Fort Collins Utilities Dual Water Systems Study

Final Report

Prepared by:
Jeanne Cole
Dan Fourness
Sybil Sharvelle (PI)
Neil Grigg (Co-PI)
Larry Roesner (Co-PI)

Department of Civil and Environmental Engineering
Colorado State University
Fort Collins, CO

July 13, 2015

Sponsored by:
City of Fort Collins Utilities
700 Wood St.
Fort Collins, CO 80521

Acknowledgements

Contributions from the following people, from the City of Fort Collins, were instrumental in this study:

Jon Haukaas (City of Fort Collins Utilities) for initiating the project and providing guidance throughout the study.

Technical Liaisons and Contributors:
Donnie Dustin, City of Fort Collins Utilities
Keith Elmund, City of Fort Collins Utilities
Ken Morrison, City of Fort Collins Utilities
Lisa Voytko, City of Fort Collins Utilities[1]
Brian Campbell, City of Fort Collins Utilities[1]
Sue Paquette, City of Fort Collins Utilities
Roger Buffington, City of Fort Collins Utilities
Chris Parton, City of Fort Collins Utilities
Andrew Gingerich, City of Fort Collins Utilities
Bill Switzer, City of Fort Collins Utilities
Bill Whirty, City of Fort Collins Parks Division
Katy Bigner, City of Fort Collins Utilities and Sustainability Services
Nature in the City Group, City of Fort Collins

[1] No longer employed at City of Fort Collins Utilities

Executive Summary

The objective of this study was to evaluate strategies for the dual distribution of raw water for non-potable demand (i.e. irrigation and fire demand) and potable water for indoor demand in the City of Fort Collins (City). Multi-Criteria Decision Analysis (MCDA) was used to compare four alternative dual water systems against maintaining the existing system from a triple bottom line perspective.

Motivation

Like many cities around the United States, the City of Fort Collins is investing in the repair and renewal of their aging water supply infrastructure. This offers an opportunity to evaluate the City's long-term urban water infrastructure strategy and consider alternative approaches to meeting the City's future water needs and sustainability goals. The initial motivation for the study was the question, "As the City renews its water infrastructure, should it be doing something different?" This study focuses on water supply infrastructure and how dual distribution strategies could result in benefits to the City, including:

- Decreasing water treatment energy use, operations costs, and replacement costs by reducing the volume of water treated and eliminating peak demand in summer months
- Enabling the City to use higher quality water resources to meet drinking water demand
- Improving drinking water quality by reducing water age in the potable distribution system
- Offering increased resiliency through multiple distribution paths in case of pipe failure, increasing available capacity in the existing water treatment facility and distribution system, allowing the utility to maximize their water resources, and providing infrastructure that can also be used toward implementation of alternative urban water management strategies in the future

Alternatives considered in the analysis

A triple bottom line analysis was conducted to determine the best alternative from an economic, social and environmental perspective. The following five alternatives were considered in the analysis:

1) Existing Alternative: Fort Collins' existing system consists of central water treatment, where total municipal demand is treated to drinking water standards and is then distributed to the end user via a potable only distribution system.

2) Central/Dual Alternative: Water for indoor demand is still treated at the existing central water treatment facility and then a dual distribution system delivers raw and potable water separately to the end user. The existing distribution system is used to distribute raw water to meet fire and irrigation demand and a new potable distribution system is used to distribute drinking water for indoor use.

3) Neighborhood Alternative: Raw water is conveyed to neighborhoods via the existing transmission mains. Raw water for fire and irrigation demand continues to be distributed via the existing neighborhood distribution system. Water for indoor demand is treated to drinking water standards at new neighborhood water treatment facilities and then distributed via a new potable distribution system.

4) Point-of-Entry Alternative: Raw water is distributed through the existing transmission and distribution mains to the service connection. Raw water is diverted to the irrigation system and water for indoor use is treated to drinking water standards at a Point-of-Entry water treatment system.

5) Separated Irrigation Alternative: Water for fire fighting and indoor demand will continue to be treated at the existing central water treatment facility and distributed to the end user via the existing transmission and distribution mains. New raw water irrigation systems will be installed to withdraw raw water directly from the City's network of irrigation ditches and canals to meet irrigation demand.

Methodology

MCDA was used to achieve a triple bottom line score for each alternative. The MCDA provided a common scale to evaluate qualitative and quantitative criteria to achieve an overall score for each perspective. It also allowed relative importance factors to be assigned to criteria based on stakeholder priorities. The MCDA used a weighted average method to calculate the economic, social, and environmental bottom line for each alternative. A list of criteria was developed with input from City stakeholders. Next, a set of performance metrics was developed that would be used to evaluate those criteria for an economic, social, and environmental bottom line. An MCDA was performed with all criteria weighted equally to provide a baseline for comparison with different stakeholder priorities. Relative importance input was collected from several different City stakeholder groups. Then the MCDAs were completed for each stakeholder group and finally an MCDA was completed using an average of the stakeholder responses.

Fort Collins has grown in three distinct eras over the last hundred years and, as a result, the City is made up of neighborhoods that vary in population density, land use type, layout, lot sizes, water demand, and infrastructure. To ensure these differences were accounted for in the analysis, three sample neighborhoods were selected to model the alternatives. The three sample neighborhoods represented a new development, a 1970s – 1990 development, and an Old Town neighborhood. MCDAs were conducted for each neighborhood to compare the economic, social and environmental performance of each alternative and determine if the optimal strategy differs by neighborhood type.

MCDA Results

The equally weighted and average stakeholder results were very similar, which is not unexpected when averaging the results of a diverse group of stakeholders (Figure E.1). Overall, the Central/Dual and Separated Irrigation alternatives outperformed the other alternatives. Both alternatives are feasible in comparison to the existing system. Central/Dual has consistently better economic and social performance than Separated Irrigation, while Separated Irrigation outperforms Central/Dual in environmental performance demonstrating the trade-offs between the different alternatives. Both alternatives improve water supply efficiency, flexibility and resiliency; however, Central/Dual has the additional benefits of using less energy and improving drinking water quality and Separated Irrigation has the additional benefit of increasing flows in the water corridors. It is important to note that changes to the City's water rights may be required for implementation of a Separated Irrigation alternative.

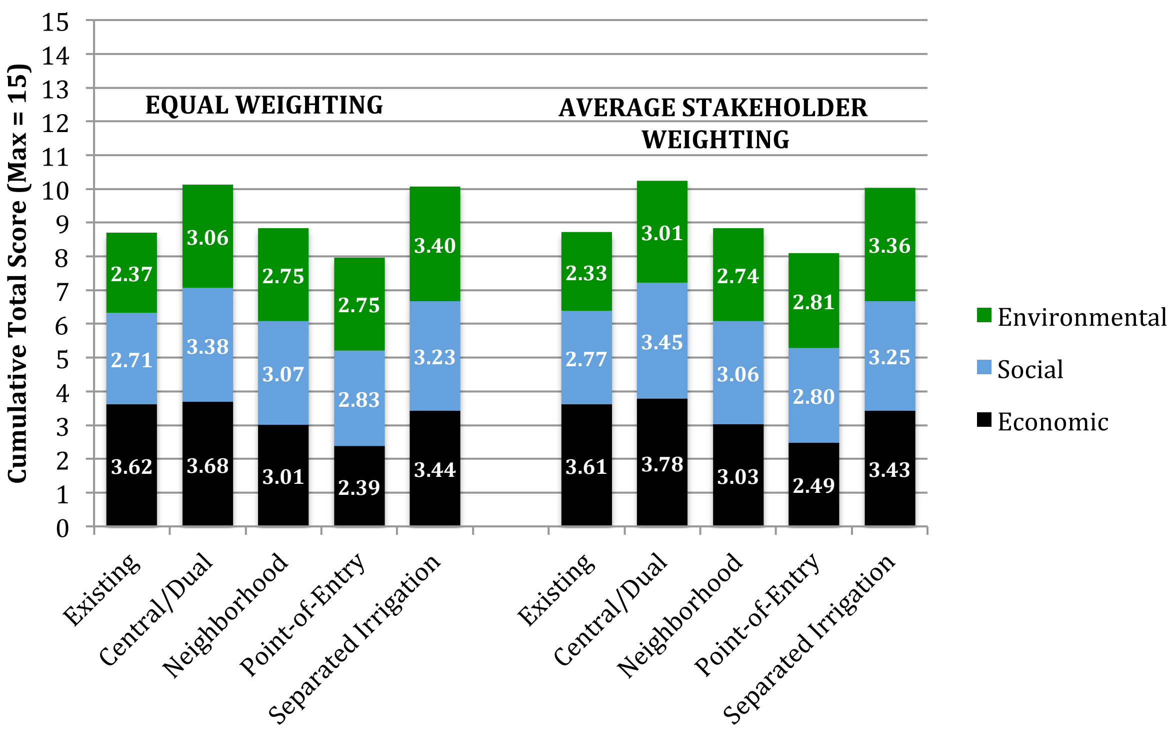


Figure E.1 – MCDA Equal Weighting and Average Stakeholder Results for Sample Neighborhood 1 (Best score for each bottom line = 5 & Best cumulative score = 15)

The stakeholder groups agreed Central/Dual and Existing were the top economic performers closely followed by Separated Irrigation, but there is less consensus among stakeholder groups on whether Central/Dual or Existing is the top economic choice. It is important to note that high economic performance does not mean the lowest financial cost. Although Separated Irrigation costs less to implement than Central/Dual, it has higher O&M costs due to the additional energy required for pumping, canal maintenance, and blowing out the irrigation system in the fall. It also only has access to the Cache La Poudre (CLP) River water resources and in the late summer months may require alternative water sources to meet landscape irrigation needs. For these reasons, Separated Irrigation does not perform as high economically as Central/Dual. Likewise, Central/Dual requires a high initial investment, but the benefits of cutting water treatment replacement costs and O&M costs by reducing the volume of water treated, eliminating peak demand in summer months, and allowing the city to save higher quality water resources for potable demand result in a higher economic performance than the existing system. The economic results suggest that it may be financially feasible to implement a dual distribution alternative that maintains central water treatment for potable supply.

From both a social and environmental standpoint, all alternatives score higher than the existing system reflecting the expected benefits associated with dual water systems. There was also more consensus among stakeholder groups on the top ranked alternatives from a social and environmental perspective. Central/Dual is the top scoring alternative on the social bottom line. Central/Dual offers the most benefits to the community by improving drinking water quality, decreasing air pollution due to GHG emissions, and providing the most resilient, flexible, and efficient infrastructure for the future. Separated Irrigation is the top environmental choice because, although it does not decrease GHG emissions, it increases flows in the CLP north of the City and improves the natural areas around the irrigation ditches, both of which are high priorities for stakeholders.

There were no substantial differences between the results for the three sample neighborhoods. Regardless of the differences between neighborhoods, Central/Dual and Separated Irrigation consistently score higher than the other alternatives. This suggests that the neighborhood differences in density of services, lot sizes, land use types and water demand collectively balance each other out.

Alternative Scenarios

Three alternative weighting scenarios were run to test the robustness of the MCDA results and to address concerns about the dilution of initial key drivers, the impact of a criterion that only applies to the Separated Irrigation alternative, and the assumption that the utility would need to conduct all maintenance in the Point-of-Entry alternative. The first scenario results showed that when the original key drivers of capital costs, O&M costs, revenue opportunities, water age, and GHG emissions were assigned the highest importance and all other criteria assigned the lowest importance, Separated Irrigation was no longer as competitive and the Central/Dual alternative became the preferred solution.

Energy use and potable water quality in the distribution system were two original key motivators for the study and the alternatives' performance in these areas had a significant impact on the results in the key drivers scenario (Figure E.2). Two issues to note with respect to energy use and potable water quality are:

1. The Neighborhood and Separated Irrigation alternatives use the most energy because the distribution system is no longer solely gravity fed. The Neighborhood alternative requires pumping for the distribution of potable water from the new neighborhood water treatment facilities and Separated Irrigation requires pumping for the distribution of raw water from the irrigation ditches.
2. The Central/Dual, Neighborhood, and Point-of-Entry alternatives all improve drinking water quality compared to the Existing alternative by decreasing the amount of time in the potable distribution system. The Separated Irrigation alternative has the highest water age of all the alternatives considered. It uses the existing distribution system for potable distribution, but has less demand than the existing distribution system in the summer because irrigation water is provided through the new irrigation system.

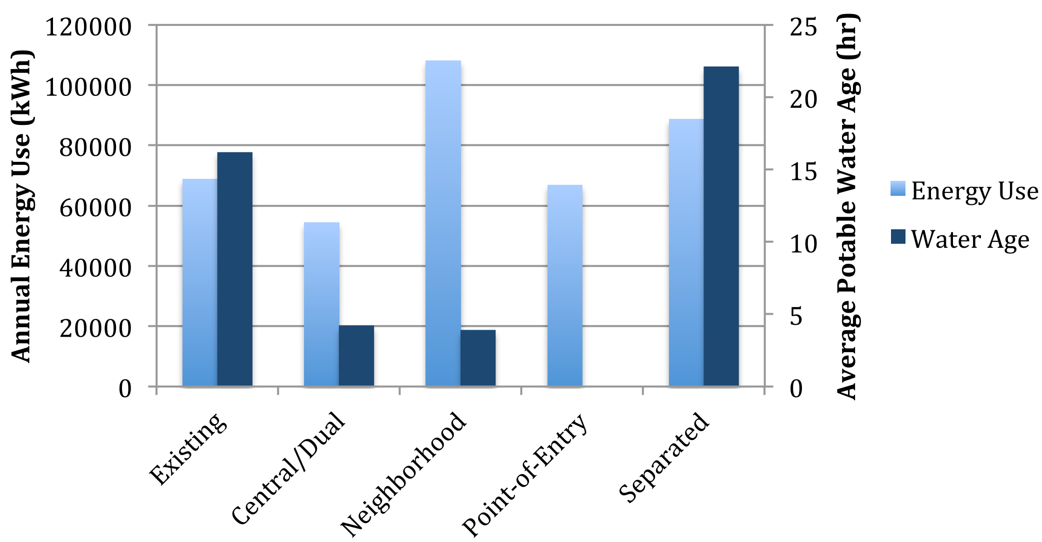


Figure E.2– Alternative Annual Energy Use and Average Water Age for Neighborhood 1

The second scenario looked at the influence of the 'Use of city water corridors' main criterion on the performance of the Separated Irrigation alternative. This criterion only applied to Separated Irrigation and when minimizing the importance of the criterion for all three bottom lines, there was a slight decrease in Separated Irrigation's social and environmental performance. However, despite the decrease in Separated Irrigation's social and environmental performance, it still remains one of the top two alternatives.

The third scenario considered how sharing O&M costs with homeowners for the Point-of-Entry alternative might affect its performance, but results found that sharing O&M costs does not produce a substantial change in Point-of-Entry's economic, social, or environmental performance. Sharing O&M responsibilities improves the ranking of the Point-of-Entry alternative slightly, making it more comparable to the Neighborhood and Existing alternatives. However, centralized treatment alternatives continue to score much higher than the Point-of-Entry alternative.

Central/Dual and Separated Irrigation were consistently the top ranked alternatives, for all sample neighborhoods, equally weighted and stakeholder-weighted results, and for the alternative scenarios, demonstrating the robustness of the results. We recommend the City consider a Central/Dual or Separated Irrigation alternative in their future planning. Although the results show there is little difference in economic performance between these two alternatives and the Existing alternative, the Central/Dual and Separated Irrigation alternatives show improved social and environmental performance.

This study provided an important step toward adoption of a more efficient, flexible, and resilient water supply system for the City's future. However, further work is needed to overcome implementation barriers, garner community acceptance and approval of an alternative water supply strategy, and a sensitivity analysis of the MCDA results should be completed to ensure the recommendations are not dependent on a small set of input parameters and hold up under a wide range of criteria weighting.

Table of Contents

List of Figures

List of Tables

Abbreviations and Acronyms

AWWA	American Water Works Association
C-BT	Colorado Big Thompson
CDPHE	Colorado Department of Public Health & Environment
Central/Dual	Alternative 1 – Central water treatment and dual distribution
CIP	Cast Iron Pipe
City	City of Fort Collins
CLP	Cache la Poudre
CSU	Colorado State University
DIC	Dissolved Inorganic Carbon
DIP	Ductile Iron Pipe
eRAMS	Environmental Risk Assessment Management System
Existing	Existing alternative – Central water treatment with potable distribution
FCU	Fort Collins Utilities
FTE	Full Time Employee
GAC	Granular Activated Carbon
GHG	Greenhouse Gases
gpm	Gallons per minute
HOA	Home Owners Association
Separated Irrigation	Alternative 4 - Raw water irrigation from the city network of irrigation ditches
KDF	Kinetic Degradation Fluxion Media
LCC	Life Cycle Costs
LCR	Lead and Copper Rule
LID	Local Improvement Districts
MCDA	Multi-Criteria Decision Analysis
MCLs	Maximum Contaminant Levels
MGD	Million Gallons per Day
Neighborhood	Alternative 2 – Neighborhood water treatment and dual distribution
O&M	Operations & Maintenance
POE	Point-of-Entry
	& Alternative 3 – Point-of-Entry water treatment with raw water distribution
PRST	Pipe Risk Screening Tool
PVC	Polyvinyl Chloride
PWS	Public Water System
RO	Reverse Osmosis

RTS	Remote Telemetry Systems
SDWA	Safe Drinking Water Act
TBL	Triple Bottom Line
TOC	Total Organic Carbon
US EPA	United States Environmental Protection Agency
UV	Ultraviolet Disinfection
VSD	Variable Speed Drive
VFD	Variable Frequency Drive
WFCWD	West Fort Collins Water District
WQCC	Water Quality Control Commission
WTF	Water Treatment Facility

I. Introduction

Recent droughts in the American West have brought the link between climate change and water supply to the front of the public consciousness. A growing population compounds the impact of shifting water supply. Colorado's population is expected to double from 5.1 million people in 2008 to 8.6 to 10 million people by 2050 (Colorado Water Conservation Board, 2011). The demand for potable water in the municipal sector is also expected to double, resulting in more energy use to meet these increasing demands and thereby exacerbating the problem.

Treating water to safe drinking water standards is energy intensive and not necessary for all intended uses (e.g. irrigation, fire protection, toilet flushing, vehicle washing, dust control, and cooling towers). The energy required to treat and distribute water is estimated between 3% and 7% of U.S. energy production (Plappally and Lienhard, 2012; Bakhshi and Demonsabert, 2012; Eisenberg, 2012). Reducing the need to treat all water to drinking water standards could have notable economic, social, and environmental benefits.

The City of Fort Collins (City) is located 65 miles north of Denver, in Larimer County, along the eastern slope of the Rocky Mountains. There are six water districts that overlap the city limits, however, this study focuses on the Fort Collins Utilities Water District in the center of Fort Collins (Figure 1.1). As the City plans to renew its aging water supply infrastructure, there is an opportunity to ask some fundamental questions that address the pressures of climate change and population growth. How can the utility meet both their future water needs and sustainability goals? How can the utility improve water quality, reduce energy consumption, and manage utility costs? Can matching water quality to the intended use help the utility meet their long-term goals? Fort Collins Utilities (FCU) commissioned a study to consider these questions as they evaluate strategies for the dual distribution of finished and raw water.

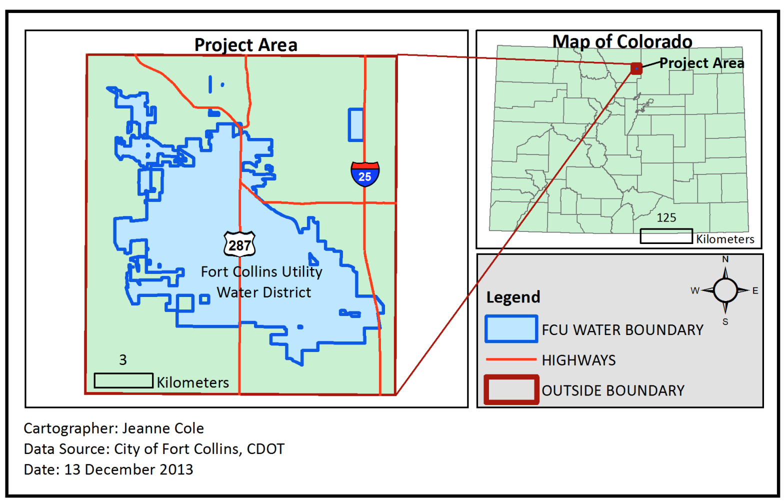


Figure 1.1 - Study Area Location

A dual water distribution system consists of two separate water distribution networks: one that delivers drinking (potable) water and another that delivers non-potable water for irrigation, fire protection, etc., to the end user. The implementation of dual water distribution systems dates back to the Roman Empire when they delivered water of poor quality for the use of marine circuses and landscape and garden irrigation to save better water quality sources for potable uses (Okun, 1997). Today dual distribution systems are used in California, Florida, Utah, Nevada, Arizona, Colorado and many other locations throughout the world.

a. Project Drivers

FCU is exploring innovative alternatives to the status quo in response to five key external drivers: an aging water infrastructure, total and peak water demand, potable water quality, population increase, and climate change.

i. Infrastructure Replacement

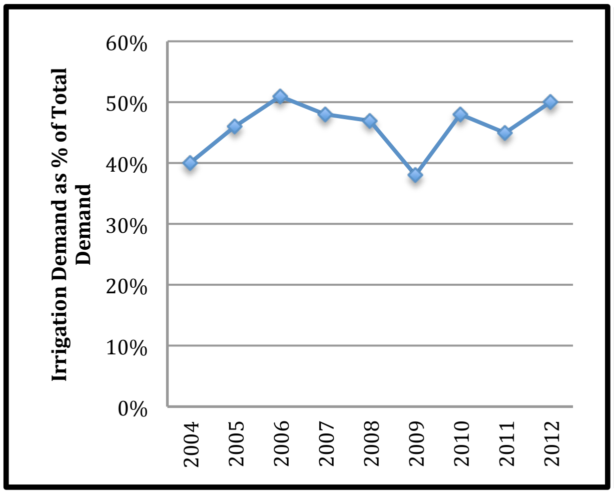
Like many cities across the United States, Fort Collins is investing in replacing their water infrastructure as it reaches the end of its useful life. The City currently spends over two million dollars a year replacing drinking water pipelines (Haukaas, 2013). This offers an opportunity to reevaluate the City's water systems and consider different approaches to meeting the City's future water needs. If an alternative strategy, such as dual distribution, can better accommodate the City's future water needs and sustainability goals, then it is more cost effective to implement this change when it is time to replace the old mains.

Image 1.1: Taken by J. Cole at Fort Collins' Utilities 10/08/2013

ii. Fort Collins Water Demand

Irrigation Demand

Approximately 40 to 50 percent of Fort Collins' total water demand treated at the water treatment facility is used for landscape irrigation (Figure 1.2). During the peak irrigation months daily demand can be up to three times the daily base demand (Figure 1.3) and monthly demand more than doubles (Figure 1.4). Water used for irrigation does not need to meet drinking water quality standards. Using potable water for irrigation requires a larger water treatment facility to meet this peak demand in the summer and drives up water treatment operational costs, such as energy and chemical consumables, in the summer. A dual water distribution system would allow the utility to match water quality to the intended use. This would result in lower water treatment facility operations and maintenance costs as well as replacement costs.



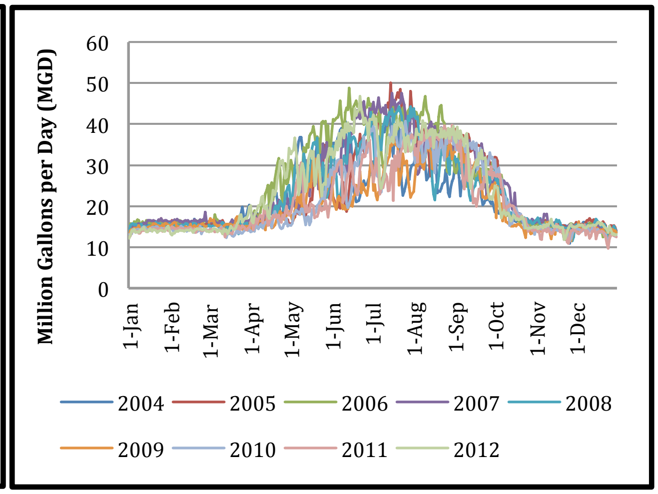


Figure 1.2 - Irrigation Demand **Figure 1.3 - Daily Demand**

Data Source: City of Fort Collins (July 19, 2013), Treated water volume, Includes Utility Service Area and West Fort Collins Water District

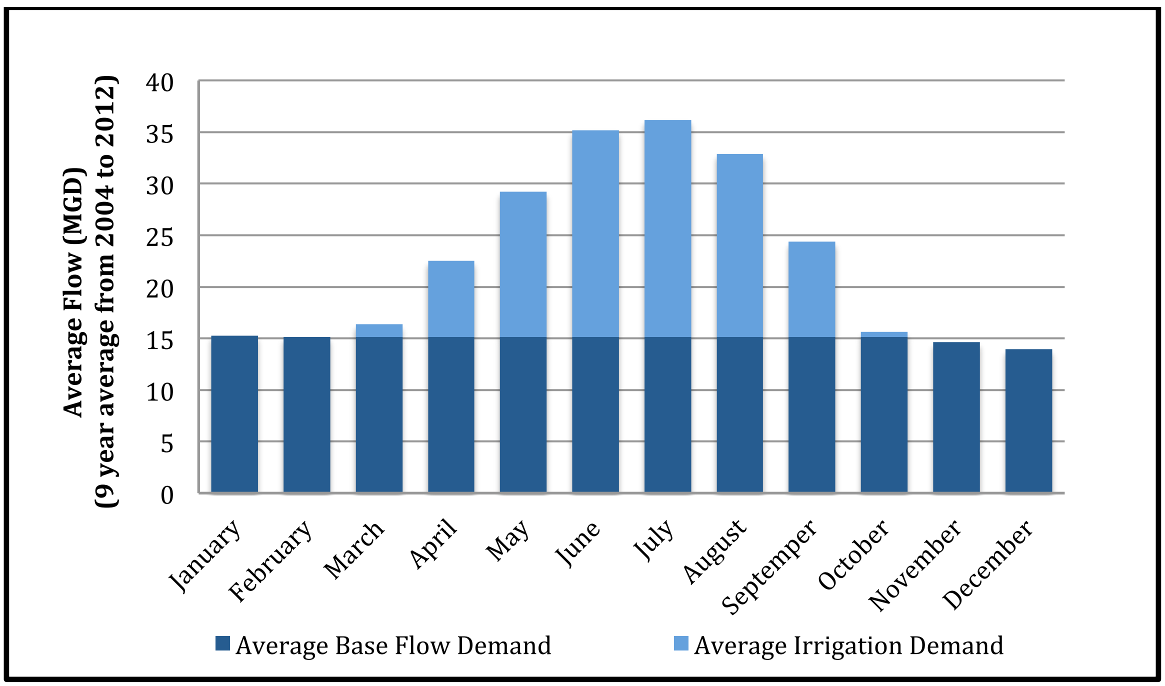


Figure 1.4 - Fort Collins Average Monthly Base & Irrigation Water Demand

Data Source: City of Fort Collins (July 19, 2013), Treated water volume, Includes Utility Service Area and West Fort Collins Water District

Fire demand

Fire demand represents a very small portion of the city's total demand, however the distribution system must be sized to meet this demand should a fire event occur. This leads to oversized distribution systems for daily demand resulting in longer distribution times than if the system was not sized for fire protection.

There are several benefits to the City by reducing the amount of treated water: 1) the City can save on energy and water treatment costs, 2) it allows the City to save the better water quality and more flexible Horsetooth sources, which can be stored, to meet potable water needs, 3) it reduces the needed capacity at the water treatment facility by decreasing the total volume treated and by eliminating the peak demands in the summer months.

iii. Improving drinking water quality

The concern with designing potable water distribution systems to also carry fire flows is that full capacity is only required during an infrequent fire event. During normal operations, the larger diameter pipes required for fire flow result in slower velocity, and a longer residence time in the distribution system. Longer residence times can lead to water quality degradation due to loss of chlorine residual, increase in disinfectant by-products concentrations, and biofilm growth. Several studies have looked at the benefits to drinking water quality by moving demand for fire protection to a non-potable distribution system (Okun, 1997; Digiano et al., 2009; Kang and Lansey, 2012). Digiano et al. (2009) found that dual distribution with non-potable for fire and irrigation demand decreased the average water age in the potable distribution system from 16.5 to 4.4 hours. Kang and Lansey (2012) found that dual distribution with non-potable for fire, outdoor, and toilet demand decreased the average water age from 11.4 to 7.2 hours.

If the City implemented a dual water distribution system alternative, it could use the existing distribution system for fire and irrigation demand and add a new potable only distribution system. The new distribution system design for potable water demand only would result in smaller pipe diameters, faster velocity, less time in the distribution system, and an improvement in potable water quality to the end user.

iv. Population Increase

The population in the FCU water service area is expected to increase by approximately 24% by 2050 from 2010 population estimates, which is an annual growth rate less than 1% (Table 1.1). While Larimer County's population is anticipated to grow between 1 to 2% annually and Weld County, directly to the east of Fort Collins, is expected to grow by more than 2.5% annually from 2010 to 2040 (Gordon et al., 2015). This is a strong motivator for regional water security. Municipalities will need to have water supplies and treatment capacity to meet this growing demand.

Table 1.1 - City of Fort Collins Water Utility Population and Water Use Projections (Dustin, 2013)

Year (1)	Utility Service (2) Area Population	WFCWD (3) Population	Total Population	Projected (4) Water Use (AF)
2010	125,000	4,000	129,000	26,500
2020	139,900	4,150	144,050	31,600
2030	147,700	4,300	152,000	34,100
2040	153,000	4,450	157,450	35,700
2050	155,200	4,600	159,800	36,500

(1) These projections come from analysis of Metropolitan Planning Organization Traffic Analysis Zone (TAZ) data and the City Planning Department's Buildable Lands Inventory. The data from these sources only projects to 2035, but reasonable estimates of additional growth have been made through 2050 which is the assumed period when the water utility's service area will be built out.
(2) The Utility Service Area includes all water utility customers that are not within the West Fort Collins Water District (WFCWD) or the Fort Collins Loveland Water District (FCLWD) agreement area.
(3) The WFCWD growth is based on a total increase of 15% between 2010 and 2050.
(4) Projected water use is calculated as the total population times the indicated use rate in gallons per capita per day (times associated conversion factors) plus large contractual use (LCU), all divided by 0.97 to consider a 3 percent loss upstream of the treatment plant. The LCU increases from 4,000 to 8,510 acre-feet to the indicated rate similar to the other use.

The expected population increase in the City and Larimer County is higher than that expected in the FCU. The area in FCU is mostly developed with little area available for new development. Growth in the FCU service area is focused on higher density redevelopment. Higher density development could increase potable demand and a dual distribution system would free up capacity in the existing potable distribution system to meet this demand. Alternatively, if the existing system is used for non-potable demand, then the new potable distribution system can be designed to meet this additional demand.

There are plans for new development in Fort Collins, however, this new development tends to be outside the FCU service area in the Elco and Fort Collins Loveland Water Districts (Figure 1.5) The FCU water treatment facility has the capacity to meet future population demands in the service area. This may not be true of neighboring water districts that are anticipating higher annual population growth rates and may not have the spare capacity needed to support growing demand. This presents an opportunity to take a more regional approach to solving water resource problems in the future. Currently, the City has some water sale and exchange agreements with other surrounding water districts, such as the West Fort Collins Water District (WFCWD) and the Fort Collins-Loveland Water District. By not treating water for irrigation, FCU will reduce the needed capacity at the water treatment facility by decreasing the total volume treated and by eliminating the peak demands in summer months. This additional capacity could be used for the sale of water to surrounding water districts and facilitate further cooperation with surrounding water districts.

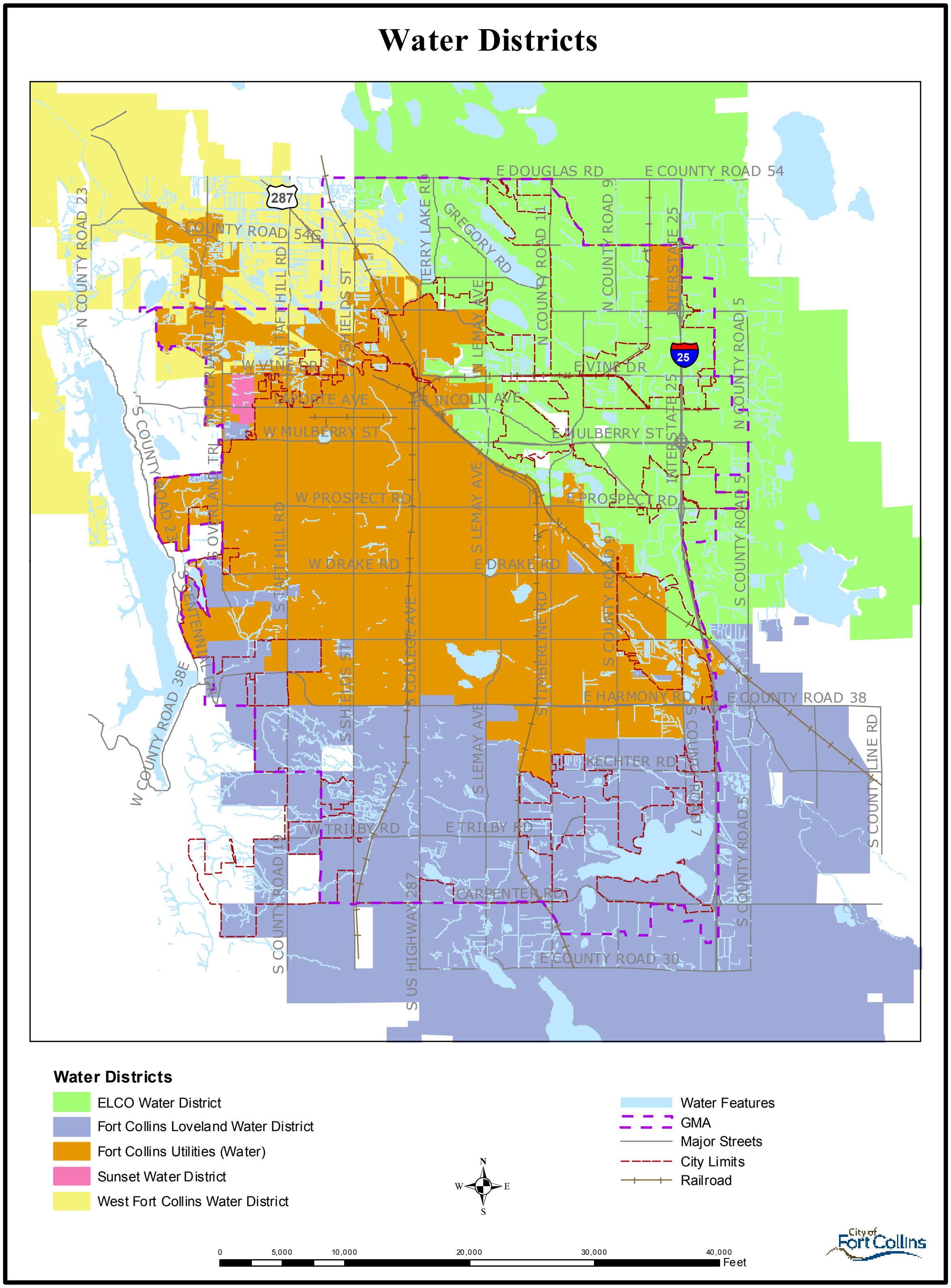


Figure 1.5 - Water Districts in Fort Collins

v. Responding to climate change

Evidence shows that anthropogenic greenhouse gas emissions have increased since the pre-industrial era and concentrations of greenhouse gases (GHGs), such as, carbon dioxide, methane, and nitrous oxide, in the atmosphere are the highest ever in at least the last 800,000 years. These concentrations have been driven by economic and population growth and are extremely likely to be the cause of the observed global warming since about 1950. (IPCC, 2014)

The recently published Colorado Climate Change Vulnerability Study found Colorado's average annual temperatures are projected to increase by 2.5 to 5 ^{o}F by 2050 relative to a 1971-2000 baseline and peak spring runoff is projected to happen 1-3 weeks earlier by the mid-21st century (Lukas and Gordon, 2015). In response to climate change, the City has recently established aggressive sustainability goals to reduce City carbon emissions by 20%, from 2005 levels, by 2020 and 80% by 2030 with the goal of reaching carbon neutral by 2050 (City of Fort Collins, 2015). A dual distribution system where irrigation demand is moved to a non-potable system would result in treating less water. This not only reduces energy and treatment costs because of a reduction in volume, but by prioritizing the better quality water sources for potable use it would reduce the amount of chemicals and energy needed to treat the water.

While the City has set important goals to reduce its impact on the environment, it must also prepare for an uncertain water future in the face of climate change. Currently, Fort Collins has limited man-made storage capacity of its own and depends primarily on a robust snow pack or storage in the Colorado – Big Thompson (C-BT) system to provide water during peak demand in the summer due to irrigation demands. Climate change threatens to potentially reduce snowpack or the timing of the snowmelt, which could threaten the utilities' ability to meet water demand in the peak months. A more resilient infrastructure would provide the utility with the additional flexibility required to respond to changing water availability and demand patterns.

A dual water distribution system would improve infrastructure resiliency by enabling the City to maximize use of their water resources and by providing multiple distribution paths to residents in case of a catastrophic failure in one of the systems. Currently, Fort Collins water supply comes from two main surface water sources: Horsetooth Reservoir and the Cache la Poudre (CLP) River. The water in Horsetooth Reservoir is from the C-BT project. This water is the most flexible because it has better quality in the spring runoff period, can be reused, and it can be stored until needed later in the season. The City also owns a variety of direct flow water rights in the CLP river and shares in several irrigation companies. Only a portion of the City's CLP direct flow water is used during the 6 to 8 week runoff period because high levels of total organic carbon (TOC) and turbidity, in the CLP during this period, results in higher water treatment costs (City of Fort Collins, 2010). A dual distribution system would allow the City to maximize their use of the CLP sources by diverting this water for irrigation use; leaving more Horsetooth sources for potable demand and irrigation later in the summer; and reduce water treatment costs during the runoff period by using the better quality Horsetooth source for potable demand rather than a blend of the two sources.

b. Project Objective

In response to these drivers, the utility is evaluating the potential of dual distribution systems to help meet these challenges. The objective of this study is to evaluate different strategies for the dual distribution of raw and finished water to decrease water production and distribution costs; decrease energy use and GHG emissions; and provide more flexibility to meet future regional water demands. Dual distribution would address the project drivers in the following ways:

- Reduce water production energy use and treatment costs by reducing the volume of water treated and by extending the availability of higher quality water sources.
- Extend the seasonal availability of stored water by maximizing the use of spring runoff in the CLP River for irrigation. Currently this water is used on a limited basis due to high treatment costs.
- Increase potable water quality by reducing time in the potable distribution system.
- Reduce the capacity needed at the water treatment facility, which would allow the city to decommission older treatment trains and save on reconstruction costs; or free up capacity to sell treated water to adjacent water districts.
- Provide more capacity in the existing distribution system or provide an opportunity to design the new potable distribution system to meet increase in indoor demand due to higher density development.

This study considers the following four dual water system alternatives and compares them to the existing system: 1) centralized water treatment and dual distribution, 2) neighborhood water treatment and dual distribution, 3) non-potable distribution with Point-of-Entry (POE) water treatment, and 4) raw water irrigation from the City network of irrigation ditches.

A triple bottom line (TBL) analysis will be used to evaluate the economic, social, and environmental benefits of the existing system and all four alternatives. A set of criteria will be evaluated from an economic, social, and environmental perspective. A multi-criteria decision analysis (MCDA) tool will be used to combine quantitative and qualitative performance metrics to obtain a TBL.

A brief summary and schematic for the existing system and the four alternatives considered in the study follow.

i. Existing System – Centralized water treatment and potable distribution system

Fort Collins' current water supply system consists of a centralized water treatment facility where all municipal water demand is treated to drinking water standards. The water treatment plant provides conventional treatment consisting of rapid mix coagulation, flocculation, sedimentation, dual-media filtration, disinfection and chemical stabilization. Fort Collins' water supply comes from two main surface water sources: Horsetooth Reservoir (C-BT project water) and the CLP River. Water from the CLP undergoes pre-sedimentation before it is blended with Horsetooth water at the treatment facility. Finished water is then distributed to the end user via a potable water distribution system (Figure 1.6).

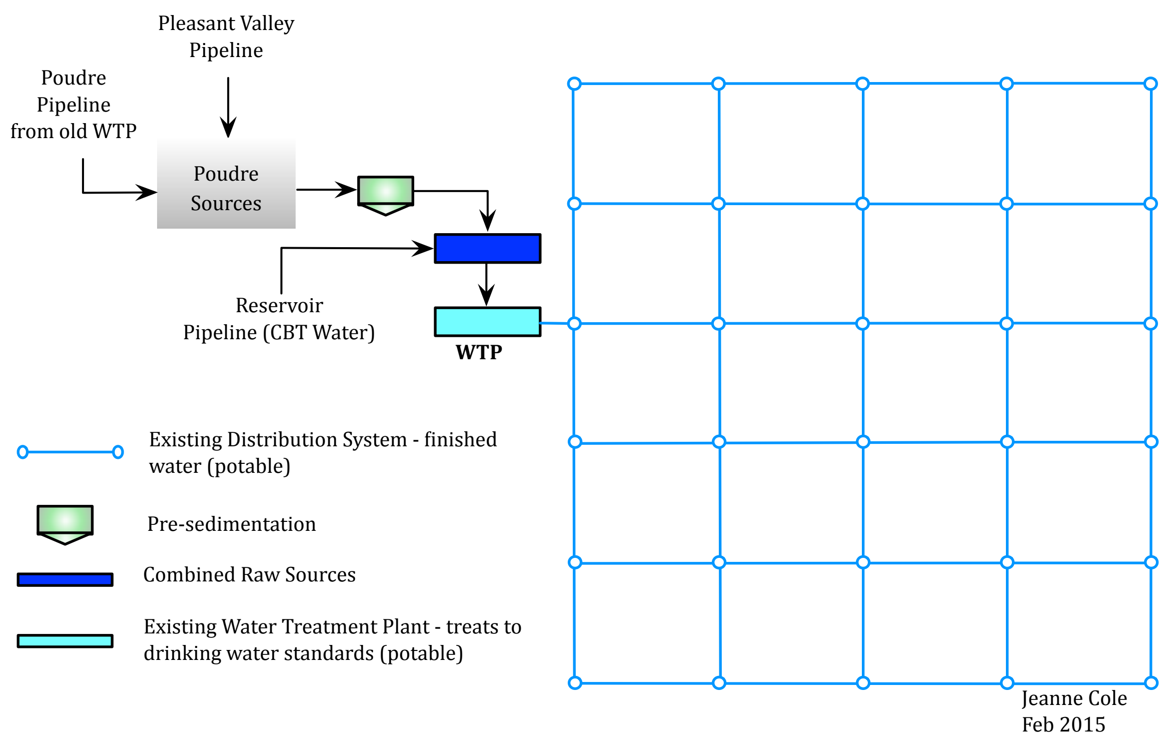


Figure 1.6 - Existing System
Centralized Water Treatment and Potable Distribution System

ii. Central/Dual Alternative – Centralized water treatment with a dual water distribution system

In the Central/Dual alternative, the existing centralized water treatment facility is still used to treat water for potable uses and then a dual distribution system delivers raw and finished water separately to water customers (Figure 1.7). The existing distribution system and transmission lines are used to distribute the raw (non-potable) water for fire flow and irrigation. New potable distribution system and transmission lines are installed for the delivery of finished water for potable demand. Raw water from the CLP River will still undergo pre-sedimentation and then be filtered, at the existing facility via a new raw water filtration system, prior to being distributed through the non-potable distribution system.

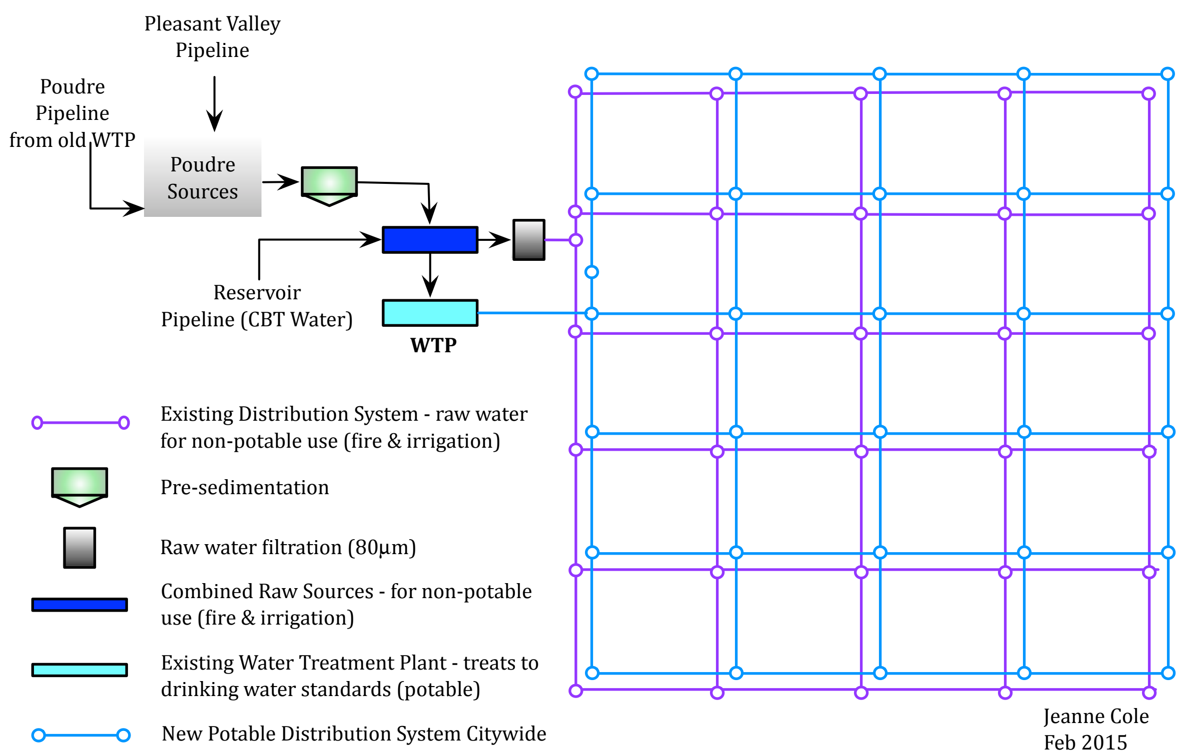


Figure 1.7 – Central/Dual Alternative
Centralized Water Treatment and Dual Distribution System

iii. Neighborhood Alternative – Neighborhood water treatment and dual distribution system

In the Neighborhood alternative, blended raw water is filtered through a new raw water filtration system at the central facility and is transmitted to neighborhoods via the existing transmission lines. Raw water for fire flow and irrigation will continue to be distributed via the existing neighborhood distribution system. Water for potable demand will be treated at new neighborhood water treatment facilities and then distributed via a new potable only distribution system (Figure 1.8).

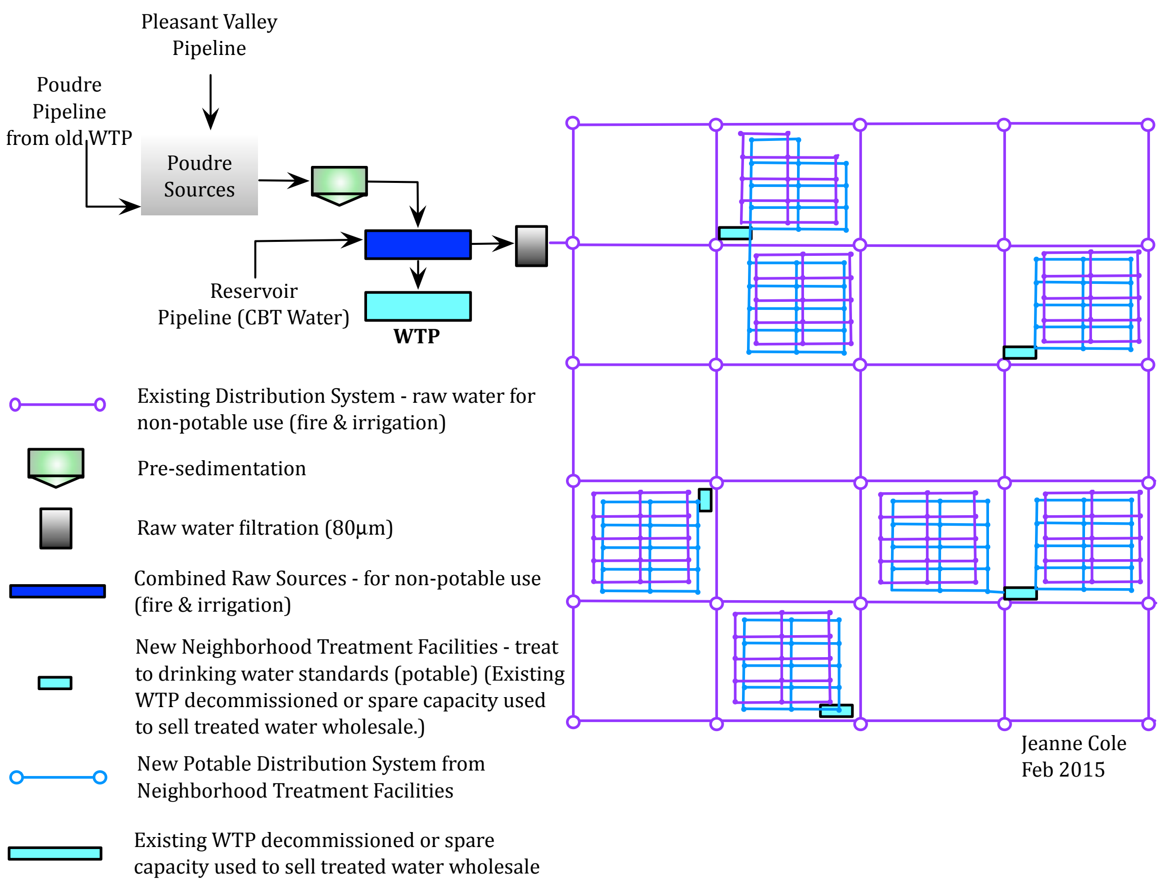


Figure 1.8 – Neighborhood Alternative
Neighborhood Water Treatment and Dual Distribution

iv. Point-of-Entry Alternative – Raw water distribution with Point-of-Entry (POE) Water Treatment

In the Point-of-Entry alternative, blended raw water is filtered through a new raw water filtration system at the central facility and distributed through the existing distribution system. At the service connection, raw water is diverted to the irrigation system and water for potable consumption will undergo treatment at a new household POE treatment system to meet drinking water standards (Figure 1.9). Fire flow will continue to be connected to the existing distribution system where raw water will now be used for fire flow.

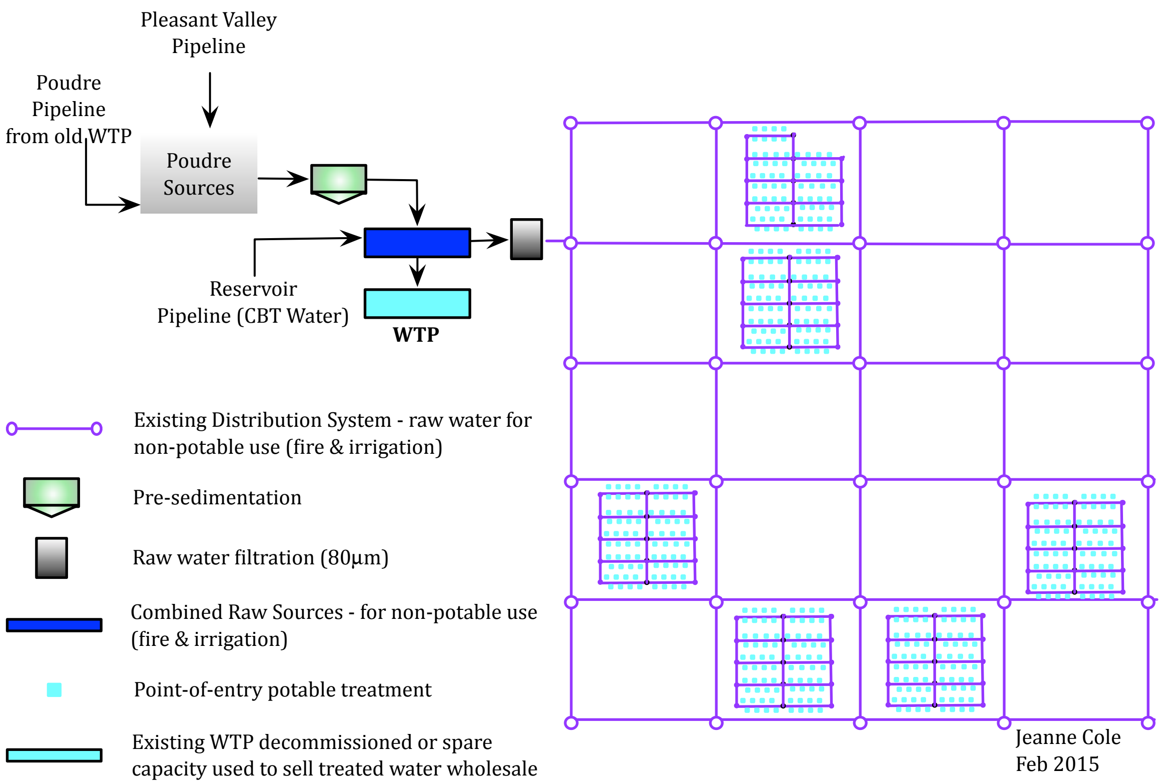


Figure 1.9 – Point-of-Entry Alternative
POE Water Treatment and No Dual Distribution

v. Separated Irrigation Alternative – Landscape irrigation with raw water from city network of irrigation ditches

The Separated Irrigation alternative takes advantage of the City's extensive network of irrigation ditches (Figure 1.10). These ditches and the CLP River provide a network of water corridors that have become an integral part of the city. They provide water for irrigation to city parks and local farmers, creating natural areas, and a habitat for wildlife. Raw water from these ditches is already currently used to irrigate a majority of the City's parks and golf courses, Colorado State University, and some local businesses and HOAs. These water corridors offer an opportunity to provide raw water irrigation for other landscape irrigation needs around the City rather than using treated water.

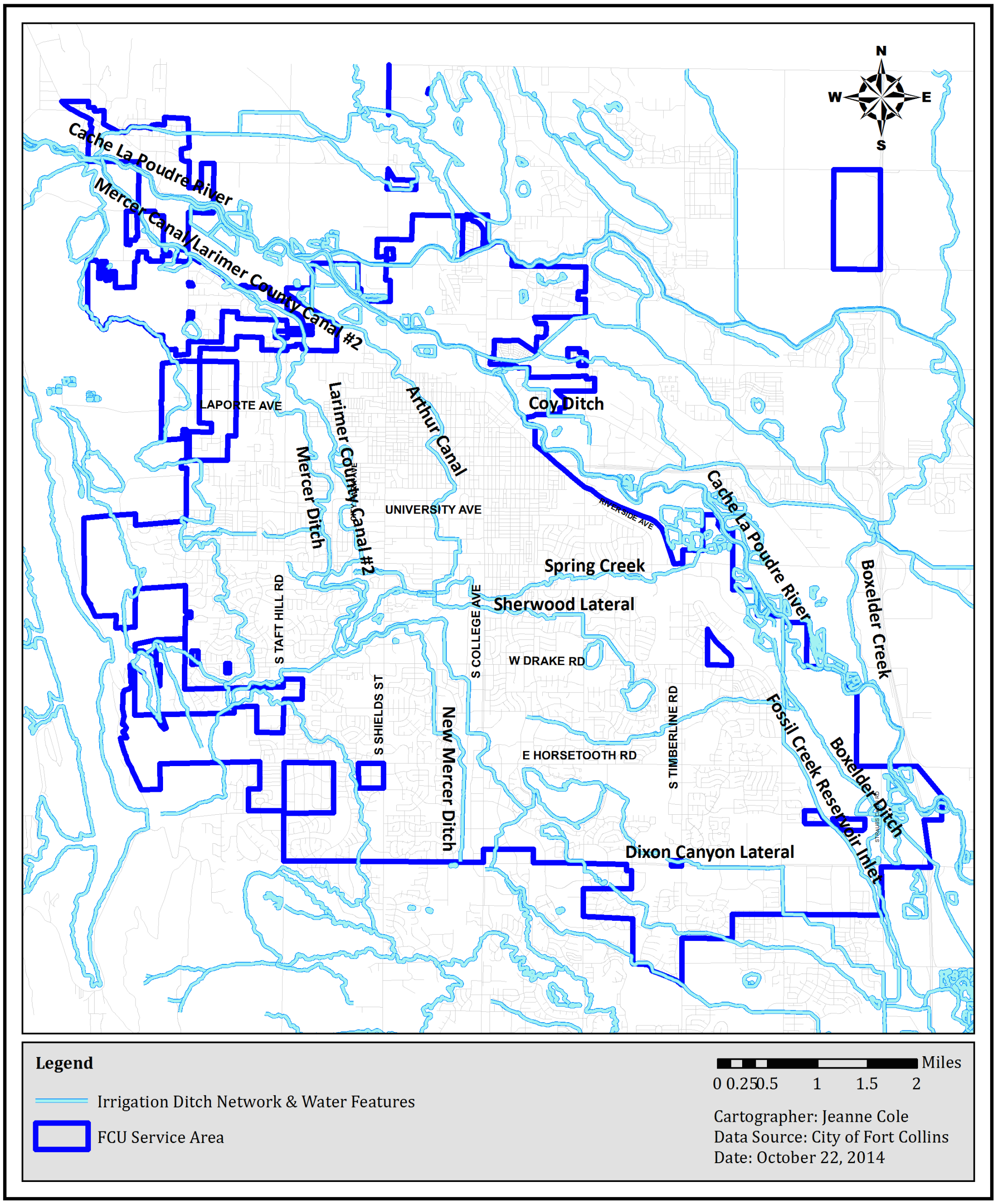


Figure 1.10 - Fort Collins Water Corridors

In the Separated Irrigation alternative, water for fire flow and potable demand will continue to be treated to drinking water standards at the central water treatment facility and then distributed via the existing potable transmission and distribution pipelines (Figure 1.11). New raw water neighborhood irrigation systems will be installed to withdraw raw water directly from the network of irrigation canals throughout the City. The new raw water irrigation systems will include a pump house with a raw water filtration system and a new raw water distribution system.

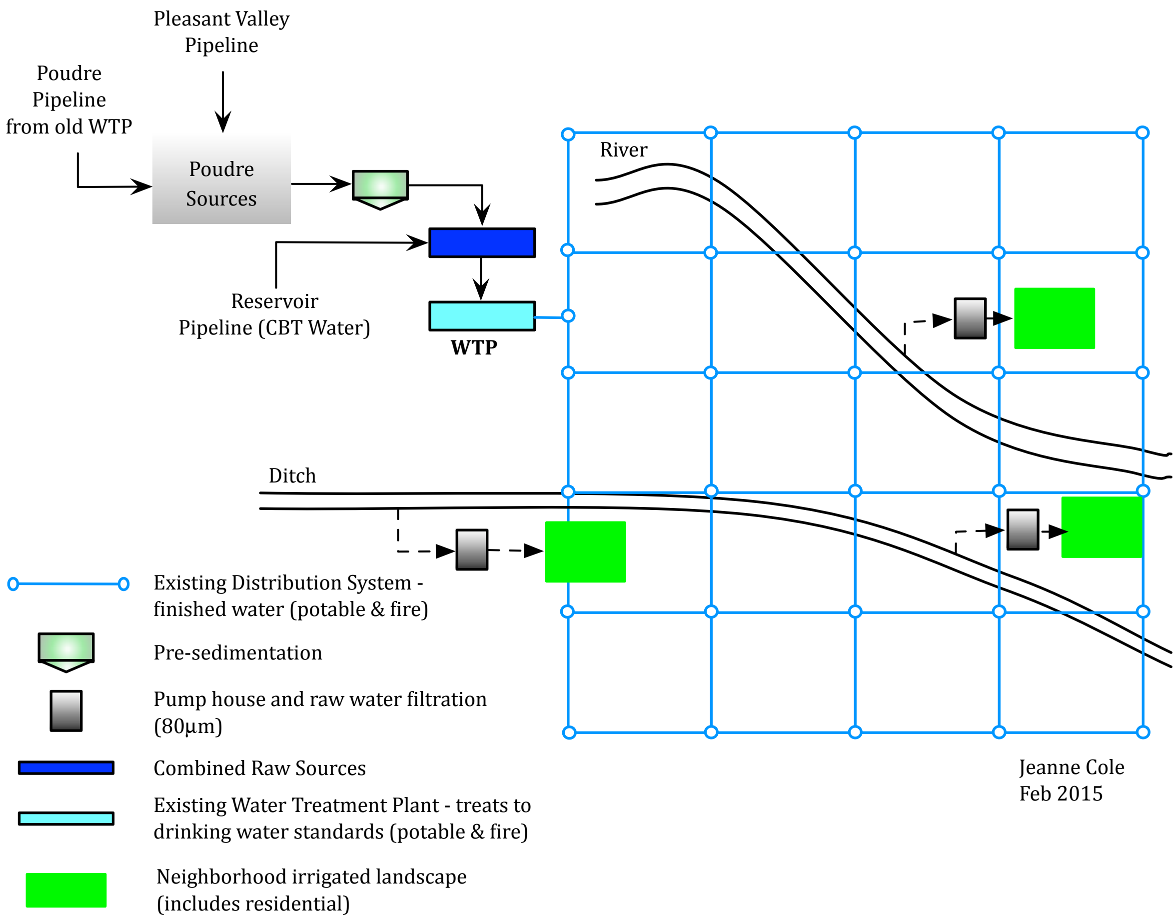


Figure 1.11 – Separated Irrigation Alternative
Landscape Irrigation with Raw Water from City Ditch Network

II. Methodology

Figure 2.1 summarizes the overall approach taken to evaluate the alternatives and the existing system.

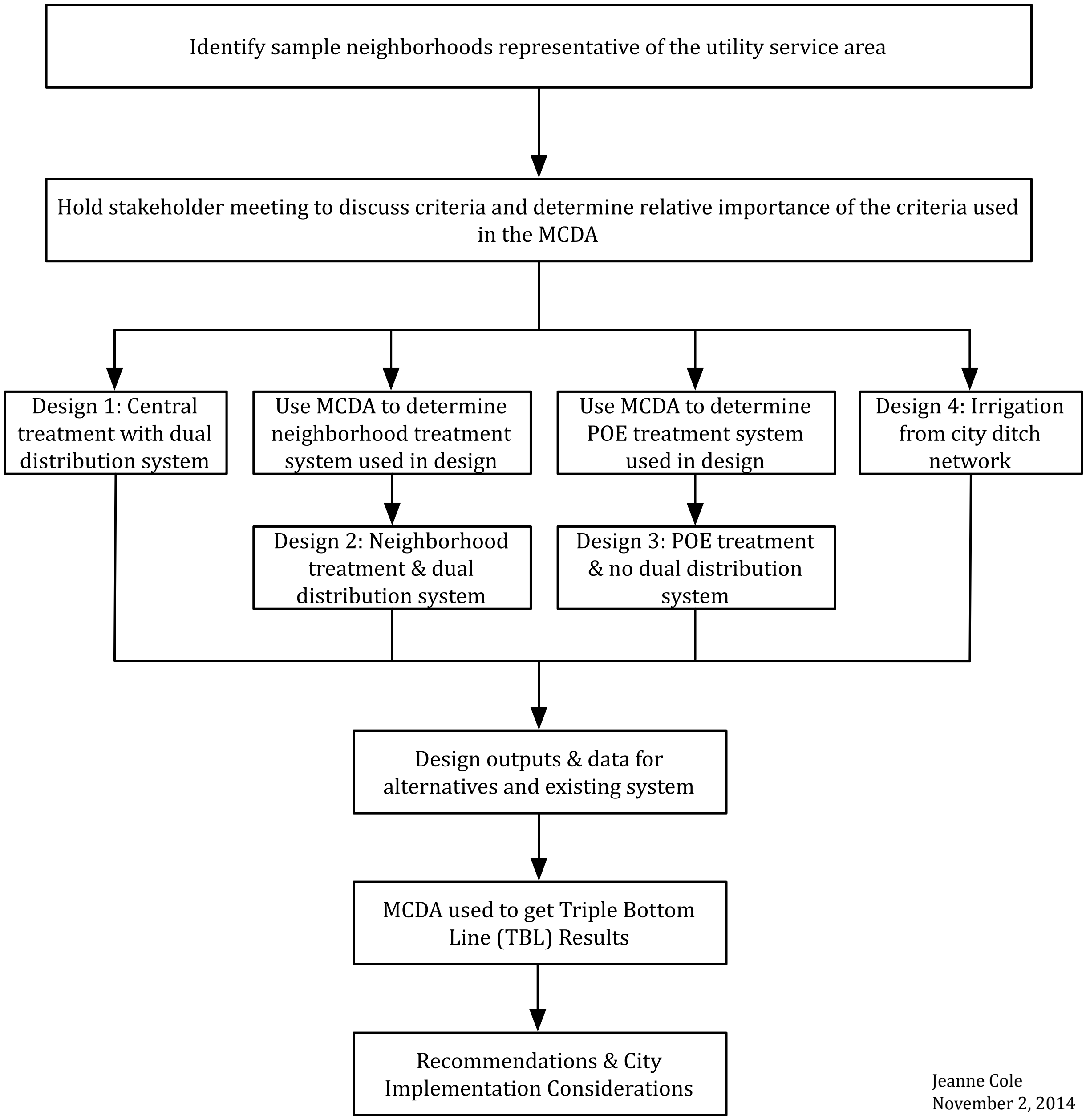


Figure 2.1 - Overall Approach

a. Sample Neighborhood Selection

Fort Collins has grown in three distinct eras over the last hundred years and, as a result, the city is made up of neighborhoods that vary in land use type, layout, lot sizes, water demand, and pipe materials used in the construction of the existing distribution system. Three sample neighborhoods, of 1-square mile, were chosen to model the alternatives and determine if there was a single ideal solution for the entire city or if the ideal solution varied by neighborhood. The neighborhoods were selected to represent the three distinct development eras, the most common land use types, neighborhoods with HOAs, and areas with high, low, and average pipe failure rates. Once the sample neighborhood locations were determined, then the following neighborhood characteristics were determined: average lot sizes, average lawn area, and water demand.

Development Era

There are three main development eras in Fort Collins. Fort Collins was a small town of about 25,000 people in 1960 and the City consisted of old town and the surrounding neighborhoods (City of Fort Collins, 2011). 1960 to the late 1990s saw an expansion of low-density residential neighborhoods and commercial corridors. After 1997, the city moved to more mixed-use developments, which focuses on more compact lot sizes, the integration of services, public facilities, and infrastructure to establish a well-defined community. Each of the sample neighborhoods selected represents one of these development eras.

Land Use Type

It was determined that the three main factors that affect design are the density of the service connections, the total demand per connection, and the proportion of the total demand that is used for irrigation. All three of these factors are a function of the land use type. The City of Fort Collins Zoning Data was used to determine the land use types most representative of the utility. A summary of land use types represented in the FCU service area is provided in Figures 2.2 and 2.3.

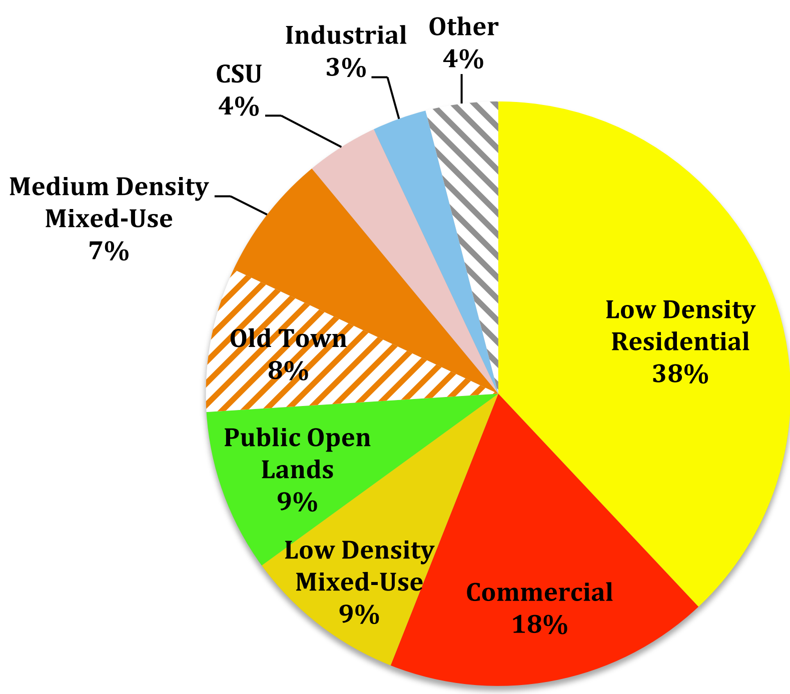


Figure 2.2 - Land Use Types Represented in FCU Service Area

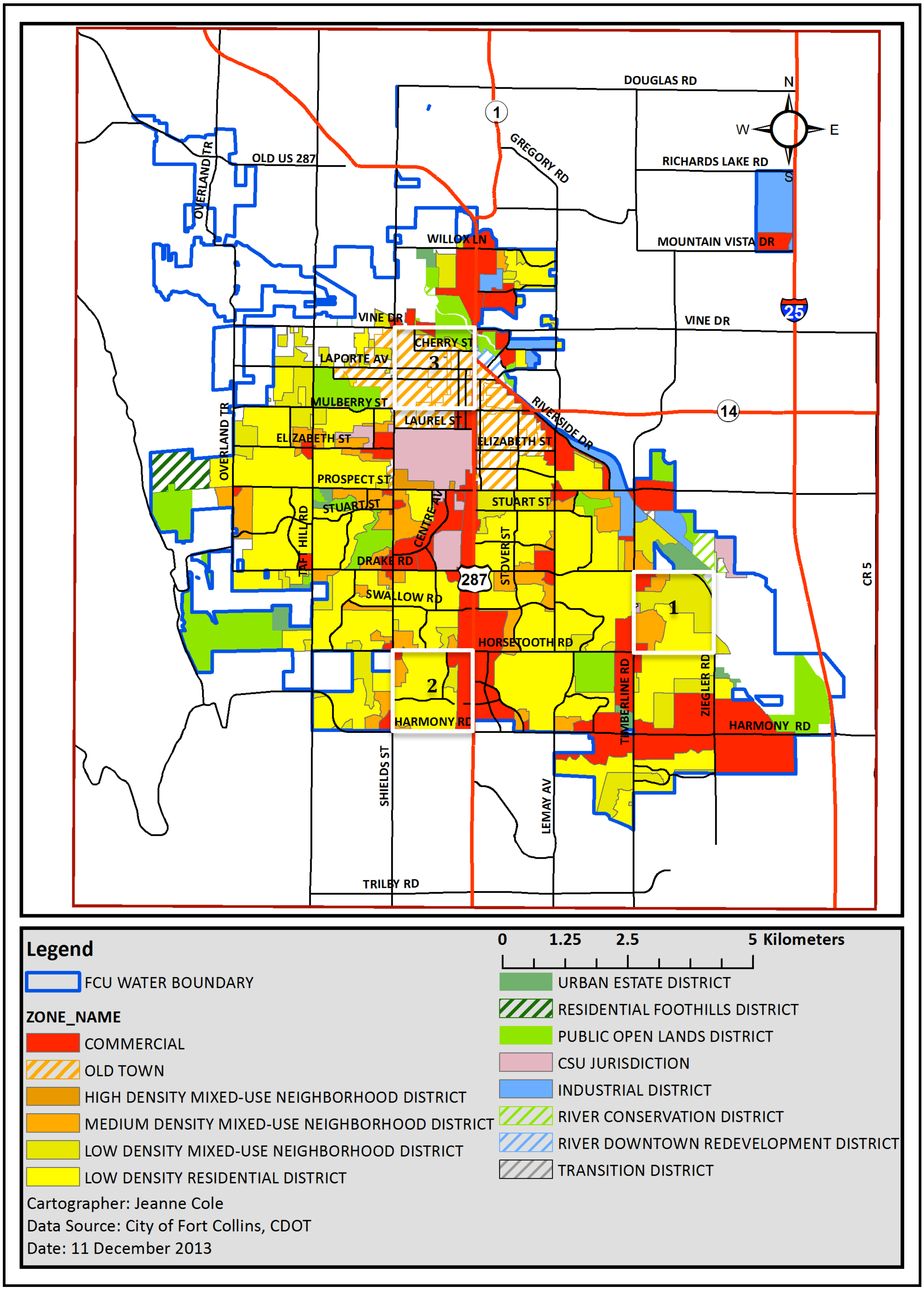


Figure 2.3 - Land Use Map of the Fort Collins Utility Water Service Area

ArcGIS10 and the NAD83 UTM Zone 13N coordinate system was used to create the land use map. All imported data was projected to the project coordinate system using the ArcGIS Projections and Transformations tool. The City of Fort Collins zoning layer was clipped to the FCU service area using the Geoprocessing Clip tool, a new attribute field was created for area, and the Geometry Calculator was used to calculate the area of the land use types. All the commercial and employment zones were combined to create one commercial land use type. Because the Old Town area is unique in its layout, an Old Town land use type was created to combine the downtown and the three neighborhood conservation zones.

It is important to note that approximately 80% of parks, golf courses and cemeteries (Public Open Lands) are already irrigated with raw water with future plans to increase this percentage (Whirty, 2013) and 95% of Colorado State University is irrigated with raw water (CSU Facilities Management, 2013). Therefore, these two land use types were excluded from the neighborhood selection. The top five land use types that represent the FCU service area are Low Density Residential, Commercial, Low Density Mixed-Use, Old Town, and Medium Density Mixed-Use in order of area represented. These five land use types represent 80% of the zoned service area and CSU and Public Open Lands represent another 13% that are already mostly irrigated with raw water. Our neighborhood selection included these top five land use types, which leaves only 7% of the service area unrepresented.

Home Owners Associations (HOAs)

It was important to include sample neighborhoods with HOAs as they tend to be large water users for the irrigation of green spaces. In the older neighborhoods, there are no HOAs. There are some HOAs in neighborhoods built after 1960 and most new neighborhoods have HOAs. In the selection of the neighborhoods, outside of old town, an effort was made to include neighborhoods with HOAs (Figure 2.4).

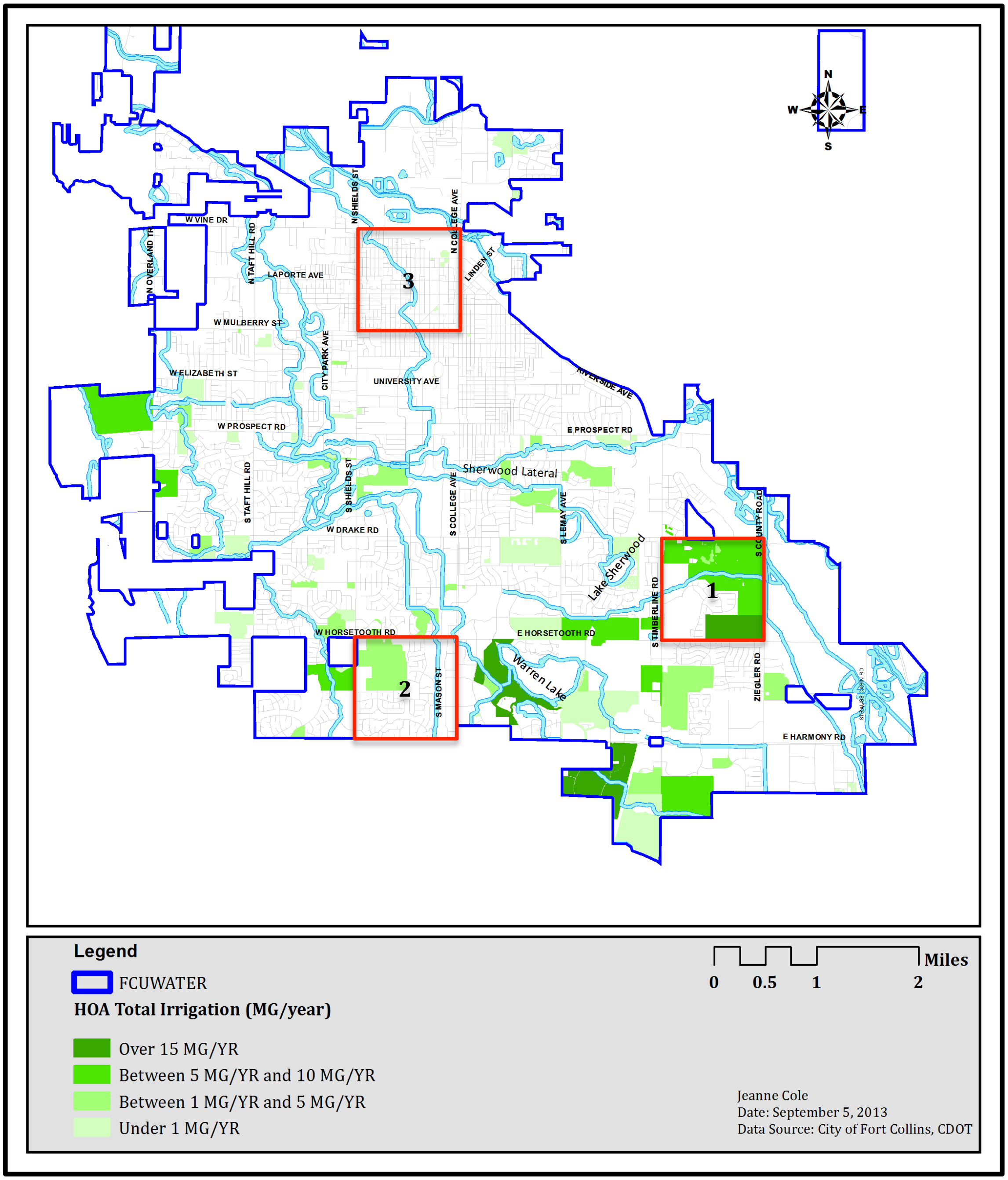


Figure 2.4 - Fort Collins Utility HOA Water Use

Pipe Service Life

Different pipe materials have different service lifetimes. The pipe material used in construction of the distribution system depends on the era in which an area was built or when infrastructure was replaced. Cast Iron Pipe (CIP) was predominately used until the 1970s when the City moved primarily to Ductile Iron Pipe (DIP) in the distribution system. The City started using PVC pressure pipe in its distribution system in the 1980s due to a lower service lifetime in CIP and DIP due to external corrosion. Identifying the areas where the City has high pipe failure rates was important to determine areas of future infrastructure replacement for implementation (Discussion Section 4.d) and to estimate the remaining lifetime of the existing infrastructure for estimating reconstruction costs. The three neighborhoods were selected to include a neighborhood with low pipe failure rates, a neighborhood with a mix of low and high pipe failure rates and a neighborhood with high pipe failure rates. Figure 2.5 shows the distribution system pipe failure rates by quarter quadrant for the City. Areas with higher than average failure rates are shown in yellow.

As previously mentioned, mixed use neighborhoods have been a focus of development since 1997. These neighborhoods typically do not have a history of distribution system failures because they are less than 20 years old. A soils map of the service area was used in conjunction with the pipe failure data to project pipe failure rates for Neighborhood 1 (Figure 2.6).

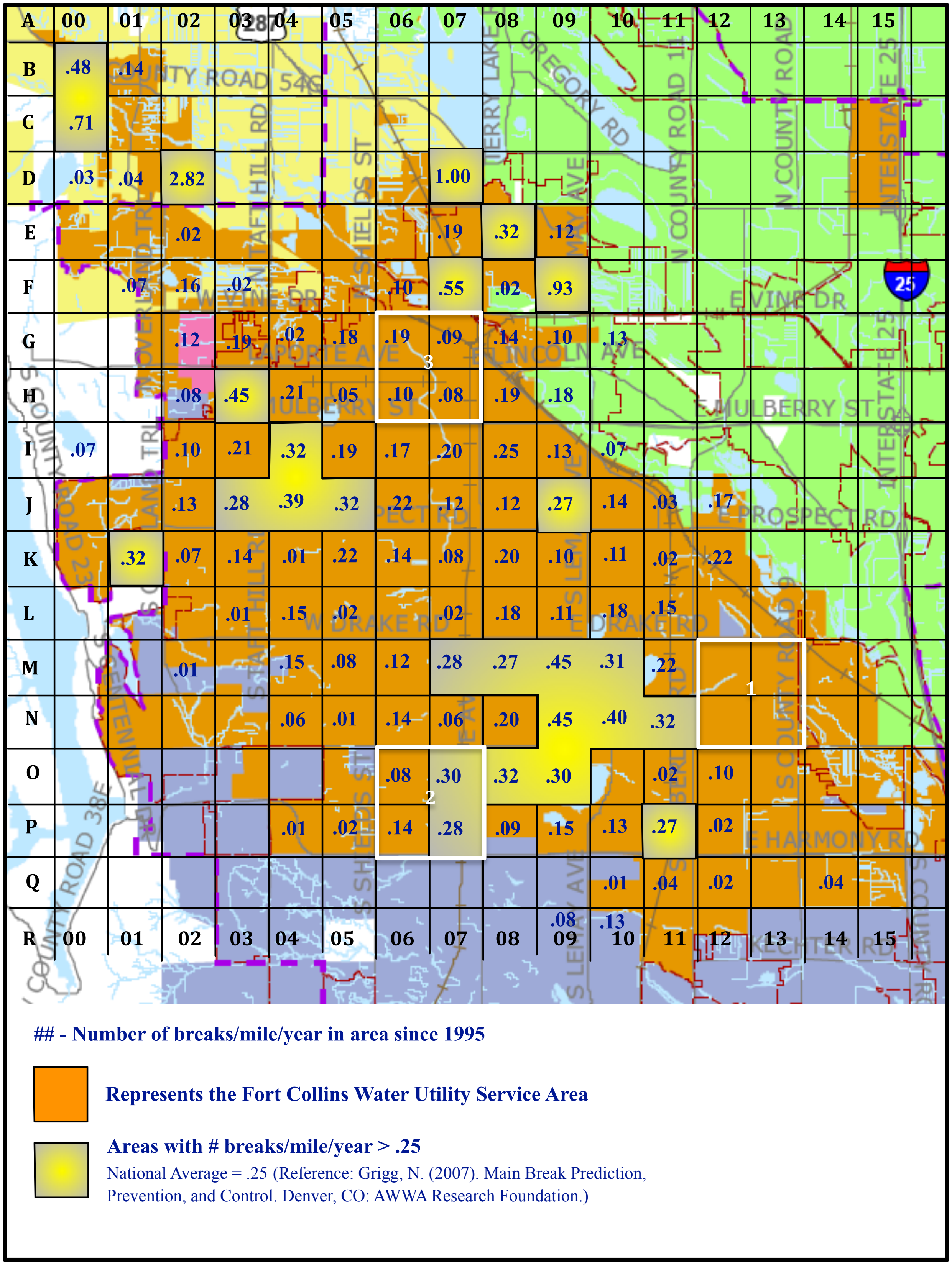


Figure 2.5 - Fort Collins Utility Distribution System Pipe Failure Rates

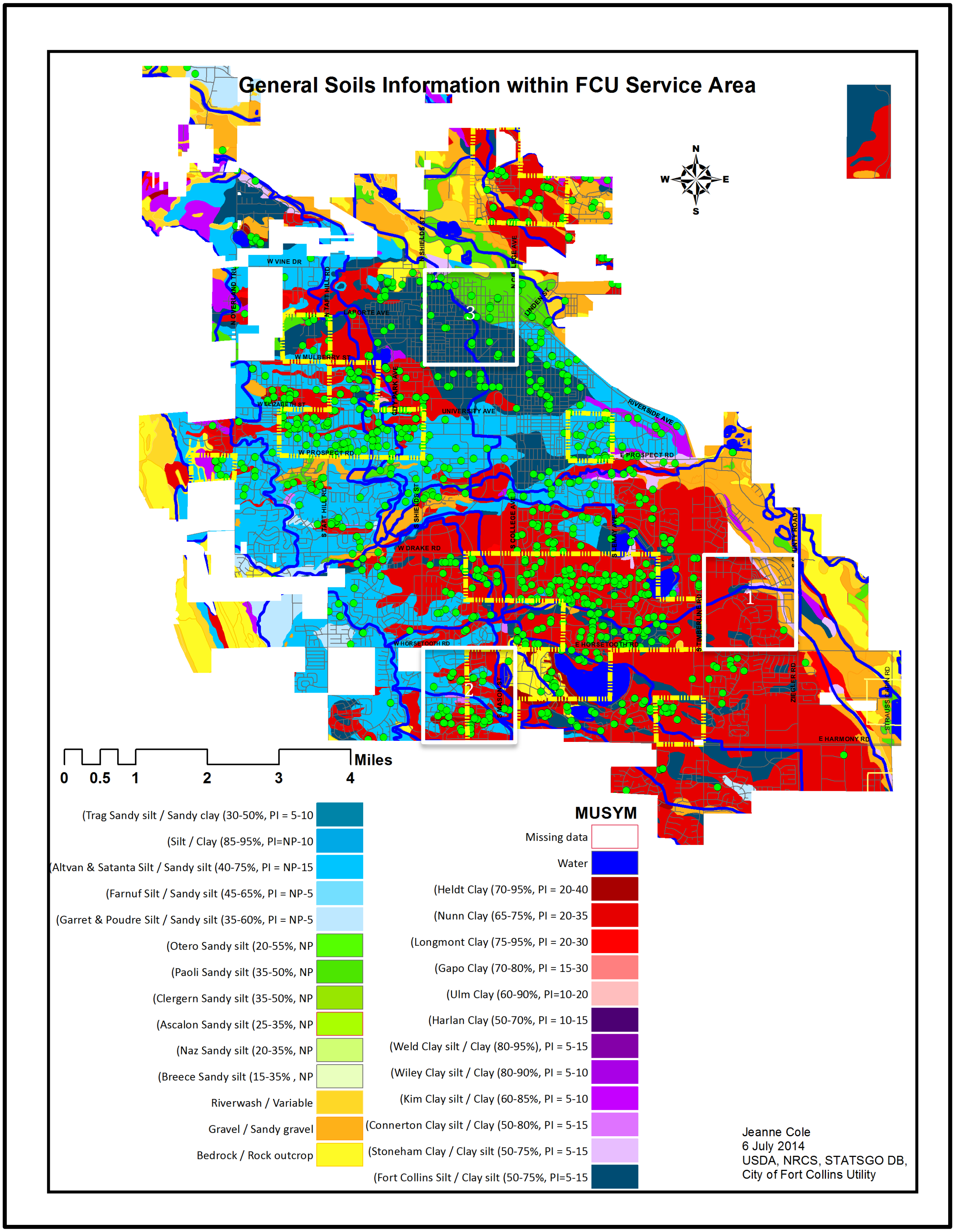


Figure 2.6 - City of Fort Collins Utility Service Area Soils Information at 5-ft Depth

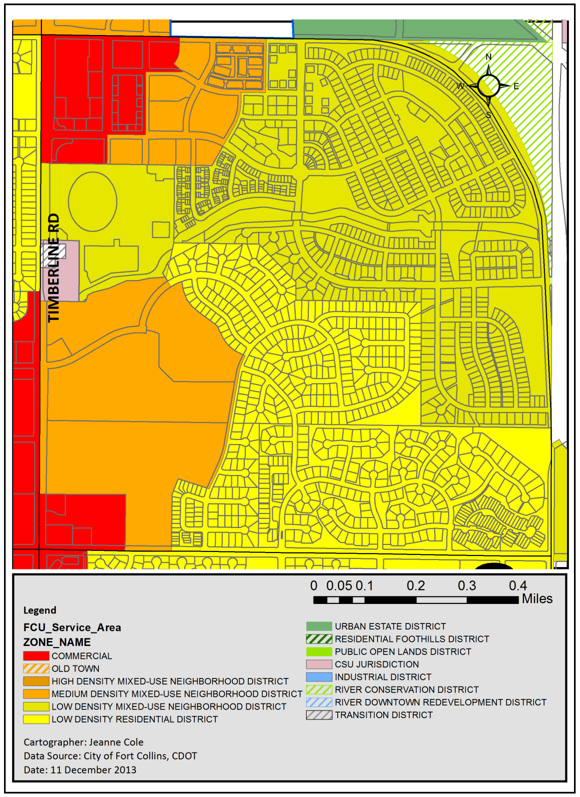
Sample Neighborhood Summary

Three sample neighborhoods of equal size, approximately 1 – square mile, were selected to represent the City. Table 2.1 and Figure 2.7 provide details on the sample neighborhoods selected.

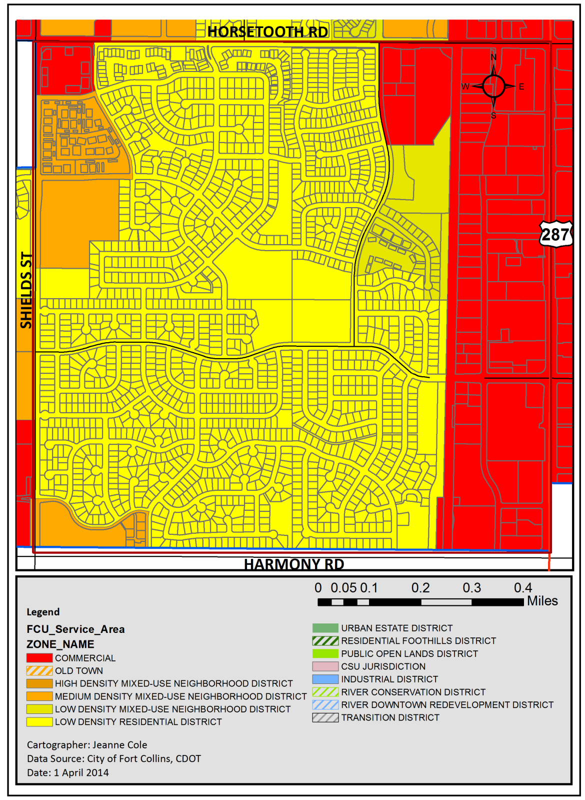
Table 2.1 – Sample Neighborhood Summary

	Neighborhood 1 **Drake to Horsetooth &** **Timberline to Zeigler**	**Neighborhood 2** **Horsetooth to Harmony &** **Shields to College**	**Neighborhood 3** **Vine to Mulberry &** **Shields to College**
Development Era	Mid 1990s +	1970s to 1990	1890 to 1950
Land Use Types **(Figure 2.7)**	50% low density or medium density mixed-use and remaining low density residential and commercial	Majority low density residential, commercial corridor along eastern boundary, with pockets of medium density mixed use	Old town comprised of downtown commercial and low and medium density conservation land use types
HOAs	Approximately 2/3 of the neighborhood has HOAs	Approximately 1/4 of the neighborhood has HOAs	No HOAs
Distribution System Information **(Details provided in Appendix A)**	16.4 miles of pipe 95% DIP and 5% PVC High failure rate Short anticipated service lifetime Average remaining life 57 years	17.1 miles of pipe 95% DIP and 5% PVC Average failure rate Average anticipated service lifetime Average remaining life 55 years	18.5 miles of pipe 75% CIP, 22% DIP, and 3% Other Low failure rate Long anticipated service lifetime Average remaining life 55 years

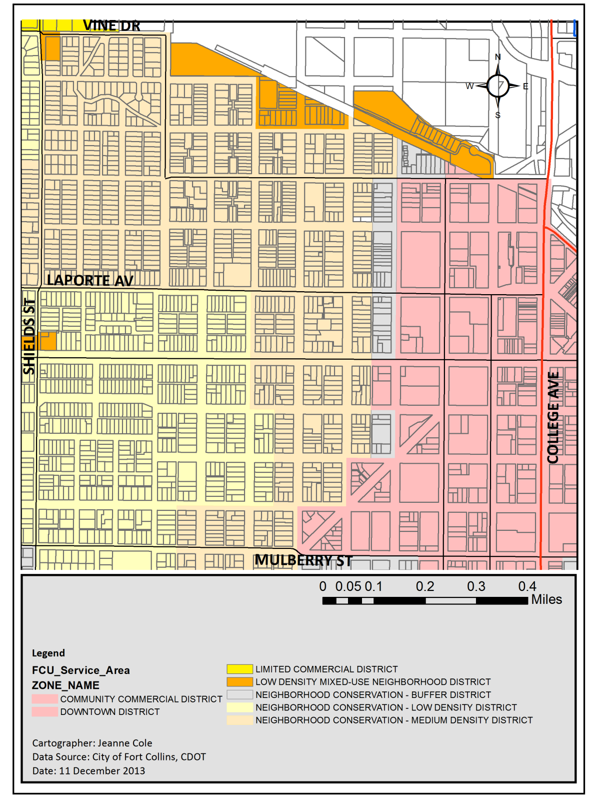
A majority of the Fort Collins Utilities service area is served by a gravity fed distribution system. For this reason, the neighborhoods selected were gravity fed neighborhoods. However, in the discussion section, high service area neighborhoods will be addressed.



Neighborhood 1: Timberline to Zeigler & Drake to Horsetooth



Neighborhood 2: Shields to College & Horsetooth to Harmony



Neighborhood 3: Shields to College & Vine to Mulberry

Figure 2.7 - Sample Neighborhoods Used in MCDA

Sample Neighborhood Characteristics

A critical component of this dual distribution study is to determine the landscape irrigation demand. Lot size, lawn area, and water demand characteristics for each of the most prominent land use types was determined. This information was important not only for neighborhood selection, but also for implementation (see discussion section 4.d) in identifying neighborhoods that use the most irrigation water.

Once again ArcGIS10 and the NAD83 UTM Zone 13N coordinate system was used. The City of Fort Collins' parcel and land cover data was used to determine the average lot sizes and the area of lawn irrigated for each type of land use. Using ArcGIS10 the parcel and land cover layers were projected to the project coordinate system and clipped to the FCU service area using the Geoprocessing Clip tool. A new attribute field was created for area and the Geometry Calculator was used to calculate parcel and land cover areas. The Geoprocessing Intersection tool was then used to intersect the clipped parcel layer and FCU zoning layer to determine the land use type of the different parcels (lots) in the service area. Table 2.2 shows a summary of the lot size and lawn area for each of the top five land use types.

Table 2.2 - Summary of Lot Size and Lawn Area for Top Five Land Use Types

Land Use Type	Average Lot Area (ft^2)	Average Lawn Area per Lot (ft^2)	Average Lawn Area as % of Total Lot Area
Low Density Residential	14,531	4,629	32%
Commercial	122,650	30,031	24%
Low Density Mixed-Use	37,297	9,795	26%
Old Town:			
Downtown Commercial	20,344	1,884	9%
Buffer Conservation	10,872	1,722	16%
Low Density Conservation	9,526	2,368	25%
Mixed Density Conservation	7,858	1,668	21%
Medium Density Mixed-Use	68,728	19,859	29%

It is important to note that for the mixed-use neighborhoods, the average area combines single family, duplex, multi-family, and commercial land use parcels. Typically, medium density mixed-use includes more multi-family buildings than low density mixed-use, which explains the larger average lot areas. Low density mixed-use includes single family, duplexes, multi-family, and commercial, which explains the larger average lot areas for low density mixed-use compared to low density residential.

Water Demand by Service Type for each Land Use

Due to the diversity of service types in mixed-use neighborhoods, it was important to calculate water demand based on customer information. Premise IDs, from the land cover data, for the different land use types were used to obtain the water demand and service type data from the Customer Information System (CIS) (Switzer, 2013). Meters are read between the 1st and 15th of the month. There is not a set schedule per service;

therefore a two-month average was taken to accommodate fluctuation. For example, February demand is the average of the data provided for February and March. Data was provided from January 2001 through August 2013. Averages were calculated for each service type under each land use type. For commercial, which contains several service sizes, a weighted average was used. The City calculates base demand by averaging the demand for months December, January, and February. This base demand represents the indoor demand. Irrigation demand was taken by subtracting base demand from the total demand for the other months. There is little fluctuation from the base demand in the months of March and November; therefore to determine the average daily irrigation demand the irrigation demand was averaged between the months of April to October.

After the average daily base and irrigation demand, for each service type in each land use type, was determined (Appendix B, Tables B.1 through B.5 for details), the number of single family, duplex, multi-family, commercial, and irrigation services were counted for each land use type in the three neighborhoods. A combination of GIS parcel data, UVIEW service line data, and Google maps was used to identify the number of services. The average base and irrigation demand calculated for each service type in each land use type (Tables B.1 through B.5) was then used to calculate the potable and irrigation water demand for each neighborhood (Tables 2.3 through 2.5 and Figure 2.6). Detailed tables showing the water demand in each neighborhood can be found in Appendix B, Tables B.6 through B.8.

Table 2.3 - Neighborhood 1 Demand Summary

Land Use Type	Service Type	# Services	Average Monthly Base Water Demand (gal/service)	Average Monthly Irrigation Water Demand (gal/service) April to October	Annual Base Demand (gallons)	Annual Irrigation Demand (gallons)
Commercial	Commercial	13	41,454	28,569	6,466,866	2,599,806
	Comm Sprinkler	6	3,514	116,226	252,984	4,881,493
Medium Density Mixed Use	Commercial	4	36,735	41,697	1,763,276	1,167,503
	Comm Sprinkler	2	6,007	220,059	144,168	3,080,823
	Multi-family	34	26,639	17,247	10,868,517	4,104,686
Low Density Mixed Use	Commercial	1	15,445	28,658	185,344	200,603
	Comm Sprinkler	11	6,007	220,059	792,922	16,944,527
	Multi-family	50	35,262	19,335	21,157,256	6,767,077
	Duplex	19	38,172	165,949	8,703,216	22,071,217
	Single	506	4,457	6,875	27,064,179	24,350,533
Low Density Residential	Single	541	5,057	7,682	32,830,044	29,091,734
	Duplex	76	7,945	7,052	7,245,840	3,751,664
	Sprinkler	4	38,172	165,949	1,832,256	4,646,572
	Total Services	***1,267***		***Total Demand (gal/yr)***	***119,306,866***	***123,658,238***
				Average Neighborhood Daily Demand (gpd)	***326,868***	***577,842***

Table 2.4 - Neighborhood 2 Demand Summary

Land Use Type	Service Type	# Services	Average Monthly Base Water Demand (gal/service)	Average Monthly Irrigation Water Demand (gal/service) April to October	Annual Base Demand (gallons)	Annual Irrigation Demand (gallons)
Commercial	Commercial	68	41,454	28,569	33,826,682	13,598,988
	Comm Sprinkler	25	3,514	116,226	1,054,100	20,339,553
Medium Density Mixed Use	Commercial	1	36,735	41,697	440,819	291,876
	Multi-family	64	26,639	17,247	20,458,384	7,726,468
Low Density Mixed Use	Multi-family	13	35,262	19,335	5,500,886	1,759,440
	Single	21	4,457	6,875	1,123,217	1,010,595
Low Density Residential	Duplex	18	7,945	7,052	1,716,111	888,558
	Single	1,453	5,057	7,682	88,172,165	78,137,944
	Total Services	***1,663***		***Total Demand (gal/yr)***	***152,292,365***	***123,753,422***
				Average Neighborhood Daily Demand (gpd)	***417,239***	***578,287***

Table 2.5 - Neighborhood 3 Demand Summary

Land Use Type	Service Type	# Services	Average Monthly Base Water Demand (gal/service)	Average Monthly Irrigation Water Demand (gal/service) April to October	Annual Base Demand (gallons)	Annual Irrigation Demand (gallons)
Commercial	Commercial	179	22,223	10,332	47,734,815	12,946,605
	Comm Sprinkler	16	3,514	204,538	674,624	22,908,251
Low Density Mixed Use	Commercial	4	15,445	28,658	741,376	802,410
	Multi-family	8	35,262	19,335	3,385,161	1,082,732
	Single	2	4,457	6,875	106,973	96,247
Conservation - Buffer	Commercial	13	16,418	14,390	2,561,265	1,309,481
	Single	85	4,493	3,831	4,582,397	2,279,162
Conservation - Low Density	Comm Sprinkler	5	2,427	36,336	145,627	1,271,760
	Single	562	4,169	5,528	28,112,457	21,747,275
Conservation - Medium Density	Commercial	15	12,309	30,183	2,215,558	3,169,212
	Comm Sprinkler	4	6,007	220,059	288,335	6,161,646
	Multi-family	1	21,431	8,451	257,177	59,158
	Duplex	12	6,429	3,305	925,777	277,625
	Single	706	4,058	4,042	34,382,339	19,976,857
	Total Services	***1,612***		***Total Demand (gal/yr)***	***126,113,881***	***94,088,421***
				Average Neighborhood Daily Demand (gpd)	***345,517***	***439,666***

Fire Flows

There are approximately 300 to 450 fire events a year. Most of these are small events that could use 50 to 1,200 gallons per event. Every 10 to 15 years a large event can occur that can require up to 1 million gallons per event (Brann, 2013). This demand is very small when compared to the 15 to 45 million gallons per day treated at the water treatment facility; therefore, fire flow demand was not included in calculating the neighborhood water demand.

The main concern for fire flows is being able to supply the capacity needed for fire fighting and not interrupt customer supply. Minimum fire flow requirements, for distribution systems meeting fire demand, is 1,500 to 2,000 gpm at 20 psi for residential and commercial respectively (Buffington, 2013). This required capacity is what determines the size of the existing water distribution system in the city. Fire flows were not considered in the design of the new distribution systems because in all alternatives considered, it is assumed the existing distribution system will still provide water to meet fire demand.

b. Triple Bottom Line (TBL)

i. Fort Collins TBL Qualitative Method

The City uses a TBL approach for future planning and decision-making to ensure comprehensive consideration of all the benefits and tradeoffs associated with a project from an economic, human (social), and environmental perspective. The City's current TBL tool is a solely qualitative analysis based off the City of Olympia and Evergreen State Sustainability Action Map. This is a very useful tool in making sure all benefits and tradeoffs are considered, even if they are difficult to quantify.

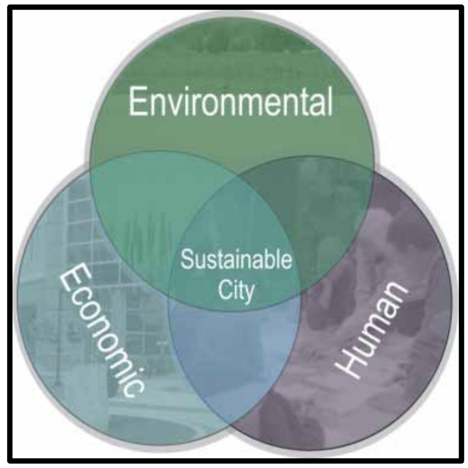


Image 2: Fort Collins' sustainability model from the City Plan (City of Fort Collins, 2011)

It was important the utility remain consistent with the TBL approach to decision making on this project. However, one of the drawbacks of the current TBL tool is that it only allows for a qualitative analysis and there is no common scale that results in a bottom line. The current tool provides a list of strengths, limitations, and opportunities from an economic, social, and environmental perspective. The utility wanted a tool that would allow for a comprehensive TBL approach, but would also result in a triple bottom line to facilitate the decision making process.

When conducting a comprehensive triple bottom line analysis, it is difficult to keep to one common unit, such as cost, or even quantify all the pros and cons of the alternatives considered. Most often alternatives are compared on a combination of qualitative and quantitative performance metrics. Without a common unit of measure or scale by which to evaluate all the performance metrics, a bottom line cannot be achieved. Additionally, most decisions involve several different stakeholders who place different levels of importance on different performance metrics and it is important to see how alternatives might be ranked differently based on different stakeholder priorities. To address these issues, a Multi-Criterion Decision Analysis (MCDA) approach was taken to compare the alternatives with the existing system to achieve a TBL.

ii. Multi-Criteria Decision Analysis (MCDA) Tool

MCDA is a systematic and transparent process for analyzing different alternatives. Alternatives are evaluated on a set of criteria and a common scale to provide an overall score for each alternative at the end of the analysis. A MCDA tool, developed by Darrell Fontane and Sybil Sharvelle at Colorado State University, was adapted to allow for a TBL analysis of the alternatives considered in this project. The tool allows for assigning relative importance factors to different criteria and sub-criteria allowing for different weighting of the criteria based on the priorities of different stakeholders. The tool uses the Weighted Average Method (WAM) in the decision analysis. The WAM is similar to a grading scale where the overall score for each alternative is achieved by the sum product of the ratings assigned to an alternative for each criterion and the relative importance (weight) assigned to each criterion.

There are four main components to the MCDA:

1. **Alternatives considered** - For this project, the alternatives considered are the existing system (Existing), centralized water treatment and dual distribution (Central/Dual), neighborhood water treatment and dual distribution (Neighborhood), raw water distribution and POE water treatment (Point-of-Entry), and landscape irrigation using raw water from the City's irrigation ditch network (Separated Irrigation).
2. **Criteria** - For this project, a set of main criteria was determined and then performance metrics for each bottom line were defined for each criterion.
3. **Ratings** - A scale is defined to rate how each alternative performs for each performance metric (or criterion). For this project, a scale of 1 to 5 was used, with 5 representing the best performance. For qualitative performance metrics, word scales are used to assign a rating between 1 and 5. Table 2.6 provides an example of a qualitative performance metric.

Table 2.6 - Example of Ratings Assigned to Alternatives for a Qualitative Performance Metric

Performance Metric	Existing	Central/Dual	Neighborhood	Point-of-Entry	Separated Irrigation
Potential health risk from a cross-connection failure	Low Risk	Moderate Risk	Very High Risk	Very Low Risk	Moderate Risk
	4	3	1	5	3

For quantitative performance metrics, a rating of 5 is assigned to the best performing alternative and 1 assigned to the worst performing alternative. Then linear interpolation is used to determine the ratings of the other alternatives. Table 2.7 provides an example of a quantitative performance metric.

Table 2.7 - Example of Ratings Assigned to Alternatives for a Quantitative Performance Metric

Performance Metric	Max/ Min	Existing	Central/Dual	Neighborhood	Point-of-Entry	Separated Irrigation
Chemical, media, filters, repairs for water treatment	Min	$171,128	$160,368	$149,659	$474,993	$160,368
		4.74	4.87	5	1	4.87

4. **Relative Importance (Weighting)** - Stakeholders assign relative importance factors to the criteria and performance metrics based on their priorities. For this project, a scale of 1 to 5 was used to rate the criteria, with 5 representing highest importance to the stakeholder. The scale used was:

   1 = Not Important

   2 = Somewhat Important

   3 = Important

   4 = Very Important

   5 = Most Important

   The relative importance factor assigned to each criterion is divided by the sum of the relative importance values assigned to the main criteria for that bottom line providing a normalized weight for each criterion. Performance metrics, for each criterion, were weighted equally.

The previously developed MCDA tool was adapted in the following ways for this project:

- Only the WAM was used in the analysis.
- Expanded to include criteria relative importance factors for up to eight stakeholder groups.
- Expanded the data input table to include three input tables for economic, social, and environmental performance metrics.
- The results output sheets were expanded to provide TBLs for:
  - Equally weighted criteria – All criteria were assigned a relative importance of 1, reflecting equivalent importance for each criterion.
  - Overall average – Relative importance factors from all stakeholders were averaged together for each criterion to represent the results of all stakeholders.
  - Stakeholder groups – Each stakeholder group had their own relative importance factor profile.

For each bottom line, the ratings for each performance metric are multiplied by the performance metric weight (as previously mentioned equal weighting was used) and then summed to provide a score for each criterion (Figure 2.8). Then the criterion score is multiplied by the normalized weight determined by the stakeholder relative importance factors assigned to that criterion. These values are summed for all the criteria, resulting in an overall score for each alternative. This process is completed for the economic, social, and environmental bottom lines.

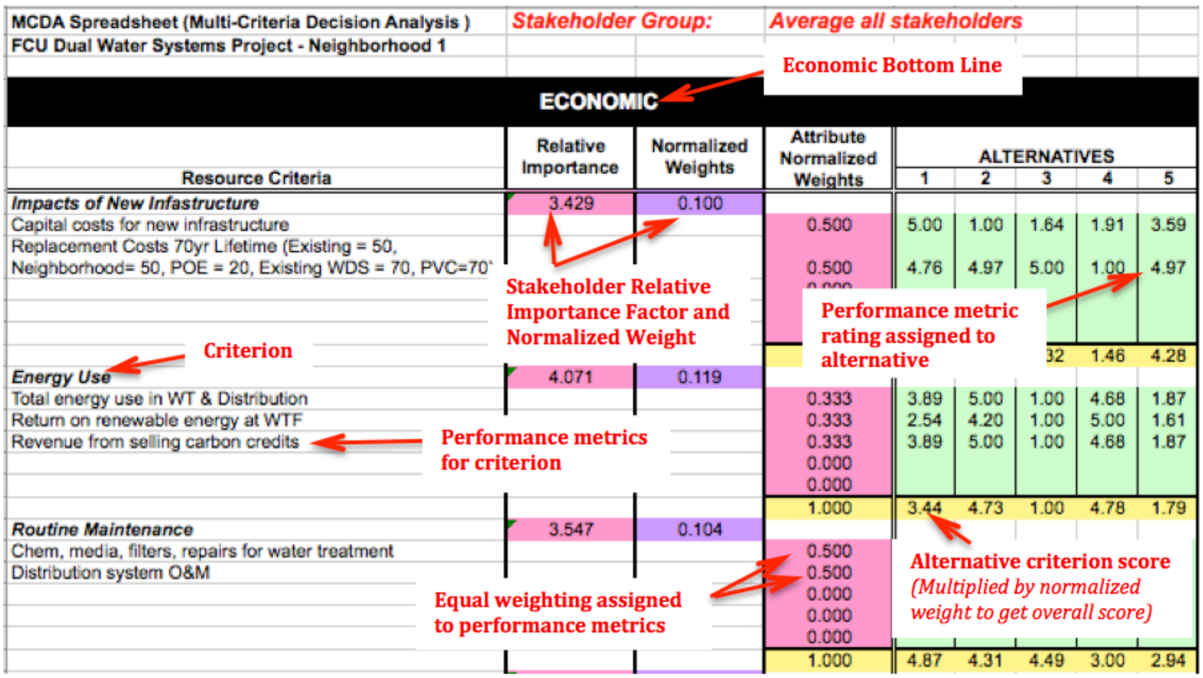


Figure 2.8 - Screenshot from TBL Results Sheet

iii. Criteria and Performance Metric Selection

The final set of main criteria used to analyze the alternatives was:

1. Impact of new infrastructure
2. Energy use
3. Routine maintenance
4. Staffing
5. Consumer water quality
6. Use of city water corridors
7. Risk of limited supply
8. Risk of rate changes
9. Opportunity for new water management strategies
10. Revenue opportunities
11. Regulatory/Political risk

After the main criteria were establish, then a set of performance metrics were developed that would be used to evaluate those main criteria for each economic, social and environmental bottom line (Tables 2.8 through 2.10).

Table 2.8 - Economic Performance Metrics

Criteria	Economic Performance Metrics
1. Impact of new infrastructure	1.1 Capital costs for new distribution and water treatment infrastructure associated with the proposed alternatives
	1.2 Replacement costs of existing and proposed alternative infrastructure
2. Energy use	2.1 Total annual energy use in water treatment and distribution
	2.2 Annual return on renewable energy at water treatment facility
	2.3 Annual revenue from selling carbon credits
3. Routine maintenance	3.1 Annual chemicals, media, filters, and repairs for water treatment
	3.2 Annual distribution system operations and maintenance (flushing, surveying, and pipe repairs)
4. Staffing	4.1 Full time employee equivalent for water treatment and distribution system operations
	4.2 Cost of workforce transitional training
5. Consumer water quality	5.1 Health care costs associated with exposure to disinfectant by-products
	5.2 Costs associated with potential cross-connection failure
	5.3 Costs associated with a source water contamination event
6. Use of city water corridors	6.1 Avoided transaction costs associated with converting water rights from irrigation to municipal
7. Risk of limited supply	7.1 Costs associated with alternative water supplies
	7.2 Risk of obsolete infrastructure
8. Risk of rate changes	8.1 Confidence in operations & maintenance projections
9. Opportunity for new water management	9.1 Savings on later implementing an alternative water management strategy that could benefit from a dual distribution system
10. Revenue opportunities	10.1 Revenue generated from using extra capacity at water treatment facility to sell treated water wholesale to neighboring communities
11. Regulatory/Political risk	11.1 Costs associated with changing an alternative back to the existing system or to make changes needed to meet new regulations
	11.2 The costs associated with increase in communication and managing public perception

Table 2.9 - Social Performance Metrics

Criteria	Social Performance Metrics
1. Impact of new infrastructure	1.1 Disruption to community – the inconvenience of construction to the community and disruption to local business
	1.2 Increase in temporary employment
2. Energy use	2.1 Health impacts associated with air pollution
3. Routine maintenance	3.1 Disruption to community
4. Staffing	4.1 Employment and job security
	4.2 Increased earning potential for a higher skilled workforce
5. Consumer water quality	5.1 Drinking water quality as a function of water age in distribution system
	5.2 Potential health risks from a cross-connection failure
	5.3 Potential health risks from a source water contamination event
6. Use of city water corridors	6.1 Enhancement of the City's water corridors
	6.2 Benefits to local ditch companies
7. Risk of limited supply	7.1 Resiliency of infrastructure to changes in supply
8. Risk of rate changes	8.1 Affordability of monthly water bill for low or fixed income households
9. Opportunity for new water management strategies	9.1 Being an innovative community and potential to increase ISFs for recreational uses
10. Revenue opportunities	10.1 Improve water security in neighboring communities and increasing jobs in Fort Collins
11. Regulatory/Political risk	11.1 Public acceptance of the alternatives

Table 2.10 - Environmental Performance Metrics

Criteria	Environmental Performance Metrics
1. Impact of new infrastructure	1.1 GHG emissions
	1.2 Temporary stormwater pollution
2. Energy use	2.1 Annual GHG emissions in CO_2e
3. Routine maintenance	3.1 Annual GHG emissions in CO_2e
	3.2 Annual chemical consumables for water treatment
4. Staffing	4.1 Employee transport GHG emissions CO_2e
5. Consumer water quality	5.1 Water quality of receiving water bodies
6. Use of city water corridors	6.1 Benefits to species and natural systems
7. Risk of limited supply	7.1 Effects variable supply could have on the City's water corridors
8. Risk of rate changes	8.1 Potential changes in irrigation water demand due to rate changes
9. Opportunity for new water management strategies	9.1 Increase in in-stream flows due to using alternative sources of water will result in benefits to species and natural systems
10. Revenue opportunities	10.1 Decreasing need for new water treatment facility construction in the regional community
11. Regulatory/Political risk	11.1 Loss of environmental benefits gained from the alternatives

iv. Stakeholder Relative Importance Factors

In order to more comprehensively evaluate design alternatives, a series of stakeholder meetings took place in which input was received from members of the City government representing a variety of departments. The goals of these meetings were to assess the applicability of the main criteria and develop weighting scenarios for different stakeholders. Two separate meetings were held on January 29, 2014 and May 22, 2014. In the first meeting stakeholders identified additional criteria and the need for a more comprehensive TBL analysis. During the second meeting stakeholders assigned relative importance factors to revised criteria on a scale of 1 to 5 with 1 being the least important and 5 the most important. The data collected at both meetings provided both critical feedback on the structure of the Multi-Criterion Decision Analysis (MCDA) approach and meaningful input on the importance of performance criteria used to evaluate design alternatives.

Input was collected from 17 stakeholders in 9 departments. After analysis of the results, this data was compiled into seven stakeholder groups based on similar responses, which were averaged together to form a group relative importance factor for each criterion. These groups included Institute for the Built Environment, Economic Health/Urban Renewal Authority, Communications & Public Involvement, FC Moves – Transportation Planning, Natural Areas, Planning, and Engineering/Utilities. Stakeholder meeting results can be found in Section 3.a. Raw data and further discussion is provided in Appendix C.

Figure 2.9 - Presentation of the rating process for MCDA criteria (Photo by Dan Fourness, May 22, 2014)

c. Alternative Assumptions & Design Specifics

This section explains the assumptions made regarding the design of all the alternatives and a brief description of the modeling and design specifics for the alternatives and the existing system.

i. Distribution System Modeling

The US Environmental Protection Agency's EPANET 2 software was used to model the neighborhood distribution systems and run different scenarios for each of the alternatives considered (Table 2.11). More details regarding EPANET modeling can be found in Appendix D.

For the existing system, an EPANET 2 model was created for each sample neighborhood to model distribution system water age and to calculate the reconstruction costs of the existing distribution system. The neighborhood distribution system models were simplified by excluding cul-de-sac distribution lines.

The same distribution system layout created for the existing distribution system was used for the design of the alternative new distribution systems to maintain consistency in the analysis.

Table 2.11 - EPANET 2 Model Scenarios

Alternative	Model Scenarios
Existing *Summary:* *- Existing central water treatment facility treats total demand* *- Existing transmission and distribution lines for potable water distribution to meet indoor, irrigation, and fire demand*	1. Model water age in existing single potable distribution system using average total demand and diurnal pattern for total water use. (Note: Average annual total demand is used, which means water age in summer will be less than that in winter because of irrigation demand in summer months.)
Central/Dual – Central water treatment and dual distribution of potable and raw water *Summary:* *- Existing central water treatment facility treats indoor demand only* *- Existing transmission and distribution lines for raw water distribution to meet irrigation and fire demand* *- New potable only transmission and distribution lines for potable water distribution to meet indoor demand*	1. Design new potable only distribution system using base demand and a peak factor of 2.5 (City of Fort Collins, 2012b). 2. Model water age in new potable distribution system using base demand and diurnal pattern for indoor use.
Neighborhood – Neighborhood water treatment and neighborhood dual distribution of potable and raw water *Summary:* *- New neighborhood water treatment facility treats indoor demand* *- Existing transmission and distribution lines for raw water distribution to meet irrigation and fire demand* *- New potable only neighborhood distribution lines for potable distribution from neighborhood water treatment facility*	1. Design new potable only distribution system and pump sizing using base demand and a peak factor of 2.5. 2. Model water age and pumping energy in new potable distribution system using base demand and diurnal pattern for indoor use.
Point-of-Entry – Single raw water distribution system with POE water treatment	No EPANET modeling required
Separated Irrigation – Addition of irrigation only distribution system from irrigation ditch network *Summary:* *- Existing central water treatment facility treats indoor and fire demand* *- Existing transmission and distribution lines for potable water distribution for indoor and fire demand* *- New raw water distribution system from irrigation ditch for irrigation demand*	1. Model water age in existing distribution system with base demand and diurnal pattern for indoor use. 2. Design new raw water irrigation only distribution system using irrigation demand and a peak factor of 6.0. 3. Model pumping energy in raw water irrigation system based on diurnal pattern for outdoor use.

All new distribution system designs were designed to meet the following requirements:

- Potable distribution system (Buffington, 2013):
  - Minimum pressures, without fire flow, in potable distribution system = 40 psi
  - Optimum pressure between 40 to 80 psi
  - Pressure reducer values required on all services where pressure is greater than 80 psi
- Peak factor of 2.5 is used for design of new potable distribution systems based on the Water Supply and Demand Management Policy (City of Fort Collins, 2012b).
- Irrigation only distribution system (Separated Irrigation Alternative) (K-Rain, 2014):
  - Minimum pressure = 25 psi
  - Optimum pressure between 25 to 50 psi
- Peak factor of 6.0 was used for the design of the irrigation only distribution system (Separated Irrigation Alternative) due to the fact that peak irrigation demand can be two times the average irrigation demand in the summer and to allow for water-wise lawn care that suggests watering between 12 a.m. and 6 a.m. when wind and evaporation rates are minimal (City of Fort Collins, 2014).
- To minimize hydraulic transients, distribution systems were designed with a maximum velocity of 5 ft/s (Haestad et al., 2003).
- The minimum diameter for the new distribution systems was 2-inches, except in commercial zones where the minimum was 6-inches to accommodate variable commercial service sizes.
- All new pressure pipe is AWWA C900 or C909 PVC Pressure Pipe or equivalent (FCU, 2011).

For water age modeling and pump energy modeling, a peak factor of 1 was used with a diurnal pattern depending on the demand type. Tables 2.12a through 2.12c show the three diurnal patterns used in the analysis. It was assumed the pumps needed, for the Neighborhood and Separated Irrigation alternatives, had variable frequency drives for optimum energy efficiency. Variable frequency drives were modeled by adding a VFD pattern in EPANET.

Table 2.12a - Total water use diurnal demand (Mayer et al., 1999)

Diurnal Pattern 1 (for modeling water age of existing d.s. meeting both potable and non-potable demand)																							
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0.37	0.38	0.58	0.48	1.06	1.20	1.54	1.68	1.49	1.25	1.22	0.94	0.96	0.82	0.91	0.98	1.02	1.20	1.40	1.42	1.14	0.94	0.53	0.50

Table 2.12b - Indoor water use diurnal demand (Mayer et al., 1999)

Diurnal Pattern 2 (for potable only water demand, use for water age modeling of Alt 1, Alt 2 and Alt 4 potable d.s., pumping energy for alt 2 new potable d.s.)																							
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0.36	0.24	0.18	0.18	0.24	0.60	1.20	1.65	1.68	1.65	1.50	1.35	1.20	1.08	1.05	1.05	1.08	1.20	1.32	1.32	1.20	1.14	0.96	0.60

Table 2.12c - Irrigation water use diurnal demand

Diurnal Pattern 3 (for Alt 4 irrigation system pumping)																							
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0.05	0.05	0.05	0.05	4.00	4.00	4.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	3.70	3.70	3.70	0.05	0.05

ii. Neighborhood-Scale Treatment

The Neighborhood alternative allows raw or lightly treated water to be transmitted through the existing distribution system to neighborhood-scale treatment facilities. Irrigation water will bypass these facilities and a new potable distribution system will then deliver treated water. Design neighborhoods from the City of Fort Collins were used to determine an average system capacity of 1.0 MGD with a peak factor of 2.5. Package plants were selected due to advantages at small capacity such as reduced design and installation costs, automated maintenance, and smaller system footprints (Clark & Morand, 1981).

After an initial analysis, five systems were selected for investigation divided into conventional and innovative technologies. The five system options were conventional treatment, conventional treatment with high-level process automation, ultrafiltration, direct filtration, and upflow adsorption-clarification with dual-media filtration. A simple equal-weighted MCDA was used to evaluate these alternatives based on five main criteria defined as cost, energy use, maintenance, performance, and implementation using both the Weighted Average Method (WAM) and Promethee Method. Each main criterion was evaluated based on several defined performance metrics.

- Cost
  - Capital cost (2014 USD)
  - Operations cost (2014 USD)
- Energy Use
  - Total energy use (kWh/year)
  - Percent recovery (%)
- Maintenance Requirements
  - Employee time required (hours/week)
  - System lifetime (years)
  - Operational complexity (qualitative)
  - Chemical requirements (qualitative)
  - Sludge production (%)
- Performance
  - Removal of *Giardia lamblia* (log removal)
  - Removal of *Cryptosporidium* (log removal)
  - Removal of viruses (log removal)
  - Influent turbidity limit (NTU)
- Implementation
  - System size (ft^2)
  - Opportunity for add-ons (qualitative)
  - Availability (qualitative)
  - Community Disturbance (qualitative)

Assumptions were made that all systems will include chlorine disinfection and clearwell storage and general buildings requirements and that such requirements would not vary substantially among alternatives. For this reason, these components were not included in the comparison of treatment technologies. Chlorination systems and clearwell storage are sized for the capacity of the treatment facility rather than the treatment technology. For more information on the neighborhood-scale treatment system selection process, refer to Appendix E.

Overall WAM scores for the five alternative small-scale system treatment packages show Direct Filtration was the top choice (Figure 2.10). Ultrafiltration was next and Up-flow Adsorption Clarification completed the top three choices which are all classified as innovative technologies. Automating conventional treatment made the system more competitive with the innovative systems but maintained distinguishable distance in score.

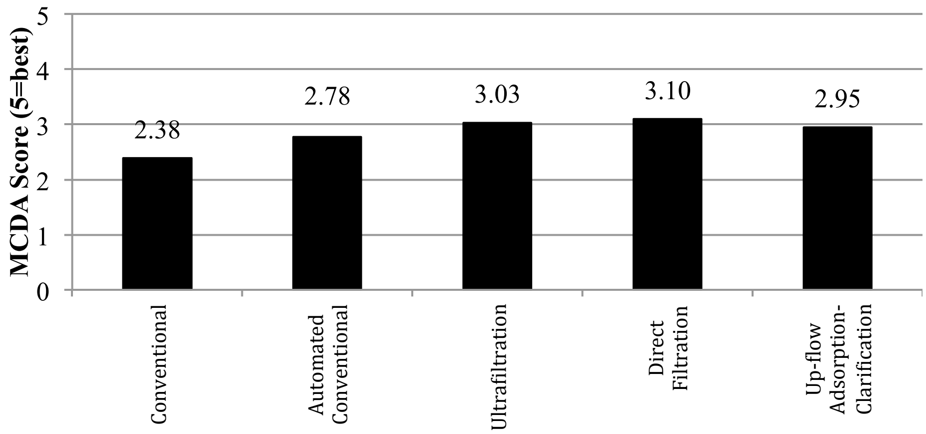


Figure 2.10 – WAM results for Neighborhood-scale system selection (Max Score = 5)

The treatment packages were also compared using the out-ranking Promethee Method in which alternatives are compared directly according to sub-criteria with the better option receiving a 1 and the lesser a 0.

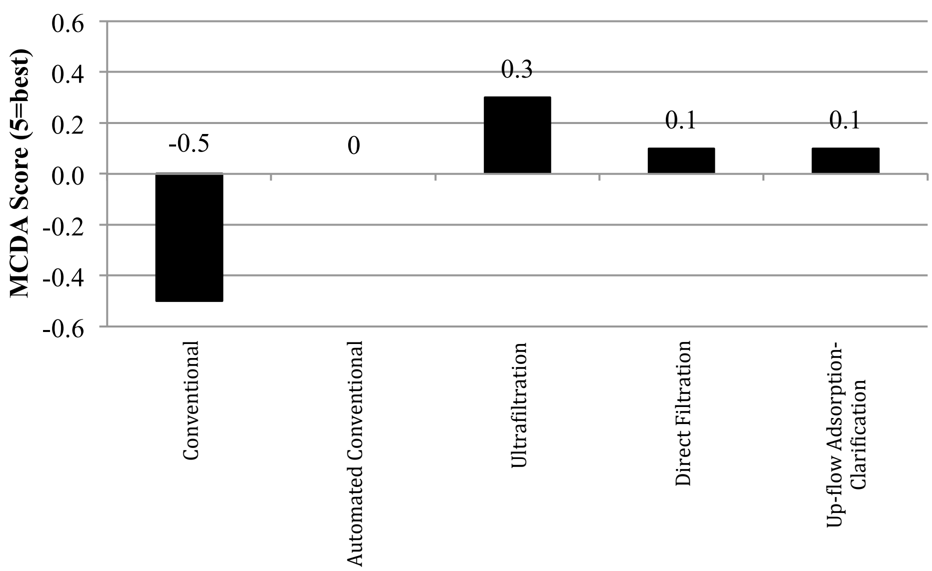


Figure 2.11 – Promethee results for Neighborhood-scale system selection

As seen in Figure 2.11, the alternatives do not maintain their ranking order among the top three options. In this analysis, this shows that the magnitudes of particular advantages and disadvantages do affect the final results for system selection. This adds to the uncertainty of the indistinguishable WAM results. An outranking method does not incorporate the relative degree of each advantage or disadvantage. Ultrafiltration is demonstrated as the strongest option.

Major advantages of Ultrafiltration are small system footprint, consistent finished water quality, better removal of *Cryptosporidium* and *Giardia lamblia* than media filtration, amenability to remote monitoring, and no addition of coagulant (U.S. EPA, 2001). Upflow Adsorption-Clarification with Dual Media Filtration also scored well in all scenarios and was considered for recommendation. Innovative package plant options consistently scored higher than conventional treatment due to the advantages of space, design and automation at smaller capacities (U.S. EPA, 2003).

The recommended Ultrafiltration Neighborhood-Scale Treatment Facility would require package plant modules with a total capacity of 1.0 MGD coupled with a 250,000 gal clearwell and chlorine injection for disinfection residual. Raw source water would be treated centrally for alkalinity, fluoridation and pH control. These systems require 1-2 operators and operations and monitoring can be optimized using centrally managed remote monitoring systems. At this capacity, each package plant would produce up to 20,000 gal/day of backwash waste volume, which would be discharged to the wastewater collection system (WesTech Engineering, Inc., 2014). A diagram of the system is shown in Figure 2.12. A proposal for this system is attached in Appendix E.

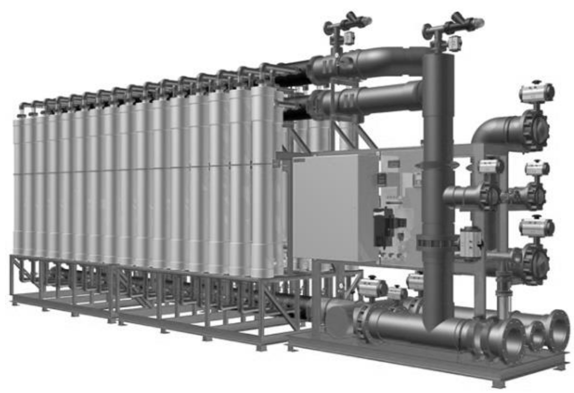


Figure 2.12 - WesTech AltaFilter Ultrafiltration Membrane System (WesTech Engineering Inc., 2014)

iii. Point-of-Entry Treatment

The Point-of-Entry alternative maintains use of the existing distribution system to deliver raw or lightly treated water to POE treatment units at each potable connection. POE treatment consists of a filtration unit and a disinfection unit used to treat all water entering the facility for potable use (Schowalter, 2006). After an initial comparison process, five system packages were selected for investigation including Reverse Osmosis, Activated Carbon/Kinetic Degradation Fluxion Media, Ultrafiltration, Reverse Osmosis with Granular Activated Carbon, and Activated Carbon with Ion Exchange. A small-scale MCDA was used to evaluate these alternatives based on main criteria including cost, energy use, maintenance, performance and implementation similarly using both the Weighted Average (WAM) and Promethee methods.

Each main criterion was evaluated based on the following criteria:

- Cost
    - Capital cost (2014 USD)
    - Operations cost (2014 USD)
- Energy Use
    - Process energy use (kWh/year)
    - Minimum pressure requirement (psi)
- Maintenance Requirements
    - Operational complexity (qualitative)
    - Component replacement frequency
    - Waste produced (qualitative)
- Performance
    - Virus removal (qualitative)
    - Influent turbidity limit (NTU)
    - Organic contaminant removal (qualitative)
    - Inorganic contaminant removal (qualitative)
    - Recovery efficiency (%)
- Implementation
    - System size (ft^3)
    - Availability (qualitative)

Overall the highest scoring treatment package is Activated Carbon/KDF with a sediment pre-filter and UV disinfection (Figures 2.13 and 2.14). For more detailed information on the treatment package selection process, refer to Appendix F.

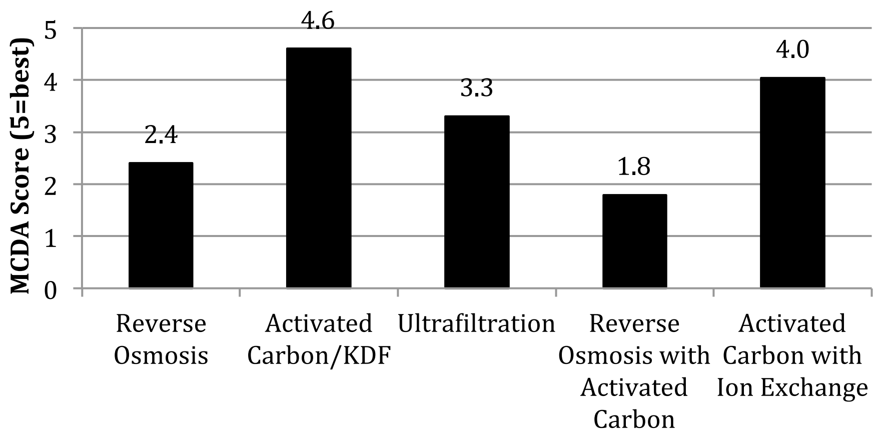


Figure 2.13 - WAM scores for POE treatment package selection

Relative rankings are maintained between alternative point-of-entry technologies using both the WAM and Promethee method (Figure 2.14). This provides the basis for a solid recommendation for the Activated Carbon/KDF with a sediment pre-filter and UV disinfection package.

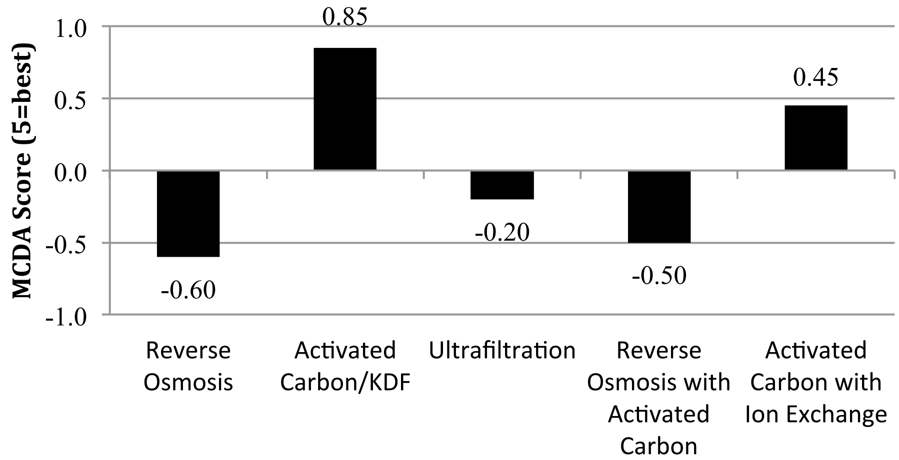


Figure 2.14 – Promethee scores for POE treatment package selection

This treatment package is a four-step process (Figure 2.15) (Pure Earth Technologies, Inc., 2014). The treatment process begins with mechanical sediment filtration to remove suspended particles at either the 1 or 5-micron level depending on water quality. The next step is electrochemical/oxidation-reduction with Kinetic Degradation Fluxion Media (KDF) for the removal of heavy metals and inorganics. Following KDF, granular activated carbon (GAC) filtration handles organic contaminants. Lastly, ultraviolet (UV) disinfection ensures that finished water meets requirements for microbial contaminants and virus removal (UV Max, 2014).

Figure 2.15 – Recommended POE treatment package
(Pelican Water Systems, KDF Fluid Treatment, Trojan UV Max, 2014)

Raw source water is treated centrally for alkalinity, fluoridation and pH control is distributed to each potable connection. This system is capable of treating fines, organics, inorganics and microbial contaminants while maintaining low capital costs and energy use with a comparatively moderate level of maintenance and operation complexity. However, it is important to note that there are many additional options for combining treatment technologies in order to target specific contaminants. Water quality monitoring during pilot testing is critical in order to determine if this package will meet treatment standards (US EPA, 2002).

In this analysis assumptions were made based on current regulations. A further discussion of regulatory barriers and alternative management strategies can be found in the Results and Discussion section. POE systems must be owned, controlled and maintained by the public water system (PWS) – Fort Collins Utilities (US EPA, 2002). Routine maintenance will include inspection of systems, replacement of sediment pre-filters, KDF and GAC media, and UV lamp and sleeves. All systems must have mechanical warnings or automatic shutoff devices to notify customers of operational problems (US EPA, 2002). Most commonly this requires an electrical conductivity and total dissolved solids meter. Systems will be installed outdoors in weatherproof protective enclosures at each connection allowing easier access for Fort Collins Utilities. A detailed monitoring plan must be approved by the State of Colorado. All systems must undergo initial monitoring in the first year of operation followed by one third of all systems in each subsequent year (U.S. EPA, 2007). Water quality sampling will be based on current monitoring at the existing Central Water Treatment Facility.

iv. Design assumptions specific to raw water distribution

Several assumptions were made with regard to the dual distribution of potable and raw water for this study.

Metering raw water for irrigation

Several studies have shown that the unmetered residential use of non-potable water for irrigation results in an increase in use (Okun, 1997; Wilkens-Wells et al., 2003; Utah Division of Water Resources, 2010). In St. Petersburg, Florida where reclaimed water is used for residential irrigation, they found that unmetered residential use of reclaimed water resulted in excessive use and plans were made to change to metered use (Okun, 1997). A Colorado State University study, on the Benefits and Costs of Pressurized Dual Water Systems in Colorado, showed single family flat rate users used approximately 39% more water than single family metered users (Wilkens-Wells et al., 2003). In Utah, 44% of outdoor residential water is provided via unmetered secondary raw water irrigation systems. The Utah Department of Water Resources found that end users in areas with raw water irrigation use 113 gpcd more water than end users, in similar communities and lot sizes, which use potable water (Utah Division of Water Resources, 2010). These studies show the importance of metering to avoid excessive water use for irrigation.

One of the main obstacles for metering raw water use is the clogging of conventional water meters. Suspended and dissolved particles can clog the moving parts in conventional meters. Utah's Division of Water Resources has facilitated several studies on the metering of raw water systems throughout the state. The studies look at different types of meters, levels of filtering, and costs of decentralized vs. centralized filtration. The fluidic-oscillation-type meter has shown the most promise for metering raw water systems as they are inexpensive (approximately $100/meter) and have no moving parts. The raw water providers conducting meter studies provide a level of filtration between 80 to 250 μm. (Richards et al., 2008)

New fluidic-oscillator-type meters were included for the new raw water service connections in this study.

Filtration of raw water

There are no water quality requirements for using raw water for irrigation. However, most raw water providers provide some level of filtration. As previously mentioned, the level of filtration used by providers in Utah ranges from 80 to 250 - μm (Richards et al., 2008).

Utah case studies have also shown that for larger raw water systems (8,000 plus connections) it is more economical to conduct filtration at a central facility (~$40/connection) than at the point of connection (~$60/connection) (Richards et al., 2008).

It was assumed that raw water will be filtered to 80-μm at the existing central water treatment facility in this study.

Distribution System Corrosion Control

Prior to water treatment, FCU did not have internal pipe corrosion issues. After the Safe Drinking Water Act, conventional water treatment was implemented and incidents of internal corrosion increased (Elmund et al., 1992). It is unclear whether changing the water quality in the existing distribution system from potable water to raw water, as proposed in the Central/Dual, Neighborhood, and Point-of-Entry alternatives, will result in an increase in the internal corrosion of CIP and lined and unlined DIP (further discussion in section 4.a.ii). It was assumed that chemical stabilization would not be required for the distribution of raw water in this study.

Chemical stabilization is needed for the potable water supply to meet the Colorado Department of Public Health and Environment (CDPHE) requirements for the Lead and Copper Rule (LCR). A minimum pH of 7.5 and a minimum alkalinity of 32 mg/L as $CaCO_3$ are required by the CDPHE (Payne, 1998). The Horsetooth source water alkalinity ranges from 26.4 to 34.5 mg/L as $CaCO_3$ (average = 29.7 mg/L as $CaCO_3$) and pH ranges from 6.95 to 7.86 (average = 7.5). The CLP source water alkalinity ranges from 8.3 to 50.8 mg/L as $CaCO_3$ (average = 24 mg/L as $CaCO_3$) and pH ranges from 6.56 to 12.5 (average = 7.6) (Morrison, 2014). The decentralized water treatment options in the Neighborhood and Point-of-Entry alternatives have not included lime or CO_2 for corrosion control; therefore it is assumed that chemical stabilization would need to be done at the existing central water treatment facility.

It should also be noted that FCU currently adds fluoride to their water. It is assumed that fluoridation for the Neighborhood and Point-of-Entry alternatives would continue at the central water treatment facility for alternatives with decentralized water treatment.

Cross-connection control

With the dual distribution of potable and raw water, comes an inherent risk in the cross-connection of the two distribution systems resulting in the contamination of the potable water distribution system. To prevent contamination of the potable distribution system due to a direct or indirect cross-connection between customer potable and raw water systems, reduced pressure principle assemblies were included for potable service lines where there is the dual service of potable and raw water (Central/Dual, Neighborhood, and Separated Irrigation alternatives). Additional recommendations for amendments to the FCU Cross-Connection Control Manual and details on additional procedures that should be implemented to minimize the risk of cross-connections can be found in Appendix K.

v. Summary of alternative designs compared to the existing system in the MCDA

(Central/Dual Alternative) Central water treatment and dual distribution

Potable water treatment and raw water filtration to 80-μm will be done at the existing central water treatment facility. The existing distribution system will carry filtered raw water for irrigation and fire flow demand. A new potable transmission and distribution system will be installed to carry potable water from the central water treatment facility to the end user. The existing potable water meters will continue to be used to meter potable water at the potable service connection and new fluidic-oscillation-type meters will be used to meter filtered raw water at the new raw water service connection. Additionally, reduced pressure principle assemblies will be installed on potable service lines to protect the potable distribution system from contamination against cross-connections.

(Neighborhood Alternative) Neighborhood water treatment and dual distribution

Raw water filtration to 80-μm, chemical stabilization to meet LCR requirements, and fluoridation will happen at the central water treatment facility. This filtered raw water will be distributed to neighborhoods via existing transmission mains. Water for irrigation and fire flow will continue through the existing distribution system and potable water treatment is conducted at new neighborhood water treatment facilities. A pump house at the neighborhood water treatment facility and a new potable neighborhood distribution system will be installed to carry finished potable water from the neighborhood water treatment facility to the end user. The existing potable water meters will continue to be used to meter potable water at the potable service connection and new fluidic-oscillation-type meters will be used to meter filtered raw water at the new raw water service connection. Additionally, reduced pressure principle assemblies will be installed on potable service lines to protect the potable distribution system from contamination against cross-connections.

(Point-of-Entry Alternative) POE treatment and single distribution system

Raw water filtration to 80-μm, chemical stabilization to meet LCR requirements, and fluoridation will happen at the central water treatment facility. This filtered raw water will be distributed to the end user using the existing transmission and distribution system. Raw water for irrigation will be diverted at the service and water for indoor demand will be treated to potable water standards at a POE treatment system. Conventional water meters will be replaced with new fluidic-oscillation-type meters to read total demand.

(Separated Irrigation Alternative) Landscape irrigation with raw water from the City's irrigation ditch network

Potable water treatment will be done at the existing central water treatment facility. The existing transmission and distribution system will carry potable water for indoor demand and fire flow. Raw water for irrigation will be diverted from neighborhood irrigation ditches to a storage basin. Storage basins will be designed to hold 72 hours of irrigation supply since many of FCU's CLP water rights are direct decree. A pump house and new raw water irrigation system will be installed to deliver filtered raw water for outdoor demand. Filtration to 80-μm will happen at the pump house. The new raw water irrigation system will only be used for irrigation and will be blown out at the end of the irrigation season. Burial depth of the new raw water irrigation pipes will be 24 to 30 – inches. The existing potable water meters will continue to be used to meter potable water at the potable service connection and new fluidic-oscillation-type meters will be used to meter filtered raw water at the new raw water service connection. Additionally, reduced pressure principle assemblies will be installed on potable service lines to protect the potable distribution system from contamination against cross-connections.

d. Performance Metric Calculations

This section includes a summary of the methodology used for each performance metric, whether it is a qualitative or quantitative metric, whether optimum performance is a minimum or maximum value for quantitative metrics, and the assumptions made for each performance metric. Appendices G through I provide the sample neighborhood calculations for the economic, social, and environmental performance metrics.

i. Economic Performance Metric Calculation Summary

A summary of the economic performance metrics and the methodology used in the calculations is provided in this section. Appendix G provides the results of the performance metric calculations for each sample neighborhood.

1.0 IMPACTS OF NEW INFRASTRUCTURE

1.1 Capital costs for new distribution and water treatment infrastructure

Summary: Includes the costs of the new infrastructure needed in the sample neighborhoods for each of the alternatives considered in the MCDA. There are no capital costs included for the existing system; this only includes the new infrastructure needed for the four alternatives to the existing system. Table 2.13 includes a summary of the new infrastructure included for each alternative.

Table 2.13 - Summary of New Infrastructure Included in Capital Costs

New Infrastructure Required	Existing	Central/ Dual	Neigh.	Point-of-Entry	Separated Irrigation
New potable transmission mains		X			
New potable distribution mains		X	X		
New raw water distribution mains					X
Raw water meters for non-potable service lines		X	X	X	X
Backflow prevention devices for potable service lines		X	X		X
New neighborhood water treatment facility			X		
New POE water treatment systems				X	
Pump			X		X
Storage basin					X
Central raw water filtration		X	X	X	X

New potable transmission and distribution system unit costs

Unit costs for pipes 6-inch diameter and higher, with and without service connections, were provided by FCU (Parton, 2014) and can be found in Appendix G, Tables G.2 and G.3. Unit costs where the utility partners with another city department and shares the costs (road repair paid by others) and where the utility pays all the costs associated with construction including road repair were provided. Adoption of a dual distribution system would be a long-term strategy and require long-term planning, which would allow for more opportunities to partner with other city departments. For this reason, it was assumed that 50% of construction of a dual system would be in partnership with another department and an average of the two costs was used in the capital cost calculations.

A linear regression was done on the unit costs for PVC pipes from 6-inch to 12-inch diameter (Appendix G, Figures G.1 and G.2) to determine the unit cost for pipes with diameter smaller than 6-inch. There is a significant jump in unit cost for pipes with a diameter of 16-inches or greater, which is why the regression only used the unit costs for up to 12-inch diameter.

A summary of the new potable transmission and distribution system unit costs used in the calculations are summarized in Table G.4 (Appendix G).

Summary of other costs included for potable and non-potable service lines

The other new costs associated with the alternatives are raw water meters for non-potable service lines, backflow prevention devices for potable service lines, pumping costs, and central filtration of raw water. Costs for the new raw water irrigation system in the Separated Irrigation alternative were taken from the 2003 CSU study, on the Benefits and Costs of Pressurized Dual Water Systems in Colorado ((Wilkens-Wells et al., 2003). This study provided a cost per point of connection, which is based on case studies of similar systems in Utah and the Colorado Front Range. Details regarding these costs are detailed in Appendix G.

Neighborhood water treatment costs

Neighborhood treatment is based on an ultrafiltration package plant with chlorine disinfection and clearwell storage. Costs for total treatment, chlorine disinfection and clearwell storage were calculated using equations from (Sharma, 2010) coupled with price quotes from a proposal from WesTech Engineering.

$$UF\ Package\ Plant\ Capital\ Cost = 0.0003(x^3) - 0.8109(x^2) + 2{,}016.9(x) + 38{,}246$$ (Sharma, 2010)

Where x = capacity in gal/min

$$Chlorine\ Disinfection\ Capital\ Cost = 3x10^{-6}(x^3) - 0.0423(x^2) + 267.76(x) + 29{,}368$$ (Sharma, 2010)

Where x = capacity in gal/min

$$Clearwell\ Capital\ Cost = 4x10^{-6}(x^3) - 0.0636(x^2) + 585.7(x) + 86{,}890$$ (Sharma, 2010)

Where x = capacity in 1000 gal

Point-of-Entry water treatment costs

POE direct capital costs included manufacturer data for treatment units, mechanical warning systems, concrete pads, and outdoor enclosures while indirect costs were estimated using a Cost Estimating Tool from the U.S. EPA (U.S. EPA, 2007). Three separate capacity POE system configurations were chosen for Single Family, Duplex, and Multi-Family/Commercial connections. Treatment system capital cost was calculated by multiplying the system configuration cost by the total number of connections in each capacity. This same process was repeated for the concrete pad and outdoor enclosure costs for the variable footprints of different capacity system configurations. Mechanical warning devices were applied to each connection. Additional direct capital costs incorporated into the Cost Estimating Tool included installation and initial year monitoring. Indirect costs incorporated permitting, pilot testing, legal costs, engineering costs, and contingency.

Type of metric: Quantitative (minimum)

Units: US $

Assumption(s):

- All new distribution system pipes are C909 PVC, PC150, or equivalent.

- The new distribution systems in the Central/Dual and Neighborhood alternatives have a burial depth of 4.5 to 5.5 feet and in the Separated Irrigation alternative a burial depth of 2 to 2.5 feet.
- Neighborhood treatment land acquisition costs based on average lot size (ft^2) and land cost ($\$/ft^2$) collected from Fort Collins GIS and local listings from real estate websites such as Zillow.com. Point-of-Entry treatment systems were sized for three connection levels: Single Family, Duplex, and Multi-Family/Commercial.
- Transmission mains were not included in the design and modeling so the following assumptions were made to estimate the costs associated with new potable only transmission mains:
  - The new potable transmission mains would only need to be ½ the diameter of the existing mains. This is a conservative estimate because the fire flow would be on the existing non-potable system and the potable demand is only 1/3 of the total peak demand in the summer.
  - It was assumed that the network of transmission mains is shared by all neighborhoods. All sample neighborhoods are 1 – square mile and the utility service area is 35 – square miles; therefore the portion of the costs associated with each neighborhood was 1/35 of the total transmission main costs.

1.2 Replacement costs of existing and proposed alternative infrastructure

Summary: Includes the costs of replacing the distribution system and water treatment infrastructure for the existing system and four alternatives. The analysis was based on a 70-year study period, the lifetime of the new PVC pipes. The value used in the MCDA was the Net Replacement Costs.

$$Net\ Replacement\ Costs_{2014\ PV} = Total\ Replacement\ Costs_{2014\ PV} - Remaining\ Value_{2014\ PV}$$

Where:

$$Total\ Replacement\ Costs_{2014\ PV} = \sum Replacement\ Costs_{2014\ PV}$$

$$Remaining\ Value_{2014\ PV} = \frac{Remaining\ life}{Lifetime} \times Replacement\ Cost_{2014\ PV}$$

Future costs were expressed in 2014 constant dollars and discounted to 2014 Present Value (PV) assuming a real escalation rate of 0% and a real discount rate of 3.375% (Reclamation Bureau, 2014). The following equation was used to calculate 2014 PV:

$$2014\ PV = F_t \times \frac{1}{(1+d)^t}$$

Where:

$F_t = Future\ cost\ in\ t\ years\ expressed\ in\ 2014\ constant\ dollars$

$d = real\ discount\ rate\ (exclusive\ of\ inflation) = 3.375\%$

$t = year\ in\ which\ cost\ incurred$

The remaining value was discounted to 2014 PV with the same equation only $F_{70} = Remaining\ Value_{2014\ PV}$ at the end of the study period.

Type of metric: Quantitative (minimum)
Units: US $

Assumption(s):

- A 70-year study period.
- The remaining value of the water infrastructure, with useful life at the end of the study period, was calculated by linearly prorating its initial cost.
- Lifetime costs of the new transmission and distribution systems are based on average service lifetimes from Appendix A, Table A.5.
- A 70–year lifetime was assumed for the new potable distribution systems in the Central/Dual and Neighborhood alternatives (Table A.5, PVC pipe).
- The Separated Irrigation alternative costs were provided as cost per connection and included new PVC raw water distribution system, pump house, storage basin, and filtration costs. The majority of these costs are for the distribution system; therefore, a lifetime of 70 years was assumed (Table A.5, PVC pipe).
- Lifetimes used for the existing distribution system varied for each neighborhood depending on the pipe materials of the existing distribution system, pipe failure rates, and types of failure. Pipe lifetimes, from the AWWA's 2012 Buried No Longer Report, for large utilities in the West Region were used for cast iron, ductile iron, and PVC pipes. The average remaining lifetimes for the existing distribution system in the three neighborhoods used in the replacement cost calculations were: Neighborhood 1 = 57-years; Neighborhood 2 = 55-years; and Neighborhood 3 = 38-years. More details can be found in Appendix A – Existing Distribution System and Pipe Failure History.
- The existing water treatment facility was initially constructed in 1967 and has undergone several expansions. An average age of 22-years was assumed for the existing water treatment facility. The existing water treatment facility was initially constructed in 1967 and has undergone several expansions. There are four flocculation-sedimentation treatment trains currently in use. One of the treatment trains was built in 1979 and modified in 1989, another built in 1988 and modified in 1989, and two built in 2000. There are 23 dual media filters. The original eight filters have been modified, six filters were added

in 1979, six more in 1988, and three in 1992. Finally, the flow blending and chemical storage facilities were built in 2000.

- All costs associated with the new distributions systems, such as raw water meters, backflow prevention, pumping and central filtration were included with the new distribution system costs.
- A lifetime of 50 years was assumed for the conventional and neighborhood water treatment systems (U.S. EPA, 2012).
- A lifetime of 20 years was assumed for the POE treatment systems (Pelican Water Systems, 2014).

2.0 ENERGY USE

2.1 Total annual energy use in water treatment and distribution

Summary: Annual energy use in each neighborhood for the treatment and distribution of water.

The Existing, Central/Dual, and Separated Irrigation alternatives all use the existing central water treatment facility for potable treatment. Energy consumption from 2008 to 2012 was averaged to determine the kWh/MG needed to treat water at the facility (Appendix G, Table G.22). This value was used to determine the annual energy used to treat potable water demand for the existing system. Since not all energy use at the existing facility is related to the volume of water treated, it was necessary to determine the percentage of the energy use proportional to the volume of water treated in order to determine the energy savings from treating less water in the Central/Dual and Separated Irrigation alternatives (Appendix G, Table G.23). Further details on the existing water treatment facility energy analysis can be found in Appendix J.

Energy use for neighborhood-scale package water treatment plants was calculated as a sum of filtration, chlorine and retained central treatment operations. Filtration energy use was provided in the proposal for an Ultrafiltration membrane system (WesTech, 2014). Chlorine disinfection operations were estimated using a range in energy consumption from 60-250 kWh/MG (Washington State University, 2014). Central treatment retained operations were estimated based on 2010 energy use at the existing facility (Appendix G, Table G.23). Collectively, the treatment energy use in kWh/MG was multiplied by the appropriate demand for each neighborhood and alternative combination to produce a total annual energy use in kWh/yr.

Point-of-entry treatment energy use is also composed of several different processes including filter backwash, UV disinfection, mechanical warning devices and retained central treatment operations. Assumptions were made for the length and frequency of backwash operations. UV disinfection and mechanical warning energy consumption was estimated based on manufacturer specifications. The same central treatment operations retained in the Neighborhood alternative were used to determine central treatment energy use based on 2010 data from the existing facility (Appendix G, Table G.23).

The existing sample neighborhoods all have gravity fed distribution. However, the Neighborhood alternative requires pumping to distribute potable water from the neighborhood water treatment facility and the Separated Irrigation alternative requires pumping to distribute raw water from the local irrigation ditches. The additional energy required for pumping, for these alternatives, was calculated using the EPANET2 models in Appendix D (Table D.9).

Type of metric: Quantitative (minimum)

Units: kWh/year

Assumption(s):

- Water quality laboratory energy use is the same for all alternatives and excluded from calculations.
- See Appendix J for assumptions in determining the percentage of energy consumption proportional to the volume of water treated at the existing water treatment facility.
- All sample neighborhoods are gravity fed for the Existing, Central/Dual, and Point-of-Entry alternatives.

2.2 Annual return on renewable energy at water treatment facility

Summary: This metric was measured by the % of energy use met with the 100 KW solar array at the existing water treatment facility.

$$\%\ return = \frac{Annual\ energy\ produced\ from\ solar\ array}{Annual\ energy\ for\ water\ treatment} = \frac{\left(\frac{(PV\ System)(S)(365)}{N}\right)}{EWT}$$

Where:

PV System = 100 KW

S = average hours of sunlight per day, S=5.2 (NREL, 2008)

N = # of neighborhoods in utility

EWT = Annual electricity for neighborhood water treatment in kWh

Type of metric: Quantitative (maximum)

Units: % return on renewable energy investment

Assumption(s):

- The benefits from solar array are distributed throughout the service area equally. Each sample neighborhood is 1 – square mile and the service area is 35 – square miles, therefore there are 35 neighborhoods.

2.3 Annual revenue from selling carbon credits

Summary: Since revenue from selling carbon credits is directly proportional to the amount of energy saved, the savings in energy use for the different alternatives was used for the MCDA.

$$Neighborhood\ Alternative\ Energy\ Savings = Existing\ Energy\ Use - Alternative\ Energy\ Use$$

Type of metric: Quantitative (indirect; maximum)

Units: kWh/year

Assumption(s):

- Energy use is directly proportional to carbon emissions
- Revenue from selling carbon credits is directly proportional to the amount of energy saved

3.0 ROUTINE MAINTENANCE

3.1 Annual chemicals, media, filters, and repairs for water treatment

Summary: This metric is a measure of the annual O&M costs excluding electricity (calculated in 2.1). The Central/Dual and Separated Irrigation alternatives costs were scaled using existing O&M costs for water production from the City of Fort Collins. Neighborhood ultrafiltration package plant O&M costs were estimated using (Sharma, 2010). Point-of-Entry treatment O&M costs were calculated as an average of values produced by a US EPA Cost Estimating Tool (US EPA, 2007) and study on water security (US EPA, 2006).

Type of metric: Quantitative (minimum)

Units: US $

Assumption(s):

- Energy use is excluded from this metric
- Peak factor = 2.5
- Point-of-Entry treatment requires an additional testing suite for each connection based on contaminants monitored at the existing Central Treatment Facility.

3.2 Annual distribution system operations and maintenance

Summary: The expenses for the Utility Distribution System Division were downloaded from Open Book: City of Fort Collins Spending Transparency between July 1, 2013 to June 30, 2014. We analyzed the itemized costs to determine variable vs. fixed costs. Annual unit fixed and variable costs were determined for the existing distribution system by dividing the totals by the total linear feet of water mains. For the Central/Dual and Neighborhood alternatives, where the new potable lines were PVC, O&M costs were adjusted because PVC pipes would not have electrolysis hole failures. The annual O&M costs for the secondary irrigation system in the Separated Irrigation alternative was estimated based on costs provided from a report that included O&M costs based on similar systems implemented in Utah and Washington. Detailed calculations can be found in Appendix G.

Type of metric: Quantitative (minimum)

Units: US $

Assumption(s):

- Only existing variable O&M costs would vary with increasing the linear feet of pipes to maintain

- All neighborhoods share in the transmission mains annual O&M costs equally. Each sample neighborhood includes 1/35 of the transmission mains O&M costs.

4.0 STAFFING

4.1 Full time employee (FTE) equivalent for water treatment and distribution system operations

Summary: For water treatment operation, each neighborhood was assigned a FTE equivalent for water treatment based on the total number of operators and maintenance personnel required for each design neighborhood.

For distribution system operations, the FTE equivalent was calculated for the number of hours needed for pipe leak repairs, flushing, and surveying for the distribution systems in each neighborhood. A random selection of work orders were used, from the WUMS database, to determine the average number of work hours per pipe leak repair and the hours per mile to flush and survey pipe.

The FTE equivalent required for pipe repair was calculated using:

FTE = (# breaks/mile/year) x (miles pipe) x (repair hours/break)

Where: # breaks/mile/year = average of four quarter quadrants in sample neighborhoods (Figure 2.5)
miles pipe = miles pipe in sample neighborhood
repair hours/break = average from WUMS data

The FTE equivalent required for flushing and surveying:

FTE = (hours/mile) x (miles pipe)

The value for water treatment is added to the value associated with distribution system maintenance for a total FTE/Neighborhood.

Type of metric: Quantitative (minimum)
Units: Full-time Employees (FTE)/Neighborhood
Assumption(s):

- Administrative staff requirements remain the same throughout all alternatives.
- Distribution system maintenance only includes pipe leak repair, flushing, and surveying.
- A full-time employee is defined as 1,920 hours/year based on 48 weeks/year

- The total number of neighborhoods in the FCU Water District is 35, based on a 35-square mile service area and 1-square mile neighborhoods. Annual base demand = 5,184 MG (Historical project demands, 2012 – Dec-Feb).

4.2 Cost of workforce transitional training

Summary: Transitional training is required for employees for new treatment technologies and cross-connection issues. This metric assigns a qualitative assessment of how different the treatment technologies will be, how many employees must be trained, and whether or not cross-connection training will be necessary.

Type of metric: Qualitative

Units: Word Scale (Lowest = 5; Low = 4; Medium = 3, High = 2; Highest = 1)

Assumption(s):

5.0 CONSUMER WATER QUALITY

5.1 Health care costs associated with exposure to disinfectant by-products (DBPs)

Summary: The age of the water in the potable distribution system was used as an indirect comparison of the health care costs associated with exposure to DBPs. A water quality analysis was run using EPANET2, for each of the alternatives, in the sample neighborhoods. (Appendix D)

Type of metric: Quantitative (indirect; minimum)

Units: Hours

Assumption(s): DBPs are directly proportional to the age in the distribution system. Health care costs from DBPs are therefore correlated to the age of water in the distribution system.

5.2 Costs associated with potential cross-connection failure

Summary: The risk of a cross-connection failure was used as an indirect comparison of the costs associated with cross-connection failure. The physical conditions considered in assessing the risks of cross-connection failure, for the alternatives, were: separation between the potable and non-potable distribution systems and service connections, average pressure of the non-potable and potable distribution systems, whether fire suppression is on the potable or non-potable systems, and the maximum elevation difference for the distribution systems.

Type of metric: Qualitative

Units: Word Scale (Lowest Risk = 5; Low Risk = 4; Moderate Risk = 3; High Risk = 2; Highest Risk = 1)

Assumption(s):

- The higher the risk of a cross-connection, the higher the costs associated with potential cross-connections.
- For the non-potable distribution systems, all garden hoses, irrigation systems, and fire sprinkler systems are hooked up to the non-potable system.

5.3 Costs associated with a source water contamination event

Summary: This metric evaluates the cost to the utility as a result of a water contamination event. Assessments were based on travel for correction and supplies and the number of locations affected.

Type of metric: Qualitative

Units: Word Scale (Lowest = 5; Low = 4; Medium = 3, High = 2; Highest = 1)

Assumption(s):

6.0 USE OF CITY WATER CORRIDORS

6.1 Avoided transaction costs associated with converting water rights from irrigation to municipal

Summary: This performance metric only applies to the Separated Irrigation alternative. Currently, some of the utilities' water rights are still designated for irrigation use. Since water from these rights cannot be used for municipal use, this is typically leased back to local agriculture (Mayer et al., 2009). The raw water used in the Separated Irrigation alternative is only used for landscape irrigation. This alternative would allow the utility to utilize these water rights still designated for irrigation use without having to change the beneficial use on the water right. However, if the utility uses these water rights, the timing and location of irrigation could change from the specified use. Additionally, it is likely water rights designated for municipal beneficial use will be needed to supplement water needed for landscape irrigation later in the irrigation season. This would result in a change of the diversion location on the municipal water rights.

This performance metric is currently excluded from the MCDA due to the complex nature of water rights in Colorado. A more detailed analysis of the City's water rights portfolio would be needed to determine if there is a potential savings for the Separated Irrigation alternative. It is difficult to determine the costs for making changes in beneficial use, diversion location, or location and timing of use to existing water rights. A lot depends on if there are any objectors to the changes the City would need to make, making cooperation with local irrigation and canal companies important before implementation.

Type of metric: Qualitative

Units: Word Scale (Large = 5; Substantial = 4; Moderate = 3; Small = 2; NA (Not Applicable) = 1)

Assumption(s): NA

7.0 RISKS OF LIMITED SUPPLY

7.1 Costs associated with alternative water supplies

Summary: The resiliency of the alternatives to water shortage was assessed for each alternative and this was used to assign a word scale for each alternative. The more resilient the alternative to water shortage, the lower the costs associated with acquiring alternative water supplies.

The scenarios considered in determining infrastructure resiliency to water shortage were: 1) drought or limited supply and 2) disruption to potable supply due to a power outage. The alternatives were rated by their level of resiliency in each scenario and then a word scale was assigned to each alternative.

Type of metric: Qualitative

Units: Word Scale (Lowest Risk = 5; Low Risk = 4; Moderate Risk = 3, High Risk = 2; Highest Risk = 1)

Assumption(s):

- The more risk of water shortage, the higher the costs to replace water shortage.

7.2 Risk of obsolete infrastructure

Summary: A qualitative evaluation of the risk of obsolete infrastructure refers to the possibility that installed infrastructure becomes unnecessary.

Type of metric: Qualitative

Units: Word Scale (Lowest Risk = 5; Low Risk = 4; Moderate Risk = 3, High Risk = 2; Highest Risk = 1)

Assumption(s):

8.0 RISK OF RATE CHANGES

8.1 Confidence in operations & maintenance projections

Summary: Confidence in the O&M projections for each alternative is evaluated qualitatively in comparison to the well-defined historical O&M costs for the existing water treatment facility.

Type of metric: Qualitative

Units: Word scale: (Very Good = 5, Good = 4, Average = 3, Poor = 2, Very Poor =1)

Assumption(s): Rate changes are dependent on changes in O&M costs.

9.0 OPPORTUNITY FOR NEW WATER MANAGEMENT STRATEGIES

9.1 Savings on later implementing an alternative water management strategy that could benefit from a dual distribution system

Summary: The goal of this metric is to estimate the savings in later implementing the dual distribution of alternative non-potable sources. The more linear feet of a dual distribution system, the less costs involved in later adding the distribution of alternative sources to meet non-potable demand.

Type of metric: Quantitative (indirect, maximum)

Units: L.F. (Same metric as Social 9.1 and Environmental 9.1)

Assumption(s):

- The more extensive the dual distribution system, the less cost involved in implementing alternative sources of supply.
- Assumed a 15-ft non-potable length for service lines.

10.0 REVENUE OPPORTUNITIES

10.1 Revenue generated from using extra capacity at water treatment facility to sell treated water wholesale to neighboring communities

Summary: The dual system alternatives free up capacity at the water treatment facility. This offers the utility an opportunity to use the spare capacity to generate revenue to help pay for the costs of implementing a dual water system alternative. The spare capacity in gallons/year was used as an indirect measure of the possible revenue that could be generated by selling water to neighboring communities.

Type of metric: Quantitative (indirect, maximum)

Units: Gallons/Year (Same metric as Social 10.1 and Environmental 10.1)

Assumption(s):

- Spare capacity at the existing 87 MGD central water treatment facility would be used to sell treated water wholesale to neighboring water districts.
- Capacity of central water treatment plant is shared across 35-square mile service area. The capacity for each 1-square mile sample neighborhood is 87 MGD/35

11.0 REGULATORY/POLITICAL RISK

11.1 Costs associated with changing an alternative back to the existing system or to make changes needed to meet new regulations

Summary: In order to meet future changes in regulations, alternative systems may need to be adjusted or returned to the existing system. Alternatives that deviate drastically from the existing system or illuminate current regulatory gaps produce a higher level of risk.

Type of metric: Qualitative

Units: Word Scale (Lowest Risk = 5; Low Risk = 4; Moderate Risk = 3, High Risk = 2; Highest Risk = 1)

Assumption(s):

- A larger deviation from the existing system will increase the risk of costs to return to the existing system or meet new regulations.
- Reversion of non-potable lines to potable requires additional measures discussed in Regulatory Barriers

11.2 The costs associated with increase in communication and managing public perception

Summary: This metric evaluates the risk of costs associated with communication and management of public perception as a result of the installation of an alternative to the existing system. Projected public perception of each alternative was estimated based on the level of the deviation from current operations including concerns for increased cost, performance, adaptability, liability, and environmental effects.

Type of metric: Qualitative

Units: Word Scale (Lowest Risk = 5; Low Risk = 4; Moderate Risk = 3, High Risk = 2; Highest Risk = 1)

Assumption(s): A larger deviation from the existing system will create a larger cost for communication and management of public perception.

ii. Social Performance Metric Calculations

A summary of the social performance metrics and the methodology used in the calculations is provided in this section. Appendix H provides the results of the performance metric calculations for each sample neighborhood.

1.0 IMPACTS OF NEW INFRASTRUCTURE

1.1 Disruption to community – the inconvenience of construction to the community and disruption to local business

Summary: The AwwaRF Asset Failure Cost Model (Cromwell III et al., 2002) was used to determine the social costs associated with the construction of new infrastructure. Only the routine social costs, of access impairment & travel delay, and customer outage & substitution, from the installation of the new infrastructure were included in this performance metric. For a summary of the model inputs and outputs for the alternatives refer to Appendix H.

Type of metric: Quantitative (minimum)

Units: US $

Assumption(s):

- New water infrastructure construction includes the following social costs: access & travel delay and customer outage & substitution.
- For a detailed list of assumptions used in the Asset Failure Cost Model, refer to Table H.1.

1.2 Increase in temporary employment

Summary: An increase in temporary employment is associated with an increase in new infrastructure. This metric is directly related to the capital cost value of each alternative, dividing the specific alternative capital cost for new infrastructure by the maximum capital cost in the design neighborhood.

Type of metric: Quantitative (maximum)

Units: Value on a scale of 0 to 1

Assumption(s):

2.0 ENERGY USE

2.1 Health impacts associated with air pollution

Summary: The health impacts associated with air pollution due to GHG emissions from energy use are directly proportional to the amount of energy use in water treatment and distribution. Refer to the economic performance metric in Appendix G for detailed calculations.

Type of metric: Quantitative (indirect, minimum)

Units: kWh/year (Same as economic performance metric 2.1)

Assumption(s):

- The higher the GHG emissions, the more air pollution and health impacts associated with air pollution.

3.0 ROUTINE MAINTENANCE

3.1 Disruption to community

Summary: Similar to the social costs associated with new infrastructure construction (economic 1.1), the AwwaRF Asset Failure Cost Model (Cromwell III et al., 2002) was used to determine the social costs associated with the routine maintenance. Only the routine social costs, of access impairment & travel delay, and customer outage & substitution, from routine maintenance were included in this performance metric. For a summary of the model inputs and outputs refer to Appendix H.

Type of metric: Quantitative (minimum)

Units: US $

Assumption(s):

- Routine maintenance disruption to community includes the following routine social costs: access & travel and customer outage & substitution.
- For a detailed list of assumptions used in the Asset Failure Cost Model, refer to Scenario 2 in Appendix H (Table H.3).

4.0 STAFFING

4.1 Employment and job security

Summary: The higher FTE/Neighborhood the higher job security. The value of FTE neighborhood equivalents was normalized by the maximum value to produce a score of 1 to 5 with 5 being the highest level of job security.

$$Job\ security = \frac{FTE/Neighborhood}{Max(\frac{FTE}{Neighborhood})}$$

Type of metric: Quantitative (maximum)

Units: Score 1-5

Assumption(s): Administration staffing will be the same for all alternatives

4.2 Increased earning potential for a higher skilled workforce

Summary: An increase in the skillset of the workforce will result in a higher earning potential for those employees. Due to this assumption, alternatives that require a higher skilled workforce represent a higher earning potential.

Type of metric: Qualitative

Units: Word scale: (None =1, Some = 2, Medium = 3, More = 4, Most = 5)

Assumption(s):

5.0 CONSUMER WATER QUALITY

5.1 Drinking water quality as a function of water age in the distribution system

Summary: A water quality analysis was run using EPANET2 for each of the alternatives to determine the water age in the sample neighborhoods (Appendix D).

Type of metric: Quantitative (minimum)

Units: Hours (Same as economic performance metric 5.1)

Assumption(s):

- DBPs are directly proportional to the age in the distribution system

5.2 Potential health risks from a cross-connection failure

Summary: Since every cross-connection failure is a potential health risk, the risk of a cross-connection failure was used. (Same as described in economic performance metric 5.2 Potential health risks from a cross-connection failure.)

Type of metric: Qualitative

Units: Word scale (Lowest Risk = 5; Low Risk = 4; Moderate Risk = 3, High Risk = 2; Highest Risk = 1)
(Same as economic performance metric 5.2)

Assumption(s): (Same as economic performance metric 5.2)

5.3 Level of adaptability to potential health risk from a source water contamination event

Summary: This metric evaluates the level of adaptability of each alternative to health risks associated with a source water contamination event. Assessments were based on response period due to travel time for correction and supplies and the number of locations affected.

Type of metric: Qualitative

Units: Word scale (Very Good = 5; Good = 4; Average = 3; Poor = 2; Very Poor = 1)

Assumption(s):

- Potential health risks from a source water contamination event are directly proportional to the level of adaptability of the water treatment system.

6.0 USE OF CITY WATER CORRIDORS

6.1 Enhancement of the City's water corridors

Summary: The Separated Irrigation alternative will result in an increase in in-stream flows (ISFs) in the irrigation ditches and in the CLP because water for irrigation demand will be diverted further downstream from the current location for the central water treatment facility. None of the other alternatives will increase ISFs.

Type of metric: Qualitative

Units: Word scale (Most = 5; More = 4; Medium = 3; Some = 2; None = 1)

Assumption(s):

- An increase in ISFs in the ditches and CLP will result in enhancement of the City's water corridors.

6.2 Benefits to local ditch companies

Summary: The Separated Irrigation alternative uses the network of irrigation ditches and this will benefit the local ditch companies because FCU will need to share in the costs of maintaining this network in the water district.

Type of metric: Qualitative

Units: Word scale (Most = 5; More = 4; Medium = 3; Some = 2; None = 1)

Assumption(s):

- Upgrades and retrofits to the existing irrigation ditch network will be required to implement the Separated Irrigation alternative.
- Increased maintenance of the irrigation ditch network throughout the urban corridor will result in fewer non pass-through costs to the ditch companies due to vandalism, urban trash, canal drowning, and restricted ROW. (Wilkens-Wells et al., 2003)

7.0 RISKS OF LIMITED SUPPLY

7.1 Resiliency of infrastructure to changes in supply

Summary:

The resiliency of the alternatives to water shortage was assessed for each alternative. The scenarios considered in determining infrastructure resiliency to water shortage were: 1) drought or limited supply and 2) disruption to potable supply due to a power outage. The alternatives were rated by their level of resiliency in each scenario and then an average of the results from the two scenarios was used to assign a final word scale.

Type of metric: Qualitative

Units: Word scale (Most Resilient = 5; Resilient = 4; Neutral = 3; Not Resilient = 2; Least Resilient = 1)

Assumption(s): Same as economic performance metric 7.1.

8.0 RISK OF RATE CHANGES

8.1 Affordability of monthly water bill for low or fixed income households

Summary: This metric reflects rate changes based on change in O&M cost from the existing O&M cost. A positive value indicates a decrease in rates while a negative value indicates an increase in rates related to higher O&M costs.

$$Affordability = O\&M(existing) - O\&M(alternative)$$

Type of metric: Quantitative (maximum)

Units: US $

Assumption(s): Rate changes are dependent on changes in O&M costs. Existing water treatment O&M cost for the entire utility = $6,469,397 with a total water production of 8,753.9 MG/year.

9.0 OPPORTUNITY FOR NEW WATER MANAGEMENT STRATEGIES

9.1 Being an innovative community and potential to increase ISFs for recreational uses

Summary: The goal of this metric is to estimate the potential to use the dual distribution systems in the alternatives to also distribute alternative sources of water, such as reclaimed, gray or stormwater, and the effects this would have on ISFs in the CLP for recreational uses. The more linear feet of a dual distribution system, the more alternative sources could be used, and the more ISFs left in the CLP.

Type of metric: Quantitative (indirect, maximum)

Units: L.F. (Same metric as Economic 9.1 and Environmental 9.1)

Assumption(s):

- The more extensive the dual distribution system, the less work involved in implementing alternative sources of supply.
- Using alternative sources of supply (reclaimed, gray, stormwater) would result in an increase in CLP ISFs.
- Assumed a 15-ft non-potable length for service lines.

10.0 REVENUE OPPORTUNITIES

10.1 Improve water security in neighboring communities and increasing jobs in Fort Collins

Summary: The dual system alternatives free up capacity at the water treatment facility. If this spare capacity is used to sell treated water to neighboring water districts, that may not have the spare capacity to meet their growing demand, then the less need for water treatment facility expansion in the region and increases the number of jobs in Fort Collins.

Type of metric: Quantitative (maximum)

Units: Gallons/Year (Same metric as Economic 10.1 and Environmental 10.1)

Assumption(s): (Same metric as Economic 10.1)

11.0 REGULATORY/POLITICAL RISK

11.1 Public acceptance of the alternatives

Summary: This metric evaluates the public perception as a result of the installation of an alternative to existing central water treatment and distribution. Projected public perception of each alternative was estimated based on the level of the deviation from current operations including concerns for increased cost, performance, adaptability, liability, and environmental effects. A larger deviation from the existing system will challenge public acceptance of alternatives.

Type of metric: Qualitative

Units: Word scale: (Very Poor = 1, Poor = 2, Average = 3, Good = 4, Very Good = 5)

Assumption(s):

iii. Environmental Performance Metric Calculations

A summary of the environmental performance metrics and the methodology used in the calculations is provided in this section. Appendix I provide the results of the performance metric calculations for each sample neighborhood.

1.0 IMPACTS OF NEW INFRASTRUCTURE

1.1 GHG emissions

Summary: This performance metric evaluates the GHG emissions associated with construction of the new infrastructure for the alternatives. New construction results in GHG emissions from transport of materials, equipment used for construction, and the embodied energy associated with manufacturing materials such as pipes. The new infrastructure capital costs (economic performance metric 1.1) were used as an indirect comparison of the GHG emissions associated with the new infrastructure. The higher the capital cost for the alternative, the larger the project, and the higher the GHG emissions.

Type of metric: Quantitative (indirect, minimize)

Units: US $

Assumption(s):

- The larger the construction project, the more GHG emissions emitted.

1.2 Temporary stormwater pollution

Summary: The footprint of the new construction for the alternatives was calculated and the alternative with the largest footprint was assigned a 1 and the alternative with the smallest footprint was assigned a 5. The footprint of the Wes Tech Trident Package System was used for the neighborhood treatment plant footprint and footprints of POE treatment systems were estimated for single/duplex service connections and multi-family/commercial service connections. The minimum trench width required by the FCU Construction Standards is a minimum clearance of 12-inches on either side of the pipe. Below is the equation used to calculate the construction footprint of the new distribution system infrastructure:

$$DS\ Footprint\ (ft^2) = \sum [pipe\ length\ (ft) \times (pipe\ diameter\ (ft) +\ 2ft)]$$

Type of metric: Quantitative (indirect, minimum)

Units: square feet

Assumption(s):

- The larger the footprint of the new construction the more temporary sediment pollution of storm water

2.0 ENERGY USE

2.1 Annual GHG emissions in CO_2e

Summary: Fort Collins uses a GHG Emission Management System (GEMS) to quantify emissions from FCU. The 2012 emission factor used for electricity in GEMS was 1,672 lbs CO_2e/MWh (City of Fort Collins Environmental Services, 2012). This was used to convert the energy use, in the economic performance metric 2.1 Total annual energy use, into CO_2e.

Type of metric: Quantitative (minimum)

Units: lbs CO_2e

Assumption(s):

- Only includes GHG emissions from electricity use

3.0 ROUTINE MAINTENANCE

3.1 Annual GHG emissions in CO_2e

Summary: This metric focuses on the GHG emissions due to maintenance vehicles and equipment.

Type of metric: Qualitative

Units: Word scale (Lowest = 5; Low = 4; Medium = 3; High = 2; Highest =1)

Assumption(s):

- GHG emissions from water treatment and distribution energy use is excluded because it was already accounted for in Environmental performance metric 2.1.
- The alternatives all include more distribution system to maintain or more water treatment facilities to maintain, therefore it was assumed that the lowest level of energy use would be for the existing system.

3.2 Annual chemical consumables for water treatment

Summary: Five critical chemicals were tracked in terms of tons/year for each alternative. These chemicals include chlorine, aluminum sulfate, calcium hydroxide, fluoride, and carbon dioxide. The reported value for central water treatment use was based on existing chemical use data and scaled by demand. While the Neighborhood and Point-of-Entry alternatives do not require coagulant, they will still require use of CaOH, F, and CO_2 prior to distribution. The Point-of-Entry alternative uses UV disinfection instead of chlorine.

Type of metric: Quantitative (minimum)

Units: Tons/Year

Assumption(s):

- The Neighborhood and Point-of-Entry alternatives include central addition of Calcium Hydroxide, Fluoride and Carbon Dioxide.

- Both the Neighborhood and Point-of-Entry alternatives must add calcium hydroxide, fluoride and carbon dioxide to the total demand at the central facility due to the lack of dual transmission
- The Point-of-Entry alternative will treat total demand. 1 MGD package plant requires 20 lb/day chlorine.

4.0 STAFFING

4.1 Employee transport GHG emissions in CO_2e

Summary: This metric is based on the number of FTE/Neighborhood. An increase in the number of FTE required for treatment and distribution becomes an increase in the number of FTE commuting to work and associated GHG emissions.

Type of metric: Quantitative (minimum)

Units: FTE/Neighborhood

Assumption(s): If employee does not work at the utility, there is no way to predict if/where that employee may work alternatively.

5.0 CONSUMER WATER QUALITY

5.1 Water quality of receiving water bodies

Summary: Evaluating the water quality of receiving water bodies, specifically the Cache la Poudre River, based on chemical addition during water treatment and distribution is dependent on the levels of chlorine and coagulant addition. Alternatives that limit chemical use will have higher quality in receiving water bodies.

Type of metric: Qualitative

Units: Word scale: (No Change = 1, Limited Benefit = 2, Some Benefit = 3, More Benefit = 4, Most Benefit = 5)

Assumption(s):

- No effects in receiving water quality from calcium hydroxide and fluoride.
- Largest environmental concerns are related to disinfection byproducts (DBPs) from chlorination and dissolved monomeric aluminum from coagulant addition. Based on research, DBPs would be a more likely issue in receiving water bodies than the monomeric aluminum issues, however they are both very small risks for receiving water bodies since these chemicals are used in potable water treatment.

6.0 USE OF CITY WATER CORRIDORS

6.1 Benefits to species and natural systems

Summary: The Separated Irrigation alternative will result in an increase in in-stream flows (ISFs) in the irrigation ditches and in the CLP, which will benefit species and natural systems.

Type of metric: Qualitative (Same as social performance metric 6.1)

Units: Word scale (Most = 5; More = 4; Medium = 3; Some = 2; None = 1)

Assumption(s):

- The more ISFs, the more benefits to species and natural systems.

7.0 RISKS OF LIMITED SUPPLY

7.1 Effects variable supply could have on the City's water corridors

Summary: This metric assigns a risk level to the potential affects variable supply could have on the City's water corridors. The existing system acts as a baseline for whether alternatives will minimize the effects on city water corridors by providing additional flow.

Type of metric: Qualitative

Units: Word scale: (Lowest Risk = 5; Low Risk = 4; Moderate Risk = 3, High Risk = 2; Highest Risk = 1)

Assumption(s):

- Increase in flow limits the negative environmental effects of variable supply in city water corridors

8.0 RISK OF RATE CHANGES

8.1 Potential changes in irrigation water demand due to rate changes

Summary: This metric is an estimate of the effects changing water rates could have on irrigation demand. If O&M costs decrease from the existing system, then the City could see an increase in water demand because the rates will be lower. If the O&M costs go up from the existing system, then the City could see a decrease in demand due to higher water rates. The equation used was:

$$Impact\ on\ demand = Existing\ O\&M - Alternative\ O\&M$$

Type of metric: Quantitative (indirect, minimum)

Units: US $

Assumption(s):

- Rate changes are a function of O&M costs

9.0 OPPORTUNITY FOR NEW WATER MANAGEMENT STRATEGIES

9.1 Increase in in-stream flows due to using alternative sources of water will result in benefits to species and natural systems

Summary: This metric estimates the potential to use the dual distribution systems in the alternatives to also distribute alternative sources of water, such as reclaimed, gray or stormwater, and the effects this would have on ISFs in the CLP. The more linear feet of a dual distribution system, the more alternative sources could be used, and the more ISFs left in the CLP.

Type of metric: Quantitative (indirect, maximum)

Units: L.F. (Same metric as Economic 9.1 and Social 9.1)

Assumption(s): (Same metric as Economic 9.1 and Social 9.1)

10.0 REVENUE OPPORTUNITIES

10.1 Decreasing need for new water treatment facility construction in the regional community

Summary: Dual system alternatives free up capacity at the water treatment facility. If this spare capacity is used to sell treated water to neighboring water districts that may not have the spare capacity to meet their growing demand, then the less need for water treatment facility expansion. Smaller facility footprints and less construction result in fewer environmental impacts.

Type of metric: Quantitative (maximum)

Units: Gallons/Year (Same metric as Economic 10.1 and Social 10.1)

Assumption(s): (Same metric as Economic 10.1 and Social 10.1)

11.0 REGULATORY/POLITICAL RISK

11.1 Negative environmental impacts from mitigation required

Summary: Two regulatory concerns were considered: 1) addition of regulation, which would specify water quality requirements for raw water irrigation, and 2) changes to water treatment monitoring and compliance. In order to meet changes in irrigation water quality or water treatment monitoring and compliance requirements, additional construction or adjustment may be required. A greater risk of necessitating these adjustments results in an increased opportunity for associated negative environmental impacts.

Type of metric: Qualitative (minimum)

Units: Word scale: (Lowest Risk = 1, High Risk = 2, Moderate Risk = 3, Low Risk = 4, Highest Risk = 5)

Assumption(s):

- No change = no environmental impact

e. Life-Cycle Costs (LCC)

A simple Life-Cycle Cost (LCC) analysis was performed for each of the alternatives in the three sample neighborhoods. The analysis includes initial capital, replacement, and O&M costs associated with each alternative. The remaining value of the water infrastructure was subtracted from the costs to give the estimated LCC (see equation below).

$$LCC = Initial\ capital\ costs + Replacement\ cost + Annual\ O\&M\ costs - Remaining\ value$$

A 2014 constant cost analysis was performed with all future costs discounted to the base date of 2014. The following was assumed in the analysis:

- A study period of 70-years was used for the analysis, which is the anticipated lifetime of the new PVC pressure pipes for the dual distribution system alternatives (AWWA, 2012).

- It was assumed that costs would change at the rate of inflation since such a long study period was used, resulting in a real escalation rate of 0%.
- A real discount rate (exclusive of inflation) of 3.375% was assumed per the Bureau of Reclamation (2014).
- Linear depreciation was used to calculate the remaining value of infrastructure at the end of the study period. Any removal costs or salvage values were excluded from the calculation.
- The anticipated service lifetimes previously mentioned, in this section for the Economic Performance Metric 1.2 Replacement Costs, were used:
  - Central and Neighborhood water treatment facilities = 50 years
  - POE water treatment systems = 20 years
  - New PVC pressure pipe = 70 years
  - Existing pipe lifetimes (see Appendix A)
  - Existing central WTF lifetime = 10 years (City of Fort Collins, 2010)

The initial capital costs were calculated in economic performance metric 1.1 and the replacement costs and remaining value calculations were calculated in economic performance metric 1.2.

Annual energy from economic performance metric 2.1 was multiplied by $0.09/kWh to obtain the annual energy cost for each alternative. $0.09/kWh is the average cost/kWh for the year 2011 (Voytko, 2013).

A uniform present value factor was used to calculate the 2014 PV of the annually recurring energy, water treatment O&M, and distribution system O&M costs from economic performance metrics 2.1, 3.1, and 3.2 respectively. The equation used to calculate the 2014 PV of annually recurring uniform costs was:

$$2014\ PV = A_o \times \frac{(1+d)^n - 1}{d(1+d)^n}$$

Where:

$A_o = Annual\ cost\ in\ 2014\ constant\ dollars$

$d = real\ discount\ rate\ (exclusive\ of\ inflation) = 3.375\%$

$n = study\ period = 70\ years$

III. Results and Discussion

a. Stakeholder Relative Importance Ratings

i. Individual Stakeholder Results

Input on relative importance of the eleven main criteria was collected from 17 representatives of city departments. Seven distinct stakeholder groups were formed from these responses by combining groups with similar relative importance profiles. These stakeholder groups are defined as Planning, Institute for the Built Environment, Economic Health/Urban Renewal, Communications & Public Involvement, Transportation Planning, Natural Areas, and Engineering. Stakeholder group relative importance factors were calculated as the average of one to seven representative responses (Figures 3.1 through 3.7). The number of representatives (n) is reported for each group. Stakeholder groups with three or more representatives display a standard deviation to show the variation of the responses for each criterion among a group. Planning provided the most balanced ratings for all criteria from a triple bottom line standpoint (Figure 3.1). The highest economic ratings were given to the impacts of new infrastructure, energy use, and consumer water quality. Consumer water quality was also a social standout and the highest environmental ratings were given to consumer water quality and revenue opportunities. The Institute for the Built Environment showed a wide range of ratings (Figure 3.2). The largest variability was in economic ratings. Environmental ratings were typically the highest followed by social. Economic Health/Urban Renewal gave emphasis to economic and social aspects of main criteria with the exception of consumer water quality and regulatory/political risk (Figure 3.3). Communications & Public Involvement displayed a wide variety of importance responses (Figure 3.4). Economic impacts of new infrastructure, energy and routine maintenance were highly rated as were social impacts of new infrastructure and regulatory/political risk and environmental use of city water corridors. Transportation Planning also exhibited balanced relative importance ratings with several economic and social outliers (Figure 3.5). Natural Areas grouped together respondents giving high environmental ratings to all criteria (Figure 3.6). Engineering demonstrated balanced importance ratings for the triple bottom line for each criterion with variability in the comparative rating between criteria (Figure 3.7).

From these profiles, it is evident that each stakeholder group provides a unique set of relative importance ratings from the triple bottom line perspective of the main criteria. Detailed stakeholder response information is provided in Appendix C.

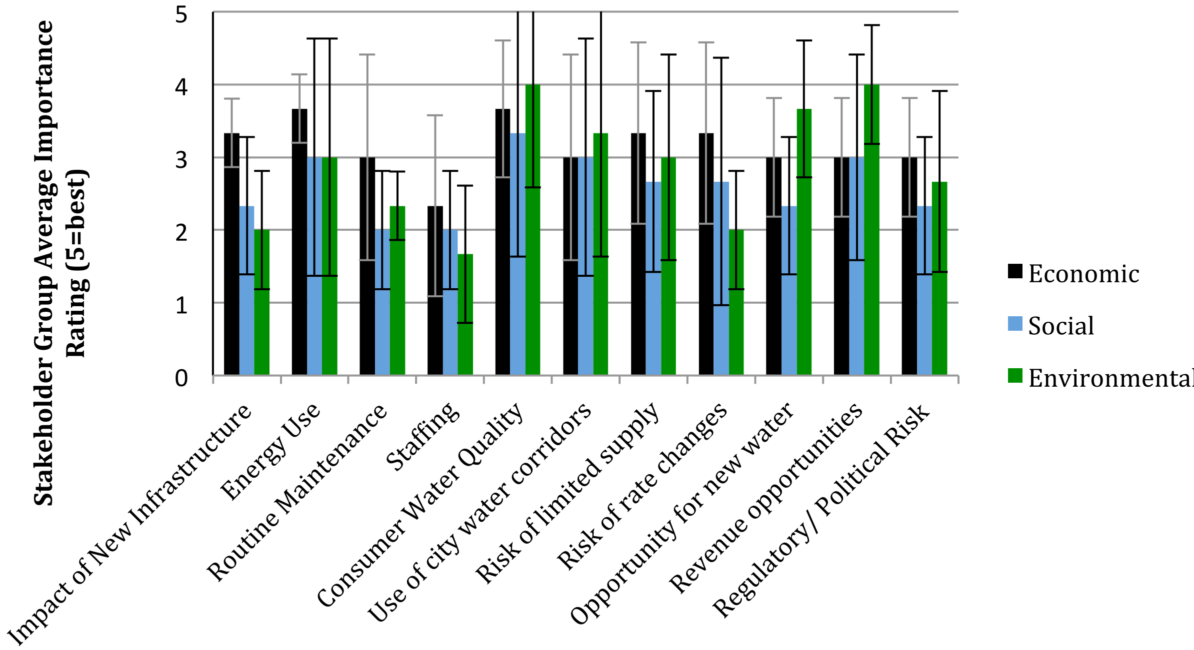


Figure 3.1 – Relative Importance Ratings for Planning +/- 1 Standard Deviation (n=3)

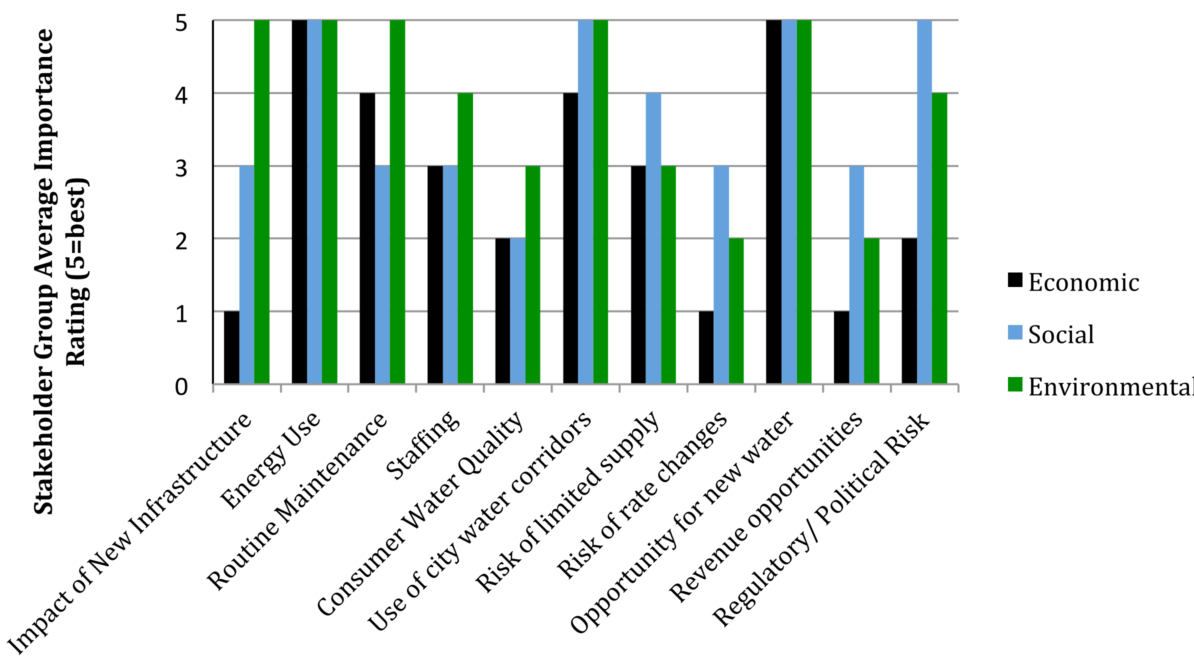


Figure 3.2 – Relative Importance Ratings for Institute for the Built Environment (n=1)

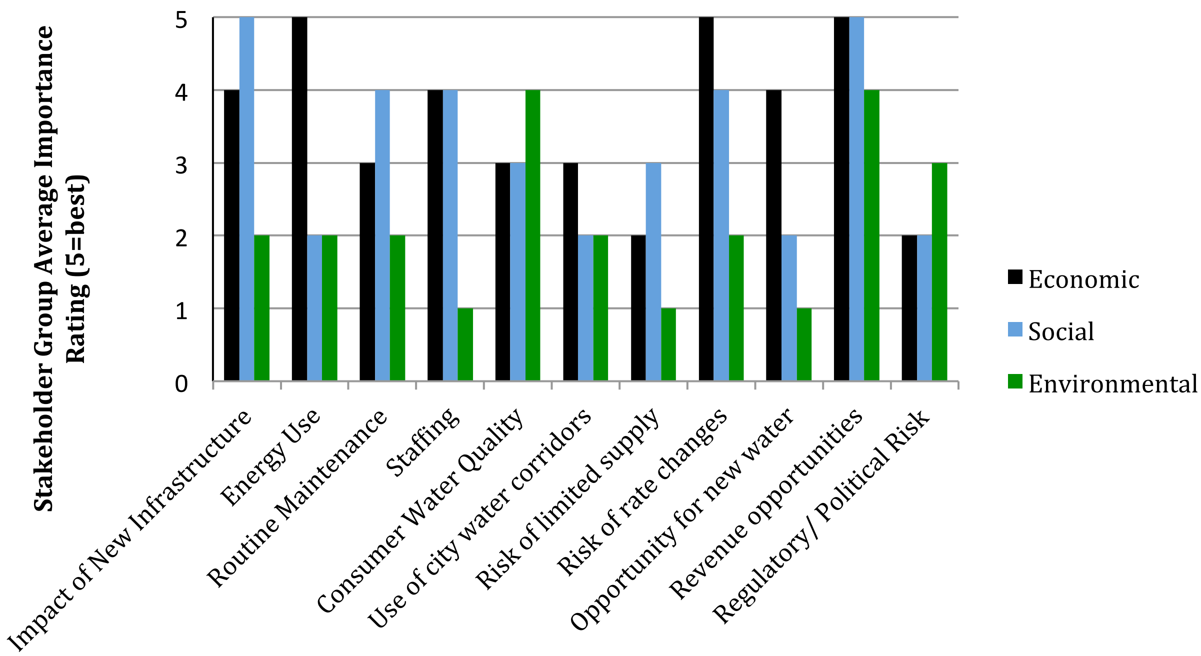


Figure 3.3 – Relative Importance Ratings for Economic Health/Urban Renewal Authority (n=1)

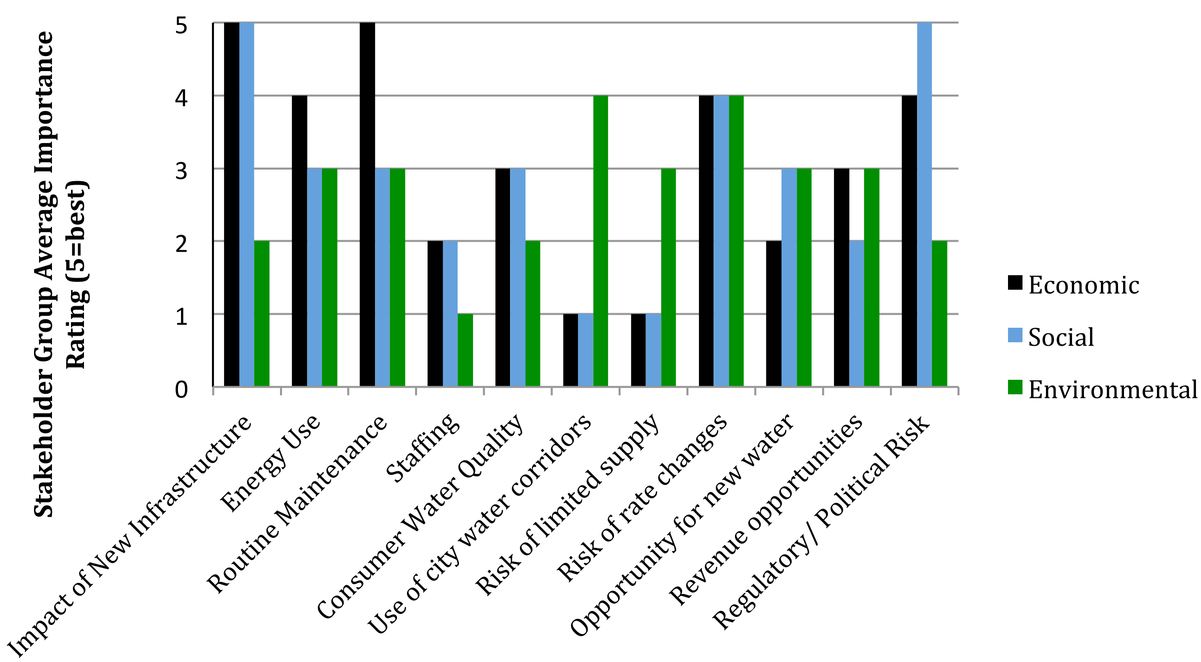


Figure 3.4 – Relative Importance Ratings for Communications & Public Involvement (n=1)

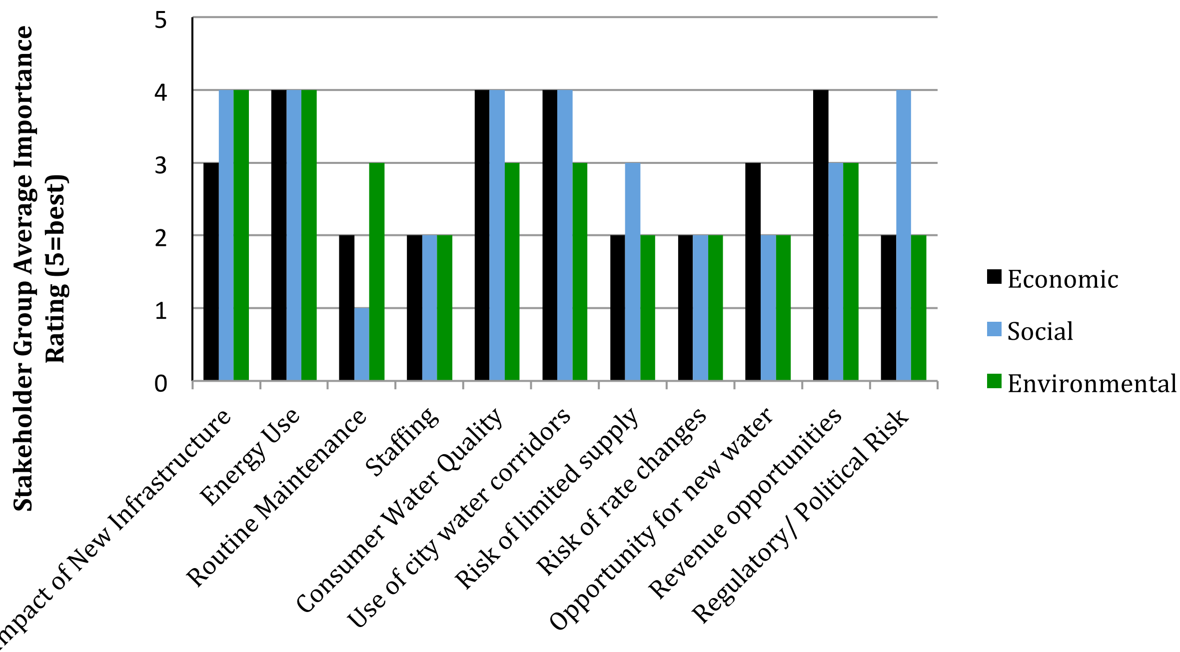


Figure 3.5 – Relative Importance Ratings for Transportation Planning (n=1)

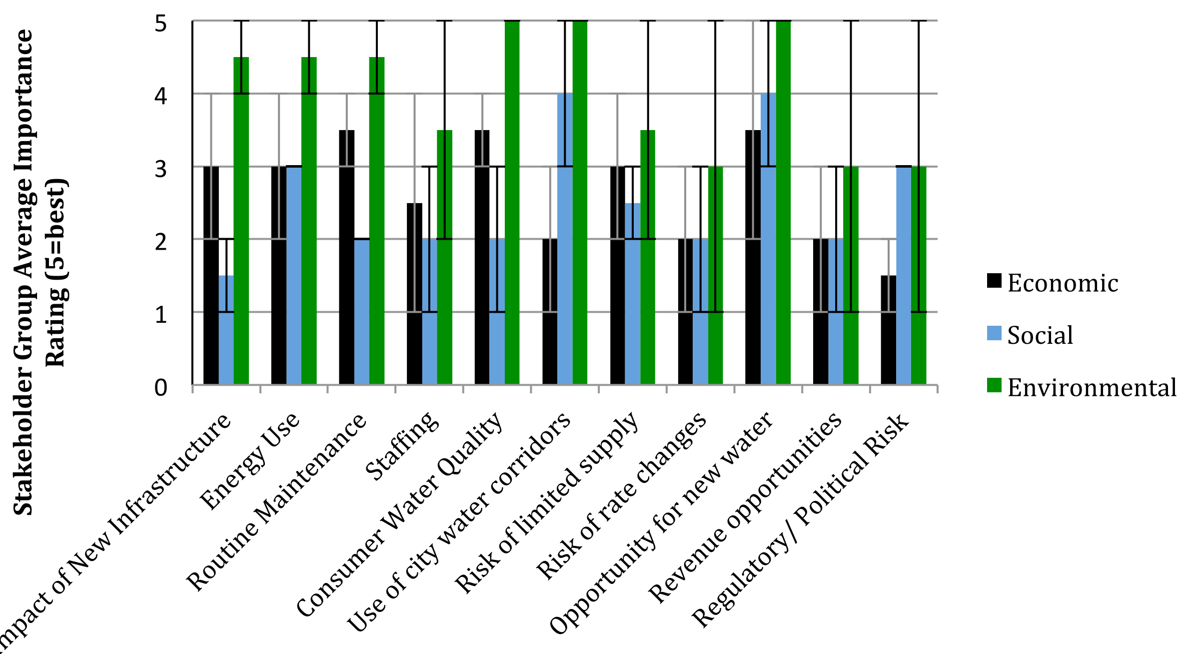


Figure 3.6 – Relative Importance Ratings for Natural Areas (n=3)

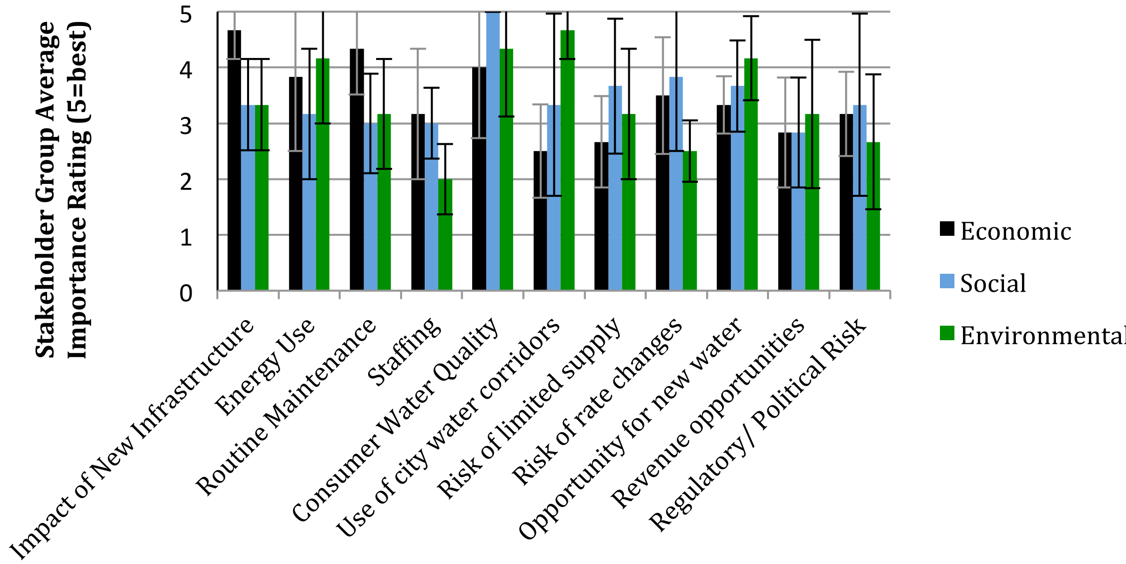


Figure 3.7 – Relative Importance Ratings for Engineering (n=7)

ii. Average Stakeholder Results

Results from averaging all stakeholder relative importance factors shows a balanced set of average ratings ranging from roughly 2.5 to 4 on a scale of 1 to 5 (Figure 3.8). The spread of responses is similar for all criteria. Four criteria received the highest ratings from an economic perspective, three from social, and four from environmental. All of these observations suggest a balanced profile created by a highly variable set of responses representing interests of departments in the City of Fort Collins.

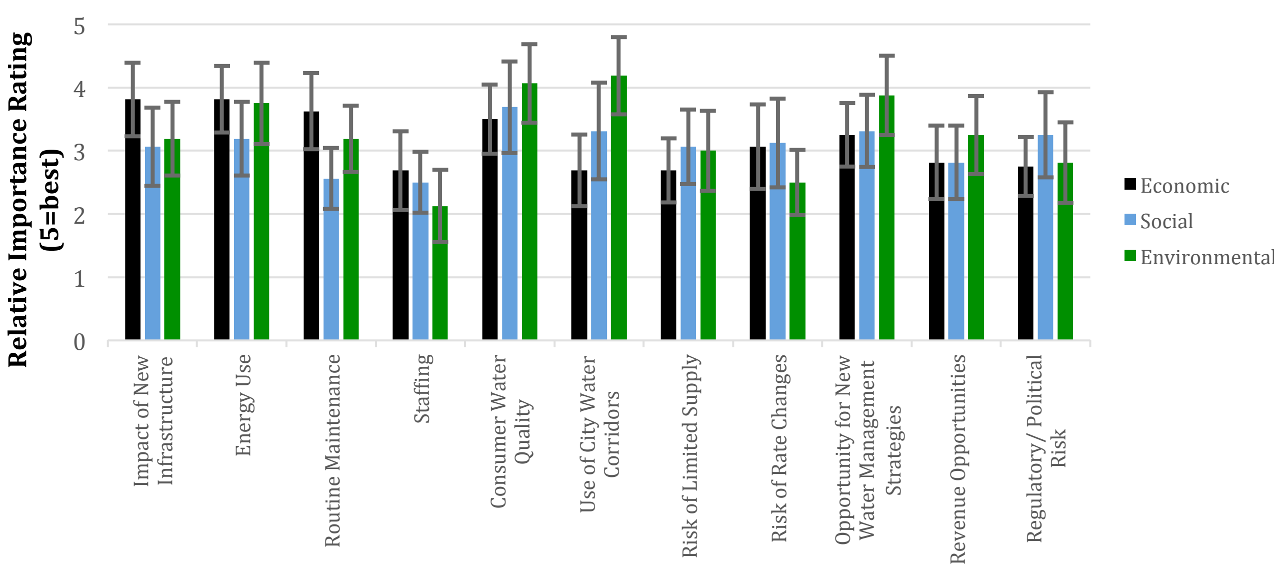


Figure 3.8 –Relative Importance Ratings for Main Criteria by Stakeholder Average +/- 1 Standard Deviation (5 = best)

Engineering/Utilities, Communications & Public Involvement and Transportation Planning each demonstrated balanced responses among the triple bottom line perspectives (Figure 3.9). Deviations from this pattern are exemplified by the low environmental importance rating from Economic Health/Urban Renewal Authority or the high environmental importance rating for Natural Areas. This average relative importance rating profile is used for the analysis of the MCDA for each design neighborhood.

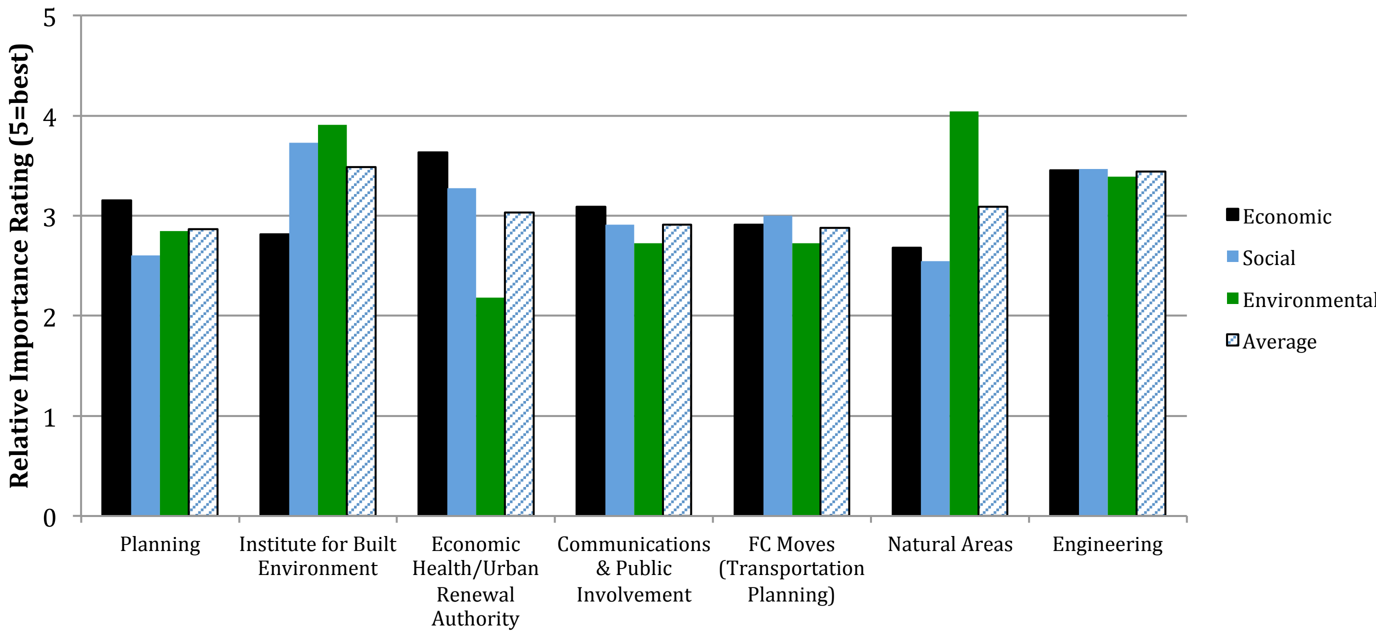


Figure 3.9 – Summary of Average Relative Importance Ratings by Stakeholder Group from a TBL Perspective +/- 1 Standard Deviation (5=best)

b. MCDA Results

To ensure the priorities of the City's stakeholders were met, and to make the most robust decision, the alternatives were evaluated using several different criteria weighting scenarios. First, equal weights for criteria were applied to determine the best performing alternative if all criteria were equally important. This approach established a baseline to measure how stakeholder priorities would affect the preferred alternative. The MCDAs were then run using the criteria weightings determined by each stakeholder group's priorities and using the average of all the group weightings. Finally, three alternative weighting scenarios were run to address concerns about the dilution of initial key drivers, the impact of a criterion that only applies to the Separated Irrigation alternative, and the assumption that the utility would need to conduct all maintenance in the Point-of-Entry alternative.

i. Equal Weighting Results

MCDA results are presented for each neighborhood with equal weighting for all criteria (Figures 3.10 through 3.12). Evaluating the TBL in the absence of stakeholder preference facilitates a baseline for the comparison of the impacts average stakeholder relative importance ratings have on the results. Despite key differences in land use breakdown, population density, distribution system layout, and water demand, the equally weighted MCDA shows very similar results for all design neighborhoods. Central/Dual and Separated Irrigation alternatives rank first and second in the TBL, with the exception of Separated Irrigation ranking closely third economically behind Central/Dual and Existing respectively. The Existing system ranks last in terms of social and environmental bottom lines in all design neighborhoods. Decentralized water treatment alternatives, Neighborhood and Point-of-Entry, score lower than the centralized treatment alternatives Central/Dual and Separated Irrigation in all cases.

Central/Dual and Existing are the highest rated economic alternatives. Separated Irrigation ranks third economically; however, it is still competitive with Central/Dual and Existing. It is important to note that high economic performance does not mean the lowest financial cost. Although Separated Irrigation costs less to implement than Central/Dual, it has higher O&M costs due to the additional energy required for pumping, canal maintenance, and blowing out the irrigation system in the fall. It also only has access to the CLP water resources and in the late summer months may require alternative water sources to meet landscape irrigation needs. For these reasons, Separated Irrigation does not perform as high economically as Central/Dual. Likewise, Central/Dual requires a high initial investment, but the benefits of cutting water treatment replacement costs and O&M costs by reducing the volume of water treated, eliminating peak demand in summer months, and allowing the city to save higher quality water resources for potable demand result in a higher economic performance than the existing system. The economic results suggest that it may be financially feasible to implement a dual distribution alternative that maintains central water treatment for potable supply.

From both a social and environmental standpoint, all alternatives score higher than the existing system reflecting the expected benefits associated with dual water systems. Central/Dual is the top scoring alternative on the social bottom line; however, Central/Dual and Separated Irrigation remain relatively close. The decentralized treatment options do not demonstrate as much of a social advantage over the existing system. Separated Irrigation receives a higher score than the rest of the alternatives in the environmental bottom line followed by Central/Dual.

Neighborhood 1

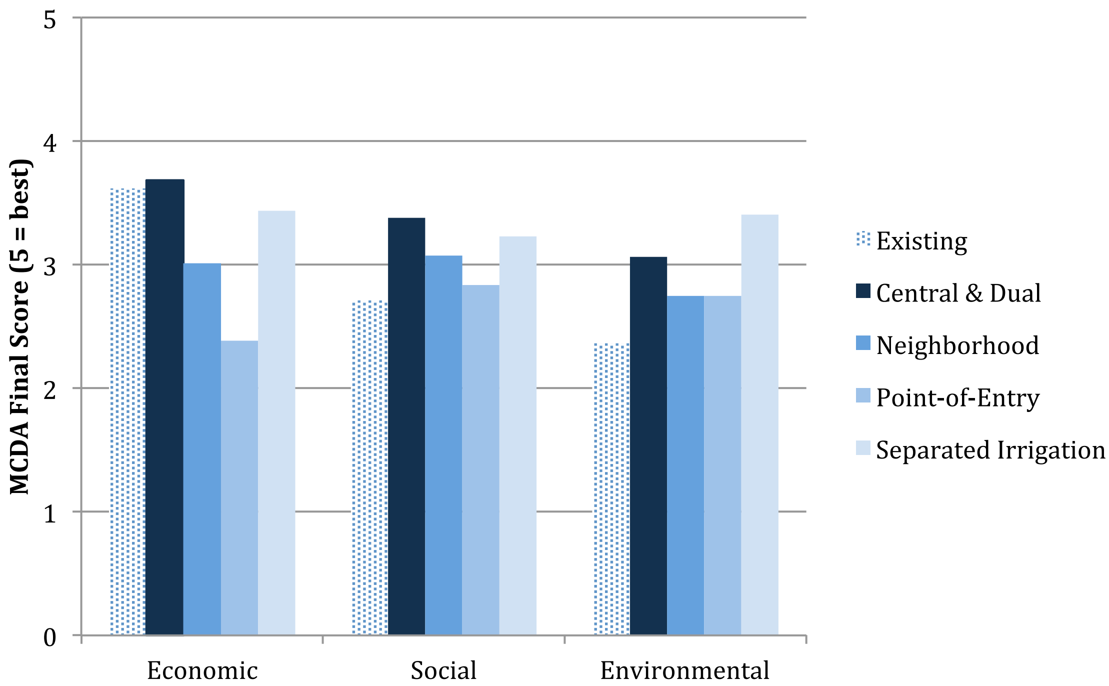


Figure 3.10 – Neighborhood #1 MCDA Equal Weighting Results (5 = best)

Neighborhood 2

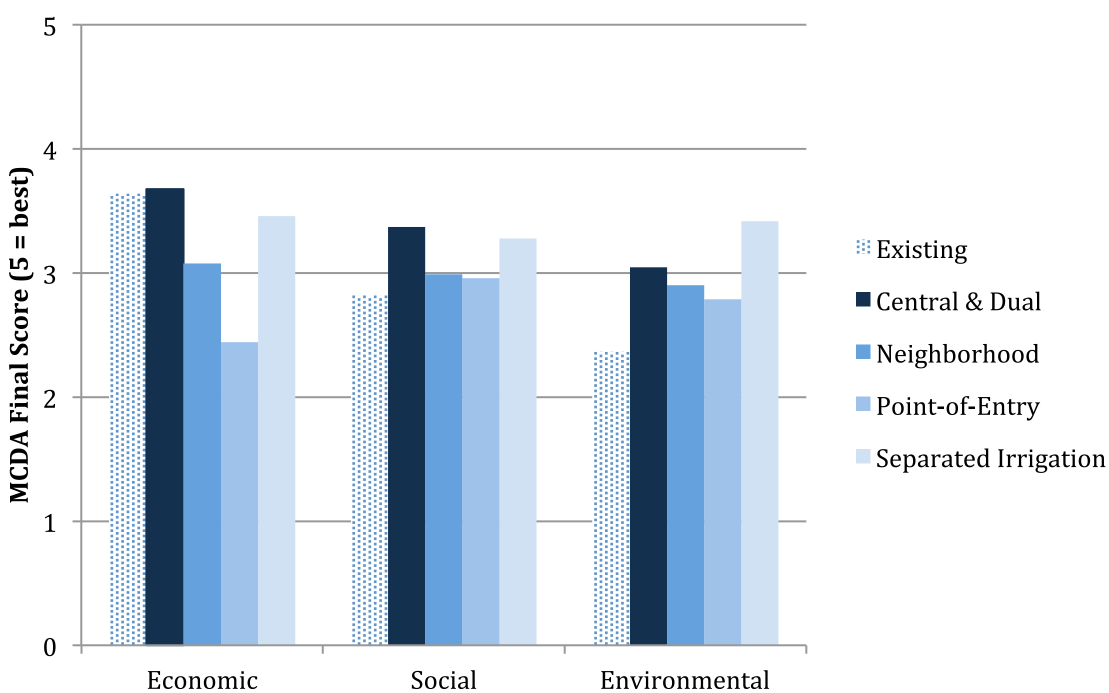


Figure 3.11 – Neighborhood #2 MCDA Equal Weighting Results (5 = best)

Neighborhood 3

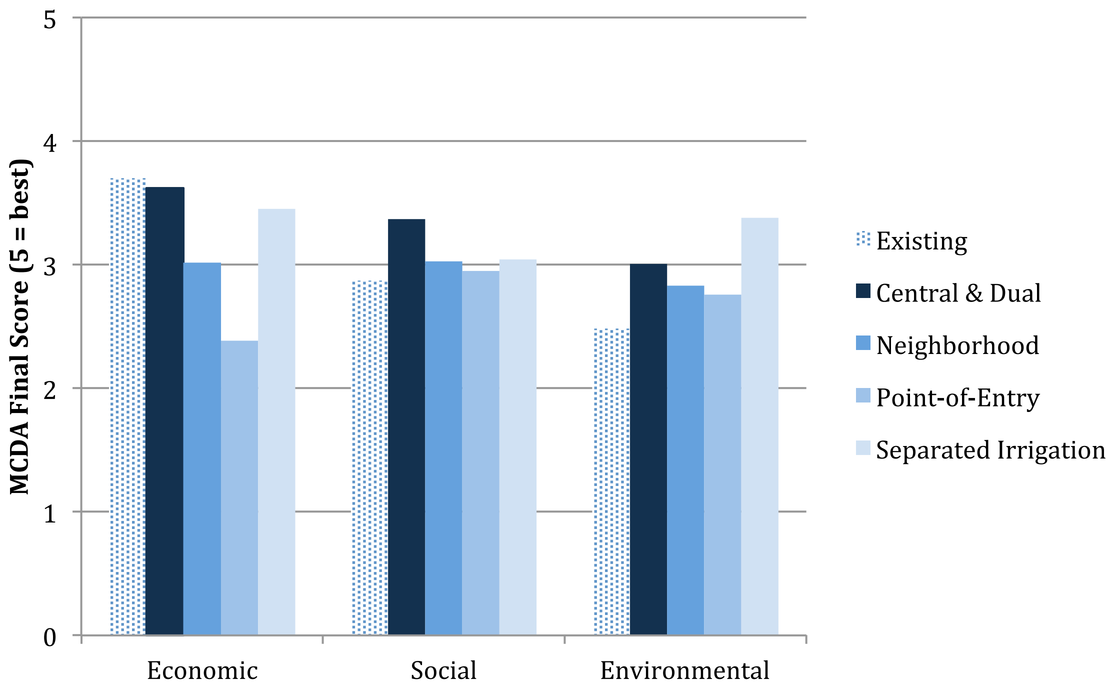


Figure 3.12 – Neighborhood #3 MCDA Equal Weighting Results (5 = best)

In total, Central/Dual and Separated Irrigation have the best performance and are equivalent to each other in cumulative score (Figure 3.13). Both alternatives are feasible in comparison to the existing system. Central/Dual has consistently better economic and social performance than Separated Irrigation, while Separated Irrigation outperforms Central/Dual in environmental performance demonstrating the trade-offs between the different alternatives. Both alternatives improve water supply efficiency, flexibility and resiliency; however, Central/Dual has the additional benefits of using less energy and improving drinking water quality and Separated Irrigation has the additional benefit of increasing flows in the water corridors. It is important to note that further analysis of the City's water rights is required to determine changes in flows through the City's water corridors in the Separated Irrigation alternative.

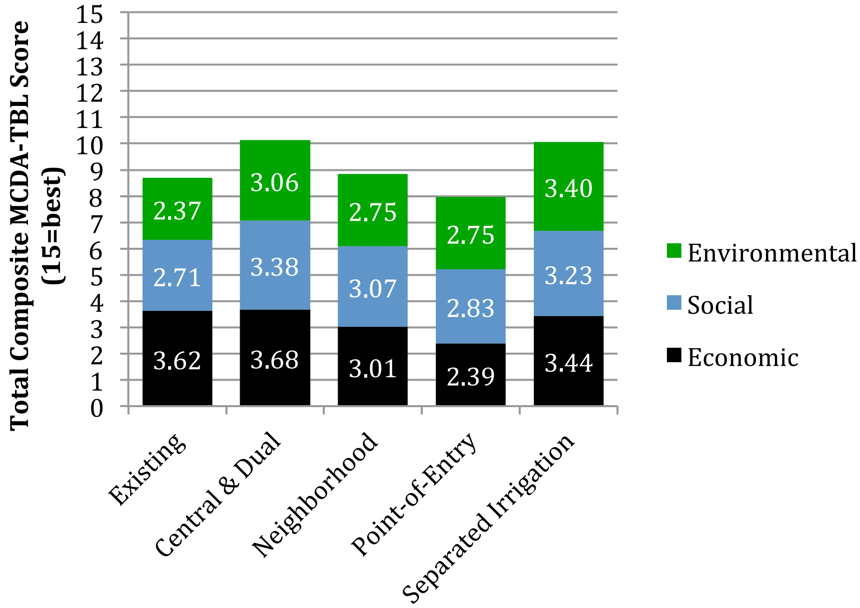


Figure 3.13 – Neighborhood 1 Cumulative Equal Weighting Results

ii. Average Stakeholder Results

The final MCDA results for each neighborhood are presented in box and whisker plots to display the average score for all stakeholder scenarios, one standard deviation in each direction and the minimum and maximum stakeholder scores (Figure 3.14).

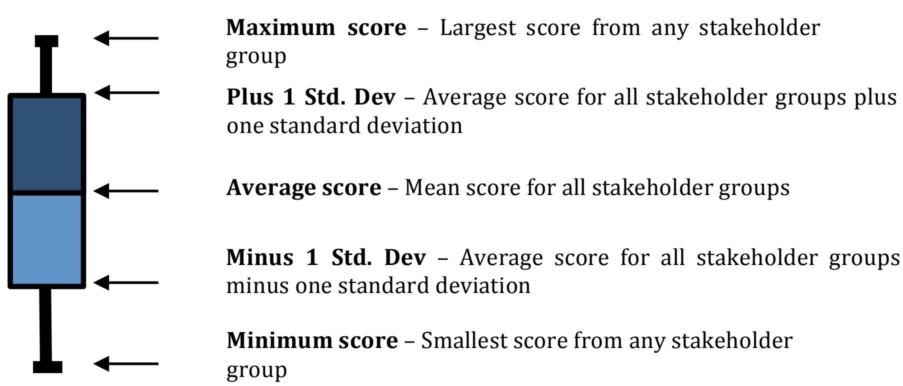


Figure 3.14 - Description of box and whisker MCDA results

Box and whisker plots are provided for MCDA results for each design neighborhood (Figures 3.15 - 3.17). The outcome is a presentation of the triple bottom line for each alternative compared against the others for each neighborhood with a visual display of the spread of the values.

Neighborhood 1

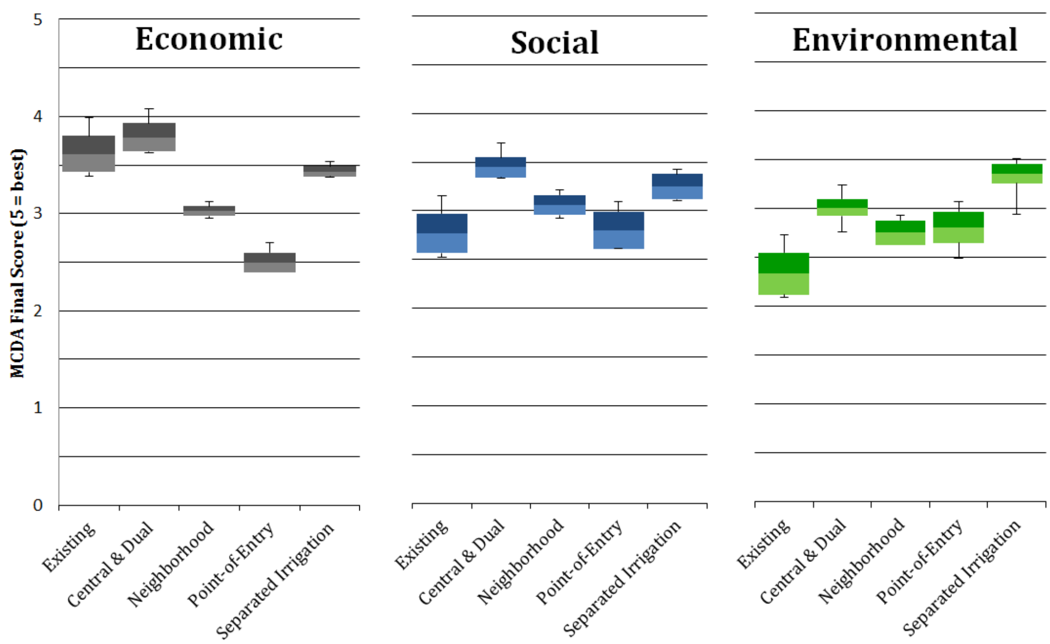


Figure 3.15 – Neighborhood #1 MCDA Stakeholder Average Results (5 = best)

Neighborhood 2

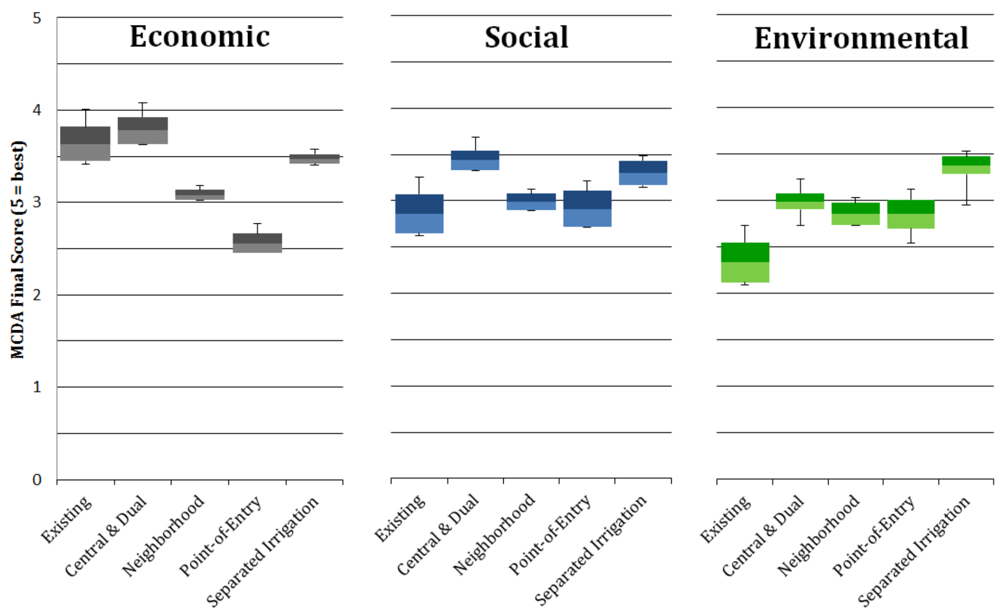


Figure 3.16 – Neighborhood #2 MCDA Stakeholder Average Results (5 = best)

Neighborhood 3

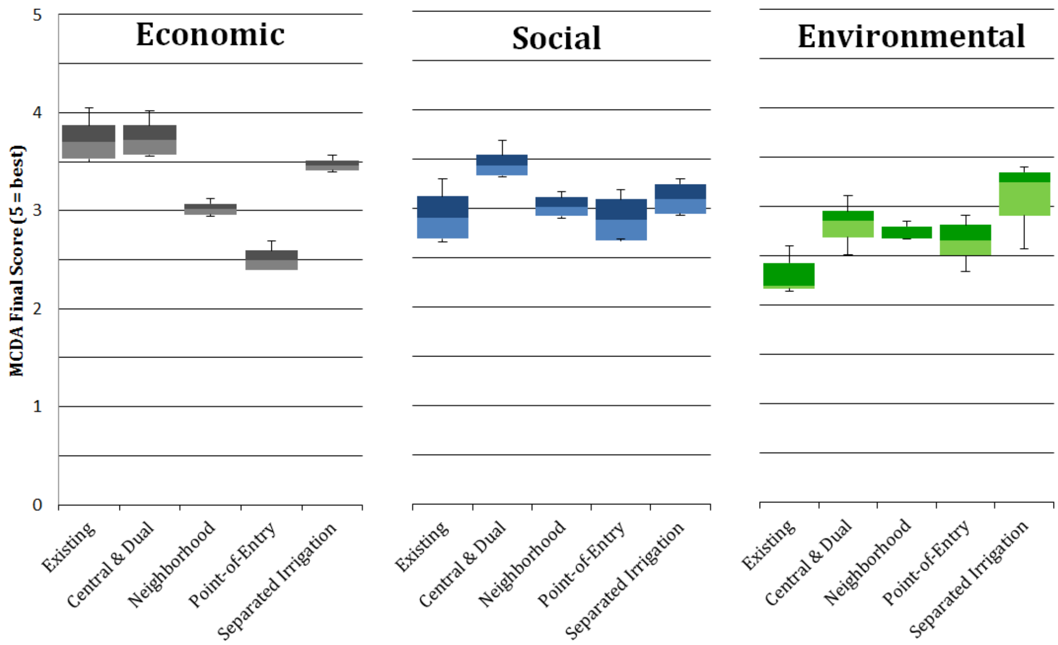


Figure 3.17 – Neighborhood #3 MCDA Stakeholder Average Results (5 = best)

Stakeholder average weighted MCDA results (Figures 3.15 - 3.17) reflect the equally weighted results (Figures 3.10 - 3.12) favoring the Central/Dual and Separated Irrigation alternatives across all sample neighborhoods, with the caveat that both score closely to the existing system economically. This outcome was expected when averaging results from a diverse group of stakeholders. The Central/Dual and Separated Irrigation alternatives have comparable overall performance, with Central/Dual having a small advantage in the economic and social bottom lines and Separated Irrigation having a larger advantage in the environmental bottom line. Separated Irrigation's environmental advantage is likely due to the fact that it is the only alternative that increases flows in the water corridors.

The degree of stakeholder consensus varies between bottom lines and alternatives (Tables 3.1 – 3.3). There is the least amount of consensus among the alternatives in the economic bottom line, with four to five of seven stakeholder groups preferring Central/Dual (Table 3.1). Depending on the neighborhood, two to three of the stakeholder groups favored Existing over Central/Dual. Separated Irrigation ranks a close third in economic performance with the smallest variance in stakeholder ratings. This shows all stakeholder groups agreed Central/Dual and Existing were the top two economic performers, but neither one substantially outperformed the other.

Table 3.1 Economic Ranking of Alternatives by Stakeholder Group for Sample Neighborhoods
Neighborhood rankings represented as N1 Ranking/N2 Ranking/N3 Ranking
1 = Highest Ranked and 5 = Lowest Ranked Alternative

Stakeholder Group	Existing	Central/Dual	Neighborhood	Point-of-Entry	Separated Irrigation
Institute for the Built Environment	2/3/2*	1/1/1	4/4/4	5/5/5	3/2/3
Transportation Planning	2/2/2	1/1/1	4/4/4	5/5/5	3/2/3
Economic Health/Urban Renewal Authority	2/3/2	1/1/1	4/4/4	5/5/5	2/2/3
Natural Areas	2/2/2	1/1/1	4/4/4	5/5/5	3/3/3
Communications/Public Involvement	1/1/1	2/2/2	4/4/4	5/5/5	3/3/3
Engineering	1/1/1	2/2/2	4/4/4	5/5/5	3/3/3
Planning	2/2/1	1/1/2	4/4/4	5/5/5	3/3/3

Table 3.2 Social Ranking of Alternatives by Stakeholder Group for Sample Neighborhoods
Neighborhood rankings represented as N1 Ranking/N2 Ranking/N3 Ranking
1 = Highest Ranked and 5 = Lowest Ranked Alternative

Stakeholder Group	Existing	Central/Dual	Neighborhood	Point-of-Entry	Separated Irrigation
Institute for the Built Environment	4/4/4*	1/1/1	3/3/3	5/5/5	2/2/2
Transportation Planning	5/5/4	1/1/1	3/4/3	4/3/5	2/2/2
Economic Health/Urban Renewal Authority	5/5/4	2/2/2	1/3/2	3/1/1	4/4/5
Natural Areas	4/5/4	2/2/1	3/3/3	4/4/5	1/1/2
Communications/Public Involvement	3/3/2	1/1/1	4/4/4	5/5/5	2/2/3
Engineering	4/4/4	1/1/1	3/3/3	5/5/5	2/2/2
Planning	5/5/5	1/1/1	3/3/3	4/4/4	2/2/2

Table 3.3 Environmental Ranking of Alternatives by Stakeholder Group for Sample Neighborhoods
Neighborhood rankings represented as N1 Ranking/N2 Ranking/N3 Ranking
1 = Highest Ranked and 5 = Lowest Ranked Alternative

Stakeholder Group	Existing	Central/Dual	Neighborhood	Point-of-Entry	Separated Irrigation
Institute for the Built Environment	4/4/3*	2/2/2	3/3/4	5/5/5	1/1/1
Transportation Planning	5/5/5	2/3/3	4/4/4	3/2/2	1/1/1
Economic Health/Urban Renewal Authority	5/5/5	4/4/4	2/2/2	1/1/1	3/3/3
Natural Areas	5/5/5	2/2/2	3/3/3	3/4/4	1/1/1
Communications/Public Involvement	5/5/5	2/2/3	4/4/4	3/2/2	1/1/1
Engineering	5/5/5	2/2/2	4/3/4	3/3/3	1/1/1
Planning	5/5/5	2/2/2	3/3/3	4/4/4	1/1/1

The social bottom line analysis shows more agreement among stakeholder groups (Table 3.2), with five to six of seven groups ranking Central/Dual as the best alternative. Five of seven stakeholder groups ranked Separated Irrigation as the second best alternative due to its anticipated improvement of the natural areas around the water corridors.

Six out of seven stakeholder groups rank Separated Irrigation followed by Central/Dual as the most environmentally beneficial alternative (Table 3.3). Separated Irrigation's performance is the top environmental choice due to the increased flows in the CLP north of the City, improvements in the natural areas around the irrigation ditches, and the importance stakeholder groups placed on this criterion.

The study evaluated the alternatives across multiple neighborhood types to measure the impact of land use type, neighborhood layout, lot sizes, water demand, and age and size of water infrastructure. All the sample neighborhoods had varied characteristics, but the results for each neighborhood all preferred the Central/Dual and Separated Irrigation alternatives according to average stakeholder weighting. These results show that the density of services, land use types and water demand collectively balance each other out. Regardless of the differences between neighborhoods, Central/Dual and Separated Irrigation consistently score higher than the other alternatives.

The equally weighted MCDA results (Figures 3.11-3.13) are very similar to the results using the average of the stakeholder relative importance of the criteria (Figures 3.15 to 3.17). A large variance is revealed in the stakeholder results for some of the alternatives, particularly the existing system in the economic and social bottom lines. The variation in results is due, in large part, to the relative importance factors of one stakeholder group. For example, the Communications & Public Involvement stakeholder group will be responsible for communicating with the public and getting them on board with a dual water system alternative. Their main concerns are associated with new costs, disruption to the community, and communication of regulatory or political risks involved with new water infrastructure. For these reasons, this group places maximum importance on impacts of new infrastructure, routine maintenance, and regulatory and political risk, which results in the existing system scoring higher than the alternatives because there is no new infrastructure and there are no new risks to communicate with no change to the existing system.

Both decentralized water treatment alternatives were not favored in the analysis. The additional costs of Point-of-Entry systems make this alternative unattractive compared to central water treatment. Neighborhood water treatment costs and additional energy required for pumping make it more economically and environmentally expensive.

iii. Analysis of Alternative Weighting Scenarios

Original key drivers scenario

The key drivers for the study were initially identified as capital costs, O&M costs (particularly energy consumption and water treatment chemical consumables), and income opportunities for economic performance; health effects due to GHG emissions and consumer water quality (water age in potable distribution system) for social performance; and GHG emissions and chemical consumables for environmental performance. Upon holding the first stakeholder meeting with the City's Nature in the City group, it was determined that more performance metrics would be needed for a comprehensive triple bottom line analysis resulting in a large number of performance metrics (49). The concern with such a comprehensive analysis is the dilution of what were considered key drivers in the beginning of the study. An alternative MCDA scenario was run, for Neighborhood 1 (Drake to Horsetooth & Timberline to Zeigler), with the criteria related to key drivers assigned a relative importance of 5 and all other criteria assigned a relative importance of 1, to determine if original key drivers were diluted. For the consumer water quality social performance metric, water age, a normalized attribute weight of 1 was assigned and the other performance metrics for this criterion were assigned a 0. All other performance metrics remained equally weighted. Figure 3.18 shows the results where the average stakeholder and key drivers scenario results are shown on the left and right respectively.

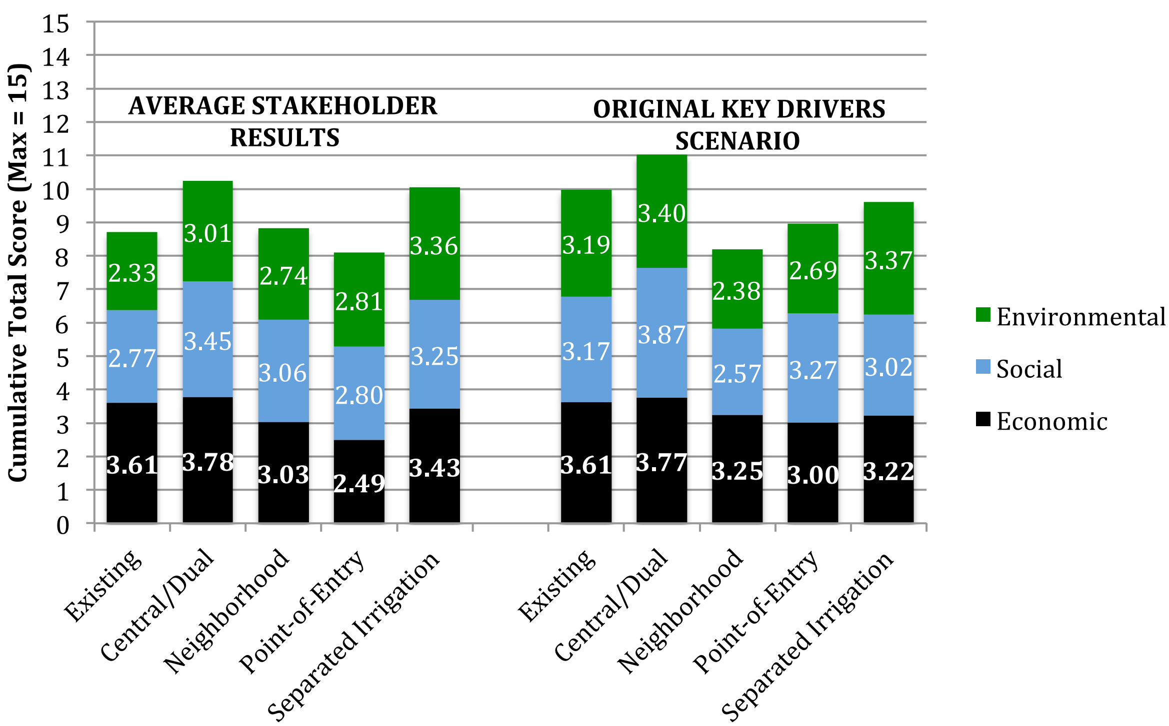


Figure 3.18 – Comparison of Original Key Drivers Scenario Results for Neighborhood 1

When the originally identified key drivers are given the highest relative importance and all other performance metrics are assigned the lowest relative importance, the Separated Irrigation alternative is not as competitive. In the original key drivers scenario, the Central/Dual alternative had the highest overall performance followed by the Existing and Separated Irrigation alternatives. Overall, the Existing, Central/Dual, and Point-of-Entry alternatives' performance increased and the Neighborhood and Separated Irrigation alternatives' performance decreased.

Economic performance shows little change in the top two preferred alternatives, Central/Dual and Existing. However, slight improvements in economic performance for the decentralized water treatment alternatives and a slight decrease in performance for the Separated Irrigation alternative made these three alternatives indistinguishable in overall economic performance. The social bottom line was affected because a greater importance was placed on water age in the potable distribution system and greenhouse gas emissions. The greater emphasis on water age raised the social scores of the Central/Dual and Point-of-Entry alternatives. The Neighborhood alternative has the second lowest water age, however, since this alternative uses more energy it showed an overall decrease. The Separated Irrigation alternative also uses more energy and has the longest water age, as a result, it moved to fourth place from a social perspective. By removing the emphasis stakeholders place on the benefit of using city water corridors and focusing on greenhouse gas emissions and chemical consumables for environmental performance, Separated Irrigation no longer outperforms Central/Dual.

Energy use and potable water quality in the distribution system were two original motivators for the study and the alternatives' performance in these areas had a significant impact on the results in this key drivers scenario (Figure 3.19). Two issues to note with respect to energy use and potable water quality are:

3. The Neighborhood and Separated Irrigation alternatives use the most energy because the distribution system is no longer solely gravity fed. The Neighborhood alternative requires pumping for the distribution of potable water from the new neighborhood water treatment facilities to the end user. The Separated Irrigation alternative requires pumping for the distribution of raw water from the irrigation ditches to the end user.
4. The Central/Dual, Neighborhood, and Point-of-Entry alternatives all improve drinking water quality compared to the Existing alternative by decreasing the amount of time in the potable distribution system. The Separated Irrigation alternative has the highest water age of all the alternatives considered. It uses the existing distribution system for potable distribution, but has less demand than the existing distribution system in the summer because irrigation water is provided through the new irrigation system.

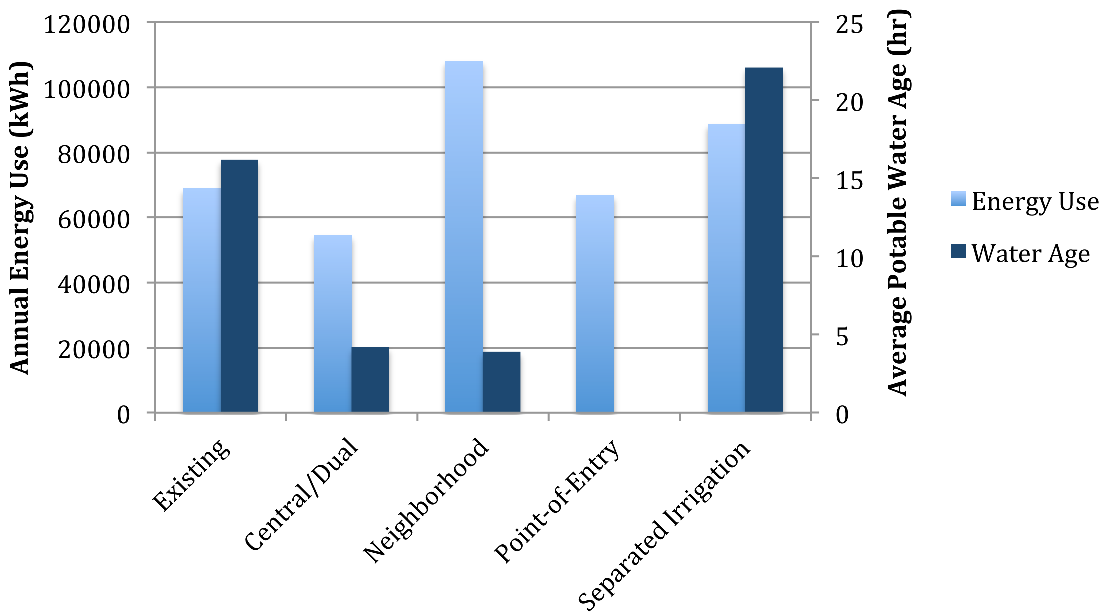


Figure 3.19– Alternative Annual Energy Use and Average Water Age for Neighborhood 1

Removing the water corridors criterion scenario

The Separated Irrigation alternative offers some benefits not considered in the original key drivers and these unique benefits are a high priority for the stakeholder groups consulted in the study. The results show the Separated Irrigation alternative is one of the top performing alternatives, with the most improvement in environmental performance. There are two factors that set the Separated Irrigation alternative apart from the others. First, the 'Use of city water corridors' criterion only applies to the Separated Irrigation alternative. Second, the average stakeholder relative importance placed on this criterion for the environmental bottom line was the highest importance assigned to any criterion (Figure 3.8). An alternative MCDA scenario was run for Neighborhood 1, with a relative importance of 1 assigned to the 'Use of city water corridors' for the social and environmental bottom lines (Figure 3.20). Note that the economic performance metric for the 'Use of city water corridors' criterion remains 0 because a more detailed analysis is needed on the City's water right portfolio to determine how this could affect the economic performance of the alternatives.

Overall, lowering the importance of the 'Use of city water corridors' criterion, which only applies to the Separated Irrigation alternative, does not substantially change the results. Despite Separated Irrigation's social and environmental performance decrease, it still remains one of the top two alternatives.

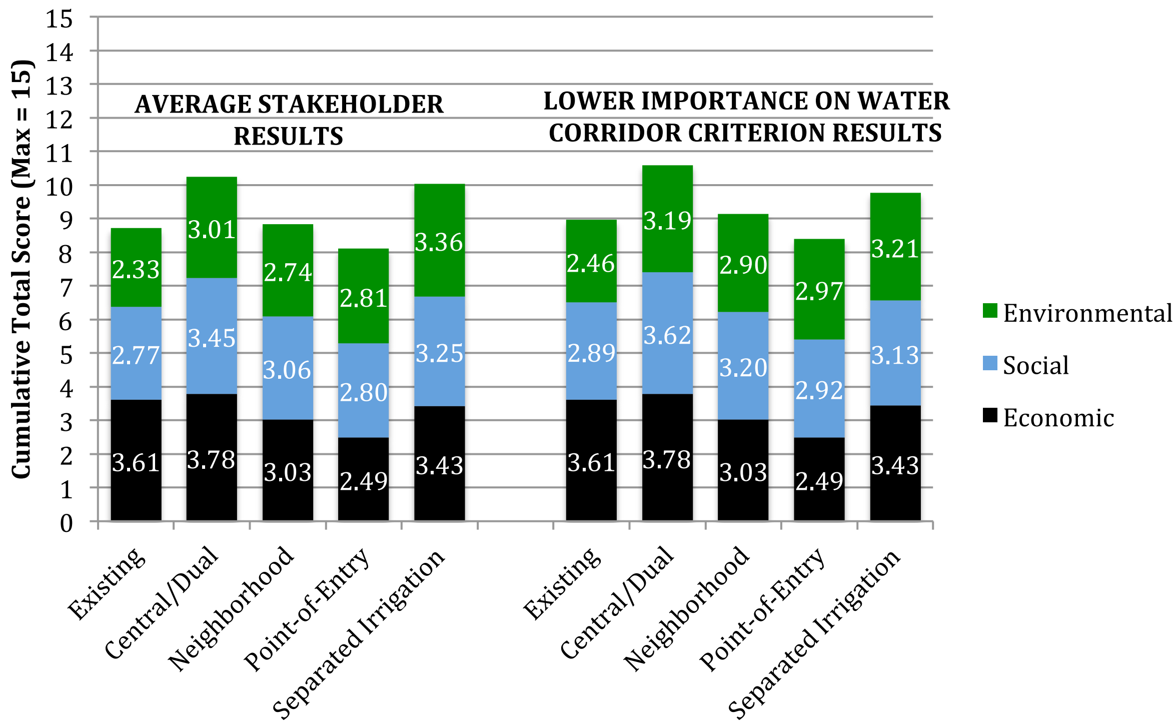


Figure 3.20–Comparison of Use of City Water Corridors Criterion Scenario Results for Neighborhood 1

Sharing Point-of-Entry O&M Costs

Point-of-entry systems require substantially more maintenance than any other alternative due to decentralization of treatment and the number of systems that must be maintained (Tables G.31 through G.33). Total O&M costs are driven by the outstanding cost for treatment system component replacement including sediment pre-filters, GAC/KDF media, and UV lamps and sleeves. Additionally, scheduling and travel related to these responsibilities make up a sizeable percentage of total requirements as shown (Table 3.4).

Table 3.4 - Maintenance Required Per Connection

Component	Freq (per year)	Duration (hr)	Hrs/Year	Cost/Year
Sediment Filter	1.6	0.25	0.40	$12.46
GAC/KDF	0.2	0.5	0.10	$3.12
UV	1.2	0.5	0.60	$18.70
Sampling	0.3	0.25	0.08	$2.60
Scheduling	0.3	0.5	0.17	$5.19
Travel	3.7	0.25	0.92	$28.56
Central Monitor	Incorporated into staffing estimate separately			
TOTAL			2.18	$70.63

In addition to O&M cost, staffing requirements are greatly increased in this alternative for the same reasons. These two drivers affect multiple performance metrics in economic, social and environmental considerations such as O&M cost, staffing requirements, employment and job security, affordability of rates (assumed to be related to O&M costs) and employee transport greenhouse gas emissions.

To evaluate the impact of the additional cost and staffing requirements associated with a citywide Point-of-Entry alternative, a cost-sharing scenario with property owners was considered. For this analysis, several assumptions were used to frame a potential approach to make the alternative more competitive. These assumptions were defined as:

- Component replacement (sediment filter, GAC/KDF media, UV lamps and sleeves) would become the responsibility of the connection owner
- 25% of assumed original maintenance would be attributed to repairs and troubleshooting measures which would remain the responsibility of the utility
- Scheduling and travel would adjust according to the amount of utility replacement needed
- Sampling would remain the responsibility of the utility
- Regulations for POE system operation would be adjusted to allow this scenario

One important note is that currently there are regulatory barriers to the delegation of operations and maintenance responsibilities to homeowners as outlined in §1412(b)(4)(E)(ii) of the Safe Drinking Water Act, which is discussed in further detail later in this section. As stated in the assumptions, this analysis disregards potential regulatory barriers.

Using Neighborhood 1, this shared O&M scenario was compared to the existing case used for analysis in this study (Figure 3.21).

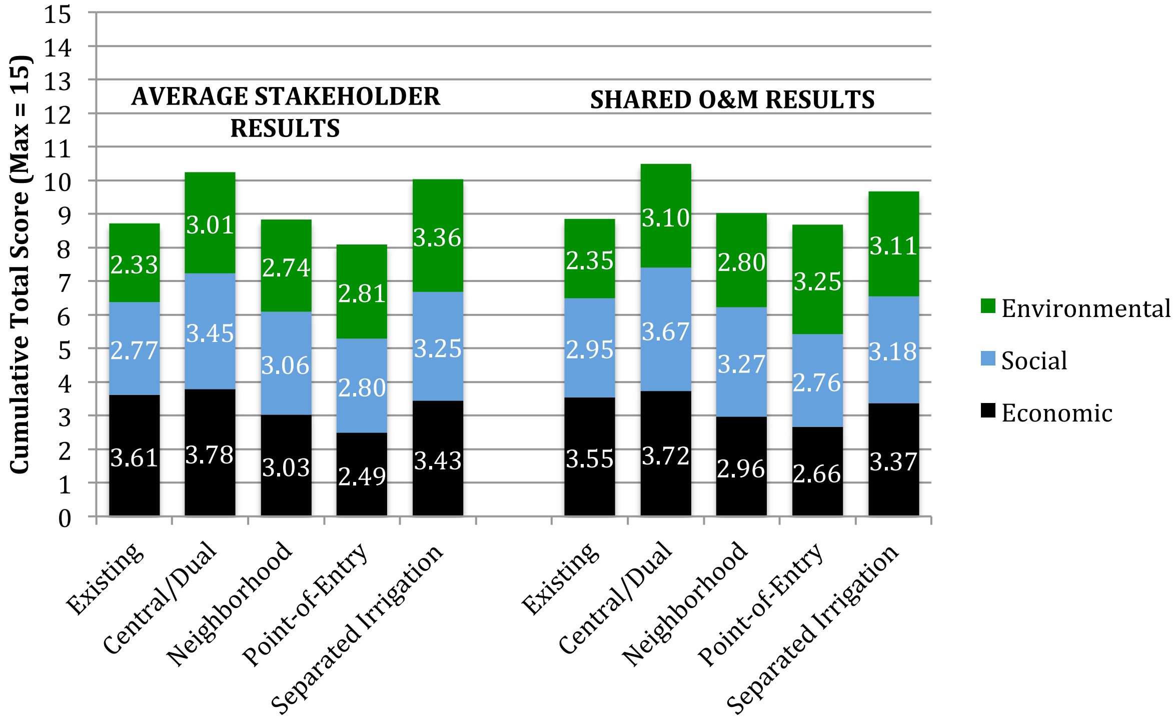


Figure 3.21 - Base scenario average stakeholder MCDA-TBL results comparison with shared O&M for POE scenario MCDA-TBL for Neighborhood #1 (Best = 15)

The results show a slight rise in overall triple bottom line, led by environmental improvement. Sharing O&M responsibilities improves the ranking of the Point-of-Entry alternative slightly, making it more comparable to the Neighborhood and Existing alternatives. However, centralized treatment alternatives continue to score much higher. This scenario demonstrates that competitiveness of point-of-entry treatment is limited by additional factors outside of O&M costs, staffing requirements, and employee transport greenhouse gas emissions.

The equal weighted results, stakeholder results, and alternative scenarios all show a preference for the Central/Dual and Separated Irrigation alternatives. This suggests a central water treatment and dual distribution strategy will represent the best solution for the City's water supply infrastructure in the future.

c. Life-Cycle Costs

Tables 3.5 through 3.7 show the results of the LCC analysis for each sample neighborhood. A study period of 70-years was used and a 2014 constant cost analysis was performed with all future costs discounted to the base date of 2014. Detailed tables can be found in Appendix L.

Table 3.5 – Neighborhood 1 LCC Results

Neighborhood 1: Drake to Horsetooth & Timberline to Ziegler					
	Existing	Central/Dual	Neighborhood	Point-of-Entry	Separated Irrigation
Initial Capital Costs	NA	$12,247,932	$11,875,638	$10,226,970	$5,478,842
Replacement Costs	$3,161,803	$2,700,718	$2,635,635	$11,723,629	$2,700,718
Annual O&M Costs	$6,552,659	$7,378,802	$7,264,542	$17,819,140	$9,928,902
Remaining Value	$(1,490,351)	$(1,429,823)	$(1,458,398)	$(1,871,358)	$(1,422,215)
Total Costs	**$8,224,111**	**$20,897,629**	**$20,317,416**	**$37,898,381**	**$16,686,247**

Table 3.6 – Neighborhood 2 LCC Results

Neighborhood 2: Horsetooth to Harmony & Shields to College					
	Existing	Central/Dual	Neighborhood	Point-of-Entry	Separated Irrigation
Initial Capital Costs	NA	$13,349,032	$12,953,769	$10,293,498	$7,194,919
Replacement Costs	$3,236,224	$2,775,139	$2,705,687	$11,859,017	$2,775,139
Annual O&M Costs	$7,844,088	$8,846,388	$9,690,100	$22,413,443	$12,276,393
Remaining Value	$(1,426,571)	$(1,366,044)	$(1,393,269)	$(1,810,836)	$(1,358,436)
Total Costs	**$9,653,740**	**$23,604,515**	**$23,956,287**	**$42,755,122**	**$20,888,015**

Table 3.7 – Neighborhood 3 LCC Results

Neighborhood 3: Vine to Mulberry & Shields to College					
	Existing	Central/Dual	Neighborhood	Point-of-Entry	Separated Irrigation
Initial Capital Costs	NA	$15,791,135	$15,528,633	$10,374,388	$6,973,727
Replacement Costs	$5,215,051	$4,753,967	$4,709,766	$13,911,974	$4,753,967
Annual O&M Costs	$9,211,988	$8,699,380	$9,522,312	$22,046,293	$11,381,139
Remaining Value	$(1,215,511)	$(1,154,984)	$(1,190,009)	$(1,603,736)	$(1,147,375)
Total Costs	**$13,211,529**	**$28,089,498**	**$28,570,702**	**$44,728,918**	**$21,961,457**

IV. Considerations for Implementation Planning

During the research process, we identified several decisions and alternatives FCU may want to consider during implementation planning, but does not impact the alternative selection. These concerns are not directly captured in the performance metrics, but should be addressed for the chosen alternative. The discussion below outlines decisions, alternative implementation ideas, and potential regulatory hurdles we recommend FCU address during the implementation planning process. These include:

a) Distribution System Considerations

i. High service neighborhoods and decentralized water treatment
ii. Internal pipe corrosion concerns
iii. Importance of implementation planning in reducing distribution system capital costs
iv. New non-potable distribution system infrastructure

b) Water Treatment Considerations
i. Existing water treatment facility
ii. Chemical stabilization and fluoridation

c) Water Quality Monitoring Considerations
i. Raw water quality for irrigation and fire fighting
ii. Decentralized water treatment monitoring considerations
iii. Drinking water regulatory barriers

d) Special considerations (Secondary Irrigation Systems)
i. Raw water irrigation system management by HOAs or canal companies
ii. Funding strategies
iii. Water rights
iv. Cooperating with canal and irrigation ditch companies
v. Water loss

a. Distribution System Considerations

There are four main issues to address regarding the potable and non-potable distribution systems in the dual water system alternatives considered. First, the sample neighborhoods chosen for the MCDA analysis are all gravity fed like the majority of the water service area. However, there are two high service areas that require pumping from the existing WTF. The energy required for pumping to these neighborhoods accounts for 25% of the energy use at the WTF (Appendix J). An alternative MCDA should be performed for these neighborhoods to determine if the preferred solution will change. Second, the concern of internal pipe corrosion in the non-potable distribution system in the Central/Dual alternative is addressed. Finally, the importance of minimizing economic costs by coordinating distribution system construction with other City infrastructure projects or new development and considerations for new non-potable distribution systems is discussed.

i. High Service Neighborhoods and Decentralized Water Treatment

The topology of Fort Collins enables a gravity fed distribution system throughout most of the service area, with the exception of two high service neighborhoods that require pumping from the central water treatment facility. In the MCDA results for the sample neighborhoods, the Neighborhood alternative was not a preferred solution because it required additional pumping costs and the lack of dual transmission prevents the separation of different quality source water. Neighborhood water treatment facilities require pumping to distribute potable water to the end user and maintain a minimum operating pressure of 40-psi. The design for this alternative assumed that dual transmission mains would not be required, which saves some initial new infrastructure costs. By making this assumption however it loses the benefit the Central/Dual and Separated Irrigation alternatives have of being able to separate different quality source water. With single transmission lines in the Neighborhood alternative, the same source water will be used for irrigation and delivered to the neighborhood water treatment plant for drinking water treatment.

The energy required to pump to these high service neighborhoods increases the WTF energy use from approximately 300 – 350 kWh/MG to 950 – 1200 kWh/MG (Appendix J). It is recommended that an alternative MCDA should be performed for these neighborhoods to determine if the preferred solution is different for these neighborhoods. Figure 4.1 below suggests some other alternatives that could be considered in the high service neighborhoods. The first five are the alternatives considered in this analysis and the remaining are suggested alternatives that may be considered in future analysis.

Table 4.1 – Additional alternatives for consideration

	Water Treatment			Existing Neighborhood Distribution System		Non-potable uses	
	Central	Neighbor-hood	POE	Gravity fed	High Service	Irrigation from ditch network	Fire & Irrigation
Existing Alternative	X			X			
Central/Dual Alternative	X			X			X
Neighborhood Alternative		X		X			X
Point-of-Entry Alternative			X	X			X
Separated Irrigation Alternative	X			X		X	
POE WT in high service neighborhood			*X*		*X*		*X*
Neighborhood WT in high service neighborhood		*X*			*X*		*X*
POE WT in high service neighborhood & ditch irrigation			*X*		*X*	*X*	
Neighborhood WT in high service neighborhood & ditch irrigation		*X*			*X*	*X*	
POE WT & ditch irrigation			*X*	*X*		*X*	
Neighborhood & ditch irrigation		*X*		*X*		*X*	

ii. Internal pipe corrosion concerns

The issue of internal pipe corrosion in the potable water system has been addressed in the alternatives. For the decentralized water treatment alternatives, it was assumed that corrosion control chemicals would continue to be added at the central water treatment facility before distribution to the neighborhood or POE water treatment facilities due to LCR requirements. This also means corrosion control in the non-potable distribution system in the decentralized water treatment alternatives will not be a concern. However, there is some concern with the internal pipe integrity of the non-potable distribution system in the Central/Dual alternative because it was assumed no corrosion control chemicals would need to be added to the raw water distributed via the existing distribution system.

Changing water quality from treated to raw water in the existing distribution system, as envisioned in the Central/Dual alternative, could result in an increase in internal corrosion. This could lead to increase in water loss, low operational pressures, and valve failures. The formation of protective scales on metal pipes is the main corrosion control mechanism for metal pipes. A change in water quality can result in re-equilibration of these existing scales and potentially result in an increase in internal pipe corrosion. The key water quality parameters for corrosion of iron pipes are alkalinity, pH, and dissolved inorganic carbon (DIC). For cement lined pipes, the key parameter is the calcium carbonate saturation point. The further away the water is from the calcium carbonate saturation point, the more calcium will dissolve from the cement lining. (AWWA M58, 2011)

If the Central/Dual alternative is implemented, we recommend a corrosion control monitoring program for the existing distribution system to ensure there is not an increase in internal corrosion. AWWA's Manual of Water Supply Practices M58: Internal Corrosion Control in Water Distribution Systems should be consulted in establishing the monitoring program protocol (2011).

iii. Importance of Implementation Planning in Reducing Distribution System Capital Costs

Implementing a citywide dual distribution system is a long-term strategy and there are opportunities for considerable cost savings to the utility if pipe installation is done when partnering with another City department. Table G.3, in Appendix G, shows that the unit cost for pipe installation can double when the utility is solely responsible for traffic control and pavement repair costs during pipe installation. This is a strong motivator for planning implementation with other City infrastructure projects or new development.

The following should be considered during implementation planning of a dual water system: areas that already irrigate with raw water, areas with large irrigation demand, areas of redevelopment or new development and future capital projects.

Areas currently irrigated with raw water and large irrigation customers

Since the main demand for non-potable water is for irrigation, it is important to identify areas with high irrigation demand. Organizations that currently irrigate with raw water present an opportunity for cooperation with other agencies. As previously mentioned, the City Parks department currently irrigates approximately 80% of city parks, golf courses, and cemeteries with raw water and 95% of the CSU campus are irrigated with raw water. These areas are shown as public open land and CSU in the land use map in the methodology section (Figure 2.3).

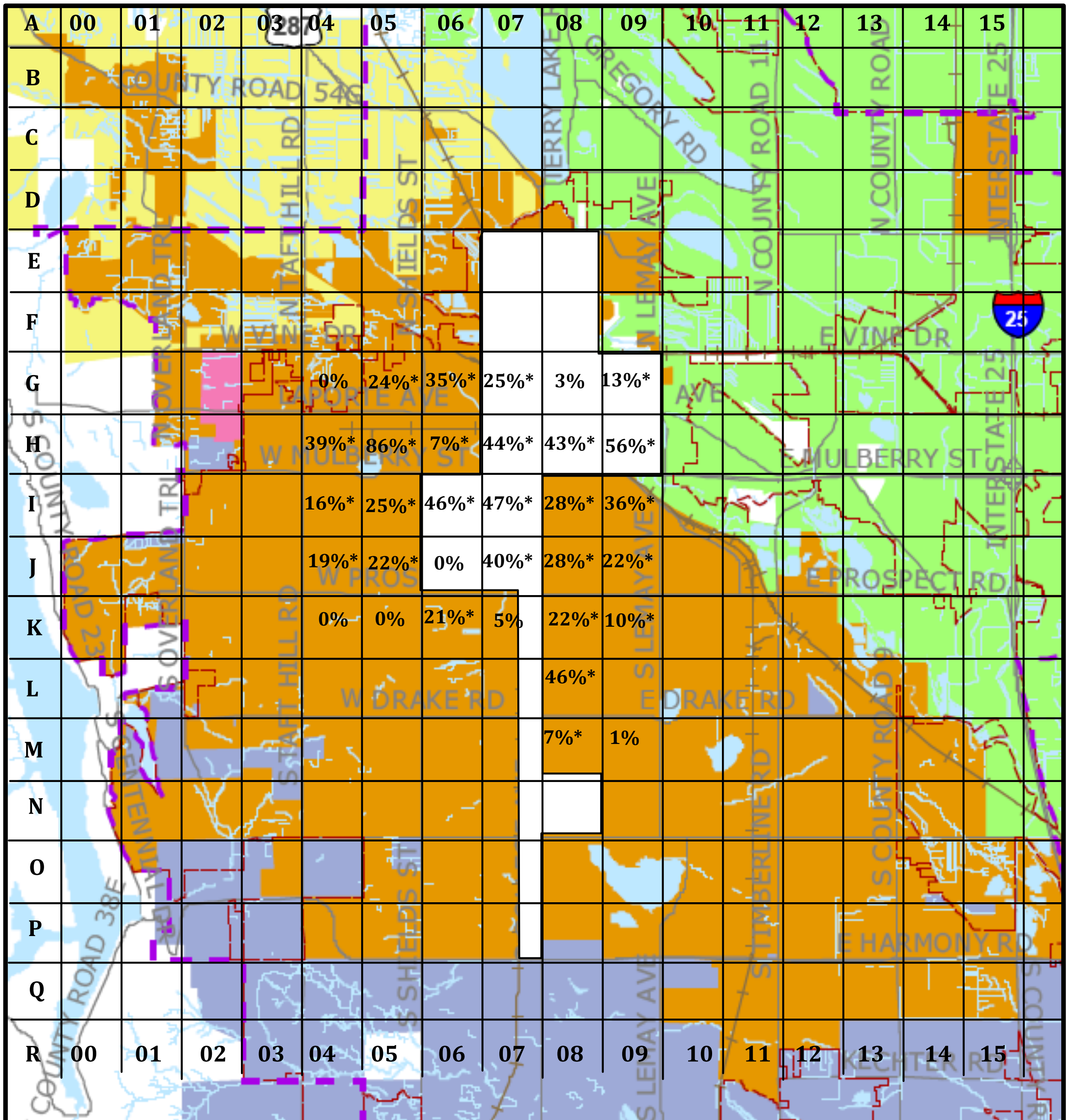
The City's HOAs are a potential first candidate for implementing a dual water distribution system. HOAs use a significant amount of water for green space irrigation. Figure 2.4, in the methodology section, show the areas where HOAs use municipal water for irrigation.

Commercial customers with irrigation services are a second likely target group. Implementation for these potential early adopters would be easier than implementing for individual homeowners and would make a significant contribution towards using raw water for irrigation citywide.

When planning implementation for residential areas, the utility will have an opportunity to optimize implementation costs per irrigable area. Tables B.1 through B.5 (Appendix B) show certain land use types use more water for irrigation use than others. For example, low density single family services use more irrigation water than low density mixed-use single family services because of the larger lot sizes. Implementation in a low density residential neighborhood would cost more per connection because the services are further apart. Optimizing the irrigable area compared to the cost per connection would enable the most efficient roll out of the dual water distribution system in residential areas.

Areas of new and re-development and future capital projects

The financial and social costs of implementing a dual distribution system are considerably less when installed as part of new development. In the FCU service area, however, there is very little area left designated for new development. The City has designated several areas for redevelopment and infill, which represent an opportunity to cost-effectively implement a dual distribution system. Additionally, there are several areas in Old Town where the existing distribution system does not meet the typical minimum size of water mains providing fire protection and serving hydrants, 6-inch minimum for loops and 8-inch minimum for dead ends per the AWWA Manual of Water Supply Practices M31: Distribution System Requirements for Fire Protection (2008). Figure 4.1 shows areas that are designated for redevelopment in white and provides the percentage of the distribution system less than 6-inch diameter pipe.



Fort Collins Utilities Water District

Redevelopment Area within FCU Water District

XX % Represents % of mains < 6" diameter (* = fire hydrant on 4" line)

Figure 4.1 – Redevelopment and areas with high priority replacement due to fire requirements

The information provided in Figure 4.1 and the pipe failure data collected in Appendix A could be used to develop a pipe risk assessment model of the existing water distribution system. This would allow the utility to prioritize water infrastructure renewal projects, which could then be coordinated with other City projects to minimize economic, social, and environmental costs. For example, CSU's freely available, open source, environmental Risk Assessment and Management System (eRAMS) Pipe Risk Screening Tool (PRST) could be used to create this model using the data collected for this study. Additional information regarding failure likelihood and consequences of failure would also need to be added to complete the model. Table 4.2 below shows the data needed for the model.

Table 4.2 – Data needed for pipe risk assessment model using eRAMS PRST
(WERF, Water Research Foundation, EPA, 2013)

Type of Data	Data	Data Available (?)	Notes
Asset	Pipe segment ID	Yes	Data collected for this study using WUMS database.
	Length (feet)	Yes	
	Pipe Diameter (inch)	Yes	
	Pipe Material	Yes	
	Installation Date (year)	Yes	
Maintenance	Number of breaks	Yes	Data collected for this study using work order data.
	Breaking Status Factor	No, add	Default set to 1 unless a break history shows several recent breaks.
	Service Factor	No, add	Use soils data collected for this study, high-pressure zone information, and high traffic area information.
Consequence	Location Factor	No, add	Assign based on ease of access.
	Repair Difficulty Factor	No, add	Assign based on site conditions.
Other	Priority	No, optional	Use to identify segments required to deliver water to large irrigation users.

iv. New non-potable distribution system infrastructure

The CDPHE Water Quality Control Commission (WQCC) Regulation No. 84 for Reclaimed Water is not directly applicable for raw water. However, if a dual distribution system is installed, the City may want the option of supplementing raw water with alternative non-potable sources such as reclaimed water in the future. Therefore, it is important for any new non-potable infrastructure to meet these standards to keep this option open.

b. Water Treatment Considerations

Several issues emerged when considering the different water treatment options represented in the alternatives considered in the analysis. These included:

- What should be done with the extra capacity at the existing water treatment facility?

- Where would fluoridation and chemical stabilization occur in the Neighborhood and Point-of-Entry alternatives?

i. Existing Water Treatment Facility

In 2000 FCU added two new treatment trains and doubled the capacity of their existing central WTF capacity, from 45-MGD to 87-MGD (City of Fort Collins, 2010), to accommodate anticipated population growth. Peak water demand, in July and August, is about half the current capacity. Implementation of a dual water system alternative would increase the available spare capacity. This excess capacity presents several opportunities for the utility. The utility could sell water to neighboring water districts to help pay for the WTF and capital costs of a dual water distribution system. The utility could decommission older sections of the WTF to save on O&M costs. Additionally, when the existing WTF reaches the end of its useful life, the City could save on replacement costs by building a smaller plant, or save on costs of alternative treatment options if less capacity is required.

ii. Chemical Stabilization and Fluoridation

Currently chemical stabilization is required to meet CDPHE requirements for the LCR. It was assumed for the decentralized treatment alternatives that chemical stabilization would happen at the existing central WTF. If one of the decentralized treatment alternatives was chosen, the amount of corrosion control chemicals will likely decrease since conventional water treatment is not used in the Neighborhood or Point-of-Entry alternative water treatment systems. Additionally, if considering a decentralized treatment option in high service neighborhoods, fluoridation and chemical stabilization would need to be included at the decentralized water treatment system. These would need to be included in any decentralized water treatment pilot study.

c. Water Quality Monitoring Considerations

With the implementation of dual water systems, several water quality issues need to be addressed including water quality in non-potable systems, monitoring requirements for decentralized water treatment, and potential regulatory barriers.

i. Raw Water Quality for Irrigation and Fire Fighting

Regulations

There are no raw water regulations for irrigation and fire fighting uses in Colorado. However, with implementation of residential raw water irrigation it is recommended that the raw water quality meet the CDPHE's WQCC standards for Existing Primary Contact Recreation as defined in Regulation 31. The Primary Contact Recreation designation refers to recreational activities where ingestion of small quantities of water is likely to occur, such as, frequent water play by children. The water quality standard for the bacteria, *E.coli*, is established as an indicator of potential pathogenic organisms. For existing primary contact, this standard is set at 126 per 100 mL for the two-month geometric mean. (CDPHE WQCC Regulation 31, 2013)

The City of Fort Collins 2012 Lower CLP and Urban Creek Water Quality Report reported on *E.coli* levels for urban creeks in Fort Collins from 2006 to 2012 (Figure 4.2).

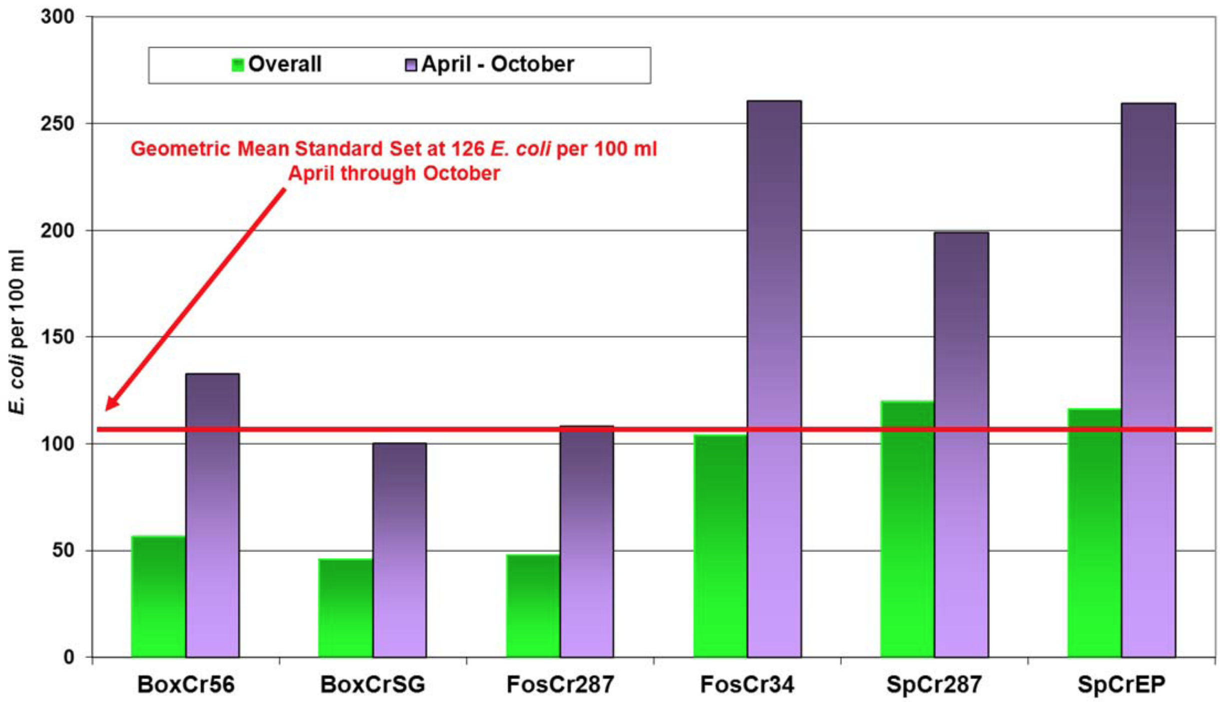


Figure 4.2 – *E.coli* Levels in Fort Collins' Urban Streams
(From Elmund et al., 2013)

Figure 4.2 shows Fort Collins' urban creeks to be in violation of the standard during April to October, which coincide with the irrigation months. This could be an indicator of the water quality in the irrigation ditch network. It is recommended that raw water be tested for *E.coli* after filtration to ensure this water quality standard is met.

Water quality in non-potable systems during winter months

Water quality in the raw water distribution system during the winter months presents a challenge. The raw water distribution system in the Central/Dual and Neighborhood alternatives will run all year. In the non-irrigation months, the only demand on this system will be for fire flow. There is very little fire demand, which means water will be stagnant in the winter months. Increasing water age could lead to Microbially Influenced Corrosion (MIC) and biofilm growth (AWWA M58, 2011), which could impact winter water quality, hydraulic performance, and water loss in the distribution system. Any implementation plan of the Central/Dual or Neighborhood alternatives would need to include mitigation measures to increase flow in the non-potable system during the winter months. Mitigation measures could include increasing flushing frequency and/or finding alternative non-potable uses in the winter, such as car washing.

ii. Decentralized Water Treatment Monitoring Considerations

Implementing a decentralized water treatment alternative requires an adjustment in water quality monitoring procedures and technology. Increasing the number of systems increases the number of monitoring locations. Neighborhood-scale treatment and point-of-entry treatment both operate under small public water system regulations (those serving fewer than 10,000 people) (U.S. EPA, 2003).

The Safe Drinking Water Act (SDWA) stipulates national general sample monitoring schedules for small systems. These regulations are based on the same acute and chronic target contaminants that large/very large systems are responsible for addressing. Table 4.3 summarizes the monitoring requirements for small systems. Monitoring frequency depends on the water source type and the size of the system.

Table 4.3 - General Sample Monitoring Schedule for Small Systems (U.S. EPA, 2003)

Contaminant	Minimum Monitoring Frequency
Acute contaminants – Immediate risk to human health	
Bacteria	Monthly or quarterly, depending on system size and type
Nitrate	Annually
Protozoa and viruses	Future requirements for Ground Water Rule may require monitoring and testing
Chronic Contaminants – Long-term health effects if consumed at certain levels for extended periods	
Volatile organics	Surface water systems – annually
Synthetic organics	Once every three years
Inorganics/metals	Surface water systems – annually
Lead and copper	Annually
Radionuclides	Once every four years

Due to the nature of these requirements, neighborhood-scale treatment and point-of-entry treatment will necessitate different approaches for monitoring strategies than the current centralized approach. One important assumption common to both alternatives is the maintenance of chemical addition at the central water treatment facility to maintain alkalinity levels, add fluoride and control pH. Raw surface water will be collected and blended at the existing facility. This will allow for continued raw source water quality monitoring at the central facility as well as the use of the existing water quality laboratory.

Neighborhood-Scale Treatment Monitoring

Small-scale package treatment plants may be equipped with sensor and operating devices that can be monitored remotely. Remote Telemetry Systems (RTS) allow operators to operate, monitor and control water treatment systems from a centralized location (U.S. EPA, 2003). This greatly reduces operations and maintenance costs and improves the level of monitoring control. Some systems are more amenable to RTS implementation and these were factored into the selection process for neighborhood-scale treatment. In particular, membrane filtration and disinfection are more amenable treatment technologies than conventional coagulation/filtration. Table 4.4 lists the amenability score for various technologies.

Table 4.4 - Amenability of RTS to Treatment Technologies for Small Systems (5=most) (U.S. EPA, 2003)

Technology	Amenability for Automation/Remote Monitoring & Control
Oxidation/Filtration	1-2
Ion exchange	3-4
Activated alumina	1-2
Coagulation/Filtration	1-2
Dissolved air flotation	1-2
Diatomaceous earth filtration	3-4
Slow sand filtration	3-4
Disinfection	4-5
Membrane filtration systems	3-4
Reverse Osmosis	3-4
Adsorption	3-4

Connecting neighborhood-scale treatment facilities through RTS is an applicable solution to monitoring decentralized facilities. The existing water treatment facility already incorporates a SCADA system collecting one-minute and 15-minute continuous data for monitored parameters (City of Fort Collins, 2010). The additional costs to incorporate these decentralized facilities into the SCADA monitoring system may be estimated using the cost ranges in Table 4.5.

Table 4.5 - Cost Estimates for SCADA System Components (U.S. EPA, 2003)

SCADA System Component	Component Option	Range of Costs
Hardware	Main Computer	$1,000-3,500
	SCADA Unit	$500-30,000
Software	Operating System	$250-750
	Telemetry System	$500-30,000
	Data Collection & Loggers	$250-8,000
Communication Medium	Telephone	$75-125
	Cellular	$250-500
	Radio	$1,500-3,500
	Satellite	$20,000-75,000
Instrumentation	Valves	$25-1,500
	Switch	$25-300
	Sensor	$350-85,000

Point-of-entry Treatment Monitoring

Point-of-entry treatment systems are required to meet maximum contaminant levels (MCLs) as dictated in the SDWA. With systems at every single potable connection in the city, continuous monitoring for every contaminant is impractical. Typical sampling programs specify target contaminants which are tested for according to a defined monitoring plan which must be approved by the state (U.S. EPA, 2002). Each system must monitor the water quality to demonstrate compliance with the SDWA. Once the system has met all contaminant goals, one third of all units must be sampled annually. Regulations are not clearly defined for a case in which the POE system receives raw or lightly treated surface water which is discussed in this section under Regulatory Barriers.

For the purposes of this analysis, target contaminants were identified according to current monitoring at the existing central water treatment facility as described in the 2010 Horsetooth Influent Water Quality Report, 2011 Cache la Poudre Influent Water Quality Report and 2010 City of Fort Collins Drinking Water Quality Policy Annual Report. These target contaminants include synthetic organic contaminants, volatile organic contaminants, barium, nitrate, selenium, and chloride. A cost for this sampling package was estimated using information from the CDPHE Laboratory Services Division – Water Testing and is summarized in Table 4.6.

Table 4.6 - Target Contaminant Sampling Costs - CDPHE Lab Services Water Testing (CDPHE, 2014)

Target Contaminant	Cost/Sample
Synthetic Organic Contaminants (SOCs)	$106.00
Volatile Organic Contaminants (VOCs)	$106.00
Barium	$20.50
Nitrate	$31.50
Selenium	$20.50
Chloride	$21.50

One third of all POE systems will undergo this suite of contaminant testing annually. Additional contaminant testing for SDWA compliance will remain a function of the central treatment facility. Remote monitoring for every system is severely limited by cost and space and would not be practical at the city-wide scale. SDWA regulations also require the use of mechanical warning devices to automatically notify customers of operational problems (U.S. EPA, 2003). These warning devices have been incorporated into the capital cost for the alternative.

iii. Drinking Water Regulatory Barriers

Disinfection Residual

Residual disinfectant is required in drinking water distribution systems to provide a final barrier against contamination. The State of Colorado outlines these requirements in the *Colorado Primary Drinking Water Regulations*, *Articles 7 and 13.* (CDPHE, 2010) There are several important stipulations outlined in these articles including that:

- All public water distribution systems must use disinfection unless a waiver has been obtained from the Water Quality Control Division
- All systems must maintain a detectable disinfectant residual in the distribution system
- Surface water systems are required to maintain a 0.2 mg/L disinfectant residual at the entry point to the distribution system

Chlorine disinfection is used in the existing water treatment and distribution system in the City. Alternatives maintaining the current central water treatment facility will meet residual disinfectant regulations. Decentralized treatment alternatives produce a regulatory concern related to the definition of the entry point. According to the Colorado Department of Public Health and Environment (CDPHE), there is no regulatory difference in the definition of transmission lines and distribution lines. A distribution line is a network that is linked to potable connections (CDPHE, 2009). The entry point is then more specifically defined as the point at which potable quality water enters a distribution system after treatment for delivery to potable connections (Ingels, 2014).

The following entry point scenarios are produced based on these regulatory interpretations,:

- *Central treatment (Existing, Central/Dual, Separated Irrigation)* – The entry point is located post treatment facility at the entrance to the potable distribution system.
- *Neighborhood treatment* – The entry point is located post treatment facility at the entrance to the potable distribution system. A disinfectant residual is not required prior to the decentralized treatment facilities.
- *Point-of-entry treatment* – The entry point is located post treatment, which is after the connection. No disinfectant residual is required due to the absence of a distribution system. As the regulation is written, a waiver must be obtained from CDPHE to forgo residual disinfection.

Point-of-entry treatment entry point and disinfection regulations must be further defined to determine whether a disinfectant residual is required. For the purposes of this analysis, it was assumed that in the absence of a distribution system with treatment at the connection, a waiver would be granted to forgo residual disinfection. This assumption provided the opportunity to use alternative technologies that do not produce a residual such as ultraviolet disinfection.

Point-of-Entry Regulations

The U.S. EPA has approved the use of centrally managed point-of-entry treatment systems in order to achieve compliance for small public water systems with maximum contaminant levels (MCLs) specified in the SDWA (U.S. EPA, 2002). There are several key regulatory barriers related to the implementation of a point-of-entry treatment alternative at a citywide scale.

Point-of-entry compliance strategies are explicitly approved for small public water systems in SDWA PL 104-182, Sec. 105, §1412(b)(4)(E)(ii). The 1996 amendments to the SDWA define small systems as those servicing less than 10,000 people. Implementation of this alternative at a citywide scale would service more than 130,000 customers in the Fort Collins Utility District. The reason that large/very large system categories have been excluded from this amendment is likely related to the limits of cost and operational requirements that define the upper bound at which decentralized treatment is no longer cost effective compared to centralized treatment (Cortruvo, 2002). Point-of-entry treatment is typically applicable to small rural or remote communities (Hamouda, 2010), usually less than a hundred connections. To approve use of a point-of-entry strategy at the city-wide scale, the regulation would need to include large/very large service populations.

Point-of-entry treatment units are required to be owned, controlled and maintained by the public water system or by a hired contractor. The public water system must maintain oversight for all responsibilities including installation, maintenance and sampling (U.S. EPA, 2002). Additionally, delegation of any of these responsibilities to a connection owner is prohibited. This regulation limits the ability of a shared operations & maintenance scenario unless waived by appropriate governing bodies such as CDPHE and U.S. EPA.

Implementation of a point-of-entry treatment alternative will also require regular access to treatment units located on customer property to perform installation, maintenance and sampling duties (U.S. EPA, 2002). The local government may pass an ordinance allowing access to treatment units for service personnel as well as requiring customers to use point-of-entry units and grant authority to the public water service to disconnect a connection that has been tampered with (U.S. EPA, 2002). This alternative design incorporates outdoor installation as a less invasive option for maintenance and sampling while also increasing security from tampering or bypassing.

Reversion to Potable Distribution System

If an alternative does not meet compliance standards, there is a risk that the alternative system would need to be reverted to the existing system configuration. Raw water irrigation transmission lines would then need to meet potable distribution standards. This conversion back to potable distribution may require more than a chlorine flush to return to potable use. Flushing procedures may include drag cleaning, hydraulic-jet cleaning or electric scraper cleaning (AWWA, 2001). Sliplining and replacement measures are significantly more expensive but may be necessary in more extreme contaminant situations (Ingels, 2014).

d. Special Considerations (Secondary Irrigation Systems)

The results show Separated Irrigation to be a competitive alternative to the existing system. This type of secondary irrigation system has been implemented in several areas across the Western United States. CSU's Sociology Water Lab and Colorado Institute for Irrigation Management conducted a study on the benefits and costs of secondary irrigation systems in Colorado (Wilkens-Wells et al., 2003). The report provided several case studies of implementations in Utah, Idaho, Washington and Colorado.

i. Raw water irrigation system management by HOAs or canal companies

Raw water for landscape irrigation has been increasing in Colorado as subdivision developers pursue alternatives to municipality raw water turn over requirements. After development, it is common practice for maintenance and operations of these systems to be turned over to HOAs. There is concern over the long-term sustainability of these fragmented systems. Common concerns include raw water irrigation systems not being maintained properly, unmetered systems resulting in excessive water use, and homeowners using municipal supplies to irrigate during times of drought.

Large-scale raw water irrigation has been successfully implemented in the Kennewick Irrigation District, in Washington. Here neighborhoods can form Local Improvement Districts (LID, *similar to HOAs*) and approach the irrigation district about becoming a member. If the irrigation district agrees, then it assists the LID in developing the neighborhood raw water irrigation system by financing the costs. The irrigation district only interacts with the LID, but development and operation costs are prorated across all homeowners in the LID. (Wilkens-Wells, 2003)

There are several other cases of large-scale implementation of raw water irrigation systems in Utah and Idaho, where canal companies maintain and operate these systems (Wilkens-Wells, 2003).

It is important to meter raw water irrigation systems because unmetered use in both HOA and canal company operated systems can result in excessive water use. However, costs of metering could be shared with the utility in charge of system administration and the HOA or canal company in charge of the neighborhood or canal company raw water irrigation system O&M. Similar to sharing POE O&M costs, sharing O&M costs with an HOA or canal company has little effect on the overall score of the Separated Irrigation alternative's ranking among the alternative. However, if the City decides to implement the Separated Irrigation alternative, different management strategies should be considered based on the lessons learned from other case studies.

ii. Funding strategies

The Separated Irrigation alternative would require improvements to the existing irrigation ditches in Fort Collins. This would benefit both FCU and the canal and irrigation companies, and may also provide access to additional methods of funding, such as state or federal loan programs focused on improving the efficiency of agriculture water deliveries.

iii. Water rights

There are several water rights issues the City will need to address before implementation of a Separated Irrigation alternative. The Colorado State Engineer's Office, does not consider using irrigation designated water rights for irrigating residential and commercial lawns or city parks and recreational facilities a change in use (Wilkens-Wells, 2003). However, if there is a change in the place or time of use from the historic practice, then this would require a change to the water right.

The source water for the Separated Irrigation alternative's secondary water system is the CLP. The City's CLP water rights portfolio consists of senior and junior water rights and many of which are direct decree. There is a possibility that these water rights may not meet the City irrigation demand in the later irrigation months and this system would need to be supplemented with C-BT water, other storage decree water rights, and/or alternative non-potable water sources. Prior to implementation of a Separated Irrigation alternative, a water right analysis would be needed to determine if CLP supplies would need to be augmented and a contingency plan established. If municipal water rights are needed to supplement irrigation, then this would result in changes to the diversion location as this water would be diverted further downstream at various ditch locations.

iv. Cooperating with canal and irrigation ditch companies

For the Separated Irrigation alternative to succeed, strong cooperation between FCU and the canal or irrigation ditch companies is critical. Future success will depend on the success of these companies. Involving these companies early in the planning process and addressing agricultural and canal company concerns will be important to successful cooperation. Below is a list of some of the agriculture and canal/irrigation company concerns identified in the CSU study, on the Benefits and Costs of Pressurized Dual Water Systems in Colorado (Wilkens-Wells et al., 2003):

- Municipalities buying up agriculture water rights and irrigated land
- Non-pass through costs associated with urbanization around canals
- Urban interests taking priority over agriculture interests
- Changing share holder make-up, increased ownership by municipal interests and how this affects the remaining agricultural community
- Increased liability issues
- Increased record keeping
- Adequate future water supplies
- Revenue generation and cost of retrofits needed for implementation

v. Water loss

One of the benefits of the City's irrigation ditch network is the surrounding natural systems they support. The City stakeholders place a high value on these environments, but the cost of this ecological benefit is water loss due to infiltration and evapotranspiration. Currently, the City's water loss is at about 6%. This water loss is due to distribution system leaks, metering and billing errors (Mayer et al., 2009). Many of the irrigation ditches are unlined, open conduits. By moving irrigation demand to unlined irrigation ditches and adding storage basins, the percentage of water loss is likely to increase for the Separated Irrigation alternative. There will be savings in the new potable irrigation distribution system because of fewer pipe leaks, but the increase in losses due to infiltration and evapotranspiration will still likely result in a net loss.

V. Conclusions

In this study a MCDA approach was taken to evaluate four dual water supply system alternatives with the existing system. The MCDA approach allowed for a triple bottom line perspective of the alternatives and facilitated a collaborative decision making process between FCU, CSU, and the City departments represented in the Nature in the City Group. Overall, the Central/Dual and Separated Irrigation alternatives outperformed the other alternatives indicating that a central water treatment and dual distribution strategy is better suited to help the City achieve their future economic, social, and environmental goals. The equally weighted and average stakeholder results were very similar, as were the results of the different sample neighborhoods representative of the City.

Economic Bottom Line

The economic results showed Central/Dual and Existing were favored slightly over Separated Irrigation. The Central/Dual overall score was slightly higher than the Existing alternative and had less variance and more agreement among stakeholders. Four to five out of seven stakeholder groups favored the Central/Dual alternative depending on the neighborhood and two to three groups favored the Existing alternative. Separated Irrigation ranked a close third in economic performance and had less variance than the top two alternatives, Central/Dual and Existing. Overall, the difference between the economic performance of the Existing, Central/Dual, and Separated Irrigation alternatives is small. The stakeholder groups agreed Central/Dual and Existing were the top performers closely followed by Separated Irrigation, but there is less consensus between stakeholders on whether Central/Dual or Existing is the top economic choice.

These results imply that maintaining the existing system is not necessarily more cost effective for the City in the long run. The Central/Dual and Separated Irrigation alternatives require larger initial capital expenditures, but they offer many savings in water treatment. Additionally, the added flexibility of a dual distribution system allows for more efficient use of the City's water resources by allowing the City to use higher quality water for treatment, resulting in additional savings in water treatment, and by using more of the surplus CLP River water rights during the spring runoff season to meet irrigation demand.

Social Bottom Line

All the dual water system alternatives performed better than or as well as the Existing alternative from a social perspective. The Central/Dual alternative had the best and most consistent performance of all the alternatives. Five to six out of seven stakeholder groups found the Central/Dual alternative to have the best social performance. The Central/Dual, Neighborhood, and Point-of-Entry alternatives all improve drinking water quality compared to the Existing alternative by decreasing the amount of time in the potable distribution system. The Separated Irrigation alternative does not improve water age. It is the same as the Existing alternative in the winter months when there is no irrigation demand. However, the Separated

Irrigation alternative has the advantage of improving the natural areas around the water corridors in the City, which had significant value for stakeholders, making this the second most favored alternative for five out of the seven stakeholder groups. Improvements to these canals and ditches also benefit local canal and irrigation companies and facilitate cooperation between municipal and agricultural interests.

Overall, the social performance results showed the Central/Dual alternative is the most socially responsible alternative by offering the most benefits to the community. It has the lowest energy use, which results in less air pollution. It improves potable water quality by reducing time in the distribution system. It has the most efficient and resilient infrastructure because it has the most finished water storage in case of an outage, dual transmission mains allow for more efficient use of the City's water resources and frees up capacity in the distribution system to meet future growth, and new plastic pressure pipe will mean fewer disruptions to potable supply due to pipe failure. Finally, a complete and separate dual distribution system provides an opportunity to use alternative sources of non-potable water in the future, provided the City has the rights to do so.

Environmental Bottom Line

All of the dual water system alternatives outperformed the Existing alternative in environmental performance, with the Separated Irrigation alternative outperforming all other alternatives. All the dual water system alternatives use fewer chemicals for water treatment than the Existing alternative because they treat less water. Neighborhood and Point-of-Entry also have the added benefit of using alternative treatment technologies, which use fewer chemicals in water treatment. Due to FCU's service area being predominately gravity fed, Central/Dual is the only alternative that uses less energy than the Existing alternative. The Point-of-Entry and Existing alternatives have similar energy use because, although the POE treatment systems use more energy than the existing water treatment facility, the distribution system is still gravity fed. The Central/Dual and Separated Irrigation alternatives offer the most complete dual distribution system, which allows the City to use alternative sources of non-potable water in the future if water rights allow it.

The Separated Irrigation alternative outperforms all alternatives and is favored by six out of seven stakeholders because of the environmental importance the City places on improvements in the City's water corridors; however, further water rights analysis will be required to determine the extent of these benefits.

Alternative Scenarios

Three alternative weighting scenarios were run to address concerns about the dilution of initial key drivers, the impact of a criterion that only applies to the Separated Irrigation alternative, and the assumption that the utility would need to conduct all maintenance in the Point-of-Entry alternative. The first scenario results showed that when the original key drivers of capital costs, O&M costs, revenue opportunities, water age, and GHG emissions were assigned the highest importance and all other criteria assigned the lowest importance, the Central/Dual alternative became the preferred alternative. The second scenario looked at the influence of the 'Use of city water corridors' main criterion on the performance of the Separated Irrigation alternative. This criterion only applies to Separated Irrigation and when the importance of the criterion was minimized there was a slight decrease in the Separated Irrigation alternative's social and environmental performance; however, the Central/Dual and Separated Irrigation alternatives still remain the preferred solutions. The third scenario considered how sharing O&M costs with homeowners for the Point-of-Entry alternative might affect its performance. The results show that sharing O&M costs does not produce a substantial change in Point-of-Entry's economic, social, or environmental performance.

We recommend the City consider a Central/Dual or Separated Irrigation alternative in their future planning. Although the results show there is little difference in economic performance between these two alternatives and the Existing alternative, the Central/Dual and Separated Irrigation alternatives show improved social and environmental performance. This suggests a dual distribution system with central water treatment is better suited to meeting the City's community and sustainability goals, without additional economic costs.

This study is an important step toward future implementation of a more efficient, flexible, and resilient approach to water supply for the City. However, further work is needed to overcome implementation barriers and to work with the community in adopting an alternative water supply strategy in the future. Although the dual distribution of raw and treated water is quite common in the Western U.S., there is currently no regulation governing the dual distribution of raw and treated water. Most dual distribution regulations focus on the use of recycled water for non-potable demand. However, where water reuse is limited due to water rights, separate raw water irrigation systems operated by HOAs, canal companies, or utilities are becoming more common. With this increase in popularity of separate raw water irrigation systems and the question of what entity is better equipped to maintain and operate these systems in the long-term, more utilities are likely to consider citywide dual distribution of raw and treated water. New regulatory framework specific to the dual distribution of raw and treated water is needed to ensure the success of these alternative management strategies in the future.

Recommendations for future research

Central/Dual and Separated Irrigation were consistently the top ranked alternatives for all sample neighborhoods, equally weighted and stakeholder weighted results, and the alternative scenarios demonstrating the robustness of the results. We recommend a sensitivity analysis of the MCDA results be conducted to ensure the recommendations are not dependent on a small set of input parameters and hold up under a wide range of criteria weighting. Assuming the results remain consistent with a sensitivity analysis, we recommend further analysis of the Central/Dual and Separated Irrigation alternatives, including high-level implementation plans.

While researching the alternatives considered in the study, we identified several decisions, alternative implementation ideas, and potential regulatory hurdles FCU address during the implementation planning process. A summary of these are included below:

a) Distribution System Considerations
   i. Is there a better alternative for high service neighborhoods?
   ii. Is corrosion control needed in the existing distribution system when it's used to distribute raw water?
   iii. Could coordinating with new development or other City infrastructure projects minimize economic costs?
b) Water Treatment Considerations
   i. What should be done with the extra capacity at the existing WTF?
   ii. Where would fluoridation and chemical stabilization occur in the Neighborhood and Point-of-Entry alternatives?
c) Water Quality Monitoring Considerations
   i. Should there be raw water quality requirements for irrigation and fire fighting?
   ii. What are the monitoring requirements for decentralized water treatment options?
   iii. How could the City address potential regulatory barriers?
d) Special Considerations (Separated Irrigation Alternative)
   i. Who manages a raw water irrigation system?
   ii. Would additional funding be available for canal improvements?
   iii. Are the existing City water rights in the CLP enough to meet irrigation demand for the entire irrigation season?
   iv. What are the canal and irrigation ditch companies concerns?
   v. Will there be an increase in water loss by using canals for conveyance of raw water?

All these questions don't apply to every alternative. We have documented all of the considerations for all the alternatives, as the best solution for the high service neighborhoods is yet to be determined. Addressing the appropriate questions for the selected alternatives will be an integral part of the implementation planning. We believe all of these issues are solvable and the utility can utilize a dual distribution system to improve the City's TBL.

VI. References

American Water Works Association. (2008). Distribution System Requirements for Fire Protection - Manual of Water Supply Practices, M31 (4th Edition). Denver, CO.

American Water Works Association. (2011). Manual of Water Supply Practices M58 - Internal Corrosion Control in Water Distribution Systems. Denver, CO.

American Water Works Association. (2012). Buried No Longer: Confronting America's Water Infrastructure Challenge. Retrieved 07/12/2014 from http://www.awwa.org/portals/0/files/legreg/documents/buriednolonger.pdf.

Aquatec-Maxcon. (2013). *WATERPURE - DF Direct Filtration Water Treatment Plants*. [Product Literature]. Melbourne, Australia.

Baker J. & Schofield C. (1982). "Aluminum toxicity to fish in acid waters." *Water Air Soil Pollution,* 18 (1982), pp. 289–309

Bakhshi, A. A., & Demonsabert, S. M. (2012). Estimating the carbon footprint of the municipal water cycle. *Journal American Water Works Association, 104*(5), 81-82. doi: 10.5942/jawwa.2012.104.0064

Brann, S. (2013). [Phone conversation regarding fire flow water demand on 08/27/2013].

Briliam Engineering Services, LLC. (2011). "Feasibility Study for a Joint Water Treatment Plant." Prepared for the La Plata Archuleta Water District and the Town of Bayfield, CO.

Brungs, W.A. (1973). "Literature review of the effects of residual chlorine on aquatic life." J. Water Pollution Control Fed. 45 (10): 2180-2193.

Buffington, R (2013). [Email correspondence regarding distribution system design requirements received 08/23/2013].

Burns, S., Adams, V., Maloney, S. (1984). "*Direct Filtration Versus Conventional Water Treatment in the Intermountain Region.*" Paper 580. <http://digitalcommons.usu.edu/water_rep/580>

Chapman, H. (2006). WRAMS, sustainable water recycling. *Desalination, 188*(1-3), 105-111.

City of Fort Collins Environmental Services. (2012). Municipal Greenhouse Gas Emissions Inventory Quality Management Plan (E. Services, Trans.). Fort Collins, CO.

City of Fort Collins Utilities (FCU). (2011). Development Construction Standards. Water Wastewater Stormwater. Fort Collins, CO.

City of Fort Collins Utilities. (2002). Cross-Connection Control Manual. Fort Collins, CO.

City of Fort Collins. (2010). City of Fort Collins Water Treatment Facilities Master Plan, Vol. 1. Fort Collins, CO.

City of Fort Collins. (2011). "Plan Fort Collins - Plan Summary." Fort Collins, CO.

City of Fort Collins. (2011-2014). "Demographic Information - Fort Collins Population Estimates 2011-2014." <http://www.fcgov.com/planning/trends.php?key=advanceplanning/trends.php> (November 12, 2014)

City of Fort Collins. (2012a). 2011 Municipal Operations Annual Sustainability Report. City of Fort Collins.

City of Fort Collins. (2012b). "City of Fort Collins Water Supply and Demand Management Policy." Fort Collins, Co. Retrieved from http://www.fcgov.com/utilities/img/site_specific/uploads/wsdm-policy.pdf.

City of Fort Collins. (2014). Water-Wise Lawn Care. Retrieved 11/19/2014, 2014, from http://www.fcgov.com/utilities/residential/conserve/water-efficiency/water-wise-lawncare

City of Fort Collins. (2015). Draft 2015 Climate Action Plan: Framework (02/25/2015). Fort Collins, CO. Retrieved 03/27/2015 from www.fcgov.com/climateprotection/

Clark, R. and Morand., J. (1981). "Package Plants: A Cost Effective Solution to Small Water System Treatment Needs," Journal of the American Water Works Association, Vol. 73, No. 1, pp 24-30.

Clarkson, C., Shrader, M. (1998). "Trident Water Treatment System." Virginia Tech. (April 9, 2014).

Colorado Department of Public Health and Environment, Water Quality Control Commission. (2013). "Regulation No. 31 – The Basic Standards and Methodologies for Surface Water Colorado." Denver, CO.

Colorado Department of Public Health and Environment. (2010). "Colorado Primary Drinking Water Regulations." Denver, CO.

Colorado Department of Public Health and Environment. (2013). "State of Colorado Design Criteria for Potable Water Systems." Safe Drinking Water Program Implementation. Policy #5. Denver, CO.

Colorado State University Facilities. (2013). "Sustainability in Facilities Management - Land and Water Use." Retrieved 12/11/2013, from http://www.fm.colostate.edu/sustain/index.cfm?page=projects/use

Colorado Water Conservation Board. (2011). "Statewide Water Supply Initiative 2010."

Corix. (2013). "Adsorption Clarification Water Treatment Plants." [*Product Literature]*, http://www.cec-ltd.com/upload/CWS_BRO_CEC_AC_v2%20LoRes.pdf (April 8, 2014)

Corix. (2013). "Adsorption Clarification Water Treatment Plants." [Product Literature]. Retrieved April 8, 2014, from http://www.cec-ltd.com/upload/CWS_BRO_CEC_AC_v2%20LoRes.pdf

Corix. (2013). "Direct Filtration." [*Product Literature],* <http://www.corix.com/corix-companies/water-systems/water-treatment/technology/direct-filtration.aspx> (May 1, 2014)

Cortruvo, J. (2002). "Approaches for Providing Potable Water in Small Systems." National Rural Water Association.

Cromwell III, J.E.; Reynolds, H.; Pearson Jr., N.; Grant, M. (2002). Costs of Infrastructure Failure. AwwaRF. Denver, CO.

Department of the Army: U.S. Army Corps of Engineers. (1999). *Design of Small Water Systems*. Washington, D.C.

Digiano, F. A., Weaver, C. C., & Okun, D. A. (2009). Benefits of shifting fire protection to reclaimed water. *Journal American Water Works Association, 101*(2), 65-+.

Dultimeier Sales. (2014). 10 - 50 HP Cast Iron Centrifugal Pump / Motor Units, Straight. Retrieved 12/8/2014, from http://www.dultmeier.com/products/0.851.863.1818.2473/1118

Dultimeier Sales. (2014). Variable Frequency Drive, 3 to 75 HP. Retrieved 12/8/2014 from http://www.dultmeier.com/prod-search.php

Dustin, D. (2013). [Email regarding population and water demand projections 07/19/2013].

Eisenberg, M. (2012). That's a Bright Idea! Using USEPA's Energy Use Assessment Tool to Control Costs. *Journal*

American Water Works Association, 104(12), 20-+. doi: 10.5942/jawwa.2012.104.0163

Elmund, G.K. (2014). [Email regarding Internal pipe corrosion control 10/22/2014].

Elmund, G.K., Alexander, B., Gertig, K. (1992). *Corrosion Control with Low Alkalinity, Low Hardness Surface Waters*. Paper presented at the AWWA Water Quality Technology Conference, Toronto, Ontario.

Elmund, K., Strong, S. and Hamdan, B. (2013). “2012 City of Fort Collins Lower Cache la Poudre River & Urban Creek Water Quality Report.” Fort Collins Utilities, Fort Collins, CO.

Elmund, K., Strong, S., Hamdan, B. (2013). 2012 City of Fort Collins Lower Cache la Poudre River & Urban Creek Water Quality Report. Fort Collins, CO: Fort Collins Utilities.

Evoqua Water Technologies. (2014). “Memcor XS Submerged Membrane System.” [*Product Literature],* < http://www.evoqua.com/en/products/membrane_filtration_separation/ microfiltration_membrane_systems> (March 10, 2014).

Fluytec. (2013). “Ultrafiltration Standard Systems.” [*Product Literature],* Erandio-Vizcaya, Spain.

General Electric. (2013). “Packaged Systems for Water and Wastewater Treatment.” [*Product Literature], GE Water & Process Technologies.* Downloadable brochure. (March 19, 2014). Phone conversation, March 22, 2014 (281-727-9306).

Golstein, R. and Smith, W. (2002). “Water & Sustainability: U.S. Electricity Consumption for Water Supply and Treatment – The Next Half Century.” *Topical Report Volume 4*, Electric Power Research Institute, Palo Alto, CA.

Gordon, E., Klien, R., Travis, W., Seidl, A. (2015). *Chapter 3 – Demography, Land Use, and Economics. In Colorado Climate Change Vulnerability Study*, edited by Gordon, E. and Ojima, D. University of Colorado, Boulder, CO and Colorado State University, Fort Collins, CO>

Gumerman, R. C., Culp, R. L., and Hansen, S. P. (1979). "Estimating Water Treatment Costs." Rep. No. EPA-600/2-79-162a-d, Municipal Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268.

Gumerman, R. C., Culp, R. L., and Hansen, S. P. (1979). "Estimating Water Treatment Costs." Rep. No. EPA-600/2-79-162a-d, Municipal Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268.

Haestad Methods; Waliski, T.M.; Chase, D.V.; Savic, D.A.; Grayman, W.; Beckwith, S.; Koelle, E. (2003). *Advanced Water Distribution Modeling and Management* (A. Strafaci Ed. First Editiion ed.). Waterbury, CT: Haestad Methods Inc.

Hambly, A. C., Henderson, R.K., Baker, A., Stuets, R.M., & Khan, S.J. (2012). Cross-connection detection in Australian dual reticulation systems by monitoring inherent flourescent organic matter. *Environmental Technology Reviews, 1*(1), 67-80.

Haukaas, J. (2013). [FCU Dual Water Systems Project Kickoff Meeting on 05/01/2013].

James, W., Craik, S., Molla, S., Suarez, A. (2012). “Direct Filtration: A Tale of Two Winters.” *AWWA Opflow*, January 2012.

Jones, R., Allen, P., Garland, J. and Wang, Z. (2008). "Evaluation of Package Water Treatment Plants for Severe Drought Conditions for City of Raleigh, NC." *Hazen and Sawyer, P.C.*

Kang, D., & Lansey, K. (2012). Dual Water Distribution Network Design under Triple-Bottom-Line Objectives. *Journal of Water Resources Planning and Management-Asce, 138*(2), 162-175. doi: 10.1061/(asce)wr.1943-5452.0000161

KDF Fluid Treatment (2014) "Point-of-Entry or Point-of-Use Water Treatment Systems," KDF Fluid Treatment, accessed 14 September 2014, <www.kdfft.com>

Kirmeyer, G., L. Kirby, B., Murphy, P., Noran, K., Martel, T., Lund, T., Anderson, J. and Medhurst, R. (1999). "Maintaining and Operating Finished Water Storage Facilities." Denver, Colo.: AWWA and AWWARF.

K-Rain. (2014). Rotary Nozzle - Adjustable Pattern Specifications. Retrieved 07/08/2014, 2014, from http://www.krain.com/rotary-nozzles-2/adjustable-pattern-rotary-nozzle.html?uasCatalog=1

Law, I. B. (1996). Rouse Hill - Australia's first full scale domestic non-potable reuse application. *Water Science and Technology, 33*(10-11), 71-78. doi: 10.1016/0273-1223(96)00408-8

Lee, J.J., Schwartz, P., Sylvester, P., Crane, L., Haw J., Chang, H., Kwon, H.J. (2003). Impacts of Cross-Connections in North American Water Supplies. Denver, Colorado: University of Southern California, Foundation for Cross-Connection Control and Hydraulic Research.

Lenntech. (2014). "Ultrafiltration membrane technology." [Product Literature]. Retrieved May, 2014, from http://www.lenntech.com/library/ultrafiltration/ultrafiltration.htm

Lenntech.Water Treatment Solutions (2014). "Ultrafiltration membrane Technology." [*Product Literature]*, < http://www.lenntech.com/library/ultrafiltration/ultrafiltration.htm> (May 8, 2014)

Lukas, J. and Gordon E. (2015). Chapter-2Colorado's Climate: Past and Future. In Colorado Climate Change Vulnerability Study. Edited by Eric Gordon and Dennis Ojima University of Colorado, Boulder, CO and Colorado State University, Fort Collins, CO.

Mayer, P. W.; DeOreo, W.B.; Optiz, E.M.; Kiefer, J.C.; Davis, W.Y.; Dziegielewski, B.; and Nelson, J.O. (1999). Residential End Uses of Water Study. Denver, CO: AWWA Research Foundation and American Water Works Association.

Mayer, P., D'Audney, L. and Bode, D. (2009). "Water Conservation Plan. Ft. Collins, CO." City of Fort Collins Utilities.

McLain, K. (2005). "Human and Environmental Risk Assessment of Calcium Hydroxide." *Washington State University, Department of Ecology*. Olympia, Washington.

Morrison, Ken (2014, 10/13/2014). [Email with raw water laboratory analysis results after 2011].

National Drinking Water Clearinghouse. (1997). "Package Plants." *Tech Brief: A National Drinking Water Clearinghouse Fact Sheet #6*.

National Research Council. (1997). "Safe Water From Every Tap: Improving Water Service to Small Communities." Table 3-4 p 64-65. *Committee on Small Water Supply Systems, Water Science and Technology Board, Commission on Geosciences, Environment, and Resources.* Washington, D.C.

New Hampshire Drinking and Groundwater Bureau. (2012). "Surface Water Treatment Plants in New Hampshire." *Environmental Fact Sheet.*

Okun, D. (1997). "Distributing reclaimed water through dual systems." *Journal American Water Works Association*, 89(11), 52-64.

Parton, C. (2014, 10/28/2014). [Email correspondence sent 10/28/2014 regarding updated unit costs for water mains.].

Payne, J.R. (1998). [Optimized Water Quality Parameter Ranges for Large Community Water Systems 07/01/1998].

Pelican Water Systems (2014) "Sediment Pre-filter Water System," Pelican Water Systems, accessed 11 June 2014, <http://www.pelicanwater.com/pre-sediment-filter-systems.php>

Peter-Varbanets M., Zurbrugg C., Swartz, C. and Pronk W. (2009). "Decentralized systems for potable water and the potential of membrane technology." Water Res 43: 245–265.

Plappally, A. and Lienhard, J. (2012). "Energy requirements for water production, treatment, end use, reclamation, and disposal." *Renewable & Sustainable Energy Reviews*, 16(7), 4818-4848. doi: 10.1016/j.rser.2012.05.022

Pollick, H.F. "Water fluoridation and the environment: current perspective in the United States. *International Journal of Occupation and Environmental Health.* 2004;10(3);343-350

PureEarth Technologies, Inc. (2014) "How Our Filters Work (what's KDF and GAC?)," PureEarth Technologies, Inc., accessed 31 October 2014, <http://www.pure-earth.com/how.html>

Reclamation Bureau. (2014). Change in Discount Rate for Water Resources Planning. Federal Register Bulletin 12/29/2014. Accessed 01/05/2015 https://www.federalregister.gov/articles/2014/12/29/2014-30426/change-in-discount-rate-for-water-resources-planning.

Foundation for Cross-Connection Control and Hydraulic Research. (2009). Manual of Cross-Connection Control (10th ed.). Los Angeles, CA: Foundation for Cross-Connection Control and Hydraulic Research, University of Southern California.

Richards, Gregory, Johnson, Michael, & Barfuss, Steven. (2008). Metering secondary water in residential irrigation systems. *Journal - American Water Works Association, 100*(6), 112-+.

Roberson, J.A.; Cassidy, J.J.; Chaundhry, M.H. (1998). *Hydraulic Engineering* (2nd ed.). New York, NY: John Wiley & Sons, Inc.

Rosseland B.O., Eldhuset T.D., Staurnes M. (1990). "Environmental effects of aluminium." *Environ. Geochem. Health,* 12 (1990), pp. 17–27

Rossman, L. (2000). "EPANET2 User's Manual." *(W. S. a. W. R. Division, Trans.).* Cincinnati, OH: National Risk Management Research Laboratory, United States Environmental Protection Agency.

Sacramento County Water Resources. (2007). County of Sacramento Rules and Regulations for Recycled Water Use and Distribution. Sacramento, CA: County of Sacramento.

San Diego County Water Authority. (2011). *San Diego County Water Authority Workshop Presentation: Dual Plumbed Systems and Cross Connection Control (California Department of Public Health)*. Accessed 10/28/2014 from http://www.slideshare.net/waterauthority/dual-plumbed-systems-and-cross-connection-control-california-department-of-public-health

San Diego County Water Authority. (2011). Technical Information for Dual Plumbed Sites. In S. D. C. W. Authority (Ed.). San Diego, CA. Accessed 10/28/2014 from http://www.sdcwa.org/sites/default/files/files/water-management/recycled/dual_plumbed_sites.pdf.

Schowalter, L. (2006). "Development of UV-based water purification systems for point of use/point of entry." *Critical National Need Idea*, submitted by Crystal IS, Inc. to National Institute of Standards and Technology (NIST).

Sharma, R. (2010). "Development of a Preliminary Cost Estimation Method for Water Treatment Plants." University of Texas – Arlington

State of Colorado. (2011). "Clarification about log removal credits granted to package plants with upflow clarification for meeting the removal requirements for Giardia lamblia, virus, and Cryptosporidium." [Letter from Gov. John Hickenlooper to Colorado Public Water Systems, July 4, 2011].

Switzer, B. (2013, 11/7/2013). [Email regarding water demand and service type data for land use types].

Tonka Water. (2014). "Packaged Treatment Systems." [*Product literature],* <http://www.tonkawater.com/package.cfm> (February 15, 2014). Phone conversation February 23, 2014 (763-252-0905).

Tucson Water. Dye Testing: Ensuring the separation of Potable and Reclaimed Water Systems. Tucson Arizona: Tucson Water.

U.S. Army Corps of Engineers. (1999). "Design of Small Water Systems." Washington, D.C.

U.S. EPA. (1979). "Estimating Water Treatment Costs." EPA-600/2-79-162b

U.S. EPA. (1979). *Estimating Water Treatment Costs.* EPA-600/2-79-162b

U.S. EPA. (1980). "Package Water Treatment Plants." Vol. 2 A Cost Evaluation*. Municipal Environmental Research Laboratory*, Cincinnati, OH.

U.S. EPA. (1991). "Technologies for Upgrading Existing or Designing New Drinking Water Treatment Facilities." CRC Press.

U.S. EPA. (1997). "Small System Compliance Technology List for the Surface Water Treatment Rule."

U.S. EPA. (1997). "Water on Tap: A Consumer's Guide to the Nation's Drinking Water." EPA/815/K-97/002. July 1997.

U.S. EPA. (2001) "Low-Pressure Membrane Filtration for Pathogen Removal: Application, Implementation, and Regulatory Issues," United State Environmental Protection Agency, Office of Water.

U.S. EPA. (2002) "Guidance for Implementing a Point-of-Use or Point-of-Entry Treatment Strategy for Compliance with the Safe Drinking Water Act," United States Environmental Protection Agency, Office of Water.

U.S. EPA. (2003) "Small Drinking Water Systems Handbook – A Guide to 'Packaged' Filtration and Disinfection Technologies with Remote Monitoring and Control Tools," United States Environmental Protection Agency, Office of Research and Development, National Risk Management Research Laboratory, Water Supply and Water Resources Division.

U.S. EPA. (2007) "Cost Evaluation of Point-of-Use and Point-of-Entry Treatment Units for Small Systems: Cost Estimating Tool and User Guide," United State Environmental Protection Agency, Office of Water.

U.S. EPA. (2008). "Costs and Benefits of Complete Water Treatment Plant Automation." AwwaRF

U.S. EPA. (2008). "Evaluation of Dynamic Energy Consumption of Advanced Water and Wastewater Treatment Technologies." AwwaRF.

U.S. EPA. (2012). "Facts About Sustainable Water Infrastructure", Retrieved October 8, 2014 from http://water.epa.gov/infrastructure/sustain/localofficials_facts.cfm

U.S. EPA. (2013). "Energy Efficiency in Water and Wastewater Facilities." State and Local Climate and Energy Program.

U.S. EPA. (2014). "Conventional Treatment." Retrieved March 10, 2014, from http://iaspub.epa.gov/tdb/pages/treatment/treatmentOverview

U.S. EPA. (2014). "Direct Filtration." Retrieved March 21, 2014, from http://iaspub.epa.gov/tdb/pages/treatment/treatmentOverview

U.S. Filter. (2000). "Unique Recovery Services for Industrial Wastes and Wastewater." <http://www.idaho-maryland.com/i/pdf/PD-May29-2007/Appen-C_WaterTreatmentSystemDescription.pdf> (April 11, 2014).

U.S. Fire Administration. (2008) Water Supply Systems and Evaluation Methods. Volume II: Water Supply Evaluation Methods. FEMA.

Utah Division of Water Resources. (2010). Municipal and Industrial Water Use in Utah. Salt Lake City, Utah.

UV Max. (2014) "UV Technology – UV Max," Viqua – A Trojan Technologies Company, accessed 15 September 2014, <http://viqua.com/uvmax/uv-technology/>

Voytko, Lisa (2013). [Email with 2011 motor information received 12/17/2013].

Wang, P., Ma, J., Wang, Z., Shi, F. and Liu, Q. (2012). "Enhanced Separation Performance of PVDF/PVP- -MMT Nanocomposite Ultrafiltration Membrane Based on the NVP-Grafted Polymerization Modification of Montmorillonite (MMT)." Langmuir 2012, 28, 4776–4786.

WesTech. (2014). "Product Specifications for AltaFilter Ultrafiltration Membrane System and Trident Package Treatment System." Proposal obtained for the City of Fort Collins, July 9, 2014.

Whirty, B. (2013). [Personal communication regarding raw water irrigation of city parks 8/28/2013].

Wilkins-Wells, J., Podmore, T. H., Anderson, R.L., Smith, S.W., Rademacher, K.L., Brown, D.K., Lee, J., Epley, W., Griguhn, A., Rowe, M.H., and Smith, C.L.Z. (2003). The Benefits and Costs of Pressurized Dual Water Systems in Colorado and the Potential Role of Canal Companies and Irrigation Districts in Providing the Pressurized Irrigation Water Supply Portion of Dual Systems: Sociology Water Lab and the Colorado Institute for Irrigation Management, Colorado State University.

VII. Appendices

Please refer to individual appendix files.