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Preliminary Analysis of GHG Production from the Lincoln Water System to Determine Operating Energy and Infrastructure Construction Impacts

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Preliminary Analysis of GHG Production from the Lincoln Water System to Determine Operating Energy and Infrastructure Construction Impacts

by

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A THESIS

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Preliminary Analysis of GHG Production from the Lincoln Water System to Determine Operating Energy and Infrastructure Construction Impacts

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The Lincoln Water System (LWS) provides water to the citizens, industries, and commercial areas within and near the City of Lincoln, Nebraska. The intent of this thesis is to determine if reductions in future per capita water demand will help reduce the building of infrastructure and reduce future pumping costs and uses the computation of greenhouse gasses to compare the effects of different degrees of water conservation.

Data analysis was performed on water production statistics and data (1994-2011) collected and provided by the City of Lincoln, Nebraska. Projections in accordance with the Lincoln-Lancaster County 2040 Comprehensive Plan were made to determine the water demand by the year 2019, taking into account the increased population. A computerized hydraulic model of the city infrastructure was used to calculate the current and future effects on needed distribution system infrastructure due to increased water demand and land growth projections. Various Scenarios were modeled to calculate the greenhouse gas emissions based on Water Demands that varied from:

- 10 percent reduction applied to the entire City,

- 30 percent reduction applied to the entire City, and
- 10 percent reduction to existing City land and 30 percent reduction to new and future developments

The results of these models were that reductions in future water demand could be achieved and the resulting Greenhouse Gas emissions were less than if the city maintains it’s present course of activity and usage. An analysis was made that shows the infrastructure of new water mains can be reduced in diameter without adversely affecting fire protection requirements.

Reduction of future water demands will help reduce future building of infrastructure. This in turn will reduce greenhouse gas production, either directly or indirectly caused by infrastructure construction and water production. By comparing the greenhouse gas emissions related to these various scenarios of current and future City growth, the benefits of reduced consumption for wise management of the available limited water resources were shown.

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Chapter 1: Introduction

1.1 Background

Many cities are making an effort to quantify their greenhouse gas (GHG) emissions with a goal of reducing those emissions. For example, mayors across the United States are taking initiative by joining The U.S. Conference of Mayors' Climate Protection Agreement (The United States Conference of Mayors, 2012). This is due to an increasing concern of greenhouse gas production associated with infrastructure that is built to accommodate growth in cities. Drinking water supply and treatment is part of this infrastructure. Some efforts have been made to compute the greenhouse gas emissions from water production and supply; this is still an emerging topic. This thesis aims to use the Lincoln Water System as a case study to examine general trends in greenhouse gas emission from water supply and treatment, both in terms of direct production from the use of electric and diesel fuel in operations, and indirect production associated with infrastructure expansion.

1.2 Lincoln Water System

As of the 2010 U.S. Census, the City of Lincoln, Nebraska had a population of approximately 262,000 (U.S. Census Bureau, 2010) and covered an area of approximately 90.8 square miles (Lincoln Department of Public Works, 2011). Lincoln currently uses water obtained from underground wells that are situated near rivers. According to the 2011 Lincoln Annual Drinking Water Quality Report, more than 11.7 billion gallons of water were pumped from these wells in 2010. On average, the city consumes 32 million gallons of water each day. Currently, the City population growth rate is 1.5 percent per year and, by the year 2040; the population is projected to increase to 500,000, according to the 2007 Facilities Master Plan Update. If current rates of water consumption are maintained, the increase in population will increase both water demand and the amount of energy necessary to deliver this water to the population.

The City currently spends annually approximately 3.1 million dollars on electrical costs for both the transmission (1.3 million dollars) and distribution (1.75 million dollars) of water from the water treatment plant to the consumers throughout Lincoln. The current energy consumption is 13 million kilowatt-hours (LWS, 2011). Lincoln Water System (LWS) has a very structured Supervisory Control and Data Acquisition (SCADA) system. This system is designed to assist in data acquisition and helps staff understand how certain pumping stations, distribution mains, water wells, and transmission systems work together as well as how to adjust the system for improved efficiency of operation. In addition, conservation efforts promoted by the City of Lincoln have educated businesses and consumers alike in methods of conserving water and replacing aging fixtures with modern ones that consume less water, therefore saving on energy. These efforts have, over time, led to a reduction in citywide water consumption, as per 2007 Facilities Master Plan Update, 50 gallons per capita-day from 1994 to 2010, despite the increase in the population of the City.

LWS population projections show that the city will double in size over the next 50 years. Conventional logic implies that new infrastructure has to be built in order to meet this demand. Infrastructure demand is quantified in Capital Improvement Programs

(CIPs), which act as a budgetary tool to oversee future infrastructure growth as set by the City planners. Over time, the CIPs looked into ways of building infrastructure that will accommodate the continued growth in population. The building of these infrastructures, however, coupled with an increasing demand in energy usage, bring about concerns of increasing Greenhouse Gas (GHG) production, both from the embedded greenhouse gas in infrastructure and direct power consumption from energy demands.

LWS is not required by any agency to compute their GHG production from the production of drinking water. But estimates of the GHG production can be made using tools such as the U.S. Environmental Protection Agency (U.S. EPA) Facility Level GHG Emissions Database and Carnegie Mellon's EIO-LCA tool. These GHG approximations can put into context the implications of different long-term strategies (scenarios) based on possible per capita water use changes.

1.3 Need for Research

GHG quantification is currently not a major part of research in the drinking water industry despite the fact that advancements are presently being made towards this field of study. This study is only a preliminary report on GHG production within the infrastructure side of drinking water production by the City of Lincoln, Nebraska. The GHG production will show the hidden costs that are not lumped into CIPs. In addition, many of the regulatory and future liabilities will force industries to comply with set rules in building construction.

It is essential that a more thorough understanding of GHG production due to infrastructure be obtained. The purpose of this research is to use LWS's qualitative and quantitative information currently available, and to supplement this data set to accurately represent the ever-growing concern of GHG production caused by infrastructure buildings. To accomplish this, a set of objectives was defined and addressed.

There were four main objectives that needed to be completed throughout the course of this research. These objectives include:

1. Calculate seasonal water usage rates and determine if there are seasonal influences by calculating per capita water use and peak to average water use trends.

2. Calculate seasonal energy usage rates and determine if there are seasonal influences by calculating per capita water use and peak to average water use trends.

3. Take a portion of LWS, using GIS models, determined from different scenarios of water use rates, assuming Lincoln's growth plan is correct, to determine differences in infrastructure construction.

4. Estimate GHG production per million gallons of water used, for operating energy required, and compare GHG production values from different future scenarios.

The given recommendations have the potential to result in policies that limit peak demand water consumption, delay infrastructure development, and support installation of equipment that will, in the long run, improve energy use in the water transmission system. The expected outcome of this report will be to identify what planned infrastructure were delayed, reduced in cost, or canceled altogether due to changes in water use – meaning that the projected quantities were larger than what actually occurred, largely due to reduction in per capita use. These values will be compared with projected infrastructure. The expected results will be a comparison of delayed infrastructure versus reduced GHG production from the infrastructure.

1.4 Thesis Overview

The study covers the transmission and the distribution systems. The Water Treatment Plant (WTP) that supplies water to Lincoln has two different treatment trains, the West (old) plant and the East (new) plant. The West plant takes its natural water from a few well fields west of the Platte River, while the East plant takes its natural water from two Ranney collector wells located on the Platte River Island. During maintenance periods, one plant is taken out of service, while the other plan meets the water needs of the City (Hilts, 2000).A review of the literature and previous work is discussed in Chapter 2. Chapter 3 contains an explanation of the materials and methods used in research. Processed raw data from LWS and results are discussed in Chapter 4. Chapter 4 also discusses the experimental results from reduced infrastructure and general outcome of GHG produced from the infrastructure. Conclusions and recommendations for future research are discussed in Chapter 5.

Chapter 2: Review of Literature

2.1 Introduction

Several factors have to be considered when determining GHG emissions from infrastructure growth. Climatic shifts have raised concerns of anthropogenic activities that affect global weather trends. A brief overview of global climatic trends, a detailed look of water conservation programs across the U.S., a comprehensive understanding of regional water and energy use in water utilities, and literature review describing current progress in comprehensive GHG trends in water production will help in the understanding of the current need to consider production effects of growth in the water industry.

In the development of a study that deals with greenhouse gas production in infrastructure, numerous sources of uncertainty exist. These uncertainties include how one selects which infrastructure are generally considered necessary and which ones can be neglected. To properly identify which infrastructure can be selected or neglected, two factors are often considered based on past experience and knowledge:

1. Routine Infrastructure Maintenance, and
2. Necessary Infrastructure Improvements (needed for future expansion).

Other uncertainties that may exist in the system include:

- Construction done to accommodate water use growth,
- Peak versus average ratio changes in the water system,

- To what degree there are predictable variations in the total amount of water consumed,
- Water produced per day, per month, per year,
- Current Lincoln population effect on water demand,
- How any green initiative helps defer construction, and
- How many commercialized or industrialized areas will be developed that will require large increases in water use along with peak fire flows.

In past literature, most research of GHG production relative to water production has been done in densely populated areas, such as California. This is discussed in California Water - Energy Relationship (Klein, 2005). The lack of studies assessing energy use in water production and related GHG emissions in the whole water sector may be partly due to the absence of clearly defined boundaries.

2.2 Climate Change and Global Water Trends

Weather variation is a sensitive topic in general. At present, 3 percent of the world's water is fresh water and the rest is undrinkable water (sea water or polluted water). Out of this 3 percent that is available for use, only 0.5 percent is used for man's fresh water needs. The other 2.5 percent is "locked-up" in the glaciers that are in Antarctica and the Artic (Water and Sustainable Development Program, 2006). In the case of Nebraska, the U.S. Bureau of Reclamation is forecasting a decline in volume in the Republican River (a river predominantly used for irrigation and shared with Kansas and Colorado). Due to frequent discharge and insufficient recharge, surface and groundwater levels are on the decline (Hovey, 2012). Though no correlation is made in the declination of water from the Republican River, normal seasonal variations, drought, and floods can all contribute to local extreme conditions.

Global warming is considered an average increase in the earth's temperature due to greenhouse gas effects as a result of both natural and human activities (Riebeek, 2010). These activities, which alter the chemical composition of the atmosphere, result in the increase of greenhouse gases that include carbon dioxide, methane, water vapor, nitrogenous, and fluorinated gases. These gases act like a transparent layer of glass around the earth, letting light and heat reach the earth's surface, but trapping the heat from the sun in the earth's atmosphere and increasing the earth's temperature (Dinçer et al., 2010). Global temperature variations have been more evident in recent times (U.S. EPA, 2008). For instance, the City of Lincoln recently experienced one of the worst droughts in years. This drought occurred during the summer of 2012 (National Climatic Data Center, 2012), forcing the City to impose mandatory water use restrictions (City of Lincoln Mayor's Office 2012 Media Releases, 2012). According to the National Wildlife Federation, all across the United States, some important trends in precipitation are being seen. The Southwest appears to be shifting to a more arid climate, in which dust bowl conditions will become the new norm. Such occurrences make global warming a major concern of human beings in this century (National Wildlife Federation, 2012).

According to U.S. EPA's Climate Change and Nebraska report (U.S. EPA, 1998), over the past century, the average temperature near Lincoln, Nebraska, has decreased by

0.2°F, and precipitation has increased by up to 10 percent in many parts of the state, except in the far western areas where precipitation has fallen by nearly 20 percent. These past trends may or may not continue into the future. Over the next century, the climate in Nebraska could experience additional changes. Projections from Intergovernmental Panel on Climate Change (IPCC , 2008) and results from the United Kingdom Hadley Centre's climate model (HadCM2), a model that monitors global and national climate variability and change, predict that by the year 2100, temperatures in Nebraska could increase by 3°F in spring and summer and 4°F in fall and winter. Precipitation is estimated to increase by 10 percent in spring, summer, and fall, and 15 percent in winter (IPCC 2008). Based on the Intergovernmental Panel on Climate Change (IPCC) report the amount of precipitation in both Northern and Southern plains, in winter months is likely to increase. Other climate models may show different results, especially regarding estimated changes in precipitation. The impacts described in the sections that follow take into account estimates from different models. The global frequency of extreme hot days in summer would increase because of the general warming trend. It is not clear how the severity of storms might be affected, although an increase in the frequency and intensity of winter storms is possible.

The Climate Extremes Index (CEI) was introduced in 1996 to summarize and present complex sets of climate variations (National Climatic Data Center, 2012). It is used to track the highest and lowest 10 percent of extremes in climate change across the lower 48 states (National Climatic Data Center, 2012). The National Oceanic and Atmospheric Administration / National Climatic Data Center (NOAA/NCDC) data models, shows that the summer of 2012 was the hottest on record, and a massive drought, accompanied by searing heat waves, gripped much of the country from the beginning of the 2012 spring through the end of the 2012 summer. The outcome of this analysis shows that we have bigger underlying issues when it comes to addressing weather effects in the near future. Old methods of water production will no longer be sufficient to meet the climate challenges that the models forecast.

States that voluntarily comply with rules and regulations have not published nor provided peer reviewed research on sustainable conservation progress that can help mitigate the current prediction of hot summers and cold winters (Ojima, 2000). Stationarity Is Dead: Whither Water Management, a Science Magazine Policy Forum report, which brings to light the idea that the environment will recover from constant human disturbances, should no longer serve as a default hypothesis in assessing environmental assumptions (Milly et al., 2008). Stationarity is dead because substantial anthropogenic change of the Earth's climate is altering the means and extremes of precipitation, evaporation, and rates of discharges of rivers (Milly et al., 2008). Despite these trends in climatic variations, researchers believe that we must be ready for changes in water supply and past trends cannot be counted upon due to non-linear transformation of the climatic variations (Craig, 2010).

For the case of Lincoln, Nebraska, the University of Nebraska School of Natural Resources-Climate and Weather Assessment forum concluded that, in 2012, July and August combined happened to be the driest on record. The total precipitation in Lincoln, Nebraska from July 1, 2012 to August 31, 2012 was only 0.63 inches. This is the driest on record for that time period in Lincoln, over the past 126 years. This is in stark contrast with the largest observed July-August combined precipitation of 17.01 inches in 1910 (Dewey, 2012). This correlation can be related to climate conditions that Lincoln, Nebraska experienced. Severe drought condition makes resources like surface water diminish. A reduction in surface water leads to lower recharge of underground aquifers. Nebraska sits on the one of the largest aquifers. At 174,000 square miles, the Ogallala aquifer covers 8 states (Fleming et al., 2012). Responsible for watering one fifth of U.S. irrigated land, the aquifer was formed over millions of years, but has since been cut off from its original natural sources. It is being depleted at a rate of 12 billion cubic metres per year. Overpumping of the aquifer has lead to a low recharge rate and a high discharge rate. Groundwater will be less directly and more slowly impacted by climate change, as compared to rivers. This is because rivers are replenished on a shorter time scale, and drought and floods are quickly reflected in river water levels. Groundwater, on the other hand, will be affected at a much slower rate. Only after prolonged droughts will groundwater levels show declining trends. Further effects of water use trends in Lincoln, Nebraska will be discussed in Chapter 4.

2.3 Regional Water Use Regulation

Nebraska relies on both surface and groundwater to meet its water needs. Thick aquifer systems, such as the High Plains or Ogallala aquifer, underlie most regions of the state (USGS, 2007). The Missouri River and its major tributaries, the Platte, the Republican, and the Niobrara, drain much of the state. Nebraska uses most of its water on agriculture. Agricultural irrigation relies heavily on groundwater. Voluntary and regulatory programs serve complementary roles in water use conservative. Such regulation, controlling water used for farming, includes the Republican River Compact which details regulations on how water can be used for farming in Colorado, Nebraska, and Kansas (Republican River Compact, 2002).

In Lincoln, Nebraska, water use is regulated under a Water Management Plan (WMP). The WMP offers a guide for using best professional judgment, considering weather conditions, weather forecasts, river flow conditions, and water system operations. Recommendations may be made to the Mayor for either initial implementation of the WMP or acceleration to an appropriate phase in the plan (LWS, 2003). The plan is intended to supplement activities of the Mayor's Water Conservation Task Force. As stated in WMP, the purpose of this Plan is to:

1. Keep water use within pumping capacity and delivery capability, based on recommendations of the LWS,
2. Define procedures to be used when the above criteria cannot be met, and
3. Familiarize citizens, businesses and industry with procedures which may be implemented when voluntary or mandatory water restrictions are required.

The Mayor’s Water Conservation Task Force is used as an educational forum that creates positive approaches to water conservation (Norris, 2012). To involve the community, the Task Force membership is made up of a diverse group of stakeholders that represent the Lincoln, Nebraska community. There are representatives of business, nurseries, builders, landscape architects, University and County Extension services, professors, government, and general citizens. The Task Force works on accomplishing certain goals. These goals include:

1. Informing and educating the citizens of Lincoln about the importance of conserving our water resources,
2. Increasing the acceptance of water conservation measures to reduce outdoor water consumption,
3. Improving domestic in home water conservation,
4. Improving water conservation and use efficiency of industrial, commercial, and business water users, and
5. Informing customers regarding water quality issues.

These rules and regulations help the City of Lincoln better manage its water system.

Water conservation practices are activities that require a conscious effort of reducing and managing water consumption. Cities across America develop water management plans to better understand water use trends in their systems. The City of Lincoln, Nebraska has developed a water management program that has been successful. A successful water management program starts with developing a comprehensive water management plan. An understanding of water conservation practices is critical in developing better management practices (BMPs). The U.S. EPA provides a summary of different cities' conservation practices (EPA Water Resources Center, 2011). The case studies discussed below highlight cities that have enforced successful water conservation practices that are currently emulated by other cities nationally.

Austin, Texas Case Study

The City of Austin receives water from the Colorado River (on Lake Austin) and the Highland Lakes system. The City developed a severe strain in the early 1980s (Austin Drought Contingency Plan, 2012), leading to the development of an Emergency Water Conservation Ordinance which initiated the City's water conservation efforts. This program has expanded to include short and long-term conservation efforts to reduce average day and peak day demands. The City of Austin has established a water conservation plan for its retail water customers. Residential and commercial facilities may use spray irrigation either before 10:00 a.m. or after 7:00 p.m. only on a designated outdoor water use day.

Commercial patio misters may operate only between 4:00 p.m. and midnight. All customers are limited to no more than two designated outdoor water use days per week, which allows up to thirty hours of irrigation (Austin Drought Contingency Plan, 2012). Austin also has initiated incentives to customers who show better water management practices. These practices encompass several incentive and rebate programs that include low-flush toilets, low-flow showerheads, landscape practices (xeriscaping), public education, and rainwater harvesting. Many of the conservation measures available involve customer participation and in some cases, lifestyle changes. These changes often take time and require continual effort to maintain their effectiveness. The overall goal is that the City of Austin reduces its water use by 40 percent before the year 2050. The City of Austin is on target as they have reduced water use by 25 percent as of 2012. Austin residents use on average 172 gallons per person per day. That is more than the 142 gallons used by San Antonio residents, but less than the 244 gallons consumed by their counterparts in Dallas, according to 2005 data from the Texas Water Development Board. The comparison with Lincoln is that Lincoln has been able to reduce water consumption by 50 gallons per capita-day since 1994 to 2010.

San Antonio Case Study

Most of San Antonio's drinking water is pumped from a massive underground reservoir, the Edwards aquifer (San Antonio Water System, 2012). In the early 1990s, the federal courts and the Texas Legislature established limits on San Antonio's primary water source. San Antonio conserves water using different methods. These methods include water conservation programs (drought restrictions, outdoor conservation programs and rebates, indoor conservation programs and rebates, commercial programs and rebates) and water recycling programs (using non-drinking water for landscape and for industrial purposes) (Buchele, 2012). These programs have led San Antonio to make significant progress in reducing per capita water use from a high of 225 gallons a day in the mid-1980s to 136 gallons per capital per day (gpcd) during the record 2012 drought (down from 142 gpcd in 2005), with a final goal of 116 gpcd by 2016 (City of San Antonio, Texas, 2012). This accounts for about a 40 percent reduction in water use . The reason why San Antonio has been so successfull comes down to price, city ordinances, conservation measures, and demographics.

National Cities Summary

The U.S. EPA provided different summaries of water conservation practices in its July 2002 Cases in Water Conservation: How Efficiency Programs Help Water Utilities Save Water report. Table 2-1 below summaries the case studies from several different leading utilities discussed in the U.S. EPA's report.

Table 2-1: Summary of Conservation Case Studies (Excerpt from US EPA Cases in Water Conservation: How Efficiency Programs Help Water Utilities Save Water and Avoid Costs)
Source: (EPA Water Resources Center, 2011)

City	Problem	Approach	Results
Albuquerque, New Mexico	A dry climate and increased population growth put a strain on Albuquerque's water supply.	Albuquerque's Long-Range Water Conservation Strategy Resolution consisted of new conservation-based water rates, a public education program, a high-efficiency plumbing program, landscaping programs, and large-use programs.	Albuquerque's conservation program has successfully slowed the groundwater drawdown so that the level of water demand should stay constant. Peak demand is down 14 percent from 1990
Ashland, Oregon	Accelerated population growth in the 1980s and the expiration of a critical water right created a water supply problem.	Ashland's 1991 water efficiency program efforts consisted of four major components: system leak detection and repair, conservation-based water rates, a showerhead replacement program, and toilet retrofits and replacement.	Ashland's conservation efforts have resulted in water savings of approximately 395,000 gallons per day (16 percent of winter usage) as well as a reduction in wastewater volume.

Table 2-1(continued): Summary of Conservation Case Studies (Excerpt from US EPA Cases in Water Conservation: How Efficiency Programs Help Water Utilities Save Water and Avoid Costs)
Source: (EPA Water Resources Center, 2011)

City	Problem	Approach	Results
Cary, North Carolina	With the population more than doubling during the past 10 years and high water demand during dry, hot summers, the city's water resources were seriously strained.	Cary's water conservation program consists of eight elements: public education, landscape and irrigation codes, toilet flapper rebates, residential audits, conservation rate structure, new home point program, landscape water budget, and a water reclamation facility.	Cary's water conservation program will reduce retail water production by an estimated 4.6 mgd by the end of 2028, a savings of approximately 16 percent in retail water production.
New York City, New York	By the early 1990s, increased demand and periods of drought resulted in water-supply facilities repeatedly exceeding safe yields. Water rates more than doubled between 1985 and 1993.	New York's conservation initiatives included education, metering, leak detection, water use regulation, and a comprehensive toilet replacement program.	Leak detection and repair, metering, and toilet replacements were particularly successful programs. New York reduced its per-capita water use from 195 gallons per day in 1991 to 167 gallons per day in 1998, and produced savings of 20 to 40 percent on water and wastewater bills.

Table 2-1(continued): Summary of Conservation Case Studies (Excerpt from US EPA Cases in Water Conservation: How Efficiency Programs Help Water Utilities Save Water and Avoid Costs)
Source: (EPA Water Resources Center, 2011)

City	Problem	Approach	Results
Phoenix, Arizona	Phoenix is one of the fastest growing communities in the United States and suffers from low rainfall amounts. The state legislature has required that, after 2025, Phoenix and suburban communities must not pump groundwater faster than it can be replenished.	Water conservation programs instituted in 1986 and 1998 focused on pricing reform, residential and industrial/ commercial conservation, landscaping, education, technical assistance, regulations, planning and research, and interagency coordination.	Phoenix's conservation program currently saves approximately 40 mgd. Phoenix estimates that the conservation rate structure alone saved 9 mgd.
Wichita, Kansas	Ten years ago, analysts determined that the city's available water resources would not meet its needs beyond the first decade of the 21st century. Alternative sources were not available at an affordable price.	Wichita utilized an integrated resource planning approach. This included implementing water conservation, evaluating existing water sources, evaluating nonconventional water resources, optimizing all available water resources, pursuing an application for a conjunctive water resource use permit, evaluating the effects of using different water resources, and communicating with key stakeholders.	Analysis of resource options for Wichita resulted in a matrix of 27 conventional and nonconventional resource options.

2.4 Energy and Electric Use per Water and Wastewater Production

To evaluate the components involved in energy use in water production requires knowledge obtained from previous research on a wide range of reports. Presented in this overview is a literature review of the general components of energy use from water production and the boundary of study. Water and wastewater treatment are intrinsically energy-intensive due mainly to the need to move large volumes of water, using pumps and electric motors, and to aerate the wastewater as part of the treatment process. The cost of the electricity used in the treatment process is based on two main components: the quantity of electricity used and the demand for electricity. In the coming years, water shortages will be a common thing. Currently, 40 to 50 percent of the world's population is facing serious water shortages (World Water Council, 2010). This number is increasing, due to climate changes, or inadequate infrastructure. Shortages lead to a push to develop networks that supply water to these areas. In the Western U.S., California has arid areas that currently utilize 2,982 miles of pipelines, tunnels and canals, and a dozen pump stations. Demand for water goes hand-in-hand with demand for energy. In California for instance, due to the arid areas, about 19 percent of electricity produced in the state is consumed by water-related services (Stokes, Horvath, 2009). Consumer Energy Report based on a University of Texas study has released a report on energy use in water delivery to citizens of the U.S., finding that no less than 12.6 percent of the nation's total annual energy consumption is consumed by water delivery utilities (Sanders, Webber, 2012).

In the Energy and Air Emission Effects of Water Supply report (Stokes, Horvath, 2009), Stokes and Horvath developed the Water-Energy Sustainability Tool (WEST). This tool can evaluate the construction, operation, and maintenance of water systems and compare the direct and indirect energy and environmental effects of alternative water sources in terms of material production, material delivery, use of construction and maintenance equipment, energy production, and sludge disposal. The use of WEST as a tool is more beneficial because it incorporates the results of hybrid Life Cyle Analysis (LCA) for all life-cycle phases and is customizable to any state in the United States. It also combines inventory data from the Economic Input-Ouput Life Cycle Assessement (EIO-LCA) as well as from commercial LCA databases. It includes water utility designs and typical operational practices of U.S. water utilities, which are herein studied for the first time as a comprehensive system, using hybrid LCA and U.S. conditions.

In California, Klein's California's Water – Energy Relationship (Klein, 2005) reports that water-related energy use consumes 19 percent of the state's electricity, 30 percent of its natural gas, and 88 billion gallons of diesel fuel every year, with an ever-growing demand. As the water demand grows, the energy demand grows too. The California Energy Commission Demand Office estimates that a total of about 9,000 Gigawatt Hour (GWh) of electricity are used annually by both water and wastewater facilities. This is based on electric and water meter data, assumptions from engineering handbooks, and other sources about the electrical requirements of certain equipment. This consumption will increase.

As new water quality regulations are implemented, energy-intensive technologies such as membranes, ultraviolet (UV) light, ozonation, and desalination will require large quantities of energy. To reduce energy costs, many utilities have already replaced older pumps and motors with newer, more efficient equipment. Due to the vast pipe network in California, city water agencies use about 1,150 kWh per million gallons to deliver water from the treatment plant to their customers (Larson et al., 2007). This is due to the fact that even the farthest reaches of the network must be kept under adequate pressure and constantly flushed because low pressure and low flow allow microbes to flourish. Distribution of treated water remains fairly constant, equaling between 80 to 85 percent of the total energy requirements (Larson et al., 2007) when treatment and distribution energy loads are combined. In summary, the state must both develop and expand best practices with existing programs to realize the substantial incremental benefits of joint water and energy resources for infrastructure management. Significant energy benefits can be reaped through the twin goals of the efficient use of water by end users as well as efficient use of energy by water systems.

According to Water & Sustainability (Volume 4), ground water supplies used by public water supply agencies are generally small compared to surface water (Smith, 2002). The system consists of wells pumping to the surface. The water is chlorinated for disinfection and removal of odor and taste. The treated water is then pumped directly to the distribution system or to above-ground and/or ground-level storage tanks where it is held until distribution. Unit electricital consumption from groundwater is estimated at 1,824 kWh per million gallons, some 30 percent greater than for surface water (Smith, 2002). The predominant consumer of electricity is pumping. About one third of the electricity is used for well pumping, while most of the balance is used for booster pumping into the distribution system. Less than 0.5 percent of the electricity is used for chlorination of the water.

With the high consumption of electricity, the water sector faces other issues, like the quality of power it gets (Smith, 2002), as well as the source of electricity. Most water processing facilities have back-up power in the event of electrical interruptions. For instance, LWS WTP has a supplmentary power from a diesel substation. This substation is used to supplement high water demands in the summer.

The Water & Sustainability: U.S. Electricity Consumption for Water Supply & Treatment—The Next Half Century Volume 4 study concludes that about 4 percent of the nation's electrical use goes towards moving and treating water and wastewater. Approximately 80 percent of municipal water processing and distribution costs are for electricity.

Other reports like the Water-Energy Nexus (Rothausen, 2011) looked at the Life Cycle Analysis (LCA) of the water industry and found that energy use from pumping water carries the highest environmental burden. The paper further noted that even though data showed that the highest impact of energy was from pumping water, so few peer-reviewed papers address energy use and related GHG emissions in the whole water sector that it was suggested that a knowledge gap exists in the academic research community.

Various studies have looked further into LCA on energy consumed in the water industry. The New York State Energy Research & Development Authority Water &

Wastewater Energy Management (New York State Energy Research & Development Authority , 2010) looked into best management practices which involved analyzing the entire water and wastewater distribution system of New York City. Obviously, the system in New York is much bigger than the system in Lincoln, Nebraska; however, this was one of the few reports that went into a detailed audit of their system and provided ways of improving energy efficiency and energy management at wastewater treatment plants (WWTPs) and water treatment plants (WTPs), two of the larger energy users under the control of a typical municipality.

LWS and wastewater treatment plants quantify their data in different reports. The last such effort in drinking water was from the report produced in conjunction with consulting companies Black & Veatch and Derceto. Data from the 2007 Facilities Master Plan Update and Derceto Aquadapt Energy Saving Program for Water Utilities were used to quantify energy use in the City of Lincoln (Lincoln Water System, 2012). LWS also has water and wastewater billing rates. Residential water is sold by the unit, where one water unit is 100 cubic feet or 748 gallons, and is determined by an increasing block structure. Under this pricing policy, an increase in water consumption results in an increase in pricing. Residential water rates are sold by the unit. Non-Residential water rates account for business customers who use a steady amount of water year round. They provide an economic base which is important for the development of the City and due to the predictable water use trend, they are billed less. The wastewater rate is based on a flat fee of $1.8 per unit and is the same for all customers (Lincoln Water and Wastewater, 2010). LWS is however billed by two different companies. The pumping system in the WTP is billed by Omaha Public Power District (OPPD). The pumping stations in Lincoln are billed by the Lincoln Electric System (LES). A detailed discussion of electricity rates, bills, and kWh is provided in Appendix A.

LWS, a non-profit governmental public utility, looks into ways to better rationalize costs billed to customers from the water sectors by providing its services for reasonable and fair user fees or rates. These fees are typically developed based on the debt service for capital improvements, operating expenses (labor, energy, chemical, etc.), and management amounts. The end goal of these fees or rates is reducing energy costs. Efficiency in the system helps LWS better understand which additional infrastructure are not necessary. Reduction of unwanted additional infrastructure may help reduce GHG that are produced from excessive energy consumption and/or building additional unnecessary infrastructure.

From a billing stand point from electric distribution utilities, LWS currently pays a "demand" in their billing structure. The demand charge is based on the customer's maximum demand for electricity (kilowatt-kW) measured during a billing period, and allows the electric utility to recover the capacity costs required to meet each customer's maximum energy needs. This demand is based on the highest month use rate. For instance if in one month in summer, August, the demand was highest, LWS will be billed the same demand for the entire year regardless of how much electricity the facility uses. Typically, summer months have the highest demand charges and in winter time, the facility has low demands. By minimizing demand charges, facilities can save tremendously on electric cost. LWS currently uses some practices like shifting loads, off-peak periods, implementing pump rules, and installing effective pumping systems that use electricity efficiently.

2.5 GHG Emissions from Drinking Water Production

Emissions of GHGs from desalination of seawater alone are 1.5-2.5 times higher than imported water sources. This increase is brought about because of higher electrical, chemical, and membrane consumptions. The author of the Water-Energy Relationship report notes that in order to meet California's water needs through imported water; this would cause California's electrical consumption to rise, hence contributing to 2.6 percent of its GHG production. Meeting all water demands from desalination would use up to 52 percent of all electricity in the state and contribute to 6 percent of its GHG (Klein, 2005). The carbon footprint currently associated with moving, treating and heating water in the U.S. is at least 290 million metric tons a year. The CO_2 embedded in the nation's water represents 5 percent of all U.S. carbon emissions, which is equivalent to the emissions of over 62 coal-fired power plants. The Carbon Footprint of Water report looked at energy production and greenhouse gas production in the water industry in U.S. (Wilson and Griffiths-Sattenspiel, 2009). The study contains suggestions on ways energy consumption can be reduced in the water industry. Wilson and Griffiths-Sattenspiel concluded that replacing water using fixtures and appliances reduces hot water use by approximately 20 percent and reducing outdoor irrigation - especially during summer months - can result in substantial "upstream" energy savings by reducing water consumption.

Water treatment facilities also need to be modified to comply with effective and efficient systems that do not consume large amounts of electricity. Pumping is currently the most energy intensive process. Water utilities address this energy intensity on the amount of electric demand that is related to the treatment, distribution, and disposal of water within water treatment plants. These demands increase during peak energy needs. The challenge lies in finding an understanding of the relationship between existing water agency electrical demands and water agency customer water use, and to understand how this water use relates to the associated electrical energy used by the water agency providing this water hence the effects on GHG produced in the variation of the above factors. Understanding the layout of a WTP helps one see the energy intensive process in the system. A typical WTP is shown below with estimates of energy used in the processes. Figure 2-1 below shows a set-up that treats water in California. This WTP has a capacity of 10 mgd. Energy in kWh per day produced in this facility from major processes amount to approximately 14,000 kWh per day in energy demand.

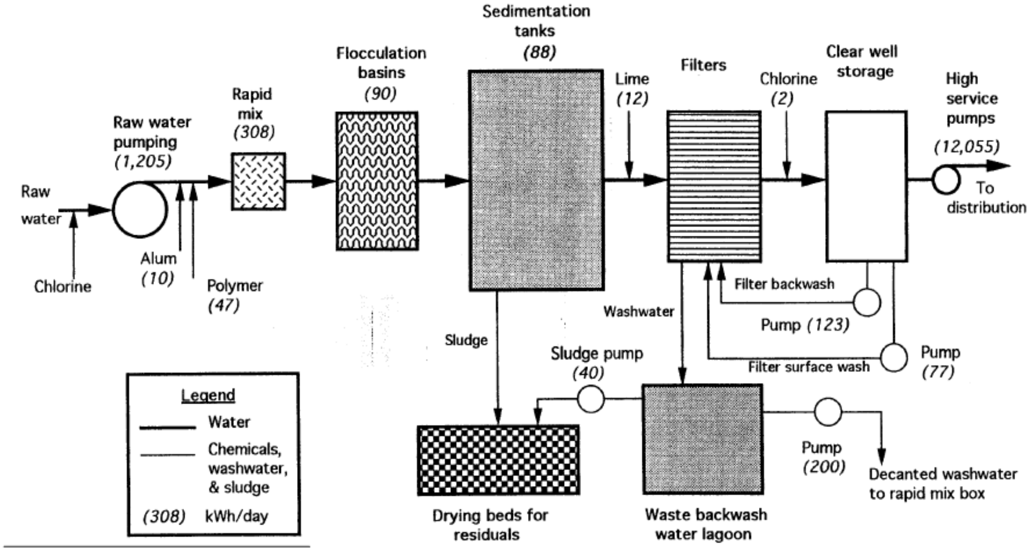


Figure 2-1: Representative Surface Water Treatment Plant Process (with Typical Daily Electricity Consumption for a 10 Million Gallon/Day Facility)
Source: (Smith, 2002)

The energy demand in a water treatment plant is shown in the figure above. The purpose of the figure above is show energy demands from different sectors of the water treatment facility. The key thing to note from the table is that pumps used most of the energy in the facility and an upgrade in the system will consequently mean that one has to upgrade the pumps in the network to reduce the hence high cost of energy consumption.

According to the Lincoln Capital Improvement Program (CIP), several infrastructure additions have been proposed in order to keep up with growing population (City of Lincoln Mayor's Office 2012 Media Releases, 2012). A quick comparison of infrastructure built or proposed over time using the CIP from 2008 to 2014 can be seen in Appendix E.

2.6 GHG Calculation Tools

Calculating emissions is a comprehensive, multi-step process. An accurate and useful inventory can only be developed after careful attention to quality control issues. Only then should emissions be estimated. Different programs are available for calculating GHG emissions. A few, however, are extensively used. This section will look at the GHG calculators used in the analysis. Direct emissions and indirect emissions will be considered. Direct emissions are emissions directly produced by the LWS or its utility provider from the use of electricity, diesel fuel, or gasoline. Indirect emissions are emissions produced by equipment, chemical, or material suppliers as part of the construction process.

2.6.1 Greenhouse Gas Equivalencies Calculator

The U.S. EPA-GHG Equivalencies calculator (U.S. EPA, 2011) was designed to help public and private sectors estimate their global warming potential (GWP), ability of a unit gas emitted in the present to trap heat in the atmosphere over a certain timeframe, indexed relative to a reference gas, CO_2, which is assigned a GWP value of 1. Units of measurement used in the equation are metric tons of carbon dioxide equivalent or $MTCO_2e$. The unit CO_2e represents an amount of a GHG whose atmospheric impact has been standardized to that of one unit mass of CO_2, based on the GWP of the gas. The tool uses million $MTCO_2e$ or $MMTCO_2e$ due to the quantities involved. These values are input in annual basis.

Data can be inputted into the calculator for the amount of electricity, renewable energy, natural gas, and diesel fuel. The calculator also allows users to sort the emissions, generation and rate data by state and U.S. total levels. Using emission data for nitrogen oxides, sulfur dioxide, carbon dioxide and mercury, the calculator helps individuals and organizations reduce their greenhouse gas emissions, develop reduction targets and accurately publicize pollution reduction strategies. These pollutants are considered to have a higher GWP hence scrutiny is placed on them. Other forms of output from non-renewable energy can also be investigated by the calculator. For instance, one can look at ways to reduce production of GHG from using conventional diesel by either switching it to bio-diesel or other forms of renewable fuels. The calculator calculates these emissions using the same non-base load output emission factor that is used to calculate avoided emission from electricity conservation (U.S. EPA , 2011). The electricity conservation and water conservation categories are based on U.S. EPA Clean Energy 2010 software - eGRID (Emissions & Generation Resource Integrated Database). eGRID is a comprehensive source of data on the environmental characteristic of almost all electric power generated in the U.S (U.S. EPA eGRID, 2012).

The calculator also references the U.S. Greenhouse Gas Inventory Report - Inventory of U.S. GHG Emissions and Sinks: 1990-2010, which is also used to reference national GHG produced in the U.S. The GHG equivalencies calculator model can compare GHG from anthropogenic emissions in different states (U.S. EPA Greenhouse Gas Inventory, 2012). The water conservation category is referenced in Water and Sustainability: U.S. Electricity Consumption for Water Supply & Treatment. The report outlines national water consumption across the U.S. and quantifies energy used in water consumption (Smith, 2002). Another equally important and comprehensive GHG calculator is the Economic Input-Output Life Cycle Assessment model.

2.6.2 Economic Input-Output Life Cycle Assessment

One relatively simple to use, publically available, life cycle assessment tool is the Economic Input-Output Life Cycle Assessment (EIO-LCA) tool created by researchers at Carnegie-Mellon University (Carnegie Mellon University Green Design Institute, 2012). EIO-LCA looks at indirect effect of GHG production and its production sources showing hot spots in the embedded GHG process. The general output in shows 10 direct inputs. This creates a common boundary assumption on the area of focus. This is done by aggregating different sectors that contribute to GHG production and quantifies how much environmental impact can be directly attributed to each sector. The Economic Input-

Output Life Cycle Assessment software, traces out the various economic transactions, resource requirements, and environmental emissions associated with the production of a particular product or service (Hendrickson, 2006). For example, a community might want to figure out greenhouse gas effects of building extra water mains that may be needed. The model outputs components that are used put in the process of installing water mains.

The model used in this research is based upon the Department of Commerce's 500 sector industry input-output model of the U.S. economy. It examines the indirect cost of GHG gas production using a cradle to grave approach of GHG quanitification (EIO-LCA, 1997). This model captures national averages from various manufacturing, transportation, mining, and related requirements to produce a product or service. It goes into detail on the life of a product, including process or service starting with raw material extraction, through manufacture to use, and recycling or final disposal. The embedded side of GHG is considered. This may include chemical production, transportation of materials, and water treatment plant operation. This LCA approach lets the individuals identify environmental impacts related to system inputs and outputs, flags any hazards, and highlights possibilities for improvements (EIO-LCA, 1997).

2.7 Summary

Chapter 2 looked at relevant literature and highlighted the issue of how little to no research has been done in regard to investigating GHG production from infrastructure. There exists an information gap in greenhouse gas production studies from infrastructure built to accommodate city growth. The literature scrutinized the published material on the assessment of the environmental impact during the whole life-cycle of supporting the ecosystem. Using the literature background gathered from Chapter 2, this report will build on the already-set foundation of looking for sustainable ways of supporting population growth. The models and software already used in previous research will be exploited in this report and the results will be represented to reflect the past, present and future trend of water and energy consumption in Lincoln, NE.

Chapter 3: Methods

3.1 Introduction

The primary goal of this study is to estimate the GHG production from both operations and infrastructure construction of a water utility. This chapter focuses on providing a brief explanation of the system and the methods used for the analysis of the City of Lincoln drinking water system data. In order to make estimates of GHG production from both operations and the infrastructure of a water utility, there is a need to find methods for greenhouse gas production. The methods used in this study are essentially ratios and conversion factors taken from the technical literature described in Chapter 2. In addition, to evaluate the potential impact of water conservation on the infrastructure, water distribution modeling computer simulation software (ArcGIS InfoWater) was used and scenarios for its application were discussed. All of these tools and methods are described in this Chapter.

3.2 Study Area Description

General statistics regarding the Lincoln Water System were obtained from the Annual Drinking Water Quality Report. In 2011, more than 11.7 billion gallons of water were pumped from these wells, where the ground water is under direct influence of surface water, to serve the 258,000 people who used an average of about 32 million gallons of water each day. With a projected population growth of up to 527,000 over the next 50 years, the Lincoln Water System needs to meet both the future water and energy demands brought about by the gradual growth in population. The City is divided into six different water service levels: Low, High, Belmont, Southeast, Cheney Booster District, and Northwest Booster District.

Data acquired from Lincoln Water System includes reports from water use, energy use, and projected future cost of proposed projects. Data from water use dates back to 1994 through 2011. Water use over previous years will help predict a trend that the City is going through and also project future water demands. Energy use data is from 2009 through 2011. This energy use is from the year additional features to the water treatment process were added. These include an ultraviolet treatment system and some variable frequency drives. As described in Section 1.2, Capital Improvement Programs (CIPs) are financial instruments used to budget future infrastructure growth. The City develops CIPs every year and projects the costs to 7 years in the future. The CIPs used for this case study were from the years 2008 through 2014. CIPs are publicly available in the City of Lincoln, Lincoln Water System website. Most water utilities focus in reduction operating cost. This research shows that reducing infrastructure cost can have as much if not more of an impact of overall energy cost than operating cost.

3.3 Methods of Data Analysis

This research was based on data obtained from LWS, including data produced from the SCADA, ArcGIS, InfoWater, and various data spreadsheets. The trends studied include temporal water production, electricity consumption, and energy use. Data obtained from the ArcGIS and InfoWater model scenarios are used to examine the peak conditions caused by high water demands. High water demands normally lead to increased peaking factors. These high peaking factors create the billing cycle all year round. The “what-if-analysis” in InfoWater allowed the study to develop alternatives that can reduce peak water demand. This, in return, shows that the city has opportunities for reducing infrastructure construction.

As described in Section 3.2, the City has 6 service levels. Service levels are designated pressure zones based on elevation in the City of Lincoln. The City uses these pressure zones to size pumps for water transmission and distribution. These service levels are shown in Figure 3-1.

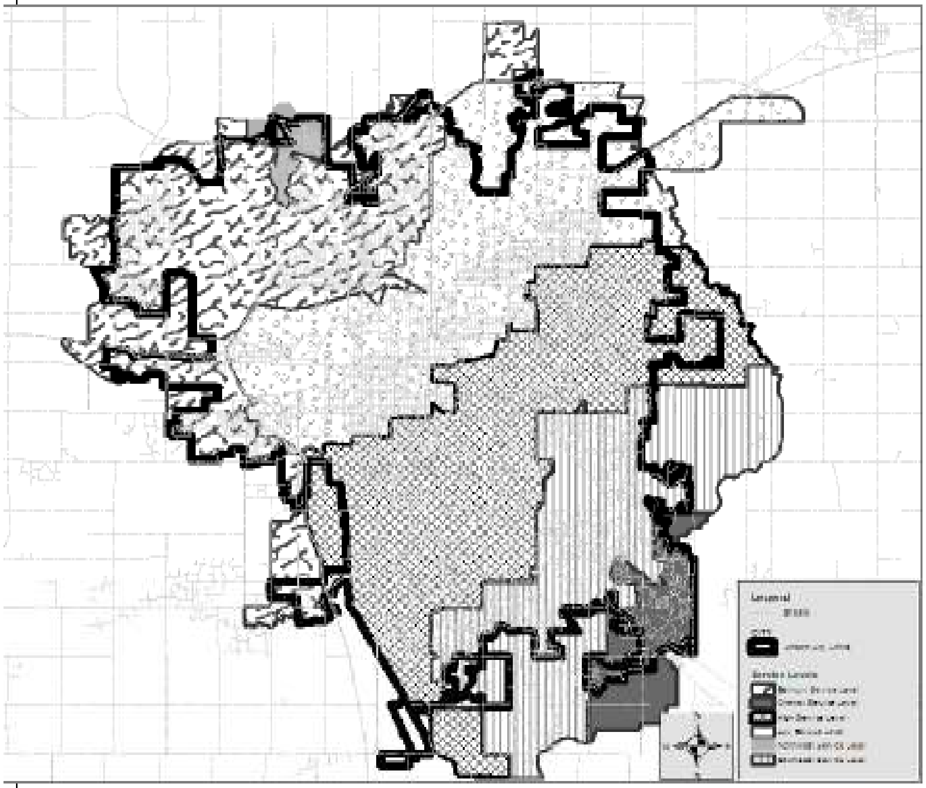


Figure 3-1: City of Lincoln - City Limits and Service Levels
Source: ESRI ArcGIS and InfoWater

Service levels are established boundaries that maintain acceptable distribution system pressures with ground elevation ranging from 1,130 feet to about 1,450 feet. The service levels represent the City of Lincoln based on different pressure due to elevation and water use. These levels are:

1. Belmont Service Level,
2. Cheney Service Level,
3. High Service Level,
4. Low Service Level,
5. Northwest Service Level, and
6. Southeast Service Level.

The water distribution model is generated in ESRI ArcGIS from a geo-database that is shared by the City of Lincoln Planning Department and City of Lincoln Public Works. The ArcGIS base scenario model includes all service levels and the transmission systems from the water treatment plants to the Lincoln distribution systems in a single model. The pipe networked is linked throughout the six service levels that run in through the city. The model is based on the LWS Facilities Master Plan that was developed in 2007.

The City of Lincoln is growing over time. Based on the 2007 Black & Veatch Master plan for the City of Lincoln, in 2007, the City population growth rate was projected to be

1.5 percent per year and, by the year 2040, the population is projected to increase to 500,000. This growth in population will increase demand of water in the City. LWS needs to build more infrastructures to support this growth in population. Already in place infrastructure may also need to be upgraded to newer and more effective systems to help the City increase efficiency in the system. Based on the CIPs that the City comes up with to look at future infrastructure growth, certain projects can be pushed back, canceled, or replaced based on how effective the current system can be improved. CIP data obtained by the City will help in cost calculation, justification of the necessity of future projects, and also identification of infrastructure needed to accommodate growth.

3.4 Distribution System Modeling Software

Water modeling software were used to performed extended-period simulation of hydraulic and water-quality behavior within pressurized pipe networks. The distribution system modeling software was designed by Black & Veatch to be a research tool that improves the City's understanding of the movement and the fate of drinking-water constituents within distribution systems. Technology based tools such as models and geographic information systems (GIS) can provide increased clarity on probable or alternative outcomes, and thus enable decision-makers to more effectively use traditional planning tools. Many of the more user-friendly models were integrated with GIS to become spatially explicit decision-support systems with relational database technology. This section provides an overview of models and GIS, as well as integrated planning and decision-making systems which were part of the next evolution of modeling capabilities. The City of Lincoln, Nebraska was modeled using InfoWater which operates in

Environmental Systems Research Institute (ESRI) ArcGIS environment. Shape files were displayed as outputs with graphical information that could be used to deduce the needed scenarios. This model, currently in use in LWS, was based on the 2002 H20MAP water mode.

Certain assumptions were applied to the current model. As stated in the 2007 Lincoln Water System Facilities Master Plan Update, the original model used in the City was created from an electronic line drawing using Microstation software and was based on the 2000 distribution system. The model developed a forecast for Lincoln, Nebraska population growth demand and water demand trends. The model is also interactive and editable for future progression in infrastructure demand and water needs. Networking of the entire system was done in InfoWater. Pipes, tanks, junctions, and reservoirs were networked with each other forming an adaptive system that shows a digitized structure of the City of Lincoln. Figure 3-1 shows the network system as generated from ESRI ArcGIS and InfoWater. The network covers the entire City of Lincoln. It was divided into various service levels depending on elevation of each service level as described in Section 3.3. The service levels have their own demands due to the influence of the surrounding population. The model isolates each service level and one can edit the service levels individually, if need be. When the system results are run, they produce the output of each service level separately, which allows the user to isolate problem spots in the service levels. Different outputs were produced on the areas of interest. The model showed elevation, pressure in water mains, velocity, flow rate, tank capacity, junction demands, reservoir head, pump flow rates, valve head loss, among other qualities.

Software used in this research was ArcGIS and InfoWater. ArcGIS is for compiling geographic data from maps, sharing and analyzing mapped information, and using maps and geographic information in a range of applications. An example of such an application is InfoWater. According to InfoWater Users Guide (InfoWater, 2005), InfoWater was designed to assist water distribution systems operators with cost and provide more reliable operations. The program uses latest advances in algorithm optimization technology and a hydraulic network simulator directly embedded into the optimization model.

Infrastructures already laid-out in ArcGIS were modified in InfoWater to include pumps, valves, tanks, reservoirs, pipes, and junctions. This infrastructure has information that can be formulated in the InfoWater algorithm database to produce viable output. Information obtained was passed back linking the operating policy for the infrastructures generated in the model. The information in the system created a digitized network that is capable of performing certain test-like run simulations on junction pressure; emulate water age analysis, model pipe velocity and flow rate, pump flow, and valve flow (Boulos et al, 2000). The aim of InfoWater software usage was to pinpoint the scheduling that best meets target hydraulic and water quality performance requirements at maximum cost savings. InfoWater is often used by utilities to:

- Generate and formulate an adaptation of future prediction of water demand on each zone,
- Formulate fire flow conditions hence assuring that production requirements are met without exceeding operation restrictions,
- Improve the operational efficiency of your water distribution system,

- Regulate and evaluate various rate schedules in regard to water time of use rates, and
- Optimize storage/pumping trade-offs, thus assuring more reliable and safer operations.

Certain limitations do exist in such modeling software. These limitations can hinder proper representations of a system like the one used in Lincoln, Nebraska. Due to the nature of the software, the limitations include:

- Model Sensitivity – Due to the networking of the pipe systems in Lincoln, one cannot isolate a particular area and focus on a service level with a goal of finding how changes in that service level can be implemented in the other service levels. The modeling software looks at the system, therefore, as a whole and
- Data cohesiveness – The data used in the study is from different time periods. The software model will use certain approximations as a convenient way to describe something projections in the system.

The model has several key outputs that can be used in making conclusive summaries on the system in the City of Lincoln, Nebraska. These outputs show the pressure points in the system that are set standards in the Water Main Design Standards set by City of Lincoln Public Works/Utilities Department. The pressure points show the areas in the City that need an improvement or upgrade due to high or low pressures. This is the key output from the software that will help make a general conclusion of which service level is affected and which need additional infrastructure to support the changes in pressure in the service level.

3.5 Greenhouse Gas Estimates

GHGs calculations are used in this study to help technical judgments on the impact of proposed infrastructure construction, and to help compare operating energy use to infrastructure construction. Two tools, U.S. EPA-GHG Equivalencies calculator and Economic Input-Output Life Cycle Assessment (EIO-LCA), are used to help make these estimates, the basis of both were explained in Section 2.6. The U.S. EPA-GHG Equivalencies calculator is used in estimating the regional average as well as the national average of operating energy, both electricity and with the use of diesel fuel that is directly used by the utility. A set of conversation factors used by U.S. EPA-GHG Equivalencies calculator (EPA, 2012) are found in Appendix C. Economic Input-Output Life Cycle Assessment used in this research help in quantifying infrastructure construction and estimating GHG produced from this activity. This looks at indirect GHG production from the City of Lincoln, Nebraska.

The EIO-LCA tool was also used to factor in embedded GHG from construction of proposed projects. EIO-LCA looks at the national GHG production. The outcome of the results from EIO-LCA will be used as a rough estimate of GHG produced from the CIP plans from the City of Lincoln, Nebraska. Section 3.5.1 and Section 3.5.2 will provide a detailed step-by-step set description of the use of these tools for estimating the greenhouse gas production.

3.5.1 U.S. EPA-GHG Equivalencies Cost Analysis Calculator

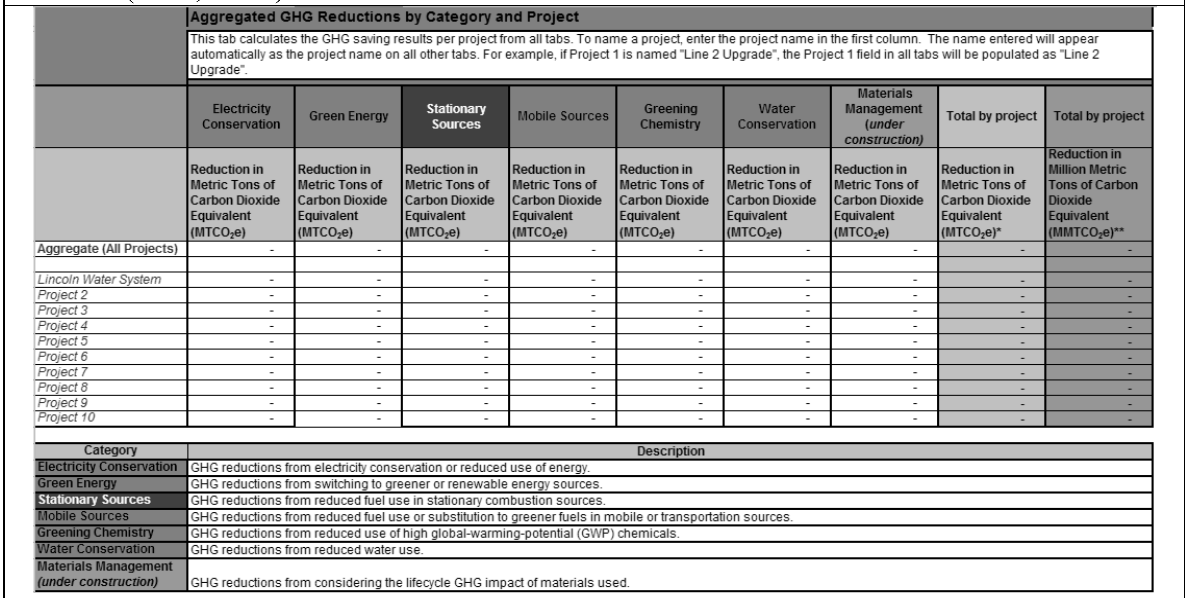
In this study, direct GHG production need to be estimated from electricity use. Electricity is the main source of energy for the transmission and distribution system.

Diesel, though rarely used and not used since 2008, supplements additional energy that the system needs to meet peak energy demand. Thus, since the electricity averages used in the GHG analysis are from 2008 to 2011, diesel is ignored from here forward. Electrical was estimated using conversation factors taken from a U.S. EPA-GHG Equivalencies Cost Analysis Calculator conversation factor spreadsheet (US EPA, 2011).

The U.S. EPA-GHG Equivalencies Cost Analysis Calculator is used in the estimation of GHG produced in the current system as well as project saving from changes made in the system (US EPA, 2011). The general lay-out of the U.S. EPA-GHG Equivalencies Cost Analysis Calculator factored in national and regional areas and gives one the flexibility of choosing which areas of concern can be investigated. The calculator is organized into 7 different categories. This analysis will only use one category (electricity conservation).

The spreadsheet calculator evaluated specific states or the nation as a whole. Each page in the spreadsheet has embedded calculation for specific sources of GHG direct emissions. The inputs in this calculator included State, electricity conserved from conservation practices, and units reported. The outputs are electricity conserved in the units that they were inputted with and GHG reduction in $MTCO_2e$. The U.S. EPA-GHG Equivalencies Cost Analysis Calculator layout is shown in Table 3-1 below.

Table 3-1 : Aggregated GHG Output from U.S. EPA-GHG Equivalencies Cost Analysis Calculator
Source: (EPA, 2011)



Aggregated GHG Reductions by Category and Project

This tab calculates the GHG saving results per project from all tabs. To name a project, enter the project name in the first column. The name entered will appear automatically as the project name on all other tabs. For example, if Project 1 is named "Line 2 Upgrade", the Project 1 field in all tabs will be populated as "Line 2 Upgrade".

	Electricity Conservation	Green Energy	Stationary Sources	Mobile Sources	Greening Chemistry	Water Conservation	Materials Management *(under construction)*	Total by project	Total by project
	Reduction in Metric Tons of Carbon Dioxide Equivalent ($MTCO_2e$)	Reduction in Metric Tons of Carbon Dioxide Equivalent ($MTCO_2e$)	Reduction in Metric Tons of Carbon Dioxide Equivalent ($MTCO_2e$)	Reduction in Metric Tons of Carbon Dioxide Equivalent ($MTCO_2e$)	Reduction in Metric Tons of Carbon Dioxide Equivalent ($MTCO_2e$)	Reduction in Metric Tons of Carbon Dioxide Equivalent ($MTCO_2e$)	Reduction in Metric Tons of Carbon Dioxide Equivalent ($MTCO_2e$)	Reduction in Metric Tons of Carbon Dioxide Equivalent ($MTCO_2e$)*	Reduction in Million Metric Tons of Carbon Dioxide Equivalent ($MMTCO_2e$)**
Aggregate (All Projects)	-	-	-	-	-	-	-	-	-
Lincoln Water System	-	-	-	-	-	-	-	-	-
Project 2	-	-	-	-	-	-	-	-	-
Project 3	-	-	-	-	-	-	-	-	-
Project 4	-	-	-	-	-	-	-	-	-
Project 5	-	-	-	-	-	-	-	-	-
Project 6	-	-	-	-	-	-	-	-	-
Project 7	-	-	-	-	-	-	-	-	-
Project 8	-	-	-	-	-	-	-	-	-
Project 9	-	-	-	-	-	-	-	-	-
Project 10	-	-	-	-	-	-	-	-	-

Category	Description
Electricity Conservation	GHG reductions from electricity conservation or reduced use of energy.
Green Energy	GHG reductions from switching to greener or renewable energy sources.
Stationary Sources	GHG reductions from reduced fuel use in stationary combustion sources.
Mobile Sources	GHG reductions from reduced fuel use or substitution to greener fuels in mobile or transportation sources.
Greening Chemistry	GHG reductions from reduced use of high global-warming-potential (GWP) chemicals.
Water Conservation	GHG reductions from reduced water use.
Materials Management *(under construction)*	GHG reductions from considering the lifecycle GHG impact of materials used.

Given that the mix of specific fossil fuels, nuclear energy, hydropower, and renewable energy sources vary place-to-place for electricity production, a location must be selected. The location can be either a state-specific conversation factor or an overall average value for the United States. The conversation factors are from U.S. EPA's Emission and Generation Resource Integrated Database (eGRID) as described in Chapter 2.6.1. Output is the GHG reduction in $MTCO_2e$.

The conversion factors used are provided below. The first is the Nebraska specific factor and the second is the U.S. national average factor.

$$\frac{1{,}972\ lbs.CO_2}{MwH} * \frac{0.454\ kg}{1\ lb} * \frac{1\ MwH}{1{,}000\ KwH} * \frac{1\ CO_2e}{1\ CO_2} * \frac{1\ MTCO_2e}{1{,}000\ kgCO_2e}$$

$$= (0.000895288)\ (A)$$

$$\frac{112\ lbs.CH_4}{GwH} * \frac{0.454\ kg}{1lb} * \frac{1\ GwH}{1{,}000{,}000\ KwH} * \frac{21\ CO_2e}{1\ CH_4} * \frac{1\ MTCO_2e}{1{,}000\ kgCO_2e}$$

$$= \ (0.00000010678\ )\ (B)$$

$$\frac{32.39\ lbs.N_2O}{GwH} * \frac{0.454\ kg}{1lb} * \frac{1\ GwH}{1{,}000{,}000\ KwH} * \frac{310\ CO_2e}{1\ N_2O} * \frac{1\ MTCO_2e}{1{,}000\ kgCO_2e}$$

$$= \ (0.00000045586)\ (C)$$

$$A + B + C = \frac{0.000900914\ MTCO_2e}{KwH}$$

For national electrical conversion, the equation below is used:

$$\frac{1{,}520.21\ lbs.CO_2}{MwH} * \frac{0.454\ kg}{lb} * \frac{1\ MwH}{1000\ KwH} * \frac{1CO_2e}{1CO_2} * \frac{1MTCO_2e}{1000kgCO_2e}$$

$$= \ (0.0006896)\ (A)$$

$$\frac{32.23\ lbs.CH_4}{GwH} * \frac{0.454\ kg}{1lb} * \frac{1\ GwH}{1{,}000{,}000\ KwH} * \frac{21\ CO_2e}{1\ CH_4} * \frac{1\ MTCO_2e}{1{,}000\ kgCO_2e}$$

$$= \ (0.0000003)\ (B)$$

$$\frac{18.41\ lbs.N_2O}{GwH} * \frac{0.454\ kg}{1lb} * \frac{1\ GwH}{1{,}000{,}000\ KwH} * \frac{310\ CO_2e}{1\ N_2O} * \frac{1\ MTCO_2e}{1{,}000\ kgCO_2e}$$

$$= \ (0.0000026)\ (C)$$

$$A + B + C = \frac{0.000692\ MTCO_2e}{KwH}$$

Detailed calculations are shown in Appendix C: Greenhouse Gas Assumption and Calculation.

3.5.2 Economic Input-Output Life Cycle Assessment

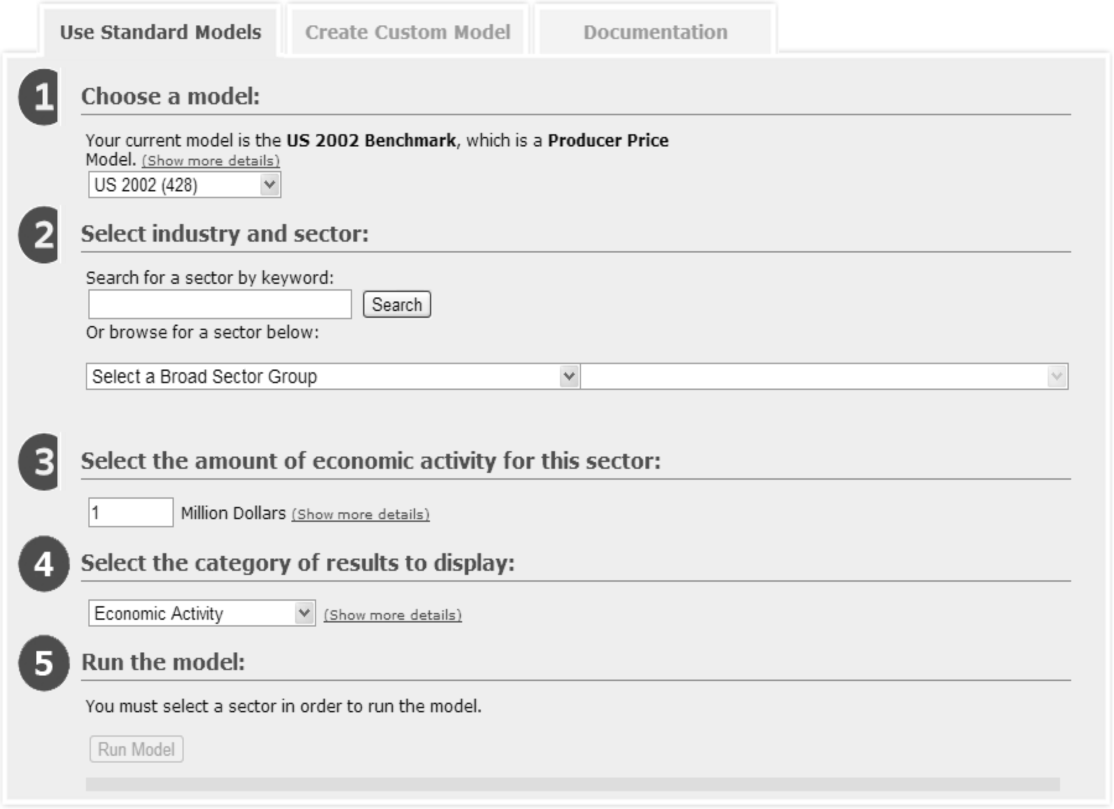
Economic input-output life cycle assessment or EIO-LCA can be used to estimate the embedded cost of GHG production for some types of materials or infrastructure. As discussed in Chapter 2.6.2, EIO-LCA is an input-output life cycle analysis tool that aggregates sector-level data to determine GHG produced in different industries. The software allows one to estimate environmental impacts from producing a certain dollar cost of any of 500 commodities or services in the United States. The EIO-LCA model used in this report is the US 2002 (428) producer model benchmark. Due to the nature of the EIO-LCA model, the model only looks at national indirect GHG production from a specific benchmark year (e.g., the most recent benchmark, 2002, was used for this study).

This EIO-LCA model estimates different environmental effects such as electricity consumption, fuel use, ore consumption, water consumption, global warming potential, and conventional pollutant emissions among other estimates. For the purpose of this analysis, only the global warming potential is calculated. For the purpose of simplicity, only one sector was selected instead of dividing the cost of multiple sectors, such as construction, pumps, or plastic pipes. The reason for selecting only one sector was that most costs originate from engineering design, construction, project management, and excavation construction, among other expenses. A small portion of the total cost comes from the materials therefore they were neglected.

The capital improvement program for the projected infrastructure for the 2008-2014 CIP, as described in Chapter 2.1, focuses on necessary infrastructure improvements. This CIP shows the most current proposed projects that the City is working on, therefore it was selected for the analysis – however, other CIPs do exist. Projected projects that are needed to facilitate future City growth will be considered in the estimation of GHGs. Based on this criteria, the cost from the projects over the last 7 year period will be used to calculate the indirect GHG produced in the City.

As shown in the figure below, different inputs are used in the model to achieve the desired output that best describes the results. The inputs for selected for the EIO-LCA are listed below (and shown in Figure 3-2):

1. Choose a model,
2. Select industry and sector,
3. Select the amount of economic activity for this sector, and
4. Select the category of results to display.



Choose a model:

Your current model is the **US 2002 Benchmark**, which is a **Producer Price** Model. (Show more details)

US 2002 (428)

Select industry and sector:

Search for a sector by keyword:

Or browse for a sector below:

Select a Broad Sector Group

Select the amount of economic activity for this sector:

1 Million Dollars (Show more details)

Select the category of results to display:

Economic Activity (Show more details)

Run the model:

You must select a sector in order to run the model.

Figure 3-2: EIO-LCA Standard Model US 2002 Producer Price.
Source: Carnegie Mellon Unversity Green Design Institute, 2012

As illustrated above, the first category is choosing the model. This category has four sub-categories with sub-sections. These sub-sections are used to further classify the goal of the analysis. The model picked in this analysis was U.S. Nation Producer Price Models with the U.S. 2002 (428) benchmark. The second category is selecting the industry and sector to be used in the analysis. This is area specific and is based on CIP, 2007 Facilities Master Plan Update, and LWS suggestions. The third category is the economic value of the project. This output can be scaled up or scaled down based on resolution that one wants to achieve in the results of the analysis. The fourth category is used to select which results will be displayed in the output. The model output can either be imported in graphical form or a spreadsheet.

To consider the GHG implications of future infrastructure construction required to address increases in population and water use growth, projected projects from the 2008-2014 CIP were considered. Based on the 2008 to 2014 CIP, the LWS infrastructure was divided into two general groups, as stated in Chapter 2. The groups include:

1. Infrastructure replacement as part of routine maintenance (e.g., security upgrade, preliminary design and engineering support for projects, control system upgrade, main break and replacement programs) and
2. Infrastructure improvements to expand the service area and capacity (e.g., new water supply well in existing wellfields, treatment plant expansion, additional supply of raw water in new wellfields).

Based on the above criteria, the infrastructures selected from the CIPs include:

1. New Water Supply Well in Existing Wellfield
2. Treatment Plant Expansion
3. Additional Supply of Raw Water in New Wellfield
4. Additional Transmission Mains and Distribution Mains

Certain assumptions and uncertainties, as described in Section 3.6, were made in the EIO-LCA model. These assumptions were based on how the model was designed and how it calculates data. For instance, the model uses a linear relationship. Thus, the environmental impact results of a $1,000 change in demand or level of economic activity will be 10 times the results of a $100 change in demand (Carnegie Mellon University Green Design Institute, 2012). Most data used was from the North American Industry

Classification System (NAICS). These made up for general generic data that gave rough estimations of embedded GHG production. The sector assumed in the EIO-LCA model from all four infrastructures selected from the CIP was Other Nonresidential Structures (Appendix C: Greenhouse Gas Assumption and Calculation). Other Nonresidential Structures as defined in EIO-LCA. This category includes various construction projects, noticeably it contains heavy and engineering construction projects (distribution line construction). The work performed may include new work, reconstruction, rehabilitation, and repairs. Specialty trade contractors are included in this group if they are engaged in activities primarily related to engineering construction projects. Construction projects involving water resources and projects involving open space improvement are included in this industry. The dollar to GHG conversion factor that can be applied to other general conversion factors is shown below.

$$\frac{MTCO_2e\ from\ EIO-LCA}{Economic\ Activity\ (\$) from\ CIP} = 0.000612\ \frac{MTCO_2e}{\$}$$

This conversion is determined by data from CIP and output from EIO-LCA. The uncertainties included in the EIO-LCA model was from old data from previous benchmarks, aggregation of sector and original data, and incomplete original data (EIO-LCA, 1997). Detailed output of the model and output results of the calculations are shown in Appendix C: Greenhouse Gas Assumption and Calculation.

3.6 Scenarios

The use of scenarios is an excellent way to stimulate discussion on future growth of Lincoln. The key focus of scenarios is uncertainty. The objective is to identify the major uncertainties affecting the strategic decisions facing a policy issue. Four scenarios were developed for this report. These scenarios are designed to offer a preliminary look at the current system by chartering the waters ahead so that the consequences of today's decisions can be played out, evaluated, and tested against the uncertainty of the future. The design of the scenarios used in this study was based on previous LWS data, Black & Veatch models, and CIPs from the City of Lincoln, Nebraska. Referring back to the LWS data, each service level was isolated and looked at separately to determine its growth, needs, and future progression. All scenarios are based on the same population growth assumptions from the based on projects made on the 2007 Lincoln Water System Facilities Master Plan Update and the growth will be in the same service zones. These scenarios include:

1. Scenario 1 (2019) – This scenario will look into City growth, with no growth in infrastructure from the year 2012 to the year 2019. This scenario looks at all the service levels,
2. Scenario 2 (10 Percent Reduction) – This looks a 10 percent reduction of the 2019 scenario across all 6 service levels,
3. Scenario 3 (30 Percent Reduction) – This examines a 30 percent reduction of the 2019 scenario across all 6 service levels,
4. Scenario 4 (10 Percent and 30 Percent Reduction) – Based on future City growth (2012-2019), the 10 percent will be implemented in service levels which are not

going to grow due to already developed infrastructure and the 30 Percent will be applied to service levels with a higher growth potential.

The justification for the different levels of water use reduction is provided subsequently. The 10 percent reduction is based on an estimate of voluntary implementation from City residents with a limited consumer information campaign. This 10 percent value is slightly higher than an estimate of a 7 percent in water use reduction was included in the Lincoln Water System Facilities Master Plan Update report. As shown in Section 4.1, the per capita water use for Lincoln has dropped by 12 percent over the past 15 years. Thus, this 10 percent reduction estimate is a mild approach to reduction of water consumption compared to other methods that can be done from a consumer stand point.

A 30 percent reduction in water use is a more aggressive approach to water conservation practices, but is smaller than that achieved by other Water Systems (such as 40 percent by San Antonio) as described in Section 2.3, in areas that are currently under development or projected to grow. It is anticipated that this 30 percent reduction could be achieved through a combination of certain tools like public information, incentive programs, rebate programs, and changes in building and plumbing codes.

Before applying this reduction to the service levels, general key assumptions have to be considered. The general key assumptions used in all the scenarios include:

1. The scenarios do not take into account seasonal climate changes. Therefore energy use and water use are only from production point.

2. One general assumption was that a Thiessen polygon was used to convert input points to output features. This means that areas that have junctions are assumed to have increased population demand but water demand was not changed by this increase in population. This can be brought about by several factors, such as better equipment installed in housing facilities, minimal leaks from the water system, and better water management practices.

3. The model used for this research was based on the 2006 calibrated InfoWater system, that LWS consultants compared with the actual system and produced identical results. This is shown in figure 3-3. The pipe network consists of water mains of various materials that vary from 4 to 56 inches pipes. Variations in pressure are to be expected due to the different pipe diameter, ground elevation, and interior diameter roughness.

4. The additional water mains will also have a high Hazen-Williams coefficient. This C value for new pipes will be 130 as opposed to the current model set up that has C values that range from 70 for the cast iron pipe to 130 for the newer replaced PVC pipe segments. Appendix A has a further explanation how Hazen-Williams coefficients affect pressure through a piping network system.

5. No pipes were designed for a size less than 8 inches, since National Fire Protection Association (NFPA) codes and City of Lincoln Water Main Design Standards specify this as a minimum for fire protection. It is also assumed that the new water mains in the outskirts of the City will only be constructed from polyvinyl chloride (PVC) pipe. The reduction in pipe size is compared with

pressure levels in the pipe, and as long as the levels are not above the Cheney service area, pressure which should range between 40 to 100 psi (Lincoln Water Main Design Standards, 2000), the reduction can be justified.

6. The population density corresponds to the Planning Commission 40 years Long Range Plan Trends.
7. Cost analysis in the scenarios examines all of the costs related to building, energy reductions, and installing new water mains.
8. Infrastructure benefit will be more evident in newer areas experiencing developmental growth.
9. Water conservation and energy conservation is not taken into consideration in the scenarios.

As a quality control measure on how effective the proposed scenarios are in appropriately modeling key pressure criteria in the distribution system, the key output from the scenario, pressure in psi, will be compared with the Lincoln Department of Public Works and Utilities design standards on pressurized water mains in the service levels. These service levels must maintain certain pressures and the models will be used to check for these discrepancies. The conditions include:

1. The Low Duty service area includes downtown, north, and northeast Lincoln. System pressure ranges from 35 to 75 psi;

2. The Belmont service area includes Belmont, the Highlands, and Air Park areas. System pressure ranges from 35 to 105 psi;
3. The High Duty service area includes the high elevations in southwest to northeast Lincoln. System service pressure ranges from 40 to 100 psi;
4. The Southeast service area includes the area of Lincoln south and east of 56th and A Street. System pressure ranges from 40 to 100 psi;
5. The Cheney Booster service area includes the area of Lincoln south and east of the Southeast service area. System pressure ranges from 40 to 100 psi;
6. The Northwest Booster service area includes the Fallbrook area and northwest portions of the Highlands. System pressure ranges from 40 to 100 psi.

3.7 Cost Estimation of Distribution System Modifications

Cost analysis is a systematic process of comparing benefit and cost of a project or a decision. Cost analysis also gives City planners ideas of how potential projected City growth will affect the City in the long run. The cost estimation can also be used to estimate GHG produced by incorporating the EIO-LCA model to estimate embedded GHG produced for installing additional infrastructure in the scenarios. There are two types of cost data in the results. One data cost is from the 2008 – 2014 CIP. Based on the CIP from 2008 - 2014, the proposed projects that will have the most impact in the cost analysis estimation will be from additional water mains in the City. This set the basis of using water mains as the cost estimation of cost analysis estimation for the City of

Lincoln. The other cost estimate is from building additional distribution system mains in the City.

3.7.1 CIP Cost Estimates from 2008-2014

The CIP is the public infrastructure and planning tool, used by the City of Lincoln, which demonstrates the financial capacity of completing those infrastructure projects needed. LWS is responsible for coordinating and implementing the capital projects identified during the next five years. That coordination includes department review of proposed funding sources, land acquisition, utility coordination, design services, construction and maintenance activities. Lincoln's CIPs are available online (e.g. http://www.lincoln.ne.gov/city/plan/long/cip/2008-14/WATER.pdf). The cost estimations will be based on the 2008-2014 CIP developed for LWS.

3.7.2 Water Main Distribution Cost Estimates

Many of the existing water mains in Lincoln are beyond their design life (up to 100 years old). At that age, they have significant scaling on the inside of the pipe that reduces the pipe diameter and the pipe walls will be thinned. Net effect is a decrease in water pressure, increasing the costs to move water through the pipes, increased risks of pipe failures, and increasing risks of pipe fouling and contamination. The City is already seeing these effects and wants to upgrade the water mains before it becomes an operational and quality of service issue. An upgrade of these water mains will ensure a better efficient system. Due to change in water main regulations, these water mains will have to be 8 inches in diameter and above. A spreadsheet developed by LWS will be used in factoring the project cost of water mains to be installed in the City of Lincoln.

Based on the cost indices, described in detail in Appendix E: Scenario Cost Analysis, These are the costs of water mains that will be needed to accommodate future City growth. The scenarios will have different water mains demand and output from InfoWater will show which addition future water mains are needed to accommodate City growth through the years 2019. The cost analysis was done in a spreadsheet from data acquired from InfoWater and McGraw-Hill Construction Engineering News Record (ENR) (Engineering News-Record, 2012). Detailed calculation using ENR and inflation calculation can be found in Appendix E. Building of infrastructure in Lincoln, Nebraska is structured in a yearly budget plan called a capital improvement program (CIP). These CIPs project population growth and a detailed comparison of cost over a certain period of years (Appendix E, Figure E-1). Several factors must be taken into consideration when deciding how to fund these projects: the rising cost of construction, inflation, and economically justifiable decisions with regard to population needs. The cost presented in this estimation is based on the inflation calculation indices, current cost indices, and the 2007 Lincoln Water System Facilities Master Plan Update. Cost data is based on the current 2012 Engineering News-Record (ENR) CCI national index. The current cost indices, based on a 20-city average, as indicated by ENR are shown below.

Due to brevity and the complexity of the Lincoln drinking water system and to get a clear resolution of the outcome in different scenarios, the research will have to focus on one area that will grow in the next decade (Cheney). As discussed in Section 3.2, the

2007 Lincoln Water System Facilities Master Plan Update looked at projected design peaking factors by service levels over the next 40 years and projections show that Cheney Service Level has the high growth potential. Located in South West Lincoln, Cheney service level was modeled for cost analysis based on water demand in this region over the next 7 years. Figure 3-3 shows the 2006 calibration model of Cheney service level. The area south east of Lincoln is project to have more growth based on the Lincoln-Lancaster 2040 CP (Lincoln-Lancaster County 2040 Comprehensive Plan, 2012).

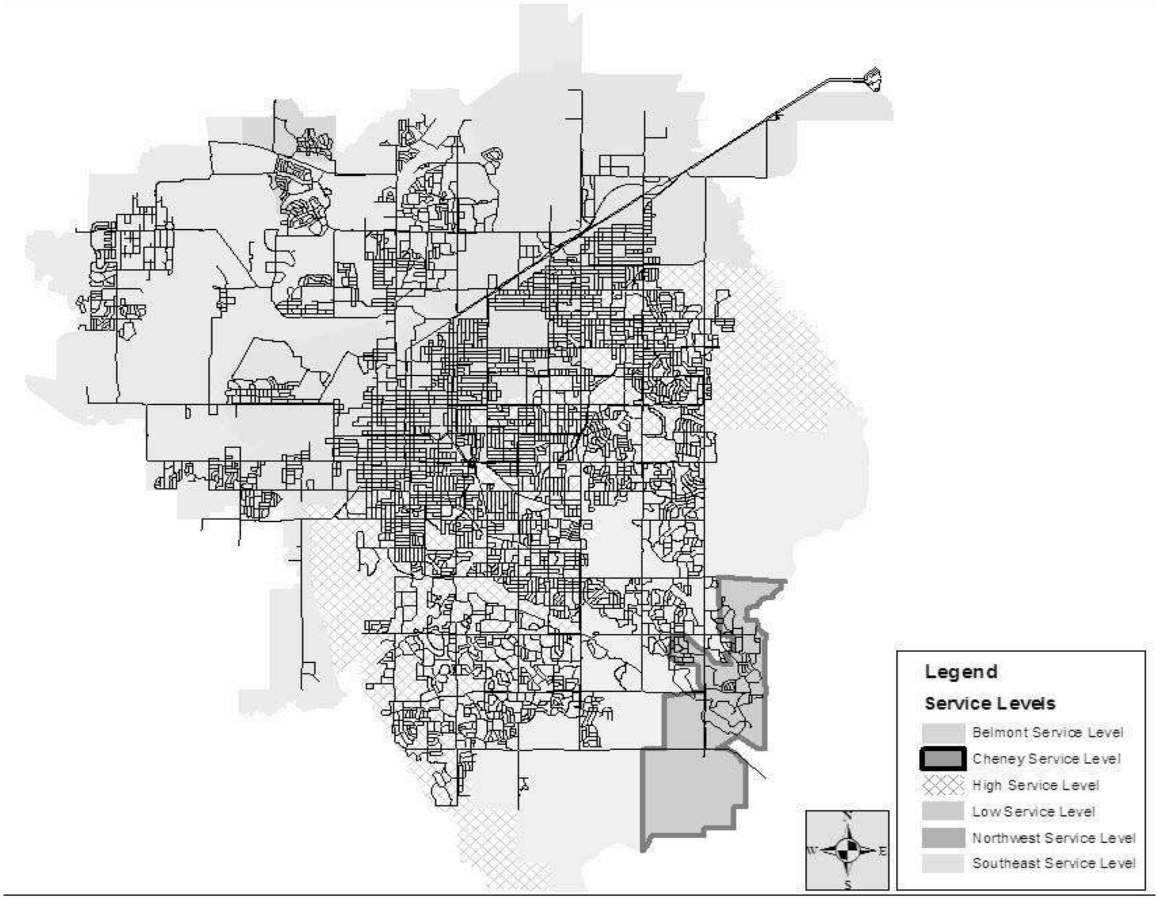


Figure 3-3: Current, 2006, Pipe Layout in the City of Lincoln, NE
Source: ArcGIS and InfoWater Scheduler

Figure 3-4 shows an expansion of water mains based on the distribution model created in ArcGIS to accommodate for the addition water demand in the system. ArcGIS factors in area of potential growth and simulates the additional pipes based on the water demand in those areas.

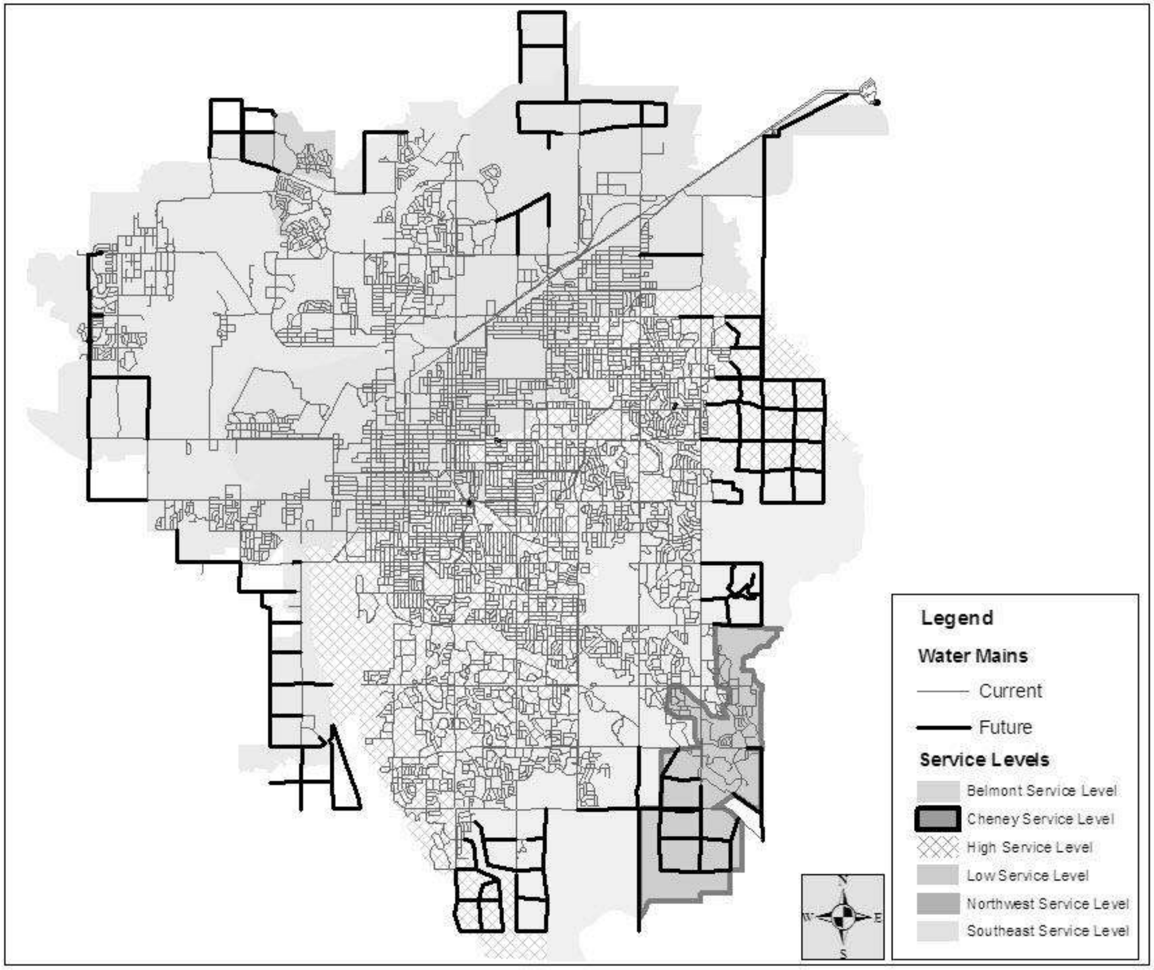


Figure 3-4: Additional pipes project in the year 2019 in the City of Lincoln, NE
Source: ArcGIS and InfoWater Scheduler

Based on the cost indices stated earlier, and based on the ArcGIS output in Figure 3-4, cost analysis centered on water main installation in the City of Lincoln between 2012 and 2019. ArcGIS has to balance the entire system hence the additional water mains in the network. Using a spreadsheet provided by LWS, the length of the future pipes are input in the spreadsheet, inflation to 2019 will be factored, and length of pipe will be converted to cost of pipe. This cost factors in engineering fees, design fees, and labor cost.

3.8 Summary

Chapter 3 discussed the methods used to approach various results in the thesis. This research is a preliminary "what-if scenario" for the City of Lincoln. The software model developed in the report will be used to evaluate the current and future infrastructure in the City. This distribution system model outcome is for informational purposes only. Data output is coupled with research and literature review, from places like California, Texas, and Nebraska. The data was used to create a basis of the methodology that acted as a guiding principle in this thesis. Model software was used to create four scenarios that were used in the report. Assumptions based on previous water use history, population growth, and water demand needs, were applied in the design of this hypothesis.

To determined direct and indirect greenhouse gas production, U.S. EPA-GHG Equivalencies Cost Analysis Calculator and Economic input-output life cycle assessment where used in the estimation process respectively. These tools are used to help Lincoln Water System better understand their technical judgments on the impact of proposed infrastructure. The quantification of the cost analysis analyses was presented. Based on inflation and projected increase in cost and adhering to City design standards, the most economical sound scenario was proposed. Pipe length was the main governing factor in calculation of the cost analysis and this is the highest cost of the project.

Four different future water use scenarios, as previously discussed in Section 3.6, were used as inputs to the modeling software to see how the City of Lincoln adapts to different situations. The models provide an estimate of the relative magnitude that one gets from altering certain conditions in the system. The City of Lincoln has six service levels. Service levels are established boundaries that maintain acceptable distribution system pressures. With ground elevation ranging from 1,130 feet to about 1,450 feet, the service levels represent the City of Lincoln based on different pressure based on elevation and water use. The summary of the scenarios is shown in Table 3-2.

Table 3-2: Summary of Scenario Layout

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**
Service Levels	Constant per capita water maximum day demand does not change until the year 2019	Per capita peak water maximum day demand reduced by 10 percent	Per capita peak water maximum day demand reduced by 30 percent	Per capita Peak Water Maximum Day Demand Reduced By 10 percent and 30 percent
Belmont	No Change	Reduction by 10 percent of 2019 Scenario	Reduction by 30 percent of 2019 Scenario	Reduction by 10 percent of 2019 Scenario
Cheney	No Change	Reduction by 10 percent of 2019 Scenario	Reduction by 30 percent of 2019 Scenario	Reduction by 30 percent of 2019 Scenario
High	No Change	Reduction by 10 percent of 2019 Scenario	Reduction by 30 percent of 2019 Scenario	Reduction by 10 percent of 2019 Scenario
Low	No Change	Reduction by 10 percent of 2019 Scenario	Reduction by 30 percent of 2019 Scenario	Reduction by 10 percent of 2019 Scenario

Table 3-2: Summary of Scenario Layout (continue)

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**
Northwest	No Change	Reduction by 10 percent of 2019 Scenario	Reduction by 30 percent of 2019 Scenario	Reduction by 30 percent of 2019 Scenario
Southeast	No Change	Reduction by 10 percent of 2019 Scenario	Reduction by 30 percent of 2019 Scenario	Reduction by 10 percent of 2019 Scenario

Chapter 4: Discussion of Results

4.1 Introduction

To achieve the objectives of this research, the analysis of the City of Lincoln's Water System (LWS) will be broken down into several analyses. The analysis performed includes:

1. Temporal and seasonal trends in water usage and energy use rates, per capita water use and peak to average water use trends, which are used to estimate the GHG production per million gallons of water,
2. Infrastructure expenditure, due to routine maintenance, service area expansion, and increased water usage,
3. Four scenarios of water use rates performed using water modeling software that is used to estimate the GHG production from infrastructure, and
4. Analysis of the impact on needed sizes of new distribution system piping of the above per capita water use reduction scenarios.

This chapter discusses the results from data acquired from LWS for which different analyses were performed. These analyses reflect the objectives set forth in Chapter 1.

4.2 Temporal Trends

Variations in water usage across the continent of the U.S. have been observed with many communities, both based on the adoption of water conservation practices and due to changes in technology. In addition, energy use has also changed over time for water production, both due to changes in water use and as energy efficiency practices are implemented. The improvements in water conservation practices have led to a decline in water sales all across North America. It is important to understand the water and energy use trends for Lincoln before considering greenhouse gas production issues.

4.2.1 Water Use

Annual Water Usage Trends

Per capita water trends for drinking water use (both average daily and maximum day) and precipitation over an 18 year period are illustrated in Figure 4-1 in terms of overall system water use in million gallons per day. Data from July 1994 to July 2012 was acquired from LWS (Lincoln Water System, 2012). The X-axis shows the progression over the years, the primary Y-axis shows the usage of water in million gallons, and the secondary Y-axis shows the precipitation. The maximum day demand of water has varied depending on the weather variations. In the broad view of things, the data shows that water use has not changed significantly despite the increase in population by almost 50,000 since 1994.

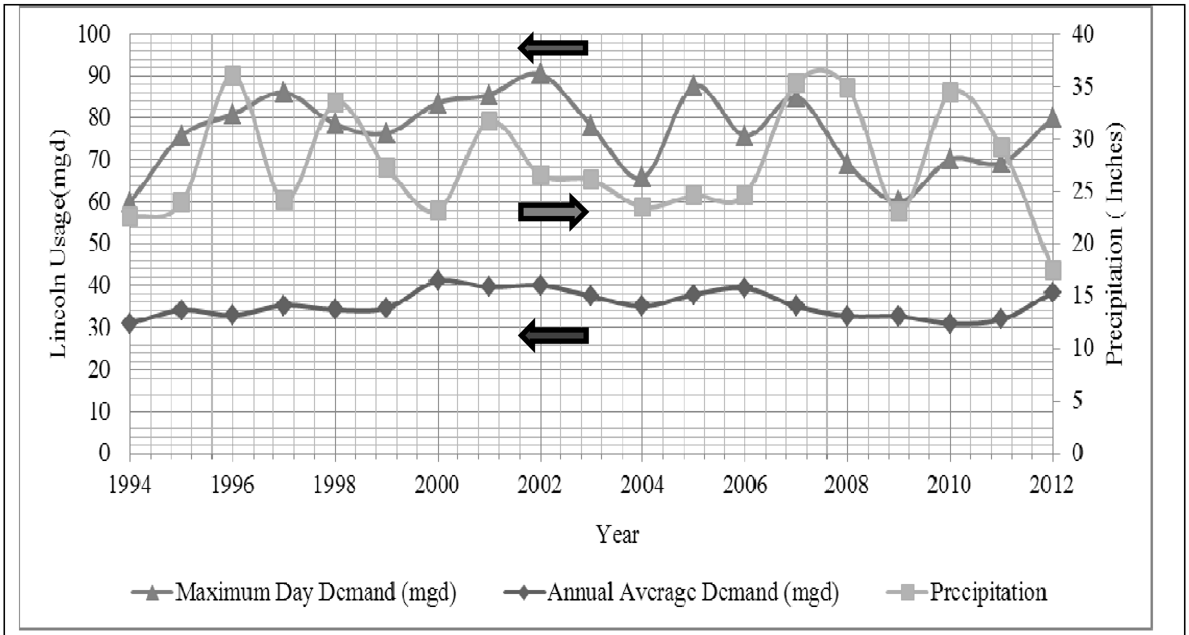


Figure 4-1: Overall Water Use from 1994 to 2012 - Lincoln, Nebraska
Source: Lincoln Water System, 2012 and UNL School of Natural Resources. Appendix B. Table B-6

Due to availability of water from the wells and no persistent weather variations (USGS, 2012), there has been a strain but water has always been available over the last 18 years. Strain in the system would be defined as extended periods when the demand for water as measured by Flow, exceeds the ability of the LWS Water Treatment Plant, to produce it. Figure 4-2 shows both the drinking water flow gallons per capita day and the wastewater flow gallons per capita-day, for the City of the Lincoln, over a 16 year period. The trend over the 16 years from the Figure 4-2 shows a gradual decline by about 30 gallons per capita-day for drinking water and 10 gallons per capita-day for wastewater. Again, this trend of declining demand occurs in spite of the increase in the population.

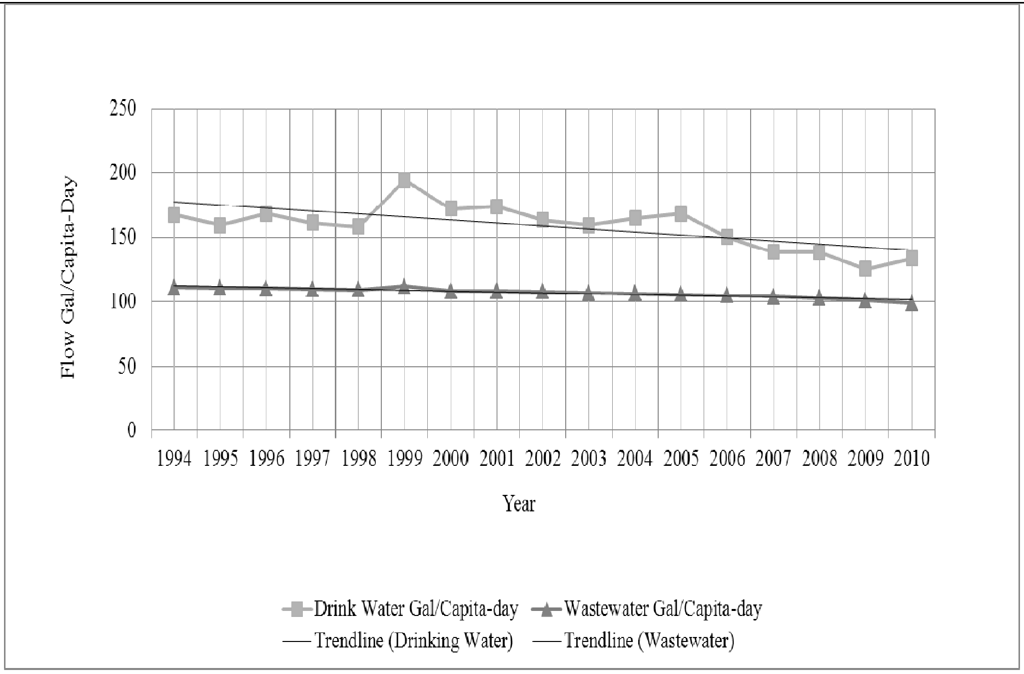


Figure 4-2: Drinking Water, and Wastewater Flow per Gallons per Capita day
Source: Lincoln Water System, 2012.Appendix B. Table B-3

Drinking water is declining because of conservation practice hence the wastewater is also declining. The gradual decline in water consumption shows a clear indication that the City of Lincoln, Nebraska manages it seems effectively and efficiently. However, the limit to water will be reached soon as the water scarcity issues arise. The City will have to adopt other water savings technics that will help on water conservation.

<u>Monthly Water Usage Trends</u>

Seasonal variability in water use is a major issue for operations and design. For a better resolution of data, one can examine trends on a monthly basis to understand where the fluctuations in the system are evident. Figure 4-3 shows a monthly trend in water output transmitted to the City of Lincoln in millions of gallons over a 2 year period. The four lowest water consumption months for Lincoln are typically December, January, February, and March. The five highest water consumption months for Lincoln are typically June, July, August, September, and October. The electric utilities have a rate structure that adds a “Demand Charge” to the monthly billing to the water utility. The demand charge is calculated based on the highest electric usage for the calendar year, which historically has always occurred in August. The challenge for the water utilities is to either reduce the peak water demand in the summer, or use other energy sources to run the pumps that produce the needed amount of water.

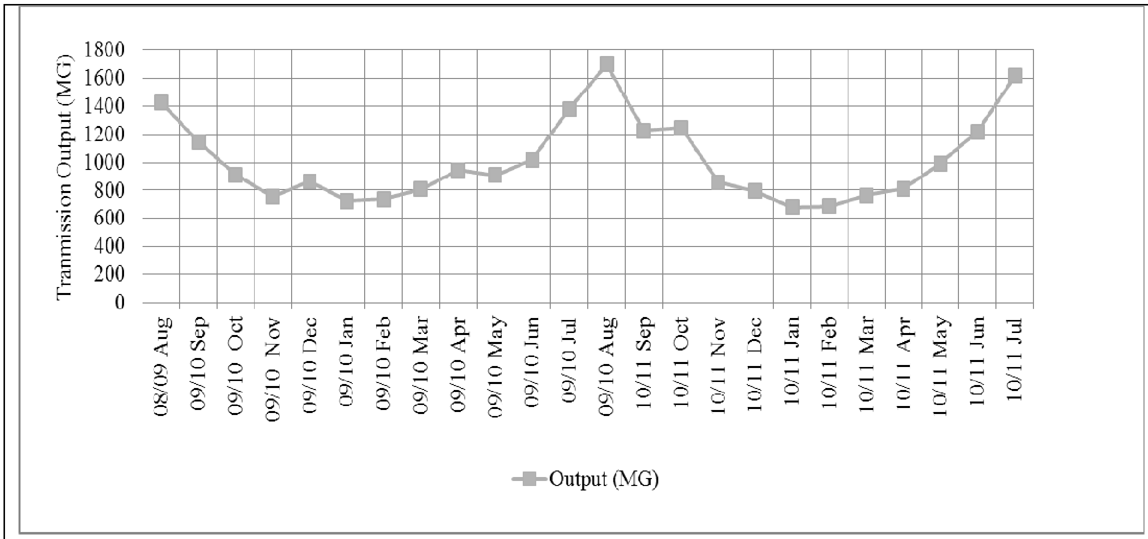


Figure 4-3: Drinking Water Annual 09/10 - 10/11 (summer and winter) Water Transmission Output
Source: Lincoln Water System, 2012. Appendix B. Table B-7

4.2.2 Energy Use

Energy issues are an important factor in the functioning of our economy and infrastructure, thus the emphasis on energy efficiency. This section evaluates the seasonal use of energy in water operations.

Annual Energy Usage Trends

General annual energy use for Lincoln can be viewed for the last 16 years, up to 2010, when a change in water pumping procedures was implemented. Figure 4-4 shows the monthly energy (electricity) use normalized by the water production. Overall energy used per million gallons gradually increased between the years of 1994 to 2002. The slight rise observed in the years 2000 to 2002, was partially due to a drought that was in effect. As Figure 4-1 illustrated, shows that the amount of precipitation per year between 2001 and 2011 was always greater than 25 inches per year. Plentiful rainfall contributed to lower summer water demand which correlates well with the relatively constant energy usage between the years of 2003 to 2010. The trend line shows that there is an overall decreasing trend, of approximately 15 percent drop over 16 years in electricity use per million gallons produced, showing that the LWS is improving the energy efficiency of the pumping and distribution system.

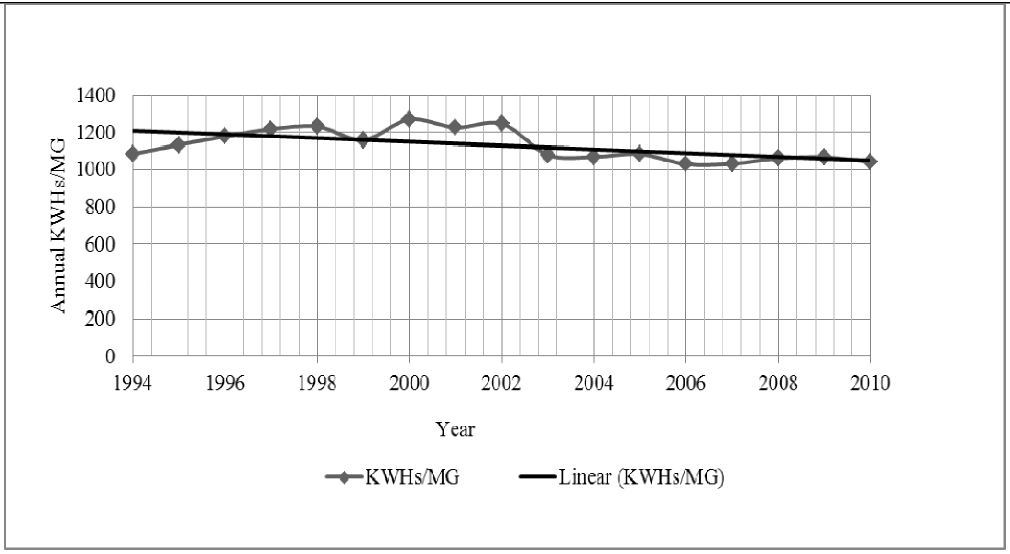


Figure 4-4: Yearly Energy Use Trends
Source: Appendix B. Table B-4

Often energy costs can be a significant portion of a utility's annual operating budget cost, thus understanding trends are important. As discussed in Section 2.4, one example of energy use per water use in the literature can be for a comparison to the LWS data. The LWS's energy use on a kWh per million gallon basis for water supply, treatment, and distribution is about half that reported in a California study of WTP (Klein, 2005). This is likely due to the efficiency of the LWS system, the limited treatment required for the LWS water, and the relatively shorter pipeline to Lincoln from the WTP than in some large California systems.

Past Monthly Energy Usage Trends

In 2010, changes were made to the water pumping strategy for the Lincoln Water System, and data was available to examine monthly energy use trends during the 2009 and 2010 periods. Figure 4-5 below shows the trend in energy use over this two-year period. The Y-axis shows the annual energy use in kilowatts-hours per million gallons of energy used for the transmission of water. The winter month of January in the year 2011 had a "out of the normal" spike. This spike can be explained partially by the way the distribution system is designed. Pumps are not always operating at their most efficient point in the pump curve at the lower flow rates. Thus they use more electricity.

In the summer months, head losses would be higher due to the higher flow rates in the system, but this is counteracted by the pumps operating at the most efficient point in the pump curve. Note that the electricity demand charge is based on the highest energy usage in kilowatt-hours that LWS incurs, which is usually during the summer period, when water production is at its peak.

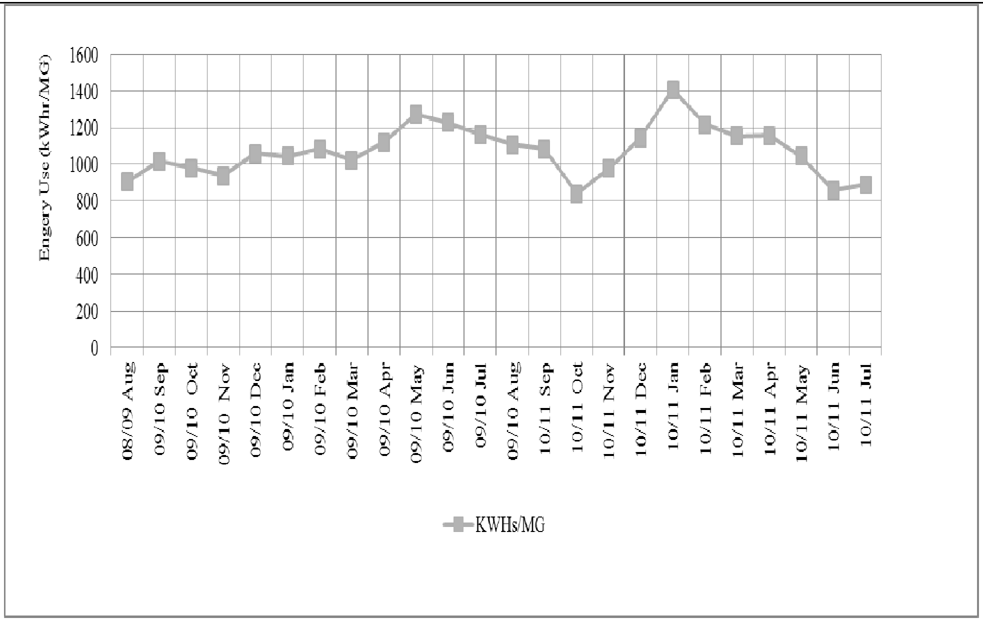


Figure 4-5: Drinking Energy Annual 09/10 - 10/11 Transmission Output
Source: Lincoln Water System, 2012. Appendix B. Table B-7

4.3 Estimates of Greenhouse Gases from Operating Energy

With increased attention focused on the potential value associated with GHG emissions, there is a need for consistent, standardized methodologies for estimating GHG emissions despite complexities in the drinking water industry. In the case of Lincoln, GHG produced from the use of operating energy in the LWS if primarily from operating energy is from the WTP and the water distribution system in the City of Lincoln, Nebraska. Power from the treatment plan and the main transmission pipelines is provided by Omaha Public Power District (OPPD). Power for pumping within Lincoln for the distribution system is provided by the Lincoln Electric System (LES). Each power utility (and each region of the country) gets their electricity from a mix of different sources, such as nuclear power, hydro, or coal. These different sources create an added complexity since a meaningful emissions comparisons and emission credits are assessed using different “carbon currency” basis. The effect of the source of electricity to GHG being produced can affect the quantity of production of GHGs. This is factored in to the result from the GHG calculators.

Tables 4-1, below, results are based on 2009-2011 energy use. This energy use, 12.7 million kWh per year is a combination of OPPD electricity use from well pumps, water treatment plan, operational energy, and pumping in water mains to Lincoln. It also includes LES distribution and operational electrical charges exercised on LWS.

One can get conversion factors that can easily be implemented to data acquired from other facilities. The equation below shows the conversation factor, as shown in Section 3.5.1, used nationwide and for the City of Lincoln.

U.S. National Average Conversion Factor:

$$12.7\,million\frac{kWh}{yr} * 0.000692\frac{MTCO_2e}{kWh} = 8{,}800\frac{MTCO_2e}{yr}$$

City of Lincoln Specific Conversion Factor:

$$12.7\,million\frac{kWh}{yr} * 0.00090\frac{MTCO_2e}{kWh} = 12{,}700\frac{MTCO_2e}{yr}$$

Based on the above results, certain conclusions can be made based on the data. These include:

1. Total life cycle GHG emissions from renewables and nuclear energy are much lower and generally less variable than those from fossil fuels. Lincoln’s main energy production is from fossil fuels.

2. The difference between the US national average values and Nebraska values is due to the differences in energy sources, with Nebraska's apparently being heavier in fossil fuel-based energy sources hence the high amount of GHG

4.4 Future Infrastructure Needs

Infrastructure is needed to help the City accommodate for future growth. Isolating what infrastructure is needed is important to help the City figure out how to better manage its resources. To evaluate the general impact of water infrastructure, two types of infrastructure for LWS can be considered. These two infrastructures, as described in Section 2.1, are:

1. Routine Infrastructure Maintenance, and
2. Necessary Infrastructure Improvements (needed to expand the system from a capacity or spatial standpoint)

The above categories can be classified further based on the 2008 – 2014 CIP. The infrastructure maintenance (e.g., security upgrade, preliminary design, and engineering support for projects, control system upgrade, main break and replacement programs) and necessary infrastructure improvements to expand the service area and capacity (e.g., new water supply well in existing wellfields, treatment plant expansion, additional supply of raw water in new wellfields). The conservative cost estimate of repairing, replacing, and updating Lincoln's drinking water infrastructure is \$ 109.1 million over the next 5 years based on the 2008 – 2014 CIP. This is the Total Infrastructure Cost averaged out over the

5 year period as shown in Figure 4-6. This CIP is available in Appendix E. Scenario Cost Analysis. As discussed in Section 3.5.2, infrastructure considered includes:

1. New Water Supply Well in Existing Wellfield,
2. Treatment Plant Expansion,
3. Additional Supply of Raw Water in New Wellfield, and
4. Additional Transmission Mains and Distribution Mains.

Major structural components of drinking water facilities have an expected useful life of 40 years – dependent in part on operation and the diligence of maintenance. As these structures deteriorate effectiveness declines leading to additional operating and maintenance and a greater potential for: permit violations and unintended discharges. The above infrastructure will be needed to sustain City growth and will also be required to make the City much more efficient as it upgrades to a better system.

Based on the 2008 – 2014 CIP, Figure 4-6 shows the projected cost of the total infrastructure, necessary infrastructure improvements, and drinking water energy (electrical) cost in the City of Lincoln. The annual infrastructure construction and maintenance expenditures for the water system are much higher than the annual cost of energy to transmit and distribute drinking water in the City, Figure 4-6 also shows the long-term cost projections of building the proposed infrastructure over time. The key point in the table is that average annual cost of building infrastructure is much higher than the energy costs for operating the system.

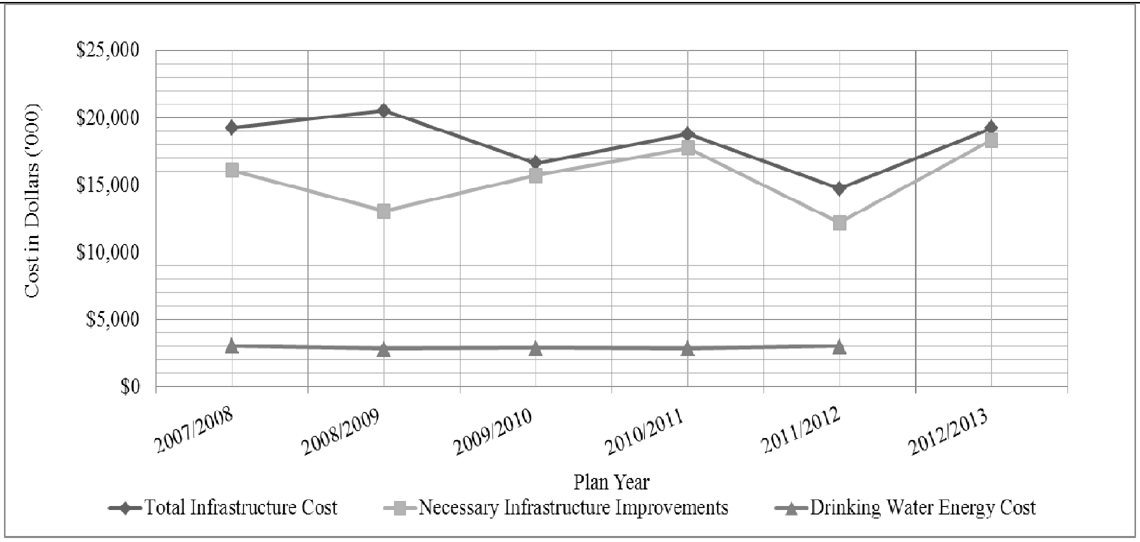


Figure 4-6: Comparison of Cost from Projected Total Infrastructure, Projected Infrastructure that are Necessary for Future Improvements, and Actual Drinking Water Energy Cost
Source: Lincoln CIP 2008-2014, LWS

4.5 Estimates of Greenhouse Gases from Infrastructure Construction

Greenhouse gases are produced not only from the use of electricity but also from the production and installation of infrastructure. This section focus on the GHG produced from future project infrastructure construction which is quantified as indirect GHG production. EIO-LCA conversation factors were used from Section 3.5.1 to make the estimate of GHG production. Section 4.4 shows the cost of infrastructure construction that will be used in estimation of GHG production. The rise in demand in new infrastructure is directly related to the population growth and water demands. Following the methods in Section 3.3 and selected scenarios described in Section 3.6, the output from EIO-LCA shows that the indirect GHG emissions from proposed infrastructure growth are significant.

Table 4-2 shows the output from EIO-LCA using data from LWS and CIP from the City of Lincoln. These are rough order of magnitude estimates. More precise LCA models and location specific data should be used when high quality estimates are needed. Table 4-2 provides the cost and a rough estimate of the associated greenhouse gasses from construction of a new well field, treatment plant expansion, additions to the raw water supply, and additional transmission mains and distribution mains.

Table 4-2: Estimated GHG from 2008-2014 CIP Based on EIO-LCA Model

Infrastructure Category	Total Expenditure for the next 7 years	Industry and Sector Number	Total MTCO$_2$e / kWh*
1. New Water Supply Well in existing Wellfield	$ 12,500,000	Sector #230103: Other nonresidential structures	7,650
2. Treatment Plant Expansion	$ 2,000,000	Sector #230103: Other nonresidential structures	1,220
3. Additional Supply of Raw Water in new Wellfield	$ 5,200,000	Sector #230103: Other nonresidential structures	3,180
4. Additional Transmission Mains and Distribution Mains	$ 73,370,000	Sector #230103: Other nonresidential structures	44,900
Total over 7 years	$ 93,070,000		56,950
Averages/Year	$ 13,295,714		8,135

*GHG per dollar conversion factor of 0.00612

The data in Table 4-2, second column, shows the funds that the Lincoln Water System is projected to spend over the next seven years. The annual average expenditure may be in the range of $13 million. As described in Section 3.5.2, the third column is based on the sector that is relevant to the engineering project in the first column. The forth column is results from EIO-LCA. This column is directly related to the second column based on a GHG per dollar conversion factor of 0.00612. This conversion factor is described in detail in Section 3.5.2.The EIO-LCA estimates (which is a US average) for the annual GHG production on an annual basis from the infrastructure production is in the range of 8,000 $MTCO_2e$. This emphasizes that infrastructure construction is almost as large source of GHG emissions in the water production sector as those from the use of utilities for water production. The GHG emissions from the operating energy for water production is 12,700 $MTCO_2e$ for Nebraska specific conversation factors or 8,800 when using US average factors, as explained in Section 4.3.

The analysis provided in Table 4-2 does not consider the GHG emissions from chemical use at the treatment plant, which is anticipated to be relatively small, compared to GHGs from utilities and infrastructure construction. The rise in demand in new infrastructure is directly related to the population growth and water demands. Having analyzed the results from the EIO-LCA, it was possible to extract relative and absolute data on cost of construction of infrastructure and greenhouse gas emissions. Some typical results are as follows:

- About 57,000 $MTCO_2e$/kWh will be produced in the next 7 years if the proposed projects are constructed.

- Based on the CIP, the total cost for all the projects will amount to 93 million dollars.

Detailed output of the GHG analysis from EIO-LCA is shown in Appendix C. A quick comparison shows that direct emission of GHG produced from operating energy is slightly larger than the indirect emission of GHG.

4.6 Scenario Output

In order to better analyze the possible impacts on the distribution system due to different changes in per capita water use, four different modeling scenarios were studied. These scenarios, as discussed in Section 3.6, incorporate variations in maximum day water demand in Lincoln based on population growth from 2006 - 2019. The original distribution model scenario of the City of Lincoln was created by Black & Veatch in 2007 for the LWS Facilities Master Plan Update. Since the focus of the scenarios was future trends for water demand, this section first gives the quantitative results for the 2006 baseline scenario, discusses the results of a similar scenario analyzed using the Lincoln 2007 Master Plan (with 7 to 10 percent water reduction), and compares these to scenario results from other alternate water reduction strategies.

The model output includes values for the pressures generated for each of the three different scenarios. The base year infrastructure, which was available in 2006, has been taken into account when designing these scenarios. The output of the data is displayed for each scenario with the discussion and summary of the output. As stated in Section 3.4, the InfoWater distribution system model is contained within an ESRI ArcGIS Geo-

Database that uses data layers that are is shared from the City of Lincoln Planning Department and City of Lincoln Public Works. The allowable pressure ranges in the city's Service Level Zones, are described in the Water Main Design Standards summarized below in Table 4-3. One of the research goals is to see if the Hydraulic Pressures in the Modeling Scenarios do not exceed, the Water Design Standards.

Table 4-3: Water Main Design Standards
Source: Water Main Design Standards – Lincoln Department of Public Works and Utilities – Chapter 2 (2000)

Service Level	Water Main Design Standards – Lincoln Department of Public Works and Utilities (PSI)
Belmont	35 to 105
Cheney	40 to 100
High	40 to 100
Low	35 to 75
Northwest	40 to 100
Southeast	40 to 100

4.6.1 Constant – Scenario: Per Capita Water Maximum Day Demand Does Not Change 2006-2019

This scenario looks at the base year, 2006, and assumed a constant population growth-rate through 2019, as discussed in Section 1.2. The consumption of water per capita, at a maximum value of 140 gallons of water each day, is assumed to remain the same, throughout this period. The basis of this scenario is to consider how the increase in population will affect the ability of the current infrastructure to perform as required. As discussed in Section 3.6, the analysis of the outcome of the model will help one understand the nature of the increase in demand and what infrastructure needs to be planned for in order to support growth.

The service level results for water pressures due to this scenario are presented in Figure 4-7. The High and Low pressures in the Distribution system are represented by dots in the output figure. White dots indicate areas of Low Pressure and Black dots indicate areas of High Pressure. Some of the criteria for Distribution System Water Main design are:

- The pressure in the system cannot fall below 35 psi.
- The pressure cannot exceed 150 psi.

The white dots that are shown in Figure 4-7, appear to be abundant in the "Low" Service Level of the city. Examination of the data shows that these lower pressures (below 35 PSI) are mainly in large diameter mains greater than 16 inches in diameter. They are also found in the mains surrounding the WTP. The Low Pressure values correspond with the Pumping Station locations. The internal pipes that are in the pump station have low pressures in the model which are a result of balancing the load within the station. As a result, these low pressures do not affect the Distribution System Fire Fighting Capacity. The Black dots which represent High Pressure values (about 150 PSI) are concentrated along the East side of Lincoln analogous with the large water main that runs parallel to 84th street. These Higher pressure values may indicate areas for future CIP improvements, including the installation of larger mains which can carry the larger amounts of water required for the scenario.

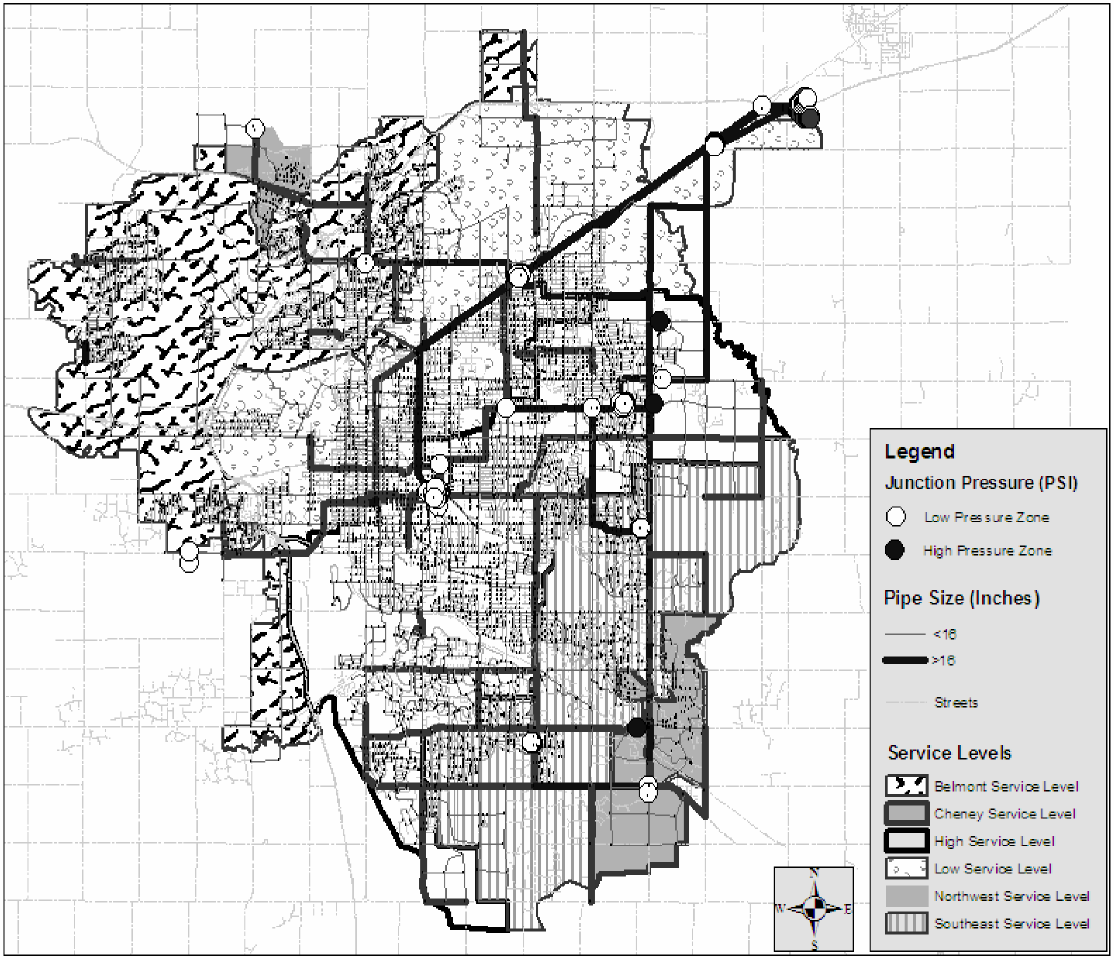


Figure 4-7: Added Infrastructure by Year 2019
Source: ESRI ArcGIS and InfoWater Scheduler

To check pressure compliance in the model, Table 4-7 lists the output pressure in the City. Column one of Table 4-4 lists the service levels as described in Section 3.4. The second column contains the average system pressures calculated in the model for the year 2019. This scenario thus falls within design standards as discussed in Section 3.6.

Table 4-4: 100 Percent of 2019 Scenario
Source: ESRI ArcGIS and InfoWater Scheduler

Service Level	100% 2019 Scenario Junction Pressure (PSI)
Belmont	88
Cheney	85
High	81
Low	63
Northwest	78
Southeast	83

4.6.2 Scenario 2: 10% Drop in Per Capita Water Maximum Day Demand

This distribution model scenario is based on the Black & Veatch conclusion, that due to the general population's ongoing replacement of water fixtures with more efficient devices, they predicted a citywide 7 percent reduction in overall water use, by the year 2019. For the purposes of this investigation, it was felt that with slight additional water conservation, the scenario could easily achieve a 10 percent reduction in water consumption. Figure 4-8 illustrates a detailed layout of the effects of a 10 percent water reduction. Notice that this Figure 4-8 has 29 low pressure dots whereas in the last scenario, Figure 4-7, had 23 low pressure white dots. This implies that the reduction in water pressure in the system could be due to the reduction in water demand. Low pressure values mainly occur in large diameter mains and in the large water mains from the WTP.

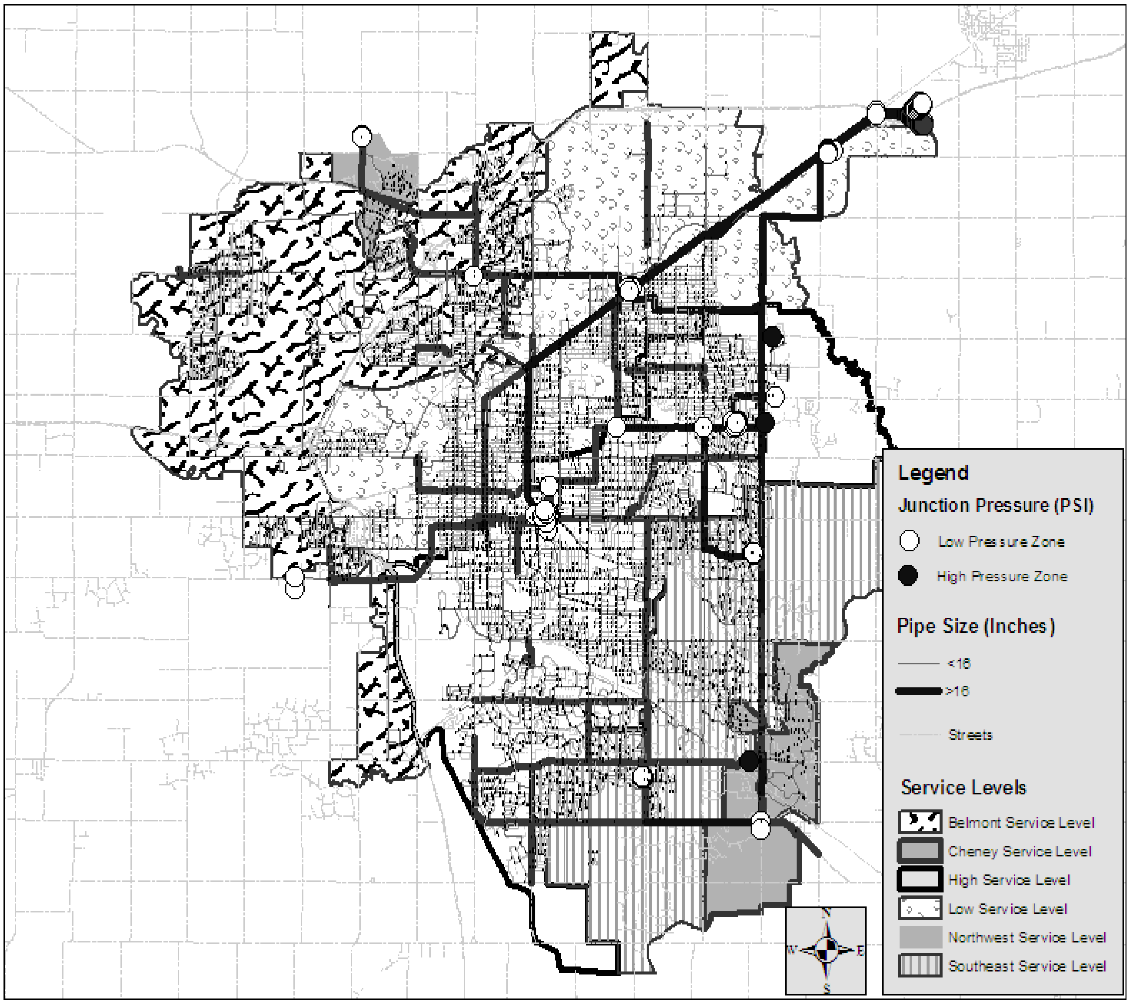


Figure 4-8: Peak Water Maximum Day Demand Reduced By 10%
Source: ESRI ArcGIS and InfoWater Scheduler

Due to a change in scenario (10 percent decrease from the 2019 scenario), Table 4-5 shows a that the average pressure in this design scenario falls within design standards as discussed in Section 3.6.

Table 4-5: 10 Percent Reduction from 2019 Scenario Source: ESRI ArcGIS and InfoWater Scheduler	
Service Level	10% 2019 Scenario Junction Pressure (PSI)
Belmont	87
Cheney	86
High	85
Low	66
Northwest	71
Southeast	76

4.6.3 Scenario 3: 30% Drop in Per Capita Water Maximum Day Demand

As discussed previously, a 30 percent reduction in the 2019 water use scenario is an aggressive approach for water conservation. The 30 percent reduction includes deploying a number of factors, including regulation, incentives, and voluntary programs. The demands in this scenario are set by decreasing the peak factors by 30 percent from the 2019 calibration values. . Figure 4-9 illustrates the lower water demands and the reduced pressure needs. A visual inspection of Figure 4-9 shows that 31 low pressure dots whereas the last scenario, Figure 4-7 (baseline scenario), had 23 low pressure dots. This indicates that certain locations have a greater reduction in water use demand. This reduction in pressure has several benefits including:

- Reduction in consumption,
- Reduction in burst frequency,
- Improvements in system performance, and
- Extended asset life.

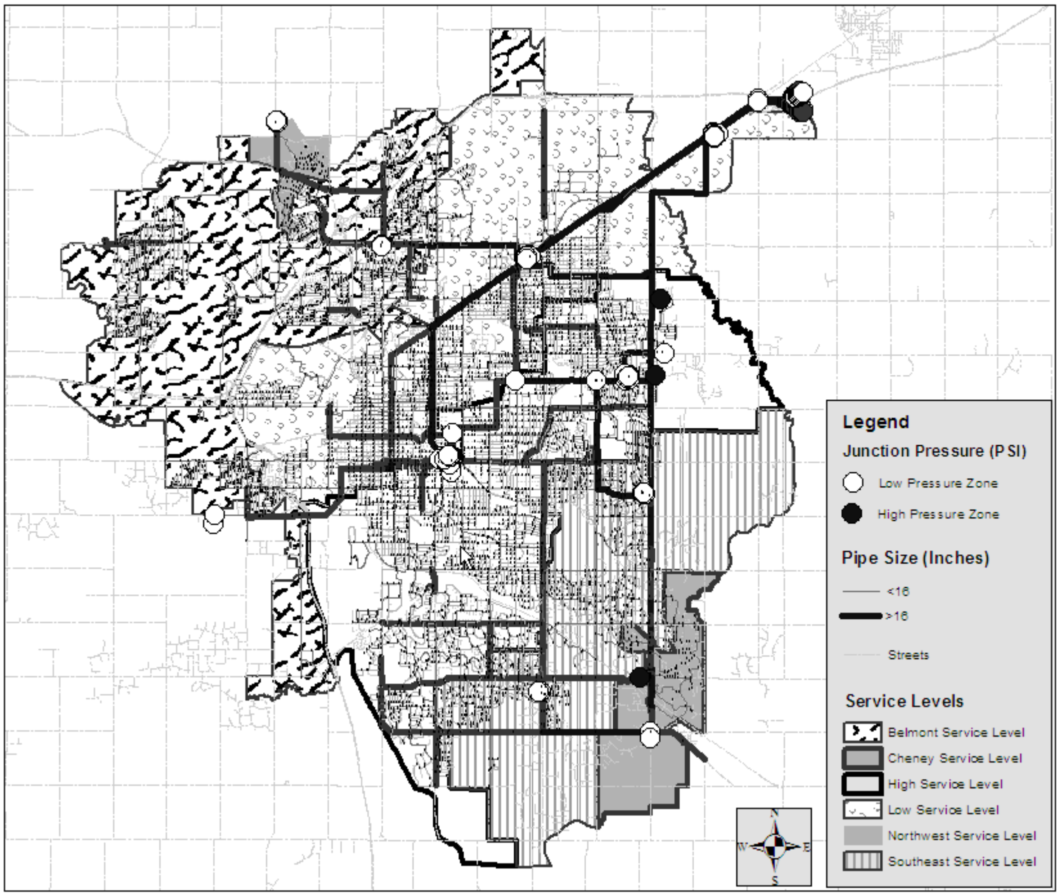


Figure 4-9: Peak Water Maximum Day Demand Reduced By 30%
Source: ArcGIS and InfoWater Scheduler

Table 4-6 shows the summary of model output results when water demand is reduced by 30 percent. Column two shows the Average pressure demand for this scenario, within each Service Level Zone.

Table 4-6: 30 Percent Reduction from 2019 Scenario
Source: ESRI ArcGIS and InfoWater Scheduler

Service Level	30% of 2019 Scenario Junction Pressure (PSI)
Belmont	88
Cheney	86
High	87
Low	69
Northwest	72
Southeast	79

4.6.4 Scenario 4: 10 & 30% Drop in Per Capita Water Maximum Day Demand

This fourth scenario, which is the 10 percent and 30 percent, represents a fair and balanced approach to water conservation. It incorporates a 30 percent target reduction for the areas of new growth, and allows existing mature portions of the city to have a 10 percent target and gradual progress along a less aggressive pathway to water conservation. This is a moderate approach applied to different service levels depending on future projected growth based on 2040 Lancaster Country Future Land Use Plan (Appendix D, Figure D-2 Amended Lincoln 2040 Plan). Based on the data provided by 2040 report, summaries were made, which focused on the different areas of future City growth. Areas with the greatest residential and commercial potential growth, like South and Southeast Lincoln, had a greater probability of being able to reduce their water consumption by 30 percent. This is because the regulation, incentives, and voluntary programs would affect Brand New Construction. Established central city areas, like Central Lincoln, which includes the Belmont, High and Low Service Levels, are already developed, and are less likely to attain water reduction of 30 percent, hence they were assigned a 10 percent water reduction in the model. Table 4-7 below gives a summary of the service levels and what their percent reductions were. The first column shows the service levels in consideration, and as earlier stated the second column shows the reduction in the model's water use in these service levels. The results from the modeling are listed in Appendix D.

Table 4-7: Service Levels Percent Reductions
Source: ESRI ArcGIS and InfoWater

Service Levels	Scenario Data
Belmont	10% Reduction
Cheney	30% Reduction
High	10% Reduction
Low	10% Reduction
Southeast	30% Reduction
Northwest	30% Reduction

Figure 4-10 shows that the model generated 27 low pressure dots whereas in the last scenario, Figure 4-7 (baseline scenario), had 23 low pressure dots meaning certain locations have a reduction in demand of water use in the system. Combining both scenarios results in a level distribution of pressure in the system.

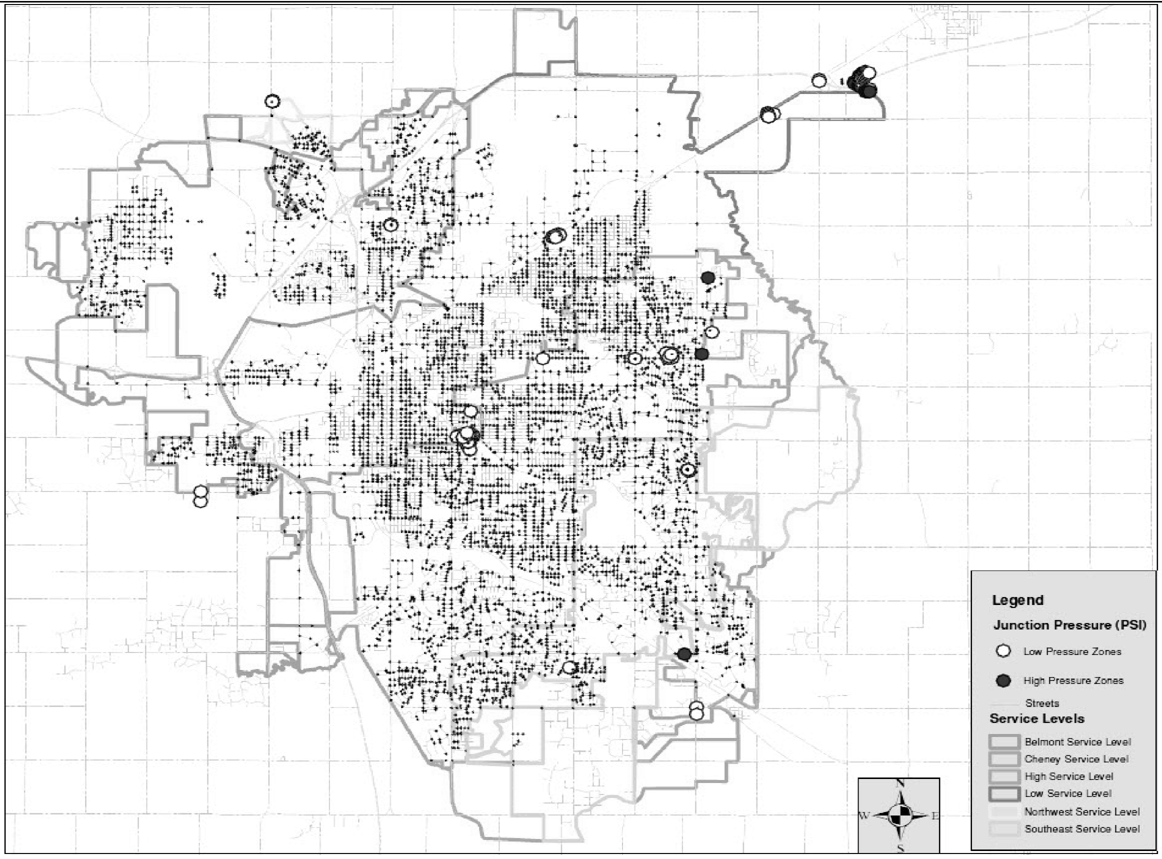


Figure 4-10: Peak Water Maximum Day Demand Reduced By 10 % and 30 %
Source: ArcGIS and InfoWater Scheduler

Table 4-8 shows the summary of water reduction by 10 percent and 30 percent. Column two shows the trends in pressure demand in the scenario. The average pressures generated by the model in the second column are also within City design standards. This is a combination of both a 10 percent reduction and 30 percent reduction in each service level. The combined reduction does decrease the overall pressure in the system.

Table 4-8: 10 Percent Reduction and 30 Percent Reduction of 2019
Source: ArcGIS and InfoWater Scheduler

Service Level	10% and 30% 2019 Scenario Junction Pressure (PSI)
Belmont	87
Cheney	86
High	85
Low	66
Northwest	72
Southeast	79

4.6.5 Discussion

Scenario 1 shows the growth-rate through 2019 will require additional infrastructure to accommodate the rise in water demand. The basis of this scenario is to consider how the increase in population will affect the ability of the current infrastructure to perform as required. For Scenario 2, the conclusion that can be deduced suggests that the system might want to consider the purchase of variable frequency drive pumps to save pumping costs and reflect the accommodations of variations in water pressure. For Scenario 3, it will be very difficult to achieve this level of reduction without enforcement of mandatory water bans and other by-laws that restrict water use. Adopting water-use efficiency practices for these areas is feasible only if the general population is convinced of their necessity, and unfortunately since water revenue is determined by consumption, will result in less revenue for the water system, thus causing significant decreases in the health of the Distribution System, due to a shortage of funds for repair and maintenance. The outcome of such a drastic reduction would require restructuring of the rate schedules as well as fine tuning the plant operation to allow for shifts in pressure and accommodate factors such as fire flow conditions.

Scenario 4 is a more attainable goal and result s in sufficient revenue for water distribution operation as well as meeting water conservation goals. This will require less immediate hardship to the population because the increased water reduction of 30 percent can be incorporated by planners and designers before occupancy. The new tenants will thus be unaware of the impact of the water reduction. They will simply embrace the xeriscaping and other methods as part of their environment. This will allow the other existing areas to transition from 10 percent reduction to 30 percent reduction without having to be out rightly coerced or forced to do so by draconian means and methods. This will be more popular and easier to accomplish with rebates, incentives and public service workshops.

4.7 Case Study - Cheney Service Level

After modeling the scenarios for the entire system, it was identified that further modeling of a specific service level would be useful for evaluating the possible benefits of reducing key distribution system lines. This modeling was performed on the Cheney Service Level. The Cheney area is anticipated to continue to grow and expand. The eventual construction of the South Beltway Highway that will connect Interstate 77 with Highway 2 (NDOR, 2012), will bring a significant increase in the development of the South and South-East areas. This analysis divides the Cheney area into two areas parts in terms of water use reductions. These distinctions are evaluated in 4 scenarios as described in Section 4.6. The analysis assumes that the per capita water use remains the same and that the population number increases following the 2007 Facilities Master Plan Update, Cheney Service Level population is projected to double, in the next 12 years, from 2,372 occupants to 5,330 (LWS, 2007).

Due to the location of Cheney, the area has the highest projected growth rate. In 2001, the Cheney Booster District was created in the southeast portion of the service area to serve new development on high ground. Cheney service level was established to maintain acceptable distribution system pressures in the south part of Lincoln. Due to brevity, Cheney will be used as an example of potential impact of water use changes on infrastructure needs and extrapolation of these implications will give City manager a broader view of city-wide implications of additional infrastructure effects to GHG production. Cheney will also be used to factor in cost analysis as it is an area that has high growth potential. Population growth in the Cheney area is projected by the Lincoln/ Lancaster County Planning Department in the Living and Working in 2040 (LP2040, 2010). Assumptions based on this population growth are:

- As the City of Lincoln continue to grow with a projected growth rate of 1.26 percent, existing demand of land will be exhibited in the South, South East, and South West side of Lincoln.
- The level of net migration from inner city to outskirts of Lincoln will increase during the projection, this means new infrastructure will be needed in this developing areas.

Based on the cost indices stated earlier in Appendix E and assumptions stated in Section 3.6, Table 4-5 shows cost analysis centered on water main installation in the City of Lincoln between 2012 and 2019 in the Cheney area. The water mains lengths are estimation from output from ArcGIS as seen in Figure 3-4 in Section 3.7.2. The price calculation is factored into a LWS spreadsheet (Appendix E) calculator that figures the inflation prices projected to the year 2019. Based on the city's growth, water demand in each scenario, and fluctuation in population, ArcGIS estimates the effect this has on the water mains in the Cheney area. Based on the scenario output (Appendix E), Table 4-9 below shows the project cost and percentage reduction based on the four scenarios.

Table 4-9: Summary of Cost Analysis Focusing in Growth in Cheney Service Level

Source: Appendix E: Cost Analysis. LWS, 2012

Scenario	Cost Estimates	Percent Reduction From Scenario if used for Design
Scenario 1: 2019	$7,580,000	0
Scenario 2: 10 Percent Reduction	$5,980,000	21
Scenario 3: 30 Percent Reduction	$5,130,000	32
Scenario 4: 10 Percent and 30 Percent Reduction	$5,290,000	30

The analysis shows that a 10 percent reduction per capita water use will result in a 21 percent reduction in the cost of distribution system infrastructure. The 30 percent reduction per capita water use has the greatest cost savings, but will be more difficult to achieve without mandatory restrictions and enforcement. This relatively large reduction in infrastructure cost is due to reduction of water demand as well as cost benefit due to reduced pipe sizes. The analysis was able to justify the reduction of 16 inch water mains with 12 inch, and 12 inch water mains reduced to 8 inch. The fourth scenario, which arguably could be the most realistic, resulted in a cost reduction of approximately 30 percent. All three scenarios with per capita water use reductions result in significant distribution system cost savings. It can't be emphasized enough, that if per capita water use reductions are occurring, these can result in very significant cost savings. Cost savings will only be realized if these water use projections are used as the basis for new and replacement distribution system design. The significance of the potential cost savings identified in the analysis of the Cheney Service Level in Scenario 4, from the other different scenarios; can be understood by identifying the magnitude of future infrastructure expenditures for distribution system expansion into new developments.

Based on future 2011-2017 CIP from the City, new distribution systems for new developments are considered. Appendix E includes a detail output of the spreadsheet of the CIP 2011-2017. Figure 4-6 lists portion of the projected total CIP (2011 – 2017) infrastructure expenditures in future years that will be expended on distribution system for new developments. Figure 4-6 illustrates the portion of the total CIP costs for each project year that is planned for distribution system construction in new developments (like Cheney).

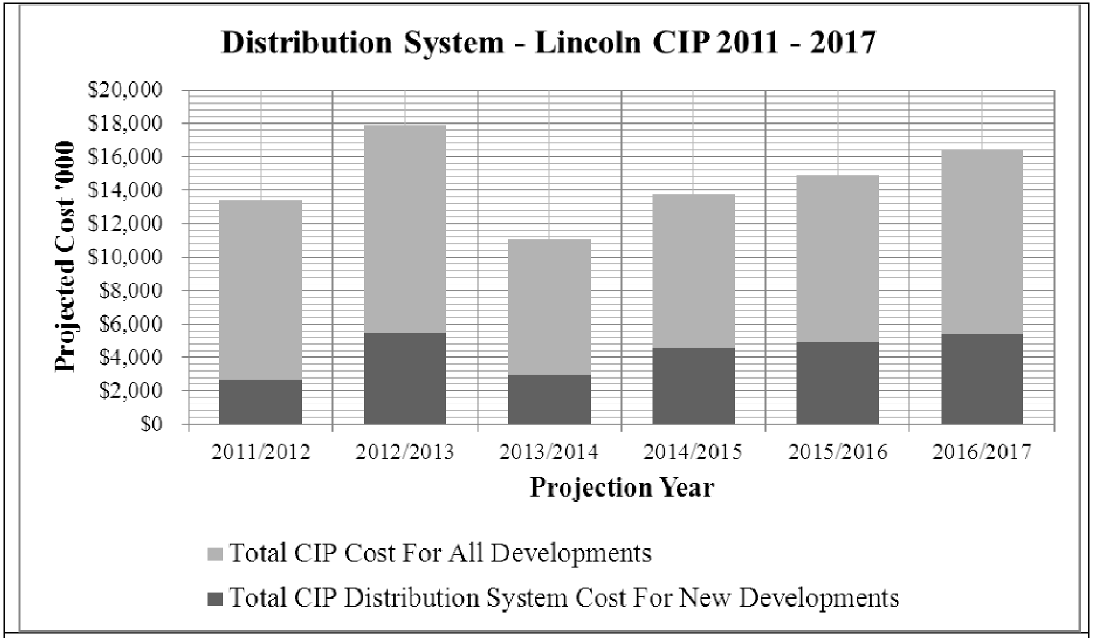


Figure 4-11: Distribution System for the City of Lincoln based on CIP from 2011-2017
Source: Appendix E. Table E-7: CIP 2011-2017 New Distribution Systems

We can extrapolate the effect of the reduction in Infrastructure cost as applied to just the Cheney area, to the entire city of Lincoln. The percentage of the total infrastructure costs that are based on new distribution system components is about 29 percent as shown in Figure 4-11. If a 30 percent reduction in new distribution system construction costs can be realized, as listed in Table 4-9 for these projections, and the cost reductions of 29 percent estimated for Scenario 4 were also taken into account, then the total infrastructure costs might be reduced by a total of 8.7 percent (e.g., 30% x 29%). Since GHG production from infrastructure is related to infrastructure cost, an 8.7 percent reduction in cost would likely mean a similar reduction in GHG production. Thus, if per capita water use reductions were realized and design codes were modified to allow reductions in some of the distribution system pipe sizes, then GHG production from infrastructure may drop by 8.7 percent. Thus the GHG production from infrastructure may drop from 8,135MTCO$_2$e/yr. to about 7,430 MTCO$_2$e/yr.

In addition, this would affect the operating energy requirements for water production and distribution, as explained in Section 4.2.1. It is reasonable to assume that the maximum GHG production for the energy requirements would similarly decrease by up to 8.7 percent.

4.8 Summary

This section reviewed temporal trends, water use, energy use, GHG production from operation and infrastructure as well as reducing water consumption by 10 percent and 30 percent in various service levels with the intent of reducing GHG production and water demand. GHG production caused by infrastructure construction is almost as large a source of greenhouse gas emissions as those from utility operating energy used for water production and distribution. Though an emerging topic, this research highlights the growing concern of GHG production in drinking water systems.

Temporal water use trends over the years were fairly predictable with no unusual spikes in the system. Energy use, however, has seen conscious efforts made to reduce them over the years. The challenge, however, is to figure out how long these declines can be sustained. There is a point of diminishing returns after the utility has directed its CIP efforts towards replacing all of the older equipment with new more efficient VFD pumps and optimized the pumping and distribution operation. Direct GHG calculation due to water production compared to the indirect GHG calculation due to infrastructure shows that there was no significant change in both cases. The major disparity was between the National GHG averages and City of Lincoln GHG averages. These two numbers varied in the case of GHG production due to the source of energy. Nebraska gets most of its electricity from fossil fuel. This source has a high GHG footprint. The EIO-LCA estimates for indirect GHG production on an annual basis from the infrastructure production is in the range of 8,000 $MTCO_2e/kWh$. This is the national average since indirect GHG sources are inherently more difficult to quantify and as per the design of the EIO-LCA model, it only looks at the national averages. This emphasizes that infrastructure construction is almost as large source of GHG emissions in the water production sector as those from the use of energy for water production.

Six service levels were considered and due to brevity the Cheney Service level was picked. Cost analysis show that infrastructure is needed for growth and reduction of water demand should keep the pressure within regulation standards. This in the long run will save the City considerable expense as the City grows. The end goal of these analyses was to help determine if the reduction in infrastructure sizing could be reasonably considered as an option, with only a few limited upgrades in the system, such as water mains and efficient pumps. The intended improvements and recommendations will also bring about indirect GHG savings due to deferred construction of the infrastructure.

Chapter 5: Conclusions and Recommendations

5.1 Introduction

Utilities are currently working to make their infrastructure and operations more sustainable, and to manage the production of available fresh water from the environment. It is important to remember that sustainability means balancing the needs of the environment with the needs of society. The early part of the 21st century has seen a growing public awareness for reducing energy and natural resource consumption, as well as the consideration of alternative energy sources. As a result, both low carbon technologies and "green" energy initiatives are no longer considered unusual or unnecessary by the general public. It is predicted by many publications that the next environmental crisis will concern the availability of fresh water. The overall objective of this research was to assess the City of Lincoln's water production in relation to GHG production from utility use in operations and infrastructure construction. To meet this objective, modeled scenarios were investigated. These scenarios looked at water production in the future and variations of water reduction over a period of time.

The first scenario looked at water production in the year 2019. This scenario's objective was to investigate which areas in the system will be strained and also determine if additional infrastructure is required to support the growth and water demand in the City. A 10 percent reduction scenario was used to determine how voluntary water conservation practices could be used to regulate water use. This was a mild approach on conservation practices. An aggressive 30 percent reduction scenario was applied to the model to see which areas would have significant changes in the system. This included using mandatory restrictions and by-laws coupled with voluntary conservation practices. The last scenario combined the 10 percent reduction and the 30 percent reduction in different service level areas. This was applied in areas that exhibit future growth and were assumed to require aggressive water restriction practices.

5.2 Conclusions

The main conclusions from this preliminary study are listed by topic. These main points related to the Lincoln Water System are listed below.

Temporal Water Use

- The trend is for a gradual decline, which over the past 16 years is approximately a reduction of 30 gallons per capita-day of drinking water and 10 gallons per capita-day for wastewater. This translates into approximately an average annual reduction of 1.1 percent.
- The LWS observes the maximum day use is during the summer, when water uses, such as landscape irrigation, is at its greatest.

Temporal Energy Use

- The LWS's overall electricity consumption averaged 13 million kWh annually over the past 16 years, but it has also shown a decreasing trend over that period reflecting improvements in pumping operations and pump energy efficiency.
- There was a 15 percent drop over the 16 years (0.9 percent annual average reduction) in energy used (kWh) per million gallons produced.

- There is currently no clear seasonal difference in energy use per million gallons produced between summer and winter seasons. This is based on the way the City of Lincoln water use is billed. The demand charge is the governing entity in billing of water all year round and it is based on the highest month of water use.
- It was noted that LWS's energy use on a kWh per million gallon basis for water supply, treatment, and distribution is roughly half that reported in a California study of water plants.

Estimates of GHG Emissions

- Lincoln Water System distribution and transmission consumed annually, on average, 12.7 million kWh between the years of 2009 to 2011. Direct GHG emissions from operating the LWS distribution system (e.g., from electricity) produces about 12,700 $MTCO_2e$ based on the Nebraska specific energy-to-GHG conversation factor and produces 8,800 $MTCO_2e$ when the U.S. National average GHG conversation factor is applied.
- A national average-based estimate of GHG production from infrastructure construction based on the EIO-LCA model estimates production is in the range of 8,100 $MTCO_2e$ per year from indirect GHG, based on the rough assumption of this study. This emphasizes that infrastructure construction can be almost as large a source of greenhouse gas emissions in the water production sector as those from the use of utilities for water production

ArcGIS, InfoWater Modeling Software and Scenario Analysis

- An increase in the quantity of infrastructure is needed in the distribution system due to population growth.

- The number of low pressure points in the distribution systems that will require pumping changes (improvements) are fewer for scenarios with a lower per capita water use. This illustrates how water demand decreases in the system for each scenario showing per capita water use reductions.
- As compared to the baseline water use scenario, it was observed that in general , the water pressure levels in the system for the other scenarios, were reduced. This reduction is from the implications caused by water demand reduction in different scenarios. An increase in water conservation practices (10 percent or 30 percent reduction) leads to a reduction in water demand in the system.

Infrastructure cost analysis

- There is a large cost for future infrastructure to the City of Lincoln through 2019. The overall projected cost from the CIP is five to seven times that of the annual cost of operating energy for the system.
- Due to numerous positive factors, Lincoln is anticipated to have significant new residential growth in the near future. A scenario analysis of a service level where new growth will occur (Cheney) shows that as per capita water use dropped, there is potential to install smaller distribution pipe sizes than current design standards call for, and still supply adequate fire flow. If smaller pipe sizes are able to be utilized, then a 29 percent cost reduction for the new distribution system construction, could be realized.. Since approximately 30 percent of the projected future infrastructure construction costs will be distribution systems in new areas, it is projected that reductions in pipe sizes for new residential construction could reduce the annual average GHG projection by roughly 700 $MTCO_2e$ per year.

5.3 Recommendations

There are many different benefits from water conservation. Some of those benefits are discussed in this study. These include benefits in terms of reduced costs (and associated greenhouse gas production) from reduced infrastructure construction and reduced energy use for water production and transportation. Water conservation can extend into the future where the LWS must develop new and expensive sources of water other than the current well field. Based on the literature review in Chapter 2, there are a number of types of approaches that can be used to enhance water conservation. Below is a list of solutions that Utilities such as the LWS, in conjunction with the City of Lincoln, could consider that would lead to significant water conservation.

- Water utilities can improve water production effectiveness by:
    - Adjusting operation schedule (on-peak and off-peak water pumping times), increasing water storage capacity to avoid regular recharging, and installing efficient water system equipment like variable frequency drives,
    - Locate service line, plumbing or irrigation system leaks quicker, allowing for prompt repairs and reducing the magnitude high magnitude of bills caused by leaks,
    - Switching from a bi-monthly billing schedule to a monthly billing schedule. This helps residents better manage their finances and better understand their water consumption habits,

  - Easy to read billing invoices that highlight the customers' areas of possible excessive water use, implement a high block pricing billing structure to represent peak water demands, and
  - Implementing water use by-laws, rebate program, and educational programs.
- Business and residential properties can improve water use efficiency by:
  - Taking advantage of rebate programs leading to an increase in water savings,
  - Replacing old equipment, like water cooling towers with much more water efficient fixtures,
  - Implementing better water use practices in lawn care like Xeriscaping of landscaping, drip irrigation, and
  - Install low water demanding fixtures like faucet aerators, low-flow and sensored faucets, low-flow showerheads, low-flush and ultra-low-flush toilets, and ultra-low-flush and waterless urinals.

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Appendices

A. Water and Energy Billing and Scheduling

LWS Water and Wastewater Rates

Residential Water Rates

Water in Lincoln, Nebraska is sold by the unit. One unit equals 100 cubic feet or 748 gallons. Water is billed per increasing block structure. The more a consumer uses the higher the consumer is billed. The billing block structure has three pricing blocks. Residents are either billed monthly or bi-monthly. The chart below illustrates the pricing block billing schedule

Price Blocks	$1.344/unit	$1.911/unit	$2.961/unit
Monthly	1-8 units	Next 15 units	All additional units
Bi-monthly	1-16 units	Next 30 units	All additional units

For example, to compute a bi-monthly use of 49 units:

16 Units * $ 1.344 = $21.50

30 Units * $ 1.911 = $57.33

3 Units * $ 2.961 = $8.88

Total number of units = 49 units.

Total Amount on billing cycle = $ 87.11 *

* The water and wastewater service charge and wastewater fee must be added in to determine your total bill.

Non-Residential Water Rates

There are currently two levels of non-residential users. Customers who used less than 12 million cubic feet the previous calendar year will pay:

Price Blocks	$1.344/unit	$1.911/unit
Monthly	1-80 units	All additional units
Bi-monthly	1-160 units	All additional units

As stated verbatim in billing structure, the non-residential customers who used more than 12 million cubic feet the previous calendar year are billed according to the high user schedule. On a calendar year basis, a "base usage" of each high user customer is determined. The base usage is an average of the water usage of each high user customer for the previous three calendar years. The following rates would apply:

- $1.276 per unit for water usage less than base to 5% above base
- $1.323 per unit for water usage 5% to 15% above base
- $1.365 per unit for water usage 15% to 25% above base
- $1.407 per unit for all water usage more than 25% above base

Omaha Public Power District (OPPD) and LWS

The quantity of electricity is measured in kilowatt-hours (kWh), and reflects the amount of physical “work” that can be performed by the electricity. Electric utility rates typically include an energy consumption charge that is based on the number of kWh consumed per billing cycle, and often the charge is further subdivided by “on-peak” versus “off- peak” consumption, where on-peak rates are higher than off-peak rates. Understanding the electric utility’s pricing policies or “rate structures” is critically important to planning energy management programs.

The WTP is the transmission side of the LWS. It is billed by OPPD. According to OPPD General Service – Large Demand memo, as of January 1, 2012, the monthly electrical billing service standards at:

1. Basic Service Charge: $155.31
2. Demand Charge :
    a. $8820.00 for the first 1000 kilowatts of demand
    b. $ 8.82 per kilowatt of all additional kilowatts of demand

The energy charge differs depending on the time of year. OPPD charges the following rates:

1. Summer:
    a. 4.85 cents per kilowatt-hour for first 300 kilowatt-hours per kilowatt of demand
    b. 4.36 cents per kilowatt-hour for all additional kilowatt-hours

Note:

The summer rate is only applicable from June 1st to September 30th

2. Winter
    a. 3.61 cents per kilowatt-hour for the first 300 kilowatt-hours per kilowatt of demand
    b. 3.12 cents per kilowatt-hour for all additional kilowatt-hours

Note:

The winter rate is only applicable from October 1st to May 31st

Demand charges, for any billing period, shall be the kilowatts as shown by or computed from the readings of the District's kilowatt-hour meters with a demand register, for the 15 minute period of Consumer's greatest use during such billing period.

Hazen-Williams Coefficients

Hazen-Williams formula is an empirical formula that uses approximate head loss in a pipe when water is flowing and the flow is turbulent. Hazen-William calculation is a simple way of determining this relationship. The imperial form (U.S. customary units) for the Hazen-Williams formula is:

$$h_f = 0.002083 * L * \left(\frac{100}{C}\right)^{1.85} * \left(\frac{gpm^{1.85}}{d^{4.8655}}\right)$$

Where:

h_f = head loss in feet of water
L = length of pipe in feet
C = friction coefficient
gpm = gallons per minute (USA gallons not imperial gallons)
d = inside diameter of the pipe in inches

Common friction factor values of C used for design purposes are:

Material	C Factor
Cast iron	100
Cement-Mortar Lined Ductile Iron Pipe	140
Concrete	100
Steel	90
Galvanized iron	120
Polyethylene	140
Polyvinyl chloride (PVC)	130

B. Spreadsheet Data Analysis of Results

Table B-1: Historical Population, Drinking Water and Wastewater in Lincoln, NE
Source: Source: U.S. Bureau of the Census Population[1], LWS[2], Lincoln Wastewater[3]

Date Of Census	City of Lincoln Total Population[1]	Drinking water[2]		Wastewater[3]		Change in Drinking and Wastewater
		Flow (MG)	Gal/capita-day	Flow (MG)	Gal/capita-day	
1994	204493	12498	167	22.77	111	56
1995	207,154	12068	160	22.99	111	49
1996	209,192	12868	168	23.15	111	57
1997	211,552	12452	161	23.26	110	51
1998	213,836	12366	158	23.43	110	49
1999	215,928	15330	195	24.20	112	82
2000	227,701	14365	172	24.64	108	64
2001	230,400	14620	174	24.95	108	66
2002	233,737	13930	163	25.23	108	55
2003	237,356	13804	159	25.42	107	52
2004	239,417	14459	165	25.53	107	58
2005	242,009	14870	168	25.63	106	62
2006	244,653	13422	150	25.70	105	45
2007	247,789	12526	138	25.76	104	35
2008	250,939	12693	138	25.79	103	35
2009	254,001	11622	125	25.69	101	24
2010	258,379	12600	134	25.55	99	35

Table B-2: Historical Drinking Water Electric Usage in Lincoln, NE

Source: LWS,2012

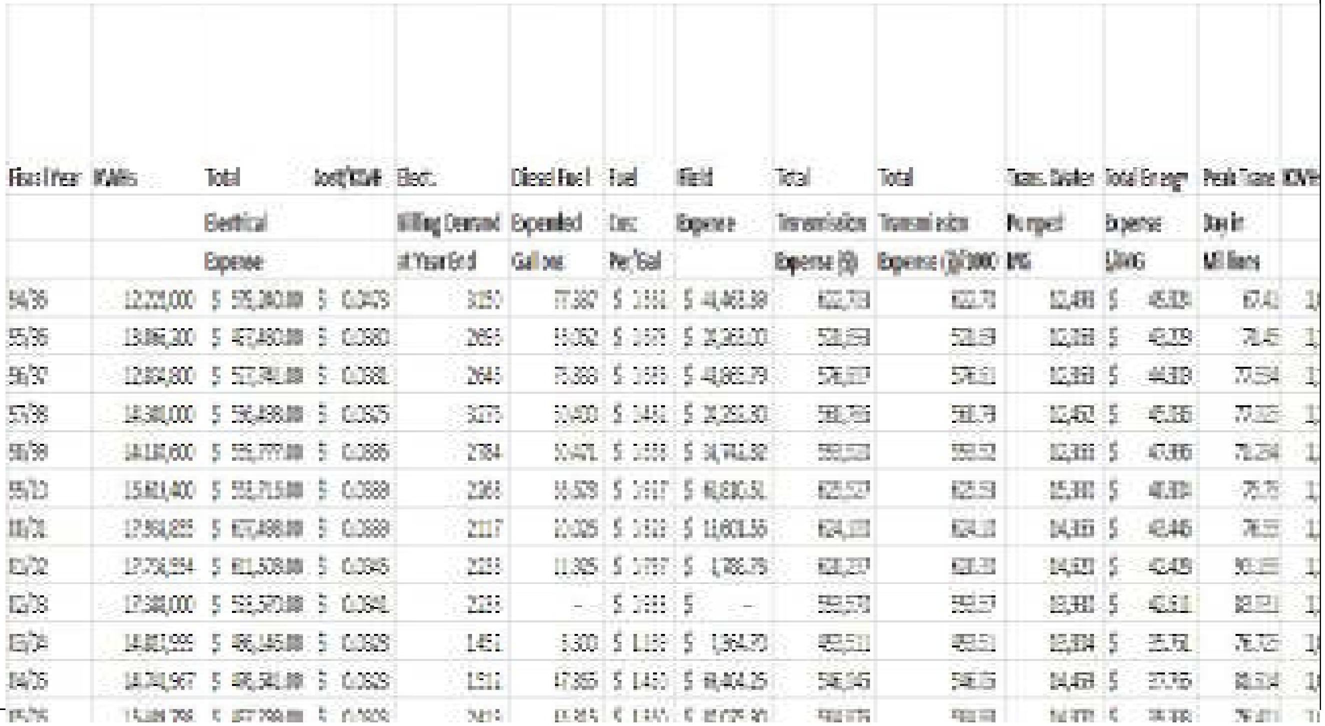

Table B-3: Historical Water Demand Parameters
Source: LWS, 2012

Year	Total Annual Pumpage BG	Lincoln Usage BG	AAD Demand (mgd)	Maximum Day Demand(MD) (mgd)	Maximum Hour Usage(MH) (mgd)	MD: AD	MH: AD	MH: MD
1994	11.30	11.30	31.00	59.90	87.80	1.93	2.83	1.47
1995	12.50	12.50	34.20	75.70	106.00	2.21	3.10	1.40
1996	12.10	12.10	33.00	80.80	118.00	2.45	3.58	1.46
1997	12.90	12.70	35.30	86.00	113.00	2.44	3.20	1.31
1998	12.50	12.60	34.30	78.50	98.00	2.29	2.86	1.25
1999	12.70	12.70	34.70	76.30	93.00	2.20	2.68	1.22
2000	15.00	15.00	41.10	83.50	128.00	2.03	3.11	1.53
2001	14.50	14.30	39.70	85.50	111.00	2.15	2.80	1.30
2002	14.60	14.50	40.10	90.40	131.00	2.25	3.27	1.45
2003	13.70	13.70	37.50	78.00	126.00	2.08	3.36	1.62
2004	12.80	12.80	35.10	65.80	100.00	1.87	2.85	1.52
2005	13.80	14.10	37.90	87.60	125.00	2.31	3.30	1.43
2006	14.00	13.30	39.40	75.70	118.00	1.92	2.99	1.56
2007	12.80	12.80	35.10	84.90	123.00	2.4	3.5	1.4
2008	12.00	12.00	32.80	69.10	118.00	2.1	3.6	1.7
2009	11.90	11.90	32.70	60.10	137.00	1.8	4.2	2.3
2010	11.30	11.30	31.00	70.10	133.00	2.3	4.3	1.9
2011	11.70	11.70	32.00	69.30	0.00	2.2	0.0	0.0
2012	14.00	14.00	38.40	80.00	173.00	2.1	4.5	2.2
Average	13.0	12.9	35.5	76.7	112.6	2.2	3.2	1.5

Table B-4: Summer and Winter Water and Energy Use
Source: LWS, 2012

Year	Total Transmission Output (MG)	KWHs/MG
09/10 August	1427.363	903.3
09/10 September	1146.651	1016.1
09/10 October	910.383	980.0
09/10 November	752.661	936.2
09/10 December	862.981	1059.1
09/10 January	725.763	1044.8
09/10 February	738.723	1084.0
09/10 March	806.559	1021.9
09/10 April	944.493	1120.2
09/10 May	908.852	1273.1
09/10 June	1019.569	1225.4
09/10 July	1378.045	1163.5
09/11 August	1698.641	1107.2
09/11 September	1225.47	1083.0
09/11 October	1246.595	838.8
09/11 November	858.316	976.7
09/11 December	794.463	1145.3
09/11 January	681.239	1406.5
09/11 February	688.843	1217.2
09/11 March	764.112	1152.1
09/11 April	812.666	1156.2
09/11 May	992.876	1044.7
09/11 June	1218.25	857.3
09/11 July	1618.26	886.9

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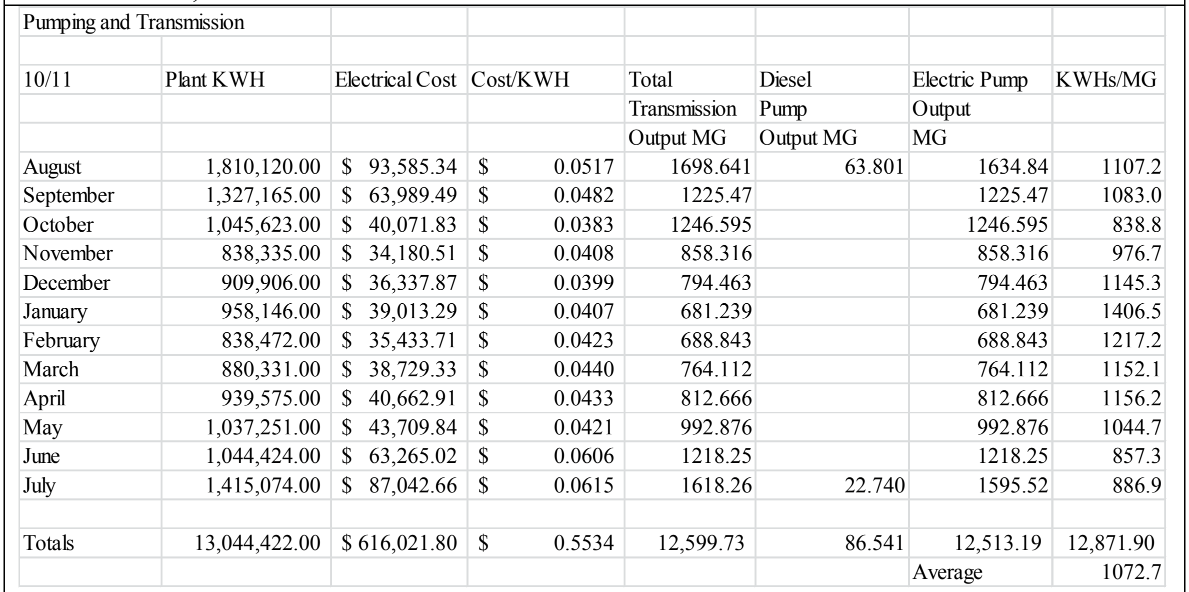
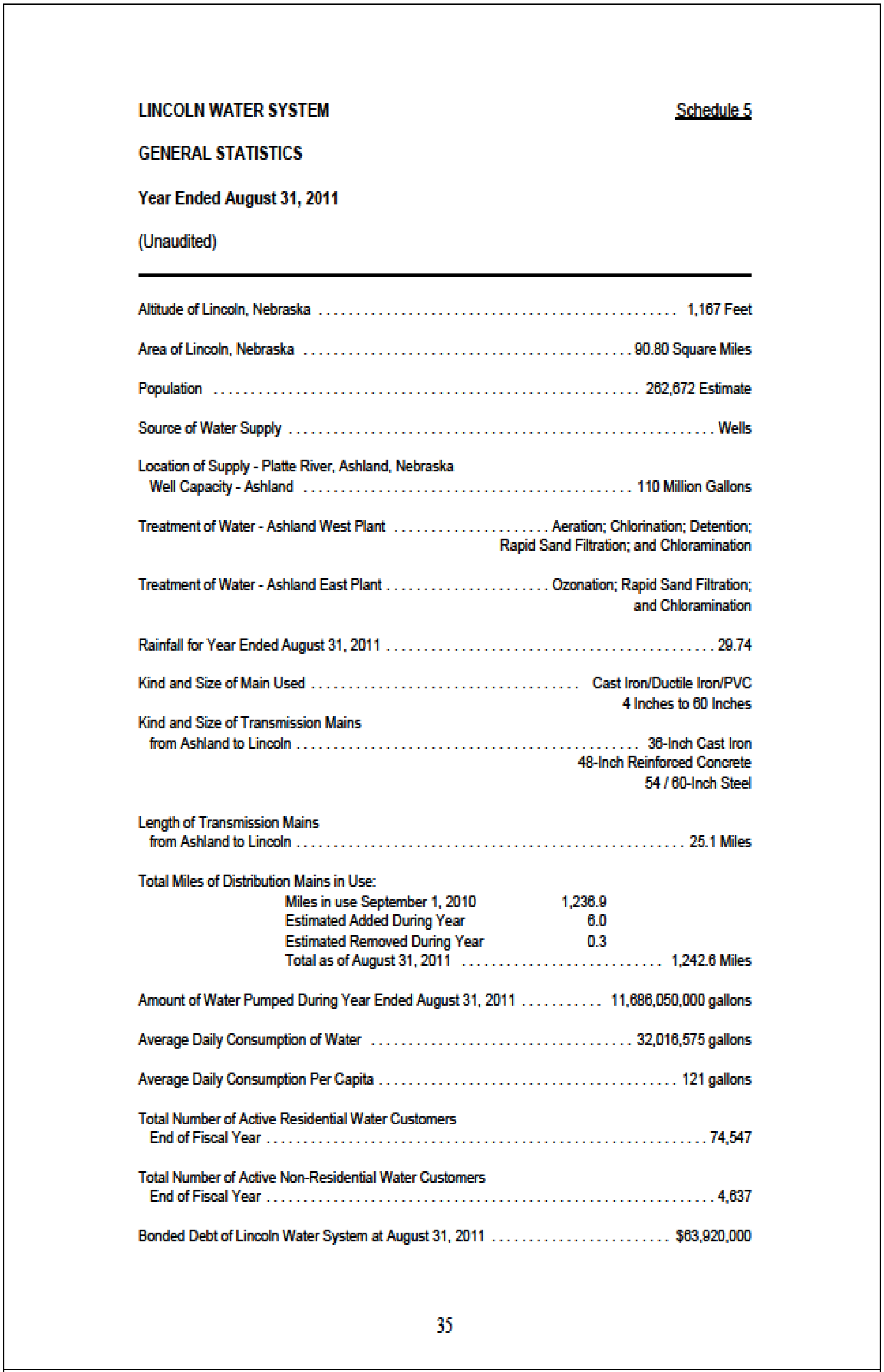
Table B-5: Drinking Water Annual 10/11 Summer and Winter Energy and Transmission

Output
Source: LWS, 2012



Pumping and Transmission							
10/11	Plant KWH	Electrical Cost	Cost/KWH	Total Transmission Output MG	Diesel Pump Output MG	Electric Pump Output MG	KWHs/MG
August	1,810,120.00	$ 93,585.34	$ 0.0517	1698.641	63.801	1634.84	1107.2
September	1,327,165.00	$ 63,989.49	$ 0.0482	1225.47		1225.47	1083.0
October	1,045,623.00	$ 40,071.83	$ 0.0383	1246.595		1246.595	838.8
November	838,335.00	$ 34,180.51	$ 0.0408	858.316		858.316	976.7
December	909,906.00	$ 36,337.87	$ 0.0399	794.463		794.463	1145.3
January	958,146.00	$ 39,013.29	$ 0.0407	681.239		681.239	1406.5
February	838,472.00	$ 35,433.71	$ 0.0423	688.843		688.843	1217.2
March	880,331.00	$ 38,729.33	$ 0.0440	764.112		764.112	1152.1
April	939,575.00	$ 40,662.91	$ 0.0433	812.666		812.666	1156.2
May	1,037,251.00	$ 43,709.84	$ 0.0421	992.876		992.876	1044.7
June	1,044,424.00	$ 63,265.02	$ 0.0606	1218.25		1218.25	857.3
July	1,415,074.00	$ 87,042.66	$ 0.0615	1618.26	22.740	1595.52	886.9
Totals	13,044,422.00	$ 616,021.80	$ 0.5534	12,599.73	86.541	12,513.19	12,871.90
						Average	1072.7

Table B-6: Demand and Total Energy Expense in Lincoln, Nebraska Source: LWS,2012		
Fiscal Year	Elect. Billing Demand at Year End	Total Energy Expense $/MG
94/95	3,150	49.82
95/96	2,696	43.23
96/97	2,646	44.81
97/98	3,276	45.04
98/99	2,784	48.00
99/10	2,268	40.80
00/01	2,117	43.45
01/02	2,238	42.43
02/03	2,238	42.61
03/04	1,452	35.75
04/05	1,512	37.77
05/06	2,419	39.33
06/07	2,328	47.27
07/08	1,401	40.95
08/09	1,372	43.89
09/10	1,048	46.03
10/11	1,152	50.16



LINCOLN WATER SYSTEM **Schedule 5**

GENERAL STATISTICS

Year Ended August 31, 2011

(Unaudited)

Altitude of Lincoln, Nebraska	1,167 Feet
Area of Lincoln, Nebraska	90.80 Square Miles
Population	262,672 Estimate
Source of Water Supply	Wells
Location of Supply - Platte River, Ashland, Nebraska Well Capacity - Ashland	110 Million Gallons
Treatment of Water - Ashland West Plant	Aeration; Chlorination; Detention; Rapid Sand Filtration; and Chloramination
Treatment of Water - Ashland East Plant	Ozonation; Rapid Sand Filtration; and Chloramination
Rainfall for Year Ended August 31, 2011	29.74
Kind and Size of Main Used	Cast Iron/Ductile Iron/PVC 4 Inches to 60 Inches
Kind and Size of Transmission Mains from Ashland to Lincoln	36-Inch Cast Iron 48-Inch Reinforced Concrete 54 / 60-Inch Steel
Length of Transmission Mains from Ashland to Lincoln	25.1 Miles

Total Miles of Distribution Mains in Use:

Miles in use September 1, 2010	1,236.9	
Estimated Added During Year	6.0	
Estimated Removed During Year	0.3	
Total as of August 31, 2011		1,242.6 Miles

Amount of Water Pumped During Year Ended August 31, 2011	11,686,050,000 gallons
Average Daily Consumption of Water	32,016,575 gallons
Average Daily Consumption Per Capita	121 gallons
Total Number of Active Residential Water Customers End of Fiscal Year	74,547
Total Number of Active Non-Residential Water Customers End of Fiscal Year	4,637
Bonded Debt of Lincoln Water System at August 31, 2011	$63,920,000

Source: Lincoln Water System: Financial Statements and Schedules Fiscal Year Ended August 31,2011

C. Greenhouse Gas Assumptions and Calculation

EPA GHG EQUIVALENCIES CALCULATOR

Source: P2 GHG Calculator - US Environmental Protection Agency www.epa.gov/p2/pubs/resources/GHGConversion.xls

1. Yearly water production from the City of Lincoln, NE – 2009-2011
   - Assumptions
     - Majority of electricity source is from coal
     - Lincoln's Annual Average Electrically use in the years 2009 to 2011 is 12,730,386 KwH
     - $MTCO_2e$ = Electricity conserved * (kWh/user-specified units) * national or regional value of the eGRID non-base load output emission rate [$MTCO_2e$/kWh]
   - Calculation on Electrical Conversion Regional Conversion Factors:
     - 1,096 to 1972 lbs.CO_2/Mwh * 0.454 kg/1lb. * 1MwH/1000 KwH* $1CO_2e/1CO_2$ * $1MTCO_2e/1000kgCO_2e$ = (0.0004972 to 0.008946) $MTCO_2e$/KwH
   - Calculation on Electrical Conversion National Conversion Factors:
     - 1520.21 lbs. CO_2/Mwh * 0.454 kg/lb. * 1MwH/1000 KwH * $1CO_2e$/1CO2 * $1MTCO_2e/1000kgCO_2e$ = 0.000692 $MTCO_2e$/KwH
   - Source
     - Environmental Protection Agency (EPA) Waste Reduction Model (WARM) Version 1.1 May 2011, http://epa.gov/climatechange/wycd/waste/calculators/Warm_home.html,
     - U.S. EPA Downloadable Document: "Unit Conversions, Emissions Factors, and Other Reference Data, 2004."

Economic Input-Output Life Cycle Assessment EIO-LCA

Source: www.eiolca.net/

1. New Water Supply Well in existing Wellfield

- Assumptions
  - EIO-LCA model applied to calculate GHG reduction
    - Model: US National Producer Price Model (2002)
    - Sector #230103: Other nonresidential structures
    - Projection time period is based on 2008-2014 CIP
    - Cost of this project is $ 12,500,000 over 7 years

- Calculation
    - Based on EIO-LCA model, $ 12,500,000 spent on this project will result in results in 7,650 $MTCO_2E$ over 7 years.

- Sources
    - Lincoln CIP 2008 – 2014, http://www.lincoln.ne.gov/city/plan/capital/
    - Carnegie Mellon Economic Input Output Life Cycle Assessment (EIO-LCA) Model, http://www.eiolca.net/

2. New Water Supply Well in existing Wellfield

- Assumptions
    - EIO-LCA model applied to calculate GHG reduction
        - Model: US National Producer Price Model (2002)
        - Sector #230103: Other nonresidential structures
        - Projection time period is based on 2008-2014 CIP
        - Cost of this project is $ 2,000,000 over 7 years
- Calculation
    - Based on EIO-LCA model, $ 2,000,000 spent on this project will result in results in 1,220 $MTCO_2E$ over 7 years.
- Sources
    - Lincoln CIP 2008 – 2014, http://www.lincoln.ne.gov/city/plan/capital/
    - Carnegie Mellon Economic Input Output Life Cycle Assessment (EIO-LCA) Model, http://www.eiolca.net/
    -

3. New Water Supply Well in existing Wellfield

- Assumptions
    - EIO-LCA model applied to calculate GHG reduction
        - Model: US National Producer Price Model (2002)
        - Sector #230103: Other nonresidential structures
        - Projection time period is based on 2008-2014 CIP
        - Cost of this project is $ 5,200,000 over 7 years

- Calculation
    - Based on EIO-LCA model, $ 5,200,000 spent on this project will result in results in 3,180 $MTCO_2E$ over 7 years.

- Sources
    - Lincoln CIP 2008 – 2014, http://www.lincoln.ne.gov/city/plan/capital/
    - Carnegie Mellon Economic Input Output Life Cycle Assessment (EIO-LCA) Model, http://www.eiolca.net/

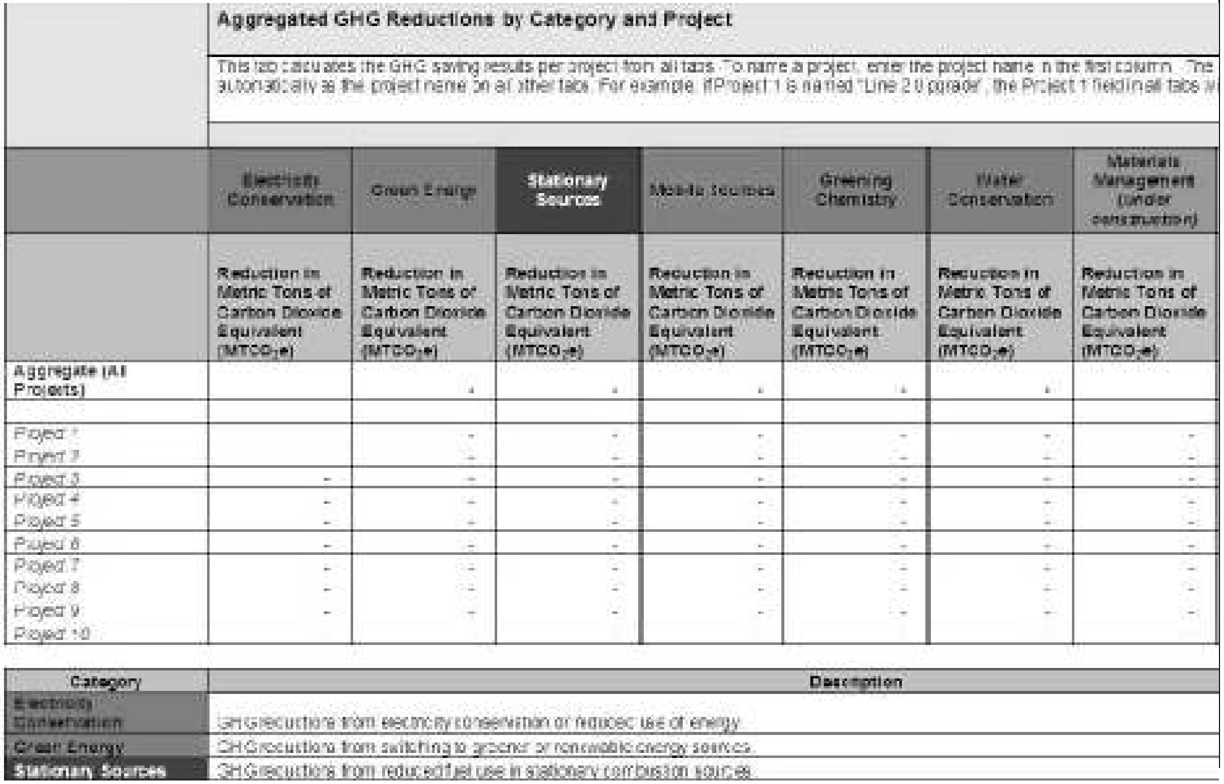
4. New Water Supply Well in existing Wellfield

- Assumptions
  - EIO-LCA model applied to calculate GHG reduction
    - Model: US National Producer Price Model (2002)
    - Sector #230103: Other nonresidential structures
    - Projection time period is based on 2008-2014 CIP
    - Cost of this project is $ 5,200,000 over 7 years

- Calculation
  - Based on EIO-LCA model, $ 5,200,000 spent on this project will result in results in 3,180 MTCO$_2$E over 7 years.

- Sources
  - Lincoln CIP 2008 – 2014, http://www.lincoln.ne.gov/city/plan/capital/
  - Carnegie Mellon Economic Input Output Life Cycle Assessment (EIO-LCA) Model, http://www.eiolca.net/

Table C-1: Aggregated GHG Reduction by Category and Project Lincoln Water System
Source: (EPA, 2011)



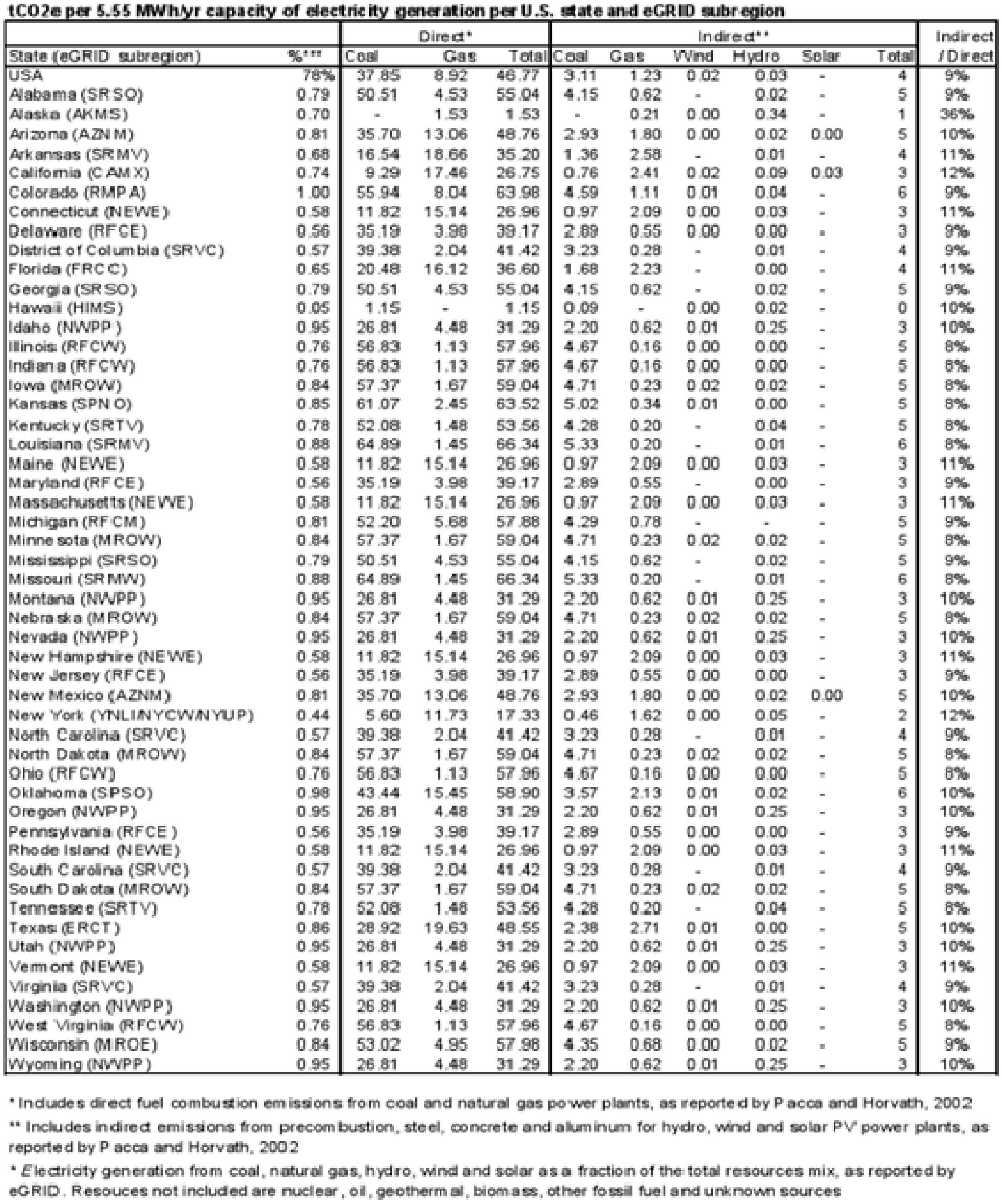
Aggregated GHG Reductions by Category and Project

This tab calculates the GHG saving results per project from all tabs. To name a project, enter the project name in the first column. The
automatically as the project name on all other tabs. For example, if Project 1 is named "Line 2 Upgrade", the Project 1 field in all tabs w

	Electricity Conservation	Green Energy	Stationary Sources	Mobile Sources	Greening Chemistry	Water Conservation	Materials Management (under construction)
	Reduction in Metric Tons of Carbon Dioxide Equivalent (MTCO$_2$e)	Reduction in Metric Tons of Carbon Dioxide Equivalent (MTCO$_2$e)	Reduction in Metric Tons of Carbon Dioxide Equivalent (MTCO$_2$e)	Reduction in Metric Tons of Carbon Dioxide Equivalent (MTCO$_2$e)	Reduction in Metric Tons of Carbon Dioxide Equivalent (MTCO$_2$e)	Reduction in Metric Tons of Carbon Dioxide Equivalent (MTCO$_2$e)	Reduction in Metric Tons of Carbon Dioxide Equivalent (MTCO$_2$e)
Aggregate (All Projects)		-	-	-	-	-	
Project 1		-	-	-	-	-	-
Project 2		-	-	-	-	-	-
Project 3	-	-	-	-	-	-	-
Project 4	-	-	-	-	-	-	-
Project 5	-	-	-	-	-	-	-
Project 6	-	-	-	-	-	-	-
Project 7	-	-	-	-	-	-	-
Project 8	-	-	-	-	-	-	-
Project 9	-	-	-	-	-	-	-
Project 10							

Category	Description
Electricity Conservation	GHG reductions from electricity conservation or reduced use of energy
Green Energy	GHG reductions from switching to greener or renewable energy sources
Stationary Sources	GHG reductions from reduced fuel use in stationary combustion sources

Table C-2: National U.S. Averages of Electricity GHG Production
Source: (Kammen, 2011)



tCO2e per 5.55 MWh/yr capacity of electricity generation per U.S. state and eGRID subregion

		Direct*			Indirect**						Indirect
State (eGRID subregion)	%***	Coal	Gas	Total	Coal	Gas	Wind	Hydro	Solar	Total	/Direct
USA	78%	37.85	8.92	46.77	3.11	1.23	0.02	0.03	-	4	9%
Alabama (SRSO)	0.79	50.51	4.53	55.04	4.15	0.62	-	0.02	-	5	9%
Alaska (AKMS)	0.70	-	1.53	1.53	-	0.21	0.00	0.34	-	1	36%
Arizona (AZNM)	0.81	35.70	13.06	48.76	2.93	1.80	0.00	0.02	0.00	5	10%
Arkansas (SRMV)	0.68	16.54	18.66	35.20	1.36	2.58	-	0.01	-	4	11%
California (CAMX)	0.74	9.29	17.46	26.75	0.76	2.41	0.02	0.09	0.03	3	12%
Colorado (RMPA)	1.00	55.94	8.04	63.98	4.59	1.11	0.01	0.04	-	6	9%
Connecticut (NEWE)	0.58	11.82	15.14	26.96	0.97	2.09	0.00	0.03	-	3	11%
Delaware (RFCE)	0.56	35.19	3.98	39.17	2.89	0.55	0.00	0.00	-	3	9%
District of Columbia (SRVC)	0.57	39.38	2.04	41.42	3.23	0.28	-	0.01	-	4	9%
Florida (FRCC)	0.65	20.48	16.12	36.60	1.68	2.23	-	0.00	-	4	11%
Georgia (SRSO)	0.79	50.51	4.53	55.04	4.15	0.62	-	0.02	-	5	9%
Hawaii (HIMS)	0.05	1.15	-	1.15	0.09	-	0.00	0.02	-	0	10%
Idaho (NWPP)	0.95	26.81	4.48	31.29	2.20	0.62	0.01	0.25	-	3	10%
Illinois (RFCW)	0.76	56.83	1.13	57.96	4.67	0.16	0.00	0.00	-	5	8%
Indiana (RFCW)	0.76	56.83	1.13	57.96	4.67	0.16	0.00	0.00	-	5	8%
Iowa (MROW)	0.84	57.37	1.67	59.04	4.71	0.23	0.02	0.02	-	5	8%
Kansas (SPNO)	0.85	61.07	2.45	63.52	5.02	0.34	0.01	0.00	-	5	8%
Kentucky (SRTV)	0.78	52.08	1.48	53.56	4.28	0.20	-	0.04	-	5	8%
Louisiana (SRMV)	0.88	64.89	1.45	66.34	5.33	0.20	-	0.01	-	6	8%
Maine (NEWE)	0.58	11.82	15.14	26.96	0.97	2.09	0.00	0.03	-	3	11%
Maryland (RFCE)	0.56	35.19	3.98	39.17	2.89	0.55	-	0.00	-	3	9%
Massachusetts (NEWE)	0.58	11.82	15.14	26.96	0.97	2.09	0.00	0.03	-	3	11%
Michigan (RFCM)	0.81	52.20	5.68	57.88	4.29	0.78	-	-	-	5	9%
Minnesota (MROW)	0.84	57.37	1.67	59.04	4.71	0.23	0.02	0.02	-	5	8%
Mississippi (SRSO)	0.79	50.51	4.53	55.04	4.15	0.62	-	0.02	-	5	9%
Missouri (SRMW)	0.88	64.89	1.45	66.34	5.33	0.20	-	0.01	-	6	8%
Montana (NWPP)	0.95	26.81	4.48	31.29	2.20	0.62	0.01	0.25	-	3	10%
Nebraska (MROW)	0.84	57.37	1.67	59.04	4.71	0.23	0.02	0.02	-	5	8%
Nevada (NWPP)	0.95	26.81	4.48	31.29	2.20	0.62	0.01	0.25	-	3	10%
New Hampshire (NEWE)	0.58	11.82	15.14	26.96	0.97	2.09	0.00	0.03	-	3	11%
New Jersey (RFCE)	0.56	35.19	3.98	39.17	2.89	0.55	0.00	0.00	-	3	9%
New Mexico (AZNM)	0.81	35.70	13.06	48.76	2.93	1.80	0.00	0.02	0.00	5	10%
New York (YNLI/NYCW/NYUP)	0.44	5.60	11.73	17.33	0.46	1.62	0.00	0.05	-	2	12%
North Carolina (SRVC)	0.57	39.38	2.04	41.42	3.23	0.28	-	0.01	-	4	9%
North Dakota (MROW)	0.84	57.37	1.67	59.04	4.71	0.23	0.02	0.02	-	5	8%
Ohio (RFCW)	0.76	56.83	1.13	57.96	4.67	0.16	0.00	0.00	-	5	8%
Oklahoma (SPSO)	0.98	43.44	15.45	58.90	3.57	2.13	0.01	0.02	-	6	10%
Oregon (NWPP)	0.95	26.81	4.48	31.29	2.20	0.62	0.01	0.25	-	3	10%
Pennsylvania (RFCE)	0.56	35.19	3.98	39.17	2.89	0.55	0.00	0.00	-	3	9%
Rhode Island (NEWE)	0.58	11.82	15.14	26.96	0.97	2.09	0.00	0.03	-	3	11%
South Carolina (SRVC)	0.57	39.38	2.04	41.42	3.23	0.28	-	0.01	-	4	9%
South Dakota (MROW)	0.84	57.37	1.67	59.04	4.71	0.23	0.02	0.02	-	5	8%
Tennessee (SRTV)	0.78	52.08	1.48	53.56	4.28	0.20	-	0.04	-	5	8%
Texas (ERCT)	0.86	28.92	19.63	48.55	2.38	2.71	0.01	0.00	-	5	10%
Utah (NWPP)	0.95	26.81	4.48	31.29	2.20	0.62	0.01	0.25	-	3	10%
Vermont (NEWE)	0.58	11.82	15.14	26.96	0.97	2.09	0.00	0.03	-	3	11%
Virginia (SRVC)	0.57	39.38	2.04	41.42	3.23	0.28	-	0.01	-	4	9%
Washington (NWPP)	0.95	26.81	4.48	31.29	2.20	0.62	0.01	0.25	-	3	10%
West Virginia (RFCW)	0.76	56.83	1.13	57.96	4.67	0.16	0.00	0.00	-	5	8%
Wisconsin (MROE)	0.84	53.02	4.95	57.98	4.35	0.68	0.00	0.02	-	5	9%
Wyoming (NWPP)	0.95	26.81	4.48	31.29	2.20	0.62	0.01	0.25	-	3	10%

* Includes direct fuel combustion emissions from coal and natural gas power plants, as reported by Pacca and Horvath, 2002

** Includes indirect emissions from precombustion, steel, concrete and aluminum for hydro, wind and solar PV power plants, as reported by Pacca and Horvath, 2002

* Electricity generation from coal, natural gas, hydro, wind and solar as a fraction of the total resources mix, as reported by eGRID. Resouces not included are nuclear, oil, geothermal, biomass, other fossil fuel and unknown sources

D. ArcGIS and InfoWater Supporting Data

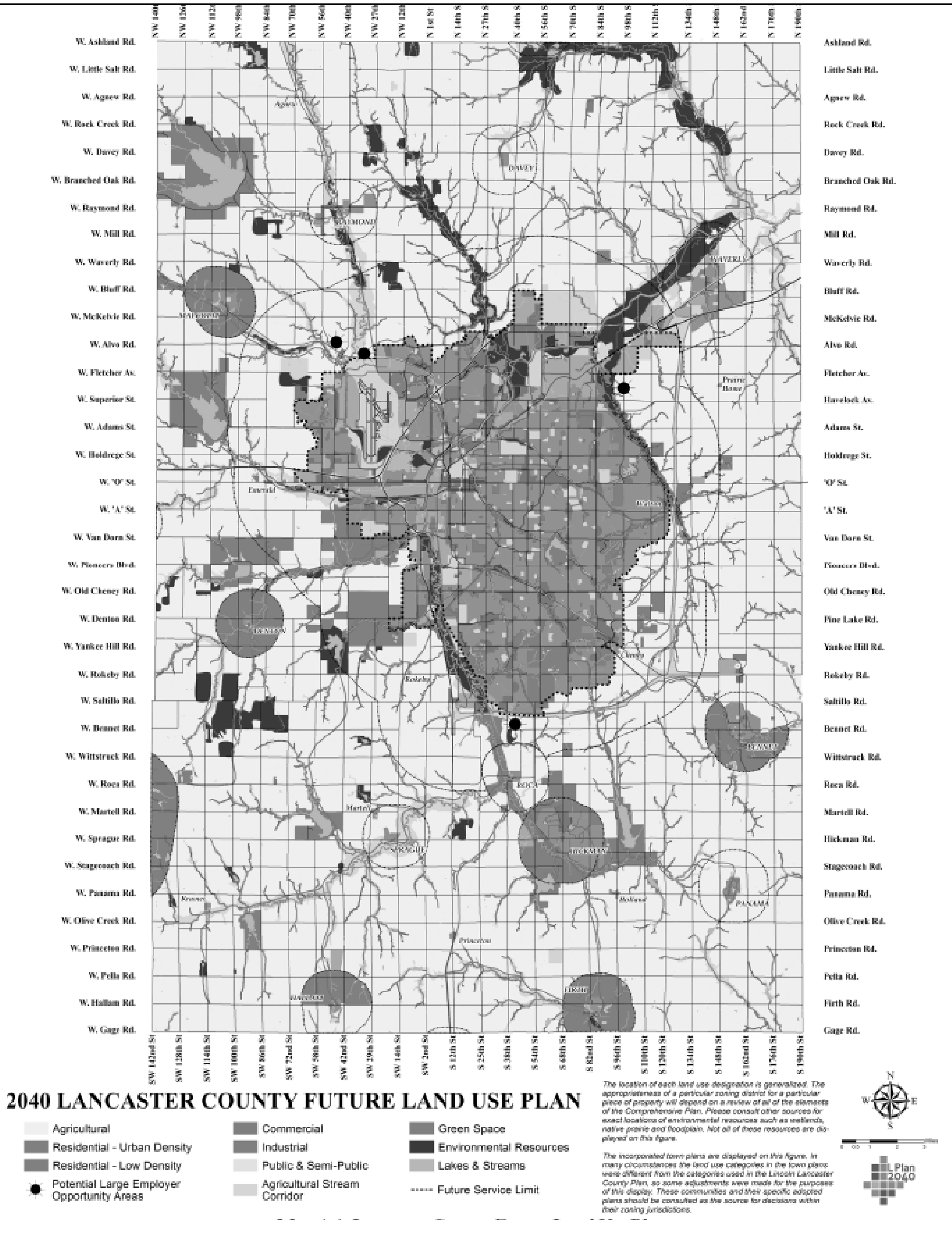


Figure D-1: 2040 Lincoln Area Future Land Use Plan
Source: Lincoln-Lancaster County 2040 Comprehensive Plan, 2012

E. Scenario Cost Analysis

Calculating Inflation Factors

Inflation consideration in any budgetary calculation is an important value. Inflation is a general increase in prices and fall in the purchasing value of money. A slight increase or decrease in most projected in CIP reports can seriously affect purchasing power over time. The US Inflation index measures the buying power of the dollar over time. This is calculated from the previous year's estimates. Accordingly the past inflation rates are shown in the table below:

Table E-1: Table of Inflation Rates by Month and Year (1999-2012)
Source: U.S. Bureau of Labor Statistics, 2012

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
2012	2.9	2.9	2.7	2.3	1.7	1.7	1.4	1.7					
2011	1.6	2.1	2.7	3.2	3.6	3.6	3.6	3.8	3.9	3.5	3.4	3.0	3.2
2010	2.6	2.1	2.3	2.2	2.0	1.1	1.2	1.1	1.1	1.2	1.1	1.5	1.6
2009	0.0	0.2	-0.4	-0.7	-1.3	-1.4	-2.1	-1.5	-1.3	-0.2	1.8	2.7	-0.4
2008	4.3	4.0	4.0	3.9	4.2	5.0	5.6	5.4	4.9	3.7	1.1	0.1	3.8
2007	2.1	2.4	2.8	2.6	2.7	2.7	2.4	2.0	2.8	3.5	4.3	4.1	2.8
2006	4.0	3.6	3.4	3.5	4.2	4.3	4.1	3.8	2.1	1.3	2.0	2.5	3.2
2005	3.0	3.0	3.1	3.5	2.8	2.5	3.2	3.6	4.7	4.3	3.5	3.4	3.4
2004	1.9	1.7	1.7	2.3	3.1	3.3	3.0	2.7	2.5	3.2	3.5	3.3	2.7
2003	2.6	3.0	3.0	2.2	2.1	2.1	2.1	2.2	2.3	2.0	1.8	1.9	2.3
2002	1.1	1.1	1.5	1.6	1.2	1.1	1.5	1.8	1.5	2.0	2.2	2.4	1.6
2001	3.7	3.5	2.9	3.3	3.6	3.2	2.7	2.7	2.6	2.1	1.9	1.6	2.8
2000	2.7	3.2	3.8	3.1	3.2	3.7	3.7	3.4	3.5	3.4	3.4	3.4	3.4
1999	1.7	1.6	1.7	2.3	2.1	2.0	2.1	2.3	2.6	2.6	2.6	2.7	2.2

Based on the data above data, and assuming that current City of Lincoln CIP (Table E-2) projections, cost of building infrastructure in the City using 2008 data has an inflation rate of 3.8 percent, a formula has to be implemented to figure out what that amount will cost in towards dollars. To calculate inflation rate, the formula used is shown below:

$$\frac{F - I}{I} * 100$$

Where:

F= Final Cost
I = Initial Cost

This formula is only used to calculate the inflation rate for a specific item, hence the results in Table E-1. For a compounded inflation cost, as is the case with all inflation rates, a different formula has to be used. This formula is shown below:

$$Pn = P(1 + i)^n$$

Where:

Pn= Total Inflated Estimated Cost
P= Base estimated cost
I=Inflation Rate
N= Difference between Base Year and Selected Year
(1+i) n = Inflation Factor

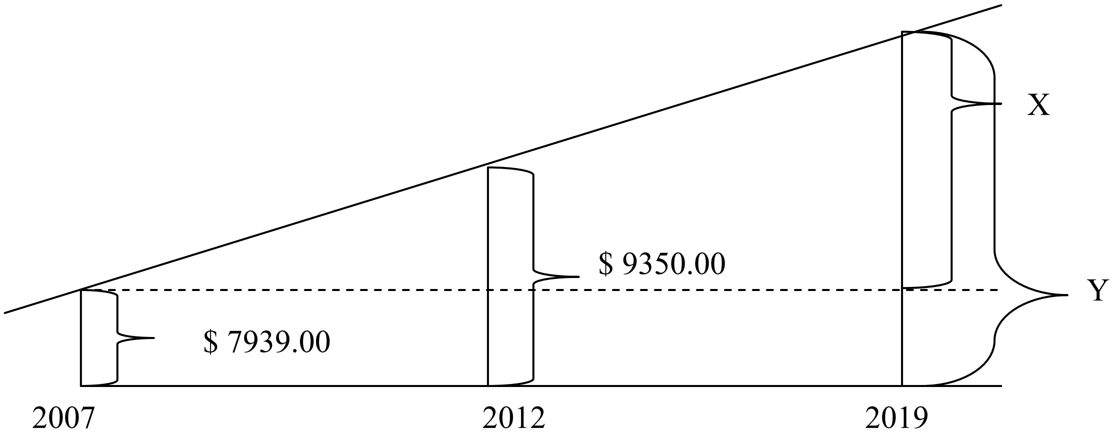
For instance the water supply well that cost $840,000 in 2008 (base year) in 2012 dollars (future year) with the inflation rate in 2008 at 3.8% will be:

$$Pn = \$\ 840{,}000\ (1 + 0.038)^4 = \$\ 871{,}924$$

In today's dollars, the CIP will have to be adjusted for inflation (among other cost) to $871,924. To better illustrate the other cost added to this inflation amount, one has to pull certain indices in to the total amount. Assume for instance that the index consists of cement (for constructing the water supply well) cost at $1.00 per unit in 2008 (ENR published the CCI index in 2008 at 8000). If today the same cost of cement is $2.00 the index would stand at 8200.

Projection to 2019 Scenario Analysis

Using ENR and assuming a straight line proportional increase in costs (Table E-6: Cheney Service Level Cost Analysis):



$$\frac{\$9{,}350 - \$7{,}939}{2012 - 2007} = \frac{X}{2019 - 2007}$$

$$X = \$3{,}386.4 \ in \ 2019$$

$$Y = X + \$7{,}939 = \$\ 11{,}325$$

$$Ratio \ is \ thus \ calculated \ as \ \frac{\$11{,}325}{\$7{,}939} = 1.426$$

The 1.426 ratio will be used to figure projected cost in the year 2019.

Calculating Fire Flow

Source: National Fire Academy, 1998, Palm Beach County Fire Rescue, 2012, and City of Lincoln Fire & Rescue Department, 2010

Fire flow analyses are incorporated in the InfoWater Model. Fire flow analysis is a common tool used to ensure adequate protection is provided during fire emergencies.

One of the goals of a water distribution system is to provide adequate capacity to contain and extinguish fires. Fire flow data is calculated based on peak day flows. The main variables that effect fire flows include:

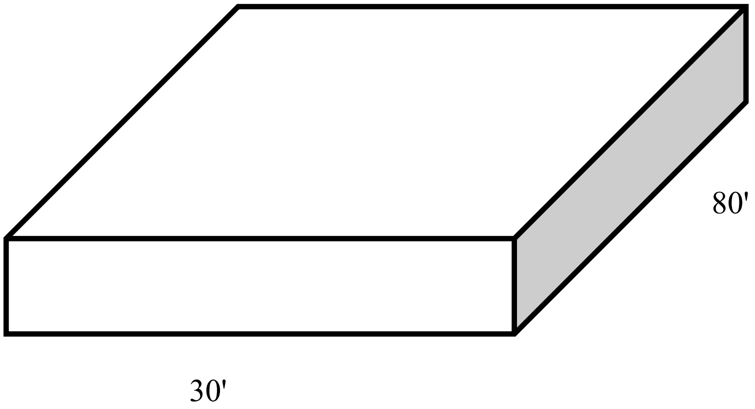
- Fire load,
- Concealed spaces,
- Building construction, and
- Configuration.

There are several fire flow formulas in use today. The National Fire Academy (NFA) formula is generally used due to its flexibility and simplicity. The basic Fire Flow formula is shown below:

$$Needed\ Fire\ Flow\ (NFF) = \frac{Length * Width}{3} x\ Percentage\ of\ fire\ involvement$$

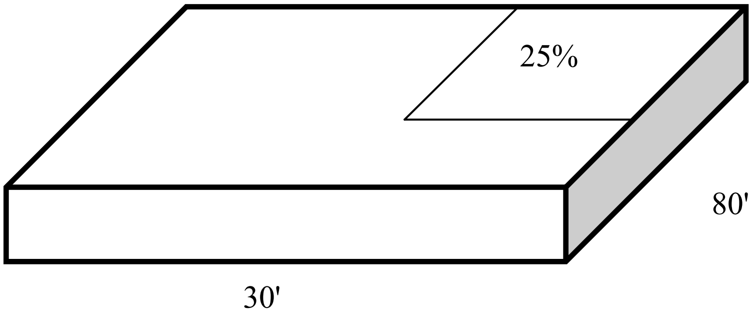
For example:

1. To calculate the fire flow for an entire building involved in a fire:



$$Needed\ Fire\ Flow\ (NFF) = \frac{30 * 80}{3} = 800\ GPM$$

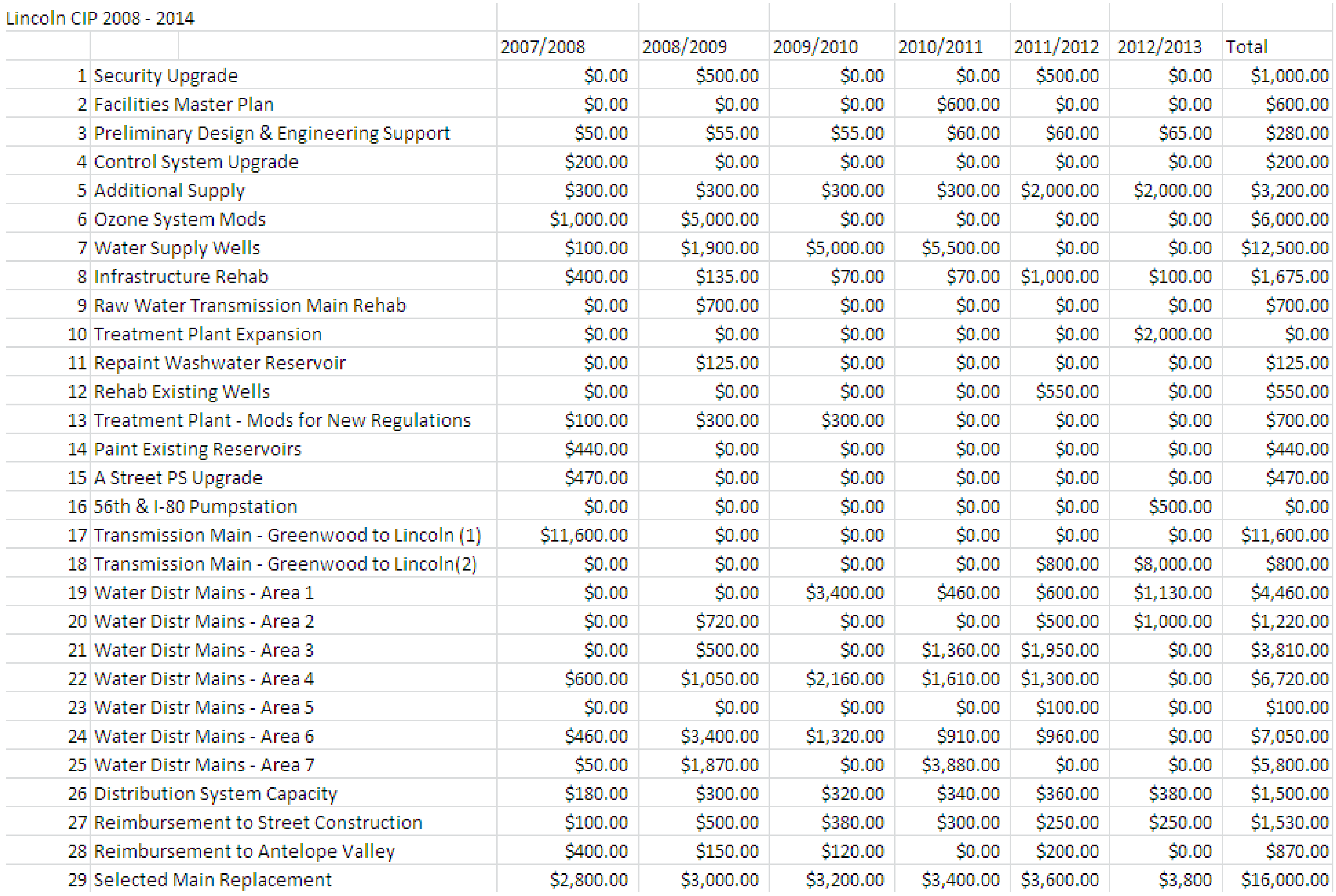
2. To calculate the needed fire flow for only a portion of the above building, a percentage of the building is figured out as shown below.



$$Needed\ Fire\ Flow\ (NFF) = \frac{30 * 80}{3} * 25\ \% = 200\ GPM$$

For additional floors, multiply the percent involved times the number of floors involved. The correct pressure should be able to produce the required gpm.

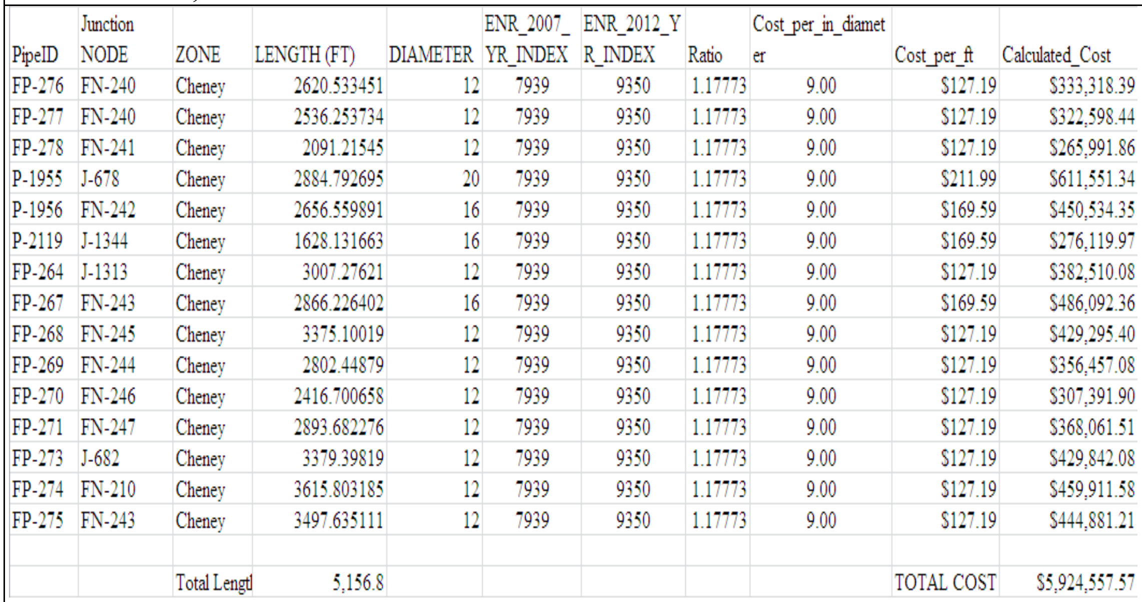
Table E-2: Lincoln CIP 2008- 2014 (Values in ‘000)
Source: LWS, 2012



Lincoln CIP 2008 - 2014

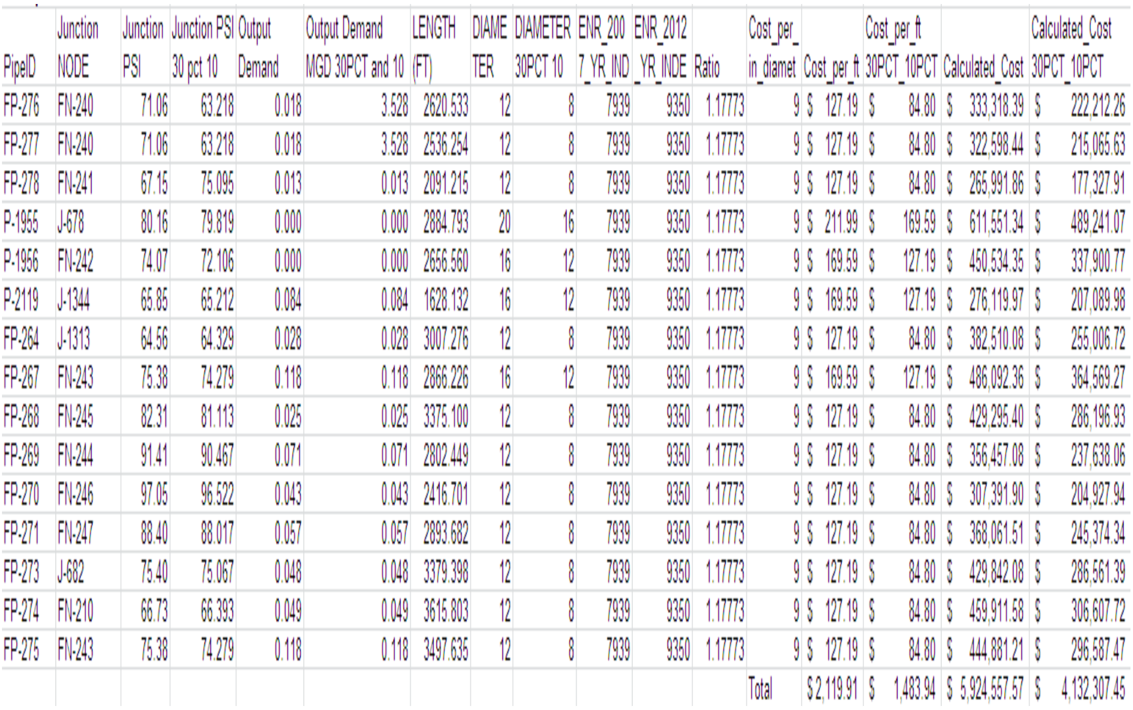
		2007/2008	2008/2009	2009/2010	2010/2011	2011/2012	2012/2013	Total
1	Security Upgrade	$0.00	$500.00	$0.00	$0.00	$500.00	$0.00	$1,000.00
2	Facilities Master Plan	$0.00	$0.00	$0.00	$600.00	$0.00	$0.00	$600.00
3	Preliminary Design & Engineering Support	$50.00	$55.00	$55.00	$60.00	$60.00	$65.00	$280.00
4	Control System Upgrade	$200.00	$0.00	$0.00	$0.00	$0.00	$0.00	$200.00
5	Additional Supply	$300.00	$300.00	$300.00	$300.00	$2,000.00	$2,000.00	$3,200.00
6	Ozone System Mods	$1,000.00	$5,000.00	$0.00	$0.00	$0.00	$0.00	$6,000.00
7	Water Supply Wells	$100.00	$1,900.00	$5,000.00	$5,500.00	$0.00	$0.00	$12,500.00
8	Infrastructure Rehab	$400.00	$135.00	$70.00	$70.00	$1,000.00	$100.00	$1,675.00
9	Raw Water Transmission Main Rehab	$0.00	$700.00	$0.00	$0.00	$0.00	$0.00	$700.00
10	Treatment Plant Expansion	$0.00	$0.00	$0.00	$0.00	$0.00	$2,000.00	$0.00
11	Repaint Washwater Reservoir	$0.00	$125.00	$0.00	$0.00	$0.00	$0.00	$125.00
12	Rehab Existing Wells	$0.00	$0.00	$0.00	$0.00	$550.00	$0.00	$550.00
13	Treatment Plant - Mods for New Regulations	$100.00	$300.00	$300.00	$0.00	$0.00	$0.00	$700.00
14	Paint Existing Reservoirs	$440.00	$0.00	$0.00	$0.00	$0.00	$0.00	$440.00
15	A Street PS Upgrade	$470.00	$0.00	$0.00	$0.00	$0.00	$0.00	$470.00
16	56th & I-80 Pumpstation	$0.00	$0.00	$0.00	$0.00	$0.00	$500.00	$0.00
17	Transmission Main - Greenwood to Lincoln (1)	$11,600.00	$0.00	$0.00	$0.00	$0.00	$0.00	$11,600.00
18	Transmission Main - Greenwood to Lincoln(2)	$0.00	$0.00	$0.00	$0.00	$800.00	$8,000.00	$800.00
19	Water Distr Mains - Area 1	$0.00	$0.00	$3,400.00	$460.00	$600.00	$1,130.00	$4,460.00
20	Water Distr Mains - Area 2	$0.00	$720.00	$0.00	$0.00	$500.00	$1,000.00	$1,220.00
21	Water Distr Mains - Area 3	$0.00	$500.00	$0.00	$1,360.00	$1,950.00	$0.00	$3,810.00
22	Water Distr Mains - Area 4	$600.00	$1,050.00	$2,160.00	$1,610.00	$1,300.00	$0.00	$6,720.00
23	Water Distr Mains - Area 5	$0.00	$0.00	$0.00	$0.00	$100.00	$0.00	$100.00
24	Water Distr Mains - Area 6	$460.00	$3,400.00	$1,320.00	$910.00	$960.00	$0.00	$7,050.00
25	Water Distr Mains - Area 7	$50.00	$1,870.00	$0.00	$3,880.00	$0.00	$0.00	$5,800.00
26	Distribution System Capacity	$180.00	$300.00	$320.00	$340.00	$360.00	$380.00	$1,500.00
27	Reimbursement to Street Construction	$100.00	$500.00	$380.00	$300.00	$250.00	$250.00	$1,530.00
28	Reimbursement to Antelope Valley	$400.00	$150.00	$120.00	$0.00	$200.00	$0.00	$870.00
29	Selected Main Replacement	$2,800.00	$3,000.00	$3,200.00	$3,400.00	$3,600.00	$3,800	$16,000.00

Table E-3: Cheney Service Level Cost Analysis 2019 Scenario 1
Source: LWS, 2012



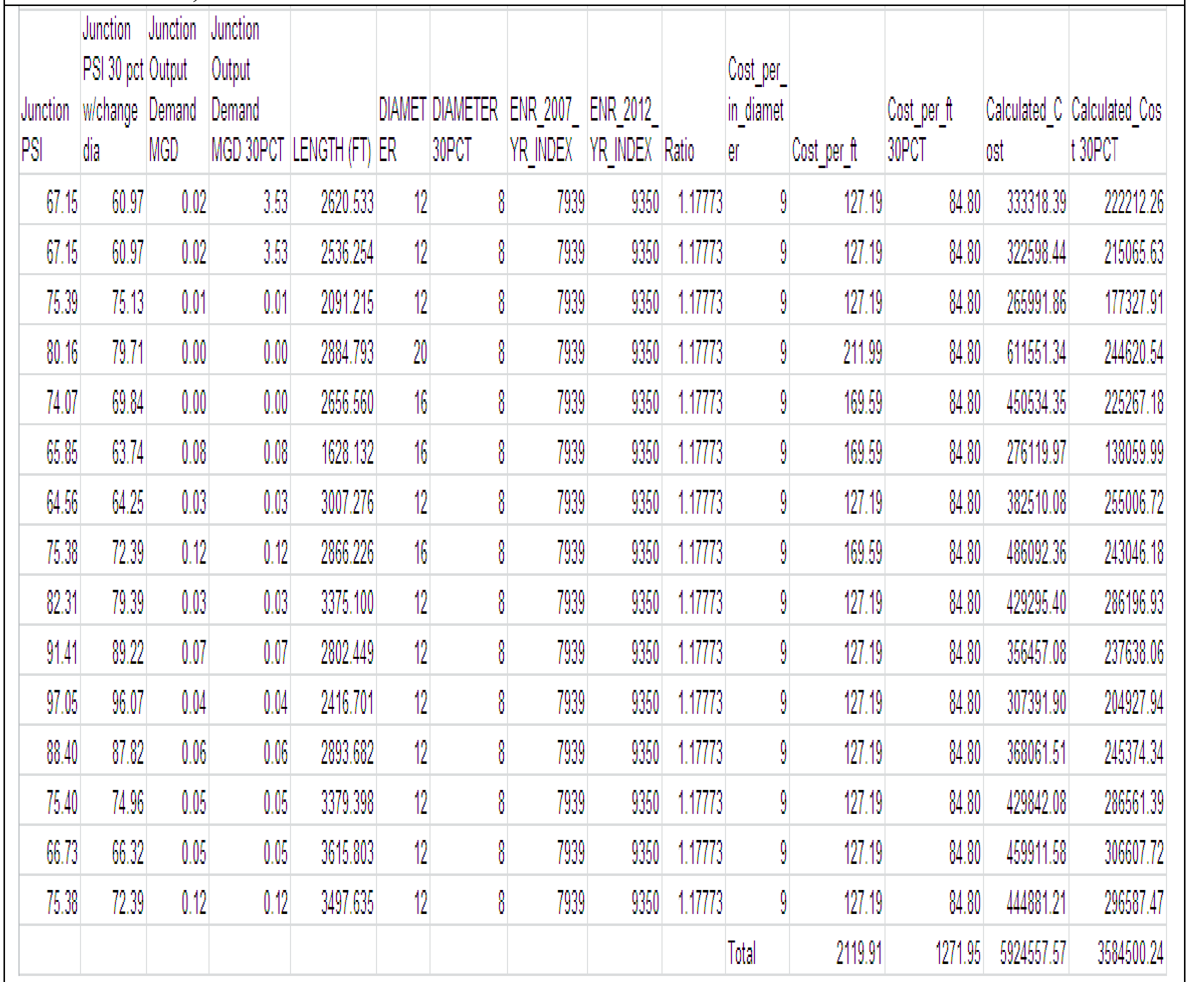
PipeID	Junction NODE	ZONE	LENGTH (FT)	DIAMETER	ENR_2007_YR_INDEX	ENR_2012_YR_INDEX	Ratio	Cost_per_in_diameter	Cost_per_ft	Calculated_Cost
FP-276	FN-240	Cheney	2620.533451	12	7939	9350	1.17773	9.00	$127.19	$333,318.39
FP-277	FN-240	Cheney	2536.253734	12	7939	9350	1.17773	9.00	$127.19	$322,598.44
FP-278	FN-241	Cheney	2091.21545	12	7939	9350	1.17773	9.00	$127.19	$265,991.86
P-1955	J-678	Cheney	2884.792695	20	7939	9350	1.17773	9.00	$211.99	$611,551.34
P-1956	FN-242	Cheney	2656.559891	16	7939	9350	1.17773	9.00	$169.59	$450,534.35
P-2119	J-1344	Cheney	1628.131663	16	7939	9350	1.17773	9.00	$169.59	$276,119.97
FP-264	J-1313	Cheney	3007.27621	12	7939	9350	1.17773	9.00	$127.19	$382,510.08
FP-267	FN-243	Cheney	2866.226402	16	7939	9350	1.17773	9.00	$169.59	$486,092.36
FP-268	FN-245	Cheney	3375.10019	12	7939	9350	1.17773	9.00	$127.19	$429,295.40
FP-269	FN-244	Cheney	2802.44879	12	7939	9350	1.17773	9.00	$127.19	$356,457.08
FP-270	FN-246	Cheney	2416.700658	12	7939	9350	1.17773	9.00	$127.19	$307,391.90
FP-271	FN-247	Cheney	2893.682276	12	7939	9350	1.17773	9.00	$127.19	$368,061.51
FP-273	J-682	Cheney	3379.39819	12	7939	9350	1.17773	9.00	$127.19	$429,842.08
FP-274	FN-210	Cheney	3615.803185	12	7939	9350	1.17773	9.00	$127.19	$459,911.58
FP-275	FN-243	Cheney	3497.635111	12	7939	9350	1.17773	9.00	$127.19	$444,881.21
		Total Lengtl	5,156.8						TOTAL COST	$5,924,557.57

Table E-4: Cheney Service Level Cost Analysis 10 Percent Scenario 2
Source: LWS, 2012



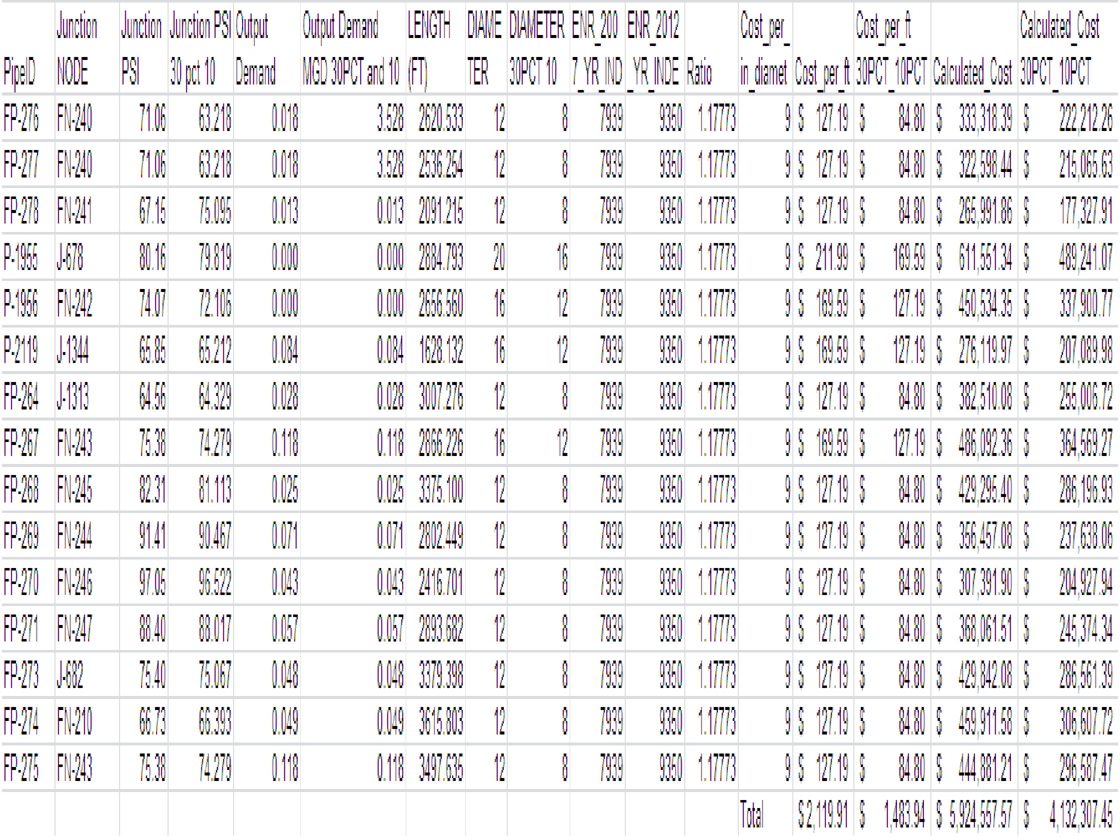
PipeID	Junction NODE	Junction PSI	Junction PSI 30 pct 10	Output Demand	Output Demand MGD 30PCT and 10	LENGTH (FT)	DIAMETER	DIAMETER 30PCT 10	ENR_2007_YR_IND	ENR_2012_YR_INDE	Ratio	Cost_per_in_diamet	Cost_per_ft	Cost_per_ft 30PCT_10PCT	Calculated_Cost	Calculated_Cost 30PCT_10PCT
FP-276	FN-240	71.06	63.218	0.018	3.528	2620.533	12	8	7939	9350	1.17773	9	$ 127.19	$ 84.80	$ 333,318.39	$ 222,212.26
FP-277	FN-240	71.06	63.218	0.018	3.528	2536.254	12	8	7939	9350	1.17773	9	$ 127.19	$ 84.80	$ 322,598.44	$ 215,065.63
FP-278	FN-241	67.15	75.095	0.013	0.013	2091.215	12	8	7939	9350	1.17773	9	$ 127.19	$ 84.80	$ 265,991.86	$ 177,327.91
P-1955	J-678	80.16	79.819	0.000	0.000	2884.793	20	16	7939	9350	1.17773	9	$ 211.99	$ 169.59	$ 611,551.34	$ 489,241.07
P-1956	FN-242	74.07	72.106	0.000	0.000	2656.560	16	12	7939	9350	1.17773	9	$ 169.59	$ 127.19	$ 450,534.35	$ 337,900.77
P-2119	J-1344	65.85	65.212	0.084	0.084	1628.132	16	12	7939	9350	1.17773	9	$ 169.59	$ 127.19	$ 276,119.97	$ 207,089.98
FP-264	J-1313	64.56	64.329	0.028	0.028	3007.276	12	8	7939	9350	1.17773	9	$ 127.19	$ 84.80	$ 382,510.08	$ 255,006.72
FP-267	FN-243	75.38	74.279	0.118	0.118	2866.226	16	12	7939	9350	1.17773	9	$ 169.59	$ 127.19	$ 486,092.36	$ 364,569.27
FP-268	FN-245	82.31	81.113	0.025	0.025	3375.100	12	8	7939	9350	1.17773	9	$ 127.19	$ 84.80	$ 429,295.40	$ 286,196.93
FP-269	FN-244	91.41	90.467	0.071	0.071	2802.449	12	8	7939	9350	1.17773	9	$ 127.19	$ 84.80	$ 356,457.08	$ 237,638.06
FP-270	FN-246	97.05	96.522	0.043	0.043	2416.701	12	8	7939	9350	1.17773	9	$ 127.19	$ 84.80	$ 307,391.90	$ 204,927.94
FP-271	FN-247	88.40	88.017	0.057	0.057	2893.682	12	8	7939	9350	1.17773	9	$ 127.19	$ 84.80	$ 368,061.51	$ 245,374.34
FP-273	J-682	75.40	75.067	0.048	0.048	3379.398	12	8	7939	9350	1.17773	9	$ 127.19	$ 84.80	$ 429,842.08	$ 286,561.39
FP-274	FN-210	66.73	66.393	0.049	0.049	3615.803	12	8	7939	9350	1.17773	9	$ 127.19	$ 84.80	$ 459,911.58	$ 306,607.72
FP-275	FN-243	75.38	74.279	0.118	0.118	3497.635	12	8	7939	9350	1.17773	9	$ 127.19	$ 84.80	$ 444,881.21	$ 296,587.47
												Total	$ 2,119.91	$ 1,483.94	$ 5,924,557.57	$ 4,132,307.45

Table E-5: Cheney Service Level Cost Analysis 30 Percent Scenario 3
Source: LWS, 2012



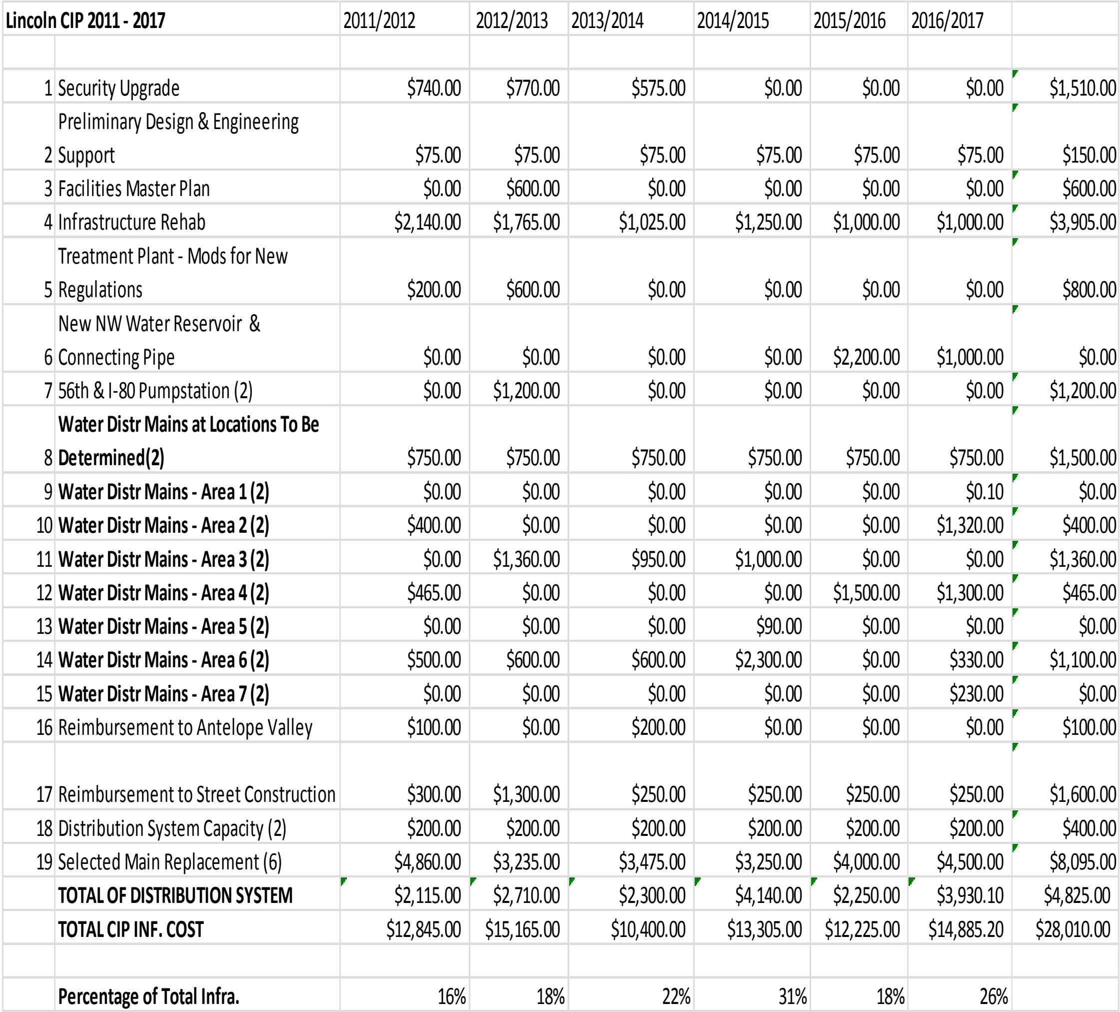
Junction PSI	Junction PSI 30 pct w/change dia	Junction Output Demand MGD	Junction Output Demand MGD 30PCT	LENGTH (FT)	DIAMETER	DIAMETER 30PCT	ENR_2007_YR_INDEX	ENR_2012_YR_INDEX	Ratio	Cost_per_in_diameter	Cost_per_ft	Cost_per_ft 30PCT	Calculated_Cost	Calculated_Cost 30PCT
67.15	60.97	0.02	3.53	2620.533	12	8	7939	9350	1.17773	9	127.19	84.80	333318.39	222212.26
67.15	60.97	0.02	3.53	2536.254	12	8	7939	9350	1.17773	9	127.19	84.80	322598.44	215065.63
75.39	75.13	0.01	0.01	2091.215	12	8	7939	9350	1.17773	9	127.19	84.80	265991.86	177327.91
80.16	79.71	0.00	0.00	2884.793	20	8	7939	9350	1.17773	9	211.99	84.80	611551.34	244620.54
74.07	69.84	0.00	0.00	2656.560	16	8	7939	9350	1.17773	9	169.59	84.80	450534.35	225267.18
65.85	63.74	0.08	0.08	1628.132	16	8	7939	9350	1.17773	9	169.59	84.80	276119.97	138059.99
64.56	64.25	0.03	0.03	3007.276	12	8	7939	9350	1.17773	9	127.19	84.80	382510.08	255006.72
75.38	72.39	0.12	0.12	2866.226	16	8	7939	9350	1.17773	9	169.59	84.80	486092.36	243046.18
82.31	79.39	0.03	0.03	3375.100	12	8	7939	9350	1.17773	9	127.19	84.80	429295.40	286196.93
91.41	89.22	0.07	0.07	2802.449	12	8	7939	9350	1.17773	9	127.19	84.80	356457.08	237638.06
97.05	96.07	0.04	0.04	2416.701	12	8	7939	9350	1.17773	9	127.19	84.80	307391.90	204927.94
88.40	87.82	0.06	0.06	2893.682	12	8	7939	9350	1.17773	9	127.19	84.80	368061.51	245374.34
75.40	74.96	0.05	0.05	3379.398	12	8	7939	9350	1.17773	9	127.19	84.80	429842.08	286561.39
66.73	66.32	0.05	0.05	3615.803	12	8	7939	9350	1.17773	9	127.19	84.80	459911.58	306607.72
75.38	72.39	0.12	0.12	3497.635	12	8	7939	9350	1.17773	9	127.19	84.80	444881.21	296587.47
										Total	2119.91	1271.95	5924557.57	3584500.24

Table E-6: Cheney Service Level Cost Analysis 10 Percent and 30 Percent Scenario 4
Source: LWS, 2012



PipeID	Junction NODE	Junction PSI	Junction PSI 30 pct 10	Output Demand	Output Demand MGD 30PCT and 10	LENGTH (FT)	DIAMETER	DIAMETER 30PCT 10	ENR_200 7_YR_IND	ENR_2012 _YR_INDE	Ratio	Cost_per_in_diamet	Cost_per_ft	Cost_per_ft 30PCT_10PCT	Calculated_Cost	Calculated_Cost 30PCT_10PCT
FP-276	FN-240	71.06	63.218	0.018	3.528	2620.533	12	8	7939	9350	1.17773	9	$ 127.19	$ 84.80	$ 333,318.39	$ 222,212.26
FP-277	FN-240	71.06	63.218	0.018	3.528	2536.254	12	8	7939	9350	1.17773	9	$ 127.19	$ 84.80	$ 322,598.44	$ 215,065.63
FP-278	FN-241	67.15	75.095	0.013	0.013	2091.215	12	8	7939	9350	1.17773	9	$ 127.19	$ 84.80	$ 265,991.86	$ 177,327.91
P-1955	J-678	80.16	79.819	0.000	0.000	2884.793	20	16	7939	9350	1.17773	9	$ 211.99	$ 169.59	$ 611,551.34	$ 489,241.07
P-1956	FN-242	74.07	72.106	0.000	0.000	2656.560	16	12	7939	9350	1.17773	9	$ 169.59	$ 127.19	$ 450,534.35	$ 337,900.77
P-2119	J-1344	65.85	65.212	0.084	0.084	1628.132	16	12	7939	9350	1.17773	9	$ 169.59	$ 127.19	$ 276,119.97	$ 207,089.98
FP-264	J-1313	64.56	64.329	0.028	0.028	3007.276	12	8	7939	9350	1.17773	9	$ 127.19	$ 84.80	$ 382,510.08	$ 255,006.72
FP-267	FN-243	75.38	74.279	0.118	0.118	2866.226	16	12	7939	9350	1.17773	9	$ 169.59	$ 127.19	$ 486,092.36	$ 364,569.27
FP-268	FN-245	82.31	81.113	0.025	0.025	3375.100	12	8	7939	9350	1.17773	9	$ 127.19	$ 84.80	$ 429,295.40	$ 286,196.93
FP-269	FN-244	91.41	90.467	0.071	0.071	2802.449	12	8	7939	9350	1.17773	9	$ 127.19	$ 84.80	$ 356,457.08	$ 237,638.06
FP-270	FN-246	97.05	96.522	0.043	0.043	2416.701	12	8	7939	9350	1.17773	9	$ 127.19	$ 84.80	$ 307,391.90	$ 204,927.94
FP-271	FN-247	88.40	88.017	0.057	0.057	2893.682	12	8	7939	9350	1.17773	9	$ 127.19	$ 84.80	$ 368,061.51	$ 245,374.34
FP-273	J-682	75.40	75.067	0.048	0.048	3379.398	12	8	7939	9350	1.17773	9	$ 127.19	$ 84.80	$ 429,842.08	$ 286,561.39
FP-274	FN-210	66.73	66.393	0.049	0.049	3615.803	12	8	7939	9350	1.17773	9	$ 127.19	$ 84.80	$ 459,911.58	$ 306,607.72
FP-275	FN-243	75.38	74.279	0.118	0.118	3497.635	12	8	7939	9350	1.17773	9	$ 127.19	$ 84.80	$ 444,881.21	$ 296,587.47
												Total	$ 2,119.91	$ 1,483.94	$ 5,924,557.57	$ 4,132,307.45

Table E-7: CIP 2011-2017 New Distribution Systems
Source: LWS, 2012



Lincoln	CIP 2011 - 2017	2011/2012	2012/2013	2013/2014	2014/2015	2015/2016	2016/2017	
1	Security Upgrade	$740.00	$770.00	$575.00	$0.00	$0.00	$0.00	$1,510.00
2	Preliminary Design & Engineering Support	$75.00	$75.00	$75.00	$75.00	$75.00	$75.00	$150.00
3	Facilities Master Plan	$0.00	$600.00	$0.00	$0.00	$0.00	$0.00	$600.00
4	Infrastructure Rehab	$2,140.00	$1,765.00	$1,025.00	$1,250.00	$1,000.00	$1,000.00	$3,905.00
5	Treatment Plant - Mods for New Regulations	$200.00	$600.00	$0.00	$0.00	$0.00	$0.00	$800.00
6	New NW Water Reservoir & Connecting Pipe	$0.00	$0.00	$0.00	$0.00	$2,200.00	$1,000.00	$0.00
7	56th & I-80 Pumpstation (2)	$0.00	$1,200.00	$0.00	$0.00	$0.00	$0.00	$1,200.00
8	**Water Distr Mains at Locations To Be Determined(2)**	$750.00	$750.00	$750.00	$750.00	$750.00	$750.00	$1,500.00
9	**Water Distr Mains - Area 1 (2)**	$0.00	$0.00	$0.00	$0.00	$0.00	$0.10	$0.00
10	**Water Distr Mains - Area 2 (2)**	$400.00	$0.00	$0.00	$0.00	$0.00	$1,320.00	$400.00
11	**Water Distr Mains - Area 3 (2)**	$0.00	$1,360.00	$950.00	$1,000.00	$0.00	$0.00	$1,360.00
12	**Water Distr Mains - Area 4 (2)**	$465.00	$0.00	$0.00	$0.00	$1,500.00	$1,300.00	$465.00
13	**Water Distr Mains - Area 5 (2)**	$0.00	$0.00	$0.00	$90.00	$0.00	$0.00	$0.00
14	**Water Distr Mains - Area 6 (2)**	$500.00	$600.00	$600.00	$2,300.00	$0.00	$330.00	$1,100.00
15	**Water Distr Mains - Area 7 (2)**	$0.00	$0.00	$0.00	$0.00	$0.00	$230.00	$0.00
16	Reimbursement to Antelope Valley	$100.00	$0.00	$200.00	$0.00	$0.00	$0.00	$100.00
17	Reimbursement to Street Construction	$300.00	$1,300.00	$250.00	$250.00	$250.00	$250.00	$1,600.00
18	Distribution System Capacity (2)	$200.00	$200.00	$200.00	$200.00	$200.00	$200.00	$400.00
19	Selected Main Replacement (6)	$4,860.00	$3,235.00	$3,475.00	$3,250.00	$4,000.00	$4,500.00	$8,095.00
	TOTAL OF DISTRIBUTION SYSTEM	$2,115.00	$2,710.00	$2,300.00	$4,140.00	$2,250.00	$3,930.10	$4,825.00
	TOTAL CIP INF. COST	$12,845.00	$15,165.00	$10,400.00	$13,305.00	$12,225.00	$14,885.20	$28,010.00
	Percentage of Total Infra.	16%	18%	22%	31%	18%	26%	

F. Abbreviations and Acronyms

BMP	Better Management Practices
CIP	Capital Improvement Program
EIO-LCA	Economic Input-Output Life Cycle Assessment
GWh	Gigawatt Hour
GHG	Greenhouse Gas
kW	Kilowatt
LCA	Life Cycle Analysis
LES	Lincoln Electric System
LWS	Lincoln Water System
MWh	Megawatt Hour
MG	Million Gallons
OPPD	Omaha Public Power District
SCADA	Supervisory Control And Data Acquisition)
U.S. EPA	United States Environmental Protection Agency
WARM	Waste Reduction Model
WWTP	Wastewater Treatment Plant
WMP	Water Management Plan
WTP	Water Treatment Plant