasts 2010-2060 *Low Growth*

IWR-MAIN Forecasted Demands (MGD) – AVERAGE DAY – LOW					
YEAR	Rogers RWD 3 no Owasso	Washington RWD 3 no Owasso	Collinsville	Owasso Proper	Owasso Greater
2010	1.92	1.24	0.57	2.65	1.37
2020	2.13	1.27	0.60	3.00	1.51
2030	2.37	1.28	0.63	3.25	1.63
2040	2.51	1.29	0.66	3.50	1.74
2050	2.70	1.31	0.67	3.77	1.85
2060	2.88	1.33	0.69	4.03	1.96

Table 44 is the daily water demand forecasts for medium growth projections for each service area. The forecasts were generated using the average annual ODOC 2006 and the City of Owasso's population forecast rates. Each service area was forecasted to meet the entire demand alone.

Table 44
Daily Average Water Demand Forecasts 2010-2060 *Medium Growth*

IWR-MAIN Forecasted Demands (MGD) – AVERAGE DAY – MEDIUM					
YEAR	Rogers RWD 3 no Owasso	Washington RWD 3 no Owasso	Collinsville	Owasso Proper	Owasso Greater
2010	1.92	1.24	0.57	2.65	1.37
2020	2.62	1.68	0.76	3.66	1.88
2030	3.62	2.26	1.10	5.10	2.59
2040	5.00	3.05	1.42	7.00	3.56
2050	6.91	4.12	1.93	9.62	4.90
2060	9.52	5.56	2.61	13.28	6.72

Table 45 is the daily water demand forecasts for high growth projections for each service area. The forecasts were generated using the City of Owasso's annual population forecast rates. Each service area was forecasted to meet the entire demand alone.

Table 45
Daily Average Water Demand Forecasts 2010-2060 *High Growth*

IWR-MAIN Forecasted Demands (MGD) – DAY - HIGH					
YEAR	Rogers RWD 3 no Owasso	Washington RWD 3 no Owasso	Collinsville	Owasso Proper	Owasso Greater
2010	1.92	1.24	0.57	2.65	1.37
2020	3.21	2.10	0.97	4.5	2.32
2030	5.43	3.54	1.67	7.6	3.92
2040	9.18	6.0	2.76	12.8	6.62
2050	15.51	10.12	4.67	21.64	11.19
2060	26.21	17.11	7.88	36.6	18.91

4.3.3.3 Water Demand Forecast: Peak

The peaking values are used later for water system design criteria under the chosen growth scenarios.

Table 46 is the peak water demand forecasts for low growth projections for each service area. The forecasts were generated using ODOC 2006 population forecast rates. Each service area was forecasted to meet the entire demand alone.

Table 46
System Peaks Growth - Low

IWR-MAIN Forecasted Demands (MGD) – SYSTEM PEAKS – LOW					
YEAR	Rogers RWD 3 no Owasso	Washington RWD 3 no Owasso	Collinsville	Owasso Proper	Owasso Greater
2010	3.15	1.28	1.07	4.3	2.3
2020	3.53	1.30	1.13	4.82	2.53
2030	3.86	1.32	1.19	5.26	2.73
2040	4.16	1.33	1.23	5.68	2.91
2050	4.47	1.35	1.26	6.12	3.10
2060	4.79	1.37	1.28	6.53	3.30

Table 47 is the peak water demand forecasts for medium growth projections for each service area. The forecasts were generated using the average annual ODOC 2006 and the City of Owasso's population forecast rates. Each service area was forecasted to meet the entire demand alone.

Table 47
System Peaks Growth - Medium

IWR-MAIN Forecasted Demands (MGD) – SYSTEM PEAKS - MEDIUM					
YEAR	Rogers RWD 3 no Owasso	Washington RWD 3 no Owasso	Collinsville	Owasso Proper	Owasso Greater
2010	3.15	1.28	1.07	4.3	2.3
2020	4.37	1.72	1.50	5.93	3.16
2030	6.0	2.33	1.97	8.19	4.34
2040	8.28	3.14	2.66	11.30	6.0
2050	11.44	4.24	3.61	15.60	8.20
2060	15.77	5.73	4.88	21.52	11.27

Table 48 is the peak water demand forecasts for high growth projections for each service area. The forecasts were generated using the City of Owasso's annual population forecast rates. Each service area was forecasted to meet the entire demand alone.

Table 48
System Peaks Growth - High

IWR-MAIN Forecasted Demands (MGD) – SYSTEM PEAKS - HIGH					
YEAR	Roger RWD 3 no Owasso	Washington RWD 3 no Owasso	Collinsville	Owasso Proper	Owasso Greater TOTAL
2010	3.15	1.28	1.07	4.3	2.3
2020	5.32	2.16	1.81	7.27	3.89
2030	9.00	3.65	3.06	12.28	6.60
2040	15.20	6.17	5.17	20.76	11.10
2050	25.70	10.42	8.73	35.10	18.76
2060	43.43	17.61	14.75	59.28	31.71

4.3.3.4 Water Demand Forecast: Consolidated

The consolidation scenario water demands are in the below tables. The average growth rate was selected for the final analysis. All scenarios include Owasso's forecasted demands under medium growth projections. Annual average water demands are used for water permit analysis, daily average demands are used for distribution storage analysis, and system peak forecasts are used for water treatment plant expansion.

The consolidation scenarios include:

1. Rogers RWD 3 + Collinsville + Washington RWD 3.
2. Rogers RWD 3 + Washington RWD 3
3. Rogers RWD + Collinsville
4. Collinsville + Washington RWD 3

Table 49 has water demands for consolidation scenario 1. This table reports decadal annual average, daily average and system peaks demands for Rogers RWD 3, Collinsville, Washington RWD 3 and Owasso.

Table 49
Water Demands - Scenario1

Year	Forecasted Demands TOTAL R3+CO+W3 Owasso		
	Annual Average (MG)	Daily Average (MGD)	System Peaks (MGD)
2010	2,830.70	7.75	12.10
2020	3,884.30	10.60	16.68
2030	5,330.30	14.67	22.83
2040	7,247.40	20.30	31.38
2050	10,046.36	27.48	43.09
2060	13,786.40	37.69	59.17

Table 50 has water demands for consolidation scenario 2. This table reports decadal annual average, daily average and system peaks demands for Rogers WD 3, Washington RWD 3 and Owasso.

Table 50
Water Demands - Scenario 2

Year	Forecasted Demands TOTAL R3+W3 Owasso		
	Annual Average (MG)	Daily Average (MGD)	System Peaks (MGD)
2010	2,622.00	7.18	11.03
2020	3,601.2	9.84	15.18
2030	4,947.10	13.60	20.86
2040	6,728.20	18.60	28.72
2050	9,342.76	25.55	39.48
2060	12,833.10	35.08	54.29

Table 51 has water demands for consolidation scenario 3 (Rogers RWD 3 + Washington RWD 3). This table reports decadal annual average, daily average and system peaks demands for Rogers RWD 3, Washington RWD 3 and Owasso.

Table 51
Water Demands - Scenario 3

Year	Forecasted Demands TOTAL R3 + Collinsville + Owasso		
	Annual Average (MG)	Daily Average (MGD)	System Peaks (MGD)
2010	2377.8	6.51	10.82
2020	3272.8	8.92	14.96
2030	4504.9	12.41	20.5
2040	6133.1	16.98	28.24
2050	8541.96	23.36	38.85
2060	11755.6	32.13	53.44

Table 52 has water demands for consolidation scenario 4. This table reports decadal annual average, daily average and system peaks demands for Collinsville, Washington RWD 3 and Owasso.

Table 52
Water Demands - Scenario 4

Year	Forecasted Demands TOTAL Collinsville + Washington 3 +Owasso		
	Annual Average (MG)	Daily Average (MGD)	System Peaks (MGD)
2010	2,129.70	5.83	8.95
2020	2,918.26	7.98	12.31
2030	3,997.3	11.05	16.83
2040	5,407.8	15.03	23.10
2050	7,504.00	20.57	31.65
2060	10,283.40	28.17	43.40

4.3.3.5 Water Demand Forecast: Individual Systems

The individual water demands are in the below tables. The average growth rate was selected for the final analysis. All scenarios include Owasso's forecasted demands under medium growth projections. Annual average water demands are used for water permit analysis, daily average demands are used for distribution storage analysis, and system peak forecasts are used for water treatment plant expansion.

Table 53 has water demands for Rogers RWD 3 and Owasso. This table reports decadal annual average, daily average and system peaks demands.

Table 53
Water Demands - Rogers RWD 3

Year	Forecasted Demands TOTAL R3 + Owasso		
	Annual Average (MG)	Daily Average (MGD)	System Peaks (MGD)
2010	2,169.10	5.94	9.75
2020	2,989.80	8.16	13.46
2030	4,121.70	11.31	18.53
2040	5,613.90	15.56	25.58
2050	7,838.36	21.43	35.24
2060	10,802.30	29.52	48.56

Table 54 has water demands for Washington RWD 3 and Owasso. This table reports decadal annual average, daily average and system peaks demands.

Table 54
Water Demands - Washington RWD 3

Year	Forecasted Demands TOTAL W3 + Owasso		
	Annual Average (MG)	Daily Average (MGD)	System Peaks (MGD)
2010	1,921.00	5.26	7.88
2020	2,635.26	7.22	10.81
2030	3,614.10	9.95	14.86
2040	4,888.60	13.61	20.44
2050	6,800.40	18.64	28.04
2060	9,330.10	25.56	38.52

Table 55 has water demands for Collinsville and Owasso. This table reports decadal annual average, daily average and system peaks demands.

Table 55
Water Demands - Collinsville 3

Year	Forecasted Demands TOTAL Collinsville + Owasso		
	Annual Average (MG)	Daily Average (MGD)	System Peaks (MGD)
2010	1,676.80	4.59	7.67
2020	2,306.80	6.30	10.59
2030	3,171.90	8.79	14.50
2040	4,293.50	11.98	19.96
2050	5,999.60	16.45	27.41
2060	8,252.60	22.61	37.67

4.3.4 Demand Assessment

The water demands for the study area were forested using low, medium, and high growth population projections for a 50-year planning horizon. The demands were forecasted for both individual and consolidated CWSs. All forecasts include Owasso's total water demands. The annual average water demands are used for water permit analysis, daily average demands are used for distribution storage analysis, and system peak forecasts are used for water treatment plant expansion.

4.4 Needs Assessment

The forecasted water demands for each consolidation scenario are used for assessing the infrastructure needs, water supply needs, and water permit needs. Owasso's water demands are included in all of the needs assessment.

4.4.1 Water Treatment Plant Size

Water treatment facilities should have a nominal capacity sufficient to treat water to meet the demands on the highest use day of the year (i.e., max day demand). First, water demands of individual CWSs are compared to the existing water treatment plant capacities over the 50-year planning horizon. The average daily demands are the forecasted daily demands under the medium growth projection.

The system peaks are added together to show the total systems' peaks (the max daily demand). It must be noted that system peaks do not necessarily happen at the same day or even the same month; however these values show the largest design criteria if the peaks were to happen at the same time.

4.4.1.1 Individual Systems

Individual water treatment plant capacities were evaluated for the expansion needs to be able to independently meet their own needs as well as the needs of Owasso. In consolidation scenarios, it is assumed that one of the existing treatment plants will be expanded to meet the forecasted demands. In the tables below the column labeled additional water required is present rate of outside water supply to the individual system. Assuming no future water treatment plant expansion and constant supply of outside water based on current rate, the shortfall/excess capacity is shown. This information will be used in the water treatment plant expansion cost estimates so a comparison can be made between consolidation scenarios and individual plants to supply water to Owasso.

Table 56 shows Washington RWD 3 decadal water treatment needs and treatment plant exhaustion point (that point at which treatment plant capacity needs to be increased). The existing plant capacity is 4.2 MGD and an expansion is currently being done that will increase capacity to 11 MGD and that is reflected in the plant capacity in the below table. In this dissertation the planning goal is to be able to meet the future water demands without additional water purchases. Washington RWD 3 current purchases are shown in the table which is approximately 15 percent of the total average demand.

Table 56
Water Treatment Needs and Treatment Plant Exhaustion - Washington RWD 3 and Owasso

WASHINGTON RWD 3 AND OWASSO					
YEAR	REQUIRED CAPACITY (MGD) Peak Demand	Daily Average (MGD)	Existing Plant Capacity (MGD)	Additional Water Req'd (MGD)*	Shortfall/ Excess (MGD)***
2010	7.88	5.26	4.2	0.79	-2.89
2020	10.81	7.22	11**	1.08	1.27
2030	14.86	9.95		1.49	-13.37
2040	20.44	13.61		2.04	-18.40
2050	28.04	18.64		2.80	-25.24
2060	38.52	25.56		3.83	-34.69

*assuming constant water supplied by outside sources (15% 2009)
**new plant online in 2011
***Column 6 (shortfall/excess) is derived by adding column 4 (existing plant capacity) and column 3 (additional water) and subtracting from column 2 (peak demand).

The expansion schedule is based upon the required water treatment needs: the existing capacity and the additional capacity that has been purchased. Washington RWD would need to expand its water treatment by the year 2030. Table 57 shows Rogers RWD 3 decadal water treatment needs and treatment plant exhaustion point (that point at which treatment plant capacity needs to be increased). The existing plant capacity is 2.5 MGD. In this dissertation the planning goal is to be able to meet the future water demands without additional water purchases. Rogers RWD 3 current purchases are shown in the table which is approximately 40 percent of the total average demand.

Table 57
Water Treatment Needs and Treatment Plant Exhaustion - Rogers RWD 3 and Owasso

ROGERS RWD 3 AND OWASSSO					
YEAR	REQUIRED CAPACITY (MGD) Peak Demand	Daily Average (MGD)	Existing Plant Capacity (MGD)	Water Req'd* (MGD)*	Shortfall/ Excess (MGD)**
2010	9.75	5.94	2.50	2.38	-4.87
2020	13.46	8.16		3.26	-10.20
2030	18.53	11.31		4.52	-14.01
2040	25.58	15.56		6.22	-19.36
2050	35.24	21.43		8.57	-26.67
2060	48.56	29.52		11.81	-36.75

*assuming constant water supplied by outside sources (40% 2009)

**Column 6 (shortfall/excess) is derived by adding column 4 (existing plant capacity) and column 3 (additional water) and subtracting from column 2 (peak demand).

The expansion schedule is based upon the required water treatment needs: the existing capacity and the additional capacity that has been purchased. Rogers RWD would need to expand its water treatment by the year 2010. Column 6 (shortfall/excess) is derived by adding column 4 (existing plant capacity) and column 3 (purchased water) and subtracting from column 2 (peak demand).

Table 58 shows Collinsville decadal water treatment needs and treatment plant exhaustion point (that point at which treatment plant capacity needs to be increased). . The existing plant capacity is 2.1 MGD. In this dissertation the planning goal is to be able to meet the future water demands without additional water purchases. Collinsville current purchases are shown in the table which is approximately 10 percent of the total average demand.

Table 58
Water Treatment Plant Size Needs and Treatment Plant Expansion-Collinsville and Owasso

COLLINSVILLE AND OWASSO					
YEAR	REQUIRED CAPACITY (MGD) Peak Demand	Daily Average (MGD)	Existing Plant Capacity (MGD)	Water Req'd* (MGD)	Shortfall/ Excess (MGD)**
2010	7.67	4.59	2.10	0.46	-5.11
2020	10.59	6.30		0.63	-9.96
2030	14.50	8.79		0.88	-13.62
2040	19.96	11.98		1.20	-18.76
2050	27.41	16.45		1.65	-25.77
2060	37.67	22.61		2.26	-35.41

*assuming constant water supplied by outside sources (10% 2009)

**Column 6 (shortfall/excess) is derived by adding column 4 (existing plant capacity) and column 3 (additional water) and subtracting from column 2 (peak demand).

The expansion schedule is based upon the required water treatment needs: the existing capacity and the additional capacity that has been purchased. Collinsville would need to expand its water treatment by the year 2010. Column 6 (shortfall/excess) is derived by adding column 4 (existing plant capacity) and column 3 (purchased water) and subtracting from column 2 (peak demand).

None of the systems included in the consolidation scenarios would be able to meet their service area water demands combined with all the demands of Owasso. However, in 2011 Washington County RWD 3 is planned to go online with its new water treatment plant with a nominal capacity of 11 MGD. By adding this capacity to its 2020 forecasts, Washington RWD 3 would be able to meet the maximum daily demand of that service area.

4.4.1.2 Consolidated Systems

If the CWSs were to consolidate, their maximum daily demands need to be added together and compared to the nominal capacities of the existing plants capacities. The assumption for the later cost calculations of consolidation scenarios is that one of the existing water treatment plants will be expanded to meet that particular scenario's treatment needs.

The below tables 59 through 62 show the maximum daily demand as well as the average forecasted daily demands for the four consolidation scenarios. Also, the outside supply (MGD) is shown. The information on these tables is used in cost estimates when one of the existing plants in the consolidation scenario is expanded to meet the forecasted future demands.

Table 59
Water Treatment Plant Size Needs - Scenario 1

SCENARIO 1 - R3 + CO + W3 + Owasso			
	REQUIRED CAPACITY (MGD) Peak Demand	Daily Average (MGD)	Outside Supply (MGD)
2010	12.1	7.75	4.84*
2020	16.68	10.6	
2030	22.83	14.67	
2040	31.38	20.03	
2050	43.09	27.48	
2060	59.17	37.69	

*55% of the existing capacity supplied from Tulsa in 2009.

For the Scenario 1 (Table 59), the consolidation could be an option after year 2010. The capacity will have to meet the forecasted peak demands. The existing combined total capacity by the individual systems in Scenario 1 is 8.8 MGD (Rogers RWD 3, Collinsville, and Washington RWD 3). An additional combined 4.85 MGD is supplied by Tulsa in 2009. In 2010 the Scenario 1 CWSs are able to meet the forecasted demands with the additional Tulsa's supply.

Table 60
Water Treatment Plant Size Needs - Scenario 2

SCENARIO 2 - R3 + W3 +Owasso			
	REQUIRED CAPACITY (MGD) Peak Demand	Daily Average (MGD)	Outside Supply (MGD)
2010	11.03	7.18	3.02*
2020	15.18	9.84	
2030	20.86	13.60	
2040	28.72	18.60	
2050	39.48	25.55	
2060	54.29	35.08	

*45% of the existing capacity supplied from Tulsa in 2009.

For the Scenario 2 (Table 60), the consolidation could take place any time after year 2010. The capacity will have to meet the forecasted peak demands. The existing combined total capacity by the individual systems in Scenario 2 is 6.7 MGD (Rogers RWD 3 and Washington RWD 3). An additional combined 3.02 MGD is supplied by Tulsa in 2009. In 2010 the Scenario 2 can meet the average daily demands (7.18 MGD) (not maximum daily demands) with their existing systems (9.72 MGD). The 2010 peak demand is 11.03 MGD for scenario 2 which is 1.31 MGD short.

Table 61
Water Treatment Plant Size Needs - Scenario 3

SCENARIO 3 - R3 + CO			
	REQUIRED CAPACITY (MGD) Peak Demand	Daily Average (MGD)	Outside Supply (MGD)
2010	10.82	6.51	2.30*
2020	14.96	8.92	
2030	20.50	12.41	
2040	28.24	16.98	
2050	38.85	23.36	
2060	53.44	32.13	

*50% of the existing capacity supplied from Tulsa in 2009.

For the Scenario 3 (Table 61), the consolidation could take place after year 2010. The capacity will have to meet the forecasted peak demands. The combined estimated total capacity by the individual systems in Scenario 3 is 4.6 MGD. An additional combined 2.30 MGD is supplied by Tulsa in 2009. In 2010 the Scenario 3 can meet the average daily demands (6.51 MGD) with their existing systems (6.90 MGD). The 2010 peak demand is 10.82 MGD for scenario 3 which is 3.92 MGD short.

Table 62
Water Treatment Plant Size Needs - Scenario 4

SCENARIO 4 - CO + W3			
	REQUIRED CAPACITY (MGD) Peak Demand	Daily Average (MGD)	Outside Supply (MGD)
2010	8.95	5.83	0.69*
2020	12.31	7.98	
2030	16.83	11.05	
2040	23.10	15.03	
2050	31.65	20.57	
2060	43.40	28.17	

*15% of the existing capacity supplied from Tulsa in 2009.

For the Scenario 4 (Table 62), the consolidation could take place after year 2010. The capacity will have to meet the forecasted peak demands. The combined estimated total capacity by the individual systems in Scenario 4 is 6.3 MGD. An additional combined 0.69 MGD is supplied by Tulsa in 2009. In 2010 the Scenario 4 are their capacity for to meet the average daily demands (5.83 MGD) with their existing systems (5.29 MGD). The 2010 peak demand is 8.95 MGD for scenario 4 which is 3.66 MGD short.

4.4.2 Distribution System Storage

Distribution storage capacities were evaluated for individual and consolidation scenarios.

4.4.2.1 Distribution Water Storage

The capacity of the distribution system storage should be equal to, or in excess of, one day's consumption with consideration of fire flow needs and emergency storage. The methodology section (Section 3) explains in detail what factors are included in the distribution storage and how these were calculated. Each existing systems' distribution tank capacities need to be inventoried. Tables 63 through 66 show the existing distribution storage for each individual system and Owasso.

Table 63
Distribution Storage – Rogers RWD 3

Tank	Capacity (GAL)
Tacora	325,000
West Foyil	207,000
Bushyhead Tower	179,000
East Foyil	66,000
Lipe Tower	30,000
Woodcrest	182,000
Keetonville	200,000
Owasso I	300,000
Owasso II	125,000
Total	**1,614,000**

Table 64
Distribution Storage – Washington RWD 3

Tank	Capacity (GAL)
2 Million Gallon Tank	2,000,000
Pavey Tank	1,000,000
Hogue Tank	560,000
Scott Tank	200,000
Miller Tank	211,000
Total	**3,971,000**

Table 65
Distribution Storage – Collinsville

Tank	Capacity (GAL)
1	500,000
2	2,000,000
Total	**2,500,000**

Table 66
Distribution Storage – Owasso

Tank	Capacity (Gallons)
Hwy 169	2,000,000
Ator	500,000
Bailey Ranch	2,000,000
Total	**4,500,000**

The future distribution storage requirements are listed in the below tables based on the average expected growth rates (as used in water demand forecasts). Tables 67 through 69 summarize the current distribution storage capacities. The final row of each table summarizes the required distribution storage available. All tables use both Owasso's and the CWSs water demands and their current capacities.

Table 67
Distribution Storage Needs – Rogers RWD 3 and Owasso

	2010	2020	2030	2040	2050	2060
% Average Day Demand	15	15	15	15	15	15
% Emergency Storage	30	30	30	30	30	30
AD Demand (MGD)	5.94	8.16	11.31	15.56	21.43	29.52
Steady State Supply (MGD) (15% of ADD)	0.89	1.22	1.69	2.27	3.21	4.43
FF-storage (MGD)	2.46	3.32	4.47	6.00	8.00	10.55
Emergency Storage (MGD) (30% of above)	2.79	3.81	5.24	7.15	9.79	13.35
Total Required Storage (MG)	6.14	8.35	11.401	15.42	21.00	28.33
Current Capacity (MG)	5.60	5.60	5.60	5.60	5.60	5.60
% Required Storage Available	**91%**	**67%**	**49%**	**36%**	**27%**	**20%**

According to the above information, Rogers RWD 3 lacks adequate future storage to meet the required distribution storage demands for Owasso and Rogers RWD 3 service area.

Table 68
Distribution Storage Needs –Washington RWD 3 and Owasso

	2010	2020	2030	2040	2050	2060
% Average Day Demand	15	15	15	15	15	15
% Emergency Storage	30	30	30	30	30	30
AD Demand (MGD)	5.26	7.22	9.95	13.61	18.64	25.56
Steady State Supply (MGD) (15% of ADD)	0.79	1.08	1.49	2.04	2.80	3.83
FF-storage (MGD)	2.92	3.92	5.24	6.98	9.24	12.17
Emergency Storage (MGD) (30% of above)	2.69	3.67	5.00	6.79	9.20	12.47
Total Required Storage (MG)	6.40	8.67	11.74	15.81	21.24	28.47
Current Capacity (MG)	7.90	7.90	7.90	7.90	7.90	7.90
% Required Storage Available	**123%**	**91%**	**67%**	**50%**	**37%**	**28%**

According to the above information, Washington RWD 3 would have adequate distribution storage to meet the required demands for Owasso and Washington RWD 3 service area in 2010. After 2020 the system has less than 100 percent of the required storage available.

Table 69
Distribution Storage Needs –Collinsville and Owasso

	2010	2020	2030	2040	2050	2060
% Average Day Demand	15	15	15	15	15	15
% Emergency Storage	30	30	30	30	30	30
AD Demand (MGD)	4.59	6.3	8.79	11.98	16.45	22.61
Steady State Supply (MGD) (15% of ADD)	0.69	0.95	1.32	1.80	2.47	3.39
FF-storage (MGD)	2.31	3.11	4.17	5.57	7.39	9.75
Emergency Storage (MGD) (30% of above)	2.28	3.11	4.28	5.80	7.89	10.72
Total Required Storage (MG)	5.27	7.16	9.77	13.16	17.75	23.86
Current Capacity (MG)	6.5	6.5	6.5	6.5	6.5	6.5
% Required Storage Available	**123%**	**91%**	**67%**	**49%**	**37%**	**27%**

According to the above information, Collinsville system will have adequate storage through 2010. After 2020 the system has less than 100 percent of the required storage available. As indicated in Table 69, a total of 7.1 MG of available storage under 2040 conditions is less than 50 percent.

4.4.3 Water Rights

The raw water supplies considered within the study area include the existing water raw water supplies: Lake Oologah, Lake Skiatook, and Caney River. The existing water rights are estimated equal to, or in excess of, projected average daily usage under medium growth scenarios. As a general rule for water resources master planning, a municipality should maintain water rights equal to, or in excess of, its projected average daily usage under drought conditions, provided that sufficient raw water storage and conveyance facilities are available.

All scenarios include Owasso's demands.

4.4.3.1 Existing Water Rights

Tables 70 through 73 show the existing and reallocated water rights for each consolidation scenario.

Table 70
Existing Water Rights – Scenario 1

SCENARIO 1 - R3 + CO + W3 + Owasso								
YEAR	Rogers 3		Washington 3		Collinsville		TOTAL	
2009	MGD	AFY	MGD	AFY	MGD	AF	MGD	AFY
Oologah	2.70	3,000	1.87	2,100	5.20	3,360	9.77	8,460
Skiatook	0.55	611.0					0.55	611.0
Caney River			23.55	26,377			23.55	26,377
Reallocation								
Skiatook	0.46	500	0.46	500			0.92	1,000

Table 71
Existing Water Rights – Scenario 2

SCENARIO 2 - R3 + W3 +Owasso								
YEAR	Rogers 3		Washington 3				TOTAL	
2009	MGD	AFY	MGD	AFY			MGD	AFY
Oologah	2.70	3,000	1.87	2,100			4.57	5,100
Skiatook	0.55	611					0.55	611
Caney River			23.55	26,377			23.55	26,377
Reallocation								
Skiatook	0.46	500	0.46	500			0.92	1,000

Table 72
Existing Water Rights - Scenario 3

SCENARIO 3 - R3 + CO								
YEAR	Rogers 3				Collinsville		TOTAL	
2009	MGD	AFY			MGD	AFY	MGD	AFY
Oologah	2.70	3,000			5.20	3,360	5.90	6,360
Skiatook	0.55	611					0.55	611
Reallocation								

Skiatook	0.46	500					0.46	500

Table 73
Existing Water Rights – Scenario 4

SCENARIO 4 - CO + W3								
YEAR			Washington 3		Collinsville		TOTAL	
2009			MGD	AFY	MGD	AFY	MGD	AFY
Oologah			1.87	2,100	5.2	3,360	7.07	5,460
Caney River			23.55	26,377			23.55	26,377
Reallocation								
Skiatook			0.46	500			0.46	500

The Tulsa Metropolitan Water Authority obtains 50 percent of its current water supply from Oologah Lake and they are currently authorized 83 percent of the reservoir’s water rights (OWRB, 2010). The existing supply by Tulsa to scenario CWSs is equated into water right volumes and “transferred’ to the consolidation partners for the purpose of this study.

4.4.3.1 Water Rights Gaps

Tables 74 through 77 show the exiting water rights with the reallocation and gaps for each consolidation scenario. The water rights stay constant throughout the 50-year planning period.

Table 74
Water Rights Gaps - Scenario 1

SCENARIO 1 - R3 + CO + W3 + Owasso (MGD)								
YEAR	Daily Av.	Existing Water Rights			Realloc.	Needed Water Rights	Add Tulsa Water Rights	Needed Water Rights if Tulsa Transfers
		Oologah	Skiatook	Caney				
2010	7.75	9.77	0.55	23.5	0.92	0	4.84*	0
2020	10.6	9.77	0.55	23.5	0.92	0	4.84*	0
2030	14.67	9.77	0.55	23.5	0.92	0	4.84*	0
2040	20.3	9.77	0.55	23.5	0.92	0	4.84*	0
2050	27.48	9.77	0.55	23.5	0.92	0	4.84*	0
2060	37.69	9.77	0.55	23.5	0.92	**-2.95**	4.84*	0

*55% of the existing capacity supplied from Tulsa in 2009.

In Scenario 1 (Table 74), the consolidated system would have excess water rights in every decade, except for 2060. These excess quantities are 26.99 MGD in 2010, 24.12 MGD in 2020, 20.07 MGD in 2030, 14.4 MGD in 2040, 7.26 MGD in 2050, and -2.95 MGD in 2060 without the supplemental Tulsa transfer.

Table 75
Water Rights Gaps - Scenario 2

SCENARIO 2 - R3 + W3 +Owasso (MGD)								
YEAR	Daily Av.	Existing Water Rights			Realloc.	Needed Water Rights	Add Tulsa Water Rights	Needed Water Rights with Tulsa Transfer
		Oologah	Skiatook	Caney				
2010	7.18	4.57	0.55	23.5	0.92	0	3.02*	0
2020	9.84	4.57	0.55	23.5	0.92	0	3.02*	0
2030	13.60	4.57	0.55	23.5	0.92	0	3.02*	0
2040	18.60	4.57	0.55	23.5	0.92	0	3.02*	0
2050	25.55	4.57	0.55	23.5	0.92	0	3.02*	0
2060	35.08	4.57	0.55	23.5	0.92	**-5.54**	3.02*	**-2.52**

*45% of the existing capacity supplied from Tulsa in 2009.

In Scenario 2 (Table 75), the consolidated system would have excess water rights in every decade, except 2060. These are 22.36 MGD in 2010, 19.70 MGD in 2020, 15.94 MGD in 2030, 10.94 MGD in 2040, and 3.99 MGD in 2050. In 2060, there is need for additional water rights of 5.54 MGD. If Tulsa's exiting water rights for the amount supplied to this scenario were transferred, the 2060 shortage would be -5.52 MGD.

Table 76
Water Rights Gaps - Scenario 3

SCENARIO 3 - R3 + CO (MGD)								
YEAR	Daily Av.	Existing Water Rights			Realloc.	Needed Water Rights	Add Tulsa Water Rights	Needed Water Rights with Tulsa Transfer
		Oologah	Skiatook	Caney River				
2010	6.51	5.90	0.55	0	0.46	0	2.30*	0
2020	8.92	5.90	0.55	0	0.46	**-2.01**	2.30*	0
2030	12.41	5.90	0.55	0	0.46	-5.5	2.30*	**-3.20**
2040	16.98	5.90	0.55	0	0.46	-10.07	2.30*	-7.77
2050	23.36	5.90	0.55	0	0.46	-16.45	2.30*	-14.15
2060	32.13	5.90	0.55	0	0.46	-25.22	2.30*	-22.92

*50% of the existing capacity supplied from Tulsa in 2009.

In Scenario 3 (Table 76), the lack of Washington RWD 3 (1.87 MGD Oologah, 23.55 MGD Caney River, and 0.46 MGD Skiatook) water rights impacts this scenario. From year 2020 throughout the planning horizon, this scenario has insufficient water rights to meet the average daily demands.

Table 77
Water Rights Gaps - Scenario 4

SCENARIO 4 - CO + W3 (MGD)								
YEAR	Daily Av.	Existing Water Rights			Realloc.	Needed Water Rights	Add Tulsa Water Rights	Needed Water Rights with Tulsa Transfer
		Oologah	Skiatook	Caney River				
2010	5.83	7.07	0	23.5	0.46	0	0.69*	0
2020	7.98	7.07	0	23.5	0.46	0	0.69*	0
2030	11.05	7.07	0	23.5	0.46	0	0.69*	0
2040	15.03	7.07	0	23.5	0.46	0	0.69*	0
2050	20.57	7.07	0	23.5	0.46	0	0.69*	0
2060	28.17	7.07	0	23.5	0.46	0	0.69*	0

*15% of the existing capacity supplied from Tulsa in 2009.

In Scenario 4 (Table 77), every decade would have excess water rights. These are 25.20 MGD in 2010, 2305 MGD in 2020, 19.98 MGD in 2030, 16 MGD in 2040, and 2.86 MGD in 2050 without supplemental Tulsa transfer.

4.4.4 Development of Project Costs

The types of costs considered in this dissertation include the construction cost of the water treatment plant and the schedule, operation and maintenance (O&M) costs of each water treatment plant, and the needed treated water storage. Below sections discuss the costs estimating methods. Costs were calculated for individual and consolidation scenarios using construction cost estimates for conventional coagulation alum coagulation process treatment, O&M costs per 1,000 gallons of water treated, and distribution storage The schedules for new plant and storage addition construction are used for discounting and inflation calculations for the 50-year planning period. The final cost estimates are discounted and include O&M costs.

4.4.4.1 Water Treatment Plant Costs

The expansion construction costs of the existing water treatment in each scenario are based on a 20-year life-cycle of a plant. The construction cost for each plant is estimated using the EPA construction cost estimates (EPA, 1979) as reported in Culp, Wesner & Culp, 1986 (pp 998, Figure 30-1). These conventional water treatment construction costs were updated and adjusted using construction cost indices (CCI): 4146 (for year 1984 when curve was generated) and 8672 (for February, 2010). This curve was then adjusted for construction cost (considering additional 35% of treatment plant cost) to get total construction cost of the plant. This value was further adjusted for administration, legal and engineering fees (considering additional 35% of total construction cost) to get the total project cost. The construction costs per size of a plant are included in Appendix D. An updated ENR Index of 8672 (February 2010) is used for all cost updates (Appendix E).

Based on personal conversations with a Professional Engineer, Mr. John Powell, from Weston Solutions, Inc., a consulting firm specializing in water and waste water systems, it was confirmed that the construction costs derived using the 1986 cost curves needed to be adjusted for construction costs as well as adjusted for administration, legal and engineering fees by considering an additional 70% to get the total project cost estimates (Williams, 1986). The typical construction cost components are included in the overall cost (Appendix C).

4.4.4.1.1 Individual WTP Expansion Schedule

Owasso's water demands are included in the individual WTP expansion schedules. The assumption is that the existing facilities will be expanded to meet the required demands throughout the planning horizon, therefore; the location of the expanded plant would be one of the existing plant sites. The expansion schedules are based on peaking demands as forecasted earlier. These demands are not annual average demands but the maximum daily demands for design flow. The expansion schedules are based on the assumptions that plants and their components have a design life of approximately twenty years. The below tables show the individual CWSs' (Washington RWD 3, Rogers RWD 3, and Collinsville) start of estimated required expansion WTP as based on the forecasted demands. The major plant expansions are estimated to include conventional water treatment plant construction for additional capacity.

Table 78
WTP Expansion Schedule- Washington RWD 3

YEAR	REQUIRED CAPACITY (MGD) Peak Demand	WTP Capacity (MGD)	Shortfall/ Excess (MGD)	Expansion Conventional WTP (MGD)	Start Construction (year)
2010	7.88	4.2	-3.05	6.8*	2009
2020	10.81	11	1.84		
2030	14.86	21	6.14	10	2020
2040	20.44	21	-0.66	20	2040
2050	28.04	41	12.96		
2060	38.52	41	2.48		

*Scheduled expansion 2011 total capacity 11 MGD.

The shortfall was calculated earlier by taking out Tulsa's supply of water. For Washington RWD 3 this is 15 percent of the total 2009 demand. In order to meet required capacity the future plant expansion is assumed to begin at least two years prior to the critical point of not meeting the required capacity. Washington RWD 3 would need to begin construction of the new plant expansion in 2025 to meet the 2030 critical point. In 2040, additional capacity would need to be constructed to meet the required capacities of 2040 onwards.

Table 79
WTP Expansion Schedule- Rogers RWD 3

YEAR	REQUIRED CAPACITY (MGD) Peak Demand	WTP Capacity (MGD)	Shortfall/ Excess (MGD)	Expansion Conventional WTP (MGD)	Start Construction (year)
2010	9.75	2.5	-6.25	17	now
2020	13.46	19.5	6.04		
2030	18.53	19.5	0.97	17	2030
2040	25.58	36.5	10.92		
2050	35.24	36.5	0.76	20	2050
2060	48.56	56.5	7.94		

The shortfall was calculated earlier by taking out Tulsa's supply of water. For Rogers this is 40 percent of the 2009 demand. In order to meet required capacity the future plant expansion is assumed to begin at least two years prior to the critical point of not meeting the required capacity. Rogers RWD 3 would need to begin construction of the new plant expansion now (2010) in order to meet the current critical point. In 2030, additional capacity would need to be constructed to meet the required capacities of 2050. In 2050, an additional capacity would need to be constructed to meet the future demands.

Table 80
WTP Expansion Schedule - Collinsville

YEAR	REQUIRED CAPACITY (MGD) Peak Demand	WTP Capacity (MGD)	Shortfall/ Excess (MGD)	Expansion Conventional WTP (MGD)	Start Construction (year)
2010	7.67	2010	7.67	2.1	now
2020	10.59	2020	10.59	15	
2030	14.50	2030	14.5	15	2030
2040	19.96	2040	19.96	28	
2050	27.41	2050	27.41	28	2050
2060	37.67	2060	37.67	44	

The above water treatment plant expansion timing is based on the forecasted maximum daily demands for the design flow. The shortfall was calculated earlier by taking out Tulsa's supply of water. For Collinsville this is 10 percent (2009). In order to meet required capacity the future plant expansion is assumed to begin at least two years prior to the critical point of not meeting the required capacity. Collinsville would need to begin construction of the new plant expansion in now (2010) in order to meet the current critical point. In 2030, additional capacity would need to be constructed to meet the required capacities of 2050. In 2050, additional capacity would need to be constructed to meet the future demands.

4.4.4.1.2 Individual WTP Construction Costs

It is assumed that the salvage values of water treatment plants are minimal. Although there will be some salvage value of infrastructure at the end of the evaluation period, it is not considered in the economic evaluation which focuses purely on a cash flow scenario. Typically, an existing water treatment plant expansion can be calculated 50 percent of the actual construction cost (Kawamura, 2000). This deduction is not reflected in these cost estimates. By estimating the construction cost as if a new plant was constructed will accommodate any future more stringent water quality requirements that the existing WTPs may have difficulty to meet with the existing treatment design.

Table 81
Individual WTP Water Treatment Plant Construction Costs

YEAR	Washington RWD 3		Rogers RWD 3		Collinsville	
	MGD	$Million	MGD	$Million	MGD	$Million
2010 (1)						
2020 (10)			17	74.62	13	54.47
2030 (20)	10	29.28	17	91.84	13	67.04
2040 (30)	20	128.25				
2050 (40)			20	148.5	16	118.8
2060 (50)						

The estimated present value of WTP construction costs for each consolidation scenario is calculated by assuming that only one of the exiting CWS will be expanded to meet the consolidation scenario’s water demands throughout the forecasting period.

4.4.4.1.3 Consolidation Expansion Schedule

The planning goal in this dissertation is to identify the timing for consolidation and the required water treatment plant expansion schedule based on decadal demands. The consolidation expansion schedules are shown in the below tables for each scenario. Each scenario expansion schedule is estimated using an assumption that one of the existing plants within the consolidation scenario will be expanded to meet the forecasted demands. The plant expansion timing is indicated in each table. The consolation scenarios are as follows:

- 1A,B,C: Rogers RWD 3 + Collinsville + Washington RWD 3
    - A: expand Washington RWD 3 (Table 82)
    - B: expand Rogers RWD 3 (Table 83)
    - C: expand Collinsville (Table 84)
- 2A,B: Rogers RWD 3 + Washington RWD 3:
    - A: expand: Washington RWD 3 (Table 85)
    - B: expand Rogers RWD 3 (Table 86)
- 3A,B: Rogers RWD + Collinsville:
    - A: expand Collinsville (Table 87
    - B: expand Rogers RWD 3 (Table 88)
- 4A,B: Collinsville + Washington RWD 3:
    - A: expand Collinsville (Table 89)
    - B: expand: Washington RWD 3 (Table 90)

Table 82
WTP Expansion Schedule - Scenario1A

Demands: Rogers RWD 3+ Collinsville + Washington RWD 3 + Owasso. Plant: Washington RWD 3						
YEAR	REQUIRED CAPACITY (MGD) Peak Demand	Outside supply (MGD)	WTP Capacity (MGD)	Shortfall/ Excess (MGD)	Expansion Conventional WTP (MGD)	Start Construction (year)
2010	12.10	4.84	4.2	-12.74	**6.80***	**2009**
2020	16.68	4.84	11	-10.52	**22**	**2020**
2030	22.83	4.84	33	10.17		
2040	31.38	4.84	33	1.62	**26**	**2040**
2050	43.09	4.84	59	9.91		
2060	59.17	4.84	59	0		

*Scheduled expansion 2011 total capacity 11 MGD.

Table 83
WTP Expansion Schedule - Scenario1B

Demands: Rogers RWD 3 + Collinsville + Washington RWD 3 + Owasso. Plant: Rogers RWD 3						
YEAR	REQUIRED CAPACITY (MGD) Peak Demand	Outside supply (MGD)	WTP Capacity (MGD)	Shortfall/ Excess (MGD)	Expansion Conventional WTP (MGD)	Start Construction (year)
2010	12.10	4.84	2.5	-14.44		
2020	16.68	4.84	2.5	-21.52	**35**	**2020**
2030	22.83	4.84	37.5	9.83		
2040	31.38	4.84	37.5	1.28	**10**	**2040**
2050	43.09	4.84	47.5	0	**15**	**2050**
2060	59.17	4.84	62.5	1.51		

Table 84
WTP Expansion Schedule – Scenario 1C

Demands: Rogers RWD 3 + Collinsville + Washington RWD 3 + Owasso. Plant: Collinsville						
YEAR	REQUIRED CAPACITY (MGD) Peak Demand	Outside supply (MGD)	WTP Capacity (MGD)	Shortfall/ Excess (MGD)	Expansion Conventional WTP (MGD)	Start Construction (year)
2010	12.10	4.84	2.10	-14.84	**30.0**	**2012**
2020	16.68	4.84	32.10	10.58		
2030	22.83	4.84	32.10	4.43	**20.0**	**2030**
2040	31.38	4.84	52.10	15.88		
2050	43.09	4.84	52.10	4.17	**15.0**	**2050**
2060	59.17	4.84	67.10	3.09		

Table 85
WTP Expansion Schedule – Scenario 2A

Demands: Rogers RWD 3 + Washington RWD 3 + Owasso. Plant: Washington RWD 3						
YEAR	REQUIRED CAPACITY (MGD) Peak Demand	Outside supply (MGD)	WTP Capacity (MGD)	Shortfall/ Excess (MGD)	Expansion Conventional WTP (MGD)	Start Construction (year)
2010	11.03	3.02	4.20	-9.85	**6.80**	**2012**
2020	15.18	3.02	11.0	-7.2	**22.0**	**2020**
2030	20.86	3.02	33.0	9.12		
2040	28.72	3.02	33.0	1.26	**25.0**	**2040**
2050	39.48	3.02	58.0	15.5		**2050**
2060	54.29	3.02	58.0	0.69		

*Scheduled expansion 2011 total capacity 11 MGD.

Table 86
WTP Expansion Schedule – Scenario 2B

Demands: Rogers RWD 3 + Washington RWD 3 + Owasso. Plant: Rogers RWD 3						
YEAR	REQUIRED CAPACITY (MGD) Peak Demand	Outside supply (MGD)	WTP Capacity (MGD)	Shortfall/ Excess (MGD)	Expansion Conventional WTP (MGD)	Start Construction (year)
2010	11.03	3.02	2.50	-11.55	**25.0**	**2012**
2020	15.18	3.02	27.5	9.30		
2030	20.86	3.02	27.5	3.62	**15.0**	**2030**
2040	28.72	3.02	42.5	10.76		
2050	39.48	3.02	42.5	0	**15.0**	**2050**
2060	54.29	3.02	57.5	0.19		

Table 87
WTP Expansion Schedule – Scenario 3A

Demands: Rogers RWD 3 + Collinsville + Owasso. Plant: Collinsville						
YEAR	REQUIRED CAPACITY (MGD) Peak Demand	Outside supply (MGD)	WTP Capacity (MGD)	Shortfall/ Excess (MGD)	Expansion Conventional WTP (MGD)	Start Construction (year)
2010	10.82	2.30	2.1	-11.02	**20.0**	**2012**
2020	14.96	2.30	20.0	5.04		
2030	20.5	2.30	20.0	-0.5	**20.0**	**2030**
2040	28.24	2.30	40.0	11.76		
2050	38.85	2.30	40.0	1.15	**15.0**	**2050**
2060	53.44	2.30	55.0	1.56		

Table 88
WTP Expansion Schedule – Scenario 3B

Demands: Rogers RWD 3 + Collinsville + Owasso. Plant: Rogers RWD 3						
YEAR	REQUIRED CAPACITY (MGD) Peak Demand	Outside supply (MGD)	WTP Capacity (MGD)	Shortfall/ Excess (MGD)	Expansion Conventional WTP (MGD)	Start Construction (year)
2010	10.82	2.30	2.5	-10.62	**20.0**	**2012**
2020	14.96	2.30	22.5	5.24		
2030	20.5	2.30	22.5	-0.30	**20.0**	**2030**
2040	28.24	2.30	42.5	11.96		
2050	38.85	2.30	42.5	1.35	**15.0**	**2050**
2060	53.44	2.30	57.5	1.76		

he expansion schedules are identical for Scenarios 3A and 3B.

Table 89
WTP Expansion Schedule – Scenario 4A

Demands: Washington RWD 3 + Collinsville + Owasso. Plant: Collinsville						
YEAR	REQUIRED CAPACITY (MGD) Peak Demand	Outside supply (MGD)	WTP Capacity (MGD)	Shortfall/ Excess (MGD)	Expansion Conventional WTP (MGD)	Start Construction (year)
2010	8.95	0.69	2.10	-7.54	**15.0**	**2012**
2020	12.31	0.69	17.10	4.10		
2030	16.83	0.69	17.10	-0.42	**15.0**	**2030**
2040	23.10	0.69	32.10	8.31		
2050	31.65	0.69	32.10	-0.24	**12.0**	**2050**
2060	43.40	0.69	44.10	0		

Table 90
WTP Expansion Schedule – Scenario 4B

Demands: Washington RWD 3 + Collinsville + Owasso, Plant: Washington RWD 3						
YEAR	REQUIRED CAPACITY (MGD) Peak Demand	Outside supply (MGD)	WTP Capacity (MGD)	Shortfall/ Excess (MGD)	Expansion Conventional WTP (MGD)	Start Construction (year)
2010	8.95	0.69	4.2	5.44	**6.8**	**2011**
2020	12.31	0.69	11	-2.0	**20.0**	**2020**
2030	16.83	0.69	31	13.48		
2040	23.10	0.69	31	7.21	**13.0**	**2040**
2050	31.65	0.69	44	11.66		
2060	43.40	0.69	44	-0.09		

The above water treatment plant expansion timing is based on the forecasted maximum daily demands for the design flow. The timing of the expansion is assumed to begin at the beginning of the decade unless noted differently. Washington RWD 3 has already begun a transmission to a larger plant and is estimated to be on-line by 2011. The cost for that expansion is not included here.

4.4.4.1.4 Consolidated Scenario WTP Construction Costs

The inflation rate of 2.1 percent is applied to all scenario expansion costs. These are annualized costs without discounting. The discounted costs are included in total costs in the Economic Evaluation. As mentioned earlier, the each scenario is expected to expand one of the existing plants within the scenario to meet the consolidated demands. Tables 91 though 94 have expansion schedules and the associated costs.

Table 91
WTP Construction Costs - Scenario 1 A, B, C

Rogers RWD 3+ Collinsville + Washington RWD 3 + Owasso. Plant: Washington RWD 3						
YEAR	Scenario 1A Plant: Washington RWD 3		Scenario 1B Plant: Rogers RWD 3		Scenario 1C Plant: Collinsville	
	MGD	$Million	MGD	$Million	MGD	$Million
2010 (1)					30.0	101.2
2020 (10)	22.0	96.59	35.0	153.53		
2030 (20)					20.0	108
2040 (30)	26.0	192.47	10.0	34.77		
2050 (40)			15.0	111.32	15.0	111.32
2060 (50)						

Table 92
WTP Construction Costs - Scenario 2 A, B

Rogers RWD 3 + Washington RWD 3 + Owasso.				
YEAR	Scenario 2A Plant: Washington RWD 3		Scenario 2B Plant: Rogers RWD 3	
	MGD	$Million	MGD	$Million
2010 (1)			25.0	84.4
2020 (10)	22.0	96.59		
2030 (20)			15.0	80.96
2040 (30)	25.0	160.36		
2050 (40)			15.0	111.32
2060 (50)				

Table 93
WTP Construction Costs - Scenario 3 A, B

Demands: Rogers RWD 3 + Collinsville + Owasso.				
YEAR	Scenario 3A Plant: Collinsville		Scenario 3B Plant: Rogers RWD 3	
	MGD	$Million	MGD	$Million
2010 (1)	20.0	67.5	20.0	67.5
2020 (10)				
2030 (20)	20.0	108.0	20.0	108.0
2040 (30)				
2050 (40)	15.0	111.32	15.0	111.32
2060 (50)				

Table 94
WTP Construction Costs - Scenario 4 A, B

Washington RWD 3 + Collinsville + Owasso				
YEAR	Scenario 4A Plant: Collinsville RWD 3		Scenario 4B Plant: Washington RWD 3	
	MGD	$Million	MGD	$Million
2010 (1)	15.0	50.63		
2020 (10)			20.0	87.75
2030 (20)	15.0	81.0		
2040 (30)			13.0	79.67
2050 (40)	12.0	64.0		
2060 (50)				

4.4.4.2 Operation and Maintenance Costs

Table 95 reports the treatment plant capacities and the associated O&M costs per 1,000 gallons treated for a conventional treatment technology that were used in the O&M costs estimates. These represent the typical average O&M cost estimates per plant size from CWSs in Northeastern Oklahoma in 2005 (Mansur, 2006).

The O&M cost used in the cost evaluation were compared to the 2009 O&M costs of the AWWA 2010 update (AWWMA, 2010). This reveals that the economies of size exists in O&M and that the O&M costs for conventional water treatment are generally cheaper than the costs associated with more advanced disinfectant treatment technologies.

Table 95
Typical O&M Costs in Northeastern Oklahoma (2005)

Treatment Plant Capacity (MGD)	O&M per 1,000 Gallons Water Treated 2005 (Mansur, 2006)
2.1	1.50
3.0	1.35
6.2	1.00
9.3	0.80
22	0.44
24	0.40
25	0.39
30	0.35
39	0.34

4.4.4.3 Water Storage Costs

Distribution system storage should be equal to, or in excess of, one day's consumption with consideration of fire flow needs and emergency storage. In this dissertation it is assumed that the distribution storage consists of three components: operating storage, fire flow storage, and emergency storage. The goal is to show when the consolidation scenarios will need to increase their treated water storage and approximate costs. The costs for the distribution storage were estimated using ICIP Cost Estimating Guide of 2007 (ICIP, 2007). The guide recommends using a $0.42 per gallon of water stored. The cost estimate includes 3.5 persons per household.

4.4.4.3.1 Individual Systems

Below tables 96 through 99 include construction cost estimates for individual systems for required storage. The costs include 2.1 percent inflation rate per year.

Table 96
Estimated Water Storage Cost – Rogers RWD 3

ROGERS RWD 3					
YEAR	Req'd Storage (MGD)	Total Storage (MG)	Difference (MG)	New Storage (MG)	Cost ($Million)
2010	1.52	1.6	0.08	2	0.8
2020	2.07	3.6	1.53		
2030	2.85	3.6	0.75	3	1.92
2040	3.92	6.6	2.68		
2050	5.38	6.6	1.22	4	3.52
2060	7.36	10.6	3.24		

Table 97
Estimated Water Storage Cost – Washington WRD 3

Washington RWD 3					
YEAR	Req'd Storage (MGD)	Total Storage (MG)	Difference (MG)	New Storage (MG)	Cost ($Million)
2010	1.78	3.9	2.12		
2020	2.38	3.9	1.52		
2030	3.18	3.9	0.72	4	2.56
2040	4.24	7.9	3.66		
2050	5.65	7.9	2.25		
2060	7.5	7.9	0.4		

Table 98
Estimated Water Storage Cost – Collinsville

Collinsville					
YEAR	Req'd Storage (MGD)	Total Storage (MG)	Difference (MG)	New Storage (MG)	Cost ($Million)
2010	0.65	2.5	1.85		
2020	0.87	2.5	1.63		
2030	1.21	2.5	1.29		
2040	1.6	2.5	0.9		
2050	2.15	2.5	0.35	2	1.76
2060	2.89	4.5	1.61		

Table 99
Estimated Water Storage Cost – Owasso

Owasso					
YEAR	Req'd Storage (MGD)	Total Storage (MG)	Difference (MG)	New Storage (MG)	Cost ($Million)
2010	4.62	4	-0.62	4	1.6
2020	6.28	8	1.72		
2030	8.56	8	-0.56	8	5.12
2040	11.57	16	4.43		
2050	15.6	16	0.4	12	10.56
2060	20.97	28	7.03		

4.4.4.3.2 Consolidated Systems

Tables 100 through 103 include the costs of water storage for the consolidation scenarios.

Table 100
Estimated Water Storage Cost – Scenario 1

SCENARIO 1					
YEAR	Req'd Storage (MGD)	Total Storage (MG)	Difference (MG)	New Storage (MG)	Cost ($Million)
2010	8.7	12	3.3		
2020	11.61	12	0.39	10	5.2
2030	15.8	22	6.2		
2040	21.32	22	0.68	16	11.4
2050	28.77	38	9.23		
2060	38.76	38	-0.76		

Table 101
Estimated Water Storage Cost – Scenario 2

SCENARIO 2					
YEAR	Req'd Storage (MGD))	Total Storage (MG)	Difference (MG)	New Storage (MG)	Cost ($Million)
2010	7.91	8.1	0.19	7	2.8
2020	10.74	15.1	4.36		
2030	14.59	15.1	0.51	16	10.24
2040	19.72	31.1	11.38		
2050	26.62	31.1	4.48	5	4.4
2060	35.83	36.1	0.27		

Table 102
Estimated Water Storage Cost – Scenario 3

SCENARIO 3					
YEAR	Req'd Storage (MGD)	Total Storage (MG)	Difference (MG)	New Storage (MG)	Cost ($Million)
2010	6.79	4.1	-2.69	9	3.6
2020	9.23	13.1	3.87		
2030	12.62	13.1	0.48	11	7.04
2040	17.08	24.1	7.02		
2050	23.13	24.1	0.97	13	11.44
2060	31.23	37.1	5.87		

Table 103
Estimated Water Storage Cost – Scenario 4

SCENARIO 4					
YEAR	Req'd Storage (MGD)	Total Storage (MG)	Difference (MG)	New Storage (MG)	Cost ($Million)
2010	7.05	6.4	-0.65	7	2.8
2020	9.54	13.4	3.86		
2030	12.95	13.4	0.45	10	6.4
2040	17.40	23.4	6.00		
2050	23.40	23.4	0.00	13	11.44
2060	31.36	36.4	5.04		

4.4.4.4 Cost Summaries

The above section has developed the construction schedule for water treatment plant and distribution storage construction. Based on the expansion schedule, the associated costs and the O&M costs were estimated. The gaps in water treatment and storage were established using the demand forecasts and the baseline existing treatment and storage capacities for each individual system and the consolidation scenario. The decadal demands establish the start of the construction schedule.

4.4.5 Economic Evaluation

The total costs of water treatment plant construction (conventional water treatment), O&M costs and treated water storage (for operational, emergency, and fire needs) costs were evaluated decadally for all scenarios 1 through 4 and for individual CWSs. The final costs were calculated for 2.1 percent inflation including annual O&M and the construction costs of water treatment plant and storage were discounted for seven percent throughout the planning period. All scenarios include Owasso demands and their storage expansion. The construction cost tables for a conventional water treatment are included in Appendix C. Construction costs for water treatment and water storage is a onetime cost at the treatment and storage expansion. The O&M costs are estimated for each year of plan operation and assumed to remain constant throughout the planning period. The entire costs were added together at end of the planning period. The total costs (millions of dollars) were divided by the total forecasted average daily water demand (MG) during the same planning period. This number (dollars/gallons) is multiplied by a 1,000 to get the cost per 1,000 gallons of water. The costs of water in typically reported in $/1,000 gallons (Oklahoma Municipal Utility Costs, 2002).

Within each consolidation scenario, there are sub-scenarios (1ABC; 2 AB; 3AB; and 4AB). The scenarios include:

- 1A,B,C: Rogers RWD 3 + Collinsville + Washington RWD 3
- 2A,B: Rogers RWD 3 + Washington RWD 3
- 3A,B: Rogers RWD + Collinsville
- 4A,B: Collinsville + Washington RWD 3

The entire 50 year planning period construction costs for water treatment and storage and the associated annual water treatment O&M costs for Scenario 1 A, B and C are shown in Table 104. The total net present cost for each scenario includes the expansion cost of Owasso's existing treatment storage.

Table 104
Total Costs – Scenario 1 A, B, C

Year	Daily Average (MGD)	**Scenario 1 A**	**Scenario 1 B**	**Scenario 1 C**
		Total Cost $	Total Cost $	Total Cost $
2010	7.75	8.5	12.1	123
2020	10.6	145.74	269	22
2030	14.67	2.15	2.09	190
2040	20.3	382.38	87.79	23
2050	27.48	1.85	216.63	217
2060	37.69	2.4	1.85	1.85
**TOTAL $*		567.89	614.29	571.4
$/1,000 GAL		**1.31**	**1.42**	**1.32**

*Owasso included. **Discounted 7%, inflation 2.1%, and annual O&M.

The entire 50 year planning period construction costs for water treatment and storage and the associated water treatment O&M costs for Scenario 2 A and B are shown in Table 105. The total net present cost for each scenario includes the expansion cost of Owasso's existing treatment storage

Table 105
Total Costs – Scenario 2 A, B

Year	Average Daily Demand (MGD)	**Scenario 2 A**	**Scenario 2 B**
		Total Cost $	Total Cost $
2010	7.18	6.12	88.6
2020	9.84	145.7	1.76
2030	13.6	20	172
2040	18.6	200.17	2
2050	25.55	10.36	225.14
2060	35.08	2.41	1.3
TOTAL $*		414.82	520.69
$/1,000 GAL		**1.03**	**1.30**

**Owasso included. **Discounted 7%, inflation 2.1%, and annual O&M.

The entire 50 year planning period construction costs for water treatment and storage and the associated water treatment O&M costs for Scenario 3 A and B are shown in Table 106. The total net present cost for each scenario includes the expansion cost of Owasso's existing treatment storage.

Table 106
Total Costs – Scenario 3 A, B

Year	Average Daily Demand (MGD)	**Scenario 3 A**	**Scenario 3 B**
		Total Cost $	Total Cost $
2010	6.51	69.11	69.11
2020	8.92	2.09	2.09
2030	12.41	201.92	201.92
2040	16.98	2.04	2.04
2050	23.36	238.75	238.75
2060	32.13	1.85	1.85
TOTAL $*		545.8	545.8
$/1,000 GAL		**1.49**	**1.49**

*Owasso included. **Discounted 7%, inflation 2.1%, and annual O&M.

The entire 50 year planning period construction costs for water treatment and storage and the associated water treatment O&M costs for Scenario 4 A and B are shown in Table 107. The total net present cost for each scenario includes the expansion cost of Owasso's existing treatment storage

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Table 107
Total Costs – Scenario 4 A, B

Year	Average Daily Demand (MGD)	**Scenario 4 A**	**Scenario 4 B**
		Total Cost $	Total Cost $
2010	5.83	55.11	5.36
2020	7.98	2.18	132.6
2030	11.05	153.83	13.31
2040	15.03	2.1	150.49
2050	20.57	147.27	24.21
2060	28.17	1.85	2.73
TOTAL $*		392.37	358.67
$/1,000 GAL		**1.21**	**1.11**

*Owasso included. **Discounted 7%, inflation 2.1%, and annual O&M.

The entire 50 year planning period construction costs for water treatment and storage and the associated water treatment O&M costs for individual systems are shown in Table 108. The total net present cost for each scenario includes the expansion cost of Owasso's existing treatment storage.

Table 108
Total Costs – Individual Systems

Year	AD (MGD)	**Rogers RWD 3**	AD (MGD)	**Washington RWD 3**	AD (MGD)	**Collinsville**
		Total Cost ($)		Total Cost ($)		Total Cost ($)
2010	5.94	6.88	5.26	2.56	4.59	5.5
2020	8.16	113.5	7.22	4.1	6.3	84.1
2030	11.31	165	9.95	57.5	8.79	118.42
2040	15.56	2.1	13.61	255.8	11.98	2.16
2050	21.43	295.31	18.64	20.97	16.45	234.49
2060	29.52	1.85	25.56	27.26	22.61	1.85
TOTAL $*		614.57	80.24	398.2	70.72	476.52
$/ 1,000 GAL		**1.83**		**1.36**		**1.85**

*Owasso included. **Discounted 7%, inflation 2.1%, and annual O&M.

Since all the costs assume that one of the existing water treatment plants will be expanded to meet the forecasted demands, the assumption is that each evaluation period is a total of 50 years. The net present costs for each scenario was calculated for 1,000 gallons of water. All evaluated cases include water demands of Owasso and their storage requirements. All costs were adjusted for inflation. The total costs are included in spreadsheets in Appendix D.

4.4.5.1 Economic Evaluation Output

The analyses of the results indicate the following:

- The cost comparisons between consolidation scenarios and individual systems show that costs of individual systems are approximately 20 percent higher per gallon, expect for Washington RWD 3 which is presently building excess capacity and these costs are not reflected in this cost evaluation; however, the built capacity is.
- Comparison of <u>Scenario 1 A, B and C</u> leads to the following results:
  - Net present costs per 1,000 gallons:
    - 1A: $1.31
    - 1B:$1.42.
    - 1C:$1.32.
  - The per unit costs of water are lower for 1A during the first half of the planning horizon due to the fact the Washington RWD 3 starts the planning period without expansion requirements. During the second period of the planning horizon, the plant capacity is

    exhausted and new capacity is constructed. The trend is the opposite for scenarios 1 B and 1 C: the construction costs occur early in the planning period. The construction costs of Washington RWD 3 plant existing plant expansion (2011) are not captured in this cost estimate (1A). If that cost was included in this estimate, the unit cost of water would be higher for 1A.
  - Scenario 1 serves the largest number of people compared to scenarios 2, 3 and 4 (7.3% larger than 2; 15% larger than 3; and 25.2% larger than 4).
- Comparison of <u>Scenario 2 A and B</u> leads to the following results:
  - Net present costs per 1,000 gallons:
    - 2A: $1.03.
    - 2B: $1.30.
  - The overall water demands for Scenario 2 are approximately 7.3 percent less than in Scenario 1; 9% more than in Scenario 3; and 20% more than in Scenario 4.
  - The lowest unit cost of water is in 2A.
- Comparison of <u>Scenario 3 A and B</u> leads to the following results:
  - Net present costs for 1,000 gallons:
    - 3A: $1.49.
    - 3B: $1.49.
  - The population served is approximately 5% less than in Scenario 1, 8.5% less than in Scenario 2, and 13% less than in Scenario 4.

  - The required water treatment plant expansion and storage addition are the same in both 3A and 3B. The costs are also the same. The existing plants and storage are approximately the same size.
- Comparison of <u>Scenario 4 A and B</u> leads to the following results:
  - Net present costs for 1,000 gallons:
    - 4A: $1.21.
    - 4B: $1.11.
  - Has the smallest service area.
- Comparison of individual systems leads to the following results:
  - Net present costs for 1,000 gallons:
    - R3: $1.83.
    - W3: $1.36.
    - C: $1.85.
  - Individual systems are approximately 20 percent more expensive per gallon of water, except for Washington RWD 3.
  - Collinsville alone option service area is approximately 3.5% smaller than Scenario 4. The cost per 1,000 gallons is $1.85 for Collinsville and the cheapest option in Scenario 4 is $1.11.
  - Rogers alone option service area is approximately 8% smaller than Scenario 3. The associated costs with these are $1.83 per 1,000 gallons for Rogers compared to $1.49 per 1,000 gallons for Scenario 3.

Based on the economic evaluation of consolidation scenarios to be able to meet the new consolidated water service areas including Owasso the associated costs were estimated. The consolidation recommendation based on the net present cost is Scenario 2 A (Rogers RWD 3 and Washington RWD3) with Rogers RWD 3 water treatment plant expansion. This scenario does not capture the largest service area: Scenario 1 has the largest service area. The individual system service areas are obviously smaller than the consolidated areas. Two out of three individual systems have larger unit costs of water compared to the consolidated systems expect for Washington RWD3. This new treatment plant system is already being built and the cost of the construction of the plant was not reflected in these. The new plant will be able to accommodate Owasso's service area during the first part of the planning period and with one plant expansion in 2040. The discounted costs associated with this are $1.36 per thousand gallons.

V. ANALYSIS

5.0 Analysis and Discussion

This dissertation answered the general question of when and where consolidation of rural and medium size community water systems is appropriate and should be considered as a solution to address the growing water demands of a single critical community. To this end, a planning support system was developed, applied and consolidation recommendation were identified. This Planning Support System is applicable to urban fringe communities.

The PSS consists of two analysis modules: Problem Analysis and Solution Analysis. The Problem Analysis module helps the planner to identify the user-specified characteristics that are considered to negatively impact future water demands in the study area. Using a tool from the Theory of Constraints and the Root Cause Analysis, a Current Reality Tree is constructed as a problem solving method to address water resources core problem in the identified study setting. The core problem explains the current reality of the critical community's water resource problem.

In the Solution Analysis module, a physical consolidation is proposed as a solution to the core problem as identified in the Root Cause Analysis. The water system consolidation scenarios are assembled by using evaluative screens to identify the existing water system structures and dependencies on one-and-another. The use of these screens and the criteria developed for water system combinability aid in delineating the consolidated systems. In the Technical Analysis sub-module of the Solution Analysis, the developed cooperative scenarios' water demands are forecasted over a 50-year planning period. The Technical Analysis consists of future demand forecasting of individual CWSs and consolidation scenarios under three growth scenarios: high, medium, and low. Medium growth rates are used for the different needs assessments. The different water supply options are evaluated for their feasibilities based on their existing water treatment capacities, water storage, and water rights. All scenarios are forecasted to be independent of the other water systems. In the Economic Evaluation sub-module of the Solution Analysis, the decadal costs of meeting the forecasted demands are evaluated. The costs included are the construction costs for water treatment plant and the distribution storage. The final output of the PSS includes the costs as well as the feasibilities of consolidation based on the future water treatment capacities, available allocated water supply, and the required treated water storage.

The PSS was used to select the larger study setting of Northeastern Oklahoma and the critical community of Owasso. The CRT within the PSS was used to identify the core problem of Owasso's water resource problem. This was found to be lack of long-term planning. The PSS guided the selection of possible water supply partners. These are: Rogers County Rural Water District (RWD) No. 3, Washington RWD No. 3, and the town of Collinsville. The water supply partners were then combined together into feasible consolidation scenarios to meet their and Owasso's water demands without additional supplies. These combinations are:

- Rogers RWD 3 + Collinsville + Washington RWD 3;
- Rogers RWD 3 + Washington RWD 3
- Rogers RWD + Collinsville
- Collinsville + Washington RWD 3

Each above scenario was evaluated for their treatment and storage capacities and water permits (Table 109). All scenarios will require additional treatment capacities and distribution storage. Each consolidation scenario has a different schedule for additional treatment and storage requirements. In addition, water rights gaps were identified for each scenario. For comparison purposes, the individual water system expansions were included in Table 113.

The principal findings of the application of the PSS revealed the following about the PSS (summary of the findings are included in Table 113):

- The 50-year planning horizon causes many uncertainties:
    - Assumption that the proposed solution will be valid for the entire period;
    - Long-term water demands are very difficult to forecast accurately.
        - This impacts the entire analysis that is based on the demand: infrastructure and water right needs;
    - Land-use is residential and growth patterns are assumed linear;
    - Accurate cost estimates depend on inflation and discounting.
- The excess capacity of any of the needs components in the beginning of analysis period, skewed the entire analysis period:

  - On the cost side, the excess capacity in water treatment shows as a benefit without the associated cost.
  - On the water storage side, some communities have earlier investments on excess water storage.
  - On the water supply side, recently granted individual CWS large water allocations, secures available water for that system throughout planning period.

The principal findings of the PSS application phase on the study communities revealed the following:

- The use of linear and the explanatory models in the water demand forecasting (IRW-MAIN) did not provide additional insights to the water uses in the study area. The use of explanatory variables did not provide valuable information and as a matter fact, skewed the water forecasts due the uncertainty in forecasts for climate and socio-economic explanatory variables for 50-year planning period.
- The needs assessment revealed that individual systems do not have treatment capacity to meet the maximum daily demands without purchasing treated water.
- The permitted water supply was not a factor to the scenarios when Washington RWD 3 was included.
- Individual systems are at or close to treated water storage capacity.

- Based on the water treatment expansion construction costs, O&M and distribution storage costs, the cost per 1,000 gallon of water was less for consolidated systems than for individual systems, expect for Washington RWD 3.

Table 109
Screening 2010-2060

Scenario	Description	Needs Assessment			Economic Evaluation	Recommendation
		Water Treatment Exhaustion	Distribution Water Storage Needs	Needed Water Rights (MGD) w/o Tulsa's water	Construction Costs (1,000$/GAL) Discounted Costs (7%) and 2.1% inflation	
1. Rogers RWD 3 +Collinsville +Washington RWD 3	A. Plant expansion: Washington 3	2020	2020	2060:-2.95	1.31	Expand Washington RWD 3 plant, water rights needed in 2060, need treated distribution storage in 2020.
	B. Plant expansion: Rogers 3	2020			1.42	
	C. Plant expansion: Collinsville	2010			1.32	
2. R3 + W3 +Owasso	A. Plant expansion: Rogers 3	2010	2010	2060:-5.54	1.03	Expand Rogers 3 plant, new water rights in 2060, need treated distribution storage in 2010.
	B. Plant expansion: Washington 3	2010			1.30	
3. R3 + CO+Owasso	A. Plant expansion: Collinsville	2010	2010	2020:-2.01	1.49	Expand either one of the plants, need new water rights in 2020, need treated distribution storage in 2010.
	B. Plant expansion: Rogers 3	2010			1.49	
4. CO + W3+Owasso	A. Plant Expansion: Collinsville	2010	2010	none	1.21	Expand Washington RWD 3, no new water rights needed, need treated distribution storage in 2010.
	C. Plant Expansion: Washington 3	2020			1.11	
Washington RWD 3	Washington 3 and Owasso demands	2030	2020	none	1.83	Washington water treatment plant expansion and now new water rights needed. If Washington RWD 3 expansion, then expand distribution storage in 2020.
Rogers RWD 3	Rogers 3 and Owasso demands	2010	2010	2010:-2.23	1.36	
Collinsville	Collinsville and Owasso Demands	2010	2020	2020:-1.10	1.85	

5.2 Limitations to the Study

The limitations to the study include the lack of data for assessing what components would need to be included in a long-term consolidation evaluation. The study did not evaluate the potential gains achieved by eliminating small rural water systems. These gains could be achieved in the economies of size, O&M in particular in treatment and pump costs, and improved water quality. Based on the study assumption of using the existing distribution pipelines for each scenario, distribution costs were not considered. If in the future the plants expanded their service areas beyond the study area, the distribution costs should be calculated. The study limitations extend to the assumption that consolidation can be achieved without any resistance from the communities, the exiting water systems, and the water-users.

5.3 Recommendation for Future Study

The testing of the PSS revealed that the identification of the water resources problem, the selection of the critical communities and community water systems, and the assessment of consolidation scenarios could benefit from the use of weighing factors (appraisal scores) during the planning analysis. The use of stakeholder and/or planner identified and appraised key factors and larger distal causes in the problem identification of water resources planning could reveal the ranked importance (preferences) of the problem identification. Based on the preferred problem identification, the proposed solution could be something else than water system consolidation, or perhaps the consolidation could be consist of different forms of consolidation, such as satellite form or administrative form.

Using different user-specified and stakeholder identified evaluative criteria (both quantitative and qualitative) in both problem identification and solution analysis, would allow appraisal scores to dictate the importance of the problem and the solution. The decisions would have both subjective and objective elements and hence there would not be a single “correct” answer/solution. The decisions would reveal the prioritization based on preferences of the planner and/or the stakeholder. For the future research, I would like to expand the PSS to include a decision analysis model, such as EVAMIX, to further to evaluate the feasibilities of CWS consolidations. I would like to evaluate how the preferences of water-users, water plant managers, and water resources planners would impact the consolidation prioritization recommendation. Also, I would add more variables, such distribution and industrial growth projections into the analysis.

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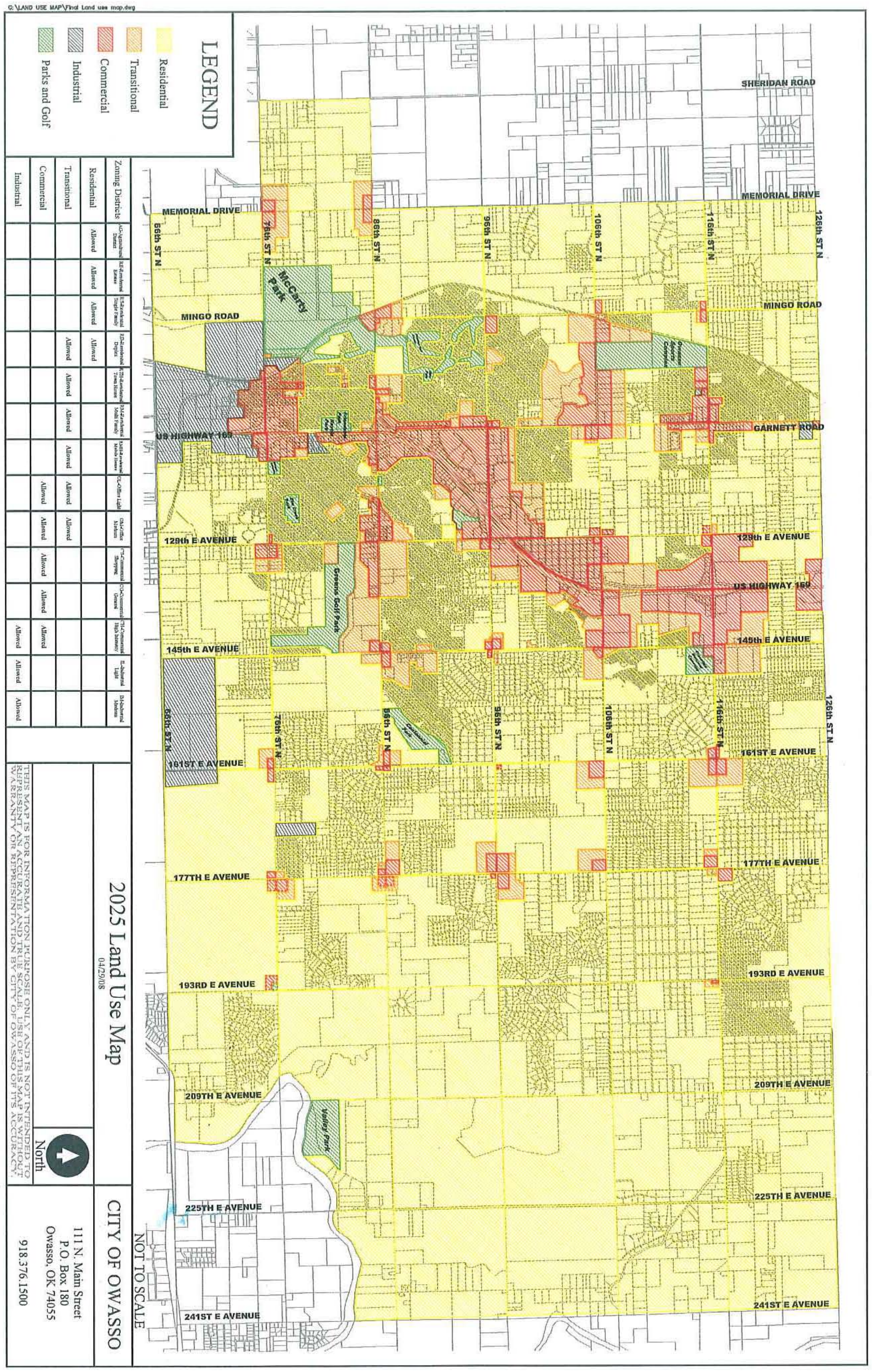
APPENDIX

APPENDIX A

Figure 1 – Owasso Land-Use Map (2008)



Zoning Districts	AG-Agricultural District	RE-Residential Estate	RS-Residential Single Family	RD-Residential Duplex	RTH-Residential Town House	RM-Residential Multi Family	RMH-Residential Mobile Home	OL-Office Light	OM-Office Medium	CS-Commercial Shopping	CG-Commercial General	CH-Commercial High Intensity	IL-Industrial Light	IM-Industrial Medium
Residential	Allowed	Allowed	Allowed	Allowed										
Transitional				Allowed	Allowed	Allowed	Allowed	Allowed	Allowed					
Commercial								Allowed	Allowed	Allowed	Allowed	Allowed		
Industrial												Allowed	Allowed	Allowed

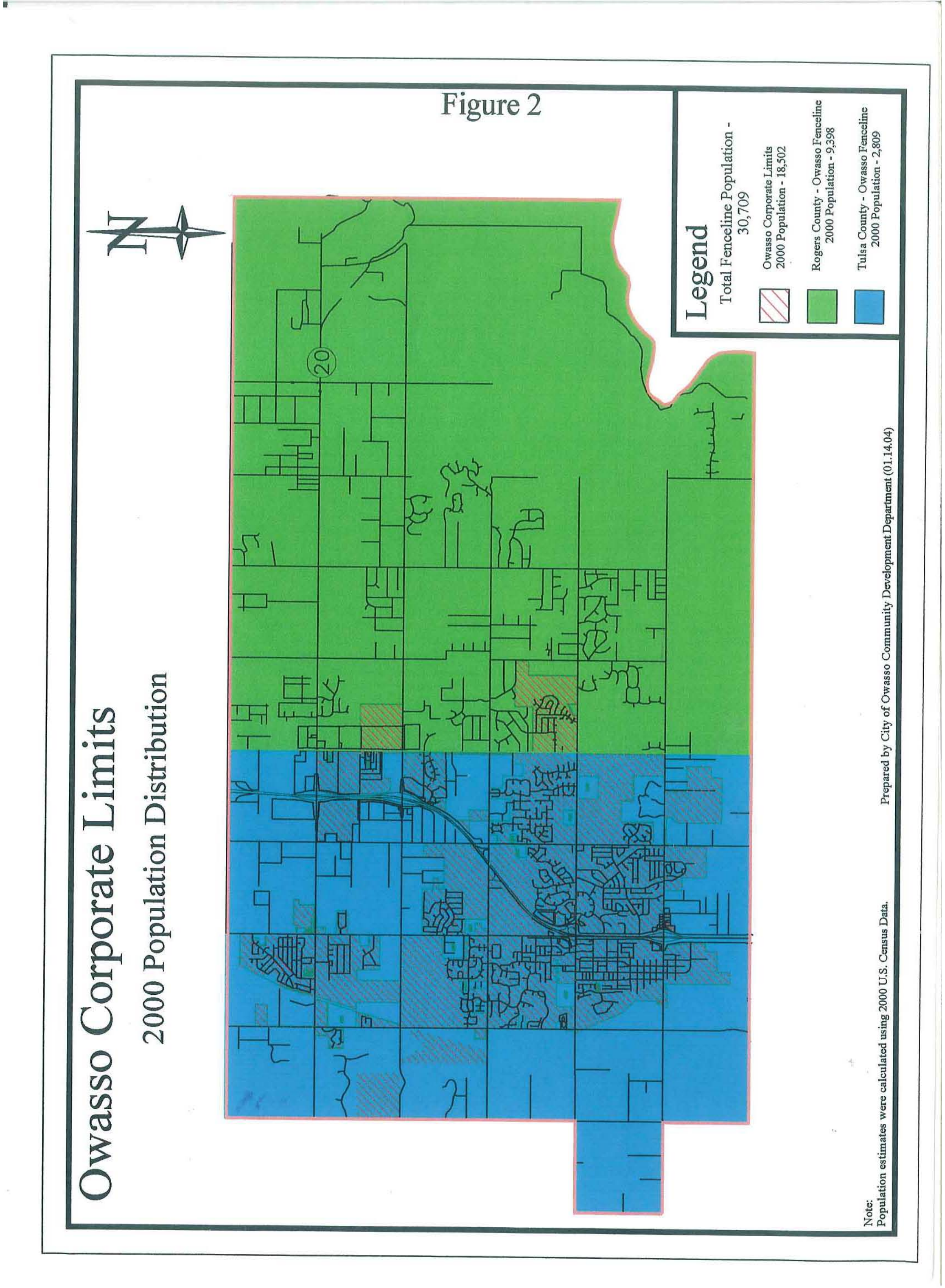
2025 Land Use Map
04/29/08

THIS MAP IS FOR INFORMATION PURPOSE ONLY AND IS NOT INTENDED TO REPRESENT AN ACCURATE AND TRUE SCALE. USE OF THIS MAP IS WITHOUT WARRANTY OR REPRESENTATION BY CITY OF OWASSO OF ITS ACCURACY.

CITY OF OWASSO

111 N. Main Street
P.O. Box 180
Owasso, OK 74055
918.376.1500

Figure 2 – Owasso Corporate Limits (2004)



Source: City of Owasso, 2004

Figure 3 – Owasso West Land-Use 2008

Figures 3-6 based on INCOG (2009) ESRI GIS Shapefiles.

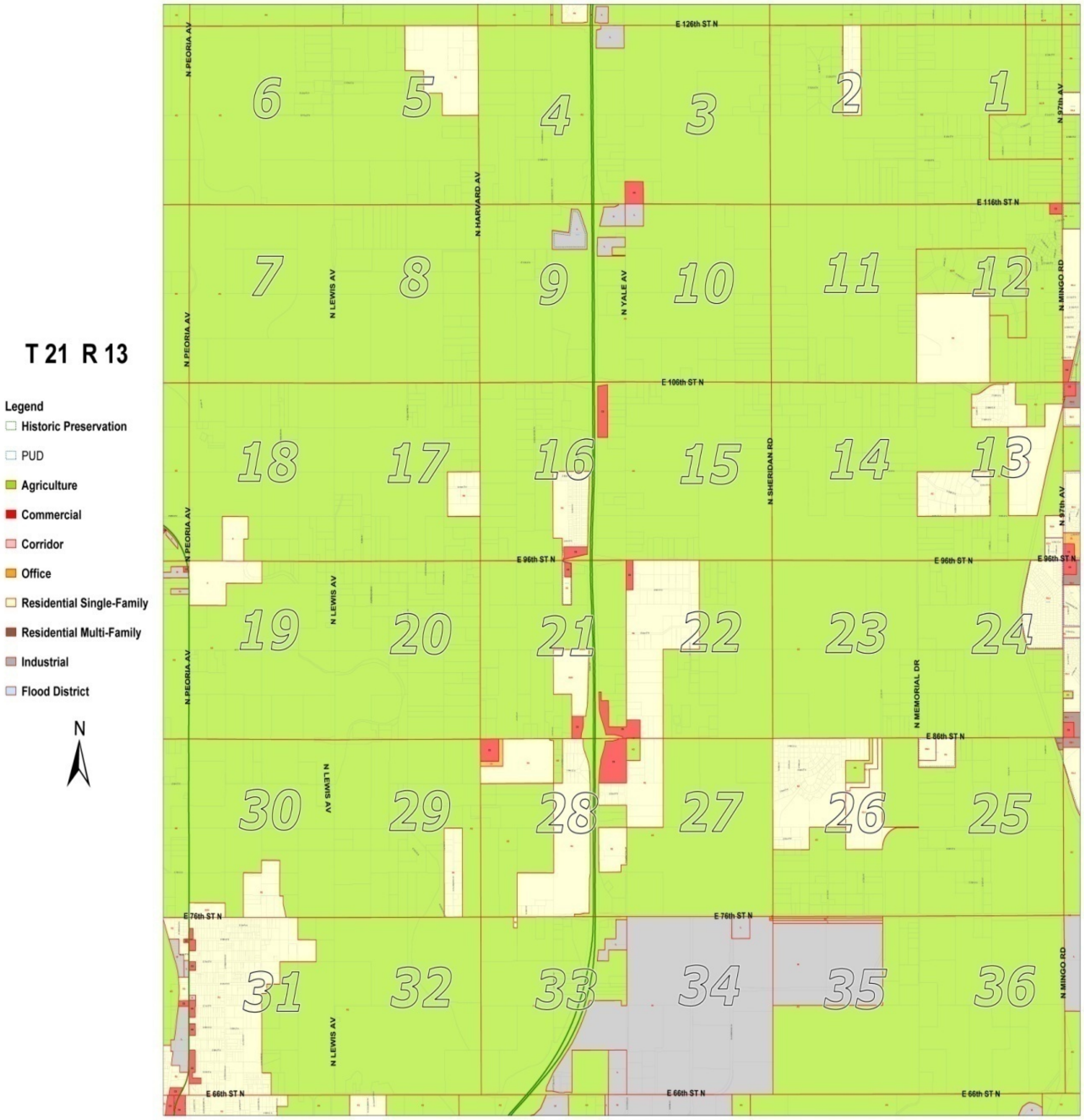


Figure 4 – Owasso Land-Use 2008

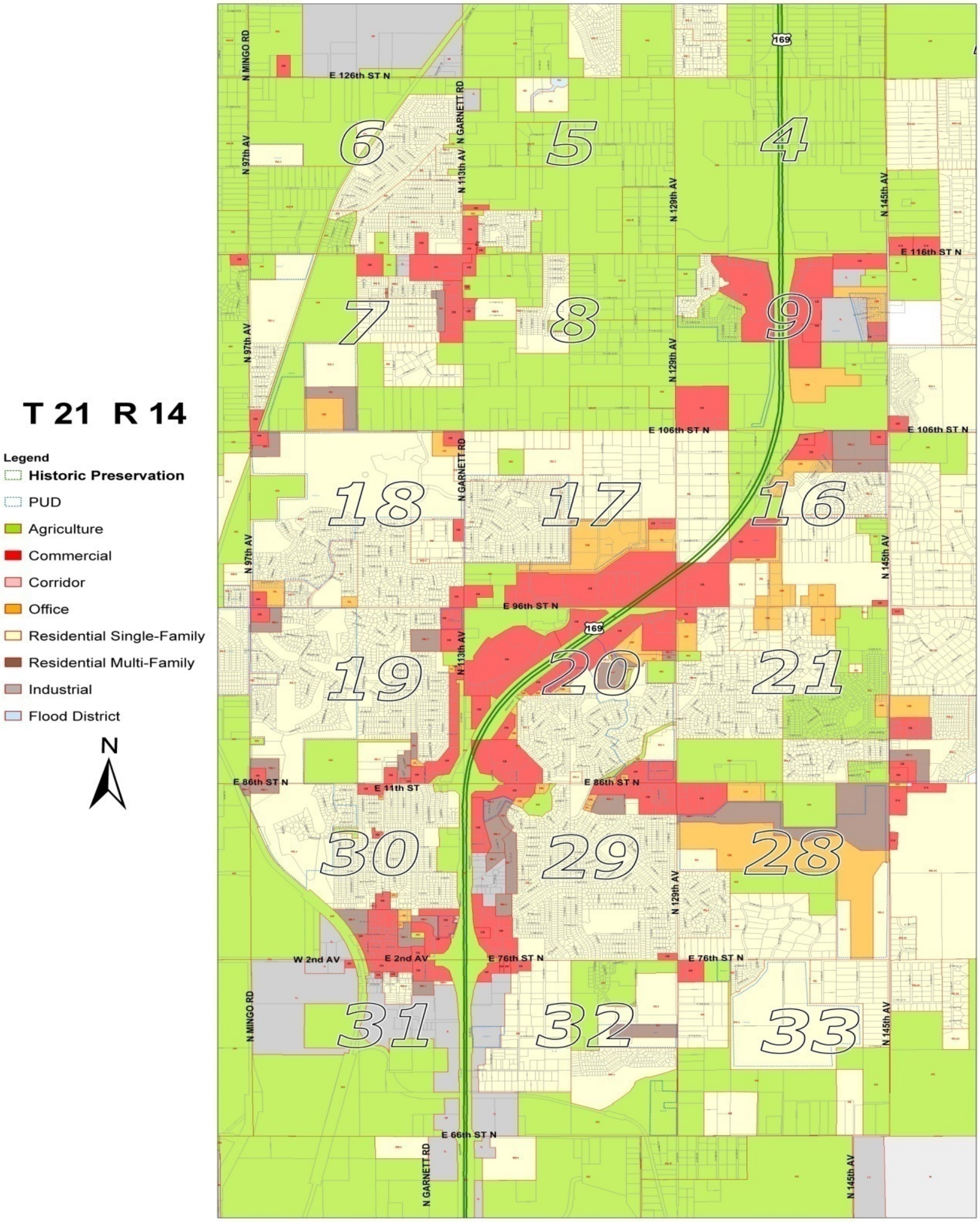


Figure 4 - Collinsville West Land-Use 2009

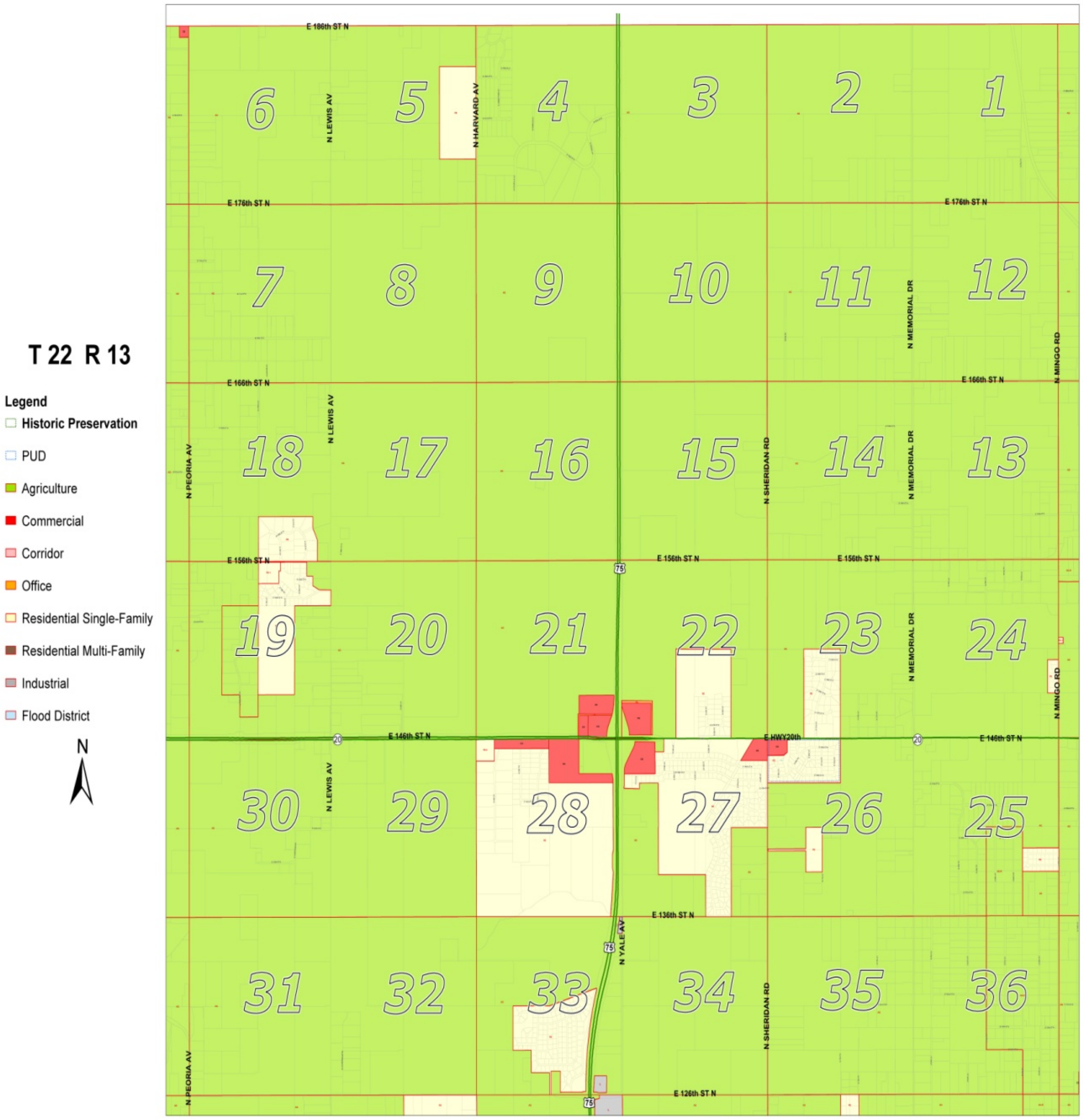
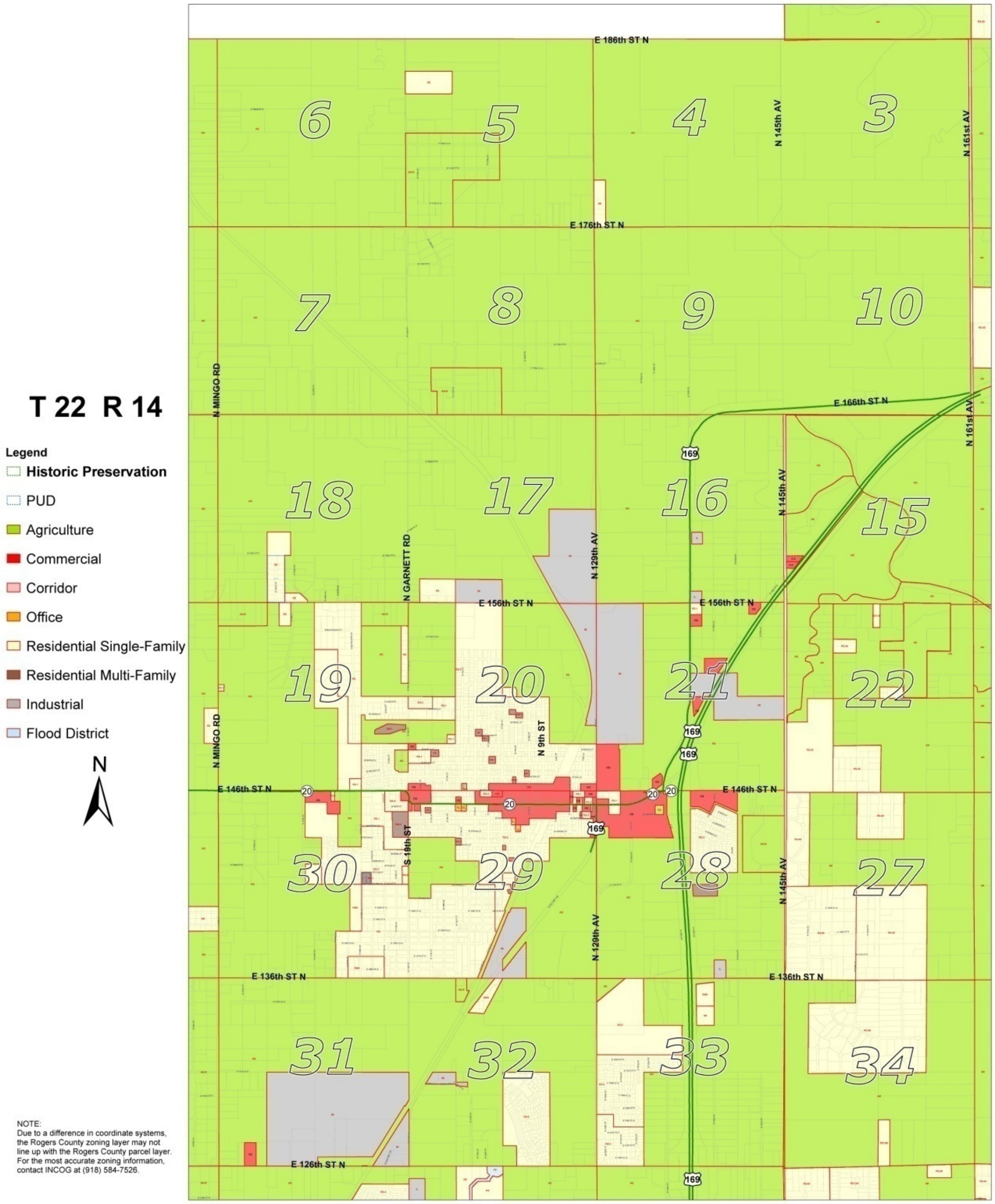


Figure 5 - Collinsville Land-Use 2009



NOTE:
Due to a difference in coordinate systems, the Rogers County zoning layer may not line up with the Rogers County parcel layer. For the most accurate zoning information, contact INCOG at (918) 584-7526.

APPENDIX B

Oologah Lake

Oologah Lake is located on the Verdigris River. Oologah Lake dam impounds the Verdigris River at river mile 90.2, which is two miles southeast of Oologah, Oklahoma and 22 miles northeast of Tulsa, Oklahoma in Rogers and Nowata counties (USACE). The lake is about 2 miles southeast of Oologah Town in Rogers County on State Highway 88, and about 27 miles northeast of Tulsa, approximately 5 miles east of US Highway 169 and the town of Oologah, and 10 miles northeast of the Washington County RWD No. 3 North Water Treatment Plant. The lake was completed in 1963 (construction began 1950, final structure completed in 1974) for flood control, water supply, navigation, recreation, and fish and wildlife propagation (Watershed Study 2001). The lake is owned and operated by the federal government (USACE) (Oologah Lake Management Plan, 2008, Oklahoma Department of Wildlife Conservation). Oologah Lake has 209 miles of shoreline, covers 31,040 surface acres (12,562 ha), and stores 552,210 acre-feet of water on average (Watershed study 2001). All storages are based on a drainage area of 4,339 square miles for this project lake, which includes all upstream projects (USACE).

WATER QUALITY: Oologah Lake's water quality is monitored by the Oklahoma Water Resources Board (OWRB) as part of their Beneficial Use Monitoring Program (BUMP 2003). Oologah Lake was classified eutrophic (trophic class) with average turbidity of 20 nephlometric turbidity units (NTU's) (according to

2003 sampling 25% of the sampled and measured values were greater than the Oklahoma Water Quality Standards - OWQS of 25 NTU).

The quality of raw water from Oologah Lake varies from fair to poor. Raw water data for this supply has shown that the water is typically high in hardness and alkalinity, moderately high in terms of color, and highly variable in turbidity. The 2003 BUMP report calculated a trophic state index (TSI), using Carlson's TSI (chlorophyll-a), of 46. Salinity was 0.10 – 0.23 ppt. Specific Conductivity 161-451.9 µS/cm which shows a low to moderate level of dissolved salts. The pH in the lake was neutral to slightly alkaline (7.10 to 8.65) during the study period (2003 BUMP). Oologah lake was also found to be moderately hard to hard (157 ppm as CaCo3) (Watershed Study 2001). Thermal stratification in Oologah Lake is not prevalent during fall, winter, or spring. The surface total Nitrogen was 0.33 mg/L to 1.13 mg/L, surface total phosphorus 0.026 mg/L to 0.109 mg/L and the Nitrogen to Phosphorus ratio 12:1 (phosphorous limited). The total hardness generally ranges between 150 and 190 parts per million (ppm) as calcium carbonate ($CaCO_3$). Alkalinity is typically less than the hardness and averages approximately 100 to 120 ppm as $CaCO_3$.

Table 1 - Lake Oologah

Feature	Elevation (ft)	Area (ac)	Capacity (ac-ft)	Equivalent runoff (inches)
Top of Dam	687.0	-	-	-
Maximum Pool	678.25	92,160	2,927,430	23.33
Top of Flood Control Pool	661.0	67,117	1,559.279	12.43
Flood Control Storage	638.0-661.0	-	1,007,060	8.02
Top of Conservation Pool	638.0	31,043	552,235	4.40
Navigation, Municipal & Industrial Water Supply	592.0-638.0	-	545,300(1)	4.35
(1) 342,600 ac-ft for water supply, 168,000 ac-ft for navigation, and 34,700 ac-ft for 50-year sediment.				

Source: USACE Pertinent Data Book, 2004

Skiatook Lake

Skiatook Lake is located on Hominy Creek, a tributary of Bird Creek in the Verdigris river basin, about 5 miles west of Skiatook in Osage County, and about 18 miles northwest of Tulsa. The lake was construction was completed in 1984 (started in 1974) for flood control, water supply, water quality control, recreation, and fish and wildlife. The Tulsa District of the Corp of Engineers (USACE) completed Skiatook Lake in 1984. The designated federal purposes for this lake include water supply, flood control, water quality, recreation and fish and wildlife. There is a federally designated 62,900 acre-feet of reservoir storage in Skiatook Lake for water supply. The OWRB has established a yield for water rights designated for water supply of 15,680 acre-feet (i.e., 14 MGD). There is also a federally designated 233,000 acre-feet of storage in Skiatook Lake for water quality control. The OWRB also has established a yield for water rights designated for water quality control of 69,440 acre-feet (62 MGD). According to

OWRB, there are plans to reallocate water from water quality storage in the future.

WATER QUALITY: The Skiatook Lake water quality is equal to or better than the Oologah Lake. There tends to be less sediment and therefore less turbidity however it is subject to a relatively high organic load and subject to taste and odor problems.

According to BUMP 2003, the lake was classified as mesotrophic (trophic class) with moderate primary productivity. The 2003 BUMP report calculated the trophic state index (TSI), using Carlson's TSI (chlorophyll-a), of 47. The average turbidity 13 NTU (7% of the sampled and measured values were greater than the Oklahoma Water Quality Standards - OWQS of 25 NTU). Water clarity rating was good. The salinity was measured 0.07– 0.15 ppt. The specific conductivity ranged from 7.5 5 µS/cm – 305.5 5 µS/cm which shows a very low to moderate level of dissolved salts. The pH in the lake was neutral to slightly alkaline: pH 6.80 – 8.05. Nutrients (surface) included total Nitrogen 0.35 mg/L to 1.02 mg/L, total phosphorus 0.006 mg/L to 0.054 mg/L, and Nitrogen to Phosphorus Ratio 29:1 which indicated the lake was Phosphorus limited.

Table 2 - Lake Skiatook

Feature	**Elevation (ft)**	**Area (ac)**	**Capacity (ac-ft)**	**Equivalent runoff (inches)**
Top of Dam	756.0	-	-	-
Maximum Pool	750.8	20,300	868,00	45.97
Top of Flood Control Pool	729.0	13,690	500,700	26.52
Flood Control Storage	714.0-729.0	-	-	-
Initial			178,00	9.43
After 100-Year Sediment			176,100	9.33
Top of Conservation Pool	714.0	10,190	322,700	17.10
Conservation Storage	657.0-714.0	-	-	-
Initial	-	-	311,600(1)	16.50
After 100-Year Sediment	-	-	295,900	15.67
Top of Interactive Pool	657.0	1,480	11,100	0.59
Interactive Storage	613.0-657.0	-	-	-
Initial	-	-	11,100	0.59
After 100-Year Sediment	-	-	6,700	0.36

(1) Included 62,900 for water supply (14 MGD), 233,000 ac-ft for water-quality control (62 MGD), and 15,700 ac-ft for 50-year sediment.

Source: USACE, Pertinent Data Book, 2004.

Caney River

Under the Beneficial Use Monitoring Program (BUMP) OWRB has tracked water quality data for the Caney River, in the vicinity of Ramona.

Table 3 – Caney River

Constituent	Measurements (1)	Current Limit(2)
Water Temperature	Ranged from 7 to 33 Degrees C	n/a
Dissolved Oxygen	Ranged from 4.0 to 14 mg/l	Min 4 to 5
pH	Ranged from 7.5 to 8.3	Limit 6.5 to 9
Turbidity	Ranged from 10 to 225 NTU's	Limit @ 50
Total Dissolved Solids	Ranged from 50 to 450 mg/l	Limit @ 400
Chlorides	Ranged from 1 to 140 mg/l	Limit @ 100
Sulfates	Ranged from 10 to 75 mg/l	Limit @ 100
Total Phosphorus	Ranged from 0.1 to 0.7 mg/l	Limit @ 1.0
Nitrite+Nitrate	Ranged from 0.2 to 1.5 mg/l	Limit @ 4.5

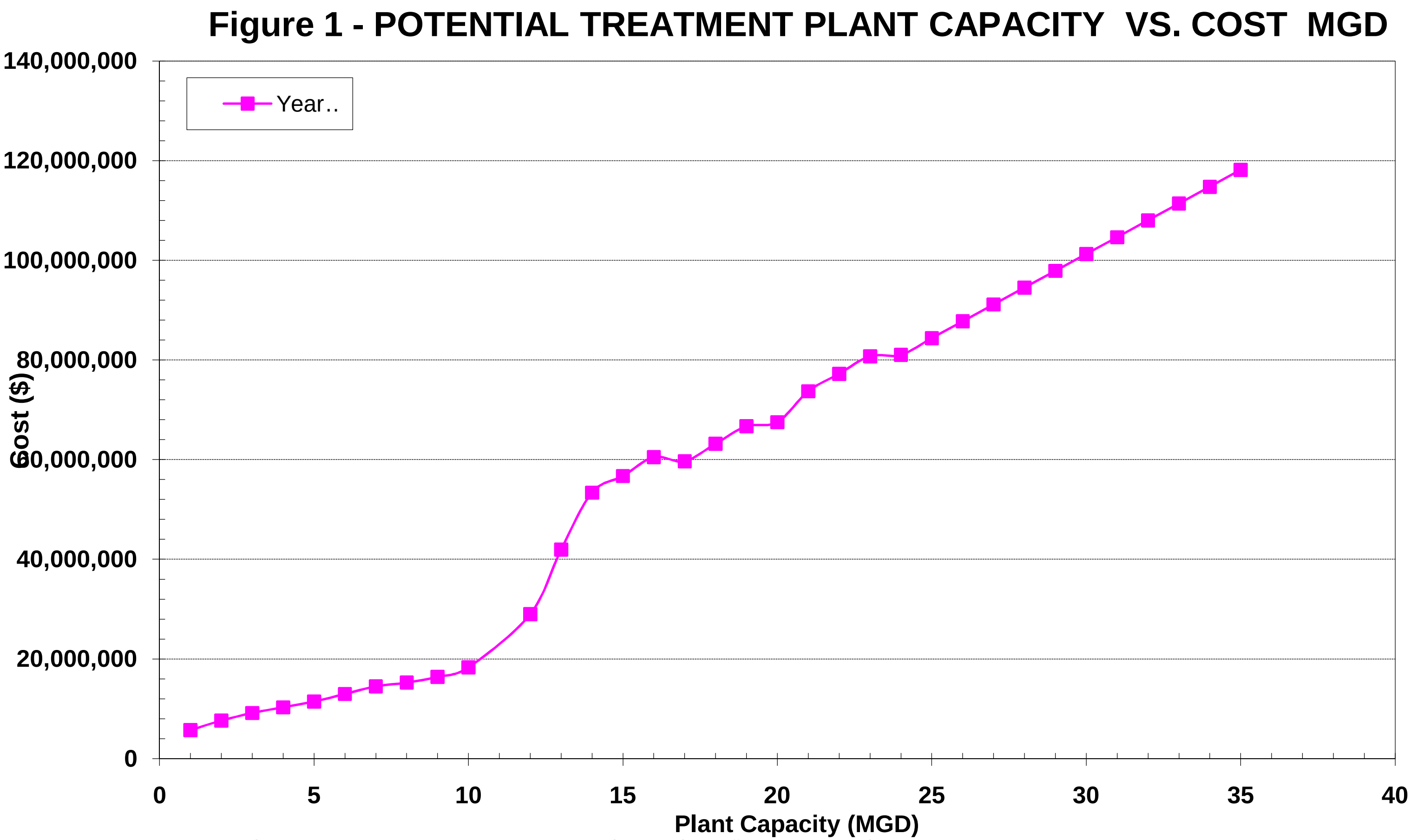
(1) Measurements are approximated
(2) Limits established by OWRB in Beneficial use Monitoring Program

APPENDIX C

Table 1 – Construction Costs Conventional Treatment

Basis 1979 EPA, updated Culp, Wesner & Culp, 1986, pp 998, Figure 30-1. Construction cost indices (CCI): 4146 (for year 1984 when curve was generated) and 8672 (for February, 2010) McGraw Hill Construction ENR Index were used to adjust the curves. This curve was then adjusted for construction cost (considering additional 35% of treatment plant cost) to get total construction cost of the plant. This value was further adjusted for administration, legal and engineering fees (considering additional 35% of total construction cost) to get the total project cost.

Plant capacity	Unit Plant Cost ($)		Construction Cost	Project Cost
MGD	Year 1984	Year 2010	Year 2010	Year 2010
1	1,500,000	3,137,482	4,235,601	5,718,061
2	2,000,000	4,183,309	5,647,467	7,624,081
3	2,400,000	5,019,971	6,776,961	9,148,897
4	2,700,000	5,647,467	7,624,081	10,292,509
5	3,000,000	6,274,964	8,471,201	11,436,122
6	3,400,000	7,111,626	9,600,695	12,960,938
7	3,800,000	7,948,288	10,730,188	14,485,754
8	4,000,000	8,366,618	11,294,935	15,248,162
9	4,300,000	8,994,115	12,142,055	16,391,774
10	4,800,000	10,039,942	13,553,922	18,297,795
12	7,600,000	15,896,575	21,460,376	28,971,508
13	11,000,000	23,008,201	31,061,071	41,932,446
14	14,000,000	29,283,164	39,532,272	53,368,567
15			42,000,000	56,700,000
16			44,800,000	60,480,000
17			44,200,000	59,670,000
18			46,800,000	63,180,000
19			49,400,000	66,690,000
20			50,000,000	67,500,000
21			54,600,000	73,710,000
22			57,200,000	77,220,000
23			59,800,000	80,730,000
24			60,000,000	81,000,000
25			62,500,000	84,375,000
26			65,000,000	87,750,000
27			67,500,000	91,125,000
28			70,000,000	94,500,000
29			72,500,000	97,875,000
30			75,000,000	101,250,000
31			77,500,000	104,625,000
32			80,000,000	108,000,000
33			82,500,000	111,375,000
34			85,000,000	114,750,000
35			87,500,000	118,125,000



Notes: Unit cost curve for conventional treatment plant referred from "Handbook of Public Water Systems by Culp, Wesner & Culp, 1986, pp 998, Figure 30-1. Construction cost indices (CCI) : 4146 (for year 1984 when curve was generated) and 8672 (for February, 2010) McGraw Hill Construction ENR Index were used to adjust the curves. This curve was then adjusted for construction cost (considering additional 35% of treatment plant cost) to get total construction cost of the plant. This value was further adjusted for administration, legal and engineering fees (considering additional 35% of total construction cost) to get the total project cost.

Table 2 – Typical Water Treatment Plant Construction Cost Components

Land Procurement
Mobilization
Local Reservoir
Civil Work (Earthwork, Grading, Paving, Fencing)
Yard Piping
Landscaping and irrigation
Operations Building (Includes Chem. Feed)
Flocculation and Sedimentation Basins
Filters
Clearwell
Pumping Facilities
Meter Vaults
Filter Washwaste Holding and Recycling
Sludge Dewatering and Solids Handling Equip.
Miscellaneous Items
Chemical Storage Facilities
Electrical and Instrumentation
Testing and Disinfecting
Contractor's Profit and Overhead (20%)
Contingency (10%)

Kawamura, 1986

Table 3 - Typical Operating and Maintenance Costs (22 MGD WTP)

	Cost Per MG Treated	Cost per 1,000 Gallons
Power Costs	$80.00	$0.08
UV Power/Patent Costs	$30.00	$0.03
Solids Handling and Disposal	$25.00	$0.03
Labor Costs	$160.00	$0.16
Chemicals	$50.00	$0.05
Supplies	$15.00	$0.02
WTP Capital Improvements	$25.00	$0.03
Repairs	$15.00	$0.02
Total O & M	$400.00	$0.40

Kawamura, 1986: Figure 2.4.12-2.

APPENDIX D

Table 1A - Economic Evaluation – Scenarios 1-4: 2010-2030
Discounted Construction Costs and O&M Costs

	2010				**2020**				**2030**		
	WTP	O&M	STO	**TOTAL***	WTP	O&M	STO	**TOTAL***	WTP	O&M	**TOTAL***
Scenario 1											
A		3.32	5.2	**8.5**	96.59	1.66		**145.7**		2.16	**2.16**
B		6.88	5.2	**12.1**	153.53	1.61		**269.0**		2.10	**2.10**
C	101.2	17	5.2	**123**		22		**21.59**	108	1.42	**190**
Scenario 2											
A		3.3	2.8	**2.80**	96.59	1.66		**145.7**		2.16	**19.99**
B	84.4	1.4	2.8	**87.2**		1.76		**1.76**	80.96	1.52	**171.94**
Scenario 3								**-**			
A	67.5	16.1	3.6	**67.5**		20.9		**20.88**	108	1.57	**201.92**
B	67.5	16.1	3.6	**67.5**		20.9		**20.88**	108	1.57	**201.92**
Scenario 4								**-**			
A	50.63	1.68	2.8	**53.4**		2.2		**2.18**	81	1.61	**153.83**
B		2.56	2.8	**2.8**	87.75	1.66		**132.6**		2.16	**13.31**

All data has been adjusted for inflation – 2.1% per/year.
DC= discounted construction cost for WTP and storage with 7%
2010 costs are not discounted.

Table 1B - Economic Evaluation – Scenarios 1-4: 2040-2060
Discounted Construction Costs
O&M Costs
Total Costs

2040					**2050**				**2060**	***TOTAL 2010-2060****
SCENARIO	WTP	O&M	STO	**TOTAL***	WTP	O&M	STO	**TOTAL***	**O&M**	
Scenario 1										
A	192.47	1.42	11.4	**382**		1.85		**1.85**	2.41	**573.09**
B	34.77	1.52	11.4	**87.79**	111.32	1.42		**216.63**	1.85	**619.49**
C		1.85	11.4	**23.15**	111.32	1.42		**216.63**	1.85	**605.78**
Scenario 2										
A	106.36	1.42		**200.17**		1.85	4.4	**10.36**	2.41	**411.50**
B		1.97		**1.97**	111.32	1.42	4.4	**225.14**	1.3	**519.34**
Scenario 3										
A		2.04		**2.04**	111.32	1.42	11.44	**238.75**	1.85	**562.96**
B		2.04		**2.04**	111.32	1.42	11.44	**238.75**	1.85	**562.96**
Scenario 4										
A		2.10		**2.10**	64	1.42	11.44	**147.27**	1.85	**390.69**
B	79.67	1.61		**150.49**		2.10	11.44	**24.21**	2.73	**356.12**

All data has been adjusted for inflation – 2.1% per/year.
DC= discounted construction cost for WTP and storage with 7%
The only 2060 expenditures were O&M. *The total 2010-2060 includes all of Owasso storage costs.

Table 2A - Economic Evaluation – Individual Water Systems: 2010-2040
Discounted Construction Costs, O&M Costs

	2010				2020				2030			
SYSTEM	WTP	O&M	STO	**Total**	WTP	O&M	STO	**Total**	WTP	O&M	STO	**Total**
R3		6.88	0.8	**7.68**	74.62	2.18		**113.0**	91.84	1.61	1.92	**165.0**
W3		2.56		**2.56**		4.09		**4.09**	29.28	2.09	2.56	**57.54**
C		5.48		**5.48**	54.47	2.85		**84.1**	67.04	1.66		**118.42**

R3 = Rogers Rural Water District 3, W3=Washington Rural Water District 3, C=town of Collinsville

DC= discounted construction cost for WTP and storage with 7%. All data has been adjusted for inflation – 2.1% per/year. 2010 costs are not discounted.

Table 2B - Economic Evaluation – Individual Water Systems: 2040-2060
Discounted Construction Costs, O&M Costs, Total Costs

	2040				2050				*2060*	***TOTAL 2010-2060****
SYSTEM	WTP	O&M	STO	**Total**	WTP	O&M	STO	**Total**	**O&M**	
R3		2.10		**2.10**	148.5	1.42	3.52	**295.3**	**1.85**	**614.57**
W3	128.25	16.13		**255.8**		20.97		**20.97**	**27.26**	**398.24**
C		2.16		**2.16**	118.8	1.4	1.76	**234.49**	**1.85**	**476.53**

R3 = Rogers Rural Water District 3, W3=Washington Rural Water District 3, C=town of Collinsville

DC= discounted construction cost for WTP and storage with 7%. All data has been adjusted for inflation – 2.1% per/year. The only 2060 expenditures were O&M. 2010 costs are not discounted. *The total 2010-2060 includes all of Owasso storage costs.

APPENDIX E

1913=100* Revised	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL AV.
1990	4680	4685	4691	4693	4707	4732	4734	4752	4774	4771	4787	4777	4732
1991	4777	4773	4772	4766	4801	4818	4854	4892	4891	4892	4896	4889	4835
1992	4888	4884	4927	4946	4965	4973	4992	5032	5042	5052	5058	5059	4985
1993	5071	5070	5106	5167	5262	5260	5252	5230	5255	5264	5278	5310	5210
1994	5336	5371	5381	5405	5405	5408	5409	5424	5437	5437	5439	5439	5408
1995	5443	5444	5435	5432	5433	5432	5484	5506	5491	5511	5519	5524	5471
1996	5523	5532	5537	5550	5572	5597	5617	5652	5683	5719	5740	5744	5620
1997	5765	5769	5759	5799	5837	5860	5863	5854	5851	5848	5838	5858	5826
1998	5852	5874	5875	5883	5881	5895	5921	5929	5963	5986	5995	5991	5920
1999	6000	5992	5986	6008	6006	6039	6076	6091	6128	6134	6127	6127	6059
1913=100	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL AV.
2000	6130	6160	6202	6201	6233	6238	6225	6233	6224	6259	6266	6283	6221
2001	6281	6272	6279	6286	6288	6318	6404	6389	6391	6397	6410	6390	6343
2002	6462	6462	6502	6480	6512	6532	6605	6592	6589	6579	6578	6563	6538
2003	6581	6640	6627	6635	6642	6694	6695	6733	6741	6771	6794	6782	6694
2004	6825	6862	6957	7017	7065	7109	7126	7188	7298	7314	7312	7308	7115
2005	7297	7298	7309	7355	7398	7415	7422	7479	7540r	7563	7630	7647	7446
2006	7660	7689	7692	7695	7691	7700	7721	7722	7763	7883	7911	7888	7751
2007	7880	7880	7856	7865	7942	7939	7959	8007	8050	8045	8092	8089	7966
2008	8090	8094	8109	8112*	8141	8185	8293	8362	8557	8623	8602	8551	8310
2009	8549	8533	8534	8528	8574	8578	8566	8564	8586	8596	8592	8641	8570
2010	8660	8672	ENR hours of common labor at the 20-city average of common labor rates, plus 25 cwt of standard structural steel shapes at the mill price prior to 1996 and the fabricated 20-city price from 1996, plus 1.128 tons of Portland cement at the 20-city price, plus 1,088 board ft of 2 x 4 lumber at the 20-city price.										

VITA

Title: A WATER RESOURCES PLANNING SUPPORT SYSTEM FOR A GROWING COMMUNITY WITH MULTIPLE WATER SUPPLIERS – APPLICATION IN OWASSO,OKLAHOMA

Major Field: Environmental Science

Education: Graduated from The University of Kent at Canterbury in 1993; received Bachelor degree in Political Science and International Relations. Masters of Science degree in Economics, Oklahoma State University in 2000. Completed the requirements for the Doctor of Philosophy in Environmental Science at Oklahoma State University, Stillwater, Oklahoma in July, 2010.

Experience: Graduate Assistant in Environmental Science Graduate Program 2001-2003. Graduate Assistant in Agricultural Economics 2004-2007. Senior Environmental Scientist and a Technical Manager for Weston Solutions, Inc. 2007-present.

Awards:
Outstanding Environmental Science Graduate Program Student Research Award 2007.
Women's Research Council Award 2007.
Air & Waste Management Association Scholarship 2005.

Professional Memberships:
The Society of Military Engineers (SAME), Tulsa Post
Chair 2009-present Chair of American Air & Waste Management Association (A&WMA)
Committee Member of Small System Continuing Education Council: American Water Works Associating (AWWA)
Water Environment Federation (WEF).

Name: Annamari Childers Date of Degree: July, 2010

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: A WATER RESOURCES PLANNING SUPPORT SYSTEM FOR A GROWING COMMUNITY WITH MULTIPLE WATER SUPPLIERS – APPLICATION IN OWASSO, OKLAHOMA

Pages in Study: 300 Candidate for the Degree of Doctor of Philosophy

Major Field: Environmental Science

Scope and Method of Study:

This research develops a two-module water resources Planning Support System (PSS) for a growing exurban community with multiple water suppliers: 1) Problem Analysis and 2) Solution Analysis modules. The PSS answers the general question of when and where consolidation of rural and medium size community water systems is appropriate and should be considered as a solution to address the water resource planning of a single critical community.

The PSS was applied in Northeastern Oklahoma. The first module screened and selected the critical community (the City of Owasso) and the individual community water systems (Rogers Rural Water No. 3, Washington Rural Water No. 3, and Collinsville) to be included in the second module. The second module delineates the consolidation scenarios to address the water resources problem in the critical community by screening water treatment capacity, distribution storage, and water rights.

Findings and Conclusions

The PSS serves as a process to incorporate community and water system characteristics during water resources planning. A Current Reality Tree identified the core problem of lack of long-term water planning. Primary screens were used in selecting feasible consolidation community water systems. Secondary screens identified gaps in water treatment, storage and water rights of the consolidation scenarios based on IWR-MAIN forecasts for a 50-year planning horizon.

The application of the PSS provided schedule for when and where consolidation of rural and medium size community water systems is appropriate and should be considered as a solution to address the water resource planning of a single critical community.

ADVISER'S APPROVAL: ______________________________

Dr. Arthur Stoecker